SECTION 2 :
DETAILED STUDY OF THE LANDSLIDE BEHIND 7C BOWEN ROAD ON 11 JUNE 1998

Fugro Scott Wilson Joint Venture

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FOREWORD

This report presents the findings of a detailed study of a landslide (GEO Incident No. HK 98/6/8) which occurred on the heavily vegetated hillside above 7C Bowen Road, Hong Kong in the morning of 11 June 1998. The landslide debris came to rest on the rear yard of the residential building of 7C Bowen Road. No one was injured in the landslide.

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

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

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1. INTRODUCTION

At about 9:40 a.m. on 11 June 1998, a landslide occurred on the heavily-vegetated hillside above 7C Bowen Road, Hong Kong (Figure 1 and Plate 1). The landslide debris travelled down the hillside and came to rest at the rear yard of Bowen Mansion, 7C Bowen Road. There were no casualties in the landslide.

Following the landslide, Fugro Scott Wilson Joint Venture (FSW) was commissioned by the Geotechnical Engineering Office (GEO) to carry out a study of the failure under the 1998 Landslide Investigation Consultancy (LIC).

The principal objectives of the study were to document the facts about the landslide, present relevant background information and establish the probable causes of the landslide. This report presents the findings of the study which comprised the following key tasks:

(a) desk study, including a review of relevant documentary records relating to the history of the site, examination of aerial photographs and old topographic maps of the site, and analysis of rainfall data,

(b) interviews with witnesses of the landslide and other concerned parties,

(c) topographic survey, geological mapping and detailed observations and measurements at the landslide site,

(d) ground investigation field works and laboratory testing,

(e) theoretical stability analyses of the slope that failed, and

(f) diagnosis of the probable causes of the landslide.

2. THE SITE

2.1 Site Description

The landslide occurred within the hillside between the passing bay of a waterworks access road off Magazine Gap Road and the crest of a registered cut slope (Slope No. 11SW-B/CR183) behind 7C Bowen Road. The soil/rock cut slope is about 9 m high and inclines at about 55° to 90° to the horizontal. At 7C Bowen Road is a 5-storey residential building, known as Bowen Mansion, situated a few metres in front of the cut slope.

The area of the hillside where the landslide occurred was covered with trees and heavy vegetation before the landslide. The gradient of the hillside ranges from 25° to 40° and its overall slope angle is about 30° to the horizontal. The height from the crest of the cut slope behind Bowen Mansion to the access road is about 40 m.

The waterworks access road above the landslide scar is a vehicular access off the Magazine Gap Road, leading to the Magazine Gap Road No. 2 Fresh Water Service Reservoir (MGRSR). The MGRSR is situated at the eastern end of the access road and is approximately

350 m to the east of the landslide scar. The access road is about 5 m in width and locally at the passing bay it is about 9.3 m wide. Both the access road and the passing bay are paved with concrete. On the uphill side of the passing bay is a sub-vertical registered cut slope (No. 11SW-D/C307), which has a maximum height of about 6 m and a 300 mm surface U-channel at the slope toe.

Based on the as-built records provided by the Water Supplies Department (WSD), the waterworks access road with a passing bay above the landslide area was formed in the early 1960s. The access road and passing bay were formed by cutting into a ridge, resulting in forming a cut slope (No. 11SW-D/C307). The results of the topographic survey carried out by the Survey Division of the Civil Engineering Department in July 1998 show that the levels of the access road and passing bay above the landslide site are consistent with the levels given in the WSD's as-built records. The topographic survey results also show that the level of the access road is dipping from west to east along the road, as well as towards the uphill side across the road with average gradients of about 1 in 10 and 1 in 30 respectively. The level difference between the outward side and inward side of the road is about 300 mm.

2.2 Water-carrying Services

According to information provided by the WSD and site inspections carried out by FSW after the landslide, there was an exposed (i.e. above ground) 40-mm diameter galvanized iron (GI) water main along the outward side of the access road and across the crest of the landslide scar. The approximate alignment of this water main is shown on Figures 2 and 3. The WSD advised that this pipe was installed in 1985 for supplying fresh water from Magazine Gap Road to the jogging track on top of MGRSR and that the pressure of the water main was about 9 bars.

