INVESTIGATION OF SOME SELECTED LANDSLIDES IN 1998 (VOLUME 1)

GEO REPORT No. 108

Fugro Scott Wilson Joint Venture

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

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PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. A charge is made to cover the cost of printing.

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

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

EXPLANATORY NOTE

This GEO Report consists of three Landslide Study Reports on the investigation of selected slope failures that occurred in 1998. The investigations were carried out by Fugro Scott Wilson Joint Venture (FSW) for the Geotechnical Engineering Office as part of the 1998 Landslide Investigation Consultancy.

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

(a) establishment of an improved slope assessment methodology,

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

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

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

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1	Detailed Study of the Natural Terrain Landslide at No. 30 Pak Sha Wan on 9 June 1998	5
2	Detailed Study of the Landslide at the Outward Bound School on 9 June 1998	51
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The Landslip Investigation Division of the Geotechnical Engineering Office worked closely with the LI Consultants and provided technical input and assistance to the landslide studies.

SECTION 1 : DETAILED STUDY OF THE NATURAL TERRAIN LANDSLIDE AT NO. 30 PAK SHA WAN ON 9 JUNE 1998

Fugro Scott Wilson Joint Venture

This report was originally produced in June 1999 as GEO Landslide Study Report No. LSR 1/99

FOREWORD

This report presents the findings of a detailed study of the landslide (GEO Incident No. ME 98/6/22) that occurred on 9 June 1998 at the natural hillside above Pak Sha Wan Village, Sai Kung. The landslide comprised a narrow depletion zone with a broader deposition area, involving an estimated total volume of approximately 300 m^3. The landslide ran along and adjacent to an ephemeral drainage line and through the grounds of two village properties. Damage occurred to external structures, and homes were inundated with mud and muddy water, but no one was injured in the incident.

The key objectives of the detailed study were to document the facts about the landslide, present relevant background information and establish the probable causes of the failure. The scope of the study 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 J Hall 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

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1. INTRODUCTION

A landslide (GEO Incident No. ME 98/6/22) occurred during the evening of 9 June 1998 towards the end of a period of heavy rain, affecting two properties in Pak Sha Wan Village, Sai Kung. The landslide involved the failure of the natural hillside, and the debris was deposited above and on the platforms formed for village houses. No fatalities or injuries were reported. Immediately following the landslide, the GEO recommended the temporary evacuation of one dwelling, No. 30 Pak Sha Wan Village.

Following the failure, Fugro Scott Wilson Joint Venture (the 1998 Landslide Investigation Consultants), carried out a detailed study of the incident 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 Venture (FSW).

The key objectives of the detailed study were to document the facts about the landslide, present relevant background information and establish the probable causes of the failure. The scope of the study was limited to site reconnaissance, desk study and 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 all known relevant documents pertaining to the site and the sequence of events leading up to the landslide,

(b) aerial photograph interpretation (API),

(c) interviews with witnesses of the landslide,

(d) detailed observations and measurements at the site,

(e) analysis of rainfall records,

(f) theoretical stability analysis, and

(g) diagnosis of the probable causes of failure.

2. THE SITE

2.1 Site Description

The location of the landslide site is shown in Figure 1 and general views are shown in Plates 1 to 4. A sketch plan of the landslide is shown in Figure 2, and a section through the landslide is given in Figure 3.

The failure occurred in a shallow ephemeral stream course which drains an east-facing hillside behind the village of Pak Sha Wan. The peak of the hill stands at around 130 mPD, sloping down to a level of 40 mPD immediately behind the village. The village extends down to Hiram's Highway at a level of around 16 mPD. The sloping ground between the highway and the sea is occupied by boatyards. The landslide depletion area extends from about 85 mPD to 40 mPD approximately.

The catchment area of the valley in which the landslide occurred is approximately 12,000 m^2, being around 200 m long with an average width of 60 m.

The hillside generally slopes at approximately 30° to 35° in the upper reaches of the landslide area, but the gradient reduces to an average of about 25° over most part of its length. The average inclination at the initial source area is slightly greater at about 26° to 28° (Figure 2). The valley sides sloped towards the drainage line at a typical angle of up to around 18° prior to the landslide, based on information from existing 1 to 1 000 scale topographic maps. According to local knowledge the drainage line is generally dry, and only maintains a flow during or following heavy rainfall.

The main landslide trail terminated at a masonry retaining wall, marking the upper limit of development of Pak Sha Wan Village, below which several terraced platforms step down towards Hiram's Highway.

Based on information provided by the Water Supplies Department and the Drainage Services Department, together with FSW's field observations after the landslide, no underground water-carrying services are present within the catchment of the zone of depletion of the landslide.

2.2 Maintenance Responsibility

Land status documents provided by the District Lands Office (DLO) confirm that the landslide site is located on unallocated Government land. House No. 30 Pak Sha Wan Village falls within the license area of GLL S11988, which was re-issued, with a new cutting-away clause, in October 1992. As no cutting-away has been carried out since this time, it would appear that the licensee is not required to take up the responsibility of maintaining the land beyond the licensed area. DLO also confirmed in September 1998 that they do not have any records to suggest that the licensees have any maintenance responsibility for the slope in question.

3. SITE HISTORY AND PREVIOUS ASSESSMENTS

3.1 Site Development History

The site development history has been determined from a review of the available aerial photographs (Appendix A) and relevant documentation. The main objectives of the API were to confirm site history and assess site conditions. A plan showing the key observations of the API is shown in Figure 4.

In terms of the topographical setting, the landslide site forms one of a number of drainage lines radially draining a local peak. The subject drainage line, which faces southeast, has similar linear valley features either side of it. The valley approximately 50 m to the northeast has a slightly larger catchment area, and the drainage line is consequently better developed. It can be seen to be more deeply incised, with steeper side slopes. The valley approximately 50 m to the southwest has a smaller catchment area than the landslide site, and is correspondingly less well-defined, with no incised water channel and less steep sloping flanks.

In the earliest (1963) aerial photographs, the site of No. 30 Pak Sha Wan Village appears partly formed and cleared, but with no building erected. The clearance area does not span the ephemeral drainage line. A slightly incised line marks the centre of the drainage line as high up the valley as the crest of the landslide, indicative of the extent of ephemeral water flows.

By 1968, what appear to be two small parallel terraces have been constructed on the southern side of the drainage line, approximately 20 m upslope of the site of No. 30 Pak Sha Wan Village. These may have been either grave sites or agricultural developments.

The house at No. 30 Pak Sha Wan Village had been constructed by 1973, although its platform does not appear to extend completely across the ephemeral drainage line at this time. The terracing noted some distance upslope in the 1968 photographs is still apparent. Agricultural activities appear to be taking place between the platform and the terracing.

Conditions in 1984 appear much the same as 1973, except that agricultural activities may have ceased and become overgrown, although the area is partly shielded from view due to the angle of sight. A footpath is evident crossing the valley about mid-way, close to the crest of the 1998 landslide.

The 1986 photographs indicate that the platform for No. 30 Pak Sha Wan Village has been extended across the drainage line, with a diversionary surface drainage channel along the northern boundary of the platform. A large elliptical area extending approximately 20 m up the drainage line has apparently been largely stripped of vegetation which was possibly associated with agricultural activities.

Throughout the period covered by the photographs inspected (viz. 1963 to 1996), a steady increase in the density of trees is apparent on the natural hillside above Pak Sha Wan. There is no indication that the source area of the 1998 landslide had previously been affected by development.

3.2 Past Landslides

Based on GEO's landslide database and examination of low-level aerial photographs dating from 1963, no previous landslides have been identified in the vicinity of the landslide site. GEO's Natural Terrain Landslide Inventory (King, 1997 and Evans et al, 1997), compiled using high-level aerial photographs, also includes no past failures on the affected hillside.

3.3 Previous Studies and Inspections

A search of various Government archives has indicated that the affected hillside has not been the subject of any specific previous inspection or assessment prior to the current landslide study.

The GEO's Geotechnical Area Studies Programme (GASP) Report IX (Geotechnical Control Office, 1987), produced for regional appraisal and outline strategic planning purposes at a scale of 1:20 000, designated the terrain on the Engineering Geology Map as an area where the "stability of weathered material...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". The GASP Physical Constraints Map classifies the area as within an area of "slopes on in-situ terrain which are generally steeper than 30° (other than those delineated as colluvial or unstable)". The Generalised Limitations and Engineering Appraisal Map zones the area immediately behind the existing development zones, as a "zone of constraints for development", although this grades into a "zone of potential for development" further up the hillside, beyond the landslide site. The GASP Terrain Classification Map categorises the landslide site as a concave slope with a gradient of between 30° to 40°, and with no appreciable erosion.

4. DESCRIPTION OF THE LANDSLIDE

4.1 Eye-witness Accounts of the Landslide

Some limited information on the landslide has been obtained from eye-witness accounts of the incident. A shipyard worker made the first observation of indications of debris movement on the seaward side of Hiram's Highway. He noted "heavy, muddy water" flowing from the culvert that forms the continuation of the ephemeral drainage line beneath the road, in the afternoon of 9 June 1998. He could not however be specific about the precise timing.

The occupant of No. 29 Pak Sha Wan Village noted debris flowing along the flooded drainage channel through the village at around 18:00 hours. He was sufficiently concerned to repeatedly check the situation over the next two hours, observing that the flow increased in volume and density until the whole platform area of No. 30 and most of No. 27 Pak Sha Wan Village were inundated with outwash, by about 20:00 hours. The occupants of both these houses arrived home later that evening, after the occurrence of the landslide.

4.2 Field Mapping and Observations After the Landslide

The extent and profile of the landslide scarp and landslide debris were determined by field measurements made during the site inspections, the pre-existing topography was established from existing 1:1 000 topographic maps of the area. The extent of the landslide is shown in Figure 2, and a section through the landslide is given in Figure 3. The terminology used to describe the various aspects of this landslide is generally in accordance with that adopted by King (1997). Detailed descriptions of the various materials encountered are summarised in Table 2.

The site was first inspected by FSW on 30 June 1998 and later mapped in detail on 15 July 1998.

The landslide formed a shallow channel of 7 to 10 m width, approximately 90 m long, through colluvial soils (hereafter referred to as the scar). The scar was relatively linear, with a slight deviation from the line of the drainage channel for about the uppermost 15 m.

The crest of the landslide was marked with an approximately 2 m-high (maximum) main scarp in friable colluvium containing numerous subangular cobble- and boulder-sized rock fragments. The largest of these were seen to have semi-elliptical shaped open voids or pipes up to 150 mm wide, around their exposed perimeter (Plates 7 and 8). No signs of distress in the form of tension cracks were observed upslope of the landslide.

The approximately 3 m-high retaining wall at the toe of the landslide had about 1 m of its structure removed by the landslide, whilst the bulk of the wall remained intact. The wall is constructed of random rock blocks laid in mortar. Much debris was deposited in front of the wall, as well as a large terminal deposit immediately above the wall. Observation of the nature of the deposit and the stream channel cutting steeply through it (Plate 10) indicates that the terminal deposit above the wall probably initially dammed the drainage line, before it was overtopped.

Upslope of the retaining wall, re-deposited remoulded colluvium typified by a soft consistency with frequent root and topsoil inclusions, was exposed along the margins of the landslide scar for the lower two-thirds of its length. The upper third of the scar showed in-situ colluvium, with topsoil above, exposed in the banks. On the basis of these observations, and typical cross sections, it is estimated that most of the landslide debris was produced in the upper third of the scar, giving an initial volume of around 240 m^3 from the source area. It is estimated that a further 60 m^3 was removed from the trail itself, mostly by erosion of a nominal 100 to 150 mm thickness of colluvium from the stream channel bed, giving a total landslide volume of approximately 300 m^3.

Along the length of the landslide scar, there were scattered rafts of intact displaced material, held together by vegetation. These appeared to be relatively unaffected by erosion with little removal of soil from around the root bowls, and may have been associated with secondary failures. Rock, occurring as weak to moderately strong purple red and grey highly to moderately weathered coarse ash tuff, was seen to outcrop in two isolated patches in the trail, at about its mid-length. During the visit on 30 June 1998, a moderate seepage (approximately 0.5 litres per second) was observed issuing from just below the lowest outcrop, and continued down the slope through a bed of angular to sub-angular cobbles and boulders of tuff, until it was eventually directed into the debris towards the base of the trail.

