SECTION 3 : DETAILED STUDY OF THE LANDSLIDE AT YUE SUN GARDEN, WO MEI ON 9 JUNE 1998

Fugro Scott Wilson Joint Venture

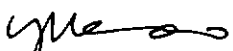
This report was originally produced in October 1999 as GEO Landslide Study Report No. LSR 8/99

FOREWORD

This report presents the findings of a detailed study of the landslides (GEO Incident No. ME 98/6/36) that occurred within the L-shaped cut slope No. 11NE-B/C513 at Yue Sun Garden, Wo Mei, adjacent to Hiram's Highway near Sai Kung on 9 June 1998. Three landslide incidents occurred within the main southwest-facing slope of the feature and involved the failure of approximately 50 m of the slope. The resulting debris, estimated at a total volume of about 1,350 m^3, inundated part of the garden nursery below, damaging a storage building, which is within a licensed area. No fatalities or injuries were reported following the landslide.

The key objectives of the detailed study were to document the facts about the landslides, present relevant background information and establish the probable causes of the failures. The scope of the study was generally limited to site reconnaissance, desk study and analysis. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 1998 Landslide Investigation Consultancy (LIC), for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 74/97. This is one of a series of reports produced during the consultancy by Fugro Scott Wilson Joint Venture (FSW). The report was written by Mr G Taylor and reviewed by Mr Y C Koo. The assistance of the GEO in the preparation of the report is gratefully acknowledged.



Y C Koo
Project Director/Fugro Scott Wilson Joint Venture

CONTENTS

1. INTRODUCTION

During the severe rainstorm of 9 June 1998, three landslides (GEO Incident No. ME 98/6/36) occurred within cut slope No. 11NE-B/C513 (formerly referred to as slope No. 11NE-B/C18 in the 1977/78 Catalogue of Slopes) adjacent to Yue Sun Garden, Wo Mei, off Hiram's Highway near Sai Kung (Figure 1 and Plate 1). The debris from the landslides inundated the eastern half of the garden nursery below, damaging an unoccupied storage building, which has subsequently been dismantled. No fatalities or injuries were reported as a result of the landslide.

Following the incidents, Fugro Scott Wilson Joint Venture (the 1998 Landslide Investigation Consultants) carried out a detailed study of the failures for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 74/97. This is one of a series of reports produced during the consultancy by Fugro Scott Wilson Joint Venture (FSW).

The key objectives of the study were to document the facts about the landslides, present relevant background information and establish the probable causes of the failures. The scope of the study was generally limited to site reconnaissance, desk study and engineering analysis. Recommendations for follow-up actions are reported separately.

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

(a) desk study, including a review of relevant documentary records and old topographic maps relating to the history of the site,

(b) aerial photograph interpretation (API),

(c) interviews with witnesses of the landslides and other concerned persons,

(d) topographic surveys, geological mapping and detailed observations and measurements at the landslide site,

(e) laboratory testing of soil and water samples collected from the landslide site,

(f) analysis of rainfall data,

(g) engineering analyses of the slope that failed, and

(h) diagnosis of the probable causes of the failures.

2. THE SITE

2.1 Site Description

The landslides occurred within the main southwest-facing slope of an "L-shaped" registered feature, No. 11NE-B/C513, on the southside of Hiram's Highway in the village of Wo Mei. The feature was formed by cutting into the west-facing slopes of a spur of Razor Hill (Che Kwu Shan), whilst Hiram's Highway has been formed by cutting into the corresponding east- and north-facing slopes of the spur as it descends into Wo Mei (Figure 1). The spur falls towards the north.

The main southwest-facing slope of the feature is about 60 m long and of maximum height, approximately 15 m, about mid-way along its length. The crest line falls towards both Hiram's Highway in the north and the junction of the main and subsidiary slopes of the feature in the south from this maximum. The angle of inclination of the main southwest-facing slope varies but is typically between 50° and 60°. The subsidiary northeast-facing slope of the feature is about 30 m in length and falls from its junction with the main southwest-facing slopes, from a maximum height of approximately 10 m to a minimum of about 1 m. The subsidiary northeast-facing slopes are very steep, being sub-vertical in places.

A series of three terraces, typically 3 m by 4 m in plan, has been constructed adjacent to the toe of the subsidiary northeast-facing slopes of the feature (Figure 2). The steps of these terraces are approximately 0.75 m, 0.75 m and 0.5 m in height respectively and each has a masonry facing. Within this part of the subsidiary slope of the feature, adjacent to the storage building (now dismantled), metal shelving has been erected which stores pots, plants and other miscellaneous ironmongery.

Both the main southwest-facing and subsidiary northeast-facing slopes of the feature are densely-vegetated.

The roadside slope, No. 11NE-B/C512 (formerly referred to as slope No. 11NE-B/C19 in the 1977/78 Catalogue of Slopes), which abuts this feature comprises an approximately 160 m-long cut slope with a maximum height of about 4.4 m. Surface water drainage provisions to this feature comprise a series of U-channels at both the crest and toe of the slope. Additionally, at its junction with slope No. 11NE-B/C513 there is a granite-faced masonry retaining wall at the toe of the slope with a shallow cut slope above (Figure 2). The wall is approximately 12 m long and of maximum height about 2.4 m whilst the cut slope above is typically 2 m high. This cut slope did not have a surface protection layer prior to the 1998 landslides. At each end of the wall are stepped channels.

The disturbed natural terrain above slope No. 11NE-B/C513, extending to the ridgeline and beyond, comprises densely-vegetated woodland with typical slope angles varying between 10° and 30°. The ground is generally hummocky in nature. The area is currently uninhabited with past development having been limited to the construction of several graves and associated access tracks on the hillside. The remains of a possible dwelling/wall have also been observed on the hillside just above the crest of the main southwest-facing slope of the feature, near its junction with the subsidiary northeast-facing slope.

The gently sloping platform area at the toe of the failed cut slope has, since 1963, been licensed by Government for cultivation, its current use being a garden nursery. The platform falls towards the adjacent watercourse to the west. A family occupies several of the buildings immediately to the west of the storage building, which was damaged during the 1998 landslides (Figure 2).

The ground that failed comprised most of the main southwest-facing slope of the "L-shaped" feature, a length of approximately 50 m, with the exception of a narrow strip, approximately 5 m wide, near the subsidiary northeast-facing slope (Figure 2). The subsidiary slope of the feature was largely unaffected by the incident. In addition to affecting the area adjacent to Hiram's Highway and a large part of Crown Land Licence Area S3295, the landslides also extended into the hillside above.

2.2 Maintenance Responsibility

According to the maintenance responsibility determined by the consultant engaged by the Lands Department for the "Systematic Identification of Maintenance Responsibility of Registered Slopes in the Territory" (SIMAR) project, the failed slope is situated partly on Government Land and partly within Government Crown Land Licence Area S3295 (Figure 1). Both portions of land have been assigned to the Lands Department for maintenance purposes.

The District Lands Officer/Sai Kung, has indicated in a letter dated 13 August 1998 that "the licensee has no maintenance responsibilities (for the slopes affected by the 1998 landslides) as the licence conditions are found irrevlant to the liabilities concerning the slope maintenance works and the remedial works required to be taken following the landslide".

Apart from routine maintenance inspections and works, including grass cutting and clearance of surface channels, carried out by the Highways Department (HyD) to the adjacent roadside slope, No. 11NE-B/C512, and the roadside portion of slope No. 11NE-B/C513, there are no records of any maintenance works having been carried out to the failed slope.

2.3 Services

As part of this investigation, FSW contacted both Government and private utility providers for details of any services in the vicinity of the landslides. The responses indicate that no utilities, in particular water-bearing services, are located within the immediate vicinity of the landslide sites.

2.4 Site History

2.4.1 General

The history of development at the site has been determined from an interpretation of a sequential series of aerial photographs (Table 1) as well as a review of the relevant available documentary records. Information sources consulted during this detailed study are

summarised in Table 2. The locations of the features referred to in this section are shown in Figures 2 and 3.

2.4.2 History of Development

In 1945, the landslide site and its immediate vicinity were largely undeveloped, consisting essentially of a sparsely-vegetated natural hillside. However, although development of the area generally, including the formation of cut slope No. 11NE-B/C513, did not commence until the late 1950's/early 1960's the old Hiram's Highway had already been constructed by 1945. The hillside has, since this time, become progressively more densely-vegetated.

File notes of an annual inspection of Crown Land Licence Area S3295, dated 5 September 1958, indicate that although the area had not yet generally been developed at this time, the Permittee was in the process of erecting a stone retaining wall and had done some cutting. Further details of these works are, however, not available.

The concerned cut slope is first observed on the 1961 aerial photographs. The platform area below the slope was bare at this time. A small, approximately ESE-WNW trending gully (possible photolineament), which appears to run from Hiram's Highway on the eastern side of the ridge down the hillside to the junction of the L-shaped cut slope, is evident on the 1963 aerial photographs. From 1964 onwards this feature has appeared increasingly overgrown with vegetation. The probable remnants of the feature were encountered during FSW's field inspections in connection with the present study (Section 3.2).

Extensive terracing and cultivation are also noted on the 1963 aerial photographs, to the west of the concerned cut slope, adjacent to the river. Cultivation on the platform below the cut slope is not evident, however, until 1967 when the first building and an access road from Hiram's Highway are noted within the site.

In the 1964 aerial photographs, a linear feature, possibly a small path or drainage ditch was noted running approximately parallel to the crest of slope No. 11NE-B/C513, within the wooded area above. This feature has also been identified during fieldwork carried out as part of the current investigation (Section 3.2).

Between 1967 and the present time several buildings have been erected and subsequently dismantled within the platform area at the toe of the cut slope. The storage building damaged by the 1998 landslides was first observed on the site in the 1988 aerial photographs. Additionally, shade racks, some of which were destroyed in the recent landslides, are first noted adjacent to the main southwest-facing slope of the feature in the 1985 aerial photographs. Within the hillside above, areas have been cleared locally and graves constructed from 1963 onwards.

Improvement works to the adjacent Hiram's Highway, comprising road widening with associated cutting of the roadside slope, No. 11NE-B/C512, next to the failed slope, were carried out in the late 1980's/early 1990's. To facilitate these works the perimeter fence in the northern corner of Yue Sun Garden was set back.

2.4.3 Previous Landslides

The GEO's landslide database indicates that there have been no recorded past landslides in the vicinity of the 1998 landslides. However, from the accounts of eye-witnesses, field inspection and examination of both high and low level aerial photographs, a history of previous instability has been determined for the landslide site.

Several relict landslides have been identified, from low level aerial photographs, within the main southwest-facing slope of feature No. 11NE-B/C513 (Figure 3), most notably in 1976 (two locations) and 1993 (one location) when significant failures (likely to be in excess of 50 m^3) occurred. In all three cases, landsliding appears to have involved the hillside above. Additionally, numerous other possible erosion/landslide scars have been noted from API within this part of the feature in the past 20 years – in 1976, 1977, 1987, 1992, 1993, 1994 and 1995 (all singular incidents with the exception of the last case when four separate incidents were noted). This history of past instability has been confirmed during interviews with longstanding members of staff at Yue Sun Garden and residents of the area. Furthermore, it is understood from discussions with members of staff of Yue Sun Garden that no formal repairs were carried out to these landslide scars. It appears that the landslide scars were simply allowed to re-vegetate, except those close to the toe of the slope which were worked to form platforms and were subsequently incorporated into the garden nursery (additional "terraces" for the plants).

In addition, a GEO staff member indicated that a minor landslide occurred within the main southwest-facing slope of feature No. 11NE-B/C513 adjacent to Hiram's Highway following heavy rainfall at the beginning of July 1997. Vegetation clearance associated with urgent repair works carried out in August 1998 following the current landslides revealed a relict landslide scar, which coincided with the above indicated location of the 1997 failure (Plate 2).

No previous instability has been noted within the steep subsidiary slope of the feature.

In 1995, the GEO commenced the Natural Terrain Landslide Study (NTLS) as part of a series of studies to investigate the landslide hazards associated with natural terrain in Hong Kong. Phase I of the NTLS comprised the establishment of an inventory of landslides on natural terrain, the Natural Terrain Landslide Inventory (NTLI), from the interpretation of high level aerial photographs dating from 1945 to 1994 (King, 1997). In the NTLI, no relict landslide scars were identified on the hillside between the ridgeline and slope No. 11NE-B/C513. The API carried out as part of this study has confirmed these observations with the exception of the relict landslide scar to the southeast of slope No. 11NE-B/C513, in a depression on the western face of the ridge (Figure 3).

2.5 Previous Studies and Assessments

2.5.1 Slope Registration

In the 1977/78 Catalogue of Slopes prepared by consultants engaged by the Government, the concerned cut slope was registered as No. 11NE-B/C18 whilst the adjacent roadside slope abutting Hiram's Highway was registered as slope No. 11NE-B/C19. The first

recorded inspections of these features were carried out by the consultant on 29 May 1978. At the time of inspection the condition of cut slope No.11NE-B/C18 was assessed as "fair". There were no seepages or signs of distress evident within the slope at this time although the possibility of past instability at this site was noted.

The condition of the adjacent roadside cut slope No. 11NE-B/C19 was also assessed as "fair" at this time. No seepages were evident during the inspection on 29 May 1978 although signs of distress, in the form of minor cracks in the chunam surface protection layer, were noted. Additionally, "minor slip scars" were recorded in the north of the feature.

2.5.2 Geology

The Hong Kong Geological Survey's 1:20 000 scale map, Sheet 11 Hong Kong and Kowloon Solid and Superficial Geology (GCO, 1986a), indicates that the landslide site is underlain by Mesozoic volcanic rocks, fine ash vitric tuff, of the Ap Lei Chau Formation of the Repulse Bay Volcanic Group, Upper Jurassic in age (Figure 4). Quaternary debris flow deposits have also been mapped occupying the upper reaches of the adjacent valley, whilst alluvial deposits have been noted at its mouth next to the landslide site. Additionally, eutaxite units have been mapped immediately NNW and to the south of the landslide site. In the north the eutaxite may extend beneath the adjacent alluvial deposits. Sandstone has also been mapped SSE of the landslide site, beside the southerly eutaxite units (see also below). In addition, a NNW-SSE trending fault has been mapped parallel to the ridgeline and adjacent to the southerly eutaxite units. The accompanying geological memoir (GCO, 1986b) confirms this interpretation.

The engineering geology map from the Geotechnical Control Office's (GCO, renamed GEO in 1991) Geotechnical Area Studies Programme (GASP) Report VII, Clear Water Bay (GCO, 1988a), generally confirms the above stratigraphic sequence indicating that the landslide site is underlain by "dominantly pyroclastic rocks" of the Repulse Bay Formation. In the accompanying commentary on weathering and soil development it is noted that the "rock usually produces a thin (< 1 m) soil horizon, followed downwards, especially on lower slopes, by yellowish brown sandy completely weathered material overlying less weathered, locally strongly jointed rock below an average 11 m". Furthermore, it states that the "stability of weathered material and also of highly jointed rock masses may be suspect, especially during or immediately after prolonged heavy rainfall. Failures are quite common, especially in over-steepened slopes. Rapid surface run-off is common".

In addition, geological photolineaments are shown to the east (approximately parallel to the general alignment of Hiram's Highway on its approach to Wo Mei) and southeast of the landslide site. This latter photolineament has a similar orientation, approximately ESE-WNW, to the gully/possible photolineament identified during the API carried out as part of this detailed study, and corresponds approximately to the trend of the adjacent drainage line. An area of "sedimentary and water-laid volcaniclastic rocks" is also shown to the southeast of the landslide site, adjacent to the gully/possible photolineament, and corresponds approximately with the location of the relict landslide scar, which was also identified during the API (Section 2.4.3). It consists of thin bands of chert and sandstone, the sandstone becoming coarser to the south until it grades into a coarse tuffaceous sediment. The boundaries appear to be tectonically disturbed and the stratigraphic relationships with

the enclosing tuffs are unclear. Colluvium, concentrated within the margins of the drainage line, is also shown within the platform/terraced area below the concerned slope.

2.5.3 GASP

The GCO's GASP Report VII, Clear Water Bay, produced at a scale of 1:20 000 for regional appraisal and outline and strategic planning purposes, indicates that no past instabilities have been noted within the area affected by the 1998 landslides or its immediate environs.

The accompanying Physical Constraints Map of the GASP report indicates the presence of colluvial deposits, "which are subject to overland flow and periodic inundation", at the toe of the failed slope. An "unusual groundwater regime (delineated as floodplain on (the) Landform Map)" and "moderate or severe gully erosion" were also shown on this map adjacent to the toe of the failed slope.

2.5.4 Stage 1 Study

A Stage 1 Study Report was prepared by the Design Division of the GCO for slope No. 11NE-B/C513 during the second half of 1991. However, it appears from photographs included in the report that the slope actually inspected during this Stage 1 Study was not the cut slope beside Yue Sun Garden but the adjacent roadside slope, No. 11NE-B/C512. At the time of the Stage 1 Study this roadside slope was being modified as part of road improvement works to Hiram's Highway, and as a result no further action was deemed necessary.

2.5.5 SIFT Studies

In 1992, the GEO initiated the consultancy agreement entitled "Systematic Inspection of Features in the Territory" (SIFT), which aims to update information on existing registered slopes in the 1977/78 Catalogue of Slopes, based on studies of aerial photographs and limited site inspections. The SIFT report for slope No. 11NE-B/C513 compiled in August 1996, noted that the cut slope was formed "pre 1961" and assigned it to Class "C1", i.e. a slope "formed or substantially modified before 30.6.78".

2.5.6 SIRST Studies

In 1994, the GEO initiated the consultancy entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST) to update the 1977/78 Catalogue of Slopes and prepare a New Catalogue of Slopes.

Slope No. 11NE-B/C512 was inspected on 2 April 1996 as part of the SIRST Project. A Stage 1 Study Report was subsequently prepared for this slope. However, from the sketch plan accompanying the report it appears that the extent of the feature studied included not only the roadside cut slope, No. 11NE-B/C512, but also the majority of the adjacent slope, No. 11NE-B/C513. The only part of feature No. 11NE-B/C513 not included in this

inspection was the subsidiary northeast-facing slope. Of the two critical sections determined along this length of slope, one was situated within the recently failed area. Furthermore, an area of distress was identified within the upper part of the cut slope at this location.

Slope No. 11NE-B/C513 was visited again by the SIRST consultant on 24 February 1997. The record of the field inspection indicates that the condition of the cut slope was assessed as "fair" although "reasonable" signs of distress "near crest" and within the "midportion" of the slope were noted (based on a grading system comprising the categories severe, reasonable, minor and none). No past instabilities were inferred from these inspections and no signs of seepage were observed. The consequence category of the slope was assessed as "High". In contrast to the 1996 Stage 1 Study Report, which was also prepared as part of the SIRST consultancy, the critical section of the slope was not noted as exhibiting any signs of distress.

3. THE LANDSLIDES

3.1 Time of Failure

Three landslides occurred within slope No. 11NE-B/C513 on 9 June 1998. Three gardeners working in Yue Sun Garden below observed all three failures. They have all subsequently been interviewed by FSW as part of this detailed study. Thus it has been possible to get relatively accurate times of occurrence for each of the failures as well as some observations regarding the condition of the slope both immediately preceding and following these incidents.

The first landslide (Landslide No. 1, Figure 2) occurred at about 9:00 a.m. on 9 June 1998. The incident was reported to the GEO at 11:00 a.m. on 9 June 1998 by a GEO staff member. The staff at Yue Sun Garden advised FSW during post-landslide interviews that they had not reported this landslide to any of the appropriate authorities. An inspection of the landslide was subsequently carried out by representatives of both the GEO and HyD between 4:00 p.m. and 4:30 p.m. that afternoon.

Following continuing rainfall the second landslide (Landslide No. 2) took place at approximately 6:00 p.m. Immediately before this landslide occurred one of the eye-witnesses observed the trees at the crest of the slope "moving" before a large amount of soil, trees and vegetation "quickly came down" the slope inundating the garden nursery below.

The third landslide (Landslide No. 3) took place at the junction between the main and subsidiary slopes of the feature at about 7:00 p.m.

The staff at Yue Sun Garden also advised FSW that as with the first landslide neither of the two subsequent incidents were formally reported to any of the appropriate authorities. However, the GEO officer who inspected the first landslide noted that these subsequent landslides had occurred when he passed the site on 10 June 1998. A further joint inspection of the landslide site was subsequently carried out by this inspecting officer with representatives of HyD, District Lands Office/Sai Kung, District Office/Sai Kung, Slope Safety Section/Buildings Department and Squatter Control (Sai Kung)/Housing Department

on 11 June 1998. The original GEO landslide incident report was amended to reflect these two subsequent occurrences.

3.2 Description of the Landslides

An aerial photograph of the landslide site is shown in Plate 1 whilst a general view of the landslides is given in Plate 3.

The three landslides were all located within the main southwest-facing slope of the "L-shaped" feature, No. 11NE-B/C513 (Figure 2). The landslides comprised the failure of approximately 50 m of the slope and involved a total of about 1,350 m^3 of decomposed tuff. The debris inundated the eastern half of the Yue Sun Garden Nursery below, damaging a storage building and adjacent shade racks and covering a steel storage container (Plates 3 and 4). The storage building, which was not occupied at the time of the landslides, was subsequently dismantled. The steel storage container has also been removed to another part of the site. A plan of the landslide site and two typical cross-sections through the landslide scars, corresponding to the first and second landslides, are given in Figures 2, 5 and 6 respectively.

The first inspection of the landslide site by FSW was made during the morning of 11 June 1998. A comprehensive inspection was not possible at this time because the landslide debris was very wet and the landslide scar was potentially dangerous to traverse. Additionally, the immediate vicinity at the crest of the slope was densely-vegetated, making access difficult. Nevertheless, initial observations of the landslide site indicated that it was a large failure. Subsequent site visits were made by FSW during July 1998 to map the landslide scar and the immediate vicinity.

Landslide No. 1, involving about 200 m^3 of material, occurred beside a recent landslide scar that is believed to have resulted from a failure in 1997 (Section 2.4.3). The 1998 landslide scar was generally "spoon-shaped" in nature suggesting a rotational form of failure (Plates 2 and 5), in a sliding failure mode. The scar was about 15 m wide and 13 m long with a maximum depth of approximately 2 m. The profile of the scar varied from 50° to 60° in the mainscarp, to between 40° and 45° within the debris trail (Figure 5). The landslide debris generally comprised a loose orange brown sandy slightly clayey silt with some to occasional fine gravel whilst the material of the mainscarp consisted generally of a moist medium dense orange brown sandy slightly clayey silt with some fine gravel (Completely Decomposed Tuff). Although the material of the mainscarp was moist, no subsurface seepages were noted in this area at the time of inspection. Remnants of erosion channels were, however, noted within the landslide debris trail. Plate 6 shows the landslide scar shortly after the incident occurred.

The remains of a "spur-type" feature were noted on the southern flank of the scar of Landslide No. 1, delineating it from the adjacent landslide scar (Landslide No. 2, Plate 4). The side slopes of this "spur-type" feature varied from 50° to 60° adjacent to the mainscarp of Landslide No. 1, 40° to 50° within the mid-portion of the scar and 30° to 35° at the base of the scar. A further less pronounced "spur-type" feature, with side slopes varying between 40° and 50°, was observed immediately to the south of this feature (Figure 2).

Landslide No. 2 appears to have been essentially an extension of the first landslide southwards, along the crest of the slope towards the junction between the main and subsidiary slopes of the feature. This incident released about 1,100 m^3 of material, with the resulting scar being approximately 35 m wide and typically 25 m long with a maximum depth of about 3 m. The height of the landslide mainscarp varied generally between 5.5 m and 6.5 m although locally on the southern flank of the landslide scar it reduced to as little as 2 m. This landslide extended significantly into the hillside above. At the location corresponding to the point of maximum height of the main slope (which is approximately coincident with the distressed area noted previously during an inspection of the slope by the SIRST consultants on 2 April 1996) this extension was of the order of 5 m. General views of the scar Landslide No. 2 and in particular the mainscarp, are shown in Plates 7 and 8. The profile of this landslide scar indicates a rectilinear form of failure (Figure 6), probably in a sliding failure mode. Slope angles adjacent to the mainscarp varied between 60° and 70° whilst the landslide debris below fell in a generally westward direction with slope angles varying between 20° and 40°. The material exposed in this landslide mainscarp comprised typically a firm to stiff orange brown mottled yellow and red, speckled white (kaolinite) sandy clayey silt (CDT). A spheroidal pattern of weathering was evident. Additionally, impersistent closely to medium-spaced manganese-stained/coated relict joints were observed within exposures of this material. No subsurface seepages were observed in this mainscarp at the time of FSW's inspections. Displaced trees and rafts of debris were observed within this part of the debris trail. Concentrated surface erosion channels were also evident within the landslide debris. This material generally comprised a soft to firm orange brown sandy slightly clayey silt with occasional fine to coarse gravels. The debris at the distal end of the landslide trail adjacent to the damaged storage building also appears to have been displaced as a relatively intact slab. An inspection pit excavated within this slab generally confirmed this observation (Plate 9).

Remnants of tension cracks associated with Landslide No. 2 were observed along the mainscarp during field mapping by FSW. Vertical displacements recorded varied between 0.2 m and 1 m whilst horizontal displacements were typically of the order of 0.3 m.

Several boulders of Moderately Decomposed Tuff (MDT) with dimensions approximately 1 m x 1 m x 1.2 m were also noted within the lower half of this landslide scar adjacent to the damaged storage building (Figure 2).

The narrow strip of slope, about 5 m wide, separating the second and third landslides was not involved in the current incident although it has failed in the past (Figure 2). Relict tension cracking as well as a relict landslide mainscarp, moss covered and overgrown with other vegetation, were observed within this densely-vegetated area, and a boulder of MDT with dimensions approximately 1 m x 1 m x 1.5 m was noted lodged between trees at about mid-slope (Plate 10).

