# REPORT ON THE DEBRIS FLOW AT SHAM TSENG SAN TSUEN OF 23 AUGUST 1999

# FINDINGS OF THE INVESTIGATION

## GEO REPORT No. 169

**Fugro Maunsell Scott Wilson Joint Venture**

**GEOTECHNICAL ENGINEERING OFFICE**

**CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT**

**THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION**

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# PREFACE

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

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

R.K.S. Chan
Head, Geotechnical Engineering Office
September 2005

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# EXECUTIVE SUMMARY

On 23 August 1999, landslides occurred at the natural hillside above Sham Tseng San Tsuen, giving rise to a debris flow down a stream course. The debris flow demolished a number of squatter dwellings constructed over, and in close proximity to, the stream course in Sham Tseng San Tsuen. One fatality was reported and 13 injured persons were rescued. A comprehensive investigation into the causes of the debris flow was carried out for the Geotechnical Engineering Office during the period August 1999 to March 2000 by Fugro Maunsell Scott Wilson Joint Venture.

The debris flow occurred during a severe rainstorm with a return period of about 49 years. The rainstorm was the most severe in the area in terms of short to medium-duration rainfall since 1984 when the nearest automatic raingauge was installed.

The investigation concluded that the largest of the four landslides (600 $m^3$) within the catchment to the stream course was the primary source of the debris flow. The landslides were probably caused by elevated water pressure within the slope-forming material following the severe rainfall that preceded the failures. The affected hillside was vulnerable to rain-induced shallow failures because of the following unfavourable factors:

(a) the hydrogeological setting, involving a thin mantle of bouldery colluvium overlying relatively less permeable materials, which is favourable to the build-up of perched water tables during heavy rain,

(b) the presence of relic failures at the landslide sites which would probably have disturbed and weakened the rock mass and adversely affected the local hydrogeology by promoting direct infiltration through the open or partially infilled joints,

(c) the occurrence of a major hillfire in the 1995/1996 dry season which removed much of the vegetation cover, and

(d) progressive deterioration of the hillside involving opening up of discontinuities with time, probably associated with intermittent slope movement during heavy rain.

Details of the investigation and its findings are given in this report.

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## 1. INTRODUCTION

In the morning of 23 August 1999, a debris flow swept down a stream course from the natural hillside above Sham Tseng San Tsuen and demolished House No. 38 and its detached kitchen structure, and severely damaged several other dwellings within the squatter village (Figure 1 and Plate 1). One fatality was reported and thirteen injured persons were rescued.

Immediately following the incident, the Geotechnical Engineering Office (GEO) of the Civil Engineering Department (CED), commenced a detailed investigation into the failure. The investigation was undertaken by GEO's landslide investigation consultants, Fugro Maunsell Scott Wilson Joint Venture (FMSW).

The investigation was carried out between August 1999 and March 2000, and comprised the following key tasks:

(a) review of all known relevant documents relating to the development and assessment of the squatter village and the sequence of events leading up to the debris flow,

(b) analysis of the rainfall records,

(c) interviews with witnesses to the debris flow,

(d) topographic surveys and detailed observations and measurements at the debris flow source areas and along the trail of the debris flow,

(e) aerial photograph interpretation and engineering geological mapping,

(f) detailed ground investigation to determine the subsurface conditions by drilling, trial pitting and laboratory testing,

(g) theoretical engineering analyses, and

(h) diagnosis of the probable causes of the debris flow.

## 2. DESCRIPTION OF THE SITE

A total of four landslides (referred to as Landslides A to D in this report), occurred at a natural, lightly vegetated, west-facing hillside at an elevation of between 116 mPD and 142 mPD (Figure 2 and Plate 2). The slope gradients at the sites of the landslides vary from about 32° to 37° at Landslide A, and between about 40° and 45° at Landslides B to D. The catchment directly above the four landslides is very small because the scars are located only about 10 m (in plan) from the crest of a northeast trending ridge line.

The landslide sites lie on the eastern side of a bowl-shaped catchment, which drains to the south towards Sham Tseng San Tsuen via a narrow, rocky stream course (Figures 2 to 5 and Plate 3). The ridges enclosing the catchment are sparsely vegetated and show signs of surface

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erosion. From the toe of Landslide A to the squatter village area below, the stream course falls over 90 m vertically in a length of about 210 m, with an overall average gradient of about 24°. The stream course has developed along a fault, with intrusion of a basalt dyke. The sheared basalt dyke and granite form the stream bed, with predominantly slightly decomposed to fresh granite forming rugged stream banks which average about 2.5 m in height. A chainage line extending from the main scarp of Landslide A (Chainage 0) to Sham Tseng Nullah (approximate Chainage 320) has been established for the purposes of this investigation and features along the debris trail are related to this chainage system (Figures 2 to 5).

The stream profile is very rugged and contains a number of steep steps, including a 10 m high waterfall at Chainage 105. The highly variable nature of the local slope gradients within the stream course is indicated in Figure 6. The width of the base of the stream course (average about 1.5 m) is also highly variable, as indicated by the post-failure topographic survey contours shown in Figures 2 to 4. The base of the stream course close to the top of the 10 m high waterfall (Chainage 80 to 105) is about 0.8 m wide. The widest section is about 10 m wide at the rocky cascade (Chainage 140 to 170), where some of the debris flow material was deposited (Plate 3). The overall catchment above the 10 m high waterfall is approximately 27 000 $m^2$ in plan area.

Within the squatter village near Chainage 230 (Figure 5), the stream course has been trained into a nullah (Plate 4), which lies on the western edge of the House No. 38 platform. There is no information on the type of construction of the kitchen structure upstream of House No. 38 because only the floor slab remains after the debris flow. It can be seen from a photograph of the kitchen structure and House No. 38 taken in 1992 (Plate 5) that the kitchen structure was overgrown at that time. Photographic evidence and site inspections of the remaining part of House No. 38 indicate that the walls were constructed of a single layer of cement-rendered concrete bricks, supported by a tiled, concrete floor slab.

The nullah passes under the footbridge (comprising a concrete slab) to House No. 38 and is about 1.4 m deep by 2 m wide at the top, reducing to about 0.6 m wide at the base (Plate 6). The sites of Houses Nos. 38 and 38C are shown in Plates 7 and 8. The structure of House No. 38C comprises light, galvanised corrugated sheet construction. Under the floor slab of House No. 38C, the nullah is about 1.3 m deep by 1.5 m wide (Plate 9).

The nullah re-emerges under the bridge slab to House No. 51C where the freeboard is about 0.5 m to 0.6 m. The open nullah, which is about 2 m wide at this location, gradually increases in depth to about 2 m, before reaching the 1 m wide by 1 m high entrance to the underground section at the corner of the House No. 36TS Complex (Figure 5 and Plate 10). The House No. 36TS Complex consisted of a number of dwellings with a mixture of sheet metal and plastered brick external walls constructed on top of the 1 m high concrete upstand to the western side of the nullah.

From the eastern edge of the House No. 36TS Complex, the nullah runs largely underground to connect to the main Sham Tseng Nullah at an invert level of approximately 2 mPD at Chainage 321 (Figure 5).

## 3. DESCRIPTION OF THE DEBRIS FLOW

A photograph of the debris flow source areas on the natural hillside is shown in Plate 2. Plans of the natural hillside failures, debris trail and the damaged dwellings are shown in

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Figures 2 to 5, and an elevation of the ground profile from Landslide A along the stream course to the Sham Tseng Nullah is shown in Figure 6. A detailed topographic plan is shown in Figure 7. Sections through Landslide A are shown in Figures 8 and 9, and sections through Landslides B to D are shown in Figure 10.

The maximum depth of Landslide A, measured vertically between the approximate pre-failure ground surface (deduced from the 1:1 000 scale topographic map and photogrammetric analysis of the 1996 aerial photographs) to the inferred surface of rupture is about 3.8 m. The volume of failed material at Landslide A is estimated to be approximately 600 $m^3$, of which about 480 $m^3$ of material detached from the landslide scar, leaving a main scarp about 3.8 m high and 14 m wide. Landslides B, C and D are comparatively much smaller in volume, with a total of about 20 $m^3$ of failed material. A further 2 $m^3$ of material was released from Location E (Plate 2) to the southwest of Landslide A, which remained on the hillside and did not reach the stream course below.

The debris from Landslide A reached the opposite bank of the stream course, leaving impact marks and debris smears up to about 3 m in height (Plate 3). The debris travelled down the stream course, carrying with it vegetation, cobbles and boulders up to 2.6 m in length.

About 60 $m^3$ of debris, comprising unsorted gravel and cobbles in a silty sand matrix, was deposited upstream of the House No. 38 platform. This material is thinly smeared along the stream banks (Plates 11 and 12), and a layer up to 1 m in depth was deposited on the 10 m wide, curving portion of the stream course between Chainages 145 and 165, where the stream course splits and the debris flow probably became locally less channelised (Plate 3 & Figure 4).

Within about 5 m from the foot of the 10 m high waterfall (Plate 13) at Chainage 105, there is very little trace of any debris marks, probably because of the trajectory of the fast-moving debris flow passing over the sharp, convex lip of the waterfall. Beyond Chainage 110, obvious signs of the debris flow are evident, with a 0.4 m diameter tree having been severed close to its base (Plate 14). About 11 m downstream of the severed tree, the debris marks reach their maximum superelevation of about 4.2 m differential height across the width of the stream course (Plate 15). This superelevation suggests that the velocity of the debris flow at this point was about 11 m/s. Other superelevations further downstream suggest that the velocity of the debris flow, which was probably impeded by the rugged nature of the stream course and gradual flattening in gradient (Figure 6), had reduced to about 7 m/s by Chainage 217, i.e. about 14 m upstream of the kitchen structure of House No. 38. It is likely that the debris flow further decelerated beyond Chainage 217 where the stream course begins to widen and flatten in gradient from about 21° to 8°.

Upon reaching the House No. 38 platform, the debris passed through the kitchen structure (Figure 5), which was likely to have been totally demolished in a short space of time. The debris then probably hit the northwestern part of House No. 38, before completely blocking and filling the nullah as far as the footbridge of House No. 38, which acted as a choke point. The debris in the blocked nullah consisted of cobbles and boulders up to about 2 m in length with tree fragments (Plates 4 and 6).

A levee, containing a large tree (0.4 m in diameter), much vegetation and cobbles and boulders, was deposited above the level of the footbridge adjacent to the bridge upstand and the western section of House No. 38C (Plate 7). This levee could have contributed to concentrating the remaining debris on a path through the western part of House No. 38 and

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the central part of House No. 38C. Only the floor of much of House No. 38 remains, and an approximately 5 m wide passage was forced through the central part of House No. 38C (Plates 7 and 8). The exit point of the debris from House No. 38C is shown on Plate 9. Very little debris appears to have passed through the nullah under the floor slab of House No. 38C and the bridge slab to House No. 51C (Plate 9).

The nullah, at the location between House No. 38C and the entrance to the underground section at the House No. 36TS Complex (Plate 10), was completely choked with debris consisting of a lower layer (maximum 2 m thick) of cobbles and boulders up to 1.0 m in length with tree fragments, which was overlain by wet, silty, gravelly sand up to 0.9 m deep containing about 25% cobbles, boulders and tree fragments.

The remaining material of the debris front and debris flow body breached the wall to the House No. 36TS Complex and infilled several dwellings with debris up to about 1 m deep (Plates 16 and 17). The infill material within the upstream half of the complex is similar in grading and consistency to the upper layer of debris within the nullah. However, only rare boulders less than 400 mm in length could be found beyond the mid-point of the complex. It is inferred that the coarse material comprising the debris front was largely exhausted by deposition in the nullah, although some boulders managed to locally penetrate the external walls of the House No. 36TS Complex. The finer debris penetrated the complex and became largely arrested by the internal walls of the structure. The increasingly finer and thinner material deposited within the lower half of the complex and down Sham Hong Road is probably mainly outwash material transported by subsequent overland flow.

The horizontal travel distance of the debris flow is approximately 270 m from the crest of Landslide A to the mid-point of the House No. 36TS Complex (Figure 6). The travel angle of the debris flow, corresponding to the inclination of the line that joins the distal end of the debris flow (disregarding the outwash material) and the crest of Landslide A, is about 24°. The actual mobility of the debris flow could not be established because the debris was retarded by the squatter dwellings and the nullah. The mud lines along the stream course, together with the distribution and grading of the debris deposits on and beyond the House No. 38 platform, provide evidence of a 'classic' debris flow, which consists typically of a debris front rich in boulders (where these are present) and a more mobile debris body containing finer material pushing from behind.

Surface runoff as a result of the severe rainfall could have contributed, to some extent, to the mobility of the debris flow. However, there is no evidence of a ‘dam-break’ situation where a significant dam of debris is suddenly breached by impounded water. It is unlikely that any significant reservoir of water accumulated above the site of the initial impact marks on the stream bank because of the steep gradient of the stream course above this point. Furthermore, there is no evidence of the remnants of a breached dam anywhere along the stream course. Surface runoff discharge calculations, based on the catchment area and the rainfall intensity records from raingauge No. N10, indicate that the maximum surface runoff discharge along the stream course is not likely to have exceeded about 1.5 $m^3$/s. This amount of water is considered to be very small when compared to the discharge rate of the saturated, sandy material at the point of entry into the stream course, estimated from debris flow modelling to be of the order of 50 $m^3$/s.

Approximately 480 $m^3$ of material from Landslide A, comprising silty, gravelly sand

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with some cobbles and occasional small to medium-sized boulders was transported down the stream course. In addition to the 60 $m^3$ of debris deposited along the stream banks, about 10 $m^3$ of slurry-like debris was deposited near the eastern side of the kitchen structure of House No. 38 (Plate 18). These deposits contain about 10% (i.e. 7 $m^3$) of material entrained from the stream course.

At least 60% of the cobbles and boulders deposited in the nullah and levee, upstream of the House No. 36TS Complex are angular and slightly decomposed to fresh, with organic staining on some faces, suggesting that they could have been entrained from the stream course. The rest of the boulders, probably originated from the landslide area, are smaller, sub-rounded to sub-angular, and moderately to slightly decomposed, with no organic staining. The total volume of these deposits is about 60 $m^3$, comprising about 15 $m^3$ in the nullah adjacent to House No. 38, 10 $m^3$ in the levee and 35 $m^3$ in the nullah between House No. 38C and the House No. 36TS Complex. It is therefore estimated that these deposits contain approximately 65% of entrained material (i.e. 40 $m^3$).

It is estimated that about 420 $m^3$ of debris (including about 20 $m^3$ of entrained material comprising mainly cobbles and tree fragments with some small boulders) was deposited within and beyond the House No. 36TS Complex.

## 4. HISTORY OF THE SITE

The site history, summarised in Appendix A, has been determined from an interpretation of aerial photographs dating back to 1954 and a review of other available documentary information.

A survey map dated 1945 shows a reclaimed shoreline and light development in the Sham Tseng area. The earliest available aerial photographs, taken in 1954, show that village development had commenced at Sham Tseng San Tsuen. By 1956, a structure was present at the approximate location of House No. 38.

Village development continued up to 1963 by which time all significant structures in the immediate vicinity of House No. 38 were present. By 1972, a series of structures or extensions to existing dwellings had been constructed at the village. No further significant village development took place after this time.

The Geotechnical Area Studies Programme (GASP) Report for the area (GCO, 1987) states that the hillsides above the Sham Tseng squatter villages are areas of “general instability associated with predominantly insitu terrain”.

In connection with the Government’s Non-Development Clearance (NDC) Programme to clear vulnerable squatters on slope safety grounds, the GEO carried out inspection and re-inspection of Sham Tseng San Tsuen (including the area of House No. 38) in 1988 and 1992 respectively.

No recommendations were made for clearance of House No. 38 or its kitchen structure under the NDC Programme. The western part of House No. 38C, which was located directly over the nullah immediately south of the bridge to House No. 38, was recommended for clearance by the GEO in 1992, principally on a voluntary basis through advice and persuasion. This part of House No. 38C had not been cleared at the time of the debris flow on 23 August 1999.

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## 5. GEOMORPHOLOGICAL SETTING AND PREVIOUS INSTABILITIES

The 1:20 000 scale geological map, published by the Hong Kong Geological Survey, GCO, 1988 (Figure 11), indicates that debris flow deposits underlie Sham Tseng San Tsuen in the vicinity of the stream course, from about the location of the kitchen of House No. 38 (just below where the stream course flattens in gradient) to the main Sham Tseng Nullah, where the debris flow deposits are shown as indenting alluvium deposited along the main Sham Tseng river channel. A lobe-shaped topographic feature can be seen in a similar location on the aerial photographs which is slightly broader in extent than the debris flow deposits shown on the geological map (Figure 12).

Field mapping and post-failure ground investigations have confirmed the presence of old debris flow deposits up to 3 m thick underlying Houses Nos. 38, 38C and 36TS Complex. It is therefore inferred that, in geomorphological terms, the squatter village area in the vicinity of the stream course is primarily a deposition zone for debris flow material which has been channelized down the steep, rocky stream course over geological time. As the debris flow deposits indent the alluvium deposited along the main Sham Tseng river channel, it can be inferred that debris flow deposition at the confluence of the stream course and the main river channel has been more active over relatively recent geological time than erosion and/or deposition associated with the main river channel. According to the villagers, no debris flow events have occurred down the stream course since the squatter village was established.

The steep, rocky stream course between the House No. 38 platform and the main catchment area above the 10 m high waterfall at Chainage 105 is highly resistant to erosion and no signs of previous instabilities can be seen on the available aerial photographs. In geomorphological terms, this section of the stream course is mainly a zone of transport for material arising from the main catchment area above, over recent geological time, with little long-term deposition due to the steep gradient and activity of the stream flow during periods of heavy rain.

It is inferred from aerial photograph interpretation (API) that, in geomorphological terms, the catchment area above the 10 m high waterfall is primarily a zone of depletion (Figure 12).

Topographic depressions, probably representing relic landslides, can be identified on the 1963 low-level aerial photographs at the locations of Landslides A to D (Figure 12). There was a complete vegetation cover of grass and small bushes on these relic landslide scars at this time. The absence of visible scars on the 1954 high altitude aerial photographs probably indicates a failure at least 30 to 35 years prior to 1954, having regard to the likely rate of re-vegetation of the scars (Evans et al, 1997). The locations of the previous landslides in the vicinity of the 1999 landslide sites are shown in Figure 12.

Examination of the 1986 infra-red aerial photographs indicates that the previous instabilities at the sites of Landslides A to D may be more extensive than that can be detected from the examination of conventional visible spectrum aerial photographs. Distinct but degraded scarps close to the scarps of Landslides A to D are visible in the 1986 infra-red photographs (Figure 13). The degraded scarp at the site of Landslide A appears to extend across the full width of the August 1999 landslide and continues in a north-easterly direction to meet a zone of very light-toned terrain below the scarps of Landslides B to D, which is wider than the pre-1954 debris trail identified below these scarps. Below the degraded main

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scarp in Landslide A is a concave break in slope above a flatter area which has a convex break in slope below it (Figure 13). These may indicate the existence of a spoon-shaped depression extending across nearly the full width of the August 1999 scar of Landslide A. The above feature probably pre-dates the vegetated, inferred landslide scar identified from the 1963 conventional aerial photographs within the southern portion of Landslide A. The light-toned terrain shown on Figure 13, identified from the 1986 infra-red aerial photographs, may represent zones of previous instability, or areas of relatively lush vegetation reflecting high groundwater or seepage.

Examination of the June 1996 aerial photographs indicates that the sites of Landslides A to D were affected by an extensive hillfire, probably in the 1995/1996 dry season. The hillfire removed much of the vegetation cover (comprising shrubs and grass) from the landslide source areas and charred the full depth of the thin (< 200 mm thick) topsoil, as evidenced in the post-failure ground investigation. The extent of the hillfire is shown in Figure 12 and Plate 19.

Figure 7 shows the topographic contours derived from the 1:1000 scale topographic map of the area (which was based on pre-1980 mapping) and contours derived from photogrammetric analysis of the 1996 aerial photographs taken after the hillfire had burnt off the vegetation cover. The differences in the elevations derived from the different sources (Figure 13) may be due to the hillfire reducing the height of vegetation cover to a greater extent near the less sheltered ridge line, or accuracy of the different techniques adopted for the two surveys. It is not certain whether the differences between the two sets of contours could be partly attributed to any progressive slope movements at the site of Landslide A.

Other features which indicate more recent, apparently superficial, instability of the hillsides in the area are the landslides with associated minor debris trails (less than 20 m long), identified from the 1972 and 1982 aerial photographs, to the south of the site of Landslide A (Figure 12). The hillside above the Sham Tseng squatter villages suffered extensive instability in 1982, following severe rainfall. Many of the landslides, which have also been recorded in the Natural Terrain Landslide Inventory (NTLI) complied by the GEO using high-level aerial photographs (Figure 12), were channelised, with landslide debris reaching, or almost reaching, the villages areas. The portion of the hillside which failed on 23 August 1999 did not suffer any instability in the form of detachment of material in 1982 based on the available aerial photographs.

There is no evidence to suggest that the 1999 landslide sites have previously been modified by human activities.

## 6. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from the nearest GEO automatic raingauge (No. N10), located at Emmanuel Primary School, Castle Peak Road (Figure 1), approximately 300 m to the south of the landslides. The raingauge records and transmits rainfall data at 5-minute intervals via a telephone line to the GEO. The daily rainfall recorded by the raingauge from 23 July to 23 August 1999, together with the hourly rainfall from 21 to 23 August 1999, are shown in Figure 14.

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Records from two other nearby GEO automatic raingauges Nos. N03 and N11, which are approximately 6 km and 4 km to the east of the landslides respectively, were also examined. The pattern of rainfall and the intensities recorded at these raingauges were broadly similar to that recorded at raingauge No. N10. The record from raingauge No. N10 is therefore considered appropriate for analysis purposes.

The rain was heavy in the morning of 23 August 1999 up to the time of the debris flow at about 7:30 a.m. The 24-hour and 12-hour rainfall before the debris flow were 479 mm and 341 mm respectively. The maximum 60-minute rolling rainfall was recorded as 127 mm between 5:25 a.m. and 6:25 a.m. on 23 August 1999. Analysis of the return periods of the rainfall intensities for the 23 August 1999 rainstorm for different durations based on historical rainfall data from the headquarters of the Hong Kong Observatory (Lam & Leung, 1994), shows that the 2-hour rainfall was the most severe, with a corresponding return period of about 49 years.

The maximum rolling rainfalls for the rainstorm of 23 August 1999 have been compared with previous severe rainstorms from August 1984, when raingauge No. N10 began operation (Figure 15). The maximum rolling rainfall for the rainstorm prior to 7:30 a.m. on 23 August 1999 exceeds that from previous rainstorms for durations of between 15 minutes and 30 hours.

## 7. PROBABLE SEQUENCE OF EVENTS

The probable sequence of events has been reconstructed from accounts given by witnesses, records of the Hong Kong Police Force (HKPF) and detailed field mapping by FMSW.

According to the accounts of eye-witnesses, the bulk of the debris impacted upon the squatter village at about 7:30 a.m. on 23 August 1999. The first incident of surface water flowing across House No. 36TS Complex and along Sham Hong Road occurred at about 6:15 a.m. to 6:30 a.m., which is shortly after the time of the maximum rolling 15-minute rainfall intensity (42 mm/hr) recorded at the nearest automatic raingauge (No. N10). The Fire Services Department (FSD) arrived at Sham Tseng San Tsuen at about 7:00 a.m. and commenced rescue operations in the lower part of the village.

A resident of House No. 87, which overlooks House No. 38 and its kitchen structure (Figure 5), is reported to have seen the debris flow coming down suddenly at about 7:30 a.m. and demolishing House No. 38 and its kitchen structure within a few seconds.

Reports from HKPF indicate that 13 injured persons were rescued from the mud and sent to hospital, six of whom were admitted for treatment. The HKPF requested the FSD to attend to the location of House No. 38 at 5:22 p.m. on 23 August 1999 in order to search for the male occupant of the house when it became known that he could not be located. The occupant, who was initially obscured by debris and overland flow, was located at about 6:30 p.m. on 23 August 1999 in the nullah downstream of the demolished house at the upstream entrance of the underground section of the nullah (Plate 10). He was certified dead on arrival at hospital.

Mapping of the source areas by FMSW indicates that the debris trail from Landslide A had obliterated the trails from Landslides B to D, indicating that Landslides B to D most

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probably occurred first. It is possible that some of the debris from Landslides B to D blocked the entrance of the covered section of the nullah, contributing to the initial surface water flow across House No. 36TS Complex and Sham Hong Road, which was observed at about 6:15 a.m.

The debris flow, which impacted upon the squatter village at about 7:30 a.m., was a result of Landslide A. Back analysis of the dynamic motion of debris flow movement, together with the superelevation of debris marks along the stream course, indicate that it probably took a relatively short time (of the order of less than one minute) for the debris from the toe of Landslide A to reach the squatter village.

## 8. SUBSURFACE CONDITIONS

### 8.1 General

The subsurface conditions at the landslide sites were determined using information from desk and field studies. The desk study comprised a review of existing data, and the field study included engineering geological mapping and ground investigation.

The rocks at the landslide sites were previously mapped by the Hong Kong Geological Survey (HKGS) as fine-grained granite, becoming megacrystic (large crystal size) to the south, according to the 1:20 000 scale geological map for the area (GCO, 1988). An extract from this map covering the landslide sites is shown in Figure 11. A photolineament is shown along the stream course on the geological map. The lineament corresponds to a fault, which was mapped on site and is characterised by sheared granite and basalt with minor quartz veins locally. No faults are shown intersecting the sites of Landslides A to D.

Ground investigation commenced in September 1999 and comprised three portable triple tube sampler holes, two trial pits, two trial trenches and fourteen GEO probes (Figure 16).

### 8.2 Geology

A geological plan of the landslide area is shown in Figure 17, and geological cross-sections through the landslide sites are shown in Figures 18 to 20. The inferred profile of the interface between colluvium and weathered granite suggests that the 1999 failure occurred at the location of a probably very old landslide. Much of the colluvium may have originated from a lower landslide scarp, formed along toppling joints, which has progressed up the hillside over a long period of time as a result of weathering and intermittent small to large-scale movements of the colluvium during severe rainfall.

The lithology in the area of the landslides consisted of predominantly medium-grained megacrystic granite with a contact with fine-grained granite near the northern end of the main scarp of Landslide A (Figure 17). This approximately east-west striking contact, which is magmatic in nature (i.e. generally does not form a sharp boundary), can be traced across the ridge to the east of the scar. North of the contact, the granite is distinctly fine-grained, but becomes locally fine to medium-grained and megacrystic towards the locations of Landslides B to D.

The rock in the main scarp of Landslide A (Plates 20 and 26) varies in weathering

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grade, with highly to moderately decomposed (PW 30/50) at the southern end, becoming moderately decomposed (PW 50/90) in the central portion, and slightly to moderately decomposed (PW 90/100) near the northern end of the scarp. The difference in the degree of weathering of the insitu rock is considered to reflect the variations in grain size across the main scarp, with the coarser-grained granite being more susceptible to chemical weathering.

Three joint sets are present within the rock mass in the main scarp of Landslide A (Figure 21). Set A dips between 45° and 70° in a westerly direction. Set B dips between 50° and 80° in an easterly direction, and Set C dips between 70° and 90° in a southerly direction.

The persistence of the joints is up to 5 m (typically more than 3 m), and the spacing varies between 0.25 m and 1.0 m. The joints are typically smooth (locally rough), undulating and stepped, with iron and manganese staining, and weathered seams up to 50 mm thick.

The contoured stereographic projections shown in Figure 21 indicate that the Set A joints are not unfavourably orientated with respect to kinematic sliding of the pre-failure ground profile (approximately 37°), but they would be unfavourable with respect to the stability of the steep back-scarp (approximately 70°) following possible initial failures. The Set B joints, striking parallel to the failed slope at Landslide A, are unfavourable with respect to toppling as they form steeply-dipping weak planes.

The rock mass is disturbed in the main scarp of Landslide A. The Set B joints are open or infilled with very silty gravelly sand which has been washed in, down to a depth of about 3.5 m below ground surface (Plates 21 to 23). The disturbed fabric is evidence of past movement of the slope which may be attributed to progressive opening-up of the rock mass, possibly promoted by the disturbance caused by the previous instability. During heavy rain, the Set B joints are likely to be wholly or partially filled with water that would give rise to cleft-water pressure acting on the rear of any potentially unstable soil or rock mass.

Geological sections through Landslide A are shown in Figures 18 and 19. These indicate that the rockhead (taken to be the upper surface of PW 30/50 or better material) below the main scarp is steeply inclined at a roughly similar angle to that of the exposed scarp. The depth of superficial and completely to highly decomposed material is up to 8 m below the 1999 pre-failure ground surface. No fault or major discontinuity can be seen at the steeply inclined rockhead surface.

Plates 24 and 25 show the geology in the southern flank of Landslide A. Here, completely decomposed granite (CDG), containing highly to moderately decomposed corestones, overlies the insitu highly to moderately decomposed (PW 30/50) rock mass. Behind the main scarp, colluvium between 0.1 m and 0.3 m in thickness overlies the PW 30/50 material. In front of the main scarp, the thickness of the colluvium gradually increases downslope to a depth of about 1.2 m.

The landslide debris near the southern flank of Landslide A comprises highly to moderately decomposed granite boulders with some completely decomposed granite. The boulders could have been derived from the insitu PW 30/50 rock mass. Secondary failures of the over-steepened scarp along adversely orientated discontinuities were possible.

Trial pits TP3 and TP4 show that the landslide debris of 23 August 1999 overlies a

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layer of colluvium up to 0.3 m thick which in turn overlies CDG. This colluvium (described as dense weathered colluvium) is darker brown in colour, denser and has a finer-grained matrix than the bouldery colluvium exposed at the ground surface, and all clasts are completely decomposed. When exposed in the trial pits, the dense colluvium and the underlying completely and highly decomposed granite were very moist. No planar rupture surfaces were found in the trial pits below, within or above the dense colluvium.

In the central portion of the main scarp of Landslide A, colluvium up to 0.4 m thick overlies PW 50/90 medium-grained granite (Plate 26), whereas CDG overlies the lower part of the PW 50/90 rock mass. When first examined on 27 August 1999, a planar surface about 1 $m^2$ in area, dipping at about 50° downslope, was present in the lower part of the CDG (Plate 20). About 50 mm thickness of remoulded soil was present on the surface, which is inferred to be part of the initial surface of rupture. This surface was about 2 m in front of the final main scarps on either side, and may be evidence of secondary failures of the over-steepened scarp following the main failure.