After the landslide, a new 25-mm diameter galvanized iron water main was installed by the WSD along the uphill side (i.e. inward side) of the access road to replace the 40-mm diameter water main severed during the landslide (Figure 2).

2.3 Site History

2.3.1 Site Development History

According to the District Lands Office, the hillside where the landslide occurred falls within unallocated Government land.

The development history of the landslide site has been established from a review of available aerial photographs taken between 1924 and 1997, and old topographic survey maps of the site published between 1959 and 1974. Detailed observations from the aerial photograph interpretation (API) are presented in Appendix A. A summary of the key findings of the API is given below:

(a) The earliest aerial photographs of the site taken in 1924 show that Magazine Gap Road has been formed and that the landslide location appears to be a hillside covered by dense vegetation.

(b) The aerial photographs taken in 1949 show that a footpath approximately following the alignment of the present waterworks access road had been formed. The topography of the hillside below the access road is hummocky, suggesting the possible presence of colluvium.

(c) Aerial photographs taken in 1963 show that the MGRSR was under construction and that a vehicular access road joining the MGRSR and the Magazine Gap Road, together with the passing bay at the crest of the landslide site, had been formed. The access road and passing bay were formed by cutting into the hillside. Below the road, Bowen Mansion has been constructed with a cut slope formed at its southern boundary. Although the aerial photographs show that fill was present in a localised location about 25 m to the east of the landslide area, no signs indicating any significant fill bodies could be identified at the area that failed below the passing bay.

(d) No major changes of the passing bay and the access road above the landslide area are apparent in the aerial photographs taken from 1967 to present.

(e) No signs of seepage or high groundwater table were identified in the hillside below the passing way in the aerial photographs taken from 1924 to present.

By comparing the survey maps published in 1959 and 1967, it was found that the alignment of the footpath identified in the 1949 aerial photograph was along the downhill edge of the waterworks access road and that the passing bay was formed in the 1960s. This is consistent with the as-built records for the access road provided by the WSD (Section 2.1), which show that the access road, including the passing bay, was formed by widening an existing footpath by cutting into the uphill slope.

According to the information provided by the WSD, the original bituminous surface of the waterworks access road was replaced by concrete paving during road re-surfacing works in January 1997. The WSD also advised that apart from this road re-surfacing work, no widening or reconstruction of the access road had been carried out since its formation in the early 1960s.

2.3.2 Previous Landslide

There are no past failures in the natural terrain in the proximity of the landslide site recorded in GEO's Natural Terrain Landslide Inventory (NTLI). This is consistent with the detailed API carried out by FSW. The nearest natural terrain landslide identified in the NTLI is located about 150 m to the southeast of the passing bay and above Magazine Gap Road (Figure 8).

According to the GEO's landslide database, only one minor rock fall incident (volume of about 0.1 m^3) was reported at slope No. 11SW-8/CR183, about 40 m below the landslide site (Figure 8).

2.4 Previous Studies and Assessment

The hillside where the landslide occurred is not registered in the 1977/78 Catalogue of Slopes or in the New Catalogue of Slopes. The GEO's Consultancy Agreement "Systematic Inspection of Features in the Territory" (SIFT), which aims to identify cut slopes, fill slopes and retaining walls using API and existing topographic maps, has not identified any fill body in the vicinity of the landslide.

The two cut slopes in the vicinity of the landslide (slope Nos. 11SW-B/CR183 and 11SW-D/C307) were registered in the 1977/78 Catalogue of Slopes by consultants engaged by the Government to prepare the Catalogue. Inspections carried out by FSW after the landslide confirmed that these two slopes were not involved in the landslide.