Landslide No. 3 took place at the junction between the main and subsidiary slopes of the feature (Plate 11) and involved approximately 50 m^3 of material. This, the final landslide does not appear to have been directly connected to the first two incidents as a portion of "intact" slope (see above) was observed between this failed area and the two earlier areas of collapsed ground during FSW's post-landslide field mapping. The scar of this landslide was approximately 10 m wide and 8 m long with a maximum depth of about 1 m. The sub-vertical mainscarp, with a slope angle of about 80°, was typically 2 m deep. The remainder of the landslide scar had slope angles typically of the order of 50°. The material

exposed in the mainscarp consisted of a firm reddish brown mottled yellow and white sandy slightly clayey silt (CDT). Fragments of moderately strong light brown fine-grained moderately decomposed tuff were also noted locally within the mainscarp. The profile of the scar corresponded to a shallow, surficial type of sliding failure.

No seepages were noted during the inspections by FSW of each of the three landslide mainscarps, although it should be noted that these inspections were some time after the landslides occurred. Numerous possible erosion pipes, typically less than 5 mm in diameter, were, however, observed in the upper few metres of the landslide mainscarps. In addition, two such features with diameters in excess of 100 mm were noted. All these features were dormant during FSW's post-landslide site inspections.

In addition, the remnants of a 0.35 m wide and 0.3 m deep probable unlined drainage ditch were observed at the crest of the main slope of the feature (Plates 12 and 13). This ditch appears to have run the full length of the main slope before the 1997 and 1998 landslides, outfalling to a gully adjacent to the junction of the feature to the south (Section 2.4.2). To the north it appears that this ditch's original "outfall" was the stepped channel of the adjacent roadside slope (Figure 2). This ditch has been severed by a recent landslide (which probably occurred in July 1997) and it appears that water has flowed directly onto the slope adjacent to this landslide scar since. This probable drainage ditch was also severed by the second landslide on 9 June 1998. In addition to this ditch, a possible "snake pit" of diameter in excess of 100 mm, was noted at the high point of the main slope of the feature (Plate 14).

The corresponding travel angles of the landslide debris, determined after Wong & Ho (1996a), for the three landslides were about 34°, 30°, and 50° respectively. The travel angle is defined as the angle of inclination of the line joining the distal end of the debris trail to the crown of the landslide scar.

3.3 Consequences of the Landslides

Following the landslides, the temporary structure (storage building) damaged by the landslide debris was evacuated and subsequently dismantled. In addition, the remaining structures within Yue Sun Garden were temporarily evacuated.

Emergency works comprising fencing off the area directly affected by debris, covering the portion of the first landslide scar next to Hiram's Highway with tarpaulin and fencing off a length of the adjacent footpath, were implemented shortly after the incident.

Urgent repair works, including the provision of a shotcrete surface protection layer with weepholes to the portion of the slope affected by the first landslide, beside Hiram's Highway, were subsequently undertaken by the Highways Department (HyD) during August and September 1998. No urgent repair works have been carried out to the second and third landslide scars apart from that actioned by the Licensee. These works comprised the formation of a berm at the toe of the failed slope, adjacent to the second landslide, out of the landslide debris that resulted from this incident.

Permanent remedial works to the failed slope are to be incorporated into the HyD's forthcoming road improvement project (Hiram's Highway Improvement Phase 3: Improvement between Nam Wai and Ho Chung and Upgrading Local Access Roads).

4. SUBSURFACE CONDITIONS

4.1 General

The ground conditions at the site were determined using information obtained from both desk and field studies. Desk studies included a review of the available documentation supplemented by API, whilst field studies included the results of post-failure geological mapping.

Field mapping of the landslide site was carried out by FSW during July 1998. Bulk disturbed soil samples were collected from various locations within the landslide debris trails at this time. Classification and index tests were performed on these samples at the Public Works Central Laboratory to determine the composition and nature of the material retrieved. Two water samples were also taken one from water flowing along the distal end of the debris trail of the second landslide and the other from the adjacent watercourse (for comparative purposes). Chloride content determinations were subsequently undertaken on these samples. The test results are summarised in Table 3.

The landslide debris remained largely in place during the course of this fieldwork. Removal of debris and vegetation clearance on the slope abutting Hiram's Highway, associated with remedial works to the roadside slope, was not carried out until August/September 1998.

4.2 Previous Ground Investigations and Geological Mapping

4.2.1 Past Ground Investigations

There have been four ground investigations in the general vicinity of the failed slope (Gammon, 1985; Lam Geotechnics, 1988; Enpack, 1996; Enpack, 1997).

Based on the exploratory holes sunk during the above ground investigations, associated with various stages of the proposed road improvement works to the adjacent Hiram's Highway, the landslide site appears to be underlain principally by completely decomposed volcanics (CDV) with a surficial veneer of colluvium. The CDV is generally described as a medium dense reddish brown and yellowish brown with white speckles silty, fine- to coarse-grained sand with fine gravel. The overlying colluvial veneer, of a maximum thickness of about 4 m, is generally described as a loose reddish brown sandy silt. Rockhead, generally comprising moderately strong grey moderately to slightly decomposed fine ash tuff, was encountered at about 0 mPD. The toe of the concerned slope is at approximately 14 mPD. The joints were logged as closely to very closely spaced rough planar and undulating extremely narrow to narrow locally infilled with clay and iron oxide (< 1 mm).

It should be noted, however, that these exploratory holes are not particularly close to

the site of the 1998 landslides (Figure 2). The closest exploratory holes to the landslide site are drillholes BH12, AH5/35/5 and BH13, and trial pits TP11, TP12 and TP13 at the toe of the slope adjacent to Yue Sun Garden. Furthermore, colluvium was not observed in any of the landslide mainscarps during FSW's field mapping.

4.2.2 Field Mapping

Field mapping of the landslide site indicates that the slope that failed was composed of completely decomposed fine ash vitric tuff, of rock mass weathering grade PW 0/30. The material exposed in the landslide mainscarps can be typically described as a medium dense, orange brown and yellowish brown sandy slightly clayey silt with some fine to coarse gravels/firm to stiff orange brown (mottled yellow and red, speckled white (kaolin) in exposures) sandy clayey silt with occasional fine gravels. Additionally, closely to medium-spaced impersistent (< 0.25 m) manganese-stained/coated (< 0.5 mm) relict joints were noted in exposures towards the base of the second (major) landslide mainscarp (Figure 2 and Plate 15).

Although some manganese-coated relict joints were observed during the geological mapping in exposures within the mainscarp of the second landslide, these discontinuities were of limited persistence and not adversely orientated, and therefore are not considered to have contributed significantly to the landslide. In general, no particularly adverse geological features were mapped in the landslide scarps apart from the possible erosion pipes, which were concentrated in the upper few metres of the scarps.

The geological features mapped at the site by FSW following the 1998 landslides are shown in Figure 2 whilst typical geological sections through the slope corresponding to the first and second landslides, based on both this information and previous ground investigation records, are given in Figures 7 and 8 respectively.

4.2.3 Groundwater Conditions

The closest groundwater monitoring stations to the 1998 landslides are the piezometers installed in drillholes BH12, BH13, H7 and H8 (Figure 2). The tips of these piezometers were installed just above the soil-rock interface at 13.4 m, 13.0 m, 13.3 m and 14.5 m below the ground surface respectively. The piezometers installed in drillholes H7 and H8 were monitored on a daily basis, between 23 August 1988 and 1 September 1988, whilst those installed in drillholes BH12 and BH13 were monitored on a daily basis, between 12 and 19 August 1996. No Halcrow buckets were installed in any of these piezometers. Such limited monitoring data is inadequate to establish reliably the groundwater conditions in general.

These available groundwater monitoring records from the past ground investigations indicate that the groundwater table may generally be between 3 m and 5 m below the ground surface, at between about 9 and 10 mPD.

No seepages were noted in the landslide mainscarps during field inspections by FSW in June and July 1998 following the incidents. It should be noted, however, that these

inspections were some time after the landslides occurred. Numerous possible erosion pipes were observed in the upper few metres of the landslide mainscarps (Plate 16). These features were all dormant during FSW's site inspections in connection with this study.

Water was, however, noted to be flowing at the toe of the debris from Landslide No. 2 in a generally south-north direction towards the entrance to Yue Sun Garden (Plate 3). The eye-witnesses to the landslides stated that this water flow was not unusual, as water had been observed flowing along the toe of the slope in previous years (Section 5). This water appeared to emanate from the junction of the feature. In the past this water flow was noted as being ephemeral in nature, occurring only during the wet season and the same behaviour was observed for the water flow at the toe of the 1998 landslide debris. The flow ceased with the onset of the dry season in late September 1998.

Additionally, when the storage building, damaged during Landslide No. 2, was dismantled in July 1998, water was evident near the ground surface in the remains of the foundations. A well, approximately 5 m deep, situated between Yue Sun Garden and the adjacent watercourse, was dipped during this study on 11 August 1998 and indicated a water level of about 0.6 m below the existing ground surface. These observations suggest that the base groundwater table may be located close to the toe of the cut slope.

Overall, there is considerable uncertainty about the groundwater conditions at the landslide site because of insufficient information.

4.3 Laboratory Tests

4.3.1 Soil Samples

The particle size distribution test results (Table 3) indicate that the fines contents of the material retrieved from within the debris trails of the 1998 landslides range from 51% to 84%. The results of Atterberg Limit tests on samples of decomposed tuff from previous ground investigations in the vicinity of the landslide site (Geotechnics & Concrete Engineering, 1988; Hong Kong Testing, 1996; Hong Kong Testing, 1997) as well as the current post-landslide investigation (Public Works Laboratories, 1998) have been plotted in Figure 9. This chart indicates that, in general, the material tested plots below the A-line and may be classified as a high plasticity silt.

In addition, multi-stage consolidated undrained triaxial compression strength tests have been carried out on four samples of the decomposed tuff retrieved from within the general vicinity of the landslide site (Geotechnics & Concrete Engineering, 1988). The shear strength parameters determined from these tests were in the range $c' = 2.2$ kPa, $\phi' = 35.6°$ to $c' = 8.6$ kPa, $\phi' = 37.4°$.

4.3.2 Water Samples

Chemical tests, comprising chloride content determinations, were carried out on two water samples during the current investigation (Public Works Laboratories, 1998). The chloride contents of both samples were found to be insignificant.

5. SURFACE WATER DRAINAGE IN THE VICINITY OF THE LANDSLIDES

The natural form of the spur of Razor Hill into which the concerned feature has been cut is such that in general water sheds towards both Hirams Highway in the northeast and the concerned slope to the west. In addition, immediately to the south of the concerned feature a possible gully/drainage line runs down the western face of the spur from Hiram's Highway above (Figure 2).

Surface water drainage provisions to cut slope No. 11NE-B/C513 appear to have been limited. At the toe of the slope an unlined drainage ditch/concrete U-channel is understood to have run from the junction of the main and subsidiary slopes of the feature to about the mid-portion of the slope before diverting via another concrete U-channel to the west and ultimately outfalling to the adjacent watercourse (Figure 2).

As described in Section 3.2, the surface water drainage provisions at the crest of the cut slope consist of an unlined ditch approximately 0.35 m wide and typically 0.3 m deep. This ditch appears to have run the full length of the feature prior to the recent (1997) landslide when it was severed. A further possible drainage ditch has been identified upslope of slope No. 11NE-B/C513, which is aligned approximately parallel to the crest of the main slope of the concerned feature although no outfall is apparent. Both these drainage features were identified in the field during post-landslide mapping (Figure 2).

In addition, a small gully or footpath, trending approximately ESE-WNW from Hiram's Highway above to the junction of the main and subsidiary slopes of the concerned feature has been observed both during the API and in the field (Sections 2.4.2 and 3.2, and Figures 2 and 3). From site observations made following the landslides this feature appears to run from just below a catchpit on Hiram's Highway down to the junction of the cut slope below. At the time of inspection, the feature was overgrown with vegetation (Plate 18). Eye-witnesses to the landslides advised that during heavy rainfall it was commonplace for water to be observed flowing down probably from the above gully feature to the relatively flat terraced area adjacent to the junction of the cut slope below (Figure 2). This water then flowed across the road running approximately perpendicular to the subsidiary slope of the concerned feature before outfalling to the adjacent watercourse. This observation suggests possible inadequate maintenance of the surface water drainage network on Hiram's Highway above or that this drainage network is not adequate. Photographs taken on 9 June 1998 at the entrance to the Yue Sun Garden Nursery show that the surface water drainage network on Hiram's Highway could not cope with the water that resulted from the rainfall on that day (Plate 6).

Additionally, the eye-witnesses advised FSW that they had observed a steady flow of water along the unlined drainage ditch/U-channel at the toe of the main slope of the concerned feature during previous wet seasons and in particular following heavy rainfall. Water was also seen to be flowing along the toe of the landslide debris during post-landslide field mapping by FSW. This water probably emanated from the junction of the slope feature via the unlined drainage gully/ditch on the hillside above.

6. ANALYSIS OF RAINFALL RECORDS

The nearest GEO automatic raingauge to the landslides at Yue Sun Garden, Wo Mei is raingauge No. N08, located on the roof of the Staff Quarters (Block C), Pik Uk Prison, Pik Uk, Che Kwu Shan about 1.5 km south-southwest of the landslide site (Figure 1). This raingauge records and transmits rainfall data at 5-minute intervals via a telephone line to the GEO.

For the purposes of rainfall analysis and based on eye-witness accounts, it is assumed that the first landslide occurred at 9:00 a.m., the second landslide took place at 6:00 p.m., with the third landslide occurring at 6:30 p.m., all on 9 June 1998.

The daily rainfall recorded by this raingauge for one month preceding, and seven days following these incidents, is presented in Figure 10. This daily rainfall figure shows that the storm was concentrated around the day the landslides occurred, i.e. 9 June 1998. The corresponding hourly data for the period from 6:00 p.m. on 7 June 1998 to 4:00 a.m. on 10 June 1998 is also shown on Figure 10. Peaks in rainfall between 5:00 a.m. and 8:00 a.m., between 11:00 a.m. and 2:00 p.m., and between 4:00 p.m. and 6:00 p.m. on 9 June 1998, generally in the range 40 mm/hr to 60 mm/hr, are indicated by this figure.

Isohyets of rainfall for the 24-hour periods preceding the first and second landslides, and for the 24-hour periods between noon on 8 June 1998 and noon on 9 June 1998, and 3:00 p.m. on 8 June 1998 and 3:00 p.m. on 9 June 1998, are given for the whole of Hong Kong in Figures 11, 12, 13 and 14 respectively. These figures indicate that the rainfall conditions in the Sai Kung area continued to deteriorate from the reported time of occurrence of the first landslide, up to the time of the second landslide on 9 June 1998. In addition, it is also apparent from these figures that the rainfall intensified in the afternoon between 3:00 p.m. and 6:00 p.m.

Tables 4 and 5 present the estimated return periods for the maximum rolling rainfalls recorded at raingauge No. N08 for selected durations preceding the first, second and third landslides, based on historical rainfall data recorded at the Hong Kong Observatory (Lam & Leung, 1994). The 5-minute to 4-hour maximum rolling rainfalls recorded (i.e. short-term storms) for all three landslides were only moderately severe with return periods generally less than 10 years. The 12-hour and 24-hour maximum rolling rainfalls recorded for the second and third landslides were the most severe (351 mm and 462.5 mm, and 351 mm and 468 mm, respectively), with the corresponding return periods ranging from about 30 years to 35 years. Whilst it is acknowledged that this simplified method of analysis does not necessarily give the true rainfall return period for a particular site as several contributory factors are not taken into account (Wong & Ho, 1996b), it does, nonetheless, provide an objective ranking of the likely relative severity of the various rainfall characteristics assessed as well as allowing comparisons with analyses of other rainstorms based on the same approach.

A comparison between the patterns of rainfall preceding the first and second landslides on 9 June 1998 and those of selected previous major rainstorms recorded at raingauge No. N08 is given in Figure 15 (the equivalent plot for the third landslide is approximately coincident with that for the second landslide). It can be seen from this figure that the maximum rolling rainfalls recorded for the 4-hour to 7-day durations for the second landslide were the most severe experienced by the landslide site since installation of

raingauge No. N08 in the mid 1980's. The equivalent plot for the maximum rolling rainfalls recorded for selected durations preceding the first landslide is, however, comparable to those experienced previously at the landslide site.

7. THEORETICAL STABILITY ANALYSIS

Theoretical stability analyses using the rigorous solution of Morgenstern & Price (1965) were carried out to assist in the diagnosis of the probable causes and mechanisms of the landslides. The analyses examined the likely operative range of shear strength parameters along the postulated surfaces of rupture corresponding to landslides, Nos. 1 and 2, for different groundwater conditions at the time of failure. The third landslide took a similar form to the first failure and as such stability analysis is not considered necessary for this relatively minor failure.

Cross-sections through the two landslides on which stability analyses were carried out are presented in Figures 16 and 17 respectively. The pre-failure slope profile was established from topographical survey plans whilst the geometry of the surfaces of rupture is based on site measurements by FSW, post-landslide topographical survey and engineering judgement.

Based on post-failure site inspections by FSW, no exceptionally low strength materials appear to have been involved in the landslides. The soil strength parameters considered for the decomposed tuff of the cut slope have therefore been based on the generalised parameters given for these materials in Table 8 of Geoguide 1 (GEO, 1993) and the results of laboratory tests carried out on the decomposed tuff as part of the ground investigation in 1988 (Section 4.2.2). The soil strength parameters adopted are given in Figures 16 and 17. Various levels of transient elevated pore water pressures above the observed surfaces of rupture were assumed for the purposes of the stability analyses.

The results of these stability analyses are summarised in Figure 18. These indicate that the failures were likely to have occurred due to the development of transient elevated pore water pressures equivalent to a water level of the order of 1 m above the postulated rupture surfaces.

The results also suggest that the magnitudes of the probable operational range of shear strengths and the corresponding pore water pressure required to initiate the first landslide would have been lower than the equivalent combination of parameters required to initiate Landslide No. 2.

8. DIAGNOSIS OF THE PROBABLE CAUSES OF THE LANDSLIDES

8.1 The Modes and Likely Sequence of the Landslides

The shape of the landslide scars together with the disposition of the resultant debris as well as the eye-witness accounts is the key information upon which a reconstruction of the modes and sequence of the failures is based.

Eye-witnesses advised that three distinct landslides occurred within cut slope No. 11NE-B/C513 over a period of approximately 10 hours on 9 June 1998. The first landslide comprised a relatively shallow, spoon-shaped surficial slip, involving a sliding failure of approximately 200 m^3 of material.

Landslide No. 2 (i.e. the major failure) involved the release of about 1,100 m^3 of material and affected both the cut slope and a significant part of the hillside above. The resultant debris generally took the form of a relatively intact slab of decomposed material in a sliding failure mode. The presence of the remnants of a spur-type feature at the junction between the scars of the first and second landslides suggests that the second landslide may not have been a direct extension of Landslide No. 1. The extent to which Landslide No.1 contributed to Landslide No. 2 is not certain.

Landslide No. 3, which also occurred in a sliding failure mode and involved about 50 m^3 of material, appears to have been distinct from the previous two landslides with a section of the slope between this shallow, surficial slip and the main body of landsliding remaining intact. Overall, field mapping suggests that the failures were associated with subsurface water and that washout failure by concentrated surface water flow did not play a significant role in the landslide. A schematic representation of the inferred sequence of events is presented in Figure 19.

8.2 Factors Contributing to the Landslides

The close correlation between the rainfall recorded on 9 June 1998 and the timing of the landslides indicates that all three failures were triggered by rainfall. Furthermore, based on the information collected during this study and the results of the supporting theoretical analyses, it is postulated that the failures are attributable to a combination of the following factors:

(a) development of transient elevated water pressures following relatively severe rainfall,

(b) oversteep slope profiles with inadequate surface drainage provisions,

(c) a history of past instability,

(d) presence of erosion pipes which were noted within the upper few metres of the landslide mainscarps, and

(e) lack of slope maintenance.

8.3 Probable Causes of the Landslides

The landslides occurred in an oversteepened soil cut slope standing at an angle of between 50° and 60°. The surface drainage provisions were inadequate and there has been a lack of maintenance. The failures were probably caused by the development of transient

elevated water pressures due to direct infiltration and positive non-vertical subsurface seepage flow. Water ingress into the near-surface materials would have wetted up the soil mass. Subsequent flow through the soil mass, along preferential flow paths, would have resulted in the development of seepage pressures reducing the shear strength and causing failure.

Both the API and field inspections have revealed a history of past instability, which would have caused local weakening of the soil mass. Major past failures have affected both the cut slope and the hillside above. It appears that the past landslides were not reported to the GEO and that no proper repair works were carried out. It is therefore possible that the previously failed areas of the slope contain loose disturbed material.

The post-landslide geological mapping revealed that the landslide mainscarps comprised completely decomposed tuff, with numerous possible erosion pipes being noted within the upper few metres of these mainscarps. Such erosion features probably promoted rapid water ingress into the slope and thus contributed to the failures.

Landslide No. 1 occurred close to the scar of the 1997 landslide, which was believed to have severed the unlined drainage ditch at the slope crest. This would have promoted concentrated water flow onto the area of the first landslide resulting in enhanced infiltration.

8.4 Discussion

The landslides occurred on an old slope, which has not been the subject of detailed stability assessment or upgrading works. Given an oversteep cut profile, inadequate slope surface protection and drainage provisions, lack of maintenance and severe rainfall, the landslides in 1998 were not a surprise.

The slope has experienced a history of past failures. This clustering of landslides, including major failures that extended into the hillside above, would have provided an indication of the possibility of further large-scale instabilities. None of the past landslides is in the GEO's landslide database and it appears that the unreported failures were not attended to and therefore disturbed material may have remained on the slope prior to the 1998 incidents.

The main landslide of 9 June 1998 was the largest failure in terms of volume in the instability history of the cut slope. This illustrates that in old steep cuttings, the scale of failure may become progressively larger if there is inadequate attention given to past failures. There is insufficient information to assess whether the previous failures were part of the progressive development of a large-scale instability, or whether they were separate distinct events.

Landslide No. 1 on 9 June 1998 of about 200 m^3 in volume was followed by a larger failure (Landslide No. 2) of approximately 1,100 m^3 in volume some 9 hours afterwards. This illustrates the potential hazard of secondary failures at an unstable slope during continuing rainfall, prior to the implementation of emergency repair works. Based on the available information, it is difficult to ascertain the extent of the contribution of the first landslide to the second, main landslide. Given the unfavourable factors discussed in Section 8.2 and a substandard slope subject to severe rainfall, the second landslide could conceivably have

occurred on its own without having been triggered by the loss of lateral support as a result of Landslide No. 1.

9. CONCLUSIONS

It is concluded that the landslides, which occurred on 9 June 1998 within cut slope No. 11NE-B/C513, were triggered by rainfall. The failures affected an old oversteep slope with a history of instability but which has not been the subject of detailed stability assessment or upgrading works. The failures were probably caused by the build-up of transient elevated water pressures in the soil mass, following the severe rainfall that immediately preceded failure.

Other factors that probably contributed to the landslides are the absence of proper surface water drainage provisions on the slope, and the erosion pipes observed in the landslide mainscarps, providing preferential flow paths for water ingress. Also, lack of slope maintenance and absence of repair work to past failures probably resulted in progressive deterioration of the slope condition.

10. REFERENCES

Enpack (1996). Final Field Work Report. Contract No. GE/95/10, Works Order No. GE/95/10.32. Hiram's Highway Improvement, Stage 1 Phase 3, Improvement between Nam Wai and Ho Chung and Upgrading Local Access Roads, Ground Investigation (Section I). Enpack (Hong Kong) Limited.

Enpack (1997). Final Field Work Report. Contract No. GE/95/10, Works Order No. GE/95/10.32A. Hiram's Highway Improvement, Stage 1 Phase 3, Improvement between Nam Wai and Ho Chung and Upgrading Local Access Roads, Ground Investigation (Section II). Enpack (Hong Kong) Limited.

Gammon (1985). Site Investigation Report. Job No.882, EDD Contract No. 10/GCO/83, W.O. PW7/2/11.95. Hiram's Highway Improvement Stage I. Gammon (Hong Kong) Limited.

Geotechnical Control Office (1986a). Hong Kong & Kowloon : Solid and Superficial Geology. Hong Kong Geological Survey, Map Series HGM 20, Sheet No. 11, 1:20 000 scale. Geotechnical Control Office, Hong Kong.

Geotechnical Control Office (1986b). Geology of Hong Kong Island and Kowloon. Hong Kong Geological Survey Memoir No. 2, Geotechnical Control Office, Hong Kong.

Geotechnical Control Office (1988a). Geotechnical Area Studies Programme – Clear Water Bay. Geotechnical Control Office, Hong Kong, GASP Report no. VII, 144p. plus 4 maps.

Geotechnical Engineering Office (1993). Guide to Retaining Wall Design (Geoguide 1) (Second edition). Geotechnical Engineering Office, Hong Kong, 268 p.

Geotechnics & Concrete Engineering (1988). Material Testing Laboratory Report on Laboratory Testing. Contract No. GC/87/08, Works Order No.PW6/3/25.82 Hiram's Highway Improvement, Stage 1 Phase 1. Geotechnics & Concrete Engineering (Hong Kong) Ltd.

Hong Kong Testing (1996). Laboratory Testing Report – Soil. Contract No. GE/95/11, Works Order No. GE/95/11.7. Agreement No. CE77/95, Hiram's Highway Improvement, Stage 1 Phase 3, Improvement between Nam Wai & Ho Chung (Schedule 1). Hong Kong Testing Co. Ltd.