Although of a similar attitude to joint Set A, no evidence was found to link the surface of rupture with a relic joint. It is considered likely that this local surface of rupture lies at the interface between the CDG and the overlying colluvium, although the main part of the failure surface was within colluvium.

Plate 26 and Figure 22 show the geology of the northern portion of the main scarp and the northern flank of Landslide A. The main scarp is formed in a disturbed rock mass of slightly to moderately decomposed (PW 90/100) fine-grained granite, overlain by up to 0.3 m thickness of colluvium which contains slightly to moderately decomposed clasts. The rock mass becomes progressively looser downslope due to sliding on the Set A joints and toppling on the Set B joints and grades into colluvium of up to about 2.5 m thick (Figure 22 and Plate 26). This colluvium contains moderately weathered clasts and overlies up to 0.5 m thickness of dense weathered colluvium (Plate 27).

The landslide debris near the northern flank of Landslide A comprises moderately to slightly decomposed boulders up to 2.5 m across. The boulders could have been derived from secondary failure of the PW 90/100 rock mass, following initial failure of the colluvium in front. The trial pits for PTTS 5 and PTTS 6(A) indicate that the landslide debris directly overlies dense weathered colluvium up to 0.5 m thick, which in turn overlies insitu CDG (Plates 28 and 29). This colluvium is similar to that in Trial Pits TP3 and TP4 described above. No rupture surfaces can be identified below, within or above this dense weathered colluvium and no rupture surfaces are present in the continuous drillhole cores.

The postulated surface of rupture of the main part of Landslide A is shown in Figure 22. Near the southern flank of the scar, the inferred initial upper part of the rupture surface was formed in the thin, surface colluvium and the underlying CDG. However, the majority of the area of the surface of rupture was formed along the interface between the surface colluvium and the underlying, dense weathered colluvium.

In the central part of the main scarp of Landslide A, it is inferred that the upper part of the rupture surface passed through the interface between the surface colluvium and the PW 50/90 rock mass (Plate 20), and then passed along the interface between the surface colluvium and the underlying dense weathered colluvium. As shown in Figure 22, the

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rupture surface near the northern flank of the scar lies at the base of the surface colluvium which overlies the dense weathered colluvium. The toe of the landslide was constrained by the presence of an insitu outcrop of moderately decomposed granite.

Except for the small rupture surface shown in Plate 20, no planar surface of rupture has been identified in the scar and in the cores taken by the portable sampler. A smooth, slickensided rupture surface is unlikely to have been produced because of the coarse nature of the surface colluvium which formed the majority of the failed mass.

At the smaller Landslides B to D (Figure 20), loose to medium dense colluvium containing cobbles and boulders of CDG/HDG overlies completely and highly decomposed fine to medium-grained granite, which is locally intruded by sub-vertical, completely to highly decomposed medium and fine-grained granite dykes striking 260°. Small ‘holes’ up to 50 mm diameter (rootholes) are present within the colluvium in the scarps. Localised downslope erosion below these holes was noted when first inspected on 27 August 1999, indicating seepage had occurred. In the northern part of the scarp of Landslide B, a prominent iron-stained joint orientated sub-parallel to the post-failure ground surface (with dip and dip direction of 54°/290°) forms the base of most of the scar. As indicated in Figure 20, the lower part of the rupture surfaces have formed either at or slightly below the interface between the colluvium and insitu decomposed granite, whereas the upper part lies mainly within the colluvium.

The topsoil, which is generally less than 200 mm thick, has been blackened and charred across the sites of landslides A to D by the 1995/1996 hillfire. This has resulted in the topsoil consisting of a very loose, silty sand with negligible cohesive properties and very poor root system development. Patches of blackened bare earth and blackened boulders are present around the scarps and flanks of the landslides (Plates 24 to 26).

## 8.3 Soil Properties

A series of geotechnical laboratory tests was conducted on soil samples retrieved during the ground investigation. The tests included particle size distribution (PSD) tests, Atterberg limit tests and triaxial compression tests.

Atterberg limit and PSD tests were carried out in accordance with Chen (1994). PSD tests on the matrix of the surface colluvium indicate about 65% to 75% of sand and gravel, about 24% of silt and 2% to 12% of clay. The Plasticity Index ranges between 13% and 18%, indicating that the matrix of the surface colluvium consists predominantly of silty sand and gravel. The percentage of cobbles and boulders within the surface colluvium ranges from 30% to 50%.

The underlying dense weathered colluvium comprises mainly silty sand, with a fines content (i.e. silt and clay) of 25% to 34%. The Plasticity Index is similar to that for the surface colluvium with values of between 11% and 14%. However, the cobble and boulder-sized clasts within the dense weathered colluvium are generally completely decomposed and break down into their finer constituent particles during sieving.

The CDG comprises predominantly silty sand and gravel, with a sand and gravel content of 65% to 90%.

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The shear strength properties of the surface colluvium and CDG were assessed by consolidated undrained triaxial compression tests using samples recovered from the Landslide A site. The results of the tests are presented in Figure 23. The angle of shearing resistance ($\phi'$) of the surface colluvium and CDG are 37° and 38° respectively, with zero cohesion ($c'$). However, the actual mass shear strength of the surface, bouldery colluvium, which contains 30% to 50% of moderately weathered clasts of cobbles and boulders, will be somewhat higher. No undisturbed samples suitable for testing were retrieved from the dense weathered colluvium but it appears from field inspections that its strength will be comparable to that of the underlying CDG.

### 8.4 Groundwater Conditions

Owing to difficulties in accessing the sites of the landslides, the scarps were not inspected until 27 August 1999, when no active seepage could be seen. In addition, no seepage was encountered in any of the trial pits and exploratory holes.

Evidence suggesting a build-up in water pressure within the failed mass following severe rainfall is as follows:

(a) Rootholes left by dead bushes are present in the surface colluvium within the scarps. Erosion traces below some rootholes in Landslide B were noted, indicating that seepage within the surface colluvium had occurred.

(b) The upper surface of the dense weathered colluvium underlying most of the rupture surface of Landslide A was very moist.

Factors which are conducive to the build-up of water pressure in the near-surface slope-forming material are as follows:

(a) The surface colluvium above the layer of dense weathered colluvium and CDG in Landslide A has a loose to medium dense matrix and contains up to 50% of cobbles and boulders of HDG to MDG material, whereas the underlying materials are denser and comparatively less permeable.

(b) The presence of rootholes within the surface colluvium would probably have promoted preferential flow and rapid water ingress.

(c) Previous instabilities had occurred at the locations of Landslides A to D, which could have resulted in disturbance to the ground. Water ingress is also likely to give rise to cleft water pressures in the open or partially infilled joints.

(d) The hillfire, which occurred during the 1995/1996 dry season, resulted in the removal of the vegetation cover. This could

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have contributed to the formation of rootholes from decayed root sytems which acted as conduits for water. The removal of vegetation and charring of the thin topsoil (thus preventing 'healing' of any fissures in the colluvium below) probably made the ground more vulnerable to water ingress.

It is postulated that during heavy rain, water would have infiltrated into the ground through the surface colluvium which covered the main landslide site (Landslide A). This bouldery colluvium, being relatively permeable, would have promoted rapid surface infiltration and downslope subsurface seepage flow. The underlying dense weathered colluvium, and locally CDG, probably acted as less permeable boundaries in the ground and would have impeded through-flow of water, thus resulting in the formation of perched water tables. The hydrogeological setting of the sites was therefore favourable to the development of elevated water pressure in the surface colluvium layer at times of heavy rain, probably by perching of water on the less permeable underlying profile and build-up of cleft water pressure in the open or partially-infilled joints, or tensions cracks.

## 9. THEORETICAL STABILITY ANALYSES

Theoretical stability analyses were carried out on Landslide A to assist the diagnosis of the mechanism and causes of the failure. These analyses were aimed to investigate the likely operative range of shear strength parameters along the failure surface corresponding to different possible groundwater levels at the time of failure.

The information used in these analyses was obtained from the post-failure ground investigation, laboratory testing, and site observations and measurements. A representative cross-section of the Landslide A site and the input parameters adopted in the analyses is shown in Figure 22. For the purposes of the analyses, the pre-failure ground profile is taken to correspond to that derived from the photogrammetric analysis of the 1996 aerial photographs. A range of heights of water table perched above the dense weathered colluvium was assumed in the analyses to simulate the possible range of groundwater conditions at the time of failure. The influence of possible cleft water pressures within the rock joints immediately behind the scarp of the failure was also investigated.

The results of the analyses are presented in Figure 24 for a range of shear strength parameters of $c' = 0$ to 5 kPa and $\phi' = 32°$ to $40°$. As noted before, the mass shear strength of the colluvium is likely to be higher than matrix shear strength because of the presence of cobbles and boulders. The results indicate that for the likely ranges of shear strength parameters, a perched water table of about 1 m to 2 m above the base of the failure would have been sufficient for failure to occur. This is consistent with the field observations and the hydrogeological setting of the sites, suggesting that the supporting theoretical analysis are credible.

## 10. DIAGNOSIS OF THE CAUSES OF THE DEBRIS FLOW

The close correlation between the severe rainfall and the timing of the failures suggests that the landslides above Sham Tseng San Tsuen on 23 August 1999 were triggered by rainfall. The landslides involved the failure of natural terrain, as part of the gradual

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degradation process of marginally stable hillsides. The landslides occurred during a major rainstorm that was the most servere since 1984 (when the nearest raingauge began operation), with a return period of about 49 years.

The main landslide, which was the sources of debris flow, was controlled primarily by the surface layer of bouldery colluvium. Based on the information collected in this investigation, it is postulated that the landslides were probably caused by elevated water pressure within the surface colluvium following severe rainfall.

The hydrogeological setting involving a thin mantle of bouldery colluvium overlying dense weathered colluvium and locally weathered granite, is favourable to the build-up of water pressure in the surface colluvium, possibly by perching of water over the less permeable material below. Elevated water pressures may also result from cleft water pressure in open or partially-infilled joints, or development of seepage pressure associated with downslope groundwater flow. The failure mechanism involved the wetting up of the soil mass following water ingress, leading to the build-up of water pressure and reduction in shear strength of the surface colluvium.

The presence of open and partially-infilled joints in the rock mass suggests that progressive deterioration of the affected hillside probably occurred with time, which could have been accompanied by intermittent localised movements during periods of heavy rainfall. The situation may have been exacerbated by the previous instabilities resulting in disturbance and weakening of the rock mass.

The hillfire in the 1995/1996 dry season resulted in the removal of vegetation cover and charring of the topsoil. This would have made the terrain more susceptible to direct infiltration. Also, some of the root systems could have been decayed, creating rootholes which would further enhance water ingress into the ground.

It is noteworthy that this part of the hillside did not fail during the severe rainstorms in 1982 when the other parts of the hillside suffered extensive instability. This suggests that the terrain probably became more prone to direct infiltration and rain-induced failure as a result of progressive deterioration and/or changes in environmental conditions (e.g. hillfire).

The landslide debris became channelised upon reaching the stream course and developed into a mobile debris flow. The mobility of the debris flow might have been exacerbated by the concentrated surface water running down the stream course at the time.

## 11. CONCLUSIONS

It is concluded that the 23 August 1999 debris flow at Sham Tseng San Tsuen resulted from a landslide in the natural hillside triggered by rainfall. The landslide was caused by elevated water pressure within the slope-forming materials, following the heavy rainfall that immediately preceded the failure.

The debris flow occurred during a severe rainstorm with a return period of about 49 years. The rainstorm was the most severe in the area in terms of short to medium-duration rainfall since 1984 when the nearest automatic raingauge was installed.

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The affected hillside was vulnerable to rain-induced shallow failures due to the following unfavourable factors:

(a) the hydrogeological setting, involving a thin mantle of bouldery colluvium overlying relatively less permeable material, which is favourable to the build-up of perched water tables during heavy rain,

(b) the presence of relic failures at the landslide sites which would probably have disturbed and weakened the rock mass and adversely affected the local hydrogeology by promoting direct infiltration through the open or partially infilled joints,

(c) the occurrence of a major hillfire in the 1995/1996 dry season which removed much of the vegetation cover, and

(d) progressive deterioration of the hillside involving opening up of discontinuities with time, probably associated with intermittent slope movement, during heavy rain.

## 12. REFERENCES

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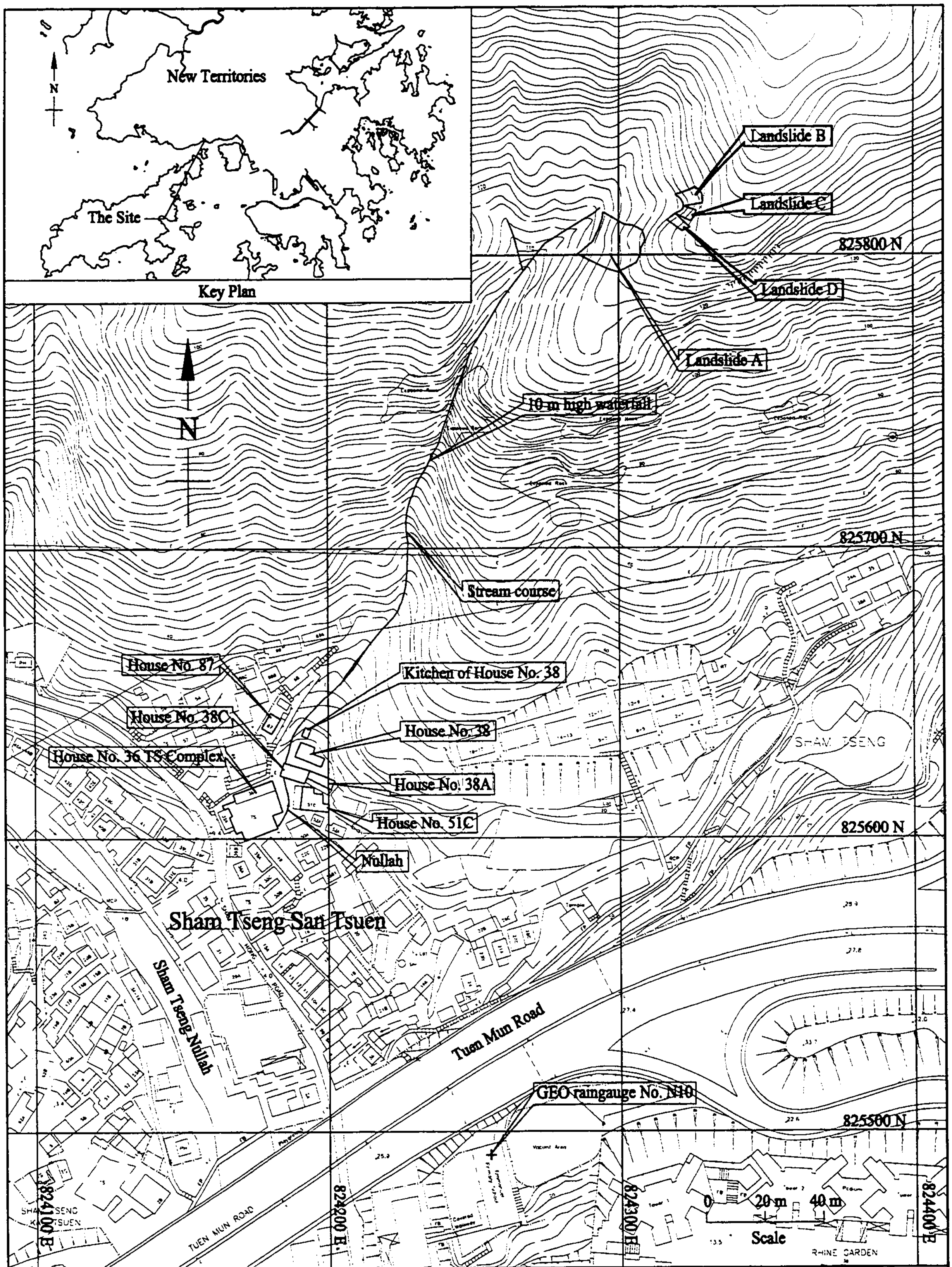


Note : Base map is extracted from Survey Sheets Nos. 6SE-17A and 6SE-17C (scale 1:1 000).

Figure 1 - Site Location Plan

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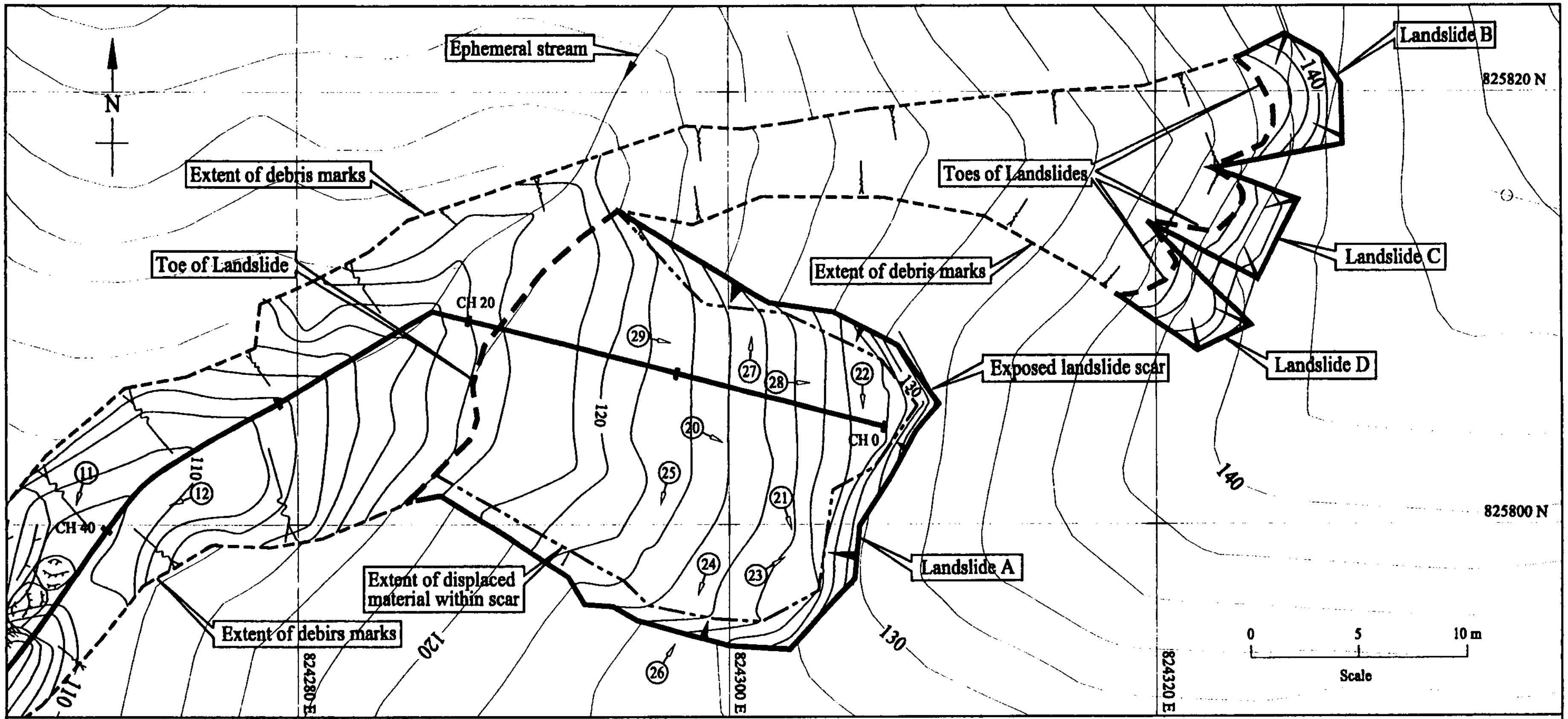


Legend :

| | | | | | |
|---|---|---|---|---|---|
| Boundary of landslide | Extent of displaced material within scar | CH 0 | Chainage along chainage line | | Sloping ground |
| Toe of Landslide | (20) | Approximate location and direction from which Plate No. 20 was taken | — 130 — | Elevation in mPD | |
| Extent of debris marks | | | | | |

Notes : (1) Base map is based on Survey Sheets Nos. 6SE-17A and 6SE-17C (scale 1:1 000) and photogrammetric analysis of 1996 aerial photographs (contours at 2 m intervals).

(2) Survey of landslide and debris flow trail was carried out between 1 September and 15 November 1999 (contours at 1 m intervals).

(3) Chainage line, established for the purposes of this landslide investigation, extends from crown of Landslide A to Sham Tseng Nullah (chainage marks at 20 m intervals) along stream course and nullah beyond CH 22.

Figure 2 - Plan of the Debris Flow and Locations of Photographs (Sheet 1 of 4)



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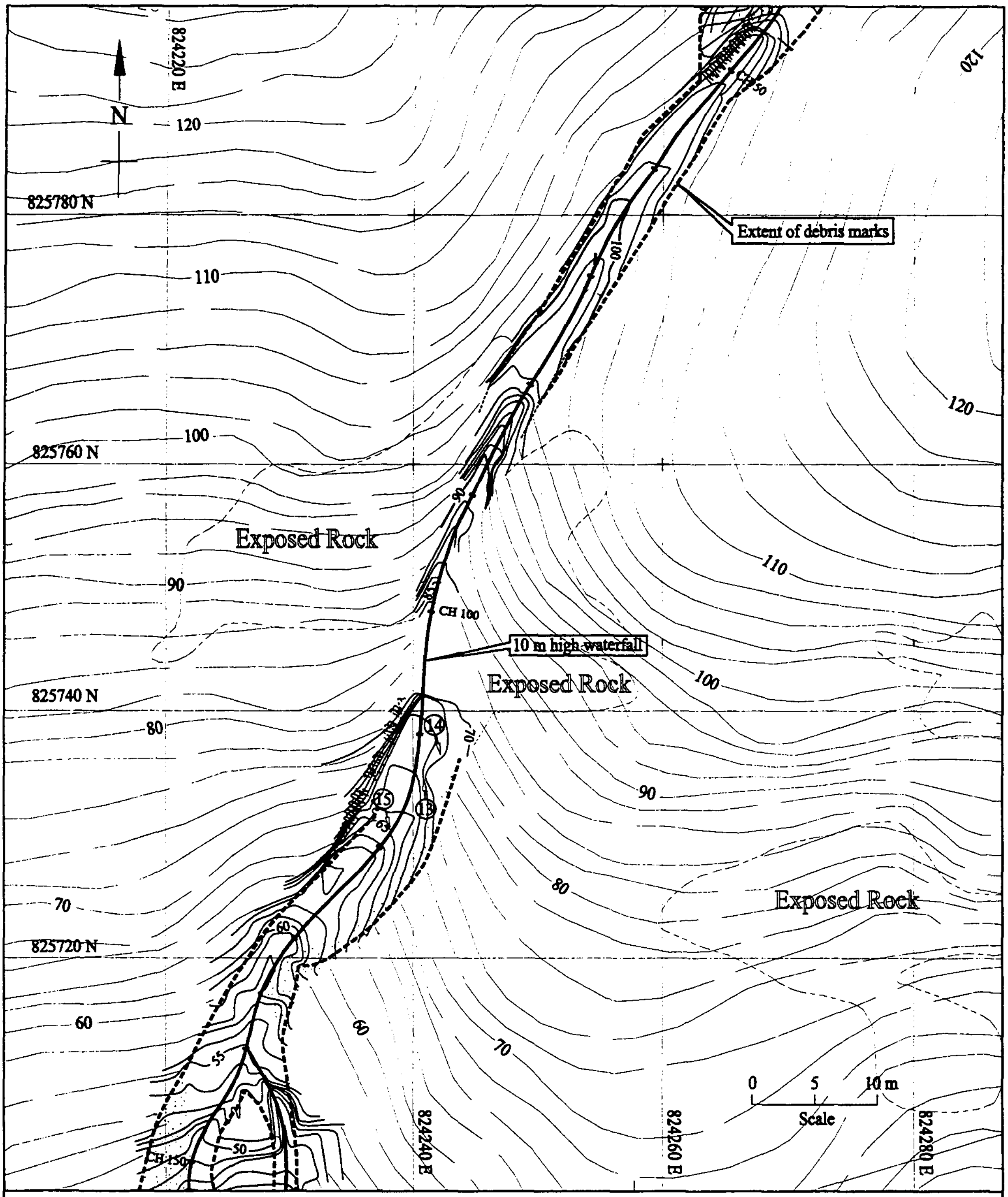


Legend :

| | | | |
|---|---|---|---|
| (14) Approximate location and direction from which Plate No. 14 was taken | CH 100 Chainage line | —55— | Elevation in mPD |

Notes : (1) Base map is based on Survey Sheet No. 6SE-17C (scale 1:1 000) (contours at 2 m intervals).

(2) Survey of stream course was carried out between 1 September and 15 November 1999 (contours at 1 m intervals).

(3) Chainage line, established for landslide investigation reference purposes, extends from crown of Landslide A to Sham Tseng Nullah (chainage marks at 20 m intervals) along stream course and nullah beyond CH 22.

Figure 3 - Plan of the Debris Flow and Locations of Photographs (Sheet 2 of 4)

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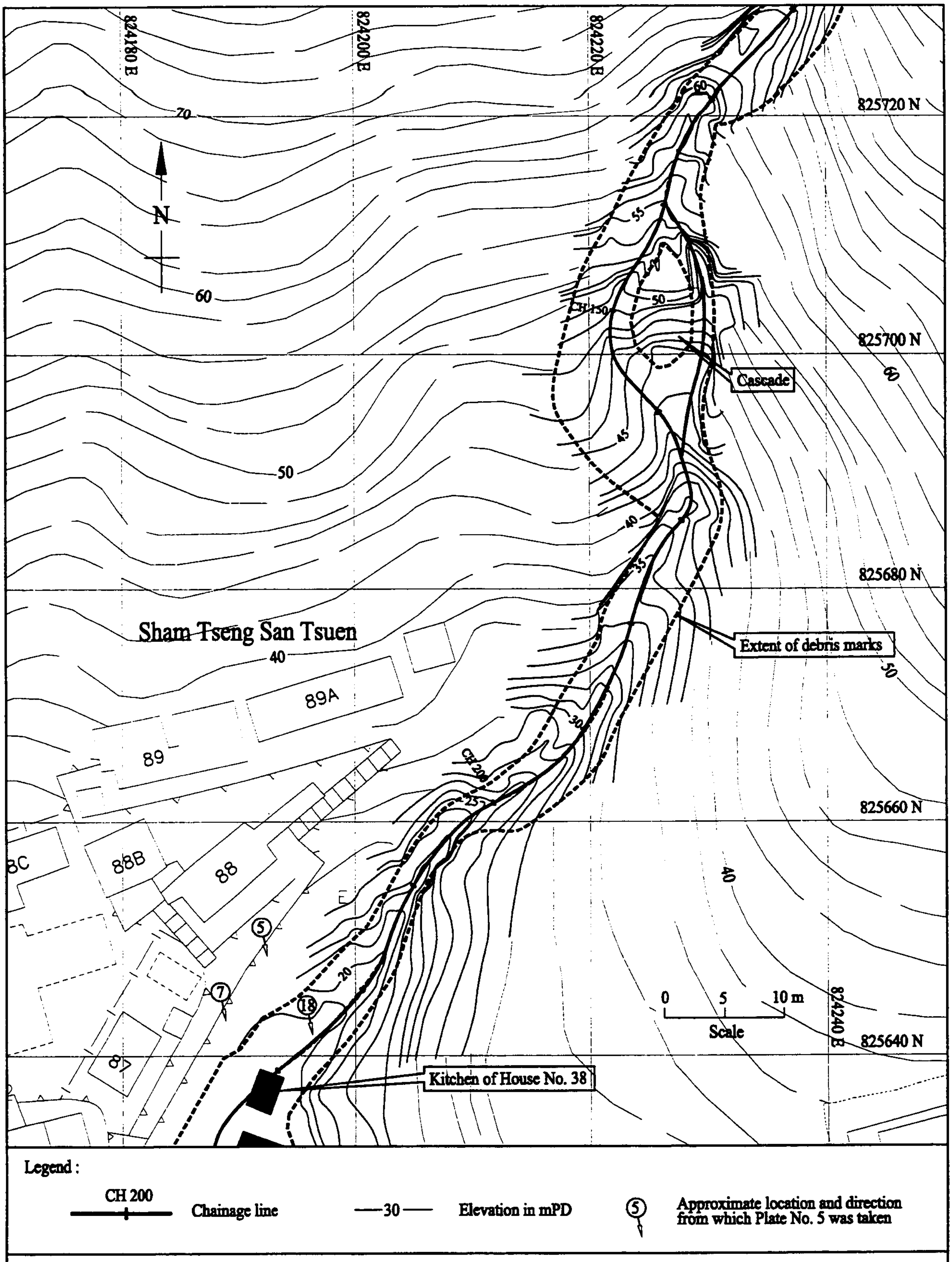


Notes : (1) Base map is based on Survey Sheet No. 6SE-17C (scale 1:1 000) (contours at 2 m intervals).
(2) Survey of stream course was carried out between 1 September and 15 November 1999 (contours at 1 m intervals).
(3) Chainage line, established for landslide investigation reference purposes, extends from crown of Landslide A to Sham Tseng Nullah (chainage marks at 20 m intervals) along stream course and nullah beyond CH 22.