During a site visit made on 4 September 1998, after two dry days following a thunderstorm, a stream was observed running for over half the length of the landslide debris trail. The source of the stream was seen to be a soil pipe within the in-situ colluvium, beneath lateral debris, forming the southwestern side scarp of the debris trail (Figures 2 and 3), at approximately 60 mPD. The water flow which was issuing into the drainage line from a southwesterly direction, was estimated to be around 1.0 litres per second. This soil pipe is shown in Plates 5 and 6.

Although the debris had been largely cleared and washed away by the time of the first inspection by FSW on 30 June 1998 (i.e. 21 days after the event), the extent of the debris deposit was determined from eye-witness accounts, and traces ("tide marks") left by the debris on buildings and fences. The debris, whilst having been channelised in the drainage line along the debris trail, was partially deposited above No. 30 Pak Sha Wan Village, but a significant volume also spread out over the level platforms of the village properties immediately downslope of the first retaining wall, as shown in Figure 2. The deposit can be broadly classified into two types both of which originate from the same colluvial source. Immediately upslope and beneath the retaining wall were lobes of remoulded colluvium occurring as soft to firm orange brown clayey sandy silt with angular gravel, cobbles and boulders of tuff, intermixed with root-bound rafts of more intact friable, firm to stiff brown sandy clayey silt with numerous gravel to cobble-sized fragments of tuff. Further away from the zone of depletion, the debris comprised very soft clayey sandy silt, which had probably settled out from a slurry and is typical of outwash associated with the effects of surface water flows. The debris left spread over the village platforms at the base of the trail was still particularly soft and wet, to the extent that it was unsafe to walk on, three weeks after the failure.

During the site visit of 4 September 1998, efforts were made to expose and inspect the former footpath that was first observed in the 1963 aerial photographs, and may have contributed to channelling water towards the landslide site. The path was identified and traced for approximately 50 m in a westerly direction from the edge of the debris trail close to the main scarp of the landslide. The overgrown path followed an uphill, sidelong route, and was seen to be about 0.5 m to 1.0 m wide. The orientation of the path, with a fall towards the centre of the drainage channel, suggests that it could have acted as an intercepting catchwater-type channel. However, the undulating nature of the surface of the path suggests that it may not have promoted significant water flow and there was no obvious evidence of severe water flow along its length (e.g. erosion). Photographs of the path are shown in Plate 9, and its location is indicated on Figure 2.

On a subsequent visit to site on 14 January 1999, the lobe of debris left at the toe of the retaining wall had been partly removed, exposing a section through the deposit. The deposit was observed to be locally made up of three separate units. The bottom comprised a layer of grey remoulded topsoil, which graded up into a layer of vegetation, including roots and tree trunks. Overlying this mat, and extending to the surface, was a layer of remoulded colluvium, with scattered intact rafts of vegetated material above. This profile indicates the order in which each distinct unit was deposited.

The travel angle of the landslide debris is difficult to quantify, mainly as a result of some of the debris having been washed over the village platforms and out to sea by surface water flow. The travel angle as measured to the toe of the main terminal deposit immediately below the retaining wall, however, is 25°. This is less than that for typical rain-induced landslides of comparable volumes (Wong & Ho, 1996a), and may be a result of the channelling effect of the drainage line.

5. SUBSURFACE CONDITIONS AT THE SITE

5.1 Geology and Previous Ground Investigations

The subsurface conditions at the site were determined from post-failure field mapping and inspection carried out by FSW, and by examination of the limited available geological data. There are no previous site investigation records available for the landslide site.

Sheet 7 of the Hong Kong Geological Survey 1:20 000 Map Series HGM20 (Geotechnical Control Office, 1986) indicates that the landslide site is underlain by coarse ash crystal tuff belonging to the Tai Mo Shan Formation.

The geology of the landslide area, based on field mapping, comprises colluvium overlying moderately decomposed tuff. The colluvium infills a linear drainage channel cut into the weathered rock. The pre-existing thickness of colluvium is difficult to gauge, but is estimated to be approximately 1 m within the source area.

The in-situ colluvium has been described from field observations as firm to stiff orange brown and dark brown sandy clayey silt with numerous angular to subangular gravel, cobble and boulder-sized clasts of coarse ash tuff of mainly Grades II / III.

5.2 Groundwater Conditions

No groundwater data (e.g. standpipe or piezometer records) exist for the landslide site. Hence an appreciation of the likely groundwater conditions needs to be obtained from observations of surface water behaviour and relevant features revealed by soil exposures.

It is considered that the main groundwater table is probably below the colluvium/decomposed tuff interface and at a depth where it is unlikely to affect the near surface soil mantle through which the landslide occurred. This is corroborated by the fact that under normal conditions, there is no groundwater intercepted by the retaining wall and the associated drainage system located at the base of the natural hillside. Similarly, outcrops of bedrock exposed by the landslide remained dry under normal weather conditions and no signs of seepage were observed during the course of this landslide study.

Based on observations of the geology of the landslide, where colluvium with soil pipes overlies less permeable decomposed tuff, the hydrogeological setting is favourable to the build-up of perched water conditions.

It can be demonstrated by simplified calculations (Appendix B) that there was probably sufficient rainfall in the 24-hour period prior to the landslide for at least one metre of colluvium, which is the typical pre-existing thickness of the deposit in the landslide source area, to become saturated as a result of direct infiltration. Even allowing for 50% surface runoff (GCO, 1984), there would have been sufficient infiltration to have filled all the voids within the shallow colluvium. Erosion pipes have been observed in both dormant and active states. These provide preferential flow paths allowing rapid recharge and wetting up, and inducing high local seepage pressures, within the slope.

The drainage line in which the failure occurred only maintains a flow of water periodically in the wet season, according to local knowledge in the village. High surface water flows are possible, however, as a result of the colluvium becoming saturated. Whilst the computation of precise amounts of surface water flow is difficult, it is possible to estimate the order of volumes involved, based on simplifying assumptions. Given the intensity of rainfall in the 12 hours preceding the landslide (359 mm) onto the 12,000 m^2 catchment area and allowing for 50% infiltration, a net surplus of about 2,000 m^3 of water would have drained by surface flow. This equates to an average surface water flow rate, at the base of the natural slope, of approximately 50 litres per second over a 12-hour period, which is fairly significant.

6. ANALYSIS OF RAINFALL RECORDS

The nearest GEO automatic raingauge No. N15 is located at Sai Kung, approximately 3 km north of the landslide site. The raingauge records and transmits rainfall data at 5-minute intervals via a telephone line to the GEO.

For the purposes of rainfall analysis, it is assumed that the landslide occurred between 18:00 and 20:00 hours on 9 June 1998, based on eye-witness accounts.

Daily rainfall for one month preceding, and seven days following the landslide, together with hourly rainfall for 48 hours before and 8 hours following the landslide, are given in Figure 5. The daily rainfall records show that the storm was concentrated around the day of 9 June 1998 (viz. the day of the landslide), with the hourly data indicating intense peaks from 03:00 to 07:00 hours, 13:00 to 14:00 hours and 15:00 to 19:00 hours, generally in the range of 40 mm/hr to 60 mm/hr.

Isohyets of rainfall for the 24-hour periods ending at 18:00 hours (the reported start of the landslide) and 20:00 hours (the reported end of the event) are shown in Figures 6 and 7 respectively. These show that the rainfall conditions continued to deteriorate throughout the period when the different phases of landsliding occurred.

Table 1 presents the estimated return periods for the maximum rolling rainfalls recorded at raingauge No. H07 for various durations based on historical rainfall data recorded at the Hong Kong Observatory (Lam & Leung, 1994). Values for time intervals ending before or after 18:00 hours and 20:00 hours respectively are given. The 24-hour and 48-hour rainfall, ending at 20:00 hours, were the most severe (562 mm and 580 mm respectively), with corresponding return periods of about 100 years and 45 years respectively, although conditions at the initiation of movement (assumed to be at 18:00 hours) were also severe, with return periods of 80 years and 35 years for the same respective durations. The rainfall data for the period ending at 20:00 hours has been plotted in Figure 8, and is compared with other selected previous major rainstorms. This shows that the 9 June 1998 rainstorm was particularly severe and was the most intense rainstorm experienced by raingauge No. N15 since its installation in 1984.

Whilst return periods for various durations within the rainstorm have been assessed based on Table 3 of Lam & Leung (1994), it is recognised that this method does not necessarily give the true return period for a particular site (Wong & Ho, 1996b). However, the approach will provide an objective ranking of the likely relative severity of the different rainfall characteristics for different rainstorms and enable comparison with analyses of other rainstorms based on the same approach.

7. THEORETICAL STABILITY ANALYSES

Theoretical stability analyses of the slope have been carried out to assist in the diagnosis of the probable contributory causes and triggering factors of the landslide. This has been carried out using the infinite slope method. Whilst it is acknowledged that this method of analysis is necessarily simplified given the fairly complex and variable ground and groundwater conditions, it is considered sufficient for the present purpose given the profile and shallow nature of the landslide.

The geological model assumed in the analyses consists of a 1 m thickness of colluvium overlying a relatively impermeable stable stratum that dips at an average slope of 25°. A sensitivity analysis has been carried out using different assumptions of groundwater conditions within the colluvium, to examine the likely range of c' and ϕ' values that might apply (Figure 9). The results suggest that for typical saturated strength parameters for the nature of the material as observed (i.e. c' up to 2 kPa and ϕ' of 30° to 35°), the groundwater condition at failure is likely to have been somewhere between an elevated water level of 0.5 m and 1.0 m above the colluvium/tuff interface with seepage flow being parallel to the ground surface.

Notwithstanding the above calculations, it is also noted that the stability of the near-surface material could also have been influenced by surface water flow along the drainage line or localised seepage flows along subsurface erosion pipes.

8. DIAGNOSIS OF PROBABLE CAUSES OF THE LANDSLIDE

8.1 Probable Sequence of the Landslide

The morphology of the landslide and the nature and strata of the debris suggests that it possibly involved the following phasing of events and modes of failure :

(a) Erosion of topsoil, followed by loosened vegetation, by concentrated surface water flows down the drainage line. The profile and nature of the terminal deposits beneath the retaining wall corroborate this initial sequence.

(b) Failure of an area of the slope near the top of the scar, possibly as a result of wetting up and build-up of transient water pressures and undercutting as the head of erosion migrated up the drainage line. The debris partially broke up and mixed with the surface water in the drainage line as it travelled downhill, possibly in the form of a channelised debris flow.

(c) Channelised movement of debris from the slip source area down the drainage line, stripping the remaining vegetation and entraining some material from the trail, depositing lateral debris along the lower margins of the trail and terminal deposit on the flatter slope both immediately above and below the retaining wall at the toe of the natural hillside.

(d) Subsequent erosion of the stripped channel floor and sides by surface water flow resulting in debris being transported onto the platforms below. Inspection of the terminal lobe above the wall suggests a possible cycle of impounding and subsequent release of surface water.

(e) Secondary failure of the obliquely-aligned area above the source area (Figure 2), due to loss of support associated with the initial slide, resulting in the deposition of rafts of vegetated and relatively intact material along the debris trail further downhill.

It is acknowledged that alternative interpretations of the exact sequence of events are possible from the evidence observed. For instance, it is possible that event (b) may precede event (a). However, it is considered that the general mode of the landslide probably involved ongoing erosion interspersed with distinct phases of sliding.

8.2 Mode of the Landslide

The landslide involved a process of instability that lasted for about two hours. The number of "pulses" of landsliding that may have occurred during this period, as evidenced by the presence of rafts of detached material on the trail, is not certain. The landslide involved failure of material at the source area and the debris was subjected to the effects of secondary washout by concentrated surface water flow down the stream channel. Given the large amount of surface water, the failed material travelled downslope in the form of a wet channelised debris flow, entraining further material from the stream channel. It is probable that further detachments and erosion occurred after the initiation of the landslide. The initial failure may or may not have involved erosion by surface water flow and may not have been particularly mobile. The relatively mobile nature of the debris was probably due to the effects of surface water and channelisation within the streamcourse.

8.3 Probable Causes of the Landslide

The correlation between severe rainfall and the timing of the landslide suggests that the failure was triggered by very severe rainfall that was concentrated in the locality.

Both surface water and subsurface water flow probably contributed significantly to the landslide, which initially involved sliding of the relatively thin surface colluvium as a result of water ingress, leading to wetting up and likely development of perched water pressure and reduction in shear strength.