Hong Kong Testing (1997). Laboratory Testing Report – Soil. Contract No. GE/95/11, Works Order No. GE/95/11.7B. Agreement No. CE77/95, Hiram's Highway Improvement, Stage 1 Phase 3, Improvement between Nam Wai & Ho Chung & Upgrading Local Access Roads, GI Section II (Schedule III). Hong Kong Testing Co. Ltd.

King, J.P. (1997). Natural Terrain Landslide Study – The Natural Terrain Landslide Inventory. Geotechnical Engineering Office, Hong Kong, Technical Note TN 10/97, 116 p.

Lam, C.C. & Leung, Y.K. (1994). Extreme Rainfall Statistics and Design Rainstorm Profiles at Selected Locations in Hong Kong. Royal Observatory Technical Note no. 86, 51 p.

Lam Geotechnics (1988). Site Investigation Report. Contract No. GC/87/05, Works Order No. PW7/2/22.84. PWP Item 322TH, Hiram's Highway Improvement, Stage 1 Phase 1. Lam Geotechnics Limited.

Morgenstern, N.R. & Price, V.E. (1965). The analysis of the stability of general slip surfaces. Geotechnique, vol. 15, pp 79-93.

Public Works Laboratories (1998). Soil Testing Report, No.719. Agreement No. : CE74/97, The 1998 Landslide Investigation Consultancy, Detailed Study at Yue Sun Garden, Wo Mei, Off Hiram's Highway, Sai Kung. Public Works Laboratories, Geotechnical Engineering Office, 12 p.

Wong, H.N., & Ho, K.K.S. (1996a). Travel distance of landslide debris. Proceedings of the Seventh International Symposium on Landslides, Trondheim, vol. 1, pp 417-422.

Wong, H.N. & Ho, K.K.S. (1996b). Thoughts on the Assessment and Interpretation of Return Periods of Rainfall. Geotechnical Engineering Office, Hong Kong, Discussion Note DN 2/96, 19 p.

LIST OF TABLES

Table 1 – Summary of Site Development from Aerial Photograph Interpretation

Year	Photograph Reference No.	Altitude (feet)	Observations (refer to Figure 3)
1945	Y00612	20000	The area is largely undeveloped. The cut slope under consideration has not yet been formed. Hiram's Highway is, however, evident.
1954	Y02710, Y02711	29200	The area remains largely undeveloped. Hiram's Highway does not appear to be paved. The cut slope affected by the 1998 landslide has still not been formed. There is a possible large landslide scar within the depression to the south of the concerned slope (not yet formed) and a linear feature (possible gully) on the northern flank of this feature.
1961	Y04923, Y04924	30000	Development of the area has commenced. The "L-shaped" cut slope under consideration in this detailed study, Slope No. 11NE-B/C513, has been formed in the western flank of the north-south trending ridge. The subsidiary slope of the feature is very steep. The feature appears quite "neat" and well-formed. The platform area below is bare. Upgrading works, comprising road realignment/widening and corresponding earthworks (cut/fill slope formation), have been undertaken to the adjacent Hiram's Highway. The linear feature (possible gully) noted in 1954 is again evident although the large landslide to the south is not.
1963	Y08516, Y08517	3900	Trees are evident on the hillside above the crest of the cut slope although there are some large areas which have been cleared of vegetation. A possible relict landslide scar has been identified to the southeast of the feature in a depression on the western face of the north-south trending ridge. In addition, there is a small, approximately EastSouthEast-WestNorthWest (ESE-WNW) trending gully in the hillside between this feature and the junction between the main and subsidiary slopes of the concerned feature. The gully appears man-made. No cultivation or buildings are evident on the platform below the cut slope. Extensive

Year	Photograph Reference No.	Altitude (feet)	Observations (refer to Figure 3)
			terracing and cultivation are, however, noted to the west of the feature, adjacent to the river. Some ravelling of the face of the main slope is evident with associated small debris fans at the toe of the feature. The source of this debris is unclear due to the reflectance of the photographs.
1964	Y10909, Y10910	1800	Good quality photographs. The cut slope is clear. A shallow failure is evident within the main slope adjacent to Hiram's Highway. Similar localised surface erosion and debris fans as in 1963 photographs evident (possibly the same feature). There are several shrubs on the cut slope. The ESE-WNW trending gully above the junction of the cut slope noted on the 1963 photographs is still visible but becoming overgrown with vegetation. It is now clear that this feature is linked to the road above via a channel A small access track (for the o/h electricity pylon?) has been cut into the eastern side of the north-south trending ridge, off Hiram's Highway. In addition, a grave has been constructed in one of the cleared areas noted on the 1963 photographs. Vegetation is re-establishing itself on the cleared area adjacent to the crest of the main slope. A linear feature, possibly a small path, running approximately parallel to the crest line of the main slope, is evident within the wooded area on the hillside above the feature under consideration. There are no indications of cultivation having taken place nor is there any evidence of building on the platform below the cut slope.
1967	Y13428, Y13429	6250	Very good quality photographs. Shrubs are evident on the cut slope. The platform at the toe of the cut slope has been

Year	Photograph Reference No.	Altitude (feet)	Observations (refer to Figure 3)
			cultivated, and small plots can be seen. In addition, there is a small building on the western edge of the platform. Also, an access road from the adjacent Hiram's Highway is noted leading onto the platform. The ESE-WNW trending gully above the junction of the feature is not so obvious on these photographs but there is a photolineament trending along a similar orientation, from the junction of the feature to the road on the other side of the hill.
1974	9299, 9300	4000	The area is mostly in shadow. Two possible landslide scars noted to the southeast of the concerned slope (in a similar area to that noted in the 1954 photographs). The north-south trending ridge is largely heavily-vegetated. Otherwise no further changes apparent.
1976	15383, 15384	4000	The concerned feature appears to have failed in two places along the main southwest facing slope. Landslipping appears to have extended into the hillside above. Mature vegetation is present on the slope between and on either side of these two slips. In addition, there may be a small erosion scar within the southern part of the main slope of the feature. Mature vegetation is also noted on the hillside above the cut slope and on the platform below. There is a new building at the toe of the slope whilst the building first noted on the 1967 photographs is no longer present. The access road onto the lower platform from the adjacent Hiram's Highway remains clear. Vegetation clearance has been carried out in an area adjacent to Hiram's Highway on the eastern side of the hill.
1977	20267, 20268	4000	Possible failed area of slope adjacent to the building at the toe (may be additional cutting associated with the erection of this building or the remnants of one of the landslips noted in 1976). The northernmost scar noted in the 1976

Year	Photograph Reference No.	Altitude (feet)	Observations (refer to Figure 3)
			photographs still appears relatively fresh, indicating possible further shallow failure although there is no debris to substantiate this observation. Buildings are now present on the cleared area on the eastern side of the hill adjacent to Hiram's Highway. Otherwise, no other changes apparent.
1984	57422, 57423	4000	The cut slope affected by the 1998 landslide is almost completely obscured by mature vegetation. One building at the toe, however, is visible. There appears to be a photolineament (possibly a path) running from the platform on the eastern side of the hill to the southwest.
1985	A00961, A00962	4000	The area below the cut slope appears to be generally 'tidier'. Several shade racks have been constructed at the toe of the main southwest facing slope of the feature. The hillside above the cut slope is heavily-vegetated. Otherwise, no further changes evident.
1986	A06319, A06320	4000	The cut slope remains heavily-vegetated. Possible shade racks at toe of cut slope. Otherwise, no further changes apparent.
1987	A10896, A10897	4000	Although the feature under consideration is largely in shadow it appears to be heavily-vegetated. A possible small erosion scar is evident on the hillside just above the main southwest facing slope of the feature.
1988	A14729, A14730	4000	Good quality photographs. A building is noted on the platform adjacent to the junction of the cut slope. Shade racks are also noted adjacent to the cut slope. Both the cut slope and hillside above appear heavily-vegetated.
1990	A23618, A23619	4000	Road widening works, with associated cutting, have been completed on the apex of the bend of Hiram's Highway forming the northern and eastern sides of the hillside (registered cut Slope No. 11NE-B/C19).

Year	Photograph Reference No.	Altitude (feet)	Observations (refer to Figure 3)
			Otherwise no further changes apparent. The slopes remain heavily-vegetated.
1991	A27526, A27527	4000	There appears to have been some vegetation trimming (or possibly hillfire?) in the area, as the cut slope, Feature No. 11NE-B/C513, is more visible in these photographs. The hillside above the cut slope, however, remains heavily-vegetated. Otherwise no further changes evident.
1992	A32818, A32819	4000	The area at the toe of the main southwest facing slope of the feature, adjacent to the junction with the subsidiary slope of the feature, has been cleared of vegetation (or possibly the remains of a small slip). In addition, areas cleared of vegetation noted on the hillside above the cut slope. Otherwise, no further changes apparent.
1993	CN4611, CN4612 A36093, A36094	4000 4000	Very good quality colour photographs. Two possible small slips noted within Slope No. 11NE-B/C513 – one behind the shade racks and one adjacent to Hiram's Highway. These slips appear to extend up into the hillside above.
1994	A39278, A39279	4000	Several additional buildings are evident on the platform at the toe of the cut slope. In addition, vegetation clearance (or possibly the remains of a small slip) noted at the back of the storage building (damaged in the 1998 landslide) adjacent to the junction of the cut slope.
1995 (Jul) (Sept)	CN9913, CN9914 CN11379, CN11380	 3500 3500	Vegetation clearance (or possibly the remains of small slips) noted behind the storage building and the adjoining shade racks at the toe of the cut slope. In addition, three possible slip scars observed adjacent to Hiram's Highway. Otherwise, no further changes apparent.
1996	CN15850, CN15851	4000	Several additional buildings appear to have been erected between the shade racks and Hiram's Highway. Otherwise, no further changes apparent.
1997	CN17264, CN17265	4000	No further changes apparent.

Table 2 – Summary of Sources of Information

Source	Documents
GEO Planning Division	(a) Relevant available aerial photographs (see Table 1 for details). (b) Natural Terrain Landslide Inventory (NTLI). (c) Terrain Classification Map
Hong Kong Geological Survey	HKGS Section's Field Notes, Field Data Master and Original Traverse Master.
GEO Mainland East Division	(a) File GCME 2/E2/98-1/ME (Parts 1-3). (b) Slope File GCME 2/E1/11NE-B/C18 (c) Slope File GCME 2/E1/11NE-B/C19
Civil Engineering Library (CEL) of the Civil Engineering Department (CED)	(a) 1977/78 Catalogue of Slopes (b) NTLI (c) SIFT Phase 2 Study Map Sheet Report 1:1000 Map Sheet No. 11NE-5A August 1996 Planning Division, GEO OG53 – 66014
Geotechnical Information Unit (GIU) at the CEL	(a) GIU Ref 6867 Site Investigation Report Job No. 882 EDD Contract No. 10/GCO/83 W.O. PW 7/2/11.95 Hiram Highway Improvement Stage I Gammon (Hong Kong) Limited November 1985 (b) GIU Ref 11668 Site Investigation Report Fieldwork Report Contract No. GC/87/05 Works Order No. PW 7/2/22.84 PWP Item 322 TH Hiram's Highway Improvement Stage 1, Phase 1 Lam Geotechnics Limited January 1989 (c) GIU Ref 26453 Contract No. GE/95/10 Works Order No. GE/95/10/32 Hiram's Highway Improvement Stage 1, Phase 3 Improvement Between Nam Wai and Ho Chung and Upgrading Local Access Roads Ground Investigation (Section I)

Source	Documents
	Final Field Work Report Enpack (Hong Kong) Limited October 1996 (d) GIU Ref 25828 Contract No. GE/95/10 Works Order No. GE 95/10.32A Hiram' s Highway Improvement Stage 1, Phase 3 Improvement Between Nam Wai and Ho Chung and Upgrading Local Access Roads Ground Investigation (Section II) Final Field Work Report Enpack (Hong Kong) Limited March 1997
GEO Slope Safety Division	SIRST Records for Slope Nos. 11NE-B/C513 and 11NE-B/C19.
GEO Publications, Reports, Maps, Memoirs	(a) Geotechnical Control Office (1988). Geotechnical Area Studies Programme – Clear Water Bay GASP Report No. VII. (b) Geotechnical Control Office (1986). Hong Kong and Kowloon: Solid and Superficial Geology. Hong Kong Geological Survey, Map Series HGM20, Sheet No. 11, 1:20 000 scale. (c) Geotechnical Control Office (1986). Geology of Hong Kong Island and Kowloon. Hong Kong Geological Survey Memoir No. 2.
GEO Landslide Incident Report Database	Records of reported and inspected landslide incidents. None relevant.
GEO Landslip Investigation Division	SIS database – slope registration details.
LPM Database	No relevant information.
GEO Design Division	(a) Slope Files – none relevant. (b) Database – no relevant information. (c) Cut Slope Master List – Slope registration details. (d) File GCD 2/A1/538

Source	Documents
Buildings Department (BD)	Plan Viewing Unit – no relevant information.
Fugro (Hong Kong) Limited	Highway's Department Hong Kong Agreement No CE29/94 Roadside Slope Inventory and Inspections, FMR Consultants (Fugro (Hong Kong) Limited, Mouchel Asia Limited, Rendel Palmer & Tritton (Asia) of High Point Rendel (Hong Kong) Limited). Neither slopes were inspected under this consultancy.
Lands Department, SIMAR Unit, Estate Management Section	Slope Report for Cut Slopes Nos. 11NE-B/C513 & 11NE-B/C19 (1) & (2).
District Lands Office/Sai Kung, Lands Department	Old survey maps and plans of the area under study.
District Survey Office/Sai Kung, Lands Department	File P.N.T.: S3295
Scott Wilson (Hong Kong) Ltd Library	Ref No. 72813 Investigation Report on Squatter and Licenced Areas – area affected by the 1998 landslide not included in this report.
Interviews with Concerned Persons	Regarding timing of various phases of landsliding.
Hong Kong & China Gas Co., Ltd	Existing utility information – Proposed High Pressure pipe at the toe of the slope under consideration.
Hong Kong Telecom Co., Ltd	Existing utility information – no existing or proposed plant within the vicinity of the landslide.
Wharf Cable Ltd	Existing utility information – no existing plant within the vicinity of the landslide.

Source	Documents
Hutchison Telephone (HK) Ltd	Existing utility information – no existing underground plant within the vicinity of the landslide.
New T&T Hong Kong Ltd	Existing utility information – no existing plant within the vicinity of the landslide.
New World Telephone Ltd	Existing utility information – no existing or proposed plant or services within the vicinity of the landslide.
WSD/ Mainland South East	Existing utility information – no existing plant within the immediate vicinity of the landslide.
HyD/NTEast	Existing utility information – no record of services within the slope immediately abutting Hiram' s Highway.
DSD/MS	Existing utility information – drainage plans viewed, no existing plant in the vicinity of the landslide.
Rediffusion (HK) Ltd	Existing utility information – no existing plant within the vicinity of the landslide.
China Light & Power Co., Ltd	Existing utility information – no existing plant within the immediate vicinity of the landslide.

Table 3 – Laboratory Test Results

Soil Sample No.		FSW 66/1	FSW 66/2	FSW 66/3
Plastic Limit (%)		35	32	29
Plasticity Index (%)		36	19	22
Particle Size Distribution				
BS Sieve	Particle Size	% Smaller by Weight		
63 mm		100	100	100
20 mm		100	100	100
6.3 mm		99	91	100
2 mm		97	84	100
600 μm		90	68	94
212 μm		85	57	87
63 μm		81	51	84
	0.020 mm	73	44	71
	0.006 mm	62	29	51
	0.002 mm	45	12	24

Note:

Visual descriptions of Soil Samples are summarized as follows:

Sample FSW 66/1 – Dry reddish brown slightly gravelly, slightly sandy SILT/CLAY.
Sample FSW 66/2 – Moist brown mottled yellow slightly gravelly, slightly sandy SILT.
Sample FSW 66/3 – Moist dark reddish brown mottled yellow slightly sandy SILT.

Water Sample No.	FSW 66/W1	FSW 66/W2
Chloride Content (as Cl^-) (mg/L)	9.8	7.1

Table 4 - Maximum Rolling Rainfalls at GEO Raingauge No. N08 and Estimated Return Periods for Different Durations Preceding the First and Second Landslides on 9 June 1998

Duration	Maximum Rolling Rainfall (mm)	End of Period (Hours)	Estimated Return Period (Years)
5 Minutes	10	06:10 on 9 June 1998	2
	10	06:10 on 9 June 1998	2
15 Minutes	20.5	03:15 on 9 June 1998	2
	23	16:55 on 9 June 1998	2
1 Hour	60.5	06:45 on 9 June 1998	2
	62	17:05 on 9 June 1998	2
2 Hours	116.5	07:25 on 9 June 1998	5
	116.5	07:25 on 9 June 1998	5
4 Hours	172.5	08:40 on 9 June 1998	6
	172.5	08:40 on 9 June 1998	6
12 Hours	250	08:55 on 9 June 1998	6
	351	17:05 on 9 June 1998	30
24 Hours	269	08:55 on 9 June 1998	4
	462.5	18:00 on 9 June 1998	32
48 Hours	274	08:55 on 9 June 1998	2
	478.5	18:00 on 9 June 1998	18
4 Days	319.5	09:00 on 9 June 1998	2
	524	18:00 on 9 June 1998	10
7 Days	398.5	09:00 on 9 June 1998	3
	604.5	18:00 on 9 June 1998	12
15 Days	480.5	09:00 on 9 June 1998	2
	688	18:00 on 9 June 1998	7
31 Days	805.5	09:00 on 9 June 1998	4
	1013	18:00 on 9 June 1998	16

Notes :

(1) Return periods were derived from Table 3 of Lam & Leung (1994).

(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to 48 hours, and from hourly rainfall data for longer rainfall durations.

(3) The use of 5-minute data for durations between 2 hours and 48 hours results in better data resolution, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.

Table 5 - Maximum Rolling Rainfalls at GEO Raingauge No. N08 and Estimated Return Periods for Different Durations Preceding the Third Landslide on 9 June 1998

Duration	Maximum Rolling Rainfall (mm)	End of Period (Hours)	Estimated Return Period (Years)
5 Minutes	10	06:10 on 9 June 1998	2
15 Minutes	23	16:55 on 9 June 1998	2
1 Hour	62	17:05 on 9 June 1998	2
2 Hours	116.5	07:25 on 9 June 1998	5
4 Hours	172.5	08:40 on 9 June 1998	6
12 Hours	351	17:05 on 9 June 1998	30
24 Hours	468	18:20 on 9 June 1998	35
48 Hours	484.5	18:20 on 9 June 1998	18
4 Days	529	18:30 on 9 June 1998	10
7 Days	610.5	18:30 on 9 June 1998	13
15 Days	694	18:30 on 9 June 1998	8
31 Days	1019	18:30 on 9 June 1998	16

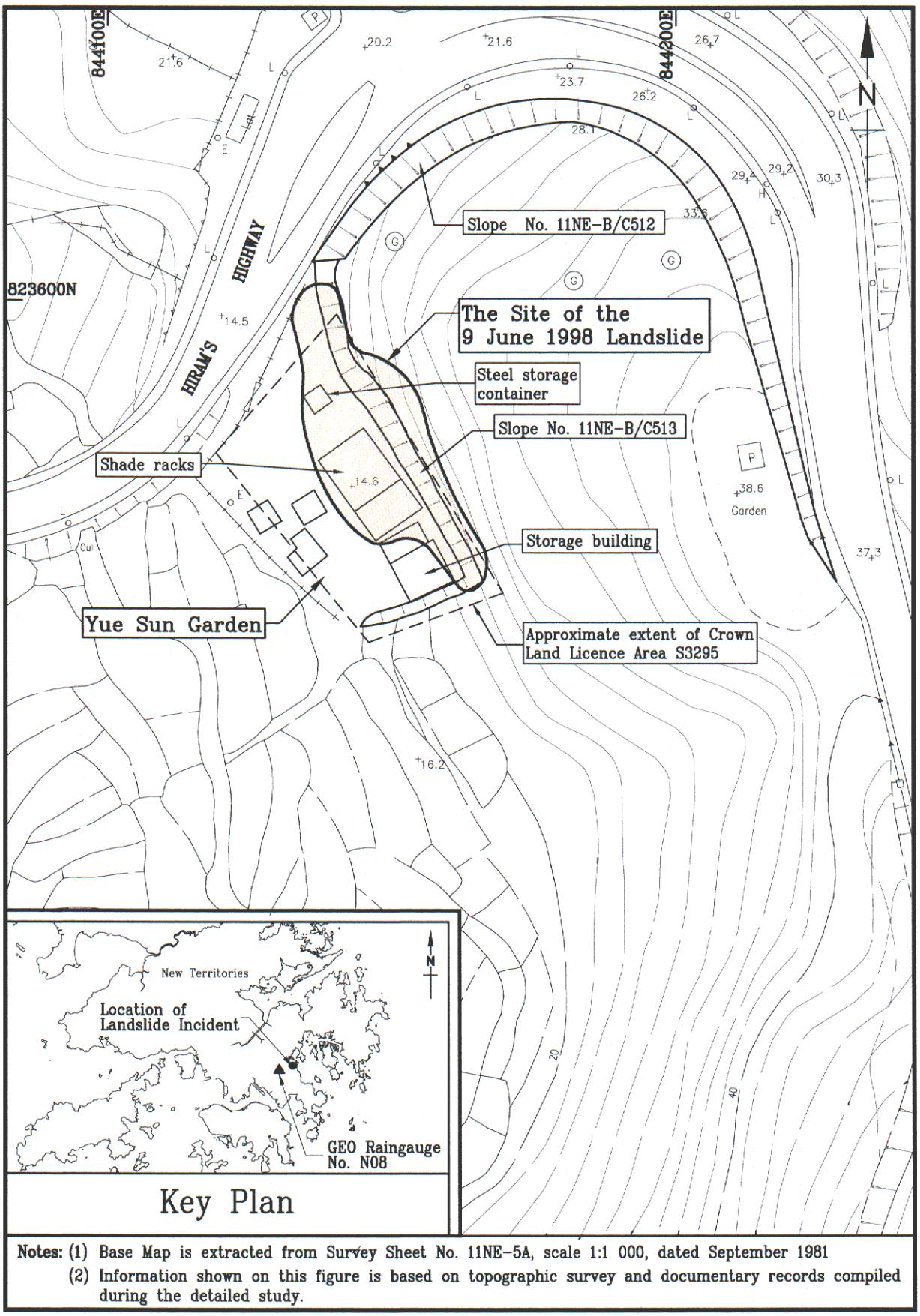
Notes :

(1) Return periods were derived from Table 3 of Lam & Leung (1994).

(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to 48 hours, and from hourly rainfall data for longer rainfall durations.

(3) The use of 5-minute data for durations between 2 hours and 48 hours results in better data resolution, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.

LIST OF FIGURES



Notes: (1) Base Map is extracted from Survey Sheet No. 11NE-5A, scale 1:1 000, dated September 1981

(2) Information shown on this figure is based on topographic survey and documentary records compiled during the detailed study.