Figure 4 - Plan of the Debris Flow and Locations of Photographs (Sheet 3 of 4)

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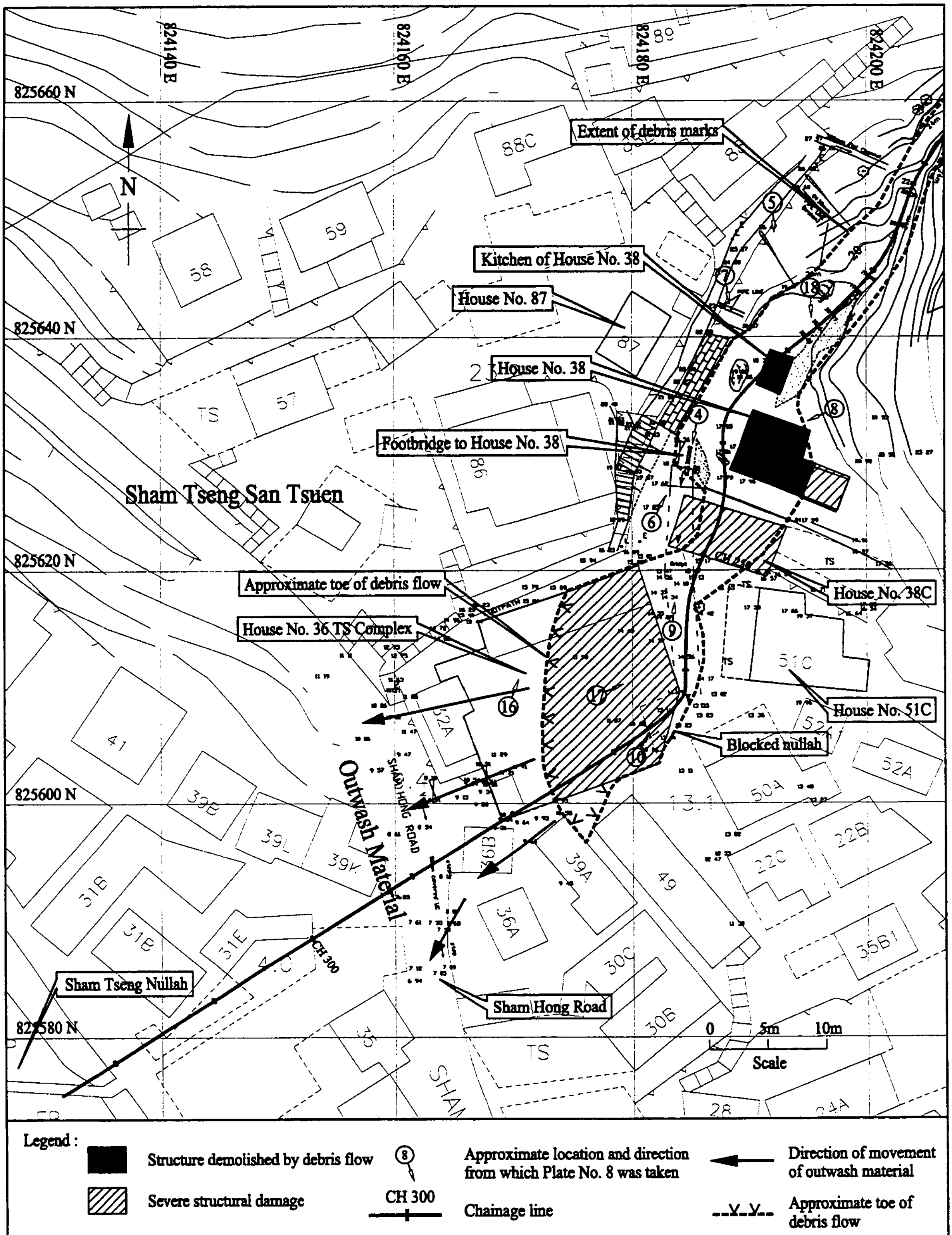


Notes : (1) Base map is based on Survey Sheet No. 6SE-17C (scale 1:1 000) (contours at 2 m intervals).
(2) Survey of landslide was carried out between 1 September and 15 November 1999 (contours at 1 m intervals).
(3) Landslide debris carried beyond the House No. 36 TS Complex as outwash material by stream flow only.

Figure 5 - Plan of the Debris Flow and Locations of Photographs (Sheet 4 of 4)

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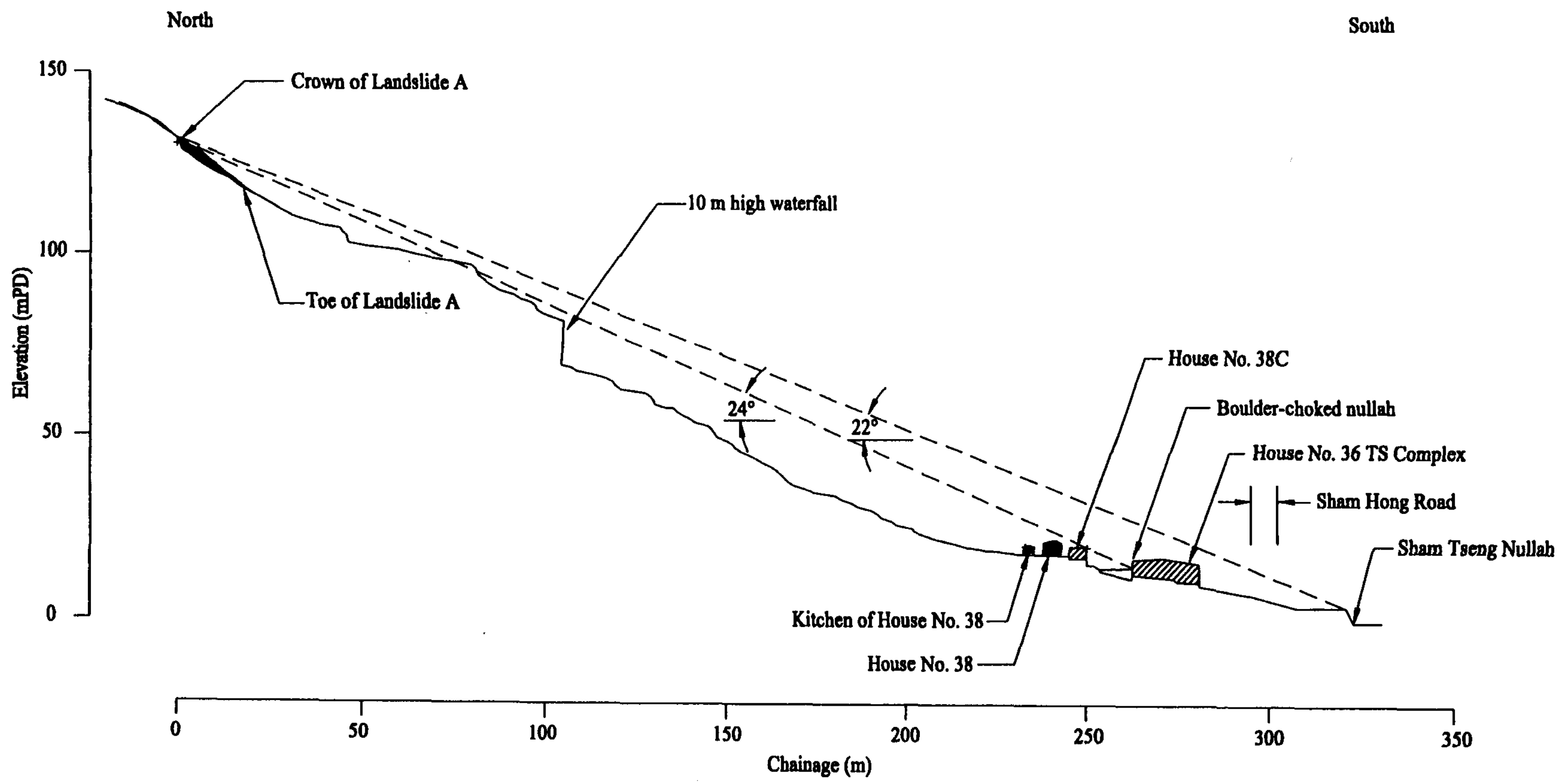


Notes : (1) Elevation from crown of Landslide A to Sham Hong Road was taken from survey carried out between 1 September and 15 November 1999.
(2) Profile from Sham Hong Road to Sham Tseng Nullah was taken from base plan of Survey Sheets Nos. 6SE-17A and 6SE-17C (scale 1 : 1 000).

Figure 6 - Elevation of Debris Flow Path

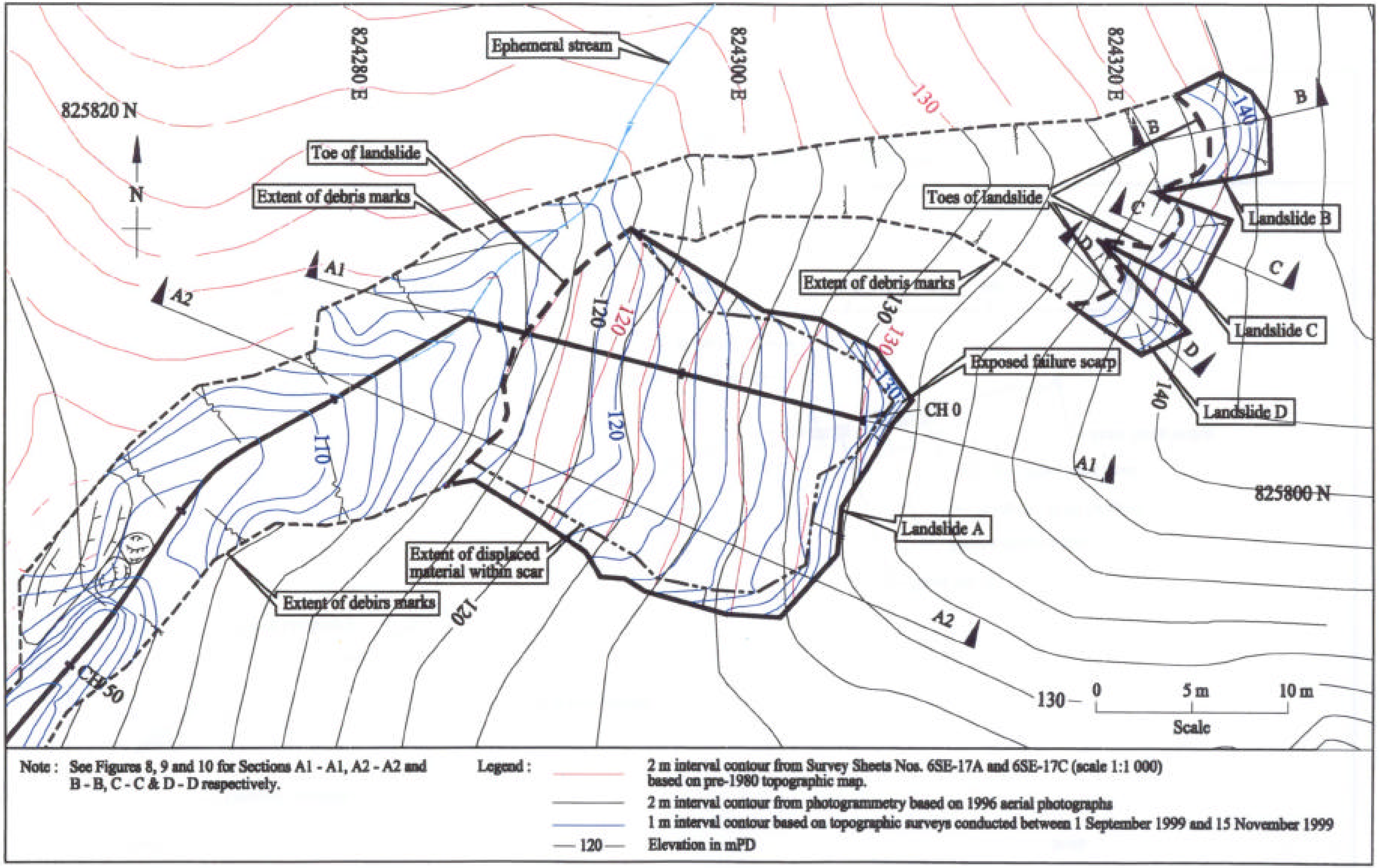


Figure 7 - Pre-failure and Post-failure Topographical Plan of the Landslides



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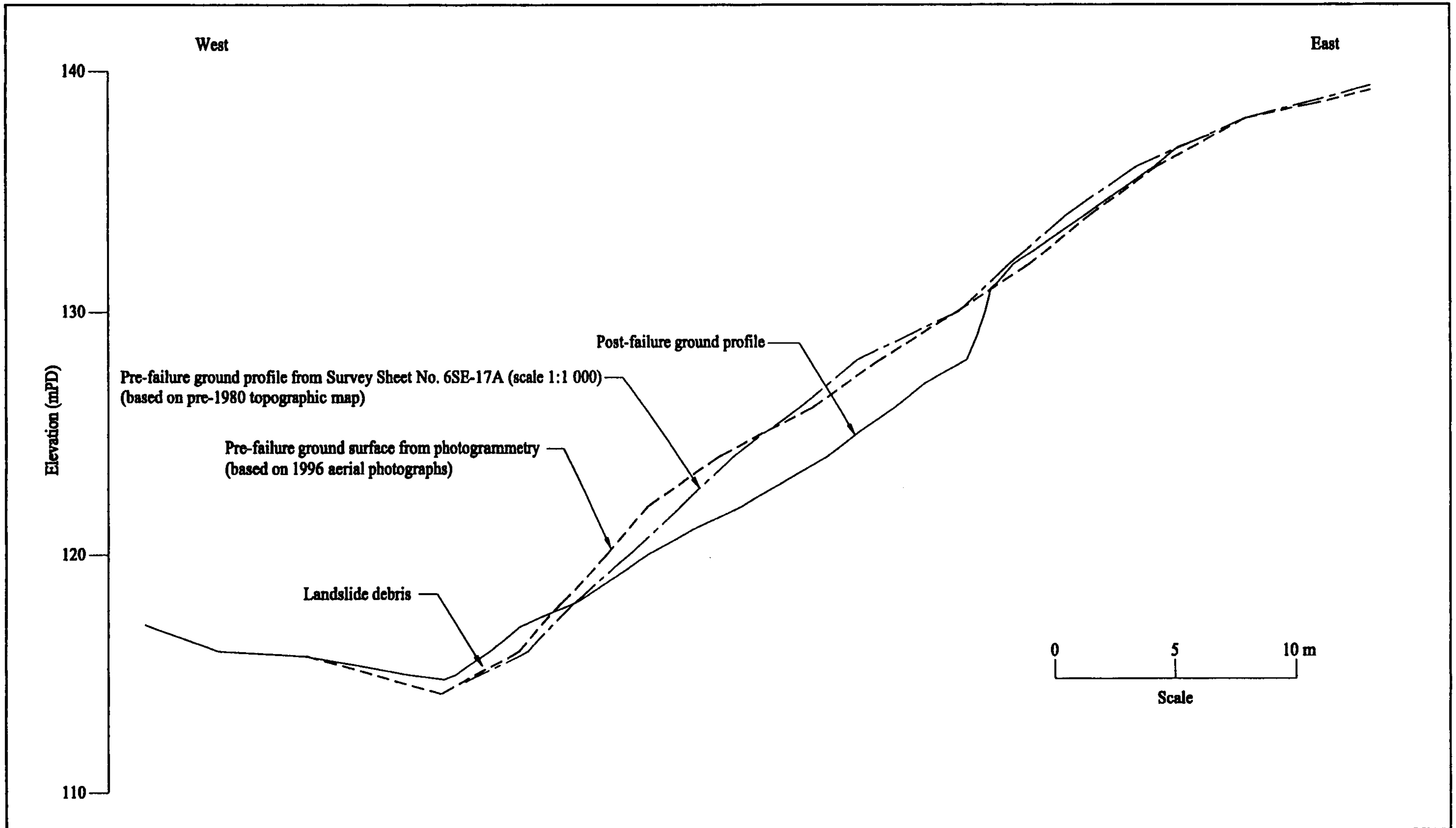
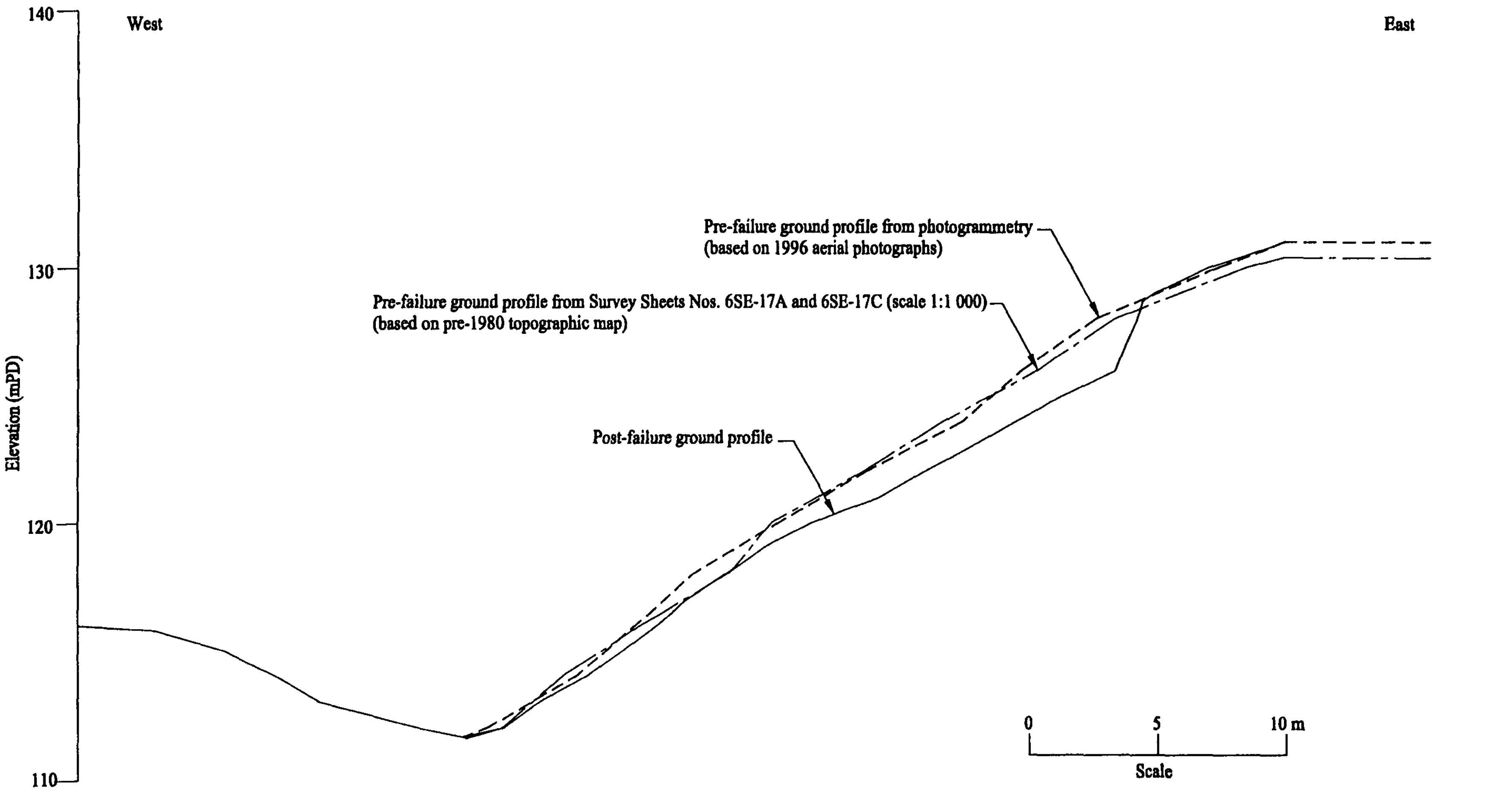



Note : See Figure 7 for location of section.

Figure 8 - Section A1 - A1 Through Landslide A




Note : See Figure 7 for location of section.

Figure 9 - Section A2 - A2 Through Landslide A



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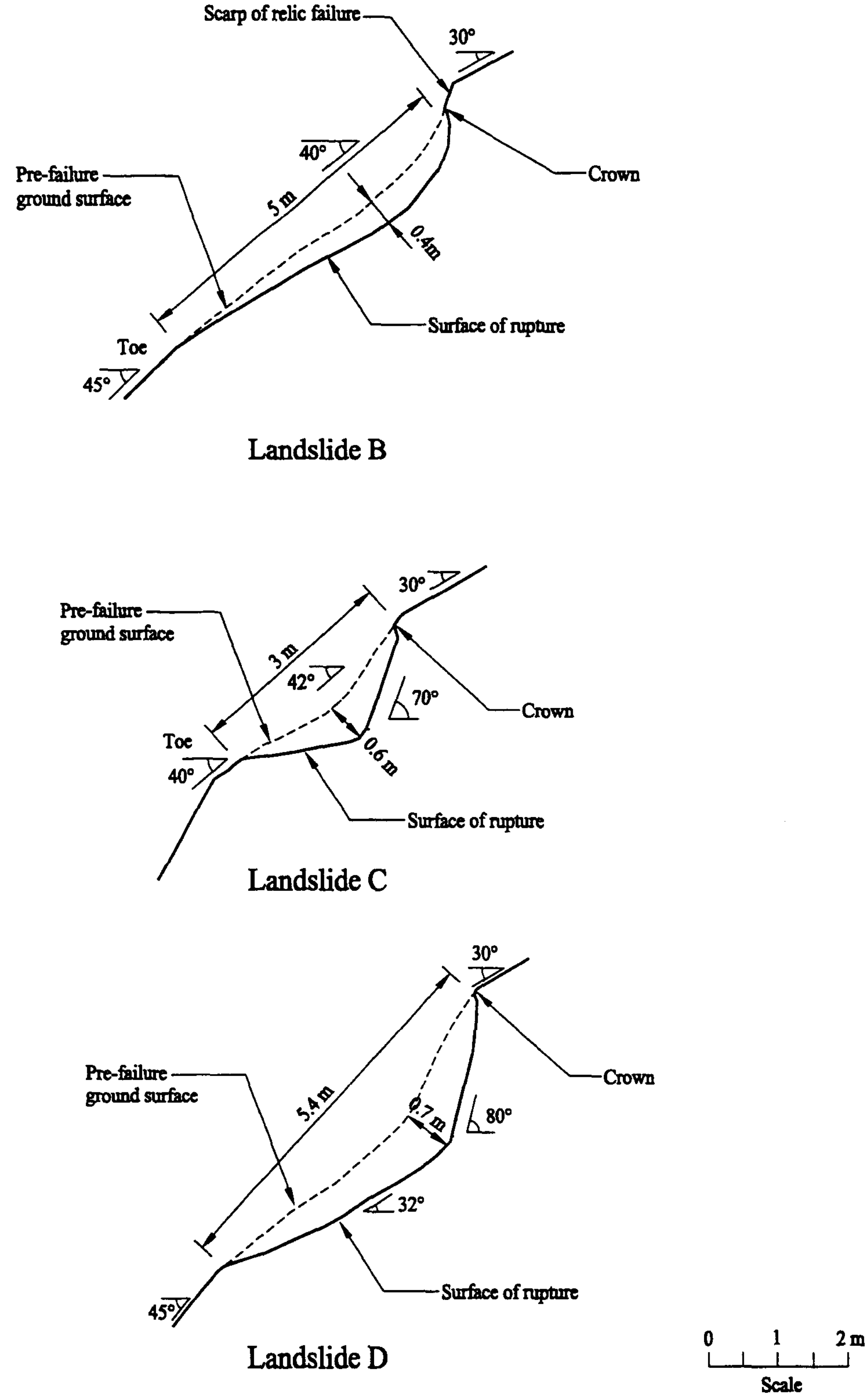


Notes : (1) See Figure 7 for locations of sections.
(2) Post-failure ground profiles determined from site measurements.
(3) Pre-failure ground profiles estimated from site observations.

Figure 10 - Sections Showing Details of Landslides B, C and D

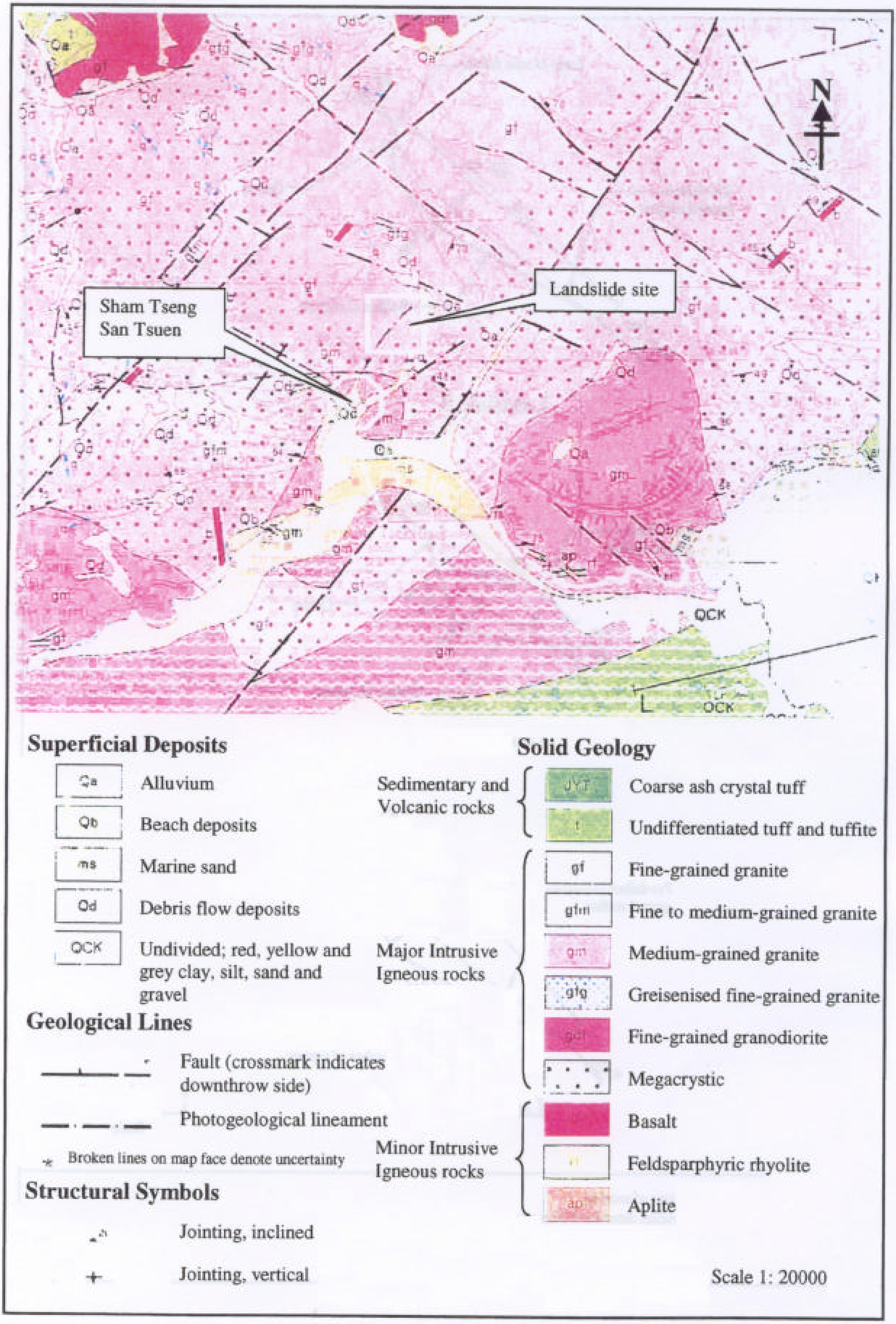


Figure 11 - Extract from Geological Map

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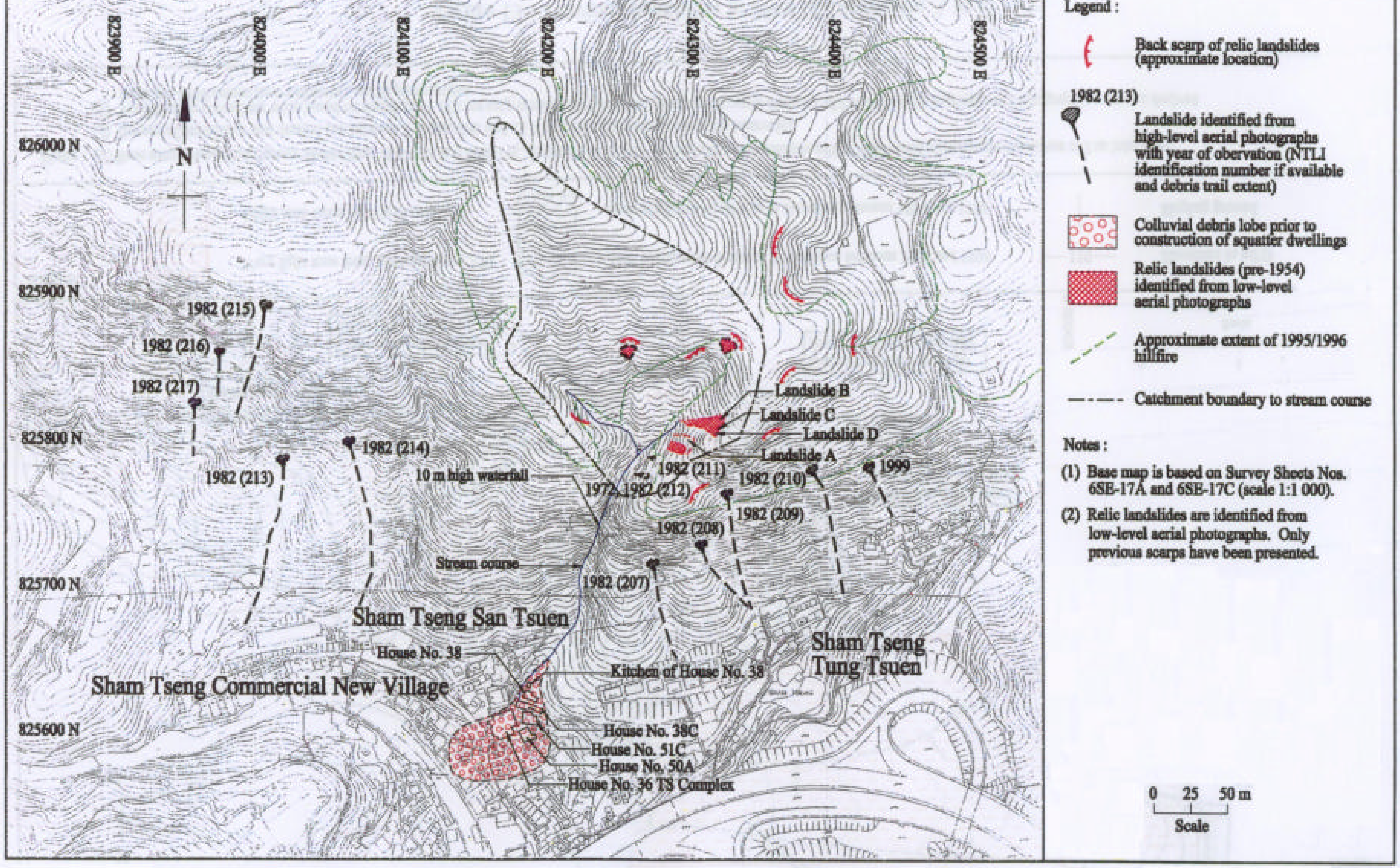
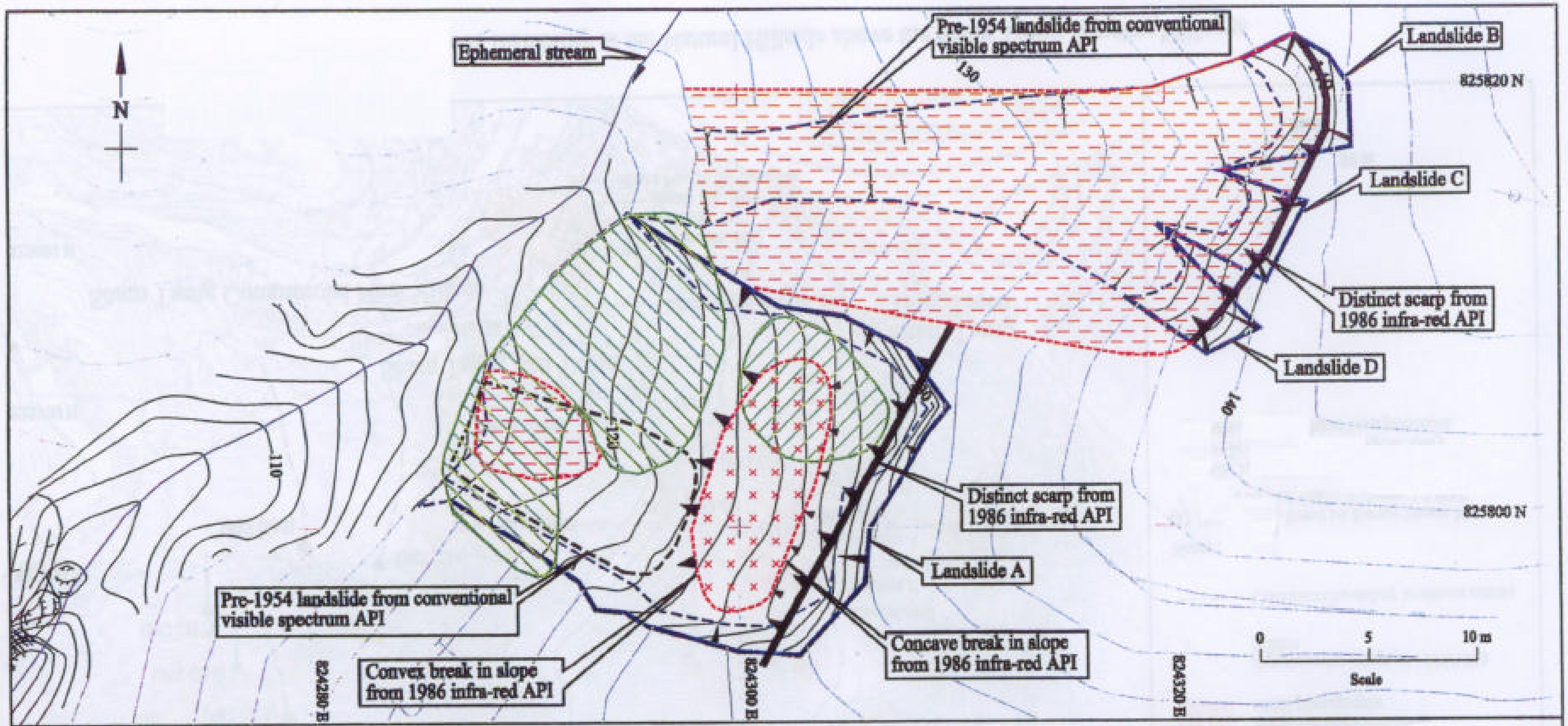



Figure 12 - Previous Instability at the Natural Hillside above the Sham Tseng Squatter Villages




Legend :

- Very light tone from 1986 infra-red API
- Light tone from 1986 infra-red API
- Area of apparent decrease in elevation between 1980 and 1996
- Area of apparent increase in elevation between 1980 and 1996
- —130— Elevation in mPD
- Sloping ground

Notes : (1) Base map is based on Survey Sheets Nos. 6SE-17A and 6SE-17C (scale 1:1 000) and Photogrammetric analysis of the 1996 aerial photographs (contours at 2 m intervals).