3. THE LANDSLIDE

3.1 Description of the Landslide

Landslide debris comprising wet soil, boulders and tree branches with a volume of about 10 m^3 was deposited at the rear yard of Bowen Mansion. The landslide scar extends downwards from the passing bay and trends in a NNE direction for the top 35 m of the scar which then turns into a NW direction before reaching the crest of the cut slope at the toe of the hillside (Figures 1 and 4). The landslide scar is about 40 m in height and its width ranges from about 10 m to 18 m. The gradient of the scar varies between 30° and 50° to the horizontal. The maximum depth of the landslide at the source area is about 2 m. General views of the landslide are shown on Plates 1 to 3.

Based on the results of the post-failure topographic survey of the landslide scar, the general topography and profile of the landslide site are presented in Figures 4 and 5 respectively. The sequence of the landslide and the site conditions before and immediately after the landslide were established through interviews of witnesses, video records of the security surveillance system installed at the rear yard of Bowen Mansion and detailed site inspections by FSW.

FSW commenced preliminary geological mapping of the landslide scar in the afternoon of 11 June 1998 and no seepages were observed from the landslide scar and the adjacent hillside. The results of the geological mapping are given in Section 4.2.

The video tape provided by the management office of Bowen Mansion shows that the landslide occurred at about 9:40 a.m. and that it was not preceded by heavy rainfall. There were no signs of progressive dislodgement of debris onto the rear yard before the landslide. The failure debris, comprising wet soil, boulders and trees branches, was deposited in a matter of seconds and came to rest on the rear yard of the building.

A detailed description of the landslide was given by a security supervisor and a caretaker of Borrett Mansions at Nos. 8 and 9 Bowen Road, a 22-storey residential building located about 100 m to the northeast of the passing bay (Figure 1). Shortly before the time of the landslide, they arrived at the 20th floor of Borrett Mansions, which is at about the same elevation as the passing bay. According to these two witnesses, the rainfall at that time was very light. During their inspection of the hillside, they observed a large amount of water spraying from the western end of the passing bay onto the hillside below. After the water spray continued for about another 5 minutes, they observed that soil, boulders and trees, initiating from the edge of the passing bay at approximately the location where the water spray was directed, suddenly slipped down the hillside, along with muddy water. Immediately after the landslide, they noticed water jetting out from the crest of the failure scar.

3.2 Observations Prior to the Landslide

As the waterworks access road is frequently used by morning walkers to go to the jogging track at the MGRSR as well as by students as a short cut to schools in Borrett Road, FSW was able to interview a total of 21 persons who used the access road.

The majority of those interviewed by FSW advised that they usually passed the waterworks access road in the morning on weekdays. Key observations provided by these witnesses are summarised below:

(a) Six witnesses noticed leakage from the water main at the crest of the landslide site a few days before 11 June 1998. Another four witnesses advised that they first observed leakage from the water main at the crest of the landslide site a few weeks prior to the landslide.

(b) One witness advised that she was at the passing bay at about 7:50 a.m. on 11 June 1998 (i.e. about two hours before the landslide) and noticed that a large amount of water was leaking in the form of a circular spray (of radius about 1 m to 2 m) from the top side of a joint of the water main close to the western end of the crest of the landslide.

(c) Another witness who was at the passing bay about one hour before the landslide reported that “the water pipe was leaking and a large amount of water was discharging onto the slope below the passing bay”. However, this witness was unable to indicate the precise location of the leakage point.

(d) One witness recalled that repair works for the water main at the passing bay were carried out a few months before the landslide.

In addition to the accounts given by the above witnesses, a gardener of Bowen Mansion reported that about 15 minutes before the landslide, he was at the rear yard of Bowen Mansion and noticed muddy water flowing down the slope immediately behind the east wing of Bowen Mansion. He also reported that the rainfall at that time was very light (i.e. drizzle).

The WSD advised that they had carried out monthly visual leakage inspections of the exposed 40-mm diameter water main and that the last inspection before the landslide was carried out at about 10:30 a.m. on 8 June 1998 and no leakage was observed at that time. The WSD also advised that their Technical Fault Report Centre had not received any complaints about leakage or burst of the 40-mm diameter water main in the past and that there was no record of any maintenance or repair works for this water main.