This landslide, involving failure near the head of a gully, can be interpreted as a natural geomorphological process, with the marginally stable colluvium in a drainage line being destabilised by severe rainfall. The former footpath which traverses the source area of the landslide could have been a contributory factor, through channelising surface water towards the landslide site.

The landslide was not in the form of a retrogressive failure. It involved a process of instability which apparently lasted for about two hours, with further detachments and debris being brought down after the initial failure as a wet debris flow. Although the initial failure and the subsequent detachments may not have been mobile, the setting of the landslide site within the streamcourse probably provided sufficient surface water to result in debris flow with mobile and wet debris.

It is notable that the landslide occurred on a relatively gentle slope with no evidence of past instability. This suggests that the failure was probably triggered under fairly high water table conditions. The adverse hydrogeological setting of a thin mantle of colluvium is favourable to the development of a perched water table. The characteristic of the intense rainstorm of 9 June 1998 with the most severe rainfall corresponding to the 24-hour duration rainfall suggests the influence of recharge from the upslope area. This reflects possible concentration of subsurface water flow from the catchment towards the landslide source area, together with direct infiltration, affecting the initial failure. The presence of erosion pipe holes probably promoted subsurface seepage towards the landslide site.

The landslide site experienced very severe rainfall (viz. return period of about 100 years), which exceeded the threshold for "high density landsliding" proposed by Evans (1997) for natural terrain landslides in Hong Kong. Whilst there are limitations with the application of such correlations to site-specific studies, this nonetheless suggests that the occurrence of natural terrain landslides at this site should not have been unexpected. The scale and spatial location of the landslide would, however, have been more difficult to predict, as these would depend on the local ground conditions and site setting as well as the rainfall characteristics.

9. CONCLUSIONS

It is concluded that the natural terrain landslide that affected the village of Pak Sha Wan on 9 June 1998 was triggered by very severe rainfall.

The failure occurred within a drainage line and was probably caused by the wetting up and development of transient elevated water pressures in the surface mantle of colluvium. Both concentrated surface and subsurface water flows, leading to water ingress into the landslide site, probably contributed to the landslide. More than one phase of landsliding has been identified and the wet debris was relatively mobile, probably as a result of channelisation within the drainage line and the effects of surface water, and it travelled downslope in the form of a channelised debris flow.

The 300 m^3 landslide occurred in natural terrain that did not exhibit obvious signs of recent or relict instability. The extent to which the disused footpath may have contributed to the failure by diverting surface water to the landslide site is uncertain.

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Table 1 – Maximum Rolling Rainfall at GEO Raingauge No. N15 and Estimated Return Periods for Different Durations Preceding the Landslide of 9 June 1998

	Search Interval Ending at 18:00 hours			Search Interval Ending at 20:00 hours		
Duration	**Maximum Rolling Rainfall (mm)**	**End of Period**	**Estimated Return Period (Years)**	**Maximum Rolling Rainfall (mm)**	**End of Period**	**Estimated Return Period (Years)**
5 minutes	14	06:15 on 9 June 1998	4	14	06:15 on 9 June 1998	4
15 minutes	33.5	06:15 on 9 June 1998	5	33.5	06:15 on 9 June 1998	5
1 hour	87.5	06:15 on 9 June 1998	4	87.5	06:15 on 9 June 1998	4
2 hours	141.5	06:25 on 9 June 1998	9	141.5	06:25 on 9 June 1998	9
4 hours	218.5	07:00 on 9 June 1998	19	218.5	07:00 on 9 June 1998	19
12 hours	358.5	17:25 on 9 June 1998	40	358.5	17:25 on 9 June 1998	40
24 hours	538.5	18:00 on 9 June 1998	80	562	19:00 on 9 June 1998	100
48 hours	554	18:00 on 9 June 1998	35	580	19:30 on 9 June 1998	45
4 days	579	18:00 on 9 June 1998	18	605	20:00 on 9 June 1998	20
7 days	632.5	18:00 on 9 June 1998	17	658.5	20:00 on 9 June 1998	20
15 days	718	18:00 on 9 June 1998	8	744	20:00 on 9 June 1998	10
31 days	1045.5	18:00 on 9 June 1998	19	1091.5	20:00 on 9 June 1998	25

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 rainfall 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 2 – Summary of Descriptions of Materials Observed at the Landslide Site

Location of Material	Type of Material	Description of Material
Exposures in the rear and side scarps of the source area	In-situ colluvium	Firm to stiff, friable, orange/brown and dark brown sandy clayey SILT with numerous angular/subangular gravel to boulder-sized fragments of mainly Grade II/III coarse ash tuff.
Exposures in the side of the landslide trail – lateral debris	Remoulded colluvium	Soft orange/brown and dark brown sandy clayey SILT with numerous angular/subangular gravel to boulder-sized fragments of mainly Grade II/III coarse ash tuff with frequent roots and rootlets and occasional topsoil inclusions.
Soil exposures in the base of the landslide trail	In-situ eroded colluvium	Soft to firm orange/brown and dark brown sandy clayey SILT with numerous angular/subangular gravel to boulder-sized rock fragments frequently covered by a bed of angular/subangular gravel to boulder-sized fragments of mainly Grade II/III coarse ash tuff.
Rafts distributed down the length of the landslide scar	Displaced intact colluvium bound by vegetation	Firm to stiff, friable, orange/brown and dark brown sandy clayey SILT with numerous angular/subangular gravel to cobble-sized fragments of mainly Grade II/III coarse ash tuff, bound by roots and rootlets.
Rock exposure in the base of the landslide trail	In-situ bedrock	Weak to moderately strong purple red and grey with black staining, highly to moderately decomposed coarse ash TUFF.
Terminal debris (a)	Remoulded colluvium	Soft orange/brown and dark brown sandy clayey SILT with numerous angular/subangular gravel to boulder-sized fragments of mainly Grade II/III coarse ash tuff with frequent roots and rootlets and occasional topsoil inclusions.
Terminal debris (b)	Remoulded topsoil	Soft grey/brown and dark grey sandy clayey SILT with numerous angular/subangular gravel to cobble-sized fragments of mainly Grade II/III coarse ash tuff with frequent roots and rootlets and intermixed vegetation.
Outwash debris	Alluvial sand and silt	Soft to very soft orange/brown coarse to fine sandy slightly clayey SILT.
Note: Terminal debris (a) was observed intermixed with terminal debris (b) immediately upslope and beneath the retaining wall (to the rear of No. 30 Pak Sha Wan). Refer to Section 4.2 for further details.		

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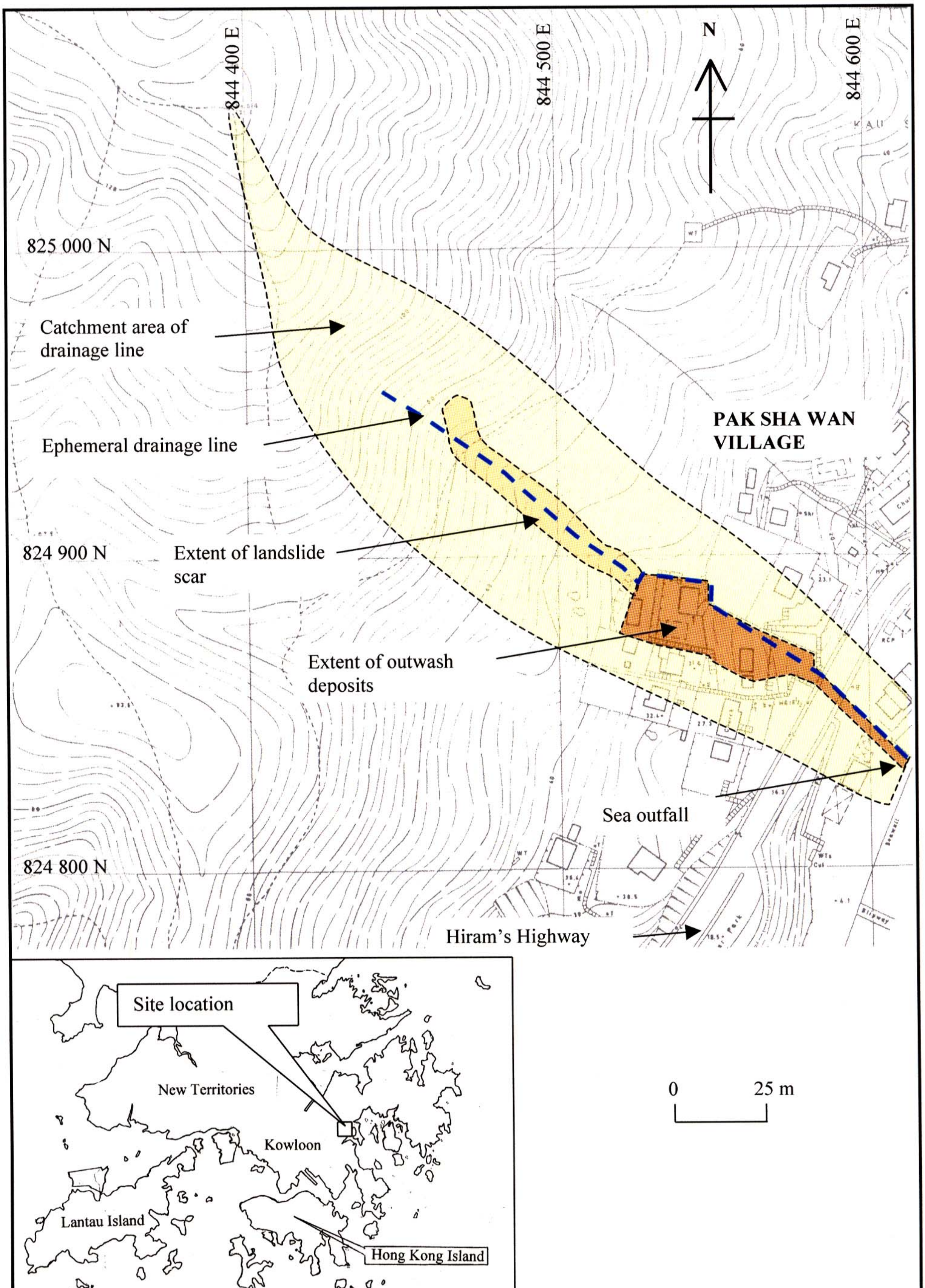
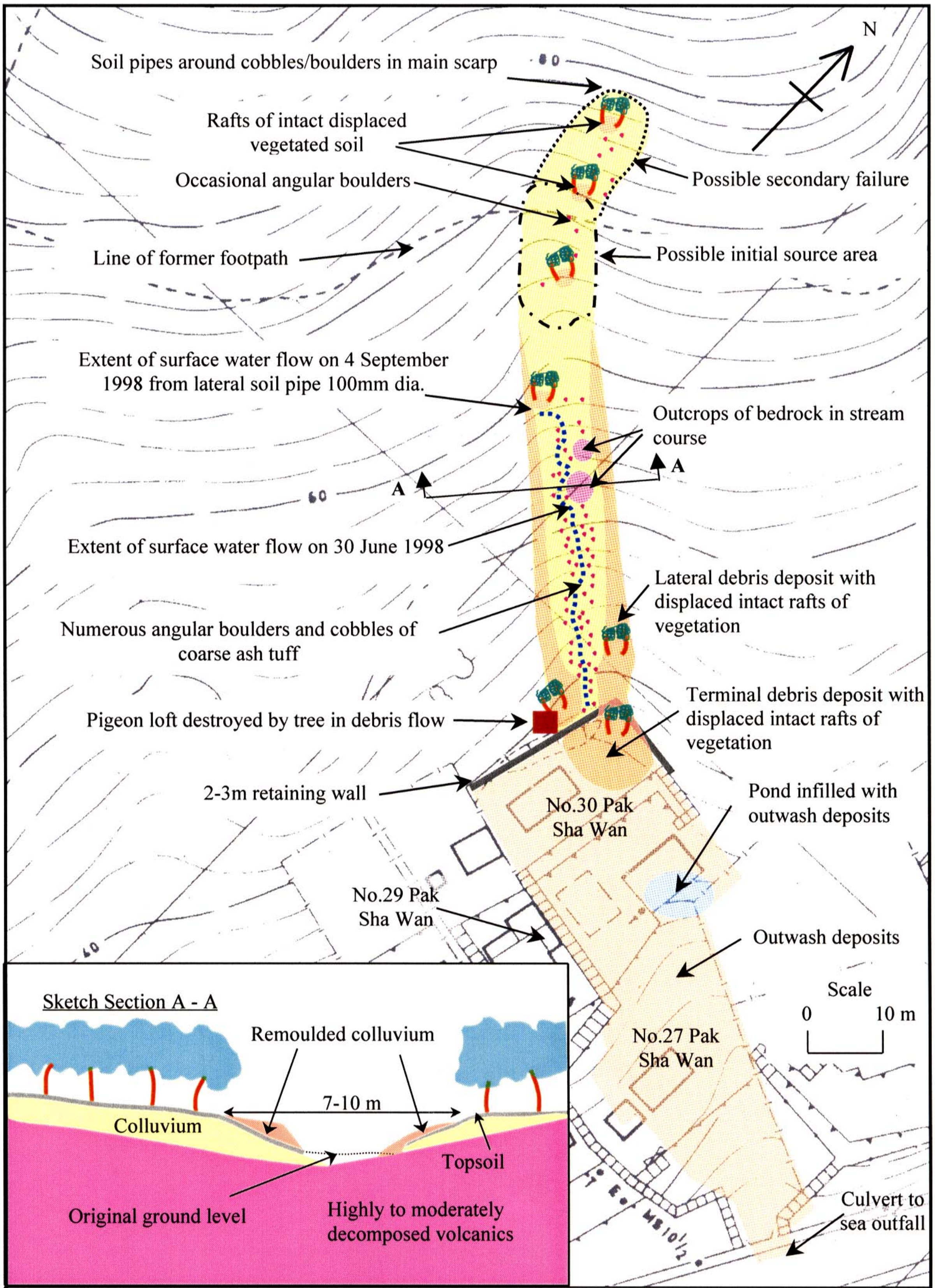


Figure 1 – Site Location Plan



Note : See Table 2 for full descriptions of materials.