(2) Survey of landslides was carried out between 1 September and 15 November 1999 (contours at 1m intervals).

(3) Variations in elevations were based on comparison of base map contours derived from photogrammetric analyses of 1996 aerial photographs and topographic contours derived from pre-1980 (exact date unknown), aerial photographs.

Figure 13 - Previous Instability at Sites of Landslides A to D



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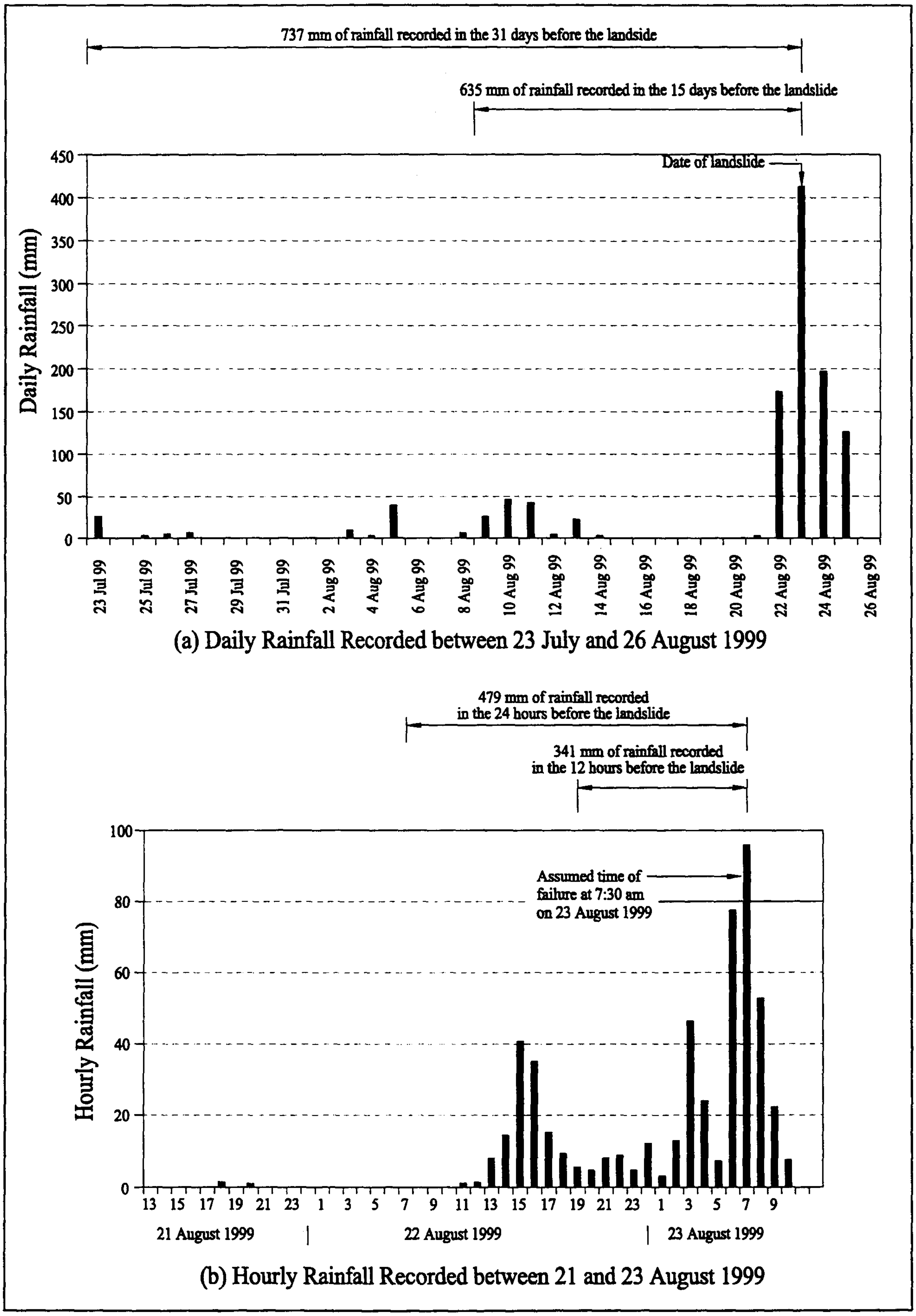


Figure 14 - Rainfall Records of GEO Raingauge No. N10

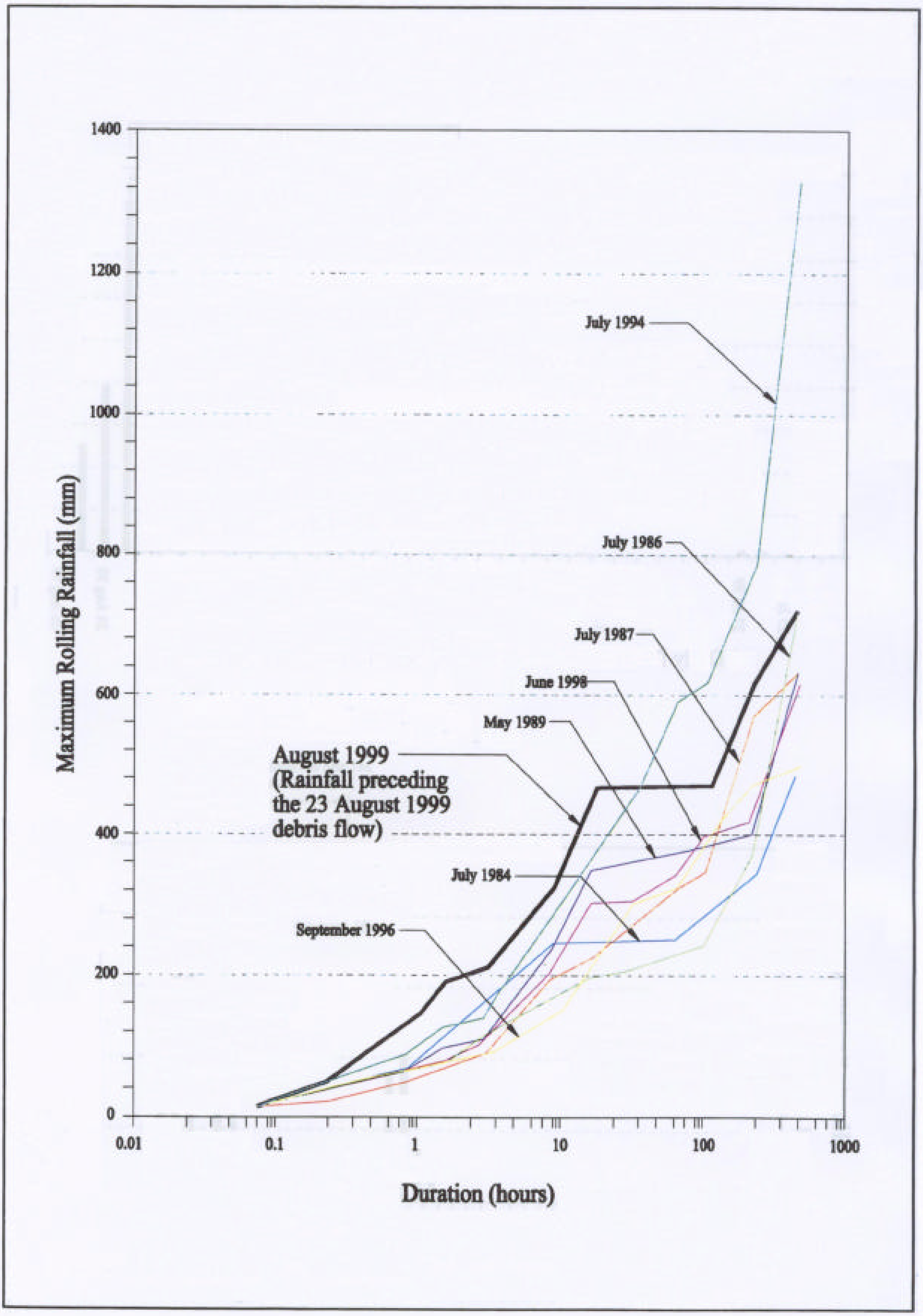


**Figure 15 - Maximum Rolling Rainfall at GEO Raingauge No. N10**

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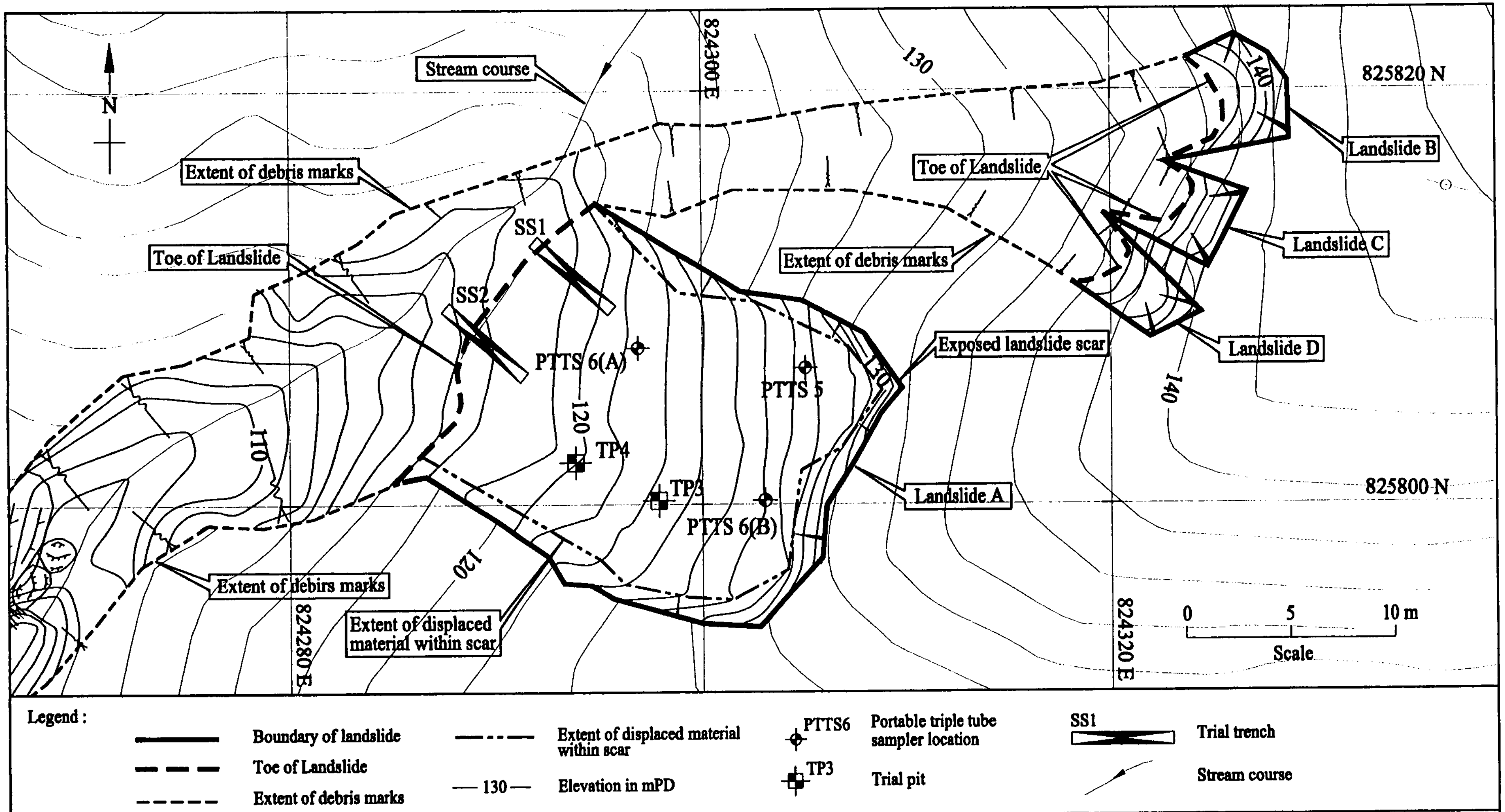


Notes : (1) Base map is based on Survey Sheets Nos. 6SE-17A and 6SE-17C (scale 1:1 000) and photogrammetric analysis of the 1996 aerial photographs (contours at 2 m intervals).

(2) Survey of landslide was carried out between 1 September and 15 November 1999 (contours at 1 m intervals).

(3) GEO Probes were carried out at approximate 4 m grid within the scar of Landslide A.

Figure 16 - Location Plan of Ground Investigation Works



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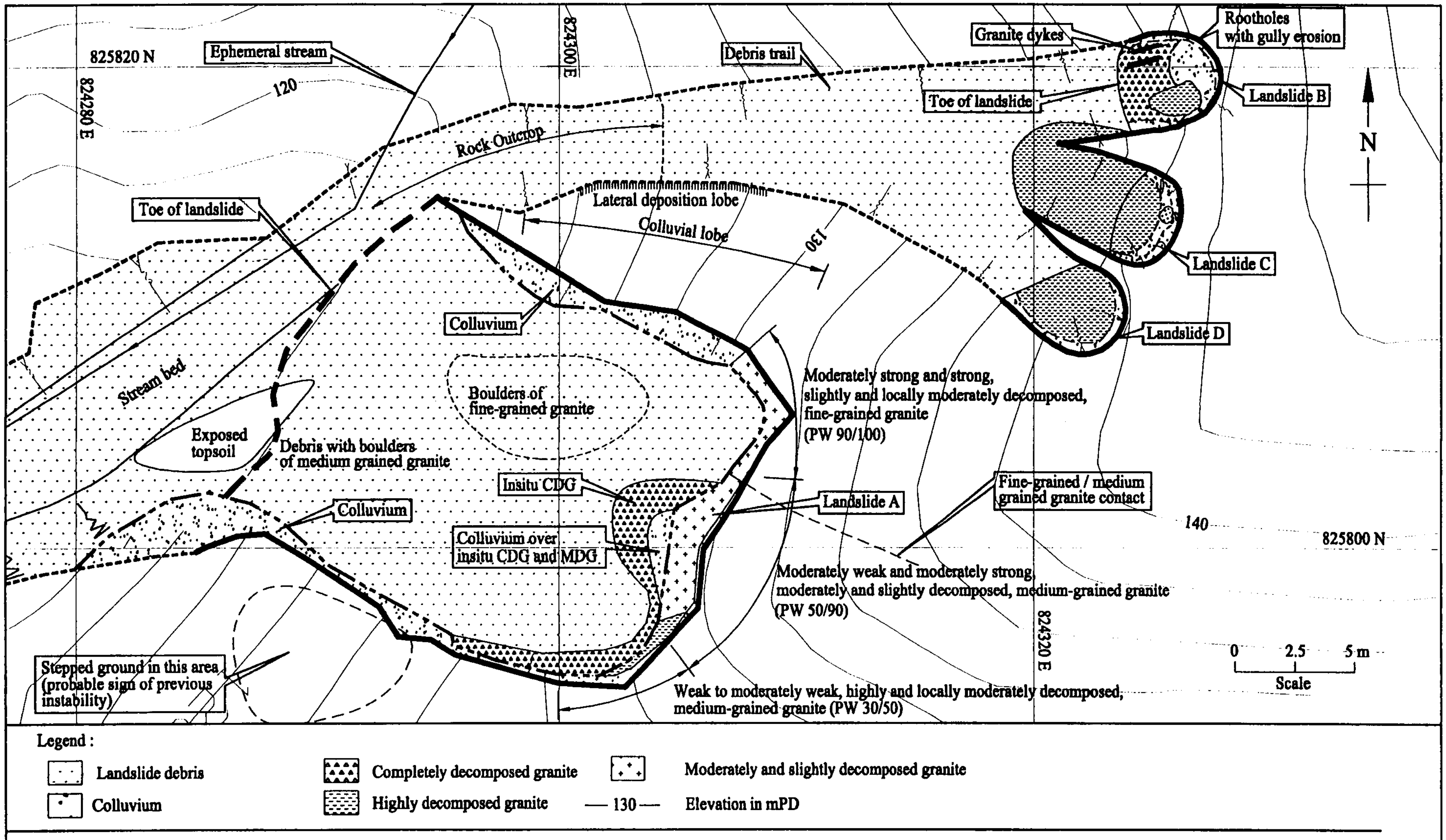


Notes : (1) Base map was taken from Survey Sheets Nos. 6SE-17A and 6SE-17C (scale 1:1 000).
(2) Survey of landslide was carried out between 1 September and 15 November 1999.

Figure 17 - Geological Plan of the Landslide Area



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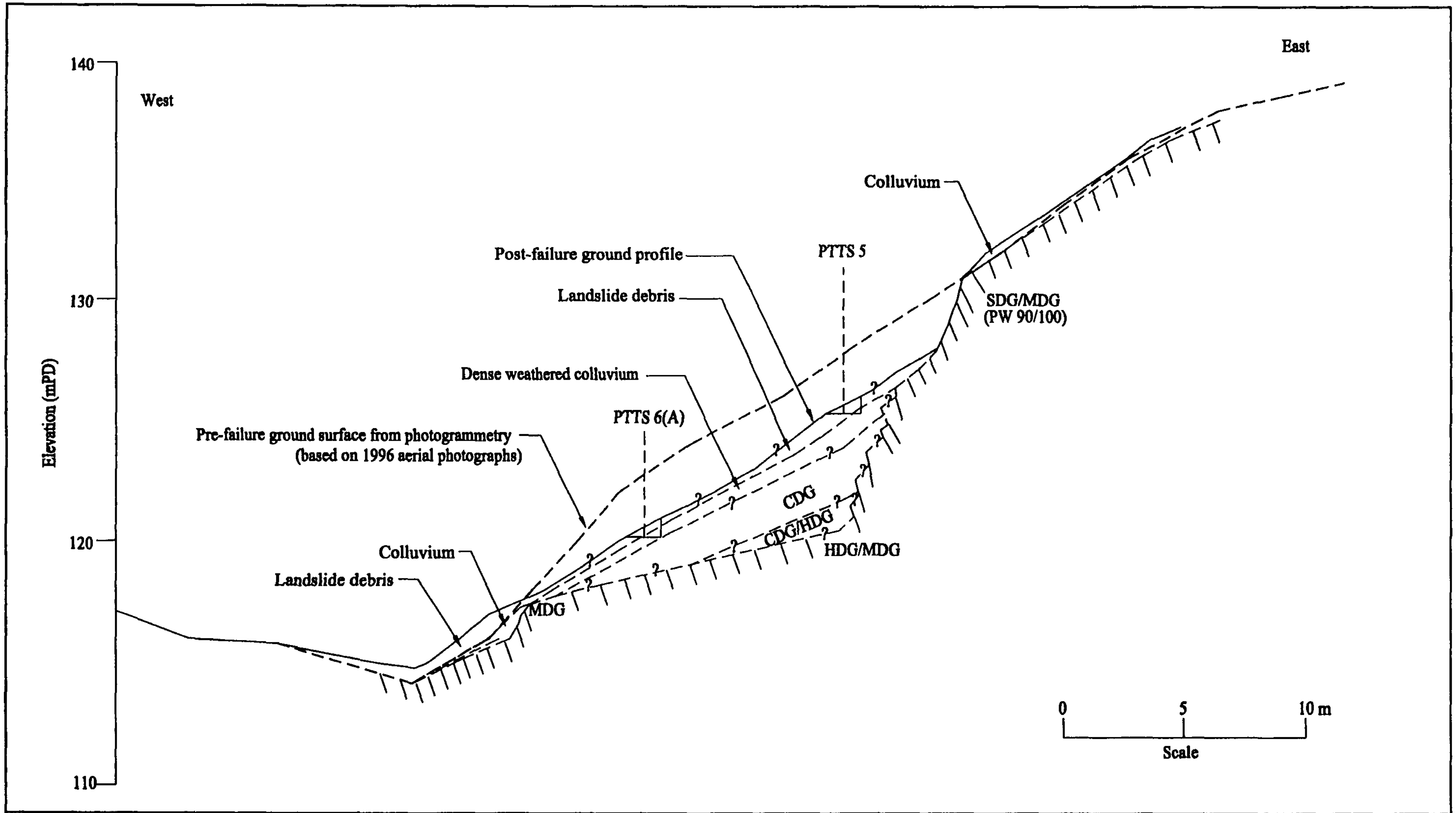


Notes : (1) See Figure 7 for location of section.

(2) Survey of landslide was carried out between 1 September and 15 November 1999.

Legend :

| | | | |
|---|---|---|---|
| PTTS | Portable triple tube sampler location | CDG | Completely decomposed granite |
| —?—?— | Inferred geological boundary | HDG | Highly decomposed granite |
| PW 90/100 | Rock mass weathering grade | MDG | Moderately decomposed granite |
| | | SDG | Slightly decomposed granite |

Figure 18 - Geological Section A1 - A1 Through Landslide A



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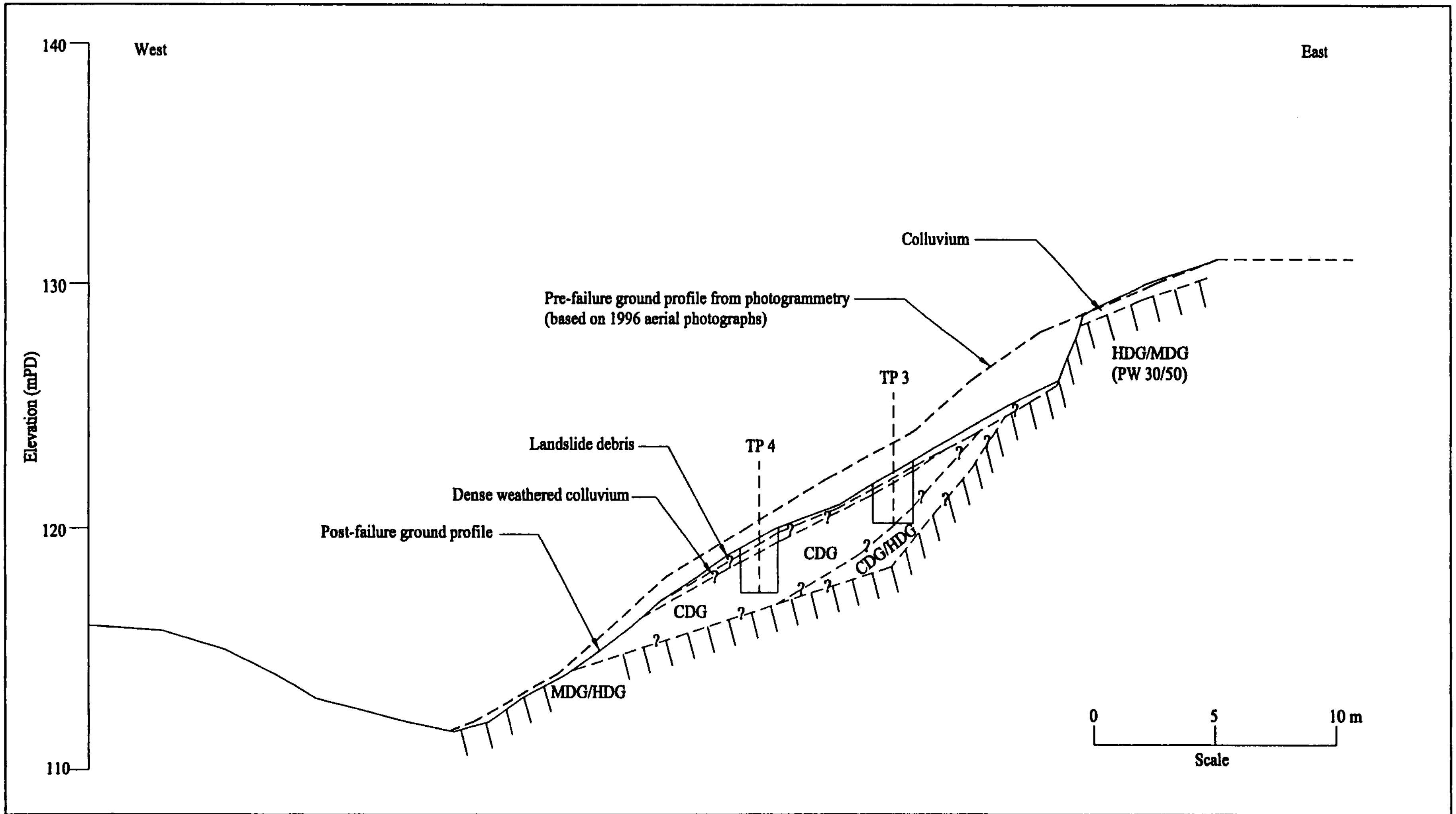


Notes : (1) See Figure 7 for location of section.
(2) Survey of landslide was carried out between 1 September and 15 November 1999.