Figure 1 - Site Location Plan

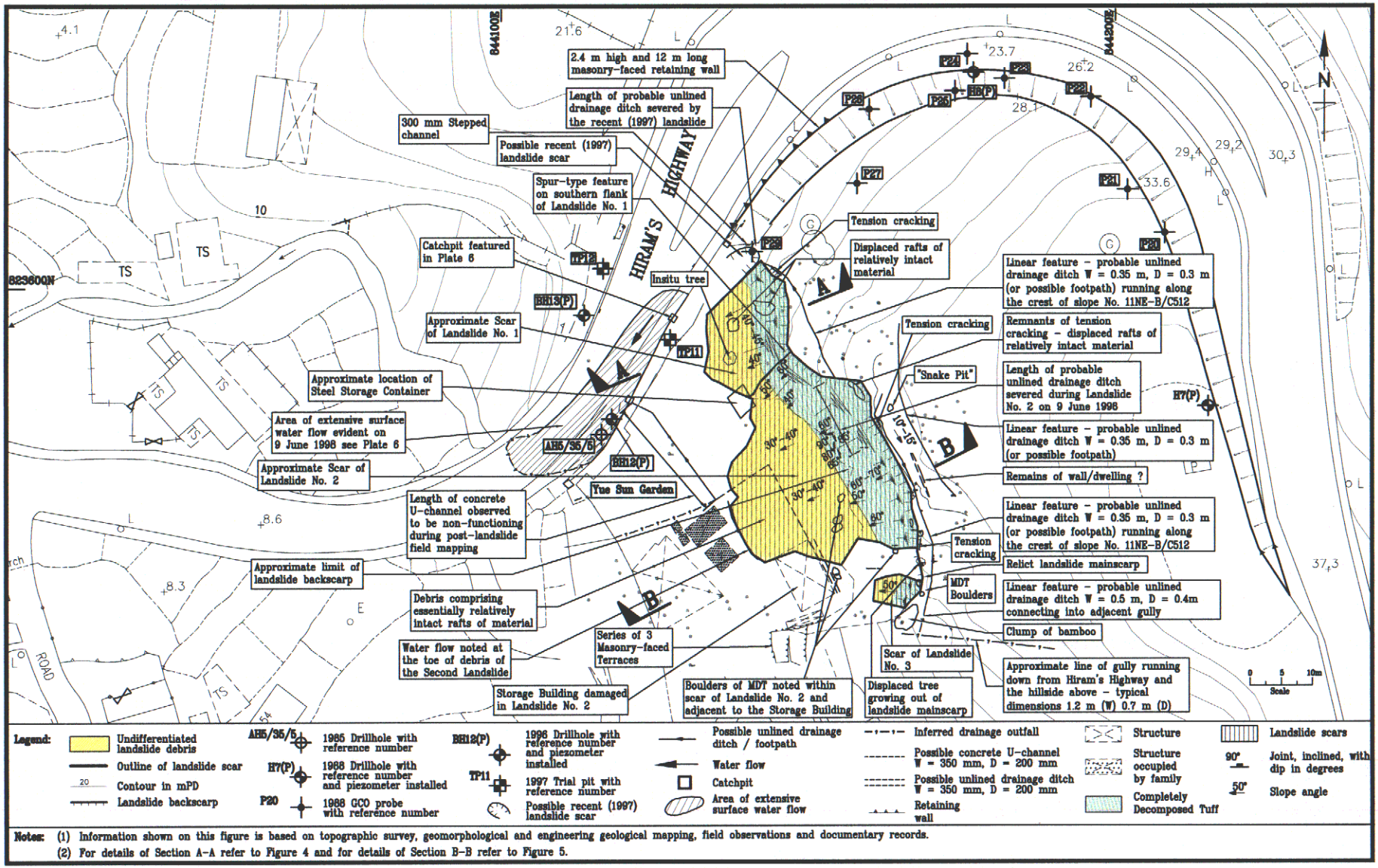


Figure 2 - Plan of the Landslides

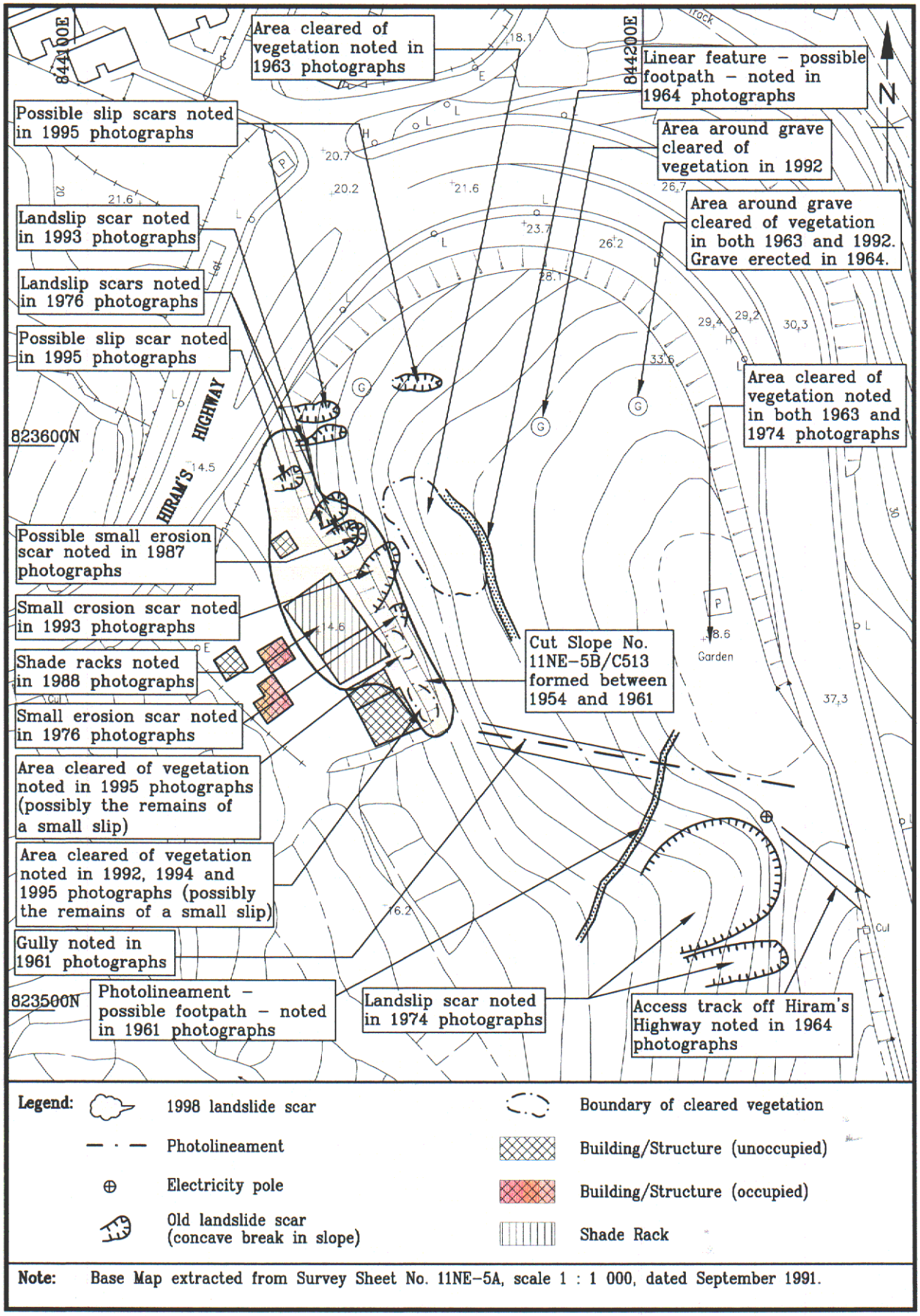
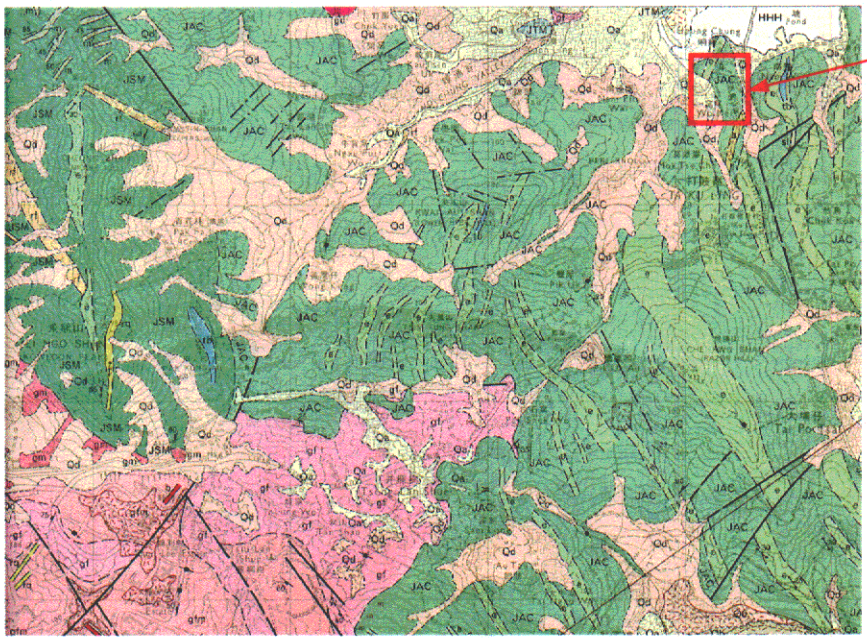


Figure 3 - History of Site Development



LEGEND:

SUPERFICIAL DEPOSITS (Onshore)

	主要物質成份 PRINCIPAL MATERIALS
	填泥和廢物 Natural earth and waste
Qb	砂 Sand
Qa	分選性頗好至中等的粘土／粉砂、砂和礫石 Clay/silt, sand and gravel; well-sorted to semi-sorted
Qat	分選性頗好至中等的砂、礫、粉砂和粘土 Sand, gravel, silt and clay; well-sorted to semi-sorted
Qd	未分選的砂、礫至漂礫，基質爲粘土／粉砂 Unsorted sand, gravel, cobbles and boulders; clay/silt matrix
Qt	礫石、中礫和漂礫 Gravel, cobbles and boulders
Qdt	Qd和Qt的混合物 Mixed Qd and Qt

SOLID GEOLOGY

	主要岩石類型／特徵 PRINCIPAL ROCK TYPES/CHARACTERS
JTM	粗火山灰晶屑凝灰岩 Coarse ash crystal tuff
JAC	細火山灰玻屑凝灰岩 Fine ash vitric tuff
JSM	細粒至粗粒火山灰凝灰岩、凝灰角礫岩和層凝灰岩 Fine ash to coarse ash tuffs, tuff-breccia and tuffite

GEOLOGICAL LINES

- Geological boundary, superficial deposits
- 1982 Fill boundary, with limit of reclamation at date shown
- Geological boundary, solid rock
- Fault (crossmark indicates downthrow side)
- Mineral vein
- Photogeological lineament

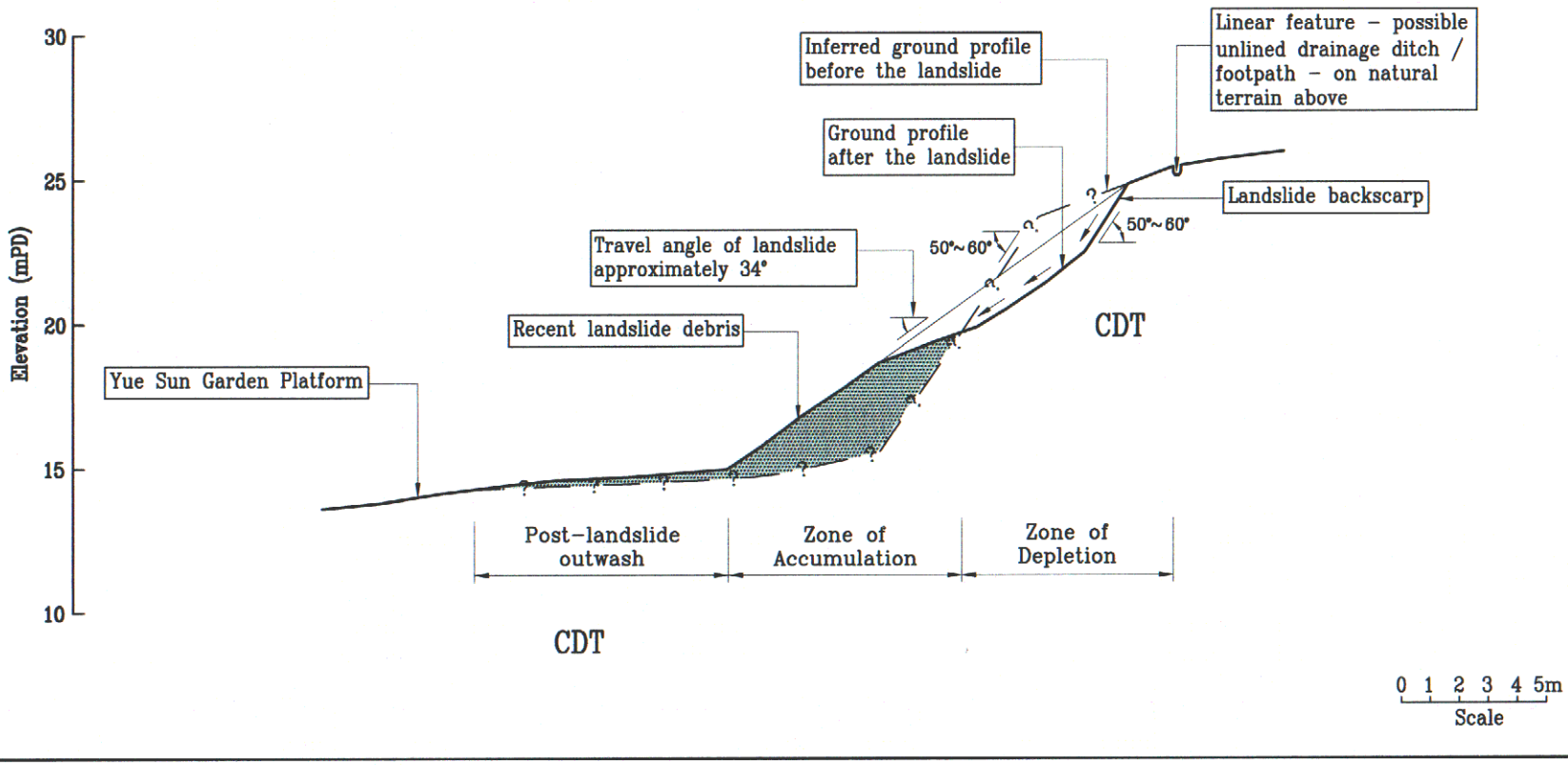
STRUCTURAL SYMBOLS

傾斜 Inclined

- Bedding
- Flow fabric
- Intrusive contact
- Jointing

Notes: Extracted from Hong Kong Geological Survey Sheet 11 (1:20,000) Map Series HGM20 (GCO, 1989)

Figure 4 – Regional Geology



Legend :

Recent landslide debris — Inferred boundary

Postulated surface of rupture — CDT — Completely Decomposed Tuff

Notes :

(1) See Figure 2 for location of section.

(2) Information shown on this figure is based on site measurements, topographical survey, post–landslide field mapping and documentary records.

Figure 5 - Section A-A through Landslide No. 1

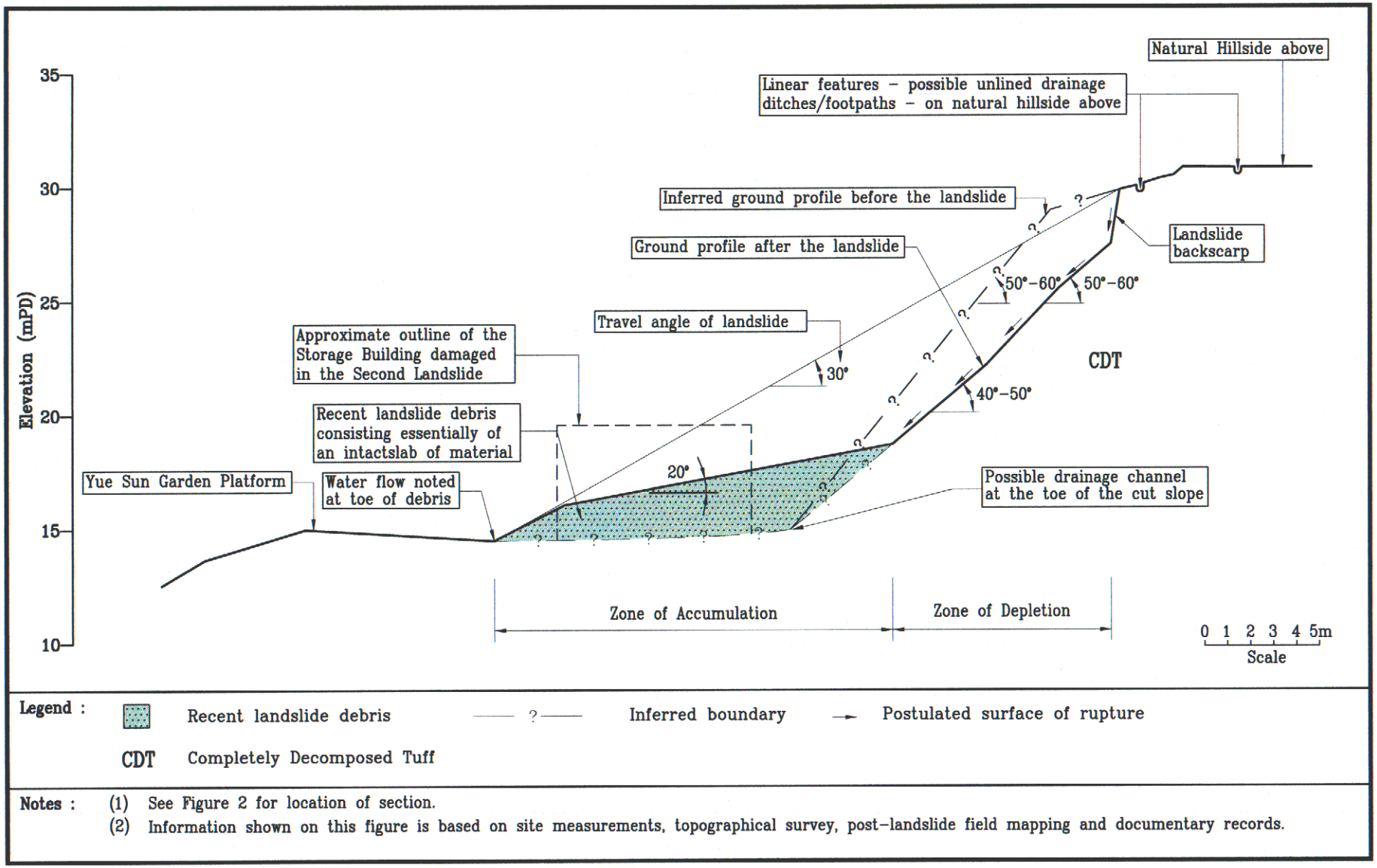


Figure 6 - Section B-B through Landslide No. 2

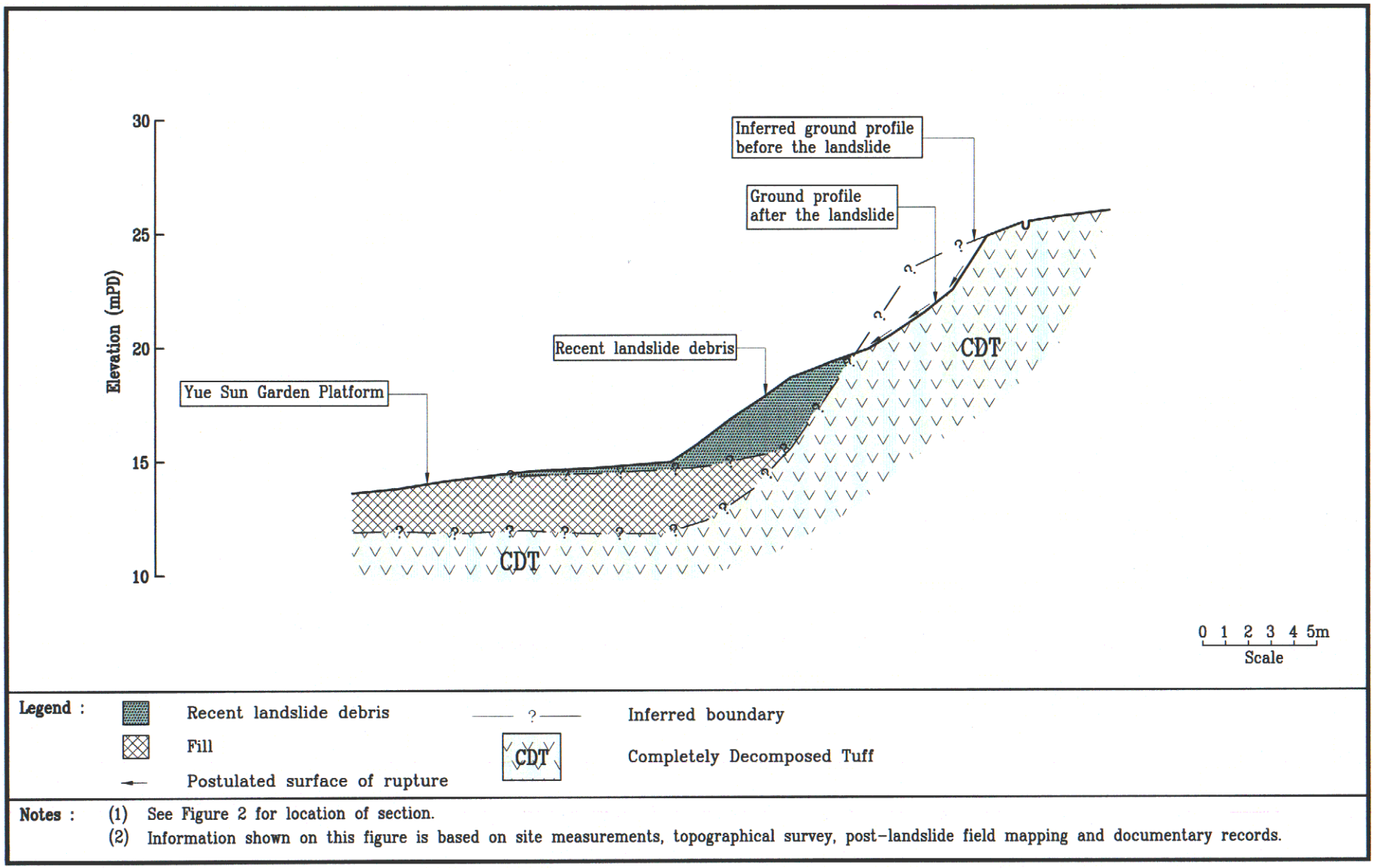


Figure 7 - Section Showing the Inferred Ground Conditions at the First Landslide Site

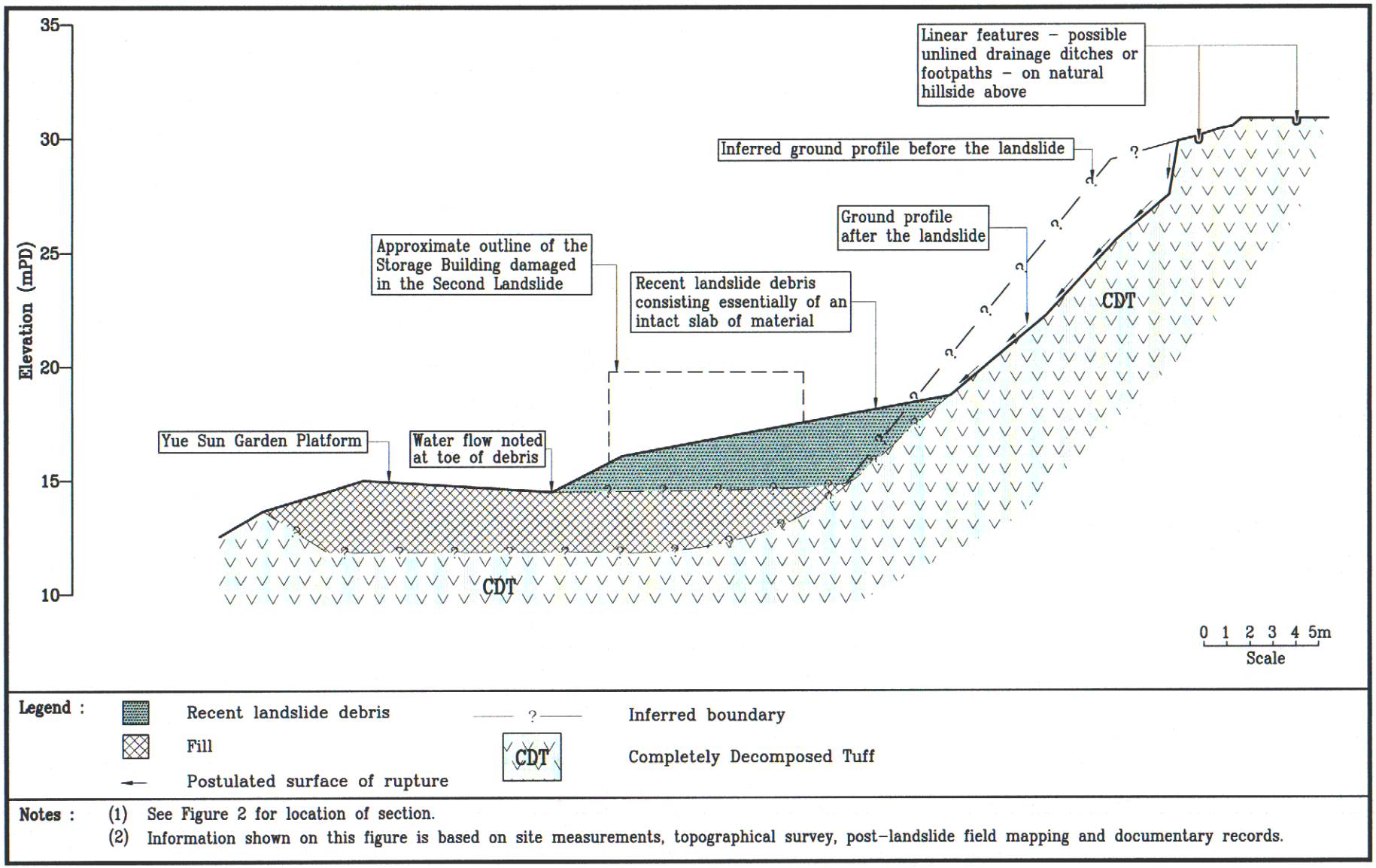
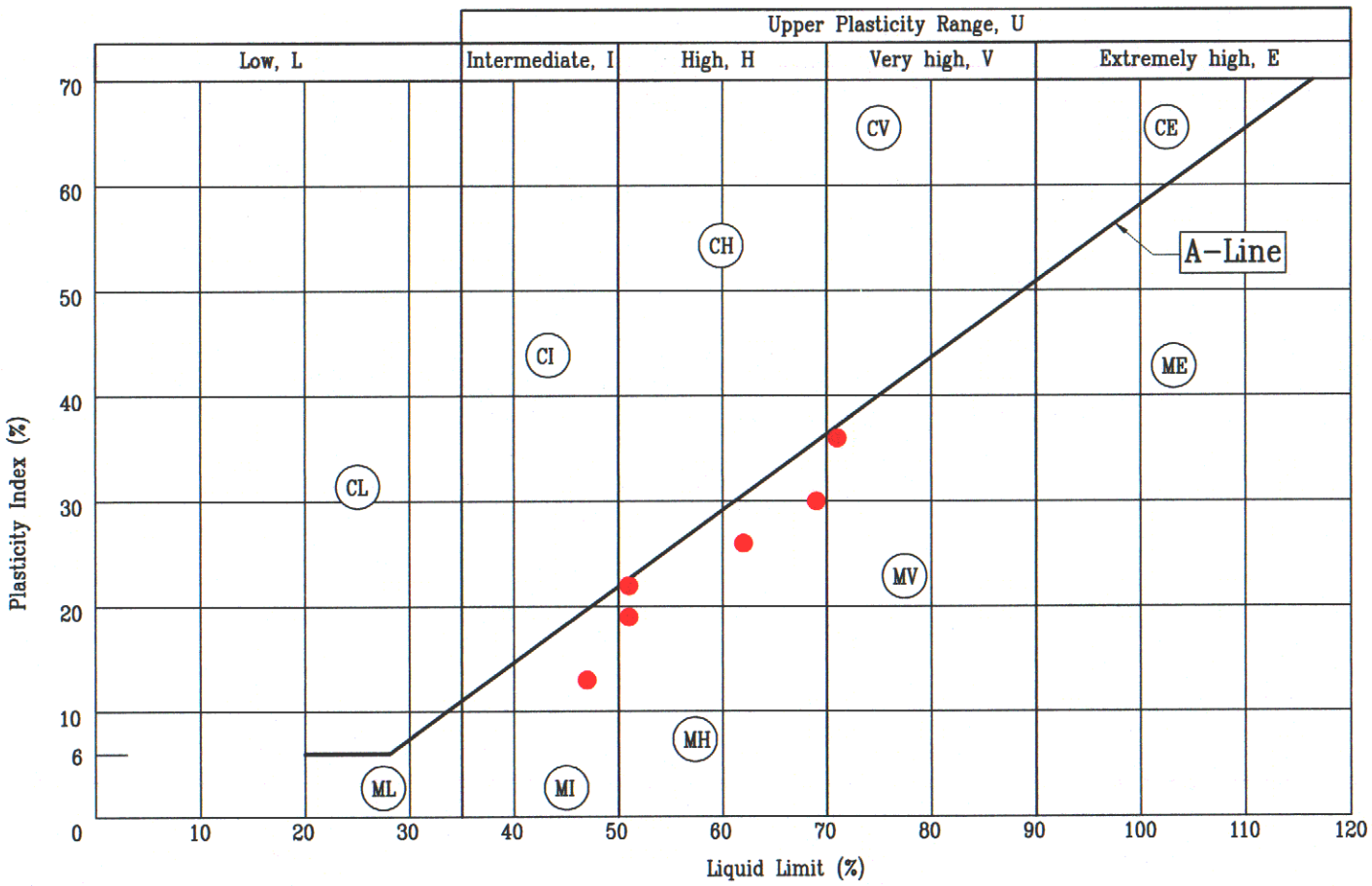


Figure 8 - Section Showing the Inferred Ground Conditions at the Second Landslide Site



Notes : (1) Plasticity determinations are made on material passing 425 μm BS sieve.
(2) Figure is based on Standard Plasticity Chart given in Geoguide 3 (GCO, 1988b).