Figure 2 – Sketch Plan of the Landslide

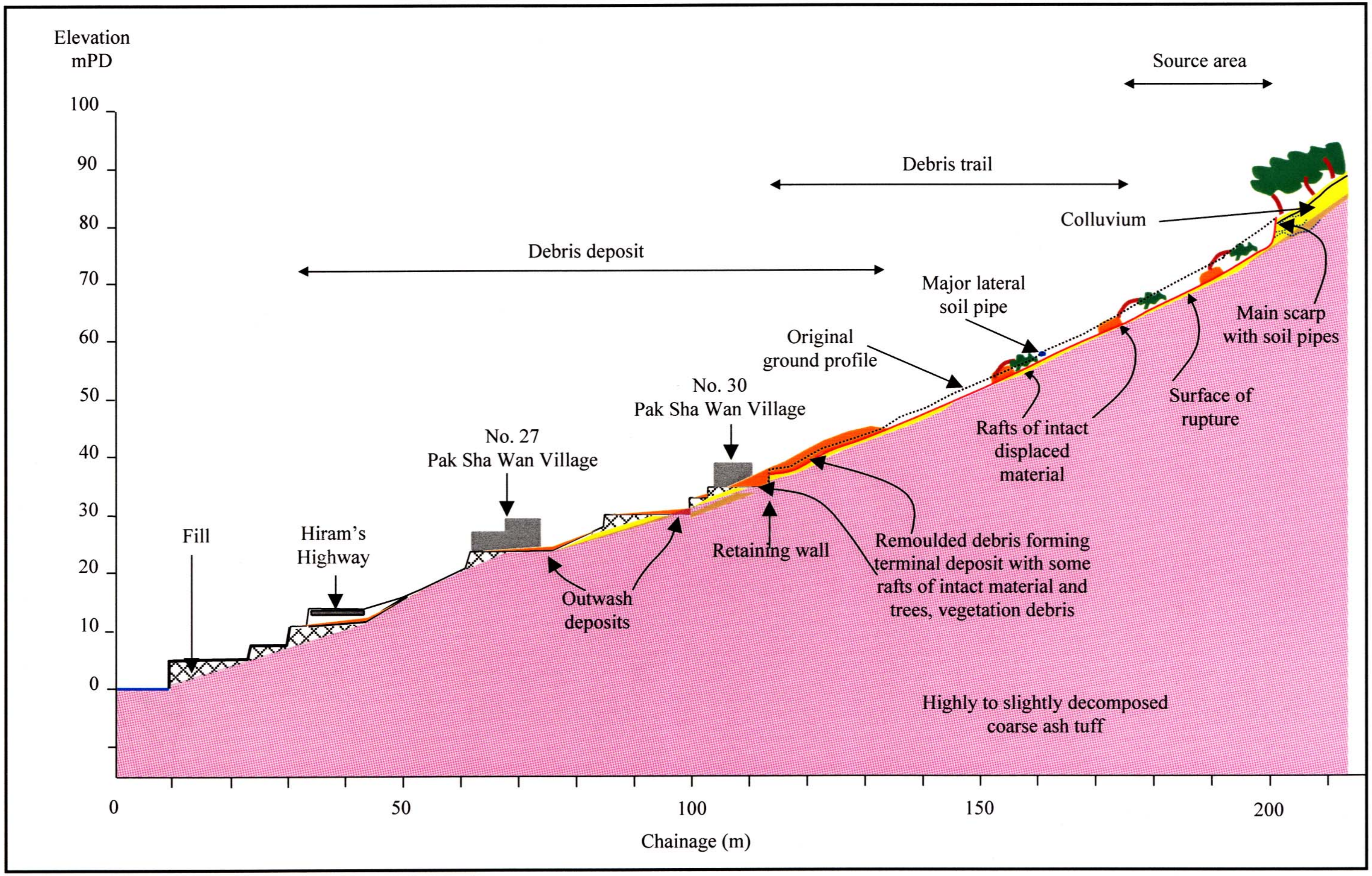


Figure 3 – Sketch Section through the Landslide

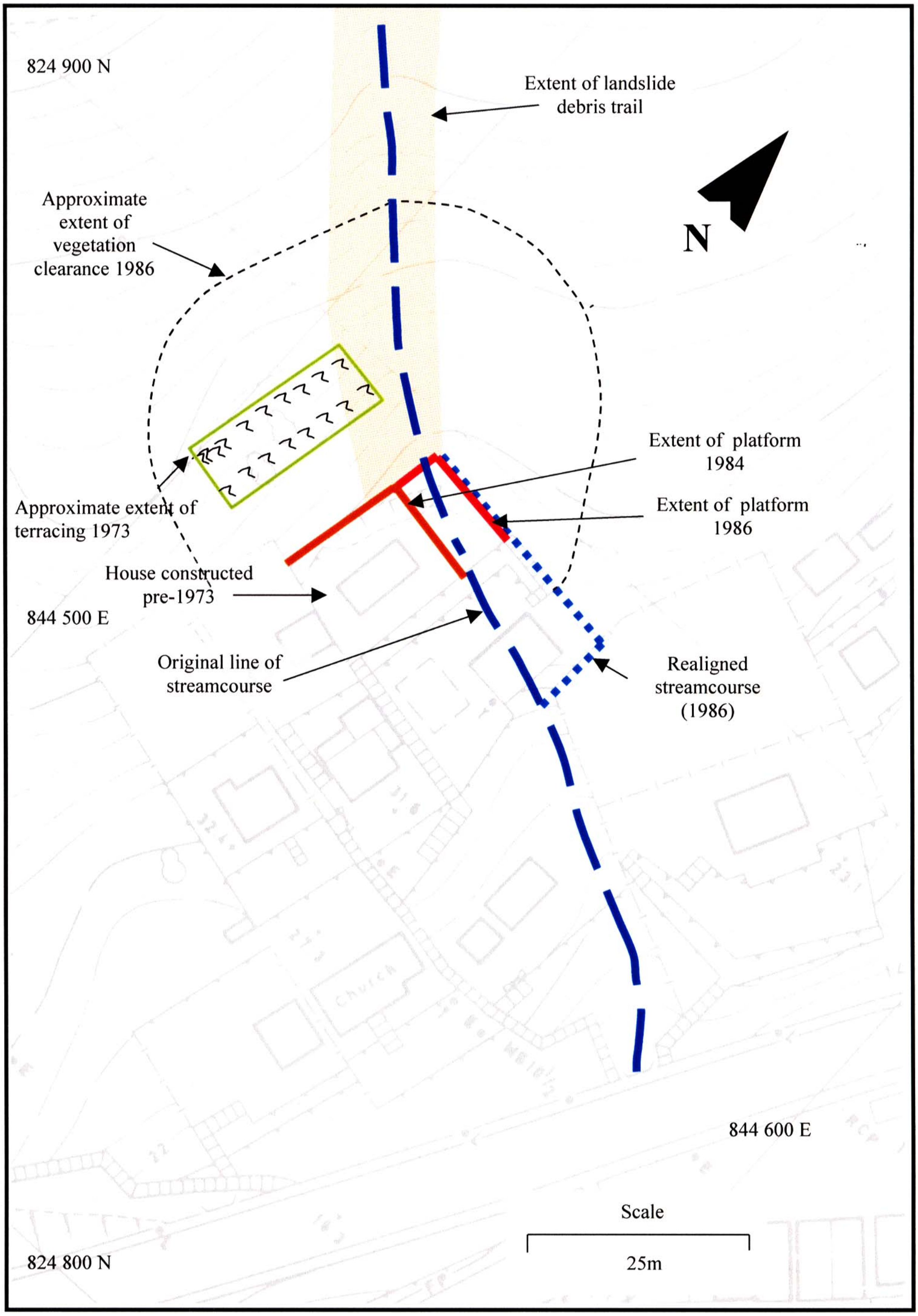
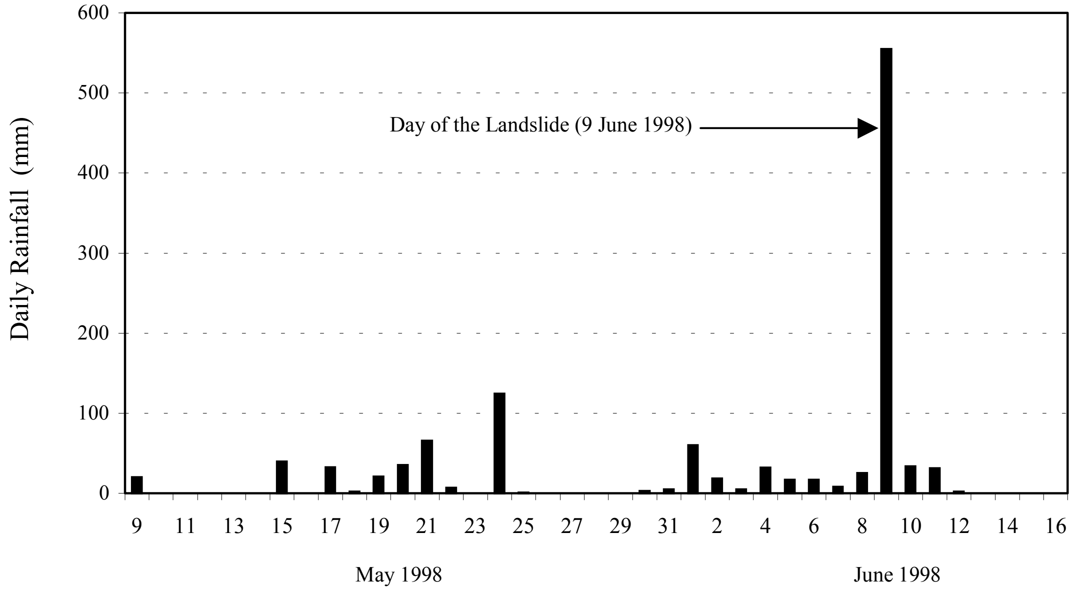
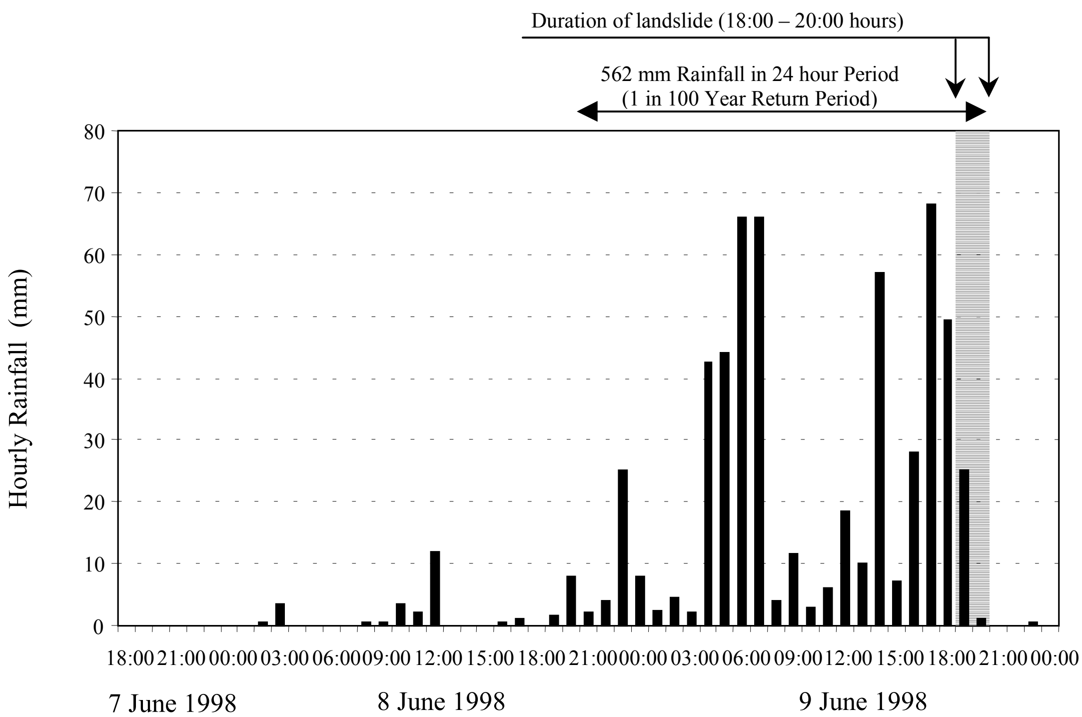