Legend :

| | | | |
|---|---|---|---|
| TP | Trial pit location | CDG | Completely decomposed granite |
| —?—?— | Inferred geological boundary | HDG | Highly decomposed granite |
| PW 0/30 | Rock mass weathering grade | MDG | Moderately decomposed granite |

Figure 19 - Geological Section A2 - A2 Through Landslide A



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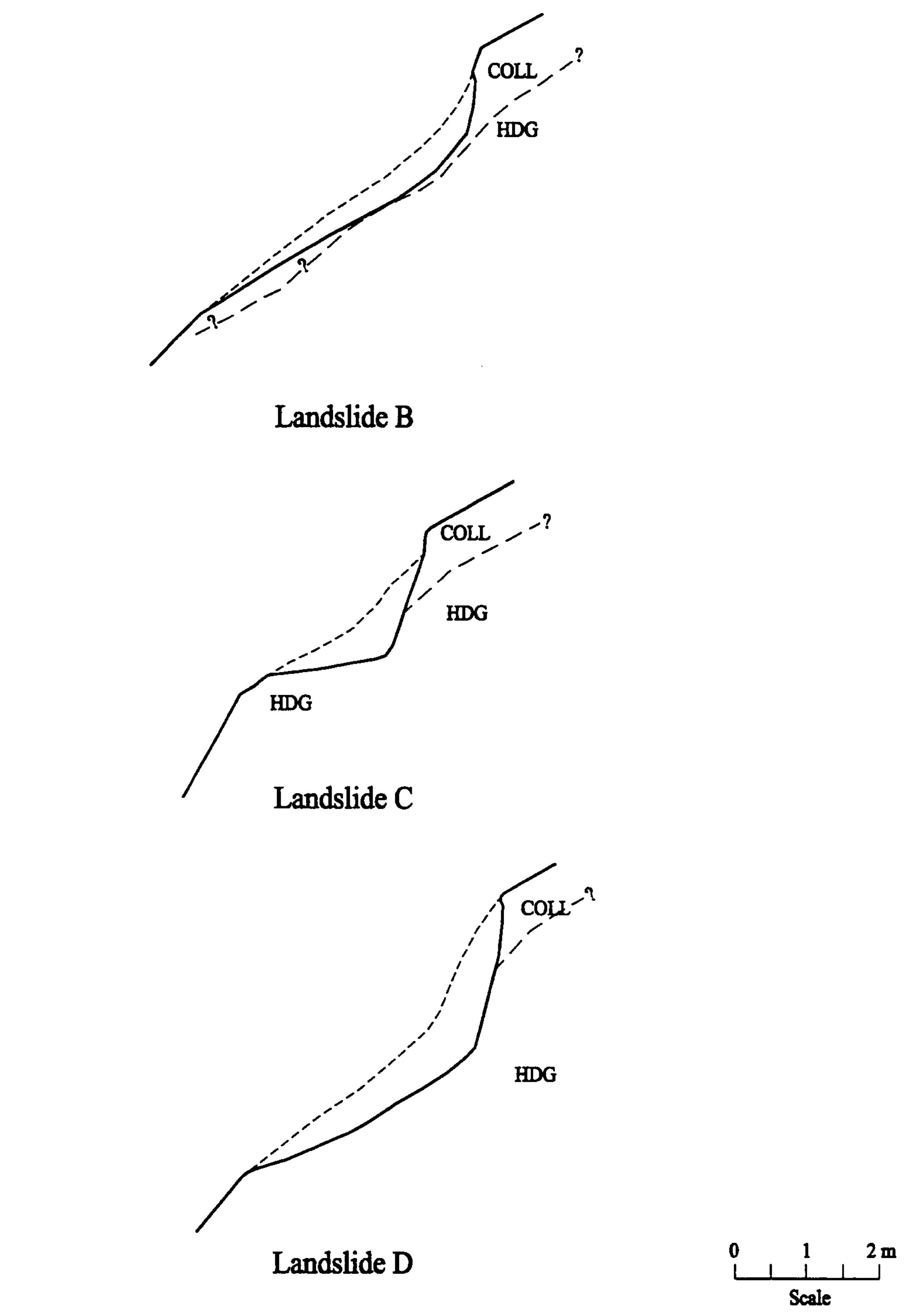


Legend :

| | | | |
|---|---|---|---|
| COLL | Colluvium | - - - - - - - - - - | Inferred pre-failure ground profile |
| CDG | Completely decomposed granite | —?— — —?— | Inferred geological boundary |
| HDG | Highly decomposed granite | | |

Note : See Figure 7 for locations of sections.

Figure 20 - Geological Sections Through Landslides B, C and D

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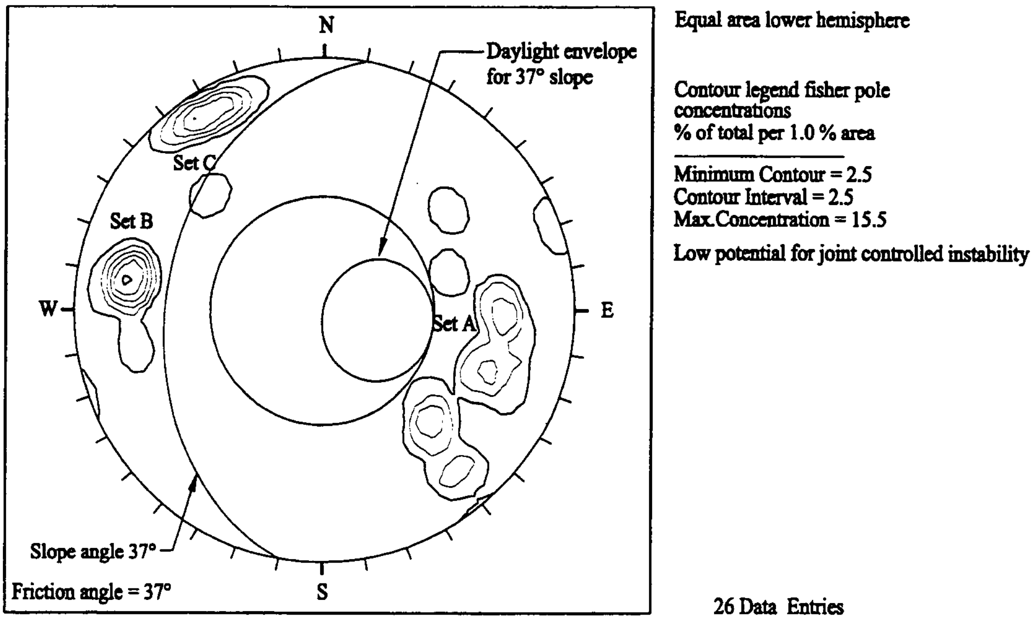
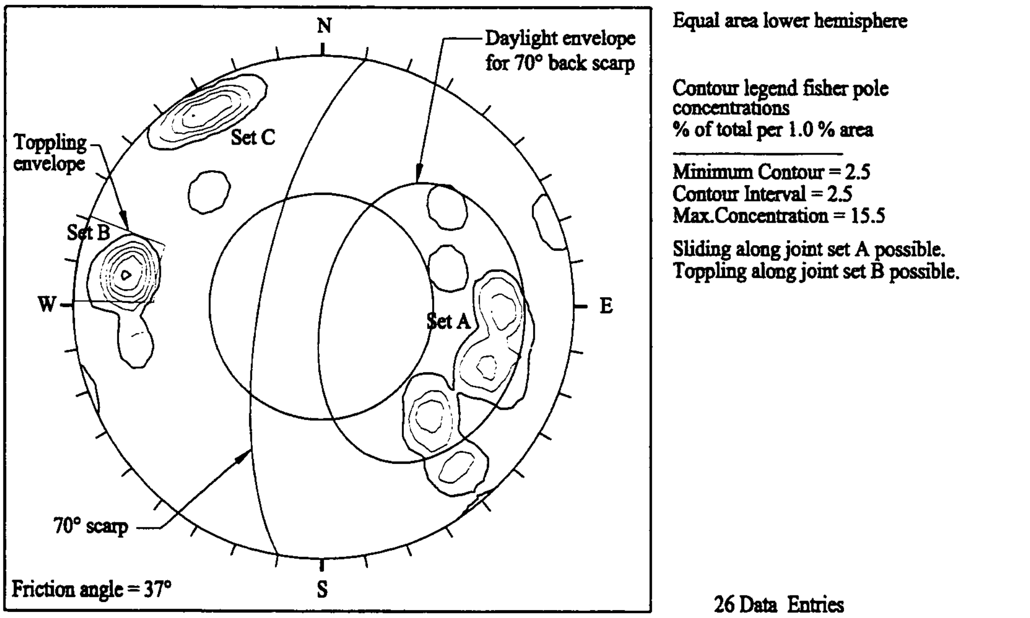



(a) Kinematic assessment of potential joint-controlled instability prior to the landslide




(b) Kinematic assessment of potential joint-controlled instability at the back scarp after failure of the colluvium / CDG material

Figure 21 - Stereographic Assessment of Potential Joint-controlled Instability at Landslide A

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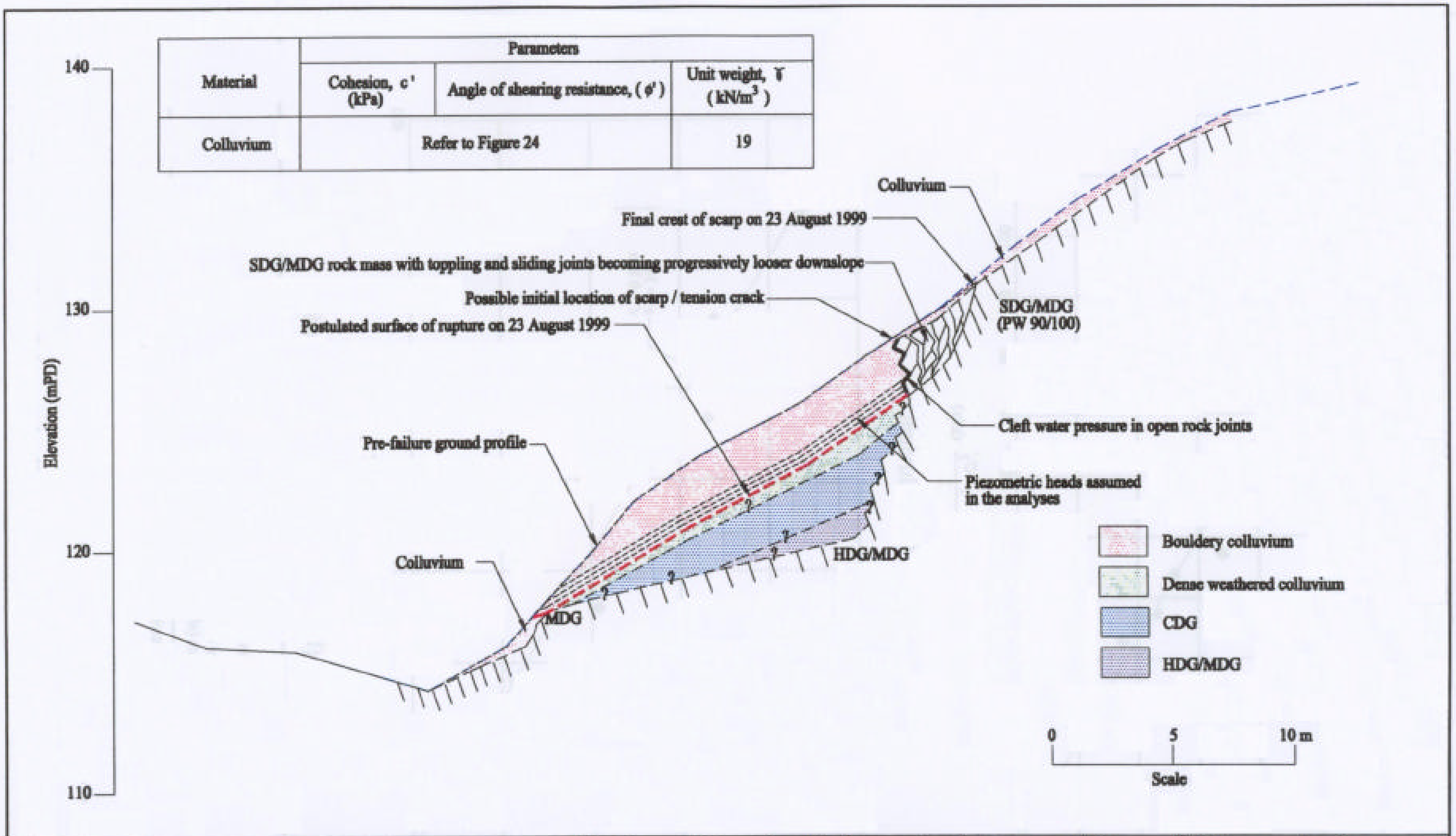


| Material | Parameters | | |
|---|---|---|---|
| | Cohesion, c' (kPa) | Angle of shearing resistance, (ϕ') | Unit weight, γ (kN/m³) |
| Colluvium | Refer to Figure 24 | | 19 |

Notes : (1) See Figure 7 for location of section.
(2) Hydrostatic pressure from ground surface assumed in open rock joint when cleft water pressures are considered in analyses.

Legend :

| | |
|---|---|
| CDG | Completely decomposed granite |
| HDG | Highly decomposed granite |
| MDG | Moderately decomposed granite |
| SDG | Slightly decomposed granite |
| PW 90/100 | Weathering zone of rock mass |
| —?—?— | Inferred geological boundary |

Figure 22 - Stratigraphical Section A1 - A1 Through Landslide A



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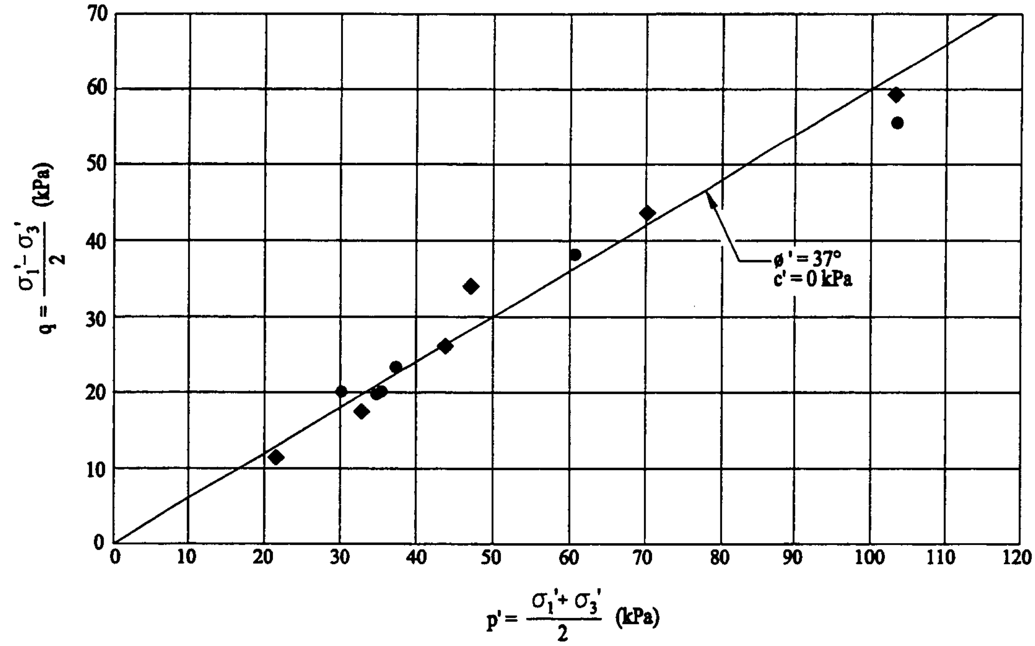
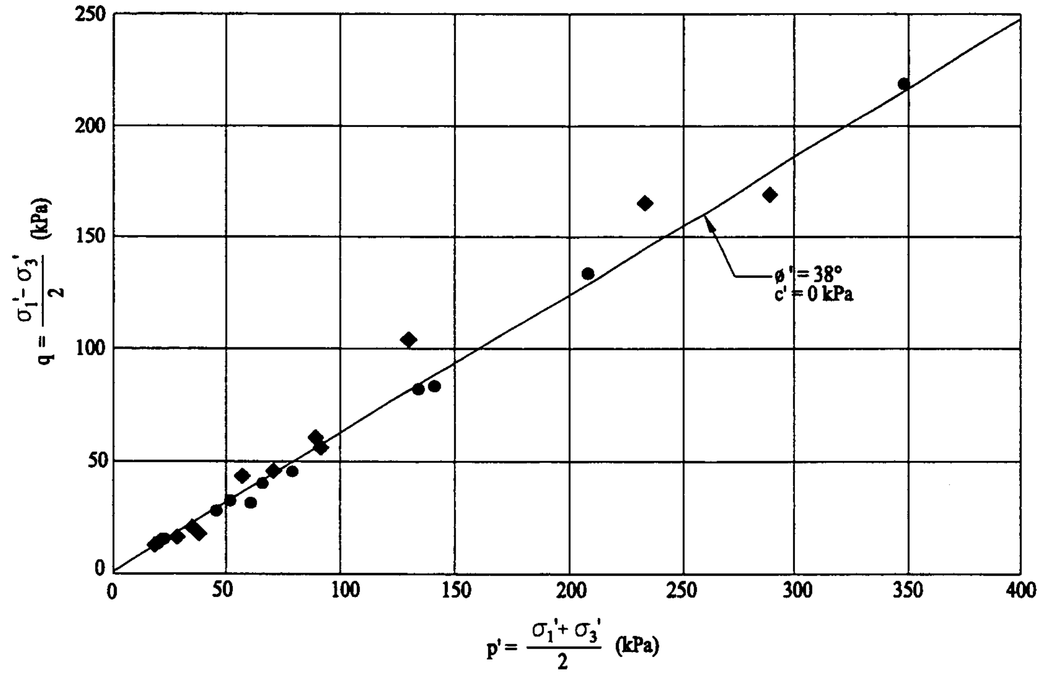



(a) Colluvium




(b) Completely Decomposed Granite

Legend :

| | | | | | |
|---|---|---|---|---|---|
| ◆ | Multi - stage | c' | Cohesion (effective) | $\sigma_1'$ | Major principal effective stress |
| ● | Single stage | ø' | Angle of shearing resistance (effective) | $\sigma_3'$ | Minor principal effective stress |

Note : The test specimens were prepared from undisturbed block or Mazier samples.

Figure 23 - Triaxial Compression Test Results for Colluvium and Completely Decomposed Granite

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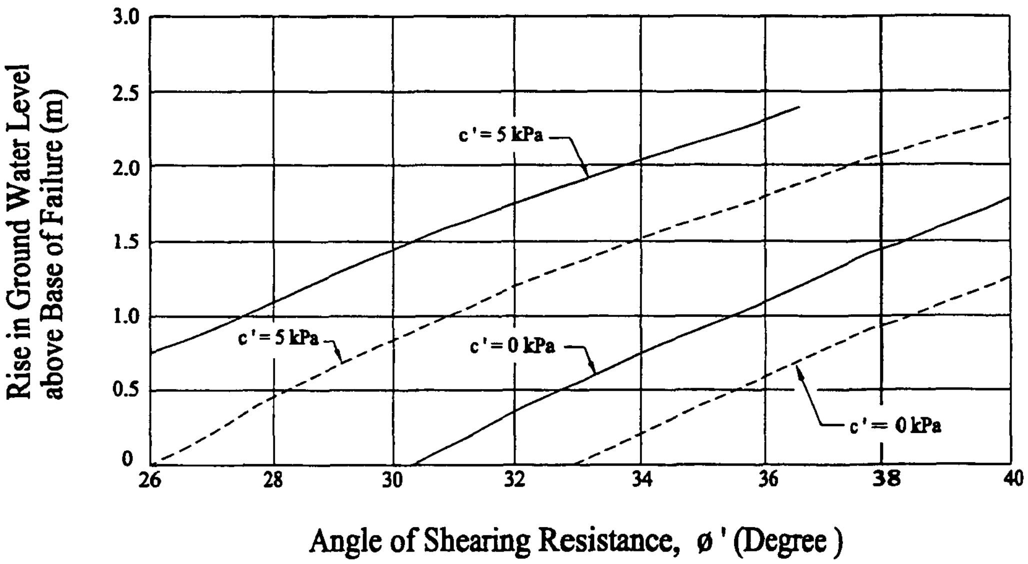


Legend :

—— Without cleft water pressure - - - With cleft water pressure

Notes : (1) Refer to Figure 22 for section analysed.
(2) Results for a Factor of Safety = 1.0

Figure 24 - Results of Theoretical Stability Analyses

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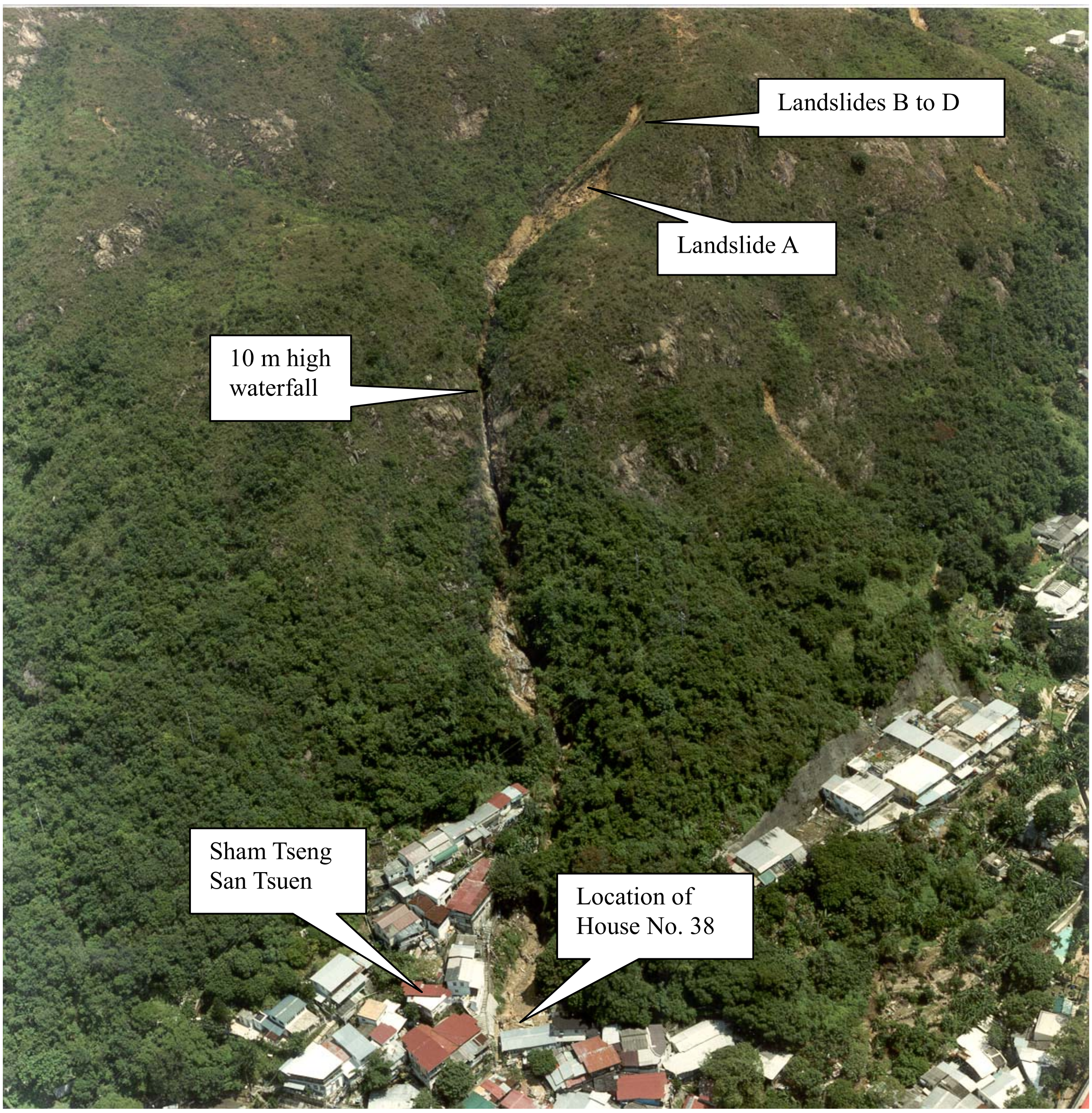


Plate 1 - Oblique Aerial View of the Debris Flow Path
(Photograph Taken on 26 August 1999)

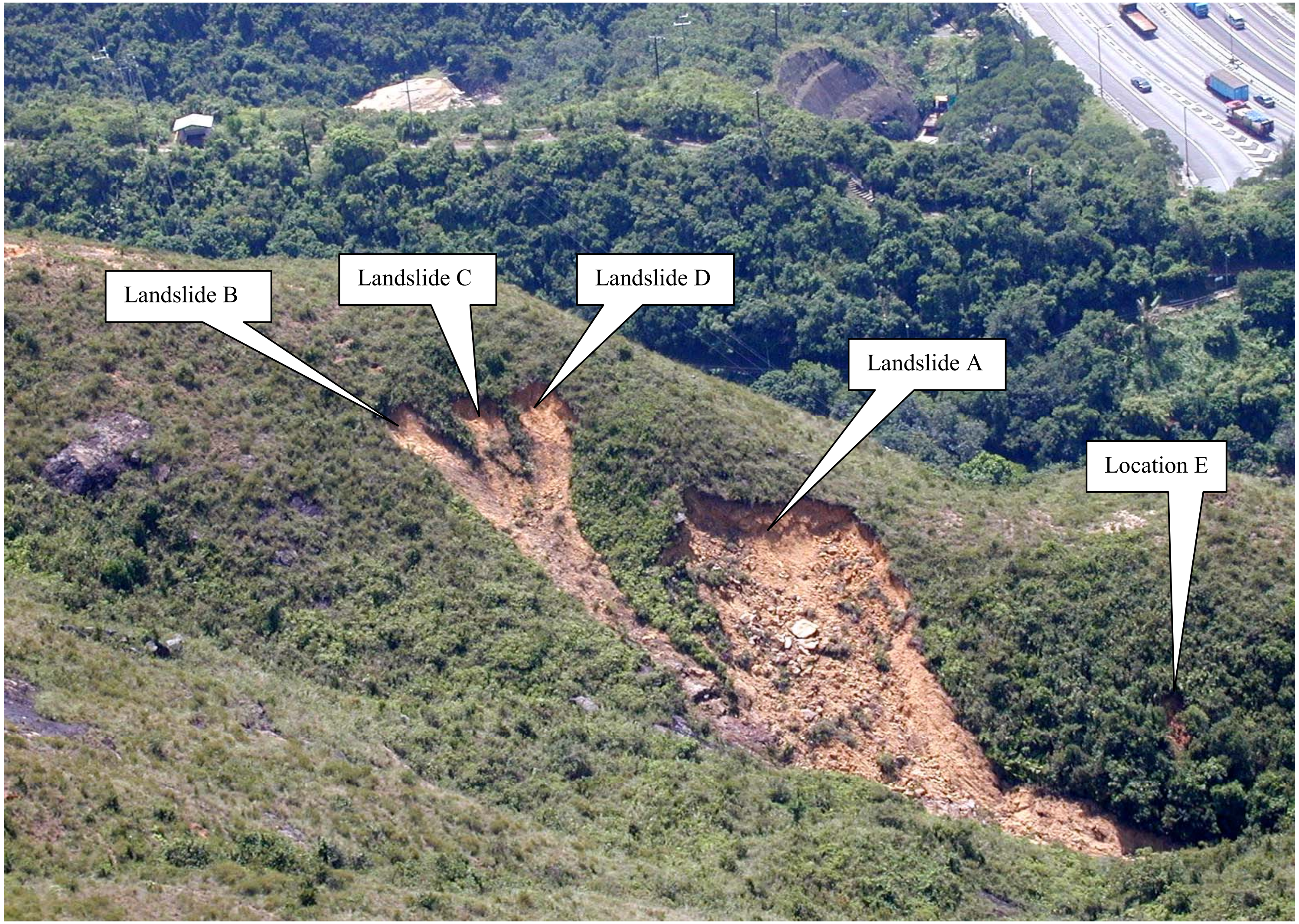


Plate 2 - Oblique Aerial View of the Landslide Sites (Photograph Taken on 26 August 1999)


Plate 3 - Oblique Aerial View of Middle to Upper Parts of the Stream Course
(Photograph Taken on 26 August 1999)

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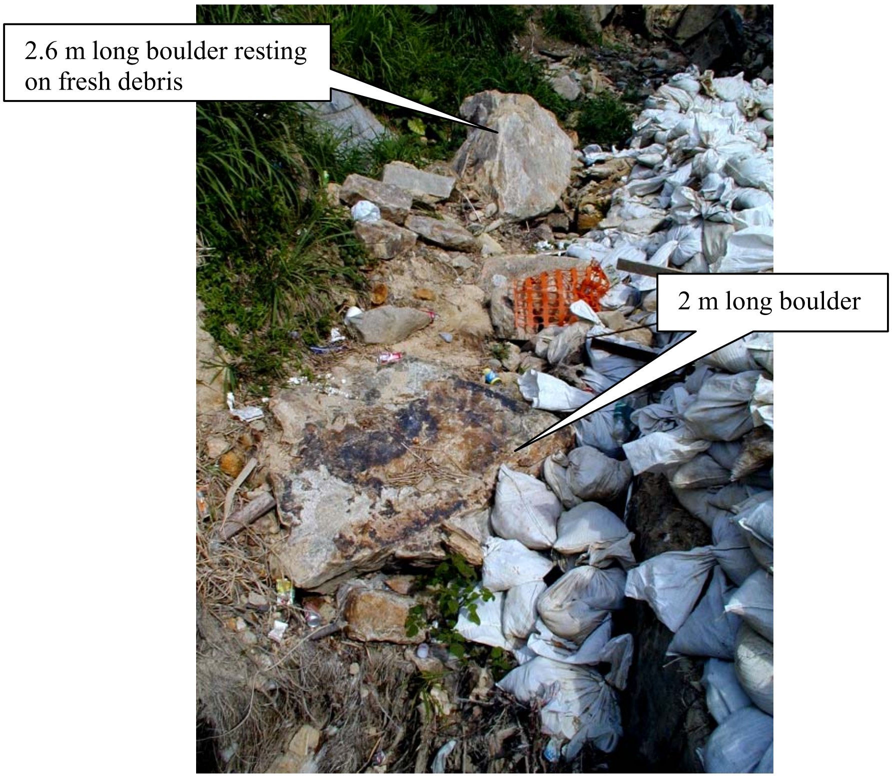


(a) Nullah upstream of footbridge to House No. 38 infilled with fresh boulders


(b) Nullah partially cleared

Plate 4 - Nullah Upstream of Footbridge to House No. 38
(Photographs Taken on 8 December 1999)