Figure 9 - Atterberg Limit Plot

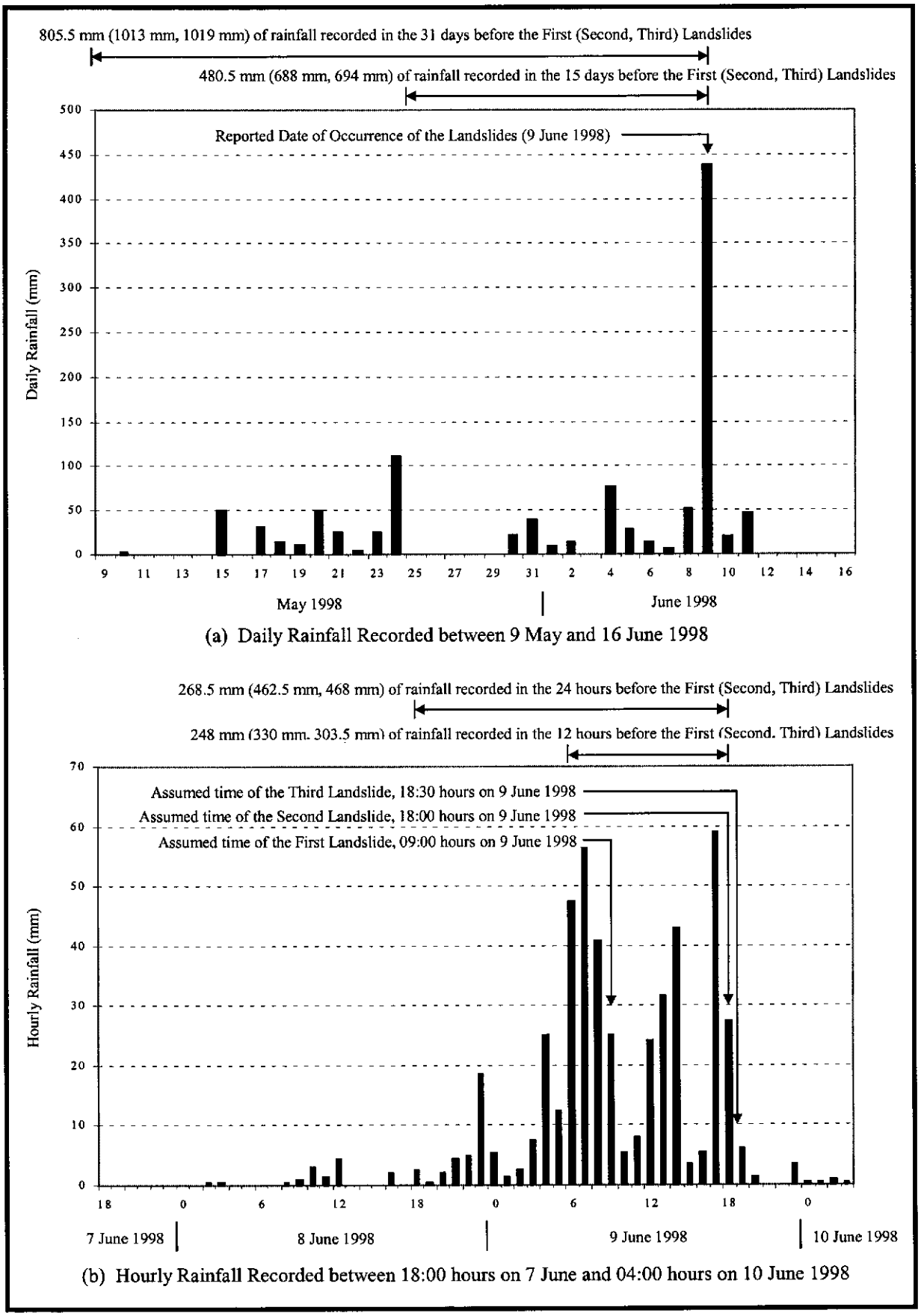


Figure 10 – Rainfall Recorded at GEO Raingauge No. N08

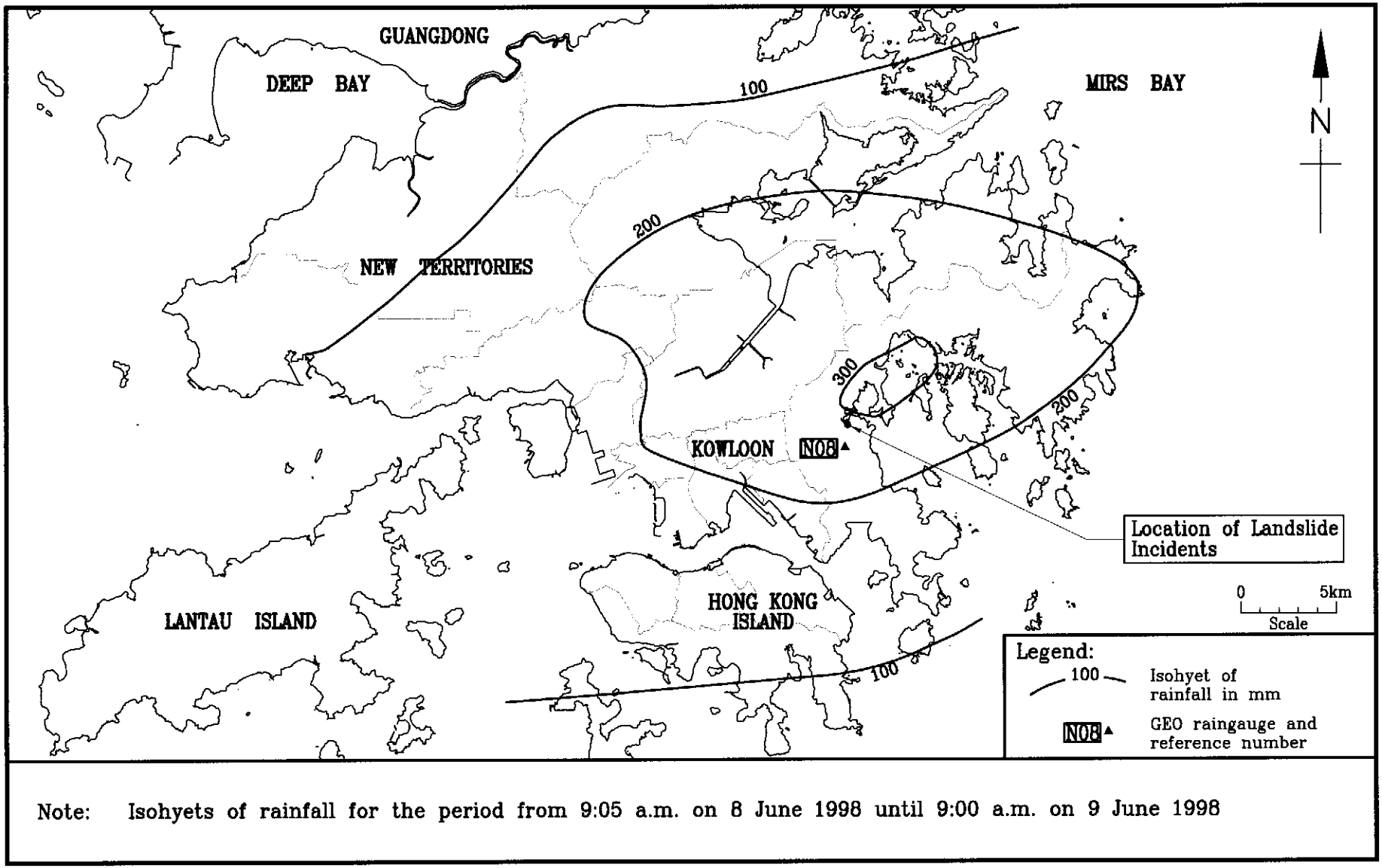


Figure 11 - Rainfall Distribution in the 24 hour Period Preceding Landslide No. 1 on 9 June 1998

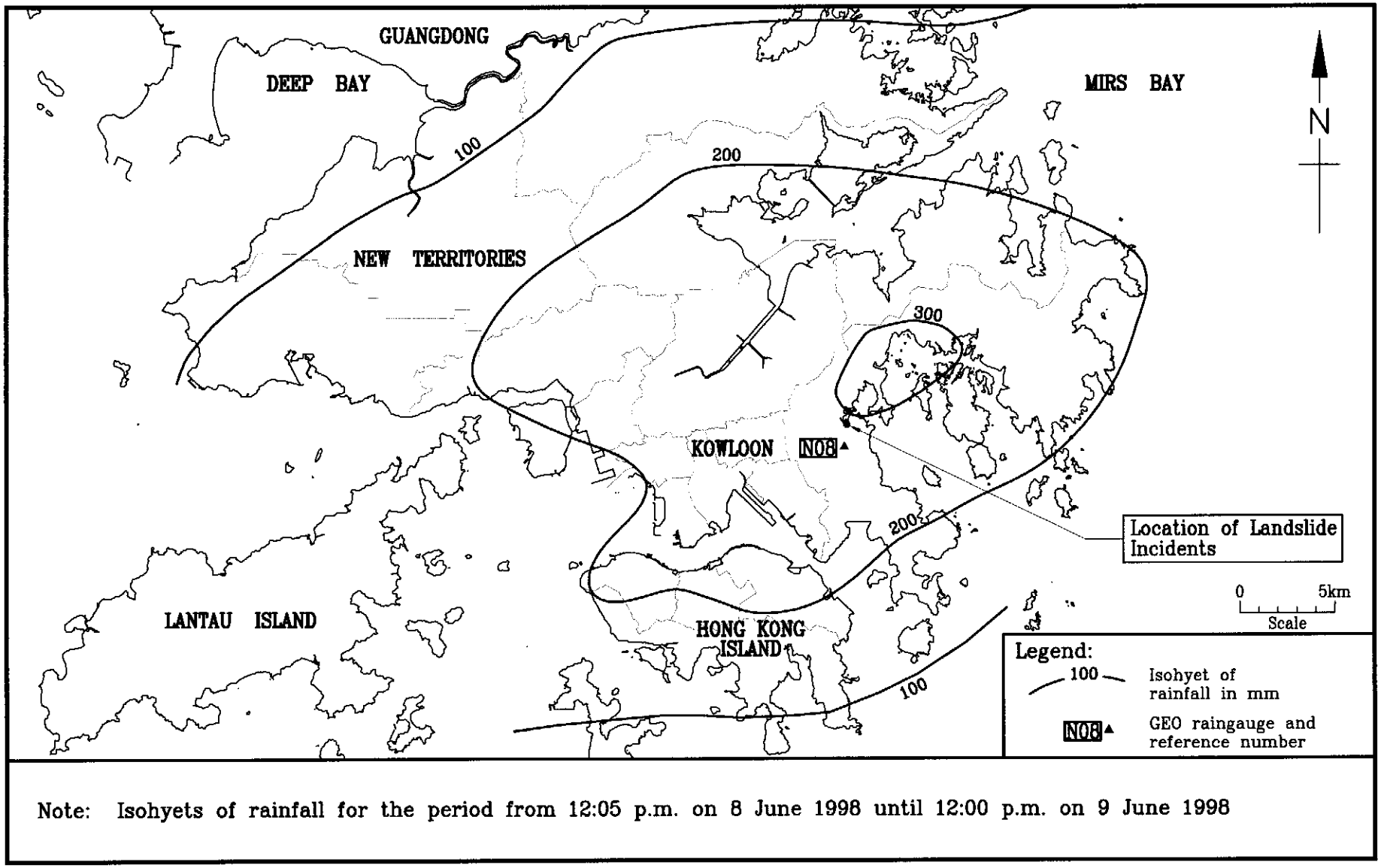


Figure 12 - Rainfall Distribution in the 24 hour Period Between Noon on 8 June 1998 and Noon on 9 June 1998

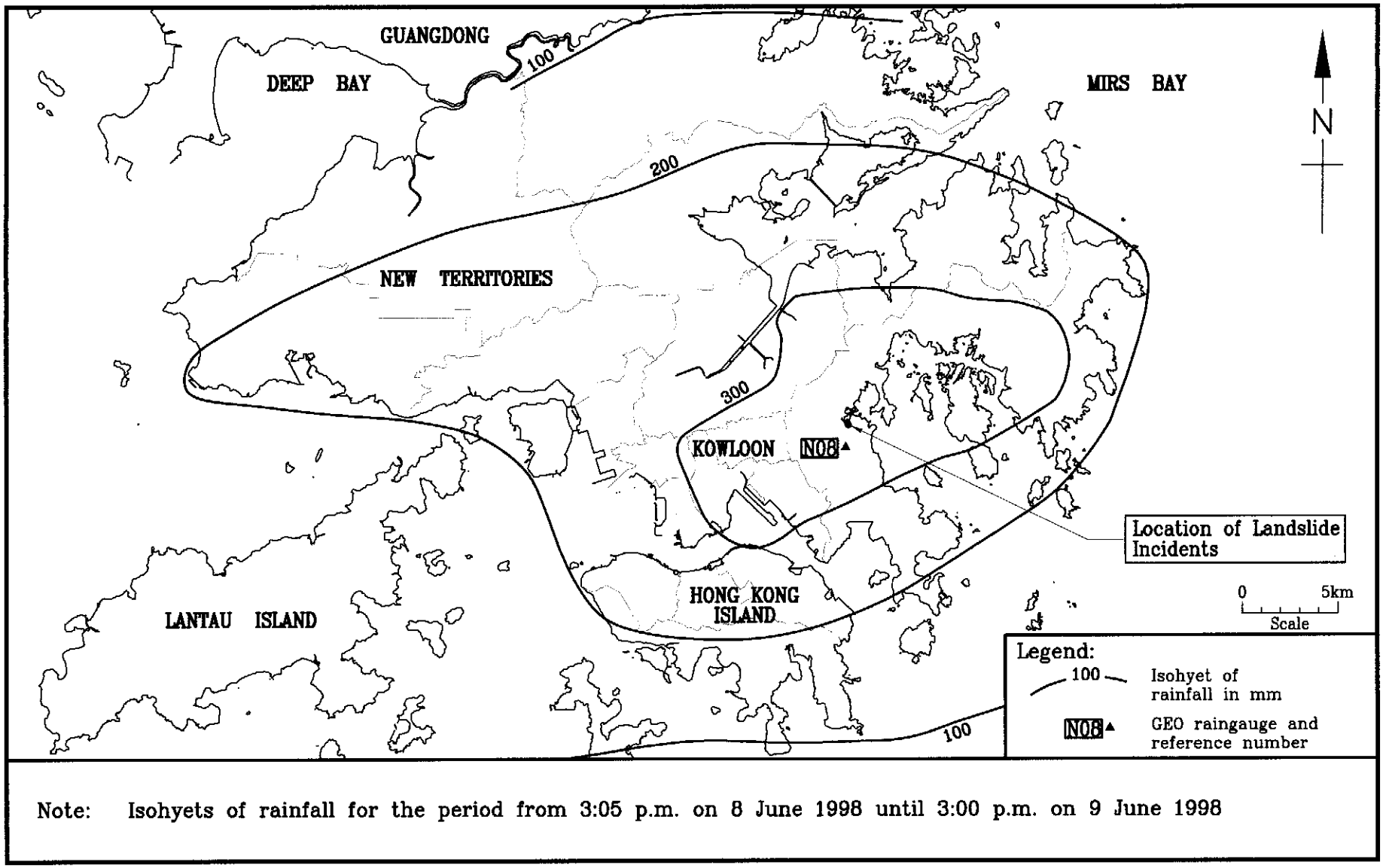
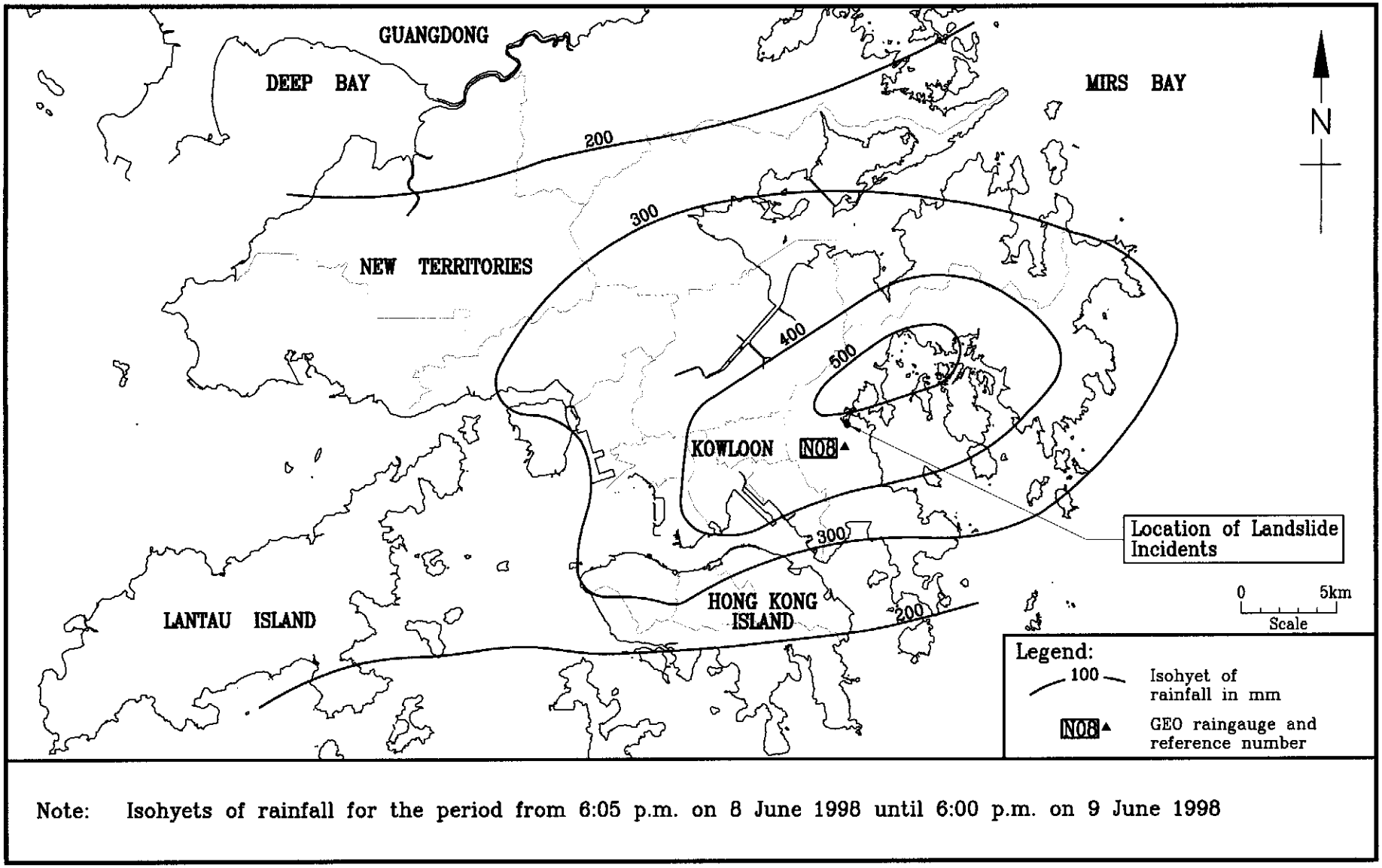
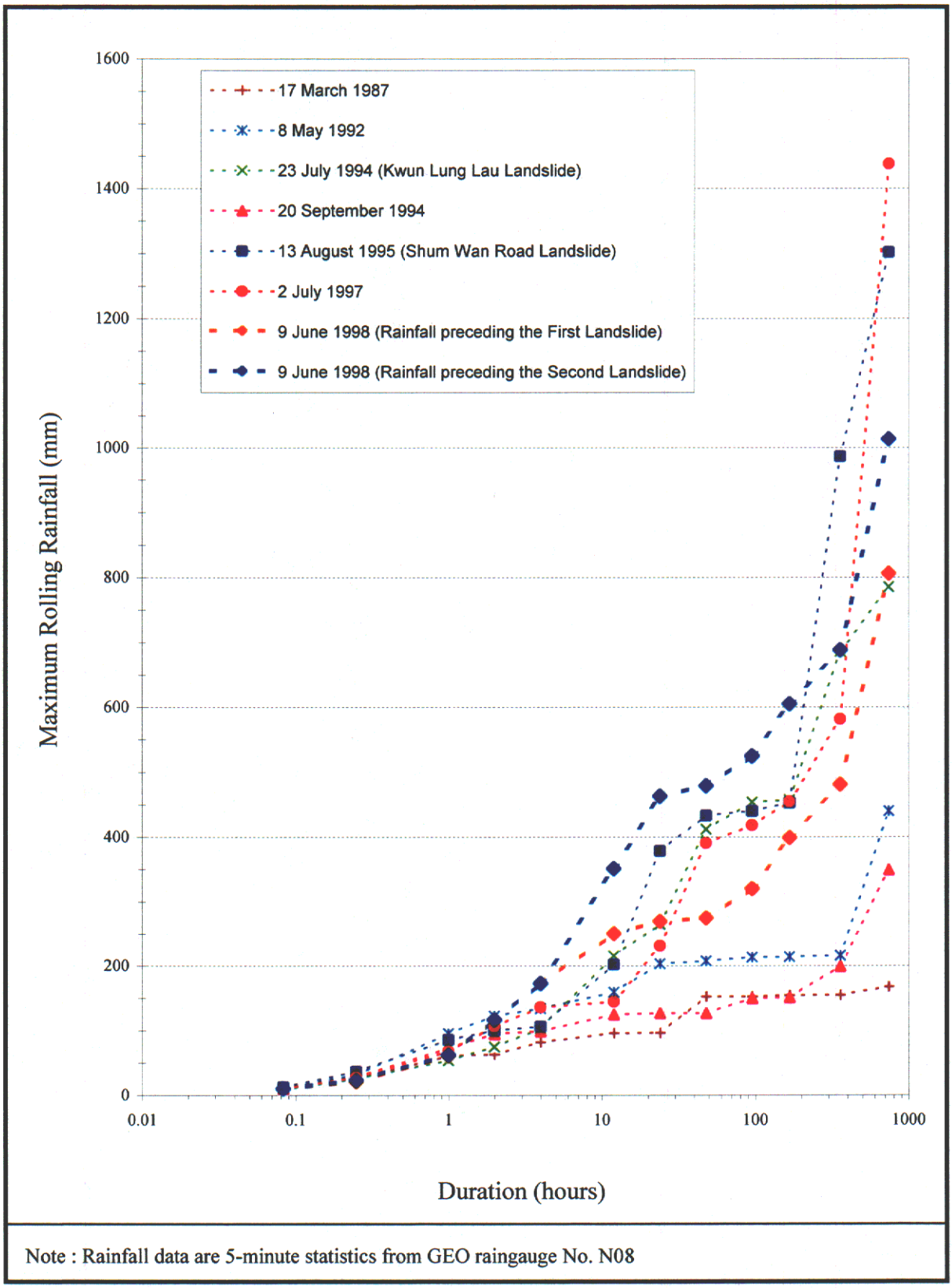


Figure 13 - Rainfall Distribution in the 24 hour Period Between 3:00 p.m. on 8 June 1998 and 3:00 p.m. on 9 June 1998