Figure 4 – Plan of Key Features Observed in API



(a) Daily Rainfall Recorded Between 9 May 1998 and 16 June 1998



(b) Hourly Rainfall Recorded Between 7 June and 9 June 1998

Figure 5 – Daily and Hourly Rainfall Records at GEO Raingauge No. N15

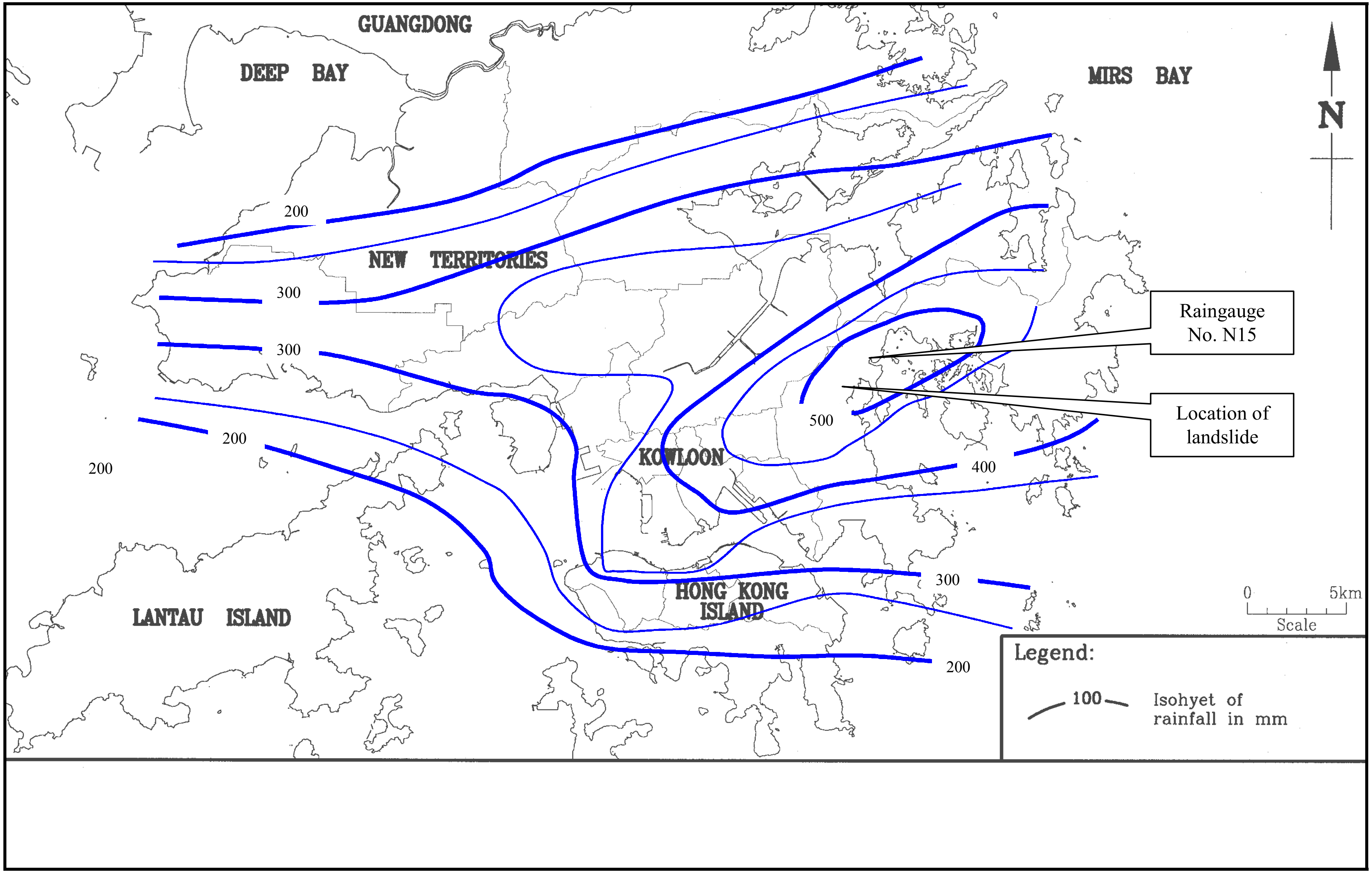


Figure 6 – Isohyets of Rainfall from 18:00 hours on 8 June 1998 to 18:00 hours on 9 June 1998

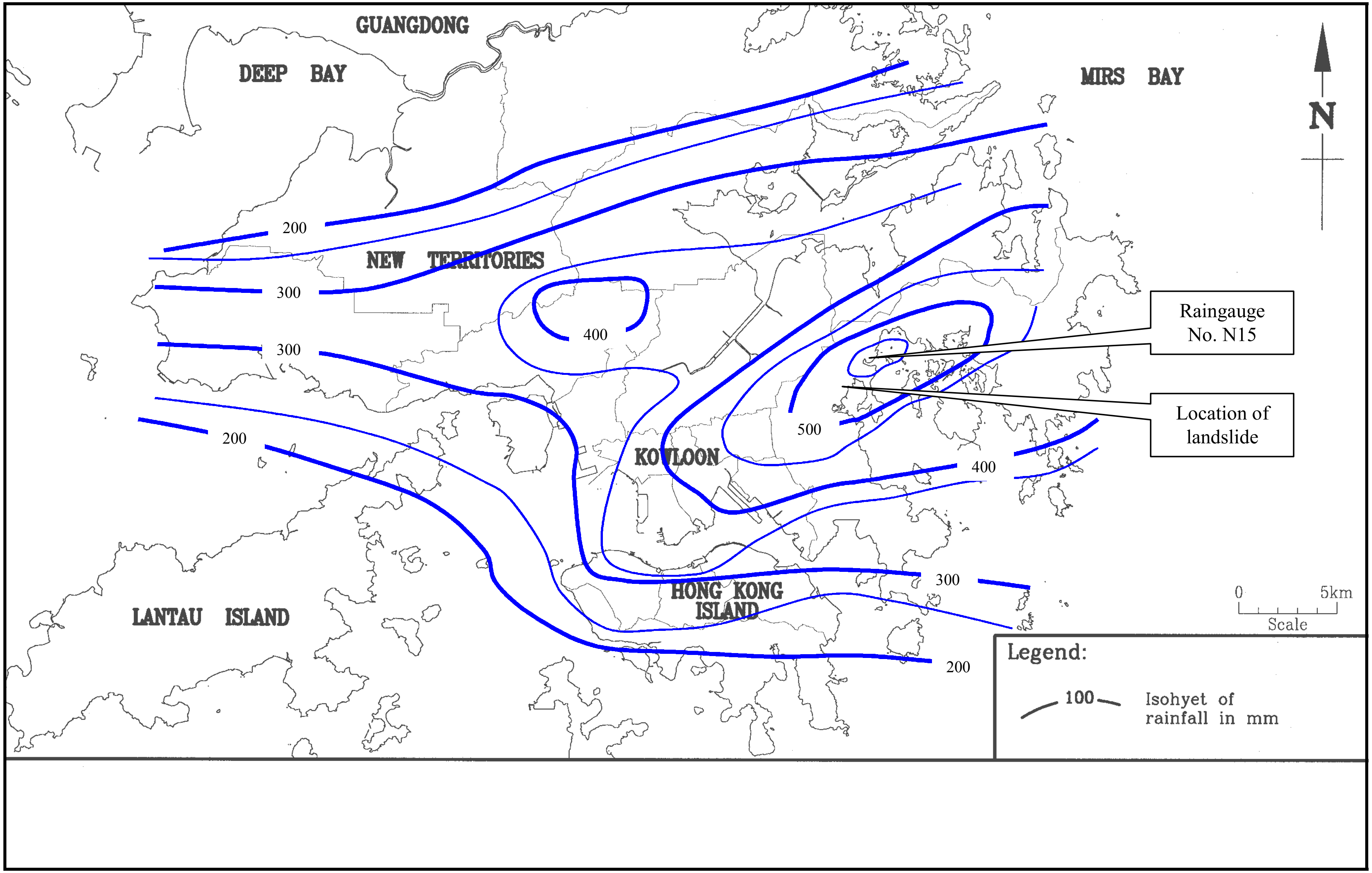


Figure 7 – Isohyets of Rainfall from 20:00 hours on 8 June 1998 to 20:00 hours on 9 June 1998