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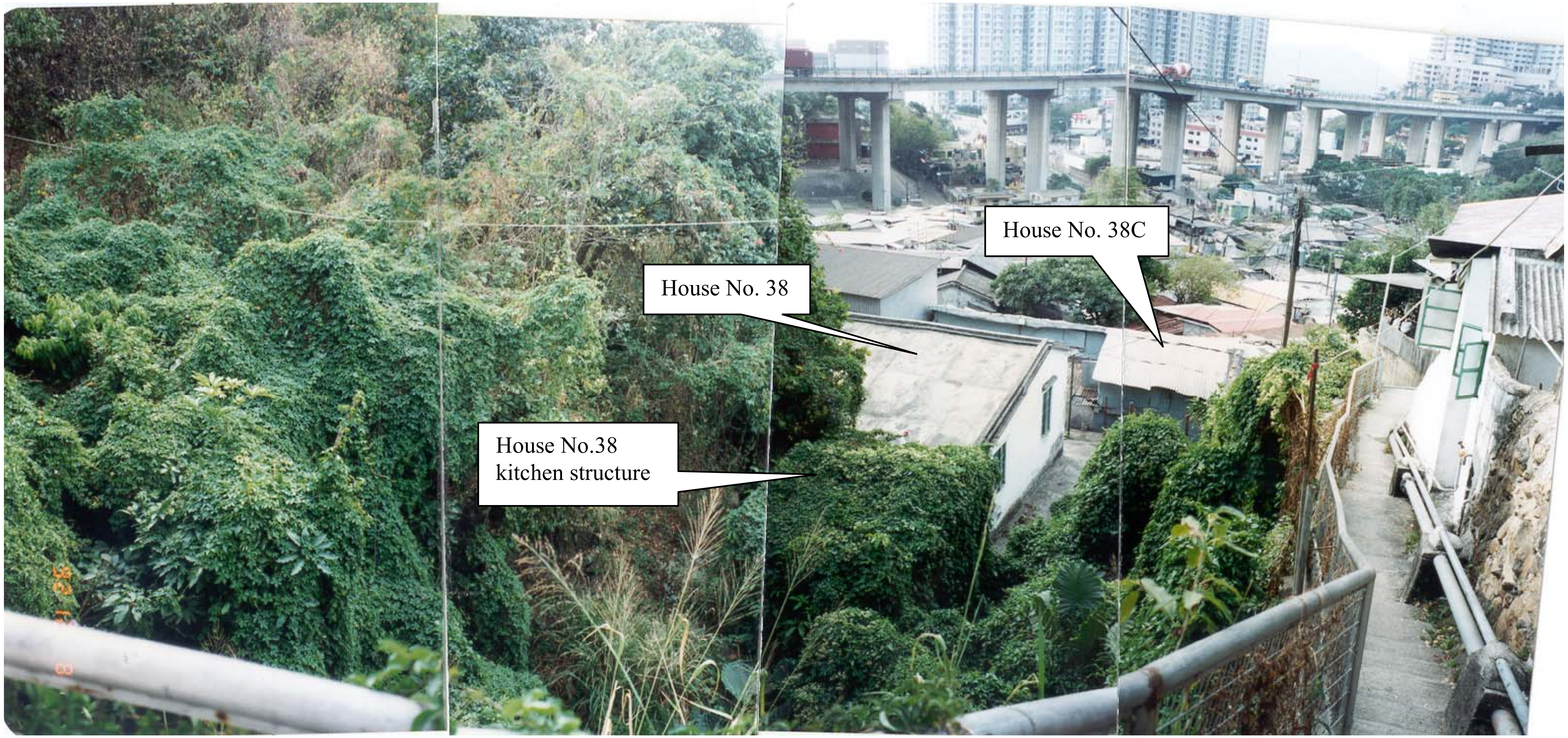


Plate 5 - View of House No. 38 and its Kitchen Structure in August 1992



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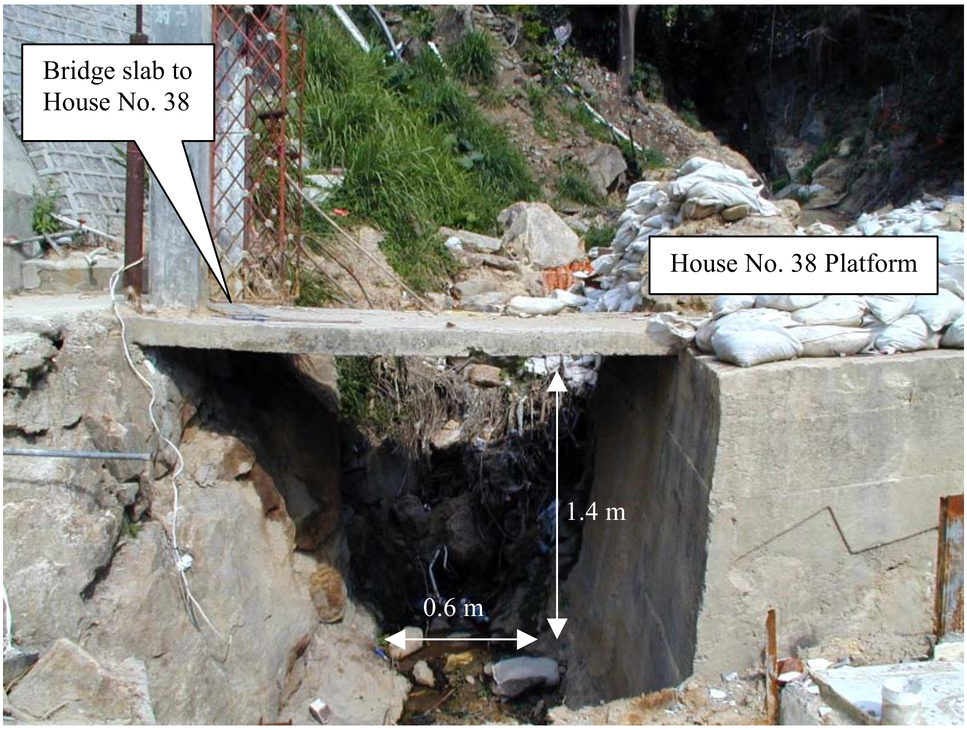
(a) Nullah beneath footbridge to House No.38 totally blocked by fresh vegetation and boulders (Photograph taken on 24 August 1999)




(b) Nullah partially cleared (Photograph taken on 8 December 1999)

Plate 6 - Nullah at Footbridge to House No. 38

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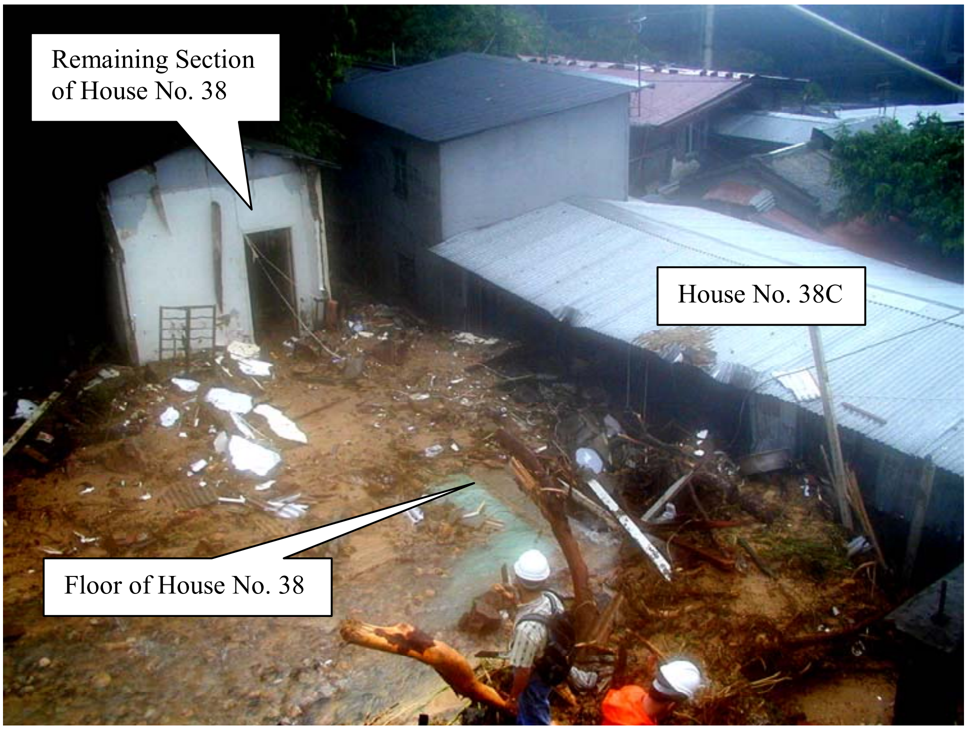


(a) Remains of House No. 38


(b) Bridge and levee at House No. 38

Plate 7 - Site of House No. 38 (Photographs Taken on 24 August 1999)

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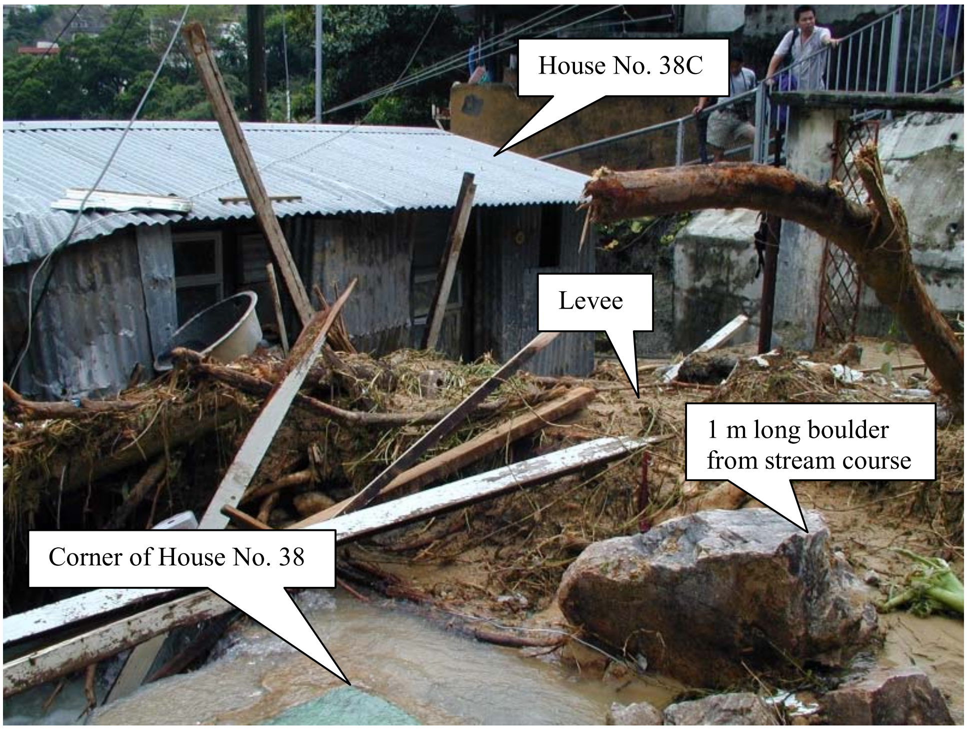


(a) Levee against House No. 38C with large tree, vegetation and boulders


(b) Path of debris flow through House No. 38C

Plate 8 - Houses Nos. 38 and 38C (Photographs Taken on 24 August 1999)

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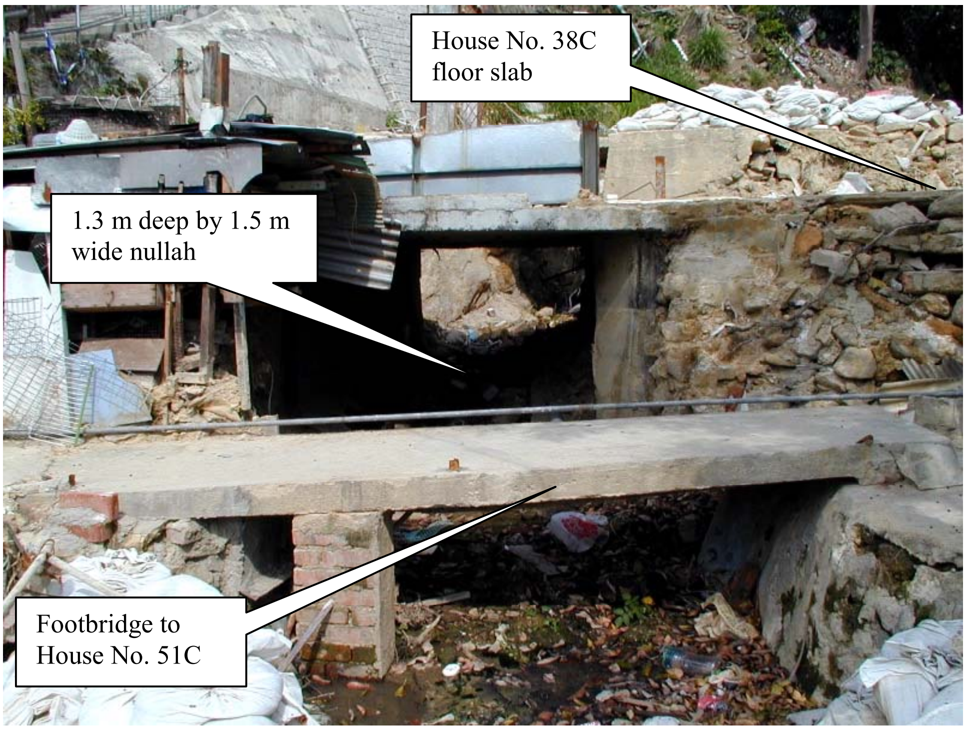
(a) View looking upstream to House No. 38C from position where the deceased was located (Photograph Taken on 24 August 1999)




(b) Nullah after clearance of House No. 38C (Photograph Taken on 8 December 1999)

Plate 9 - Nullah Downstream of House No. 38C

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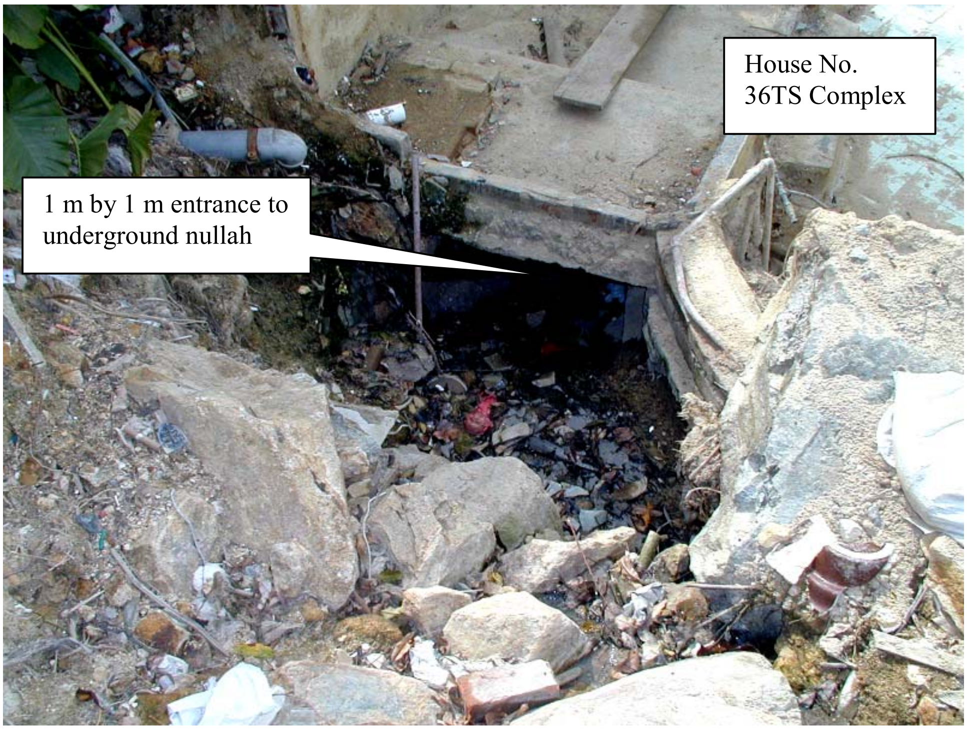
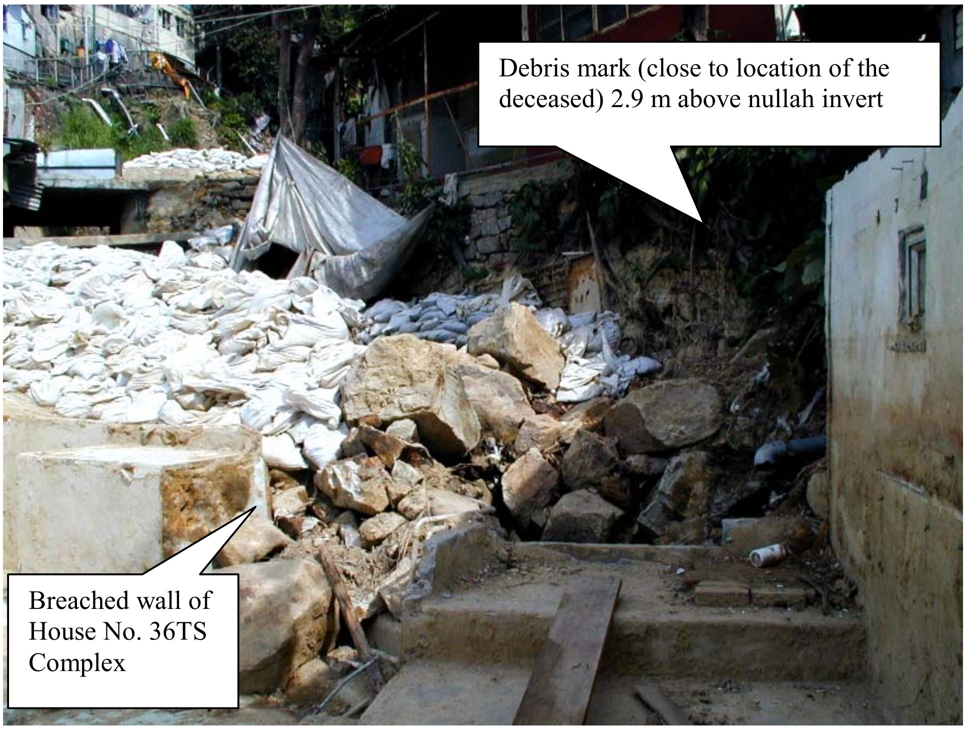



(a) Partially cleared fresh boulders at entrance to underground nullah




(b) Fresh boulders up to 0.8 m across choking nullah above House No. 36TS Complex

Plate 10 - Boulder-choked Nullah at Entrance to Underground Section at the House No. 36TS Complex (Photographs Taken on 8 December 1999)

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Plate 11 - Debris Trail from Top of 5 m High Waterfall at Chainage 45 to Top of Steep Section at Chainage 80
(Photograph Taken on 2 September 1999)



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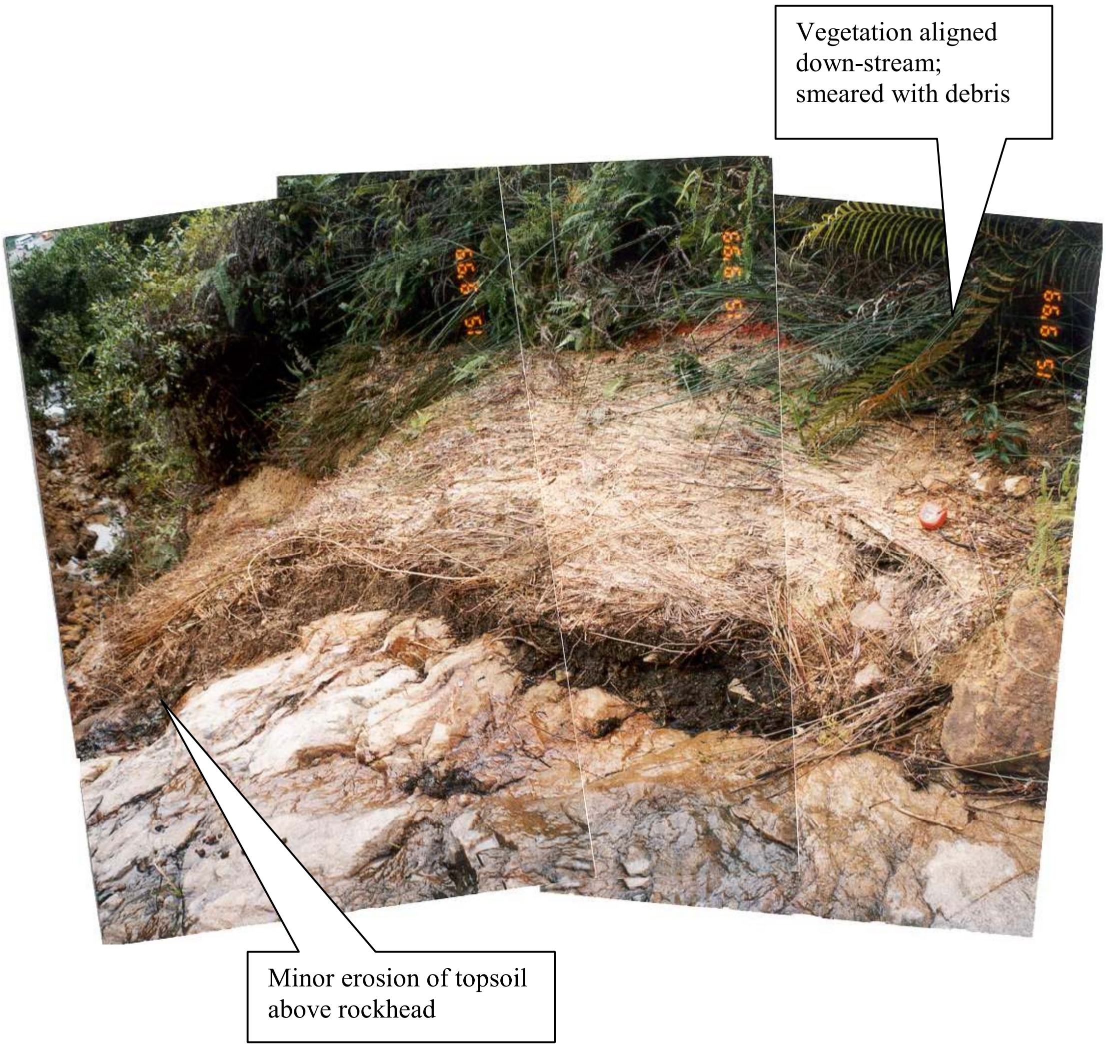


Plate 12 - Debris Trail on West Bank of Stream Course at Chainage 45
(Photograph Taken on 15 September 1999)

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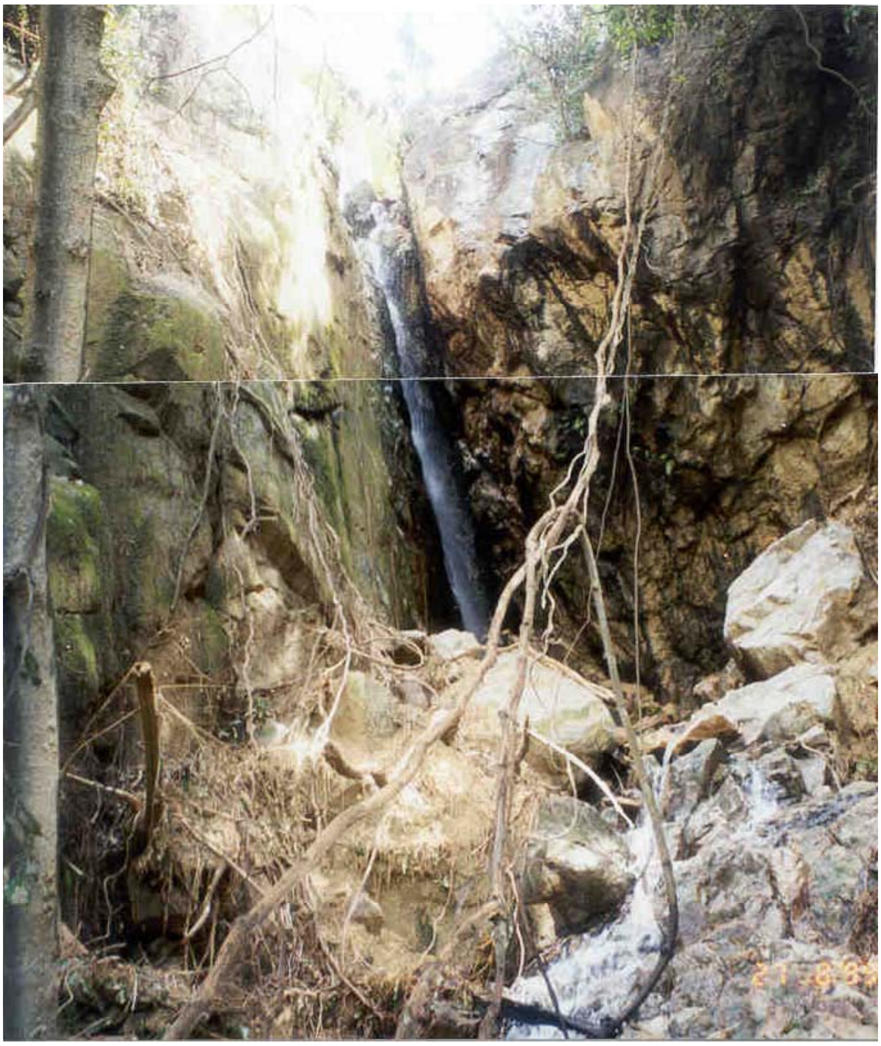

Plate13 - View of the 10 m High Waterfall at Chainage 105
(Photograph Taken on 27 August 1999)

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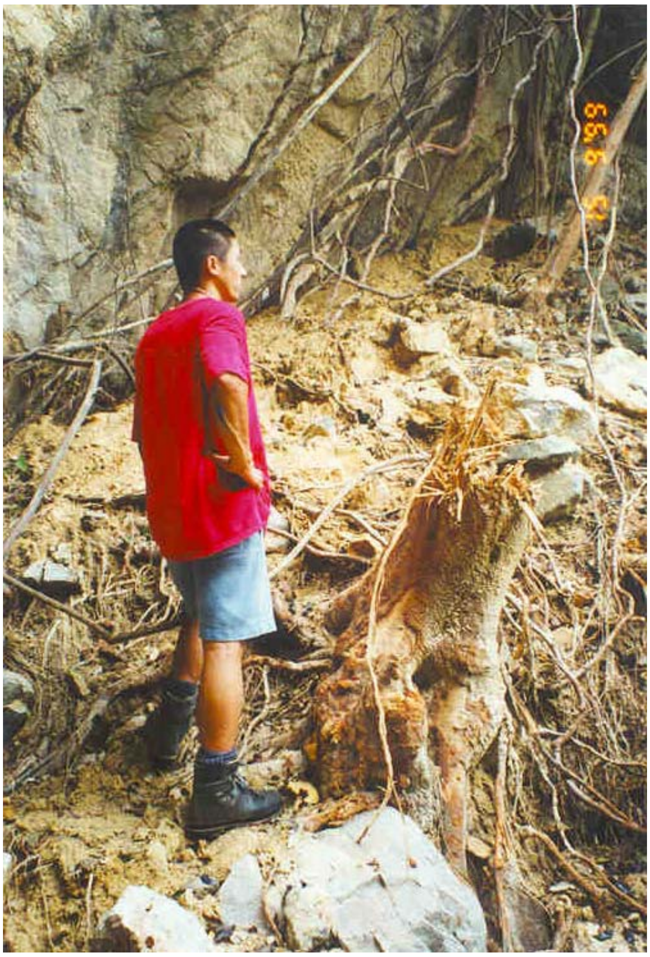


Plate14 - Severed 0.4 m Diameter Tree Stump at Foot of 10 m High Waterfall at Chainage 110 (Photograph Taken on 15 September 1999)

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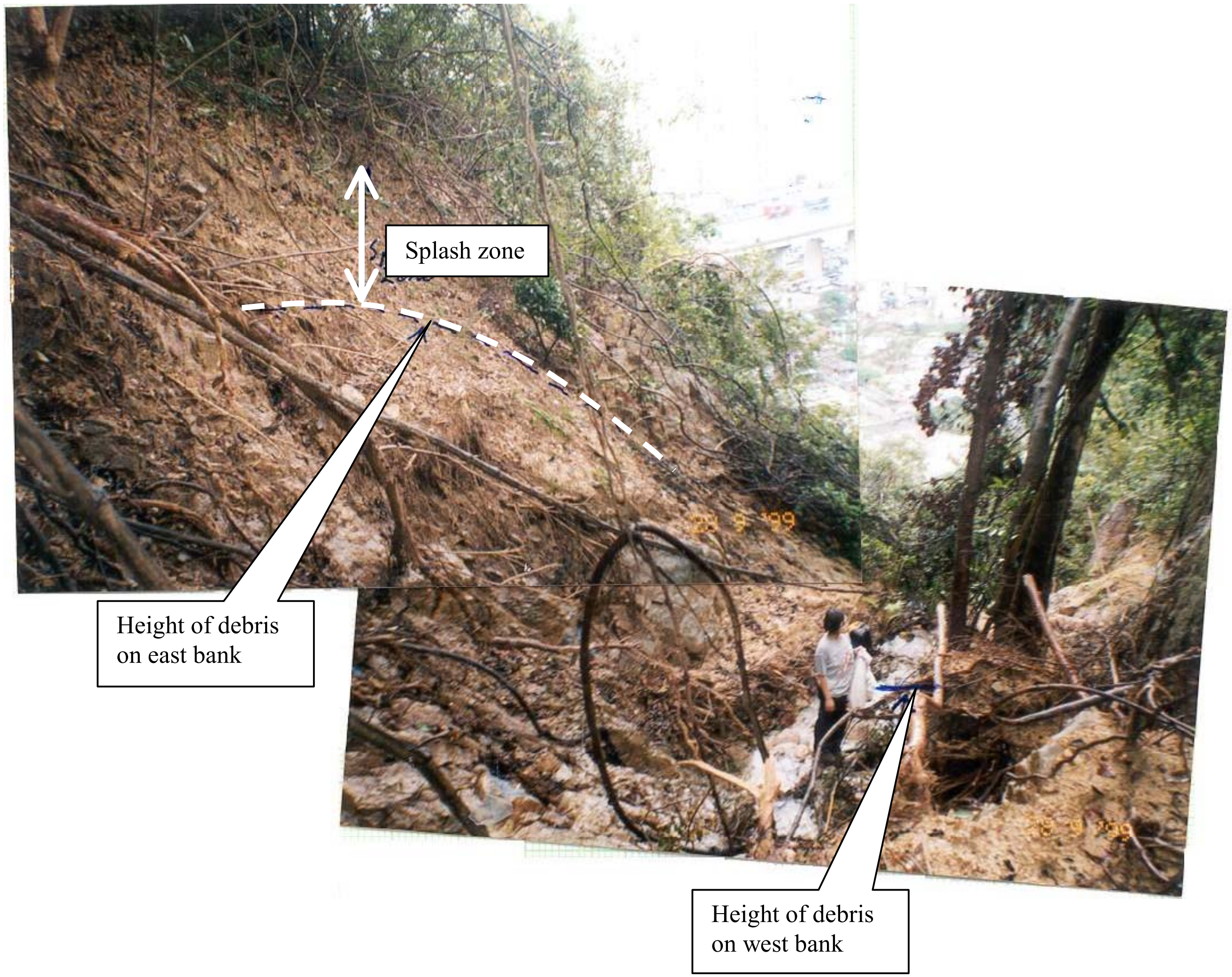