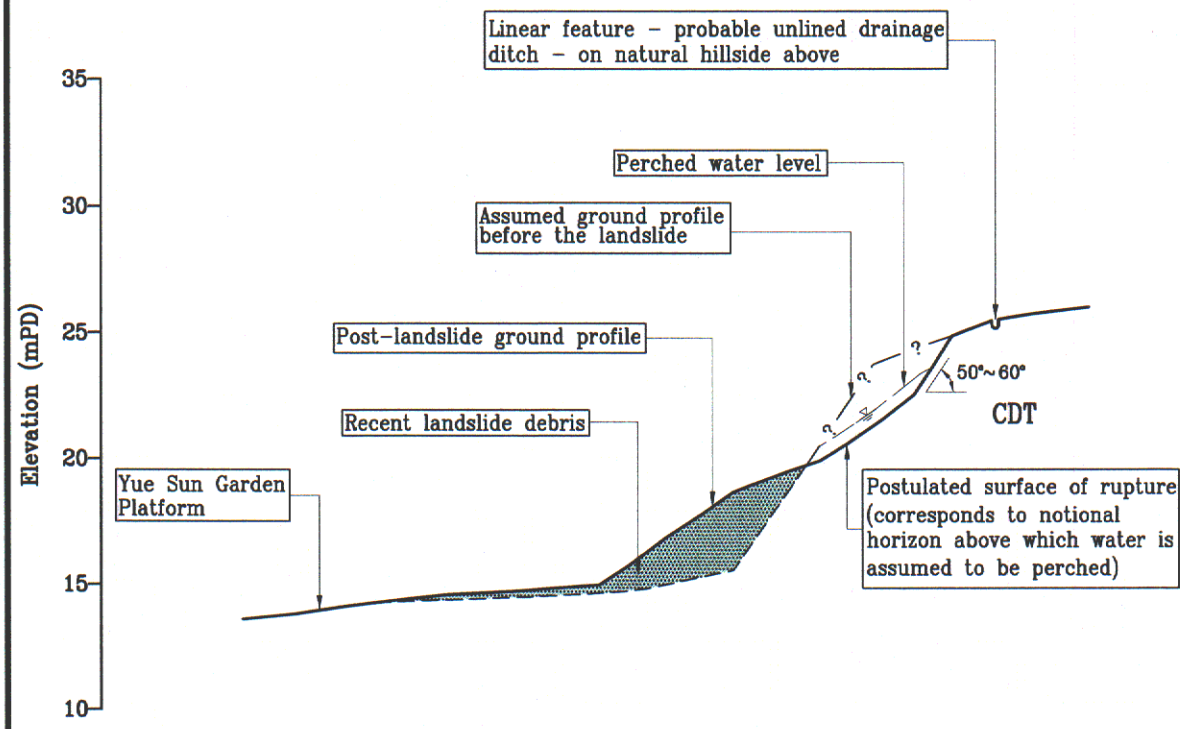
Note: Isohyets of rainfall for the period from 6:05 p.m. on 8 June 1998 until 6:00 p.m. on 9 June 1998

Figure 14 - Rainfall Distribution in the 24 hour Period Preceding Landslide No. 2 on 9 June 1998



Note : Rainfall data are 5-minute statistics from GEO raingauge No. N08

Figure 15 - Maximum Rolling Rainfalls Preceding the First and Second Landslides on 9 June 1998 (and Selected Major Rainstorms to 2 July 1997) - GEO Raingauge No. N08



Section A–A through the Landslide Site

0 1 2 3 4 5m
Scale

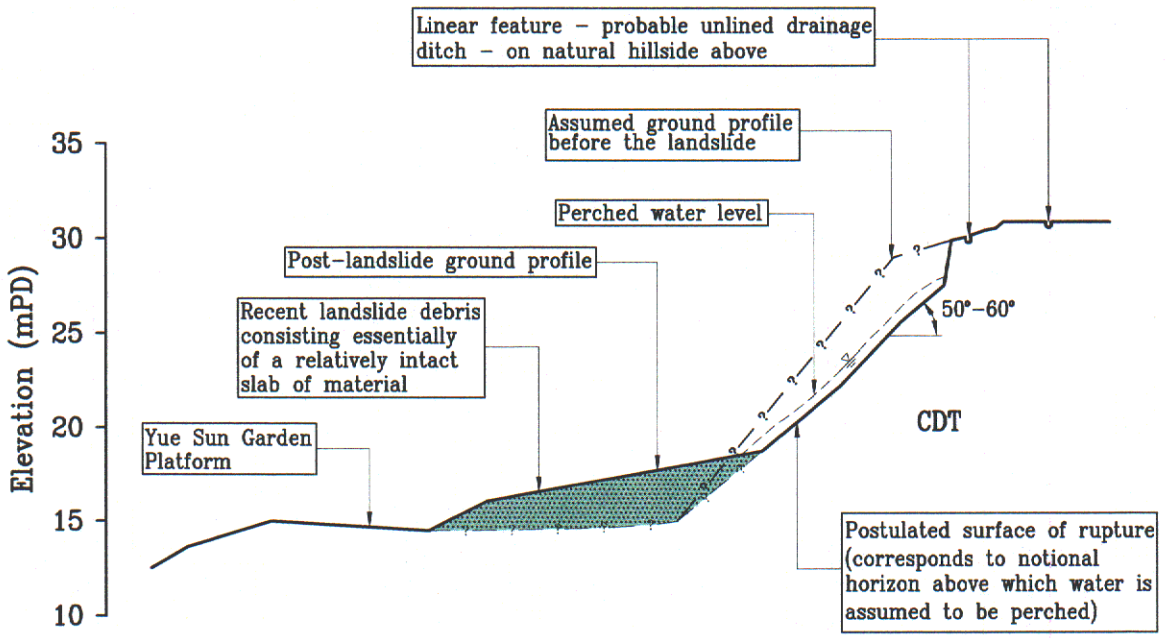
Material	Range of Parameters Used in Analysis		
	Representative Saturated Mass Shear Strength		Unit Weight (kN/m^3)
	Effective Cohesion c' (kPa)	Effective Angle of Shearing Resistance (ø')	
Completely Decomposed Tuff	0 – 10	30° – 40°	19

Legend: Recent landslide debris

CDT Completely Decomposed Tuff

Notes: (1) See Figure 2 for location of section.
(2) Information shown on this figure is based on topographic survey, geomorphological and engineering geological mapping, field observations and documentary information.

Figure 16 - Theoretical Stability Analysis - Landslide No. 1



Section B–B through the Landslide Site

0 1 2 3 4 5m
Scale

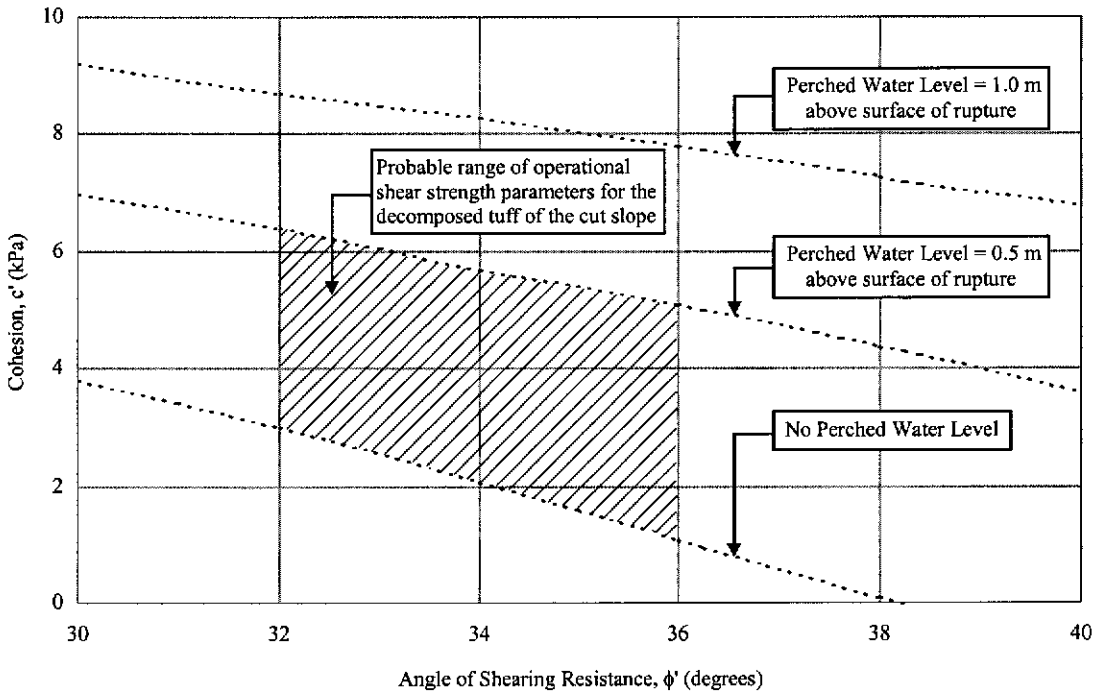
Material	Range of Parameters Used in Analysis		
	Representative Saturated Mass Shear Strength		Unit Weight (kN/m^3)
	Effective Cohesion c' (kPa)	Effective Angle of Shearing Resistance (ø')	
Completely Decomposed Tuff	0 – 14	30° – 40°	19

Legend: Recent landslide debris

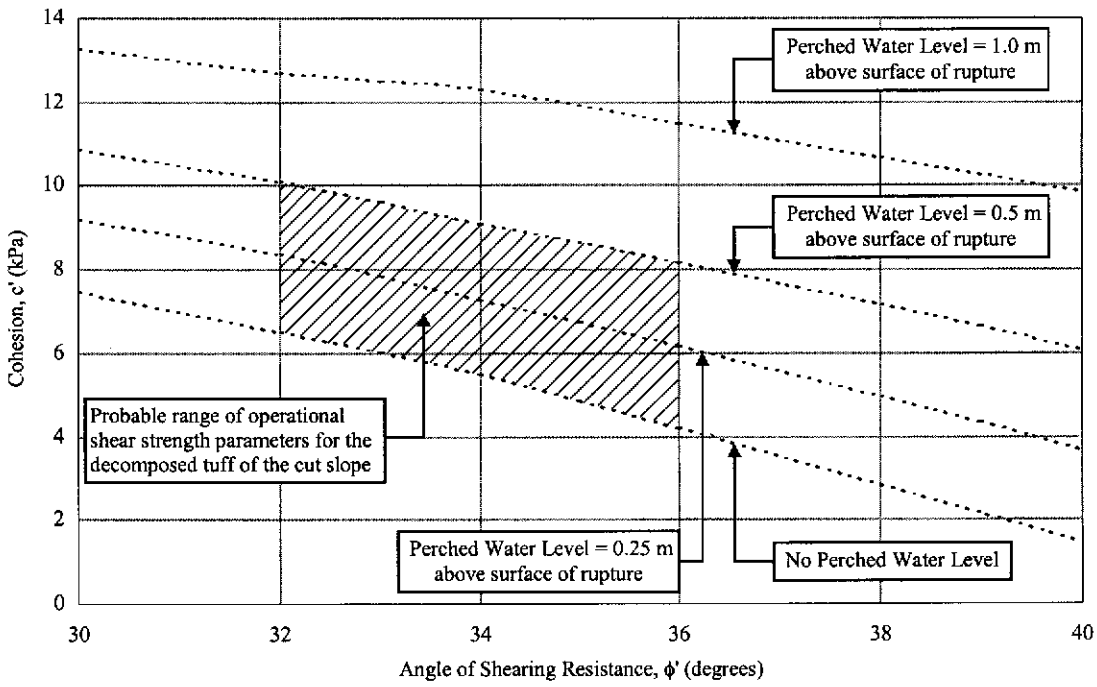
CDT Completely Decomposed Tuff

Notes: (1) See Figure 2 for location of section.
(2) Information shown on this figure is based on topographic survey, geomorphological and engineering geological mapping, field observations and documentary information.

Figure 17 - Theoretical Stability Analysis - Landslide No. 2



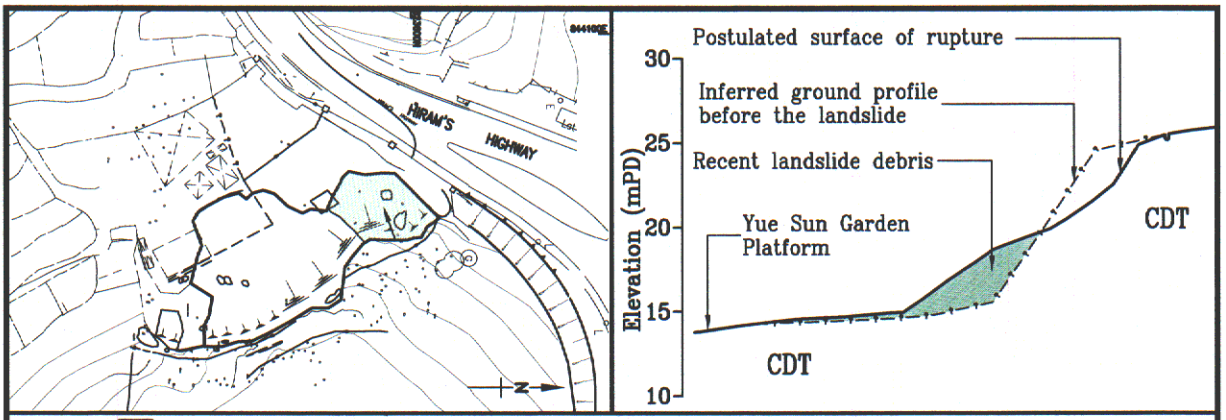
(a) Sensitivity Analyses for the First Failure



(b) Sensitivity Analyses for the Second Failure

Legend : ----- Factor of safety equal to unity (i.e. limiting equilibrium).

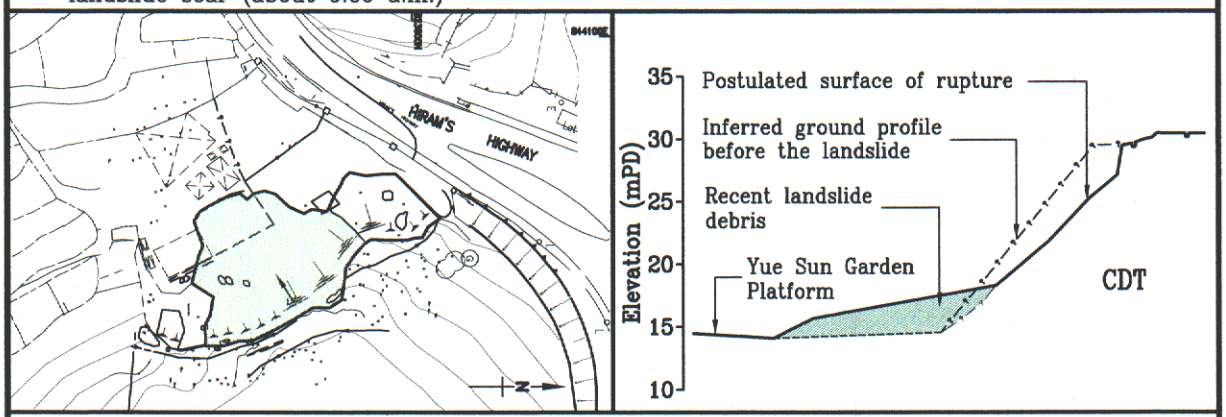
Figure 18 – Results of Sensitvity Analyses



Legend: 1998 landslide scar; Direction of movement; CDT Completely Decomposed Tuff; Inferred boundary

Note: Based on Section A–A, presented as Figure 5 in this report.

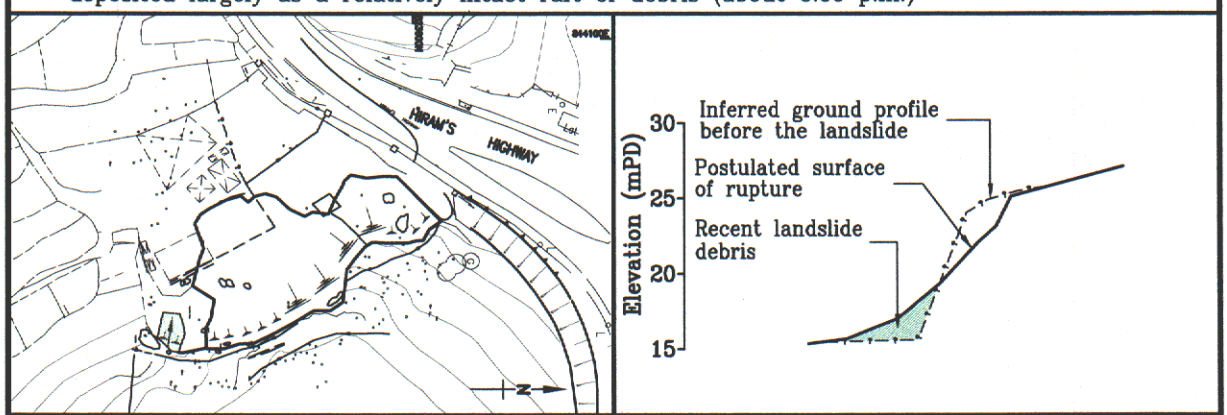
(a) Landslide No. 1 – surficial landslide adjacent to Hiram's Highway, beside a past (July 1997) landslide scar (about 9:00 a.m.)



Legend: 1998 landslide scar; Direction of movement; CDT Completely Decomposed Tuff; Inferred boundary

Note: Based on Section B–B, presented as Figure 6 in this report.

(b) Landslide No. 2 – continuation of landsliding along the crest of the slope towards the elbow of the feature. Landslide extended into the natural hillside above. Failed material deposited largely as a relatively intact raft of debris (about 6:00 p.m.)



Legend: 1998 landslide scar; Direction of movement; Inferred boundary; CDT Completely Decomposed Tuff

(c) Landslide No. 3 – surficial landslide at the elbow of the feature. Appears to be unconnected to previous landslides. Area of unfailed ground, strip of vegetation between this and the second (main) landslide within cut slope (about 7:00 p.m.)

Figure 19 - Schematic Representation of Inferred Sequence of Events

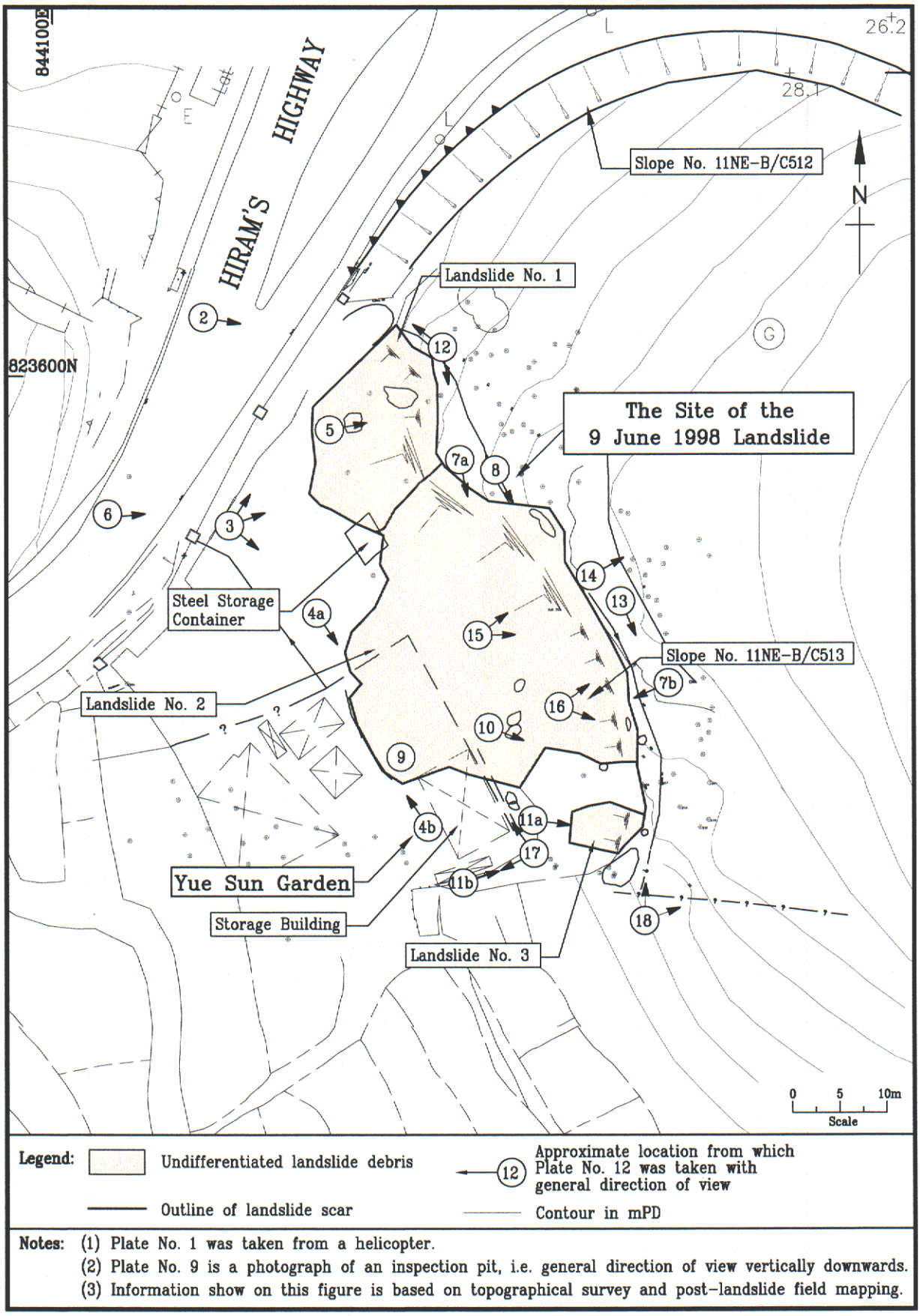


Figure 20 - Location Plan of Photographs Taken

LIST OF PLATES

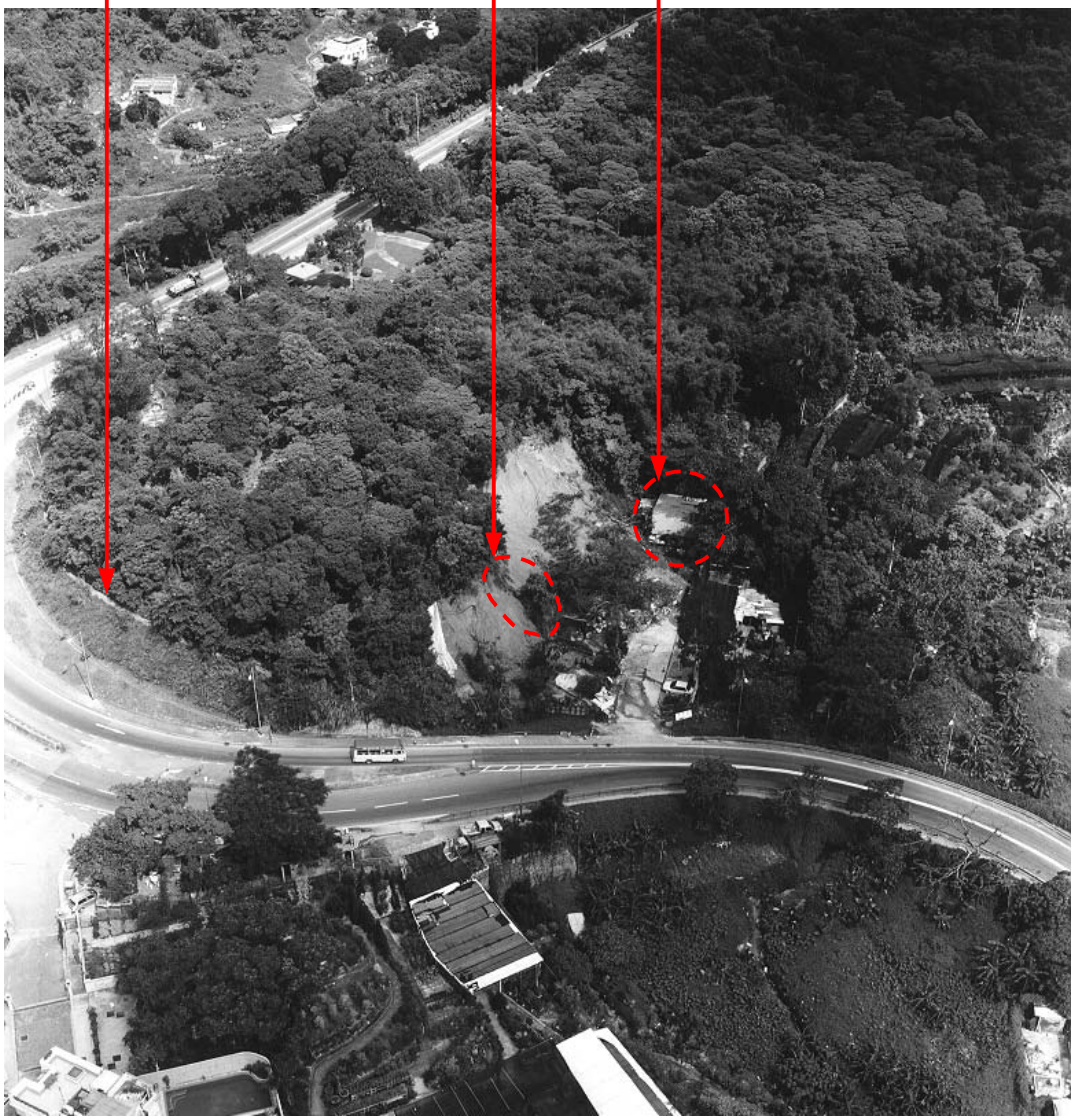


Plate 1 – The Landslides of 9 June 1998
(Photograph taken on 29 June 1998)

Note: See Figure 20 for Location of Photograph.