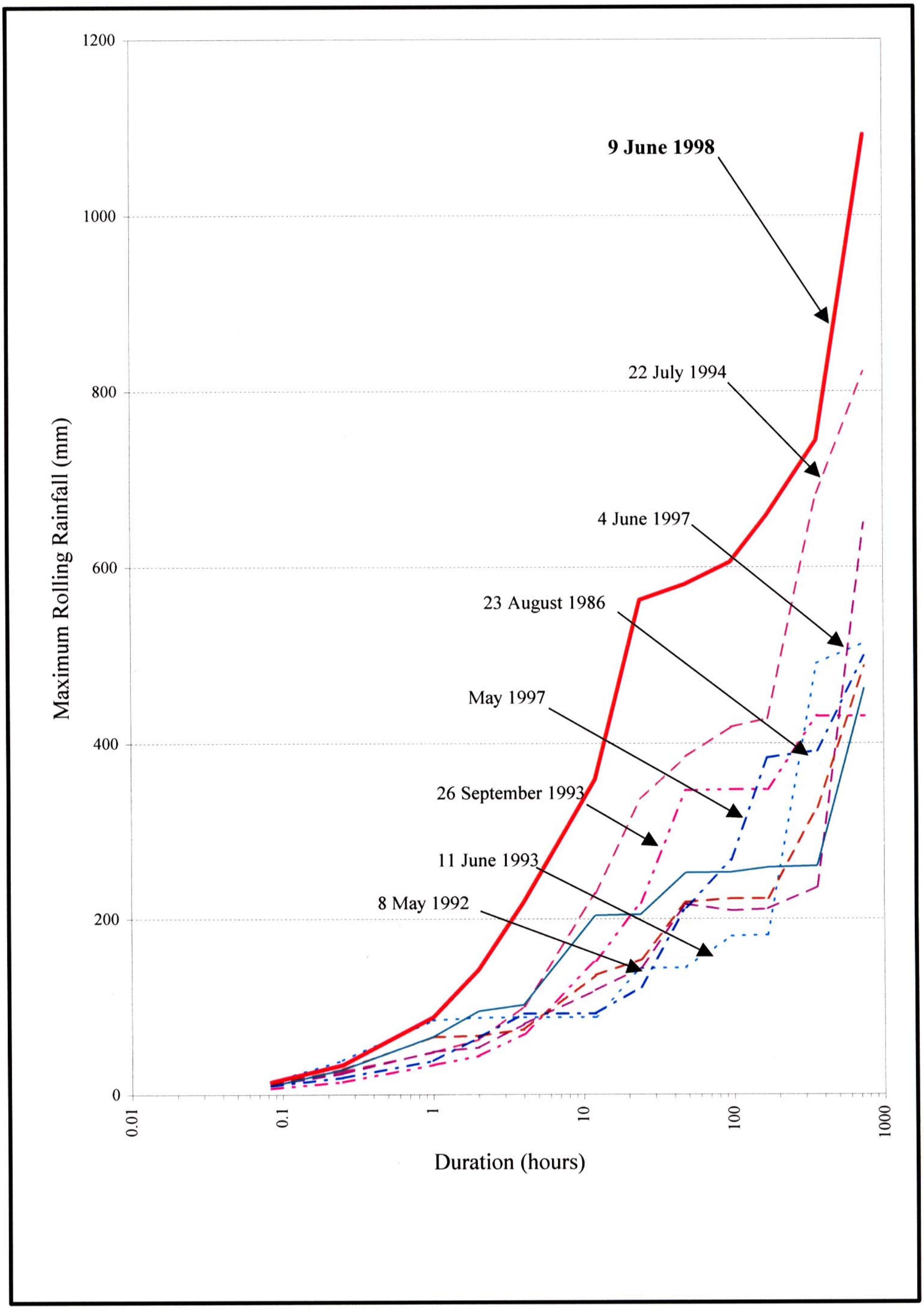
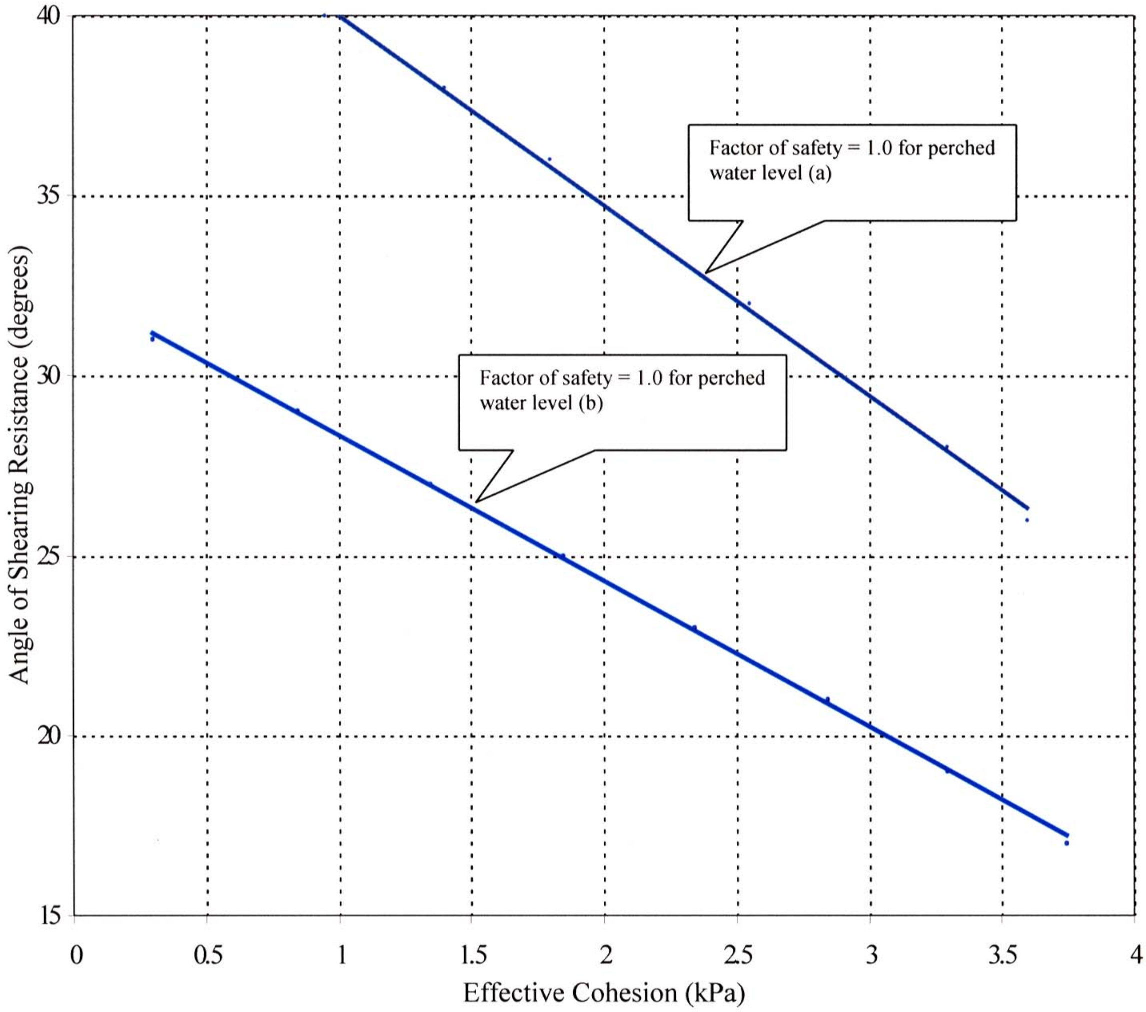


Figure 8 - Maximum Rolling Rainfall Preceding the Landslide of 9 June 1998 and that of Previous Major Rainstorms Recorded by GEO Raingauge No. N15



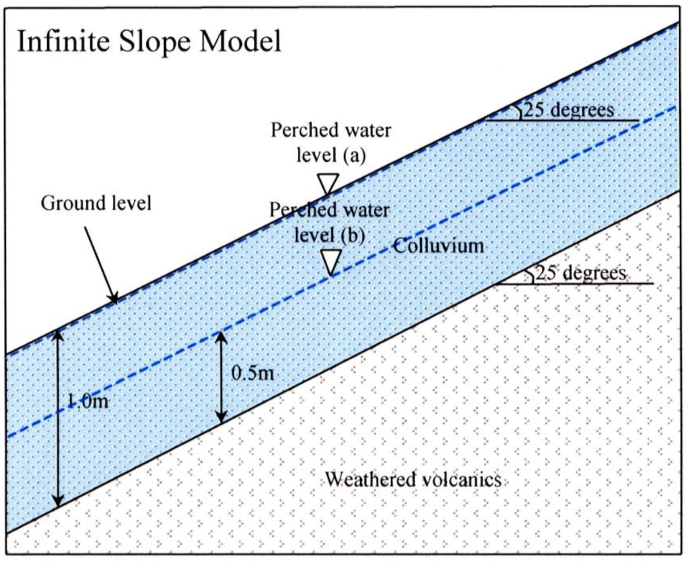


Figure 9 – Results of Theoretical Analyses

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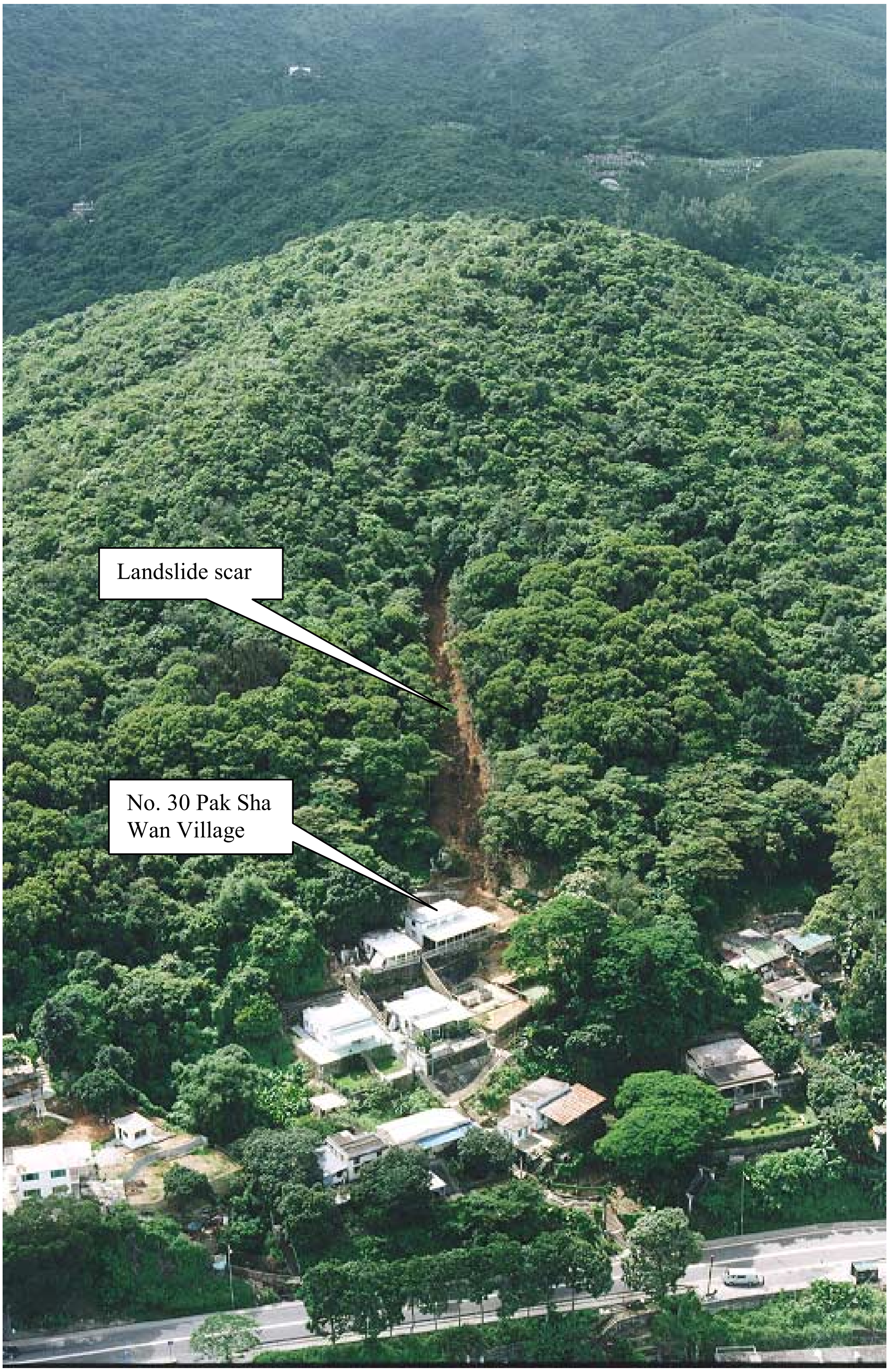


Plate 1 – Aerial View of the Landslide
(Photograph taken on 29 June 1998)

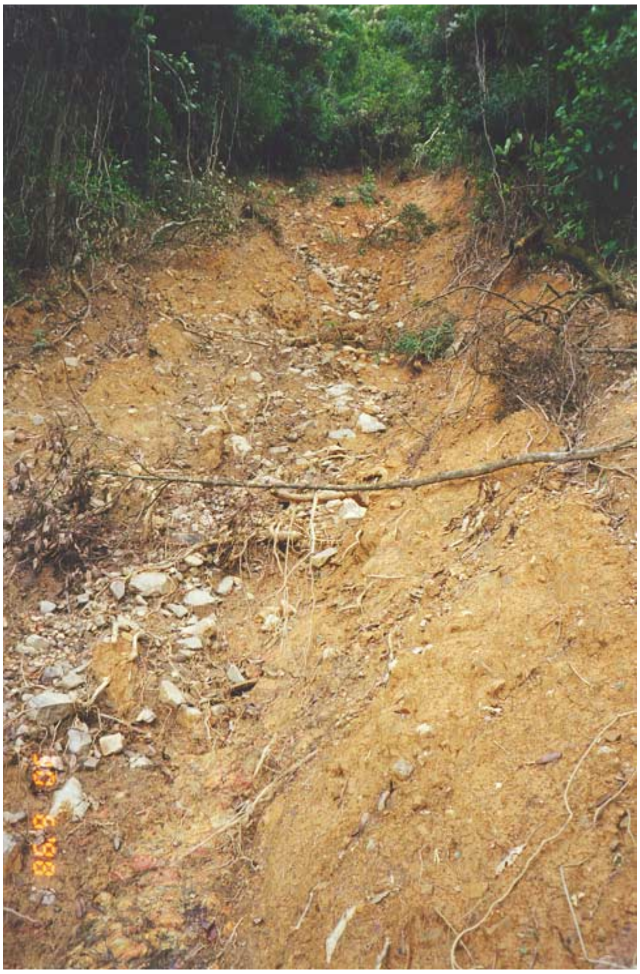


Plate 2 – General View of the Landslide
(Photograph taken on 30 June 1998)