Plate 15 - Superelevation of Debris Marks at Chainage 121 Below 10 m High Waterfall (Photograph Taken on 8 September 1999)



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Plate 16 - Slurry-like Debris Inside the House No. 36TS Complex (Photographs Taken on 24 August 1999)

Plate17 - Debris at Site of the House No. 36TS Complex During Demolition of the Structures (Photograph Taken on 27 October 1999)

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Plate 18 - Fresh, Silty Debris Overlying Old Debris (Angular Cobbles) near Site of the Kitchen Structure to House No. 38 (Photograph Taken on 25 August 1999)



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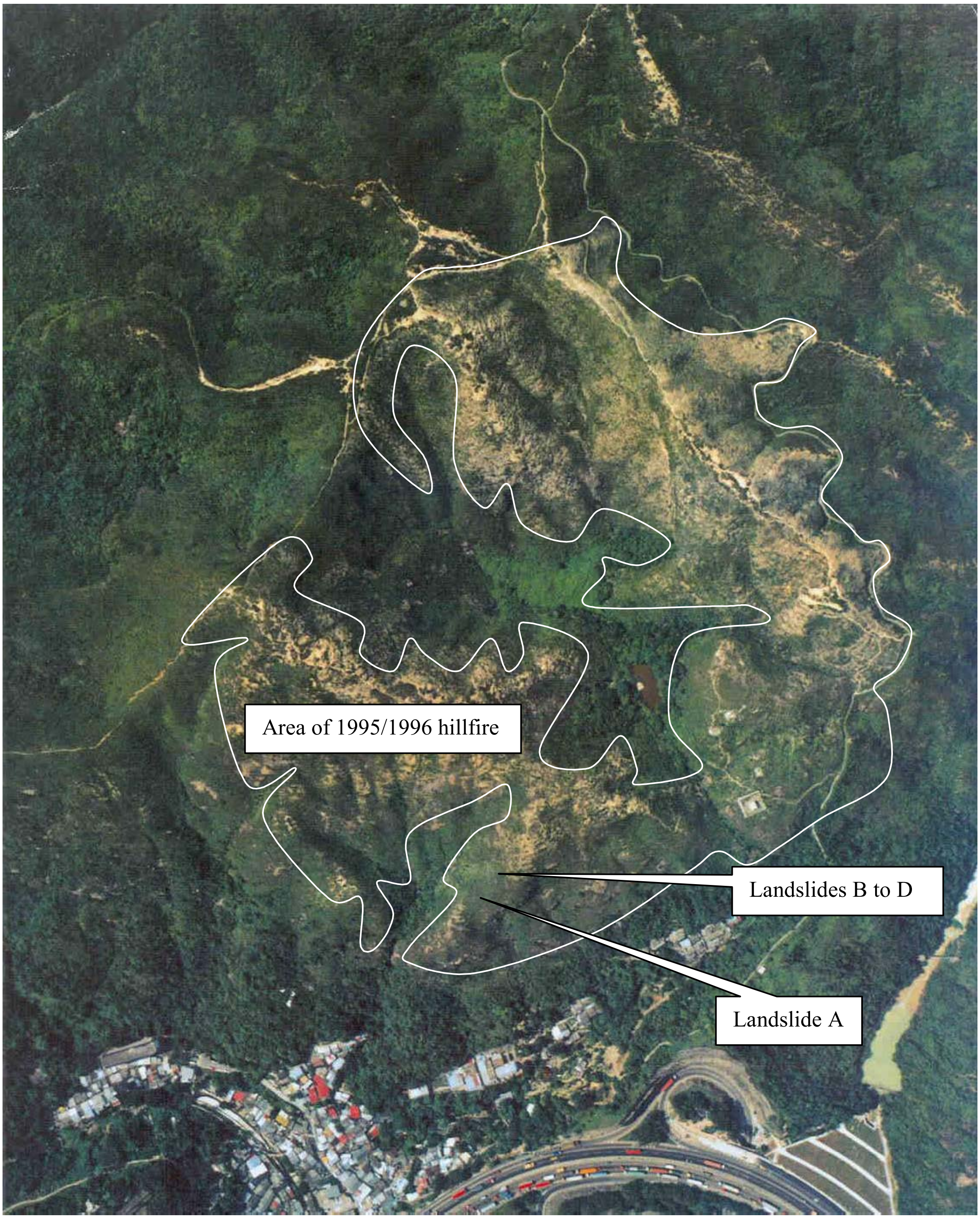


Plate19 - Aerial Photograph Showing Approximate Extent of 1995/1996 Hillfire
(Photograph Ref. No. CN14226 ; Taken on 12 June 1996)

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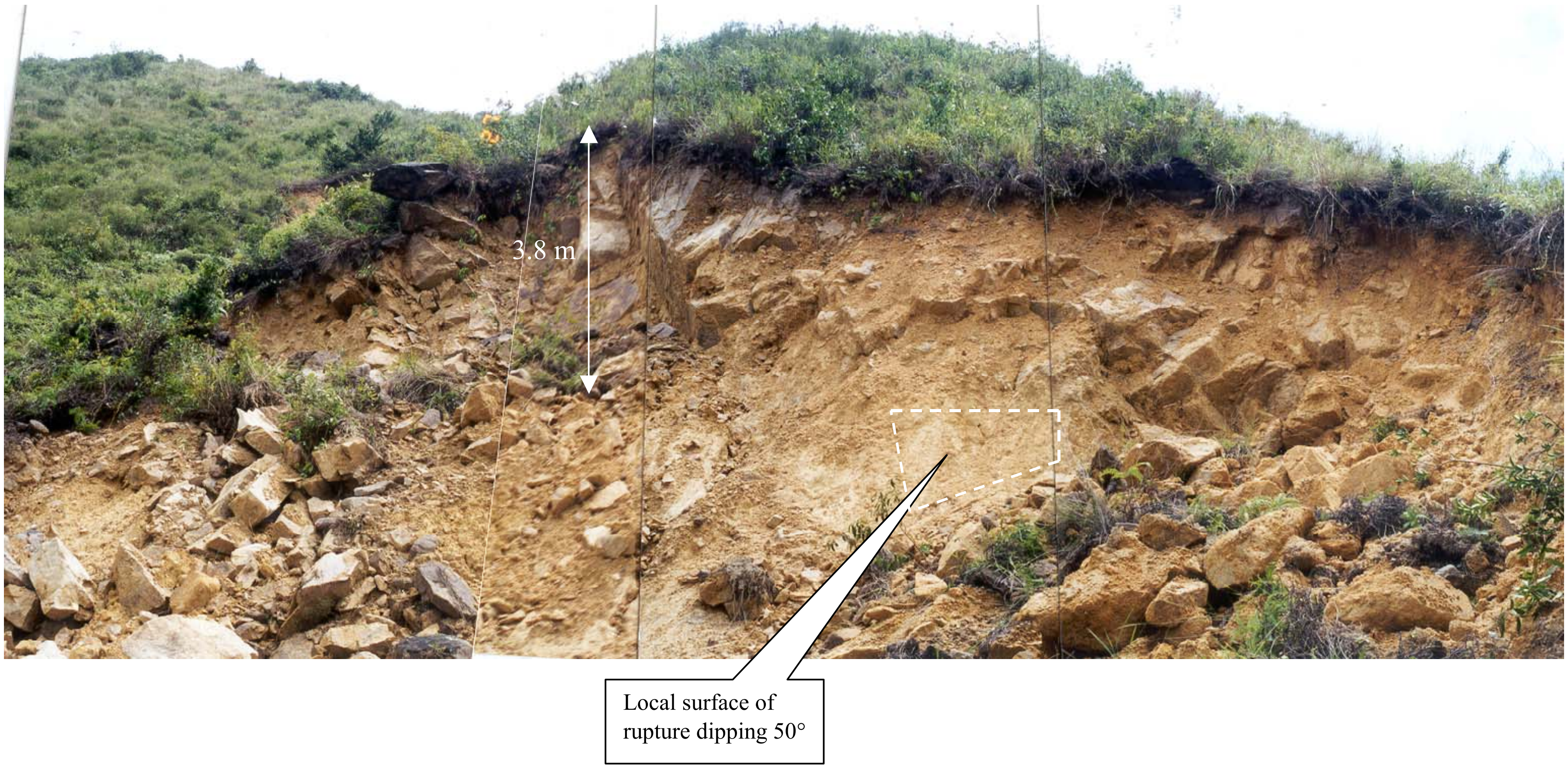


Plate 20 - View of Main Scarp of Landslide A Showing Disturbed Insitu Rock with Local Surface of Rupture in CDG in Central Portion (Photograph Taken on 27 August 1999)



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Plate 21 - Details of Adversely Orientated Open and Partially Infilled Joints in Main Scarp of Landslide A (Photograph Taken on 16 October 1999)

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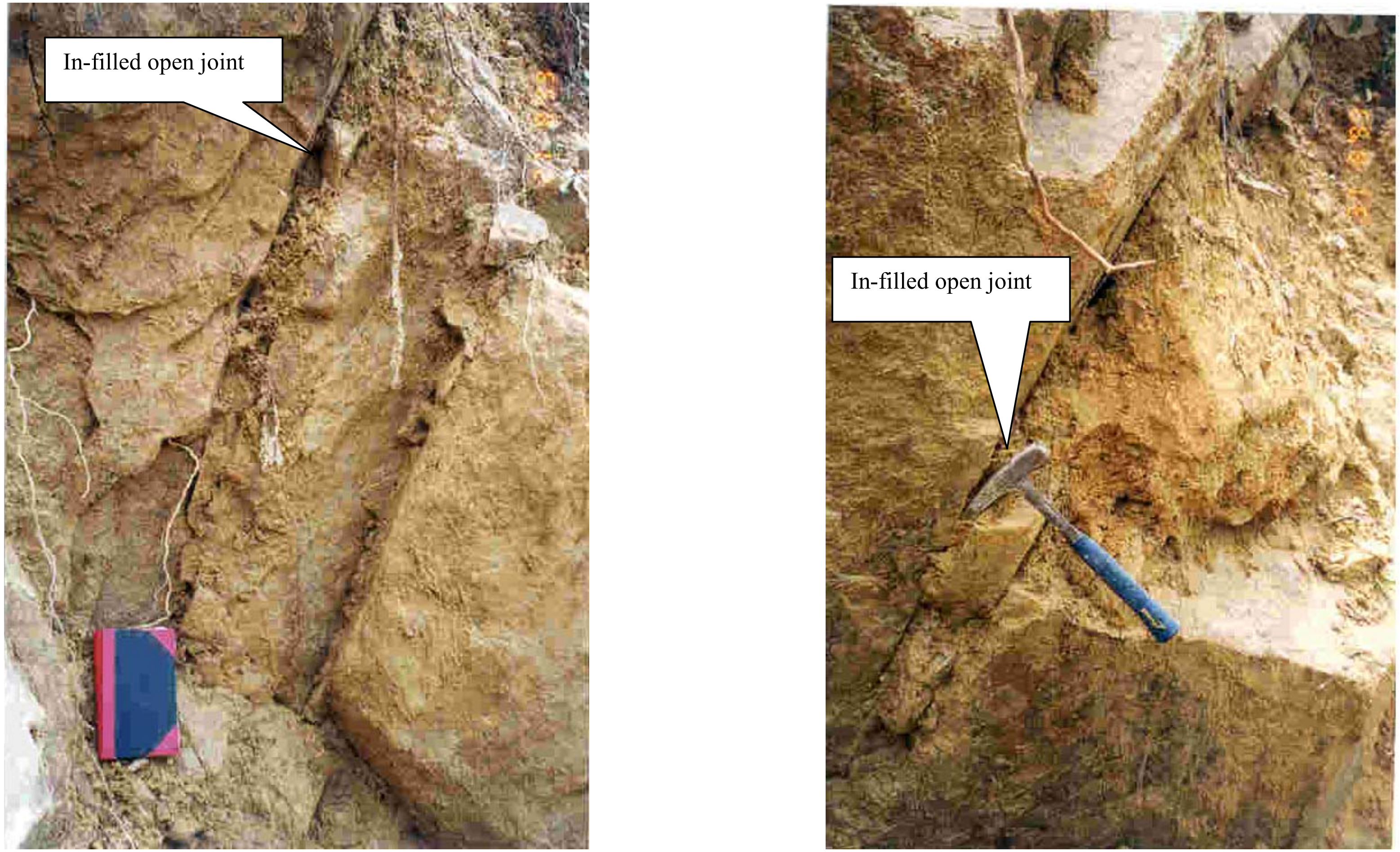


Plate 22 - Details of Open and Infilled Joints in Main Scarp of Landslide A (Photographs Taken on 31 September 1999)



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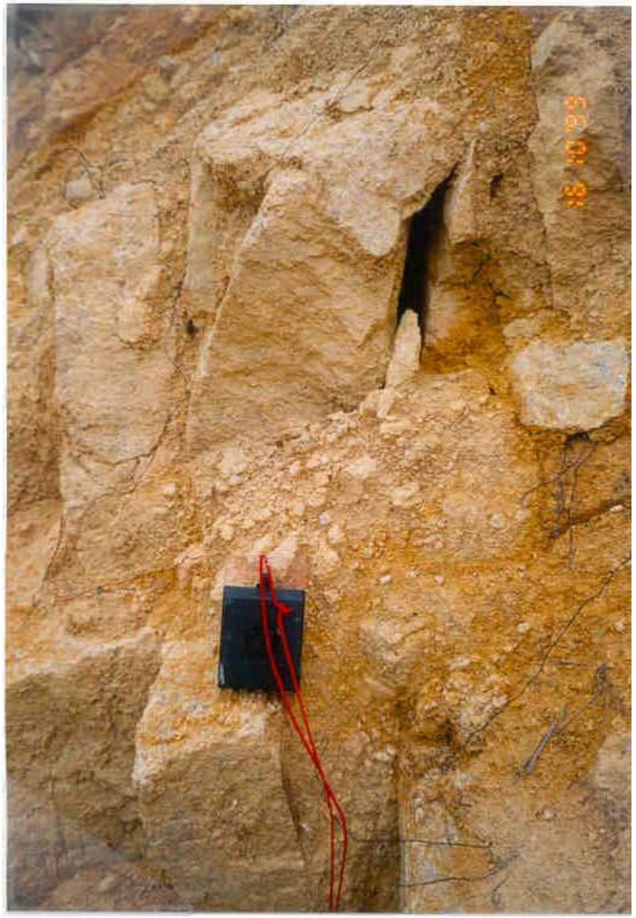

Plate 23 - Details of Open and Partially Infilled Joints in Main Scarp of Landslide A (Photographs Taken on 16 October 1999)



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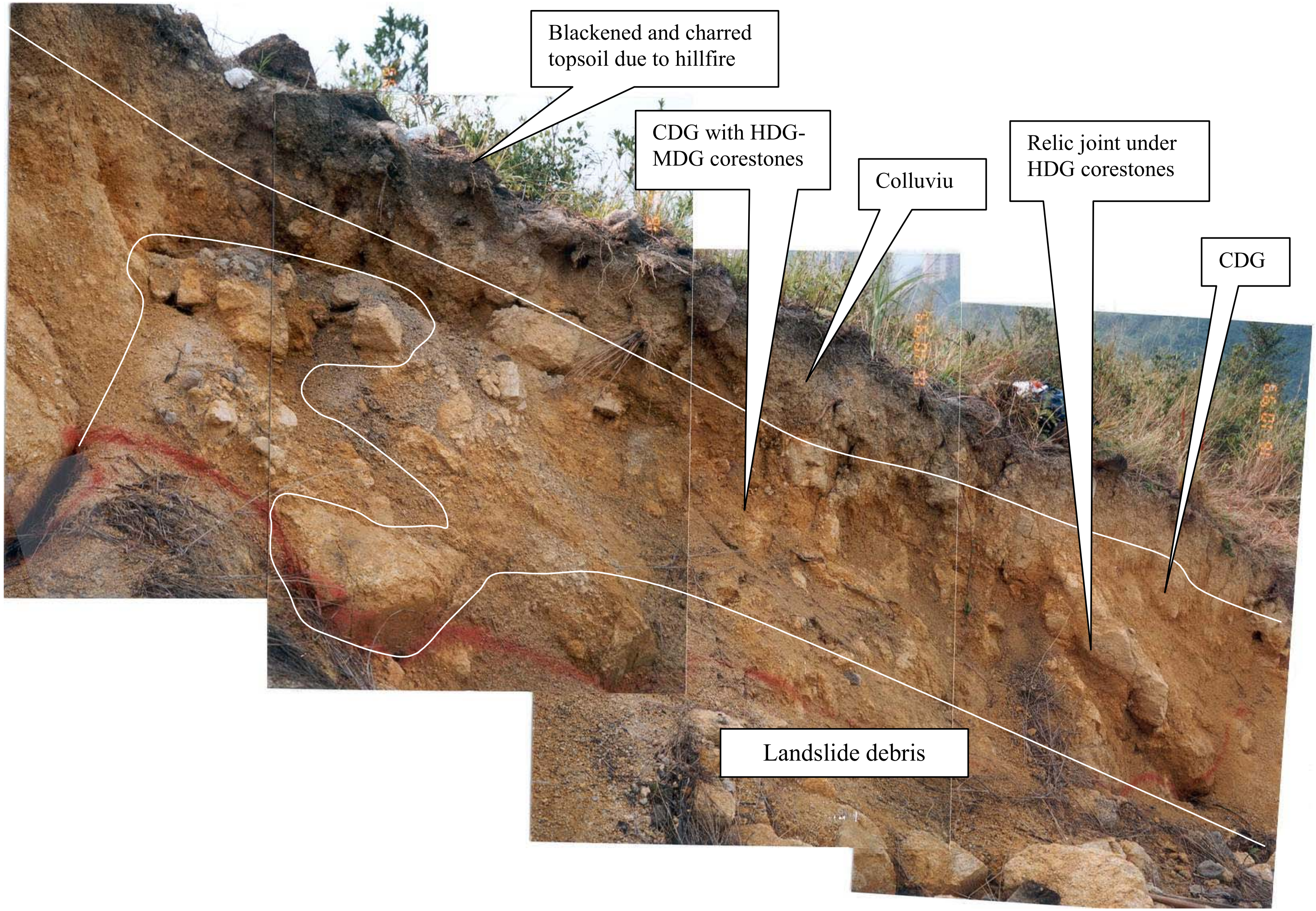


Plate 24 - Details of Upper Portion of Southern Flank of Landslide A (Photograph Taken on 16 October 1999)



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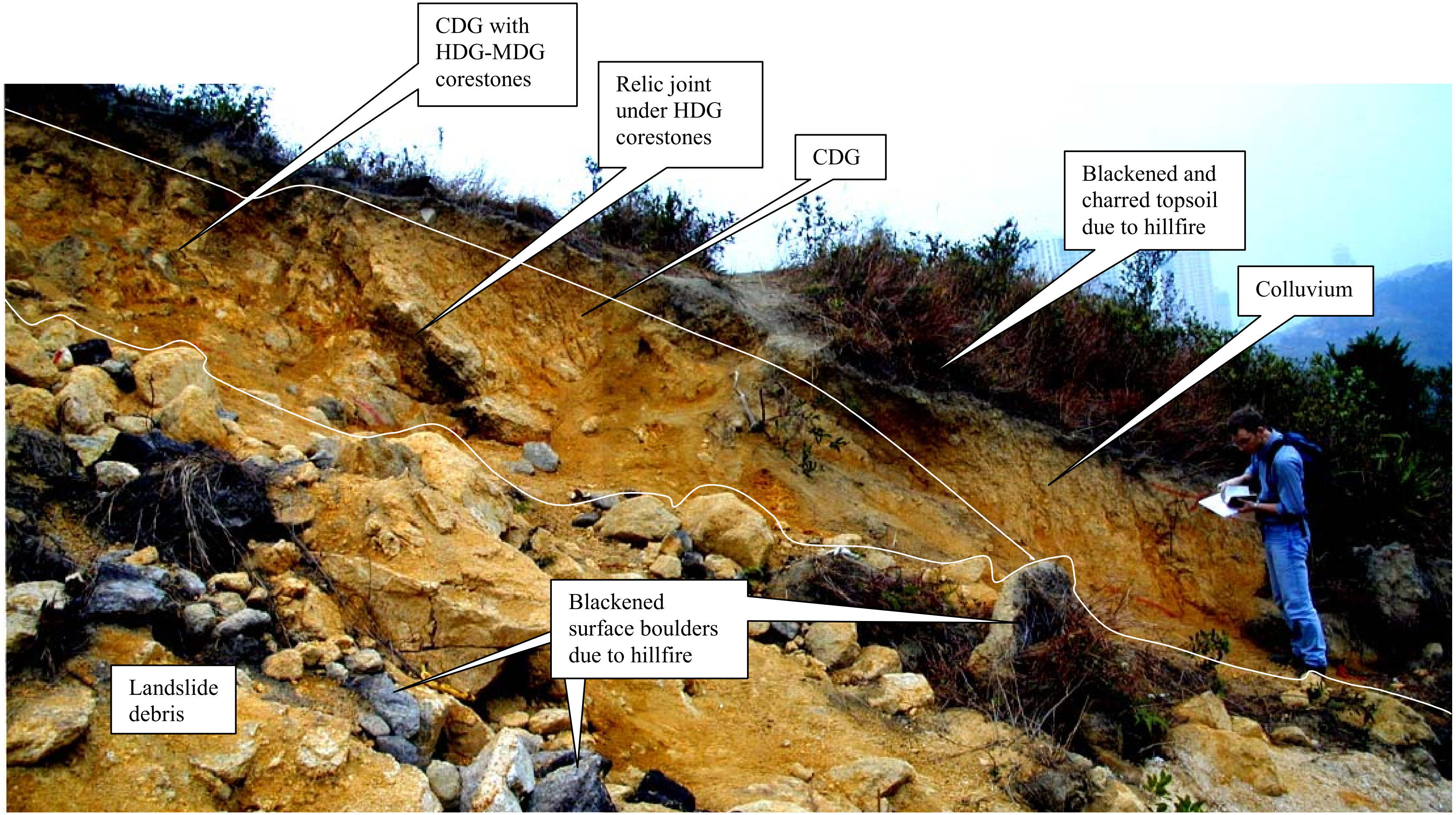


Plate 25 - Details of Upper to Middle Portion of Southern Flank of Landslide A (Photograph Taken on 16 December 1999)



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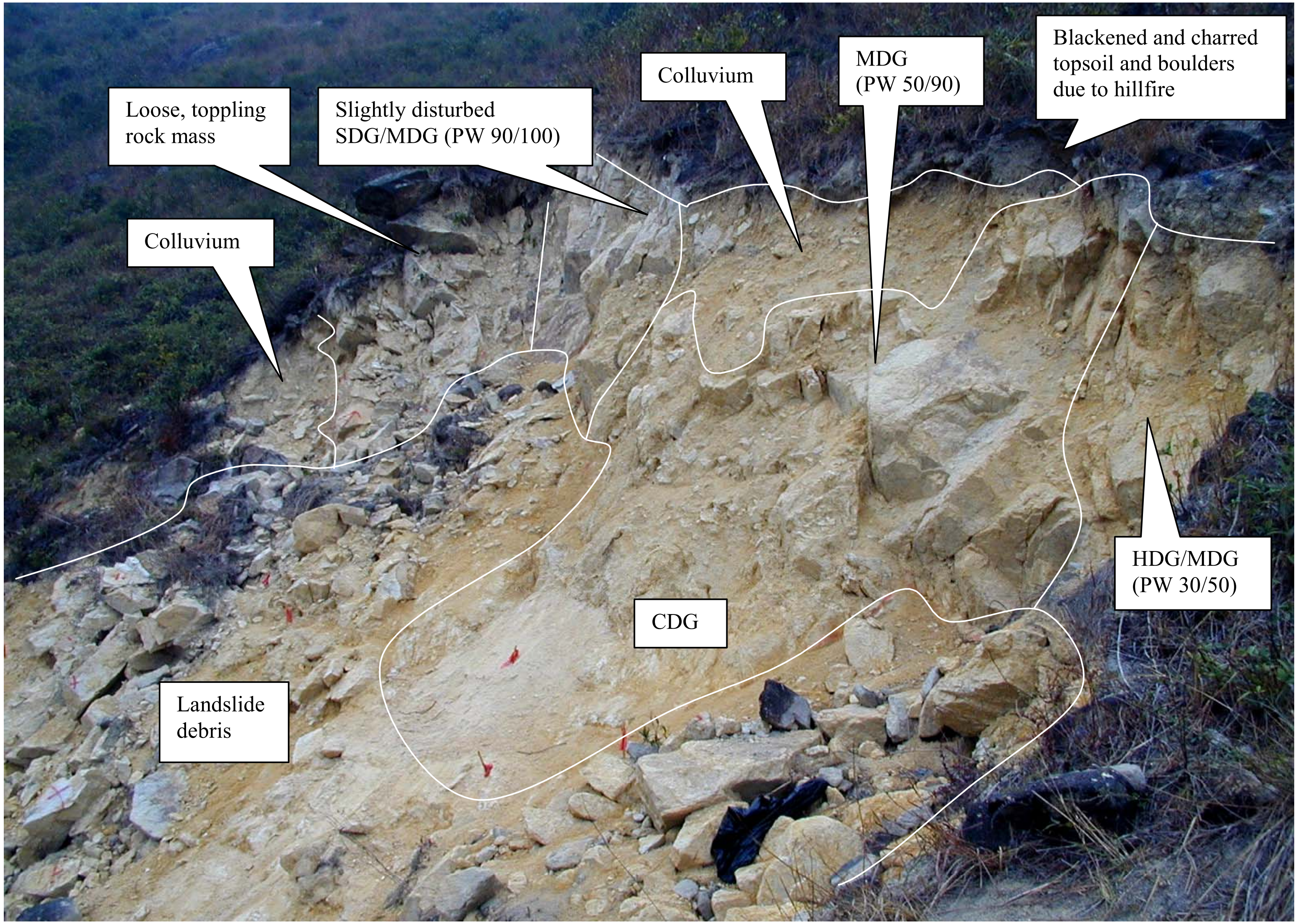


Plate 26 - Details of Main Scarp and Upper Portion of Northern Flank of Landslide A (Photograph Taken on 16 December 1999)

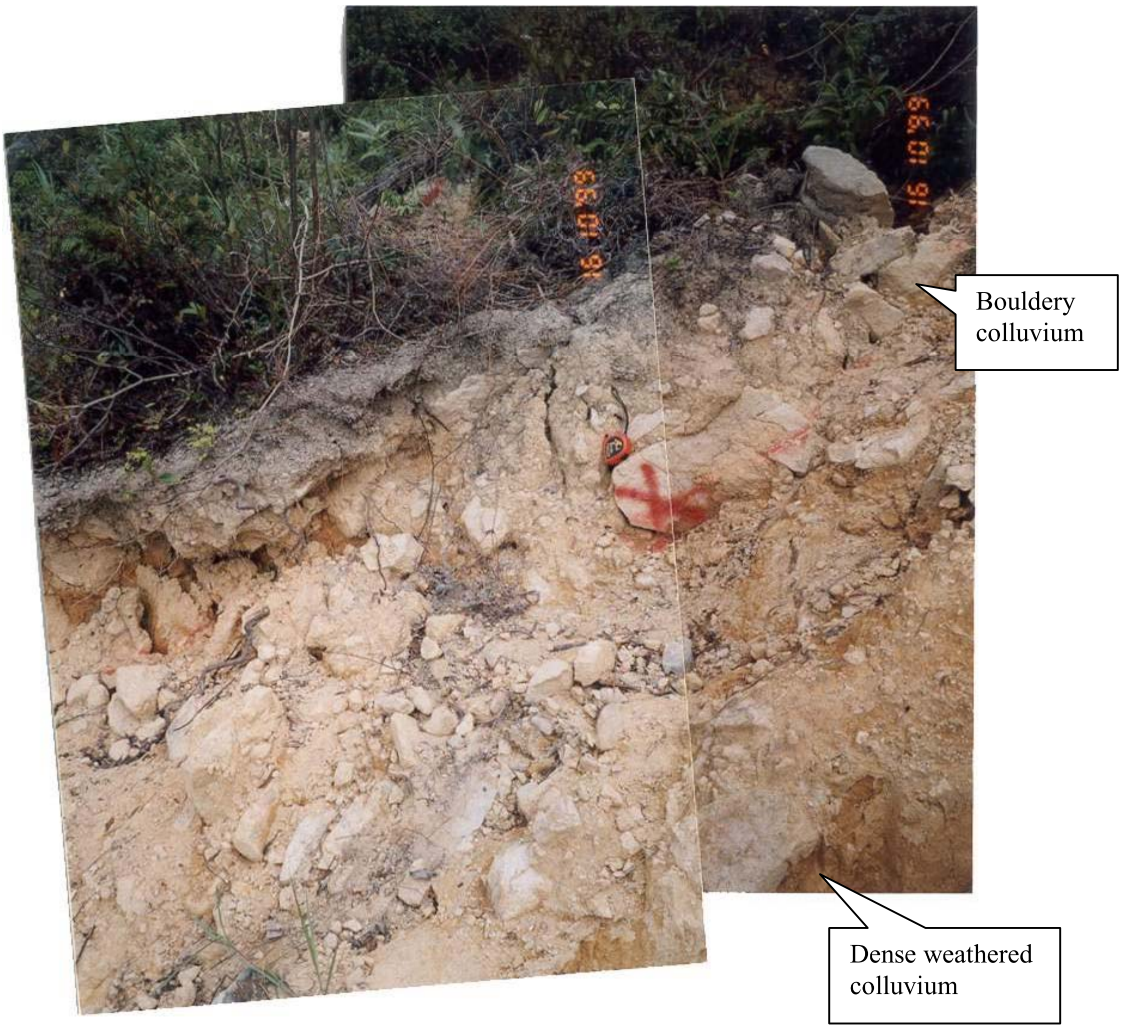


Plate 27 - Details of Surface Colluvium Overlying Dense Weathered Colluvium in Middle Portion of Northern Flank of Landslide A (Photograph Taken on 16 October 1999)