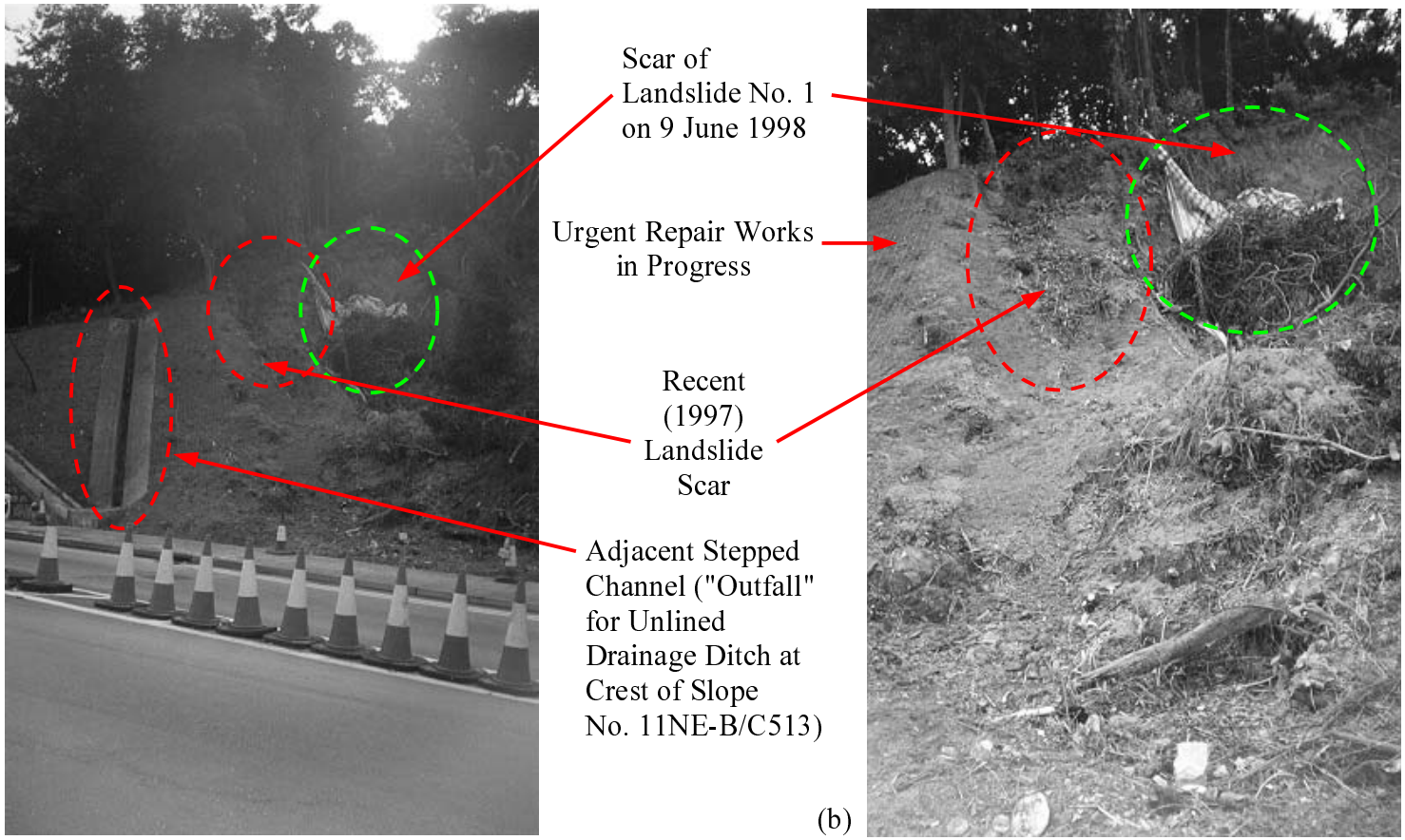


Plate 2 – General Views of a Possible Recent (1997) Landslide Scar adjacent to Hiram's Highway
(Photographs taken on 28 August 1998)

Note : See Figure 20 for Locations of Photographs.

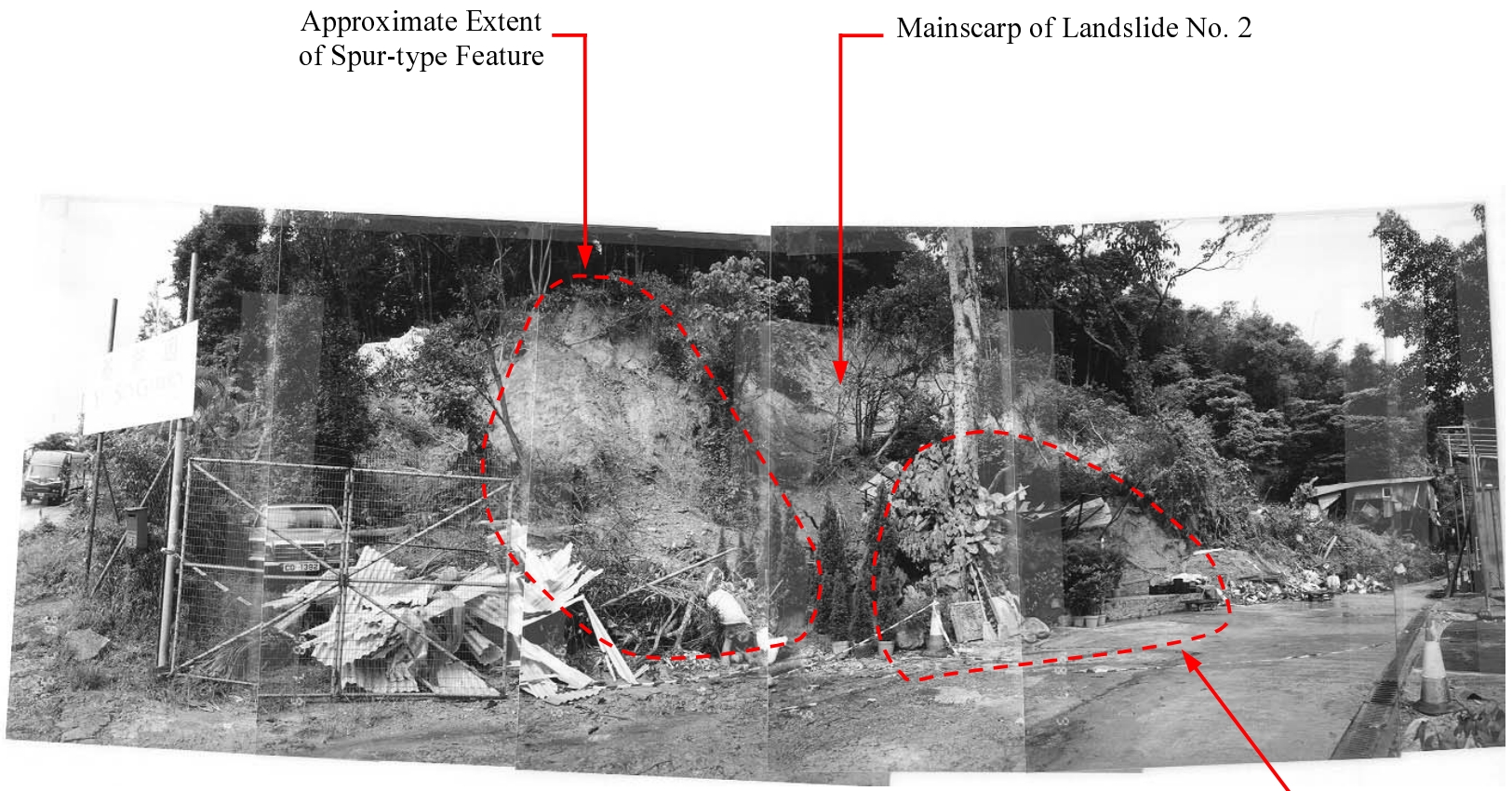


Plate 3 – General View of the Scars of Landslides, Nos. 1 and 2, from the Entrance to Yue Sun Garden (Photographs taken on 9 July 1998)

Note : See Figure 20 for Locations of Photographs.

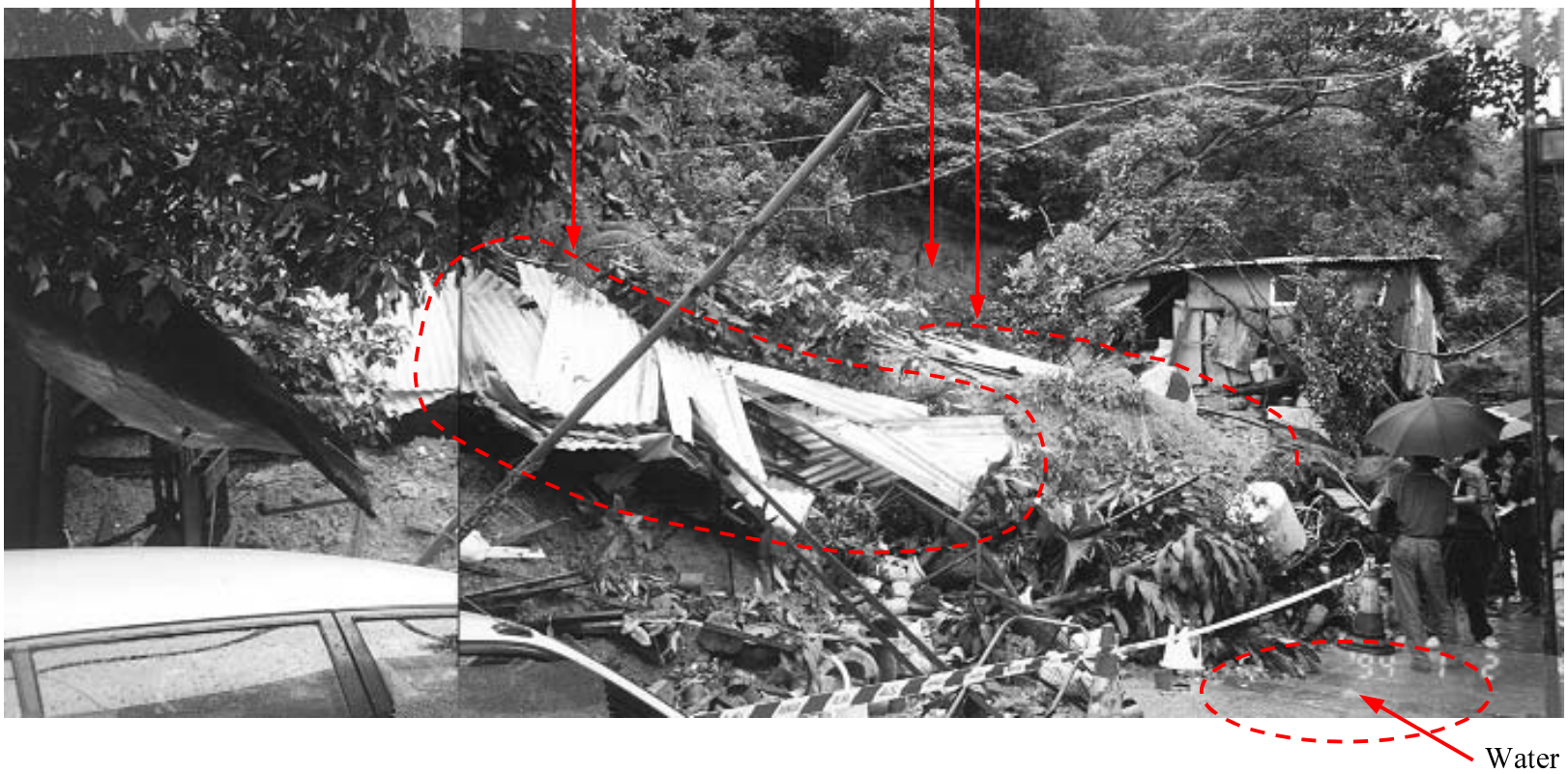


Plate 4a – General View at the Toe of the Scar of Landslide No. 2 showing the Damaged Storage Building. Note the Water at the Toe of the Debris (Photographs taken on 11 June 1998)

Note : See Figure 20 for Locations of Photographs.

Plate 4b - General View at the Toe of the Scar of Landslide No. 2 showing the Damaged Storage Building. Note the Water at the Toe of the Debris (Photographs taken on 11 June 1998)

Note: See Figure 20 for Location of Photograph.

Plate 5 – General View of the Scar resulting from Landslide No. 1
(Photographs taken on 9 July 1998)

Note: See Figure 20 for Locations of Photographs.

(a)

(b)

Plate 6 – General Views of the Entrance to Yue Sun Garden following Landslide No. 1. Note the Extensive Surface Water Flow (much of it discoloured) in both Photographs as well as the Overflowing Drainage Channel in the Foreground of the Bottom Picture (Photographs taken by the GEO on 9 June 1998)

Note: See Figure 20 for Location of Photograph.

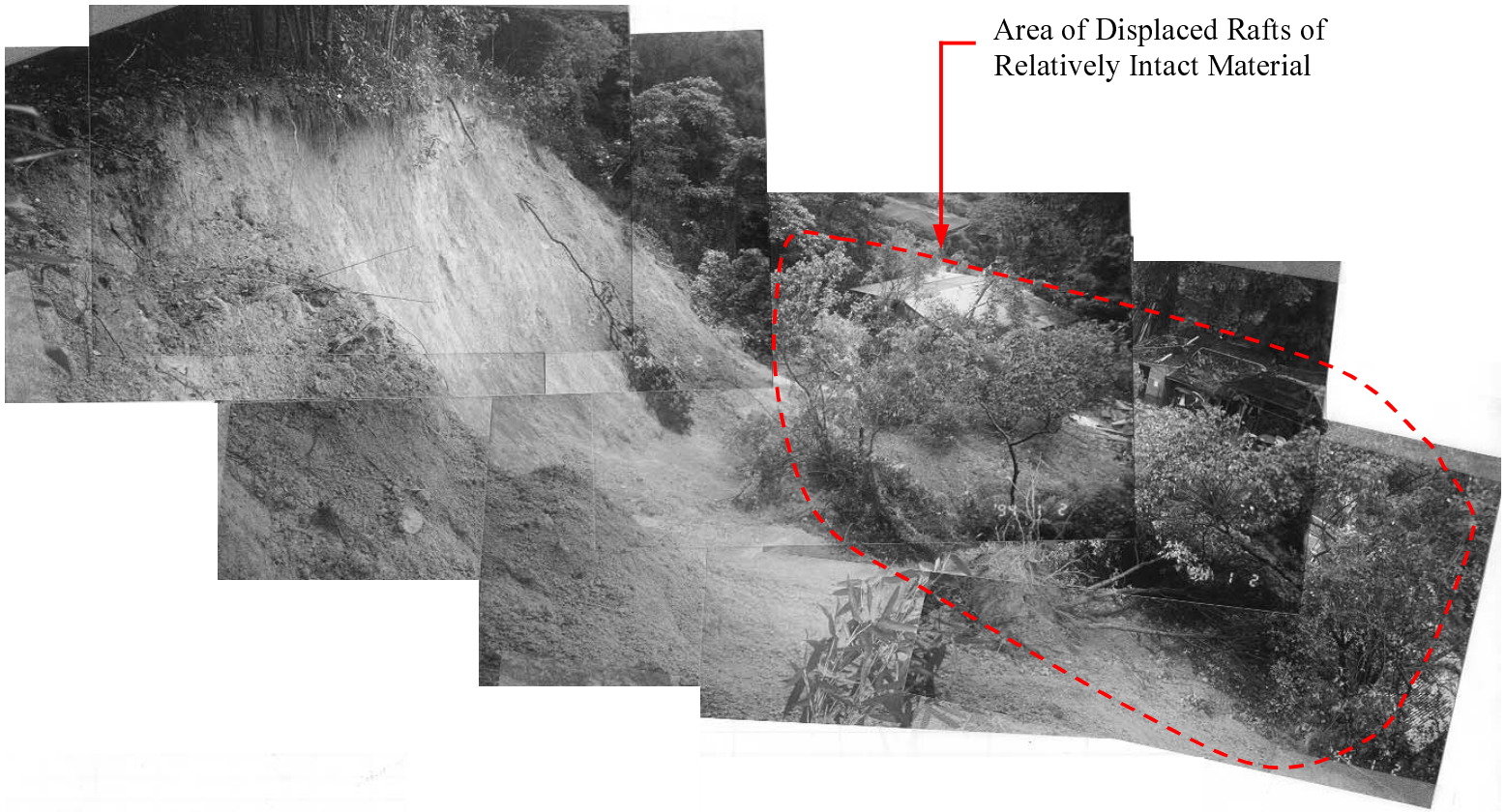


Plate 7a – General View of the Scar resulting from Landslide No. 2
(Photographs taken on 11 June 1998)

Note : See Figure 20 for Locations of Photographs.

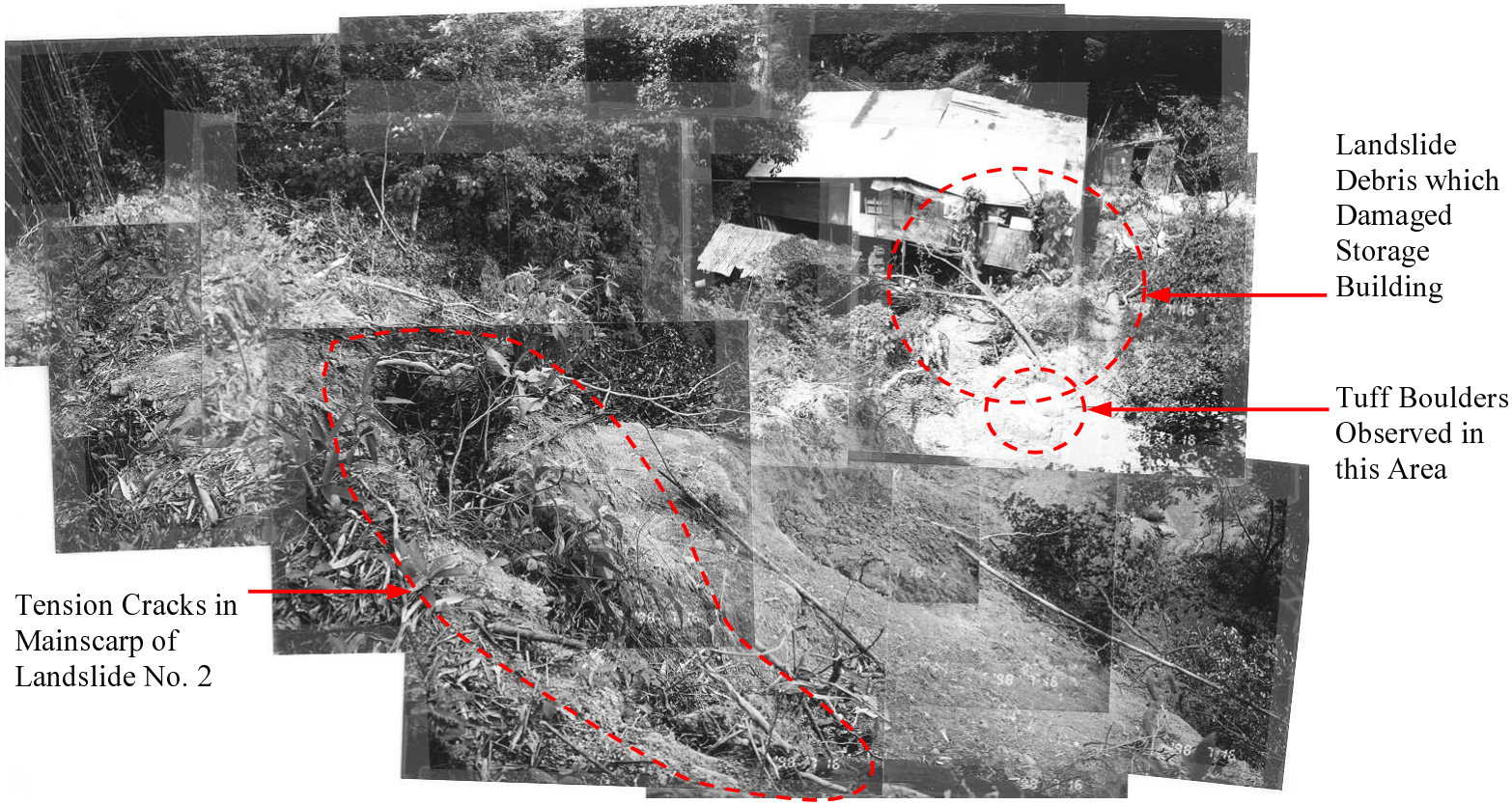


Plate 7b – General View of the Scar resulting from Landslide No. 2
(Photographs taken on 16 July 1998)

Note : See Figure 20 for Locations of Photographs.

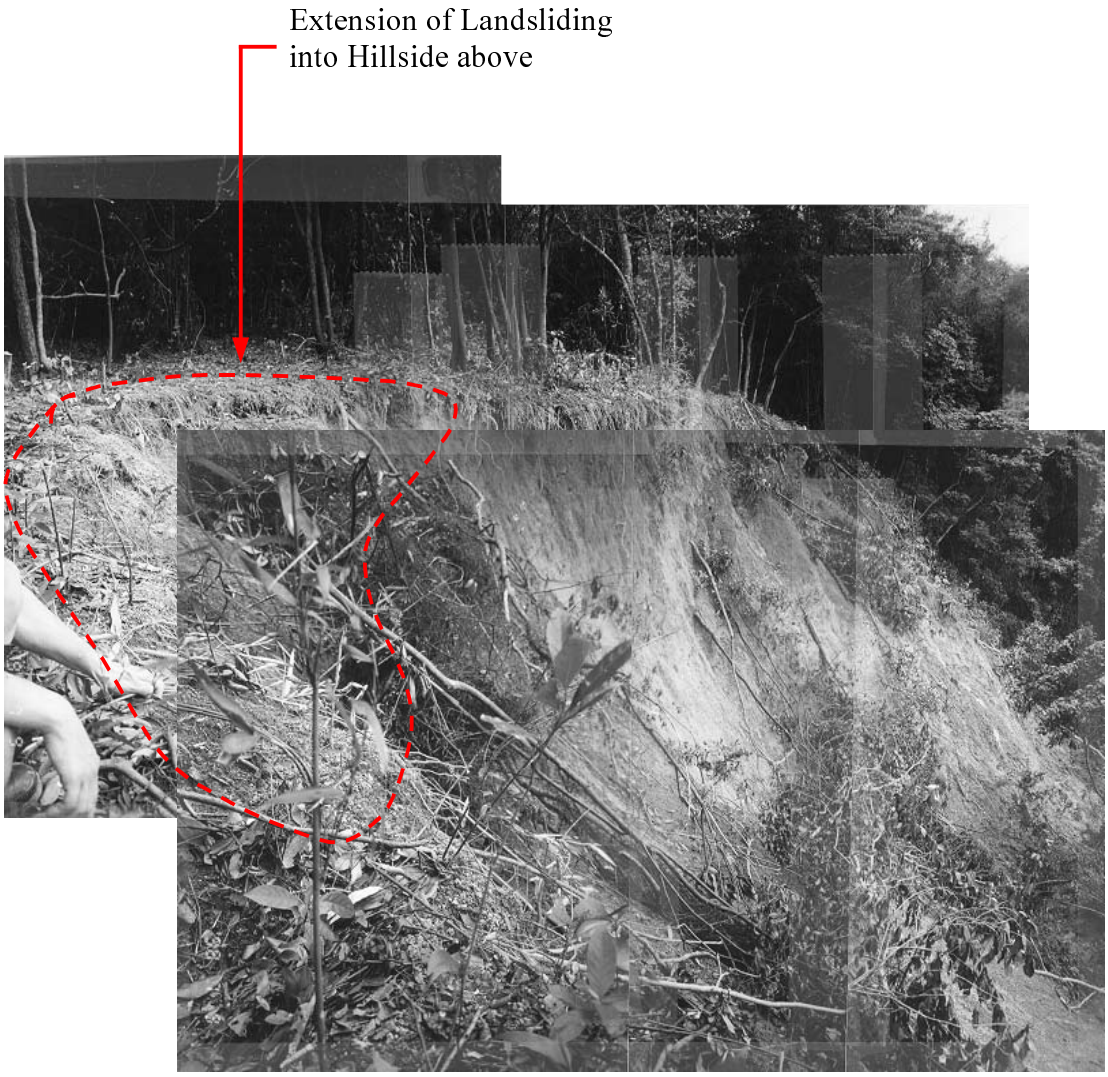


Plate 8 – General View of the Mainscarp resulting from Landslide No. 2 (Photographs taken on 9 July 1998)

Note: See Figure 20 for Locations of Photographs.

Plate 9 – Intact Nature of the Slab of Debris at the Toe of the Slope resulting from Landslide No. 2
(Photograph taken on 16 July 1998)

Note: See Figure 20 for Location of Photograph.