According to records provided by the Waste Detection Unit of WSD, two routine leakage detection tests were conducted annually on this water main by the WSD since it was installed in 1985. The leakage detection included a Leakage Noise Correlator (LNC) and/or Day Sounding & Visual Inspection (DSVI), and no leakage was found. The last leakage detection test comprising LNC and DSVI was carried out in January 1998.

3.3 Observations After the Landslide

The landslide was reported to the Fire Services Department (FSD) by the Regional Command and Control Centre (Hong Kong) of the Hong Kong Police at 9:46 a.m. on 11 June 1998 and firemen arrived at the access road above the crest of the landslide scar at about 10:20 a.m. of the same day. They advised that the rainfall at the time was very light (i.e. drizzle) and that the water pipe on the outward side of the access road was severed at a joint close to the western end of the crest of the landslide scar. Water was observed to be jetting out from the broken end of the pipe onto the landslide scar. The water jet hit the scar at a point about 8 m from the broken end of the pipe. In order to stop water from discharging onto the landslide scar, the fireman relocated the upstream section (the western section) of the broken water pipe inwards (i.e. towards the paved area of the access road).

The WSD advised that their staff arrived at the access road above the landslide site at about 11:00 a.m. on 11 June 1998 and they immediately turned off the water supply to the broken pipe. The fireman in charge of the FSD team attending to the landslide also advised that the muddy water flushing down from the crest of the landslide scar stopped at about 11:00 a.m.. Representatives of the GEO, Highways Department (HyD) and Buildings Department (BD), and the term contractors of HyD arrived at the landslide site between 11:30 a.m. and 12:30 a.m. of the same day. They all reported that the water pipe was severed at a joint close to the western end of the crest of the landslide scar.

The WSD advised that this joint is a 'simple joint' and that its use at the passing bay was necessary because curtailed sections of GI pipes were used at both sides of the joint. Although it is indicated in the WSD Manual of Mainlaying Practice (1997) that 'simple joints' shall be used for repair works to water mains, the use of 'simple joint' for permanent connection of small diameter GI pipes of less than the standard length is, according to the WSD, quite common. Based on a sample of the 'simple joint' provided by the WSD, this type of joint does not require threads to be formed at the end of pipes to be joined, and that the pipes are fixed in position by squeezing a rubber wedge in order to clamp the pipes together (Plate 6).

The FSW landslide investigation team arrived at the access road at about 4 p.m. on 11 June 1998. At that time, urgent slope repair works, comprising shotcreting of the failure scar with minimal trimming, had commenced and no obvious fill material was observed on the failure scar. Detailed mapping of the scar was not possible because of access difficulties and the urgent repair works that were in progress. The water pipe was observed to be broken at a ‘simple joint’ close to the western end of the crest of the landslide scar. Except for this ‘simple joint’, all the other joints of the water pipe consisted of screw joints. The water pipe had a bend (approximately 135°) at a location about 500 mm to the north of the simple joint and no thrust blocks were found. The ‘simple joint’ was supported on steel bars on its two sides and the section of the pipe to the east of the joint was fixed by wires onto some steel bars, poles and trees (see Figure 3 and Plates 2 & 4). These steel bars and wires appeared to have been installed before the landslide. The WSD subsequently advised that “an anchor block should have been provided but it may have been damaged and collapsed in the landslide”.

Examination of the landslide debris by FSW staff showed it to be composed of loose and wet clayey, sandy silt with cobbles, gravels and boulders, tree branches, and broken pieces of concrete kerb. As the landslide debris was constrained by the building in front of the hillside, the travel angle of the landslide debris cannot be determined reliably. Stains of muddy water splashes could be seen up to the third floor of the facade of the affected building.

Field inspection and geological mapping of the landslide site was carried out by FSW in the afternoon of 11 June 1998. The results of the geological mapping are presented in Section 4.2.