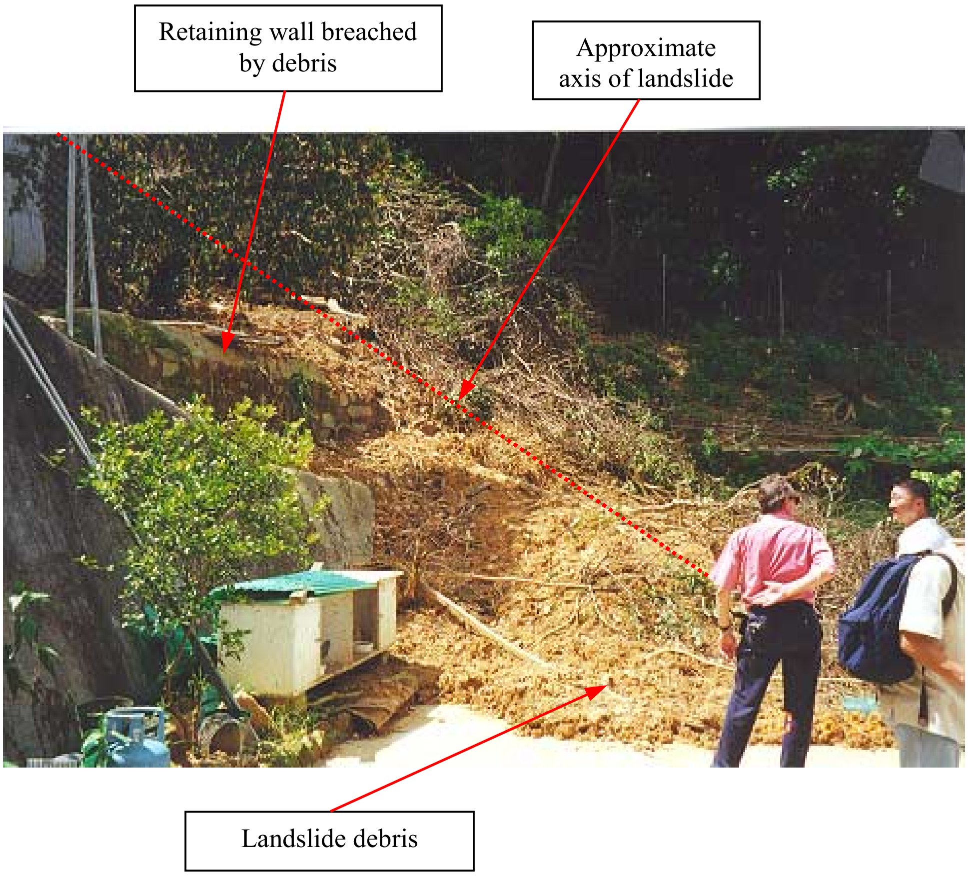


Plate 3 – View of Toe of Landslide
(Photograph taken on 30 June 1998)

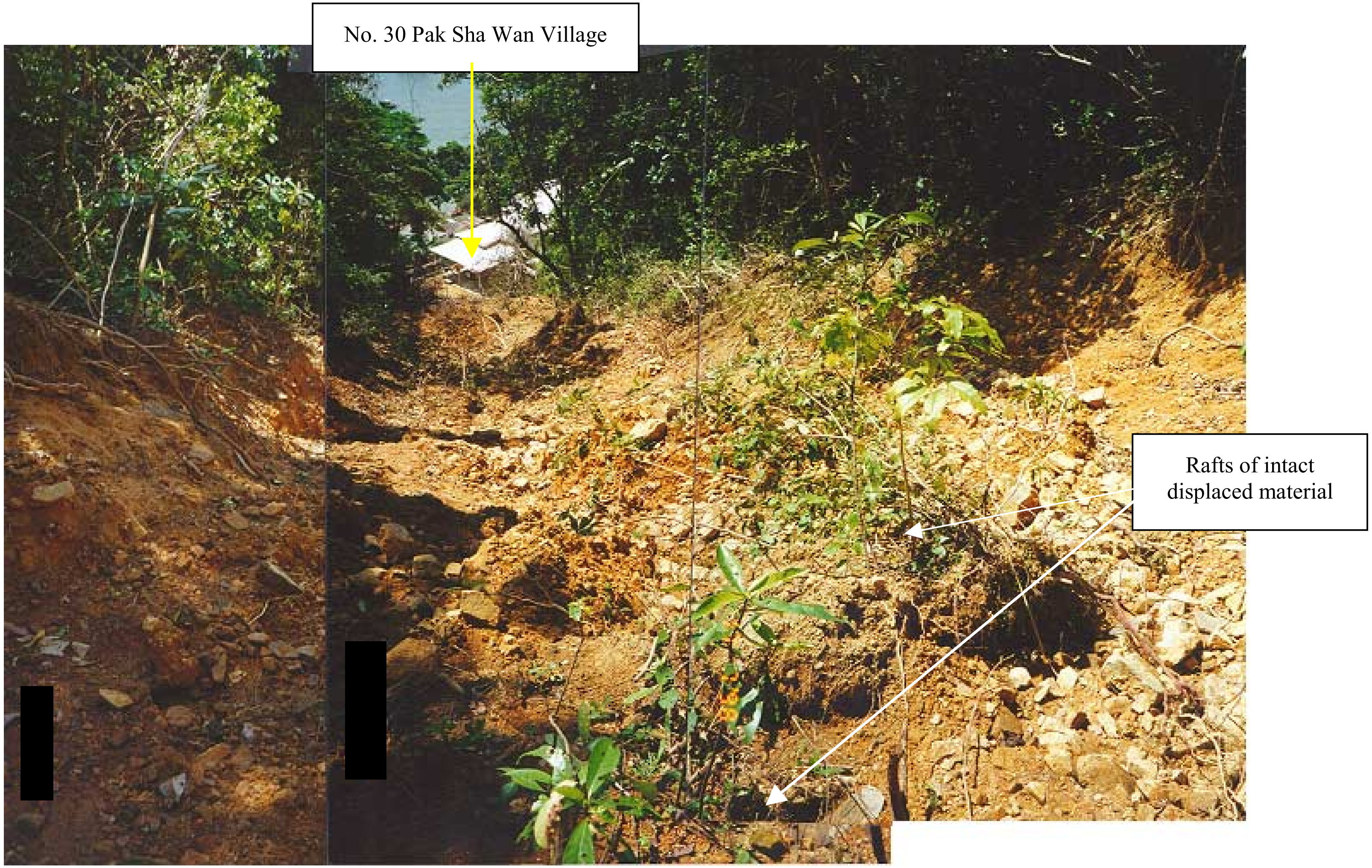


Plate 4 – General View Down the Landslide
(Photograph taken on 30 June 1998)

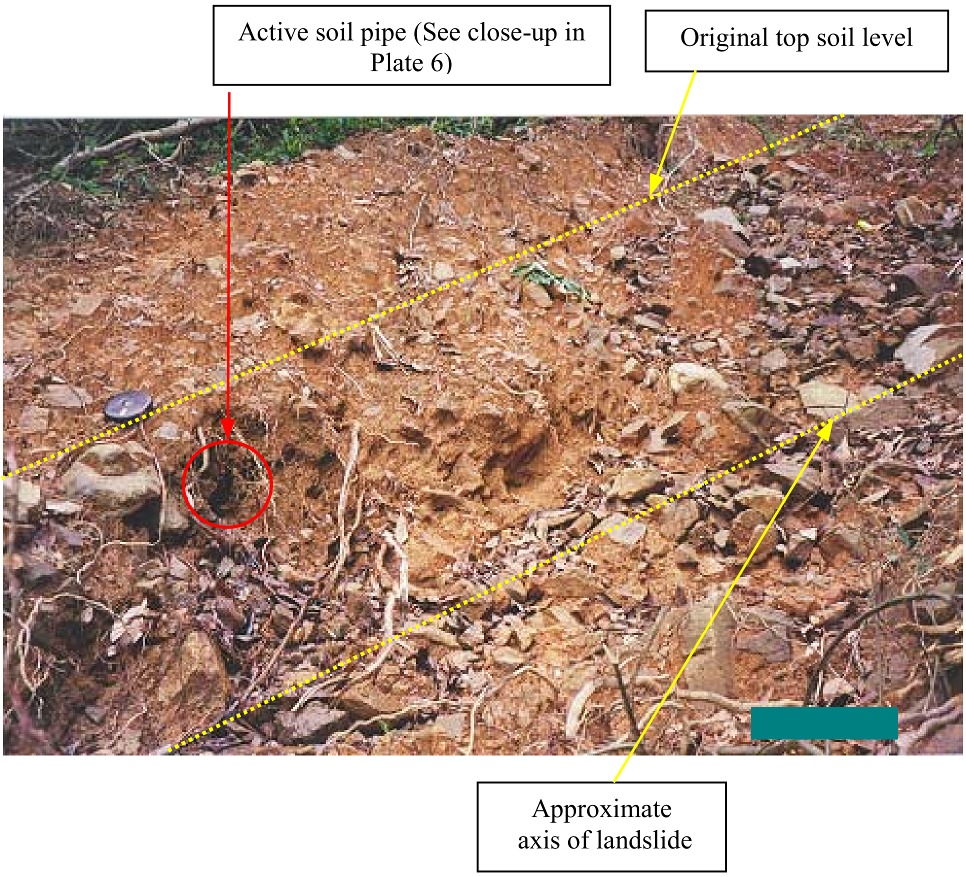


Plate 5 – View of a Soil Pipe at Side of Debris Trail
(Photograph Taken on 4 September 1998)

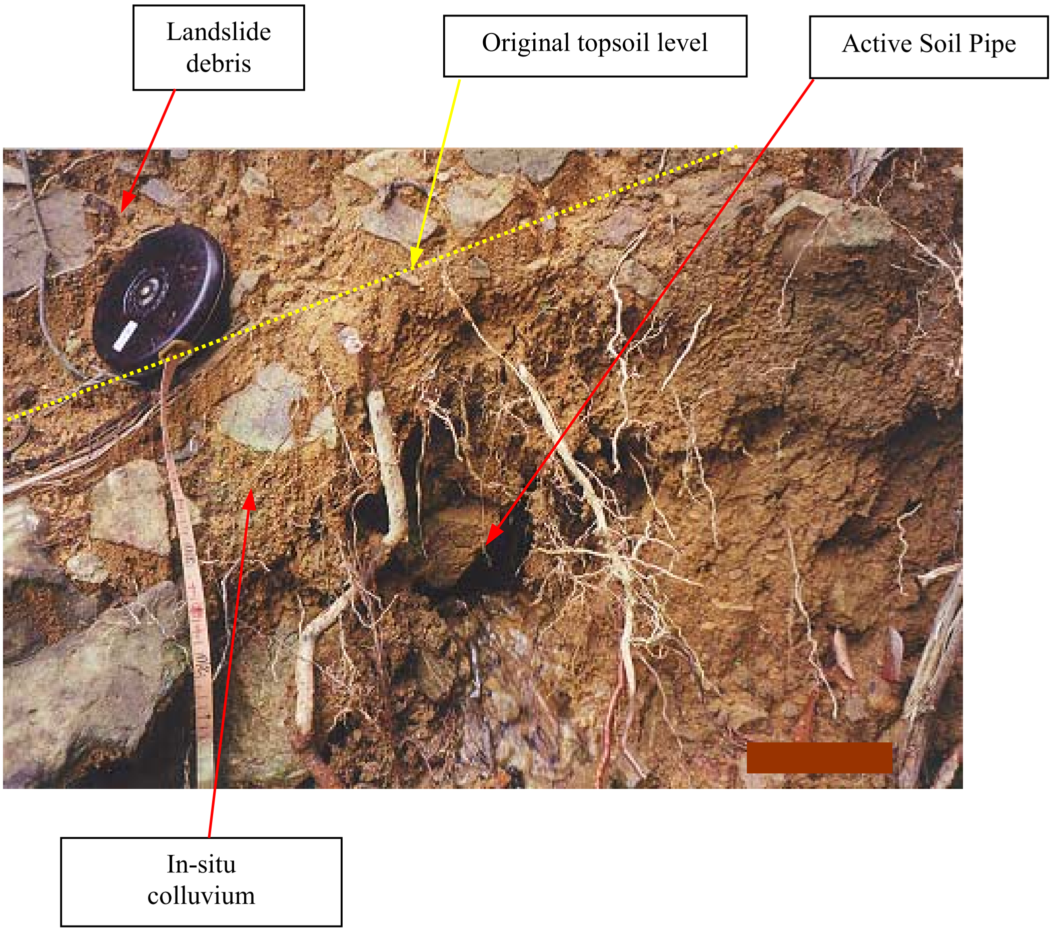


Plate 6 – Close-up of an Active Soil Pipe at Side of Debris Trail
(Photograph Taken on 4 September 1998)