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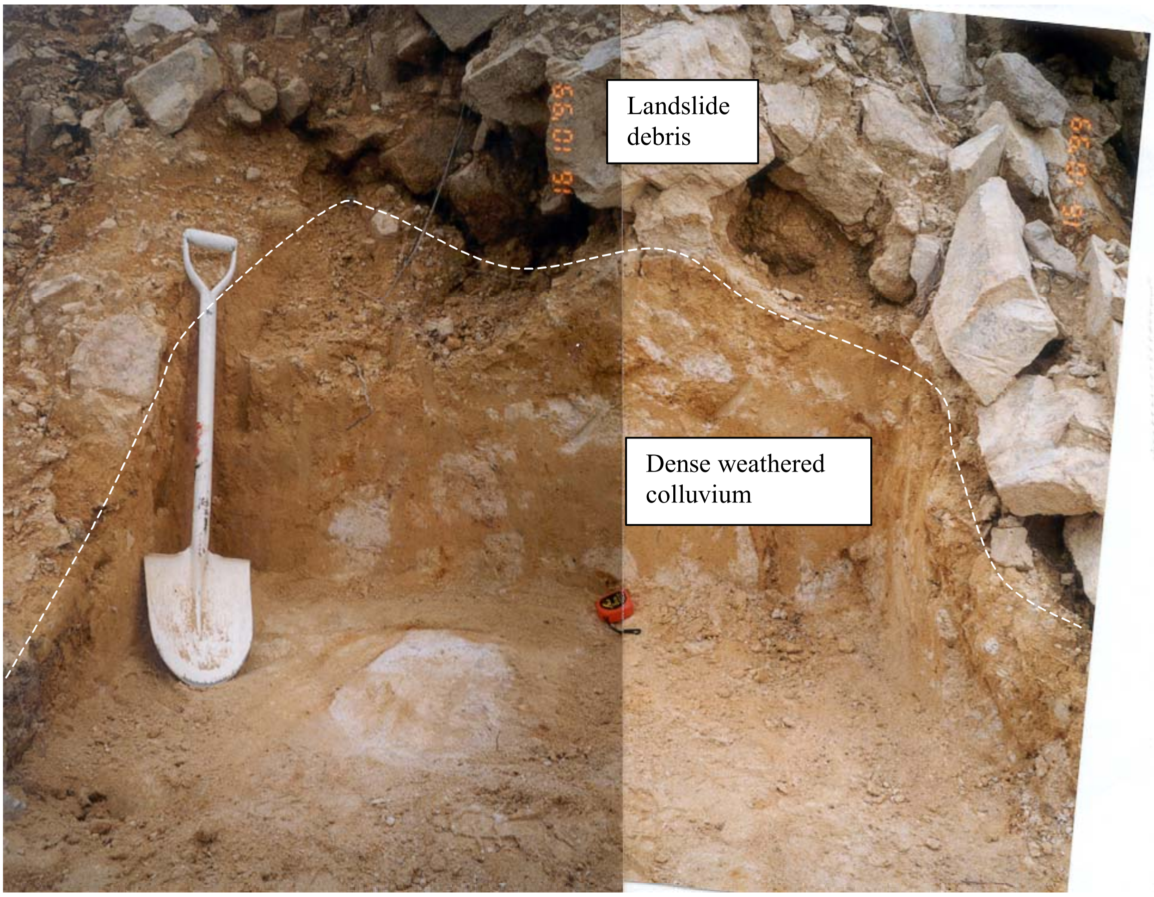


Plate 28 - Details of Landslide Debris Overlying Dense Weathered Colluvium at Location of Portable Triple-tube Sampler Hole No. PTTS 5 (Photograph Taken on 16 October 1999)

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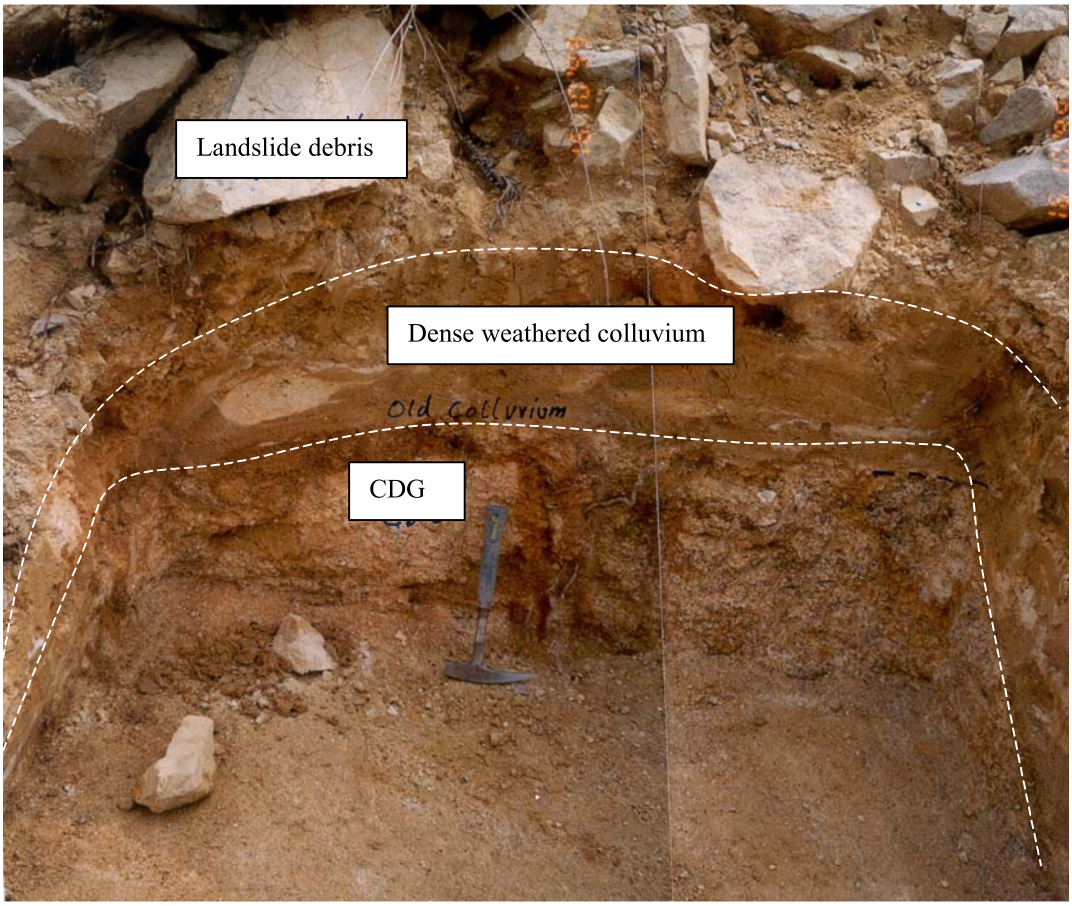


Plate 29 - Details of Landslide Debris/Dense Colluvium/CDG Sequence at Location of Portable Triple-tube Sampler Hole No. PTTS 6(A) (Photograph Taken on 16 October 1999)

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APPENDIX A

SUMMARY OF SITE DEVELOPMENT HISTORY

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CONTENTS

## A.1 INTRODUCTION

References

The development history of Sham Tseng San Tsuen Has been determined from:

(a) old survey maps,

(b) an interpretation of aerial photographs taken between 1954 and 1997, and

(c) documentary records from GEO's files.

Location of areas and features referred to in the following sections are shown in Figures A1 to A2.

A list of aerial photographs examined as part of this study is shown in Table A1.

## A.2 SITE DEVELOPMENT

The earliest available documentary record of site development is provided by a survey map dated 1945. This map shows the presence of Castle Peak Road, a reclaimed shoreline occupied by H.K. Brewery (at the location of the now demolished San Miguel Brewery) and sparse development in the Sham Tseng area. No development is indicated at Sham Tseng San Tsuen at that time.

Crown Lands and Survey Office, Map Ref. No. HIND 1009 Sheet 14, Third Edition, 1945 Revision.

Aerial photographs taken in 1954 indicate sparse development within Sham Tseng San Tsuen, with village expansion ongoing to the northern part of the village. The landslide sites are undeveloped and appear lightly vegetated.

Aerial Photos Nos. Y2726-7 (29,200 ft)

A structure is indicated at the approximate location of House No. 38 in the 1956 aerial photographs with the stream course trained to the west of the structure.

Aerial Photos Nos. Y3516-7 (16,700 ft)

The 1956 aerial photographs indicate that the northern part of Sham Tseng San Tsuen, extending southwards from the kitchen structure of House No. 38 to the approximate location of House No. 31, is constructed on a debris fan that is described on published geological maps as being colluvial in origin (Figure 11).

Yuen Long, Sheet No. 6 HGM20 Series. Solid and Superficial Geology, Hong Kong Geological Survey, 1988

The earliest aerial photographs that clearly show House No. 38 and the kitchen structure were taken in 1963. Houses Nos. 38C, 50A and 51C are present by 1963. Most of the other structures in Sham Tseng San Tsuen had been constructed by the time the 1972 aerial photographs were taken.

Aerial Photos Nos. Y8945-6 (3,900 ft)

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## A.3 PREVIOUS ASSESSMENTS

### A.3.1 Non-Development Clearance Programme

In accordance with Government's policy of offering rehousing to occupants of squatter structures who are in immediate and obvious danger or those especially vulnerable to landslide risk, studies have been carried out by the GEO (previously known as Geotechnical Control Office, GCO before 1991) to identify squatter areas and specific squatter structures needing clearance under the Non-Development Clearance (NDC) Programme since the mid-1980's. The studies include terrain classification mapping, aerial photograph interpretation (API) and reference to records of landslide casualties, to identify areas of potential landslide hazard. Huts that warrant clearance are identified following field inspections by the GEO working to a Method Statement. Recommendations by GEO for squatter clearance on slope safety grounds and the rehousing of squatter occupants on Government land are implemented by the Lands Department and the Housing Development (HD).

GCO Instruction No. 2/89 Non Development Clearance and Restoration Works in Squatter Areas which advocates the use of the Method Statement entitled "Squatter Clearance Studies for Tung Yeung, Tse Mei, Fuk Tak New and Ling Nam New (Upper) Villages"

Recommendations for clearance are generally made based on the criteria given in a Method Statement prepared by GEO. One of the criteria for clearance referred to in the Method Statement used at the time of the NDC inspections at Sham Tseng San Tsuen between 1988 and 1992, refers to "Huts supported by flimsy wooden frame on main watercourse".

Method Statement of the Squatter Clearance Studies for Tung Yeung, Tse Mei, Fuk Tak New and Ling Nam New (Upper) Villages

The above criteria were elaborated in a revised Method Statement promulgated since June 1993. According to this Method Statement, for domestic structures and associated structures (e.g. kitchens, corridors, annexes and toilets), NDC recommendations are necessary for a number of criteria, including "Huts supported by flimsy wooden frame over or adjacent to a water course, or huts over or adjacent to a water course which may become dangerous during periods of heavy rainfall due to, undermining of foundations, landslip debris and or flooding". The Method Statement further states that "In general ……. the more substantial structures (i.e. brick and concrete) should not be recommended for clearance, unless there is concern that in the event of a landslide or boulder fall, damage to the structure would be life threatening".

GEO Circular No. 4/93 Non Development Clearance and Restoration Works in Squatter Areas, dated June 1993

In April 1988, the GEO carried out an inspection of Sham Tseng San Tsuen under the NDC Programme. Clearance recommendations on slopes safety grounds were subsequently given by the GEO the HD (Figure A1). Houses Nos. 38C and 38 together with the kitchen structure of House No. 38, which were located within the NDC inspection boundaries, had not been recommended for clearance at that time.

Internal GEO memo dated 21/6/1988 and memo from GEO to HD dated 12/7/1988: GEO file ref. no. GCMW 4/13/11 sf 39

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In May 1992, the GEO undertook to re-inspect all of the previously inspected New Territories squatter villages under the NDC Programme. Site inspection at Sham Tseng San Tseun were carried out between 1 December and 11 December 1992, under the 1992/93 NDC Re-inspection Programme. The western-most part of the House No. 38C (reference no. TW4/93/A/62) was recommended for clearance because it was considered to be a "flimsy structure on watercourse" (Figure A2). House No. 38 and its kitchen structure were not recommended for clearance. The NDC recommendation was passed to the HD on 16 December 1992. The concerned part of House No. 38C had not been cleared when the 23 August 1999 debris flow incident occurred.

GEO Report No. AR 1/93 dated August 1993; Re-inspection of Squatter Villages in the New Territories: July 1992 to June 1993 Executive Summary

Memo from GEO to HD and Buildings & Lands Department dated 16/12/1992; GEO file ref. no. GCMW 4/13/11 sf 39

A.3.2 Aerial Photograph Interpretation Studies

Two aerial photograph interpretation (API) studies discussing the geomorphology and terrain stability of the hillside above Sham Tseng San Tsuen, Sham Tseng Commercial New Village and Sham Tseng Tung Tsuen were carried out in connection with the NDC inspection programme for the squatter villages in the Sham Tseng area.

The first API, carried out in May 1988, relates to Sham Tseng San Tsuen, Sham Tseng Kau Tsuen and Sham Tseng Commercial New Village. The report noted that many of the squatter dwellings in the villages are located on an alluvial/colluvial terrace on the valley floor and that "the valley slopes above the area are dissected by numerous drainage lines". It stated that the "terrain at the heads of these drainage lines has been oversteepened by erosion and therefore presents a potential source of slope instability." It also noted that "During periods of intense rainfall, run-off and water-borne debris could create problems below these slopes". The report further stated that "these low-lying areas are exposed to a flood risk" and that the "ridge-tops and upper hill-slopes overlooking the area appear to be susceptible to erosion".

API Report on Squatter Area Improvements - Non Development Clearance, Sham Tseng Village. (GCO file ref. no. GCP 1/4/250 II - memo dated 9/5/1988)

The other API, carried out in 1989, relates to Sham Tseng Tung Tsuen, some 120 m to the east of Sham Tseng San Tsuen. The report noted that "The high slopes on the northern side of the villages exhibit previous instability, mainly oversteepened terrain associated with drainage lines", and that three debris trails emanating from shallow landslide on the natural hillsides which "followed generally the natural drainage lines", can be identified in the 1982 aerial photographs.

API Report on Squatter Area Improvements - Non Development Clearance, Sham Tseng Village. (GCO file ref. no. GCP 1/4/250 II - memo dated 17/2/1989)

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Table A1 - Aerial Photographs Examined (Sheet 1 of 2)

| Date | Altitude (ft) | Photograph Number |
|---|---|---|
| 18 November 1954 | 29,200 | Y2726 & 27 |
| 28 December 1956 | 16,700 | Y3516 & 17 |
| 26 October 1961 | 30,000 | Y5043 & 44 |
| 31 January 1963 | 3,900 | Y8910 & 12 |
| 24 February 1963 | 3,900 | Y8945 & 46 |
| 20 December 1963 | 1,800 | Y11426 & 29 |
| 22 December 1963 | 1,800 | Y11441 & 42 |
| 13 December 1964 | 12,500 | Y12966 & 67 |
| 1969 | Not Known | Y15359 & 61 |
| 1972 | Low level, altitude not stated | 1606 & 08 |
| 1 November 1973 | 1,700 | 5731 & 34 |
| 20 December 1973 | 12,500 | 7968 & 69 |
| 21 November 1974 | 12,500 | 9818 & 19 |
| 19 December 1975 | 12,500 | 11796 & 97 |
| 29 January 1976 | 4,000 | 13206 & 09 |
| 16 August 1976 | 2,000 | 14612 & 13 |
| 4 November 1976 | 12,500 | 15995 & 96 |
| 23 November 1976 | 12,500 | 16556 & 57 |
| 5 December 1977 | 4,000 | 19624 & 26 |
| 10 January 1978 | 12,500 | 20733 & 34 |
| 7 December 1978 | 4,000 | 24042 |
| 26 January 1979 | 4,000 | 26323 |
| 28 November 1979 | 10,000 | 28111 & 12 |
| 29 November 1979 | 10,000 | 28172 & 73 |
| 19 January 1981 | 4,000 | 36284 & 86 |
| 26 October 1981 | 10,000 | 39109 & 10 |
| 27 November 1981 | 4,000 | 40101 & 02 |
| 10 October 1982 | 10,000 | 44556 & 57 |
| 1 December 1982 | 2,500 | 46047 & 49 |
| 24 January 1983 | 20,000 | 47106 & 07 |
| 25 January 1983 | 4,000 | 47321 & 22 |
| 22 December 1983 | 10,000 | 52154 & 55 |
| 3 October 1984 | 4,000 | 56249 |
| 1 October 1985 | 10,000 | 67207 & 08 |
| 2 October 1985 | 4,000 | 67632 & 33 |
| 4 October 1985 | 15,000 | 2694 & 95 |
| 24 September 1986 | 5,000 | A6631 & 32 (infra-red) |
| 21 December 1986 | 10,000 | A8124 & 25 |
| 5 January 1987 | 20,000 | A8424 & 25 |
| 4 June 1988 | 10,000 | A13756 &57 |
| 10 October 1988 | 4,000 | 70301 & 03 |
| 9 September 1989 | 4,000 | A18354 |
| 29 November 1989 | 10,000 | A19656 & 57 |
| 30 November 1989 | 10,000 | A19866 & 67 |

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Table A1 - Aerial Photographs Examined (Sheet 2 of 2)

| Date | Altitude (ft) | Photograph Number |
|---|---|---|
| 21 March 1990 | 4,000 | A20974 & 76 |
| 21 March 1990 | 4,000 | A20987 & 89 |
| 13 November 1990 | 4,000 | A23550 & 52 |
| 26 November 1990 | 4,000 | A24965 & 66 |
| 4 December 1990 | 20,000 | A24503 & 04 |
| 1 October 1991 | 4,000 | A27576 & 77 |
| 29 October 1991 | 10,000 | A28805 & 06 |
| 13 December 1991 | 20,000 | A29634 & 35 |
| 13 May 1992 | 4,000 | A31208 |
| 14 October 1992 | 8,000 | A32350 & 51 |
| 20 October 1992 | 4,000 | A32670 & 71 |
| 11 November 1992 | 10,000 | A33250 & 51 |
| 17 December 1992 | 20,000 | A33629 & 30 |
| 9 July 1993 | 4,000 | A35349 & 51 |
| 4 October 1993 | 20,000 | CN4421 & 22* |
| 8 October 1993 | 5,000 | CN4789 & 90* |
| 2 November 1993 | 4,000 | A36007 & 08 |
| 6 May 1994 | 5,000 | A38175 & 77 |
| 21 October 1994 | 10,000 | A39476 & 77 |
| 25 October 1994 | 20,000 | CN8245 & 46* |
| 12 February 1995 | 10,000 | CN9553 & 54* |
| 23 November 1995 | 10,000 | CN12325 & 26* |
| 21 December 1995 | 20,000 | CN13226 & 27* |
| 12 June 1996 | 4,000 | CN14226 & 27* |
| 26 November 1996 | 4,000 | A44139 & 40 |
| 27 December 1996 | 10,000 | CN16405 & 06* |
| 29 January 1997 | 20,000 | CN16574 & 75* |
| 20 June 1997 | 2,500 | A45130 & 31 |
| 1 November 1997 | 10,000 | CN19064 & 65* |

Note: All aerial photographs are in black and white except those denoted with *

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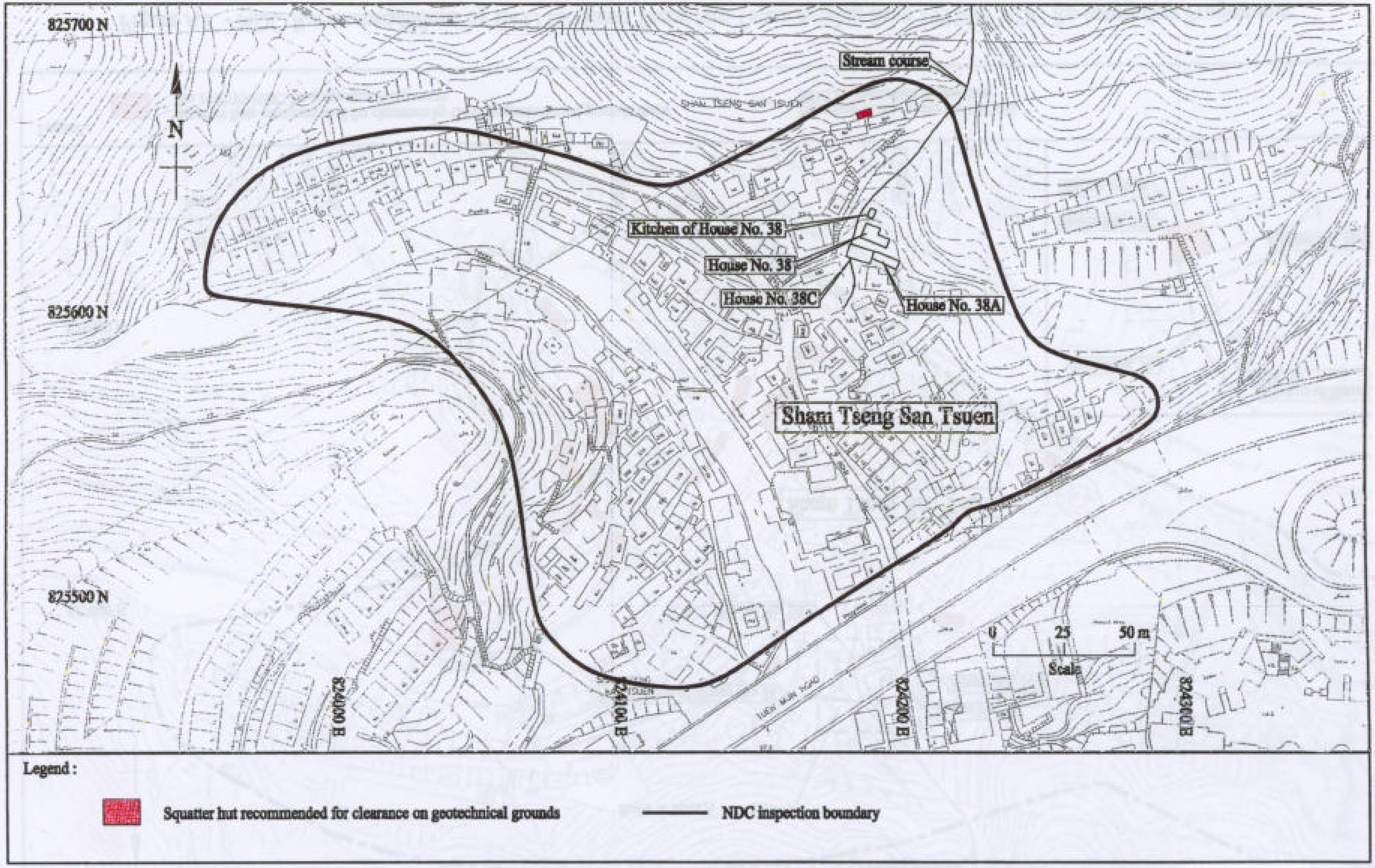


Figure A1 - Recommendations for Squatter Clearance Made by GEO Following NDC Inspections in 1988



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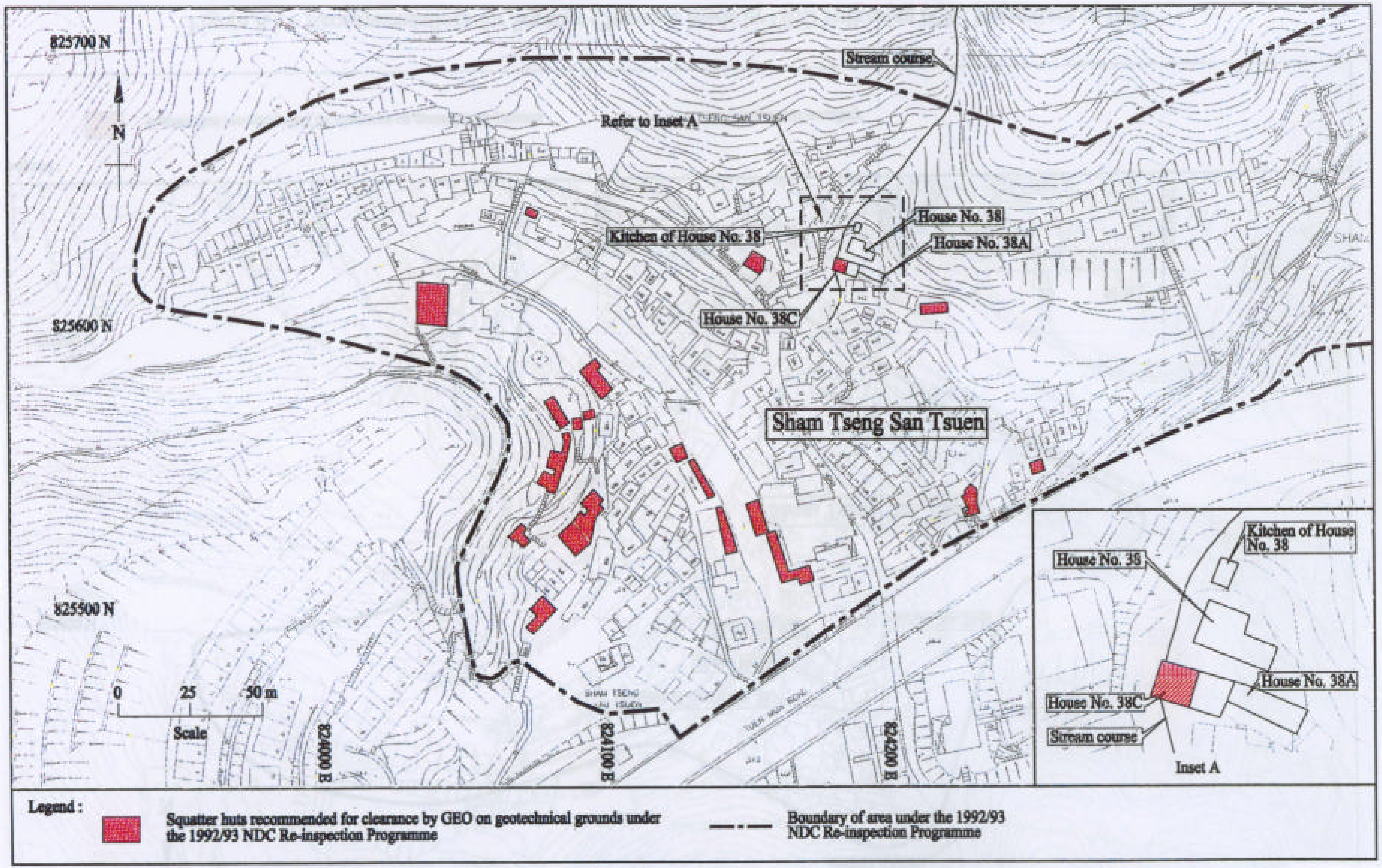


Figure A2 - NDC Recommendations by GEO for Sham Tseng San Tsuen Arising from 1992/93 NDC Re-inspection Programme



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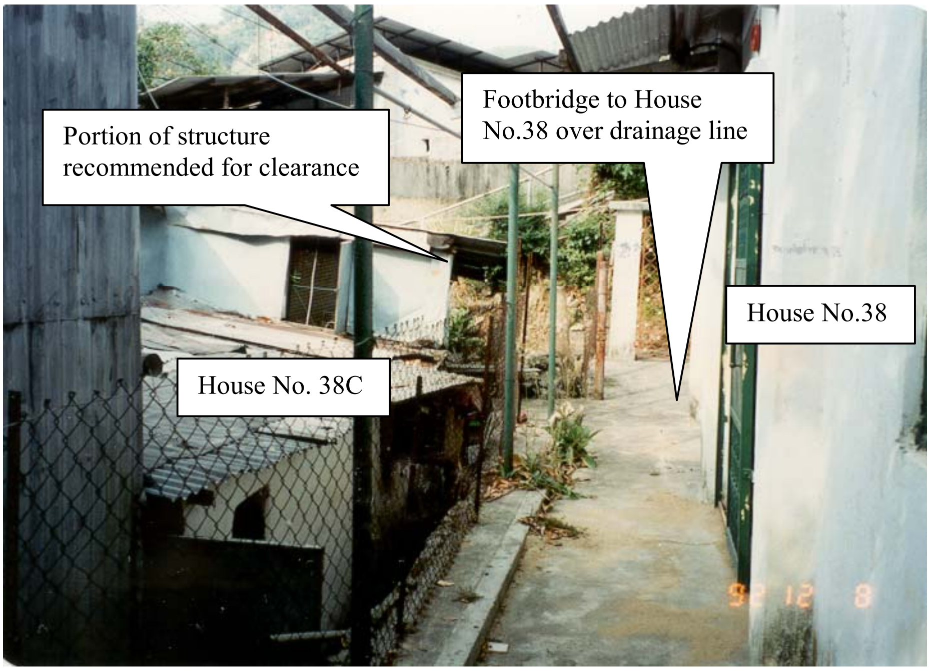



Plate A1 - Portion of Structure Recommended for Clearance at House No.38C, Sham Tseng San Tsuen (Photographs Taken during NDC Re-inspection on 8 December 1992)

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# GEO PUBLICATIONS AND ORDERING INFORMATION
# 土力工程處刊物及訂購資料

A selected list of major GEO publications is given in the next page. An up-to-date full list of GEO publications can be found at the CEDD Website http://www.cedd.gov.hk on the Internet under "Publications". Abstracts for the documents can also be found at the same website. Technical Guidance Notes are published on the CEDD Website from time to time to provide updates to GEO publications prior to their next revision.

部份土力工程處的主要刊物目錄刊載於下頁。而詳盡及最新的土力工程處刊物目錄，則登載於土木工程拓展署的互聯網網頁http://www.cedd.gov.hk 的"刊物"版面之內。刊物的摘要及更新刊物內容的工程技術指引，亦可在這個網址找到。

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## MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
## 土力工程處之主要刊物

### GEOTECHNICAL MANUALS

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

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

### GEOGUIDES

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

### GEOSPECS

| | |
|---|---|
| Geospec 1 | Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997). |
| Geospec 2 | Model Specification for Reinforced Fill Structures (1989), 135 p. (Reprinted, 1997). |
| Geospec 3 | Model Specification for Soil Testing (2001), 340 p. |

### GEO PUBLICATIONS

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|---|---|
| GCO Publication No. 1/90 | Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002). |
| GEO Publication No. 1/93 | Review of Granular and Geotextile Filters (1993), 141 p. |
| GEO Publication No. 1/96 | Pile Design and Construction (1996), 348 p. (Reprinted, 2003). |
| GEO Publication No. 1/2000 | Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 p. |

### GEOLOGICAL PUBLICATIONS

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

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

### TECHNICAL GUIDANCE NOTES

| | |
|---|---|
| TGN 1 | Technical Guidance Documents |