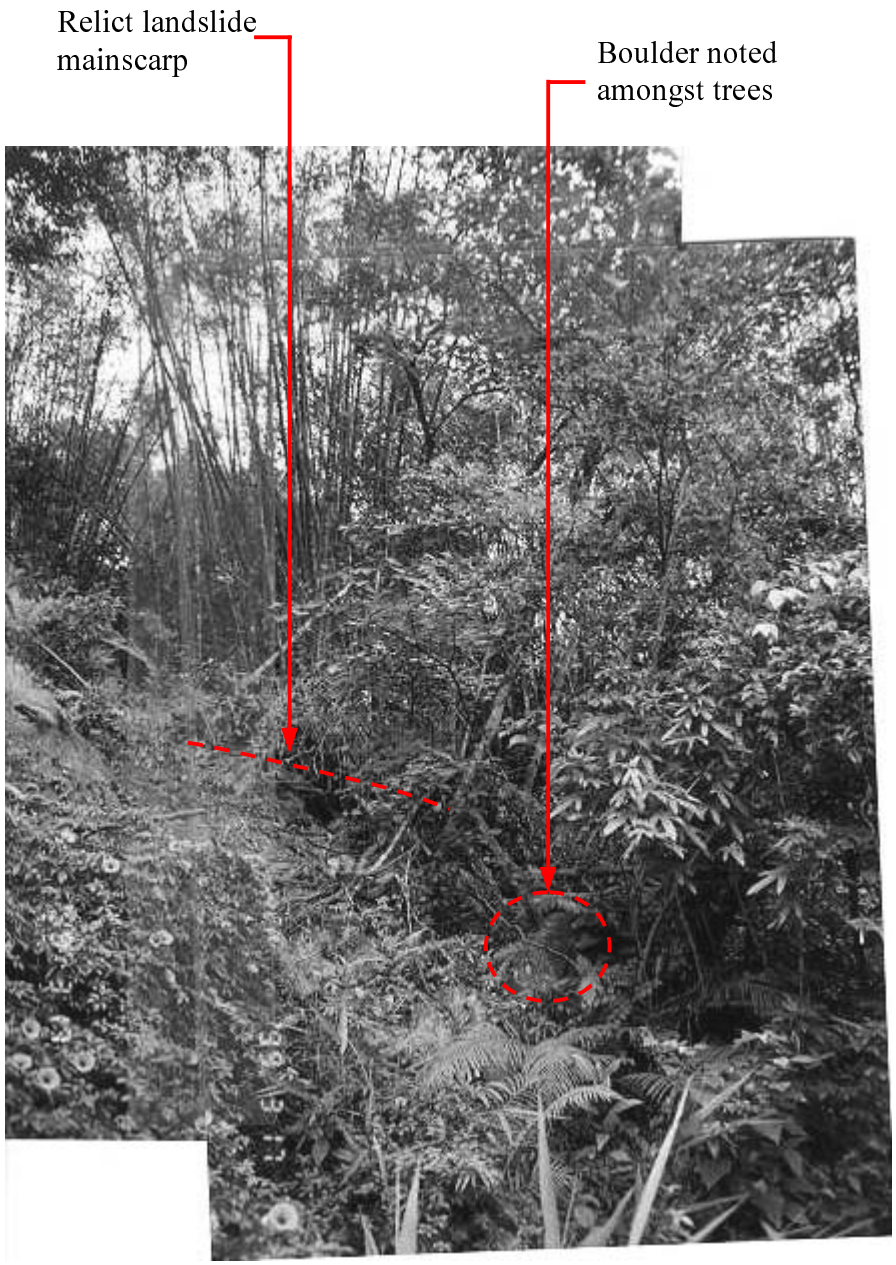


Plate 10 – The "Stable" Portion of the Main Southwest-facing Slope of the Feature between Landslides Nos. 2 and 3. The Boulder is considered indicative of Previous Instability within this part of the Slope (Photographs taken on 17 March 1999)

Note: See Figure 20 for Location of Photograph.

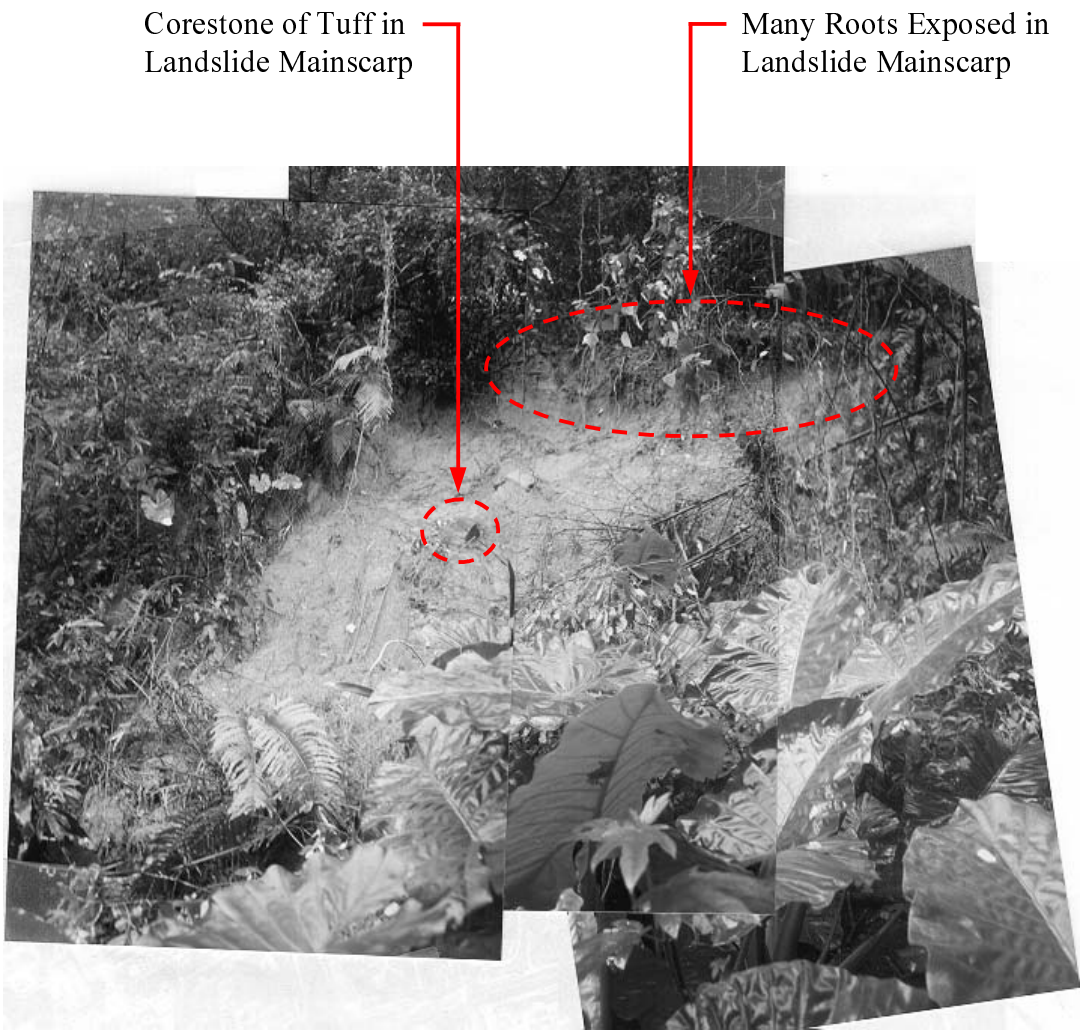


Plate 11a – General View of Scar resulting from Landslide No. 3
(Photographs taken on 11 June 1998)

Note: See Figure 20 for Location of Photograph.

Plate 11b – General View of the Scar resulting from Landslide No. 3
(Photograph taken on 11 June 1998)

Note: See Figure 20 for Location of Photograph.

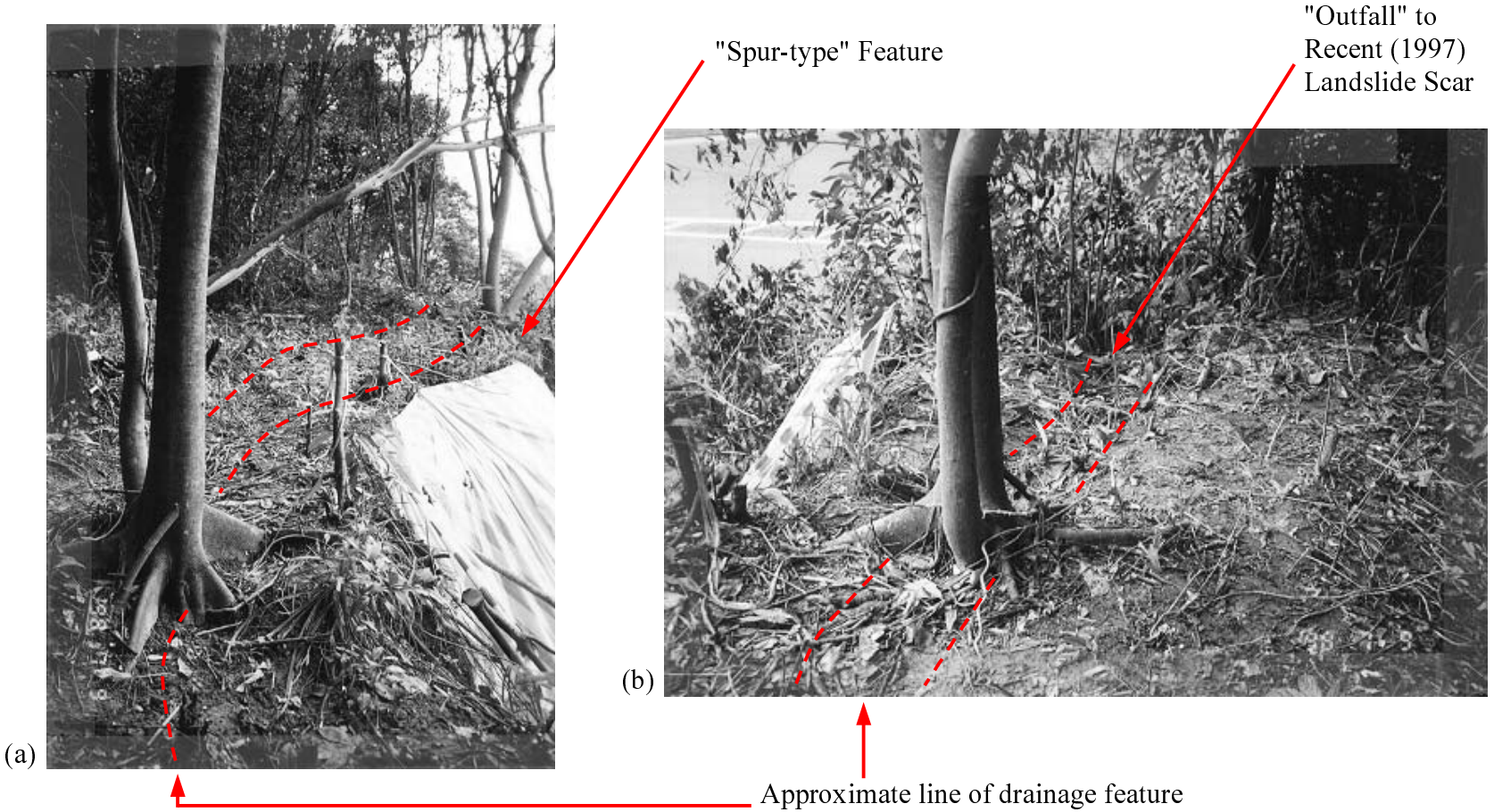


Plate 12 – Possible Footpath/Drainage Ditch running along the Crest of the Main Southwest-facing Slope of the Feature. The Drainage Ditch appears to "outfall" to the adjacent roadside slope (Photographs taken on 9 July 1998)

Note : See Figure 20 for Locations of Photographs.

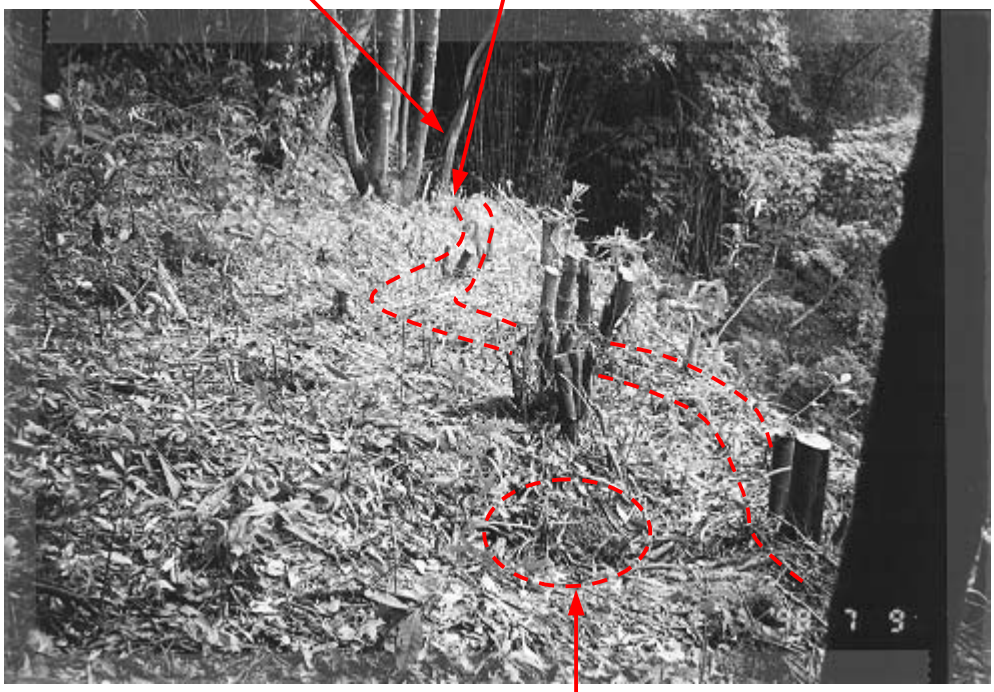
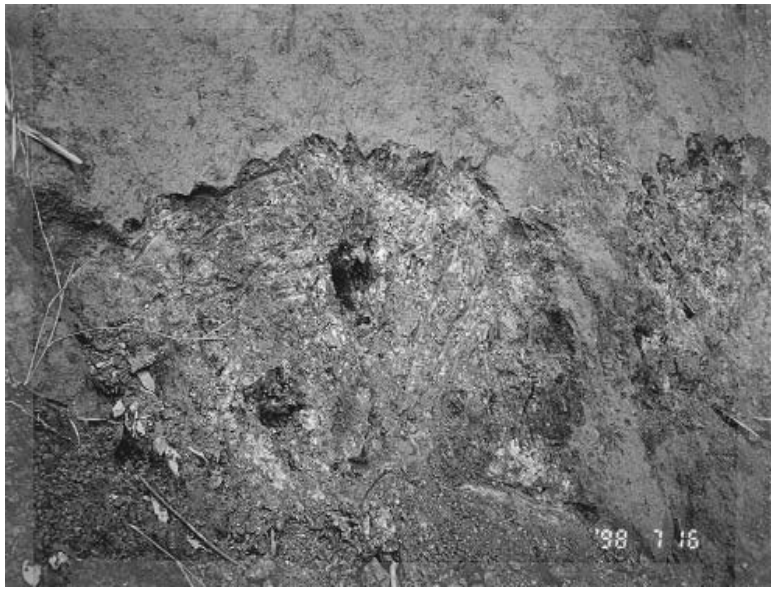


Plate 13 – Possible Footpath/Drainage Ditch running along the Crest of the Main Slope of the Feature (Photograph taken on 9 July 1998)

Note: See Figure 20 for Location of Photograph.

Plate 14 – Possible Snake Pit at the Crest of the Main Slope of the Feature, mid-way along its length (Photograph taken on 9 July 1998)

Note: See Figure 20 for Location of Photograph.

(a) 

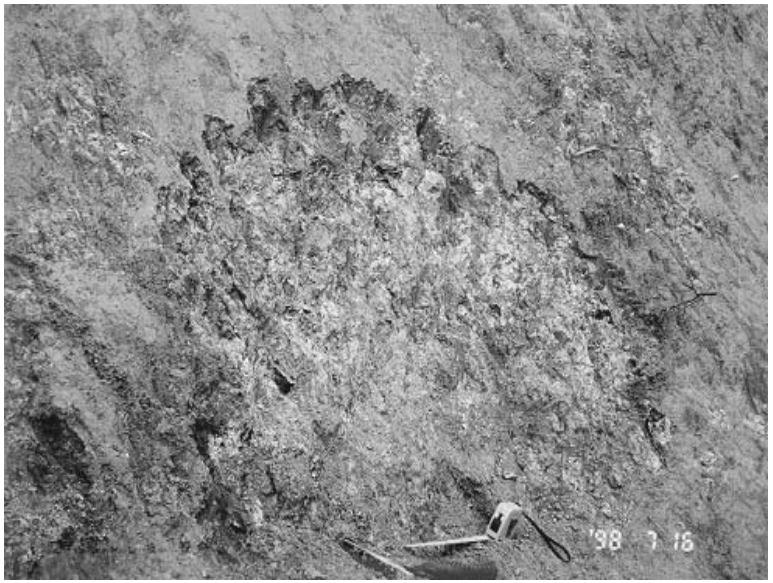
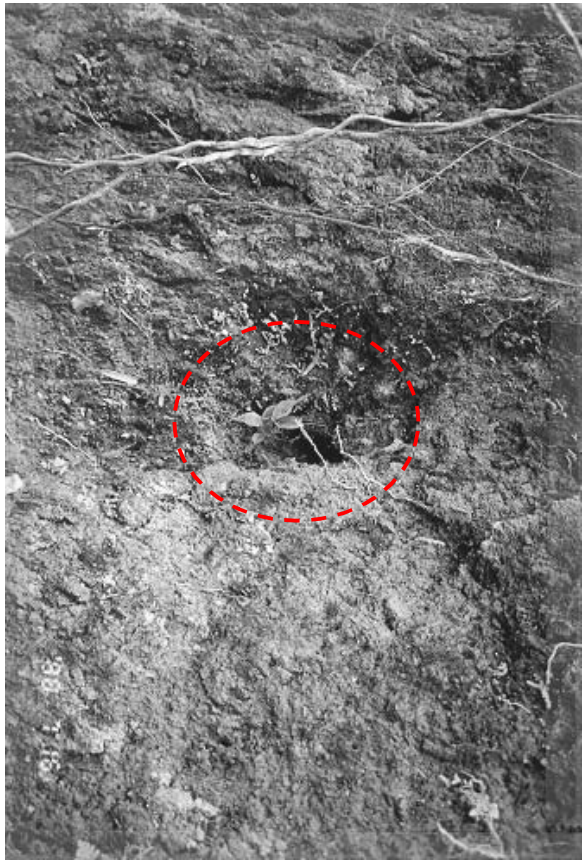
(b) 

Plate 15 – Exposures of the Decomposed Tuff in the Mainscarp of Landslide No. 2. Typical Spheroidal Weathering Profile Evident (Photographs taken on 16 July 1998)

Note : See Figure 20 for Locations of Photographs.

(a)

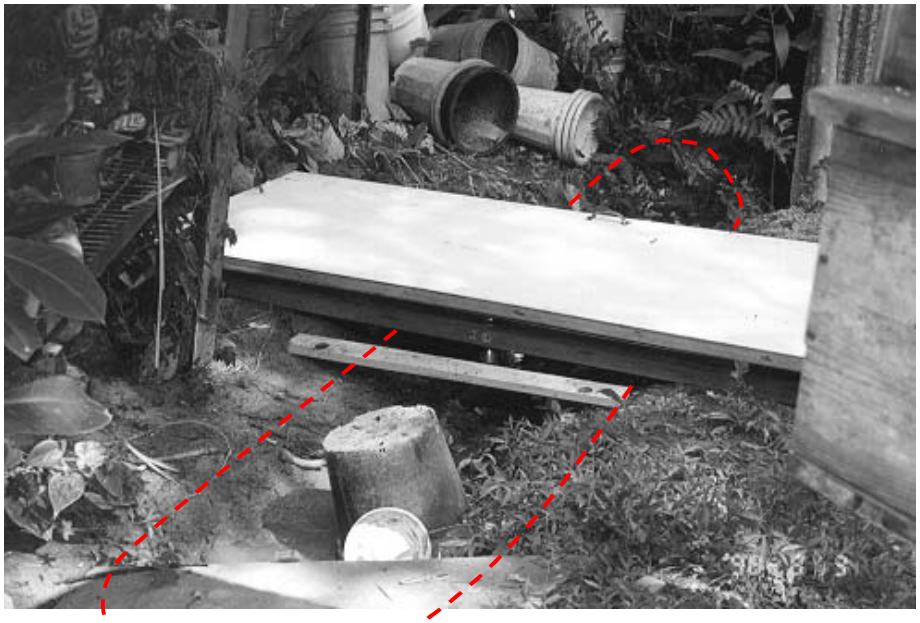


(b)

Plate 16 – Possible Erosion Pipes Observed on the Southern Flank of the Mainscarp of Landslide No. 2
(Photographs taken on 16 July 1998)

Note : See Figure 20 for Locations of Photographs.

(a)



(b)

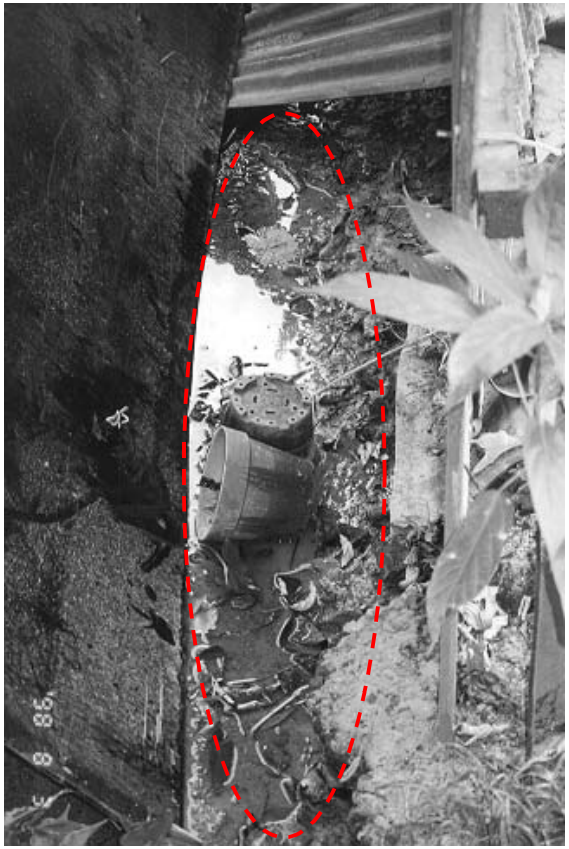


Plate 17 – Water at the Toe of the Slope, adjacent to the Junction of the Feature, behind the Damaged Storage Building
(Photograph taken on 3 August 1998)

Note : See Figure 20 for Locations of Photographs.

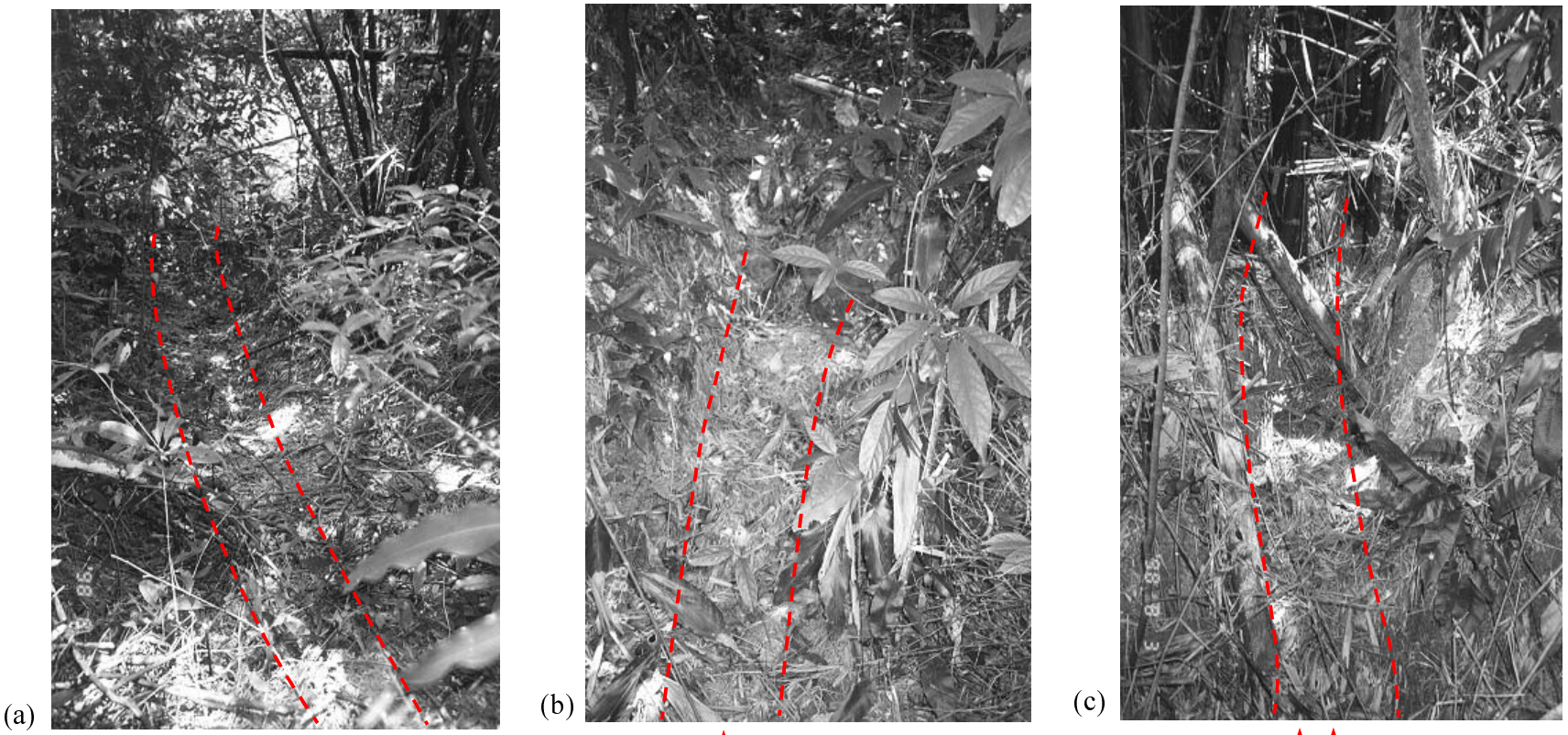


Plate 18 – Possible Gully/Linear Depression adjacent to the Junction of the Feature
(Photographs taken on 3 August 1998)

Note : See Figure 20 for Locations of Photographs.