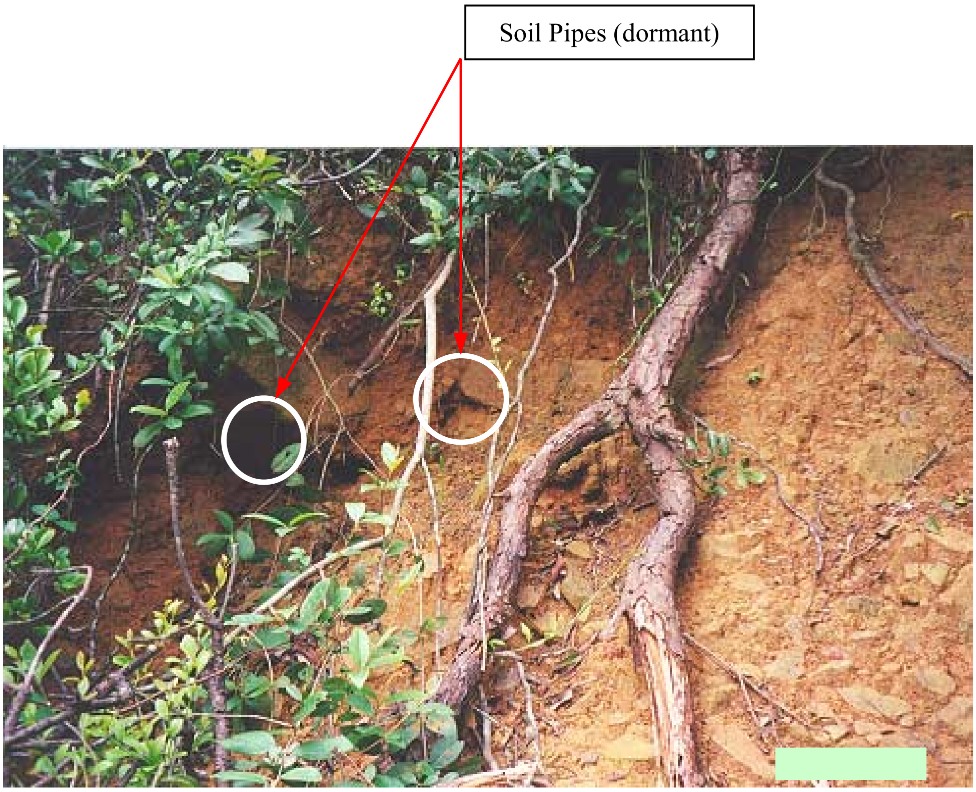


Plate 7 – View of Soil Pipes in the Main Scarp
(Photograph taken on 30 June 1998)

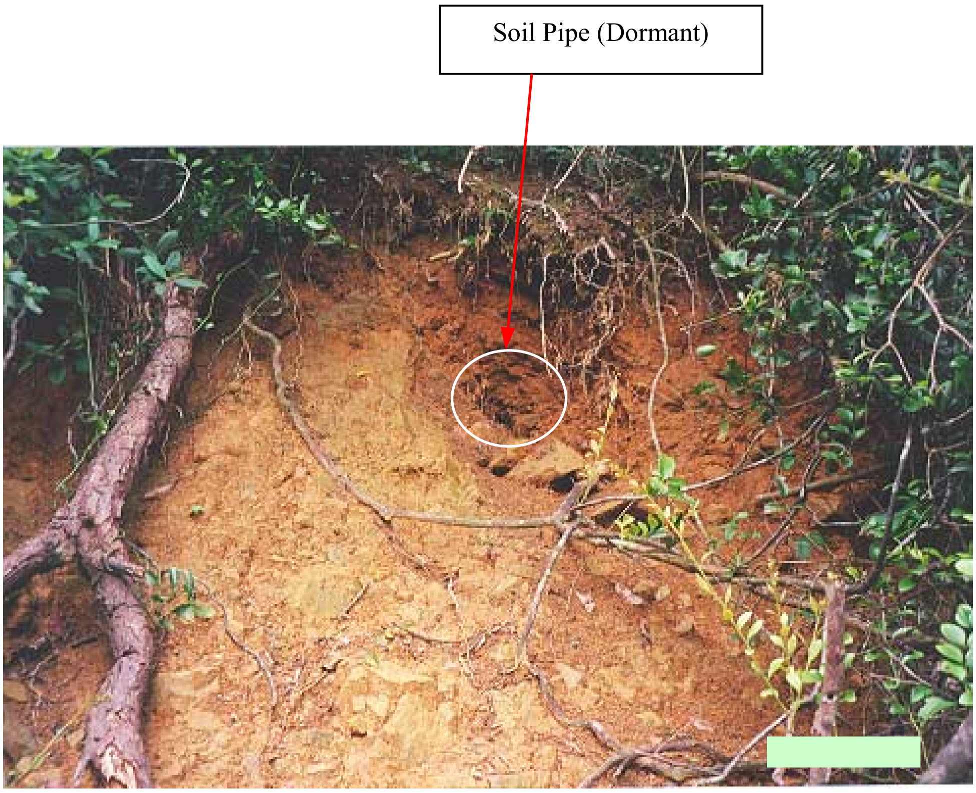


Plate 8 – View of a Soil Pipe in the Main Scarp
(Photograph taken on 30 June 1998)

Plate 9 – View along Overgrown Footpath near the Main Scarp
(Photograph taken on 4 September 1998)

Plate 10 – View of Channel Cut through Terminal Debris above Toe Retaining Wall

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

A1. INTRODUCTION

An aerial photograph interpretation (API) has been carried out as part of the desk study for the detailed study of the natural terrain landslide that occurred on 9 June 1998 at the rear of the property No. 30 Pak Sha Wan Village, Sai Kung. The main objective of the API was to confirm site history and assess site conditions. A series of aerial photographs as listed in Section 7 has been examined.

From an overview of the topographical setting, the landslide site can be seen to form one of a number of drainage lines radially draining a local peak. The subject drainage line is approximately 60 m wide (tapering towards the peak) and around 200 m long, with an estimated area of 12,000 m^2. It faces east and has similar linear features either side of it. The valley to the north has a slightly larger catchment area, and the corresponding drainage line is consequently better defined. It can be seen to be more deeply incised, with steeper sides, and could well have been subject to a similar removal of accumulated colluvium at some time in its development as the present landslide site has experienced. No direct relict landslide features are apparent on the aerial photographs however. The valley to the south has a smaller catchment area than the landslide site, and is correspondingly less well defined, with no incised water channel and shallower sloping flanks.

The site is heavily wooded, although was largely grassland in the 1960's. From the earlier photographs it can be seen that apart from a very few isolated boulders or outcrops, the topography is fairly regular with slight undulations.

A2. SITE HISTORY

1963 In these earliest photographs, the site of No. 30 appears cleared, but with no building erected. The clearing does not span the ephemeral channel, but an unsurfaced footpath leading northwards from the clearing does. A large grave is apparent on the southern flank of the channel. The whole hillside does not appear as heavily covered with trees as the present time, possibly due to grazing, and/ or war-time deforestation.

1964 No significant change

1968 What appears to be two small parallel terraces appear to have been constructed on the northern side of the drainage line, approximately 20 m upslope of the site of No. 30. An unsurfaced footpath descends from the feature to the site of No. 30. The building at No. 30 has not yet been constructed, although a part of the cut and fill platform on the south side of the valley appears to be under construction.

1973 The house at No. 30 had been constructed by 1973, although its platform does not appear to extend completely across the ephemeral drainage line. The "terracing" noted some distance upslope in the 1968 photographs is still apparent, being linked by a footpath to No. 30.

1984 Conditions in 1984 appear much the same as 1973, except that the terracing has become overgrown, although the area is partly shielded from view due to the angle of sight. A footpath is evident crossing the valley mid-way along its length, just below the top of the landslide site.

1986 The 1986 photographs indicate that the platform for No. 30 has been extended across the drainage line, with a diversionary drainage channel along the northern and eastern boundary of the platform. A large elliptical area extending approximately 20 m up the drainage line has apparently been largely stripped of vegetation, and appears agriculturally developed.

1987 No significant change

1988 No significant change, although the stripped area has become re-vegetated.

1990 No significant change

1992 No significant change

1993 No significant change

1994 No significant change

1995 No significant change

1996 No significant change. The whole hillside is now considerably more densely wooded than in the original 1964 photographs.

A3. PAST INSTABILITY

There is no obvious sign of previous instability within the catchment of the concerned drainage line. However, disturbance occurred near the toe of the landslide in the mid-1980's, in the form of cutting and filling to form the extended platform for No. 30 Pak Sha Wan Village and agricultural clearance and development including terracing above the extended platform.

A4. GEOLOGY

The geology of the drainage line comprises colluvium overlying volcanic tuff of various degrees of decomposition. The colluvium is predominantly matrix supported, with occasional cobbles and boulders.

A5. FILL

No fill has been noted except in the lower part of the platform for No. 30 Pak Sha Wan.

A6. SURFACE HYDROLOGY

Aerial photography does not indicate any natural or unusual drainage paths that may have had an impact on the landslide. Temporary footpaths are evident across the valley from time to time, and may have had an intermittent marginal influence in diverting or chanelling surface flows from their natural courses.

A7. AERIAL PHOTOGRAPHS VIEWED

Year	**Aerial Photograph No.**	**Altitude (feet)**	**Approx. Scale**
1963	Y08538, Y08539	3900	1:7,400
1964	Y12678, Y126789	1800	1:4,000
1968	Y14392, Y14393	1,000?	N/A
1973	5139, 5140	3,400	1:6,500
1984	55366, 55367	4,000	1:7,500
1986	A04163, A04164	2,000	1:3,750
1987	A09803, A09804	4,000	1:7,500
1988	A11740, A11741	4,000	1:7,500
1990	A22455, A22456	4,000	1:7,500
1992	A30194, A30195	4,000	1:7,500
1993	A35499, A35500	4,000	1:7,500
1994	A39833, A39834	4,000	1:7,500
1995	CN10977, CN10978	2,500	1:4,700
1996	CN15114, CN15115	3,500	1:6,500

APPENDIX B

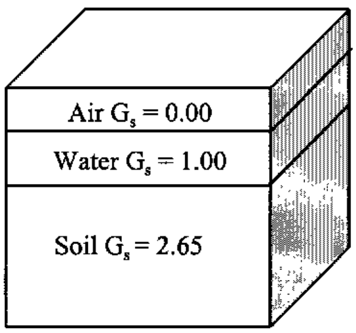
CALCULATIONS TO ASSESS SATURATION POTENTIAL OF COLLUVIAL LAYER

Check total depth of infiltration necessary to saturate 1m layer of colluvium:

Assumptions: -

Bulk density (γ) = 19 kN/m^3
Specific gravity (G_s) = 2.65
Antecedent moisture content = 10%

Consider a 1m x 1m x 1m cube of colluvium:-



Mass (kN)	Volume (m^3)
0	0.18
1.7	0.17
17.3	0.65
19.0	1.00

Calculate Mass of Constituents: -
Dry mass of soil = 19/110 x 100, = 17.3 kN.
Mass of air =0.
Therefore mass of water = 17.3/10= 1.73 kN.

Calculate Volume of Constituents: -
Volume of Dry soil = 17.3kN/ G_s = 0.65 m^3 (a)
Volume of Water = mass of water = 0.17 m^3 (b)
Volume of Air = 1 – (a) – (b) = 0.18 m^3

Check Minimum Rainfall for Saturation: -
From above, 0.18m total depth of infiltration required to saturate 1 m colluvium.
Allow for 50% surface run-off, 50% infiltration
Rainfall required = 2 x 0.18 m = 360 mm rainfall
(i.e. less than the 24 hour rainfall of >500 mm, therefore saturation possible)

Check Minimum Time for Saturation: -
Assume k = 5 x 10^{-5} m/s (mid-range, Geoguide 1)
Minimum Time Required = 1/.00005 seconds = 20,000 seconds = 5.6 hours
(i.e. saturation over 24 hours is possible)