Based on the photographs taken before the failure scar was disturbed by the urgent repair works, the following observations regarding the condition of the landslide scar may be made:

(a) except for a few mature trees, most of the vegetation and trees originally on the hillside were either removed or knocked down from the crest to the toe of the failure scar (Plate 1),

(b) very wet soil and localized ponding of water were noted on the failure scar surface (Plate 5),

(c) a large amount of cobble-sized debris was found on the failure scar surface, especially in the area close to the crest (Plate 4), and

(d) a small raft of soil knitted together by a mass of shallow and thin tree roots and on which a tree remained intact was found to have been displaced to a location about 7.5 m from the crest of the landslide scar (Plate 5).

3.4 Consequences of the Landslide

No one was injured in the landslide. The windows and two air conditioners of Flat 104 located immediately in front of the toe of the hillside were damaged by the landslide debris.

After the landslide, residents of five flats of the eastern wing of Bowen Mansion were evacuated at the recommendation of the GEO. Closure Orders were served by the BD on

Flats 104, 204, 304, 404 and 504, the roof of Flat 504 and the rear yard of Flat 104 the next day following the landslide. In addition, three car-parking spaces of Borrett Mansions at Nos. 8-9 Bowen Road were closed off as a result of the landslide.

A few hours after the landslide, HyD's contractors commenced urgent repair works on the failed slope, comprising a two-layer shotcrete surface protection (i.e. an inner layer followed by an outer layer with steel wire mesh) with weepholes. Upon completion of the application of the first layer of shotcrete on 16 June 1998, Closure Orders in respect of the affected flats of Bowen Mansion and the car parks of Borrett Mansions were lifted.

4. SUBSURFACE CONDITIONS

4.1 General

According to the 1:20 000-scale geological map for the concerned area, the geology at the landslide site comprises fine ash vitric tuff (Ap Lei Chau Formation of the Upper Jurassic Repulse Bay Volcanic Group). The subsurface conditions at the site were established using information from available documentation, together with results of geological mapping, which was carried out by FSW in June and July 1998 after the landslide, and ground investigation works carried out by GEO's term contractors in August 1998 under the direction and supervision of FSW.

4.2 Geological Mapping

Geological mapping of the landslide area by FSW was started on 11 June 1998 after the urgent slope repair works by HyD's term contractors had commenced. The landslide scar, particularly its upper part, had been partially covered by shotcrete at that time. Towards the lower part and near the base of the landslide scar, a layer of colluvium is present typically to a depth of 0.5 m below ground and underlain by moderately to slightly decomposed tuff (M-SDT). The colluvium consists of firm, light to yellowish brown, sandy, silty clay with abundant fine to coarse angular gravels and small boulders. Boulders of moderately decomposed tuff were also found scattered on the surface of the hillside, especially within the eastern flank of the landslide scar. No remnants of fill were observed. No seepage was observed from the landslide scar and the hillside during the various visits of the field mapping work.

4.3 Ground Investigation Findings

Ground investigation works comprising two surface strips and two trial pits were carried out between 21 August 1998 and 14 September 1998 by GEO's term contractors, Bachy Soletanche Group. The surface strips and trial pits are within the failure scar and their locations are shown on Figure 6. A standpipe, comprising a perforated tube with Halcrow buckets, was installed in each of the trial pits to depths about 3 m below the part-failure surface.

Trial pits excavated at the crest and on the upper portion of the landslide scar indicate that the post-failure profile of the slope is generally composed of an approximately 2 m thick colluvial deposit overlying residual soil and completely decomposed tuff (CDT). The residual soil and CDT comprise dense, sandy silt and stiff clay with occasional corestones. Surface strips below the passing bay revealed a layer of top soil overlying colluvium. The top soil comprises firm, dark grey, slightly sandy, silty clay and the colluvium comprises firm, yellowish brown, sandy, silty clay, with some gravels and cobbles. No fill was observed in the trial pits and surface strips.

Trial pit TP1, which was excavated immediately below the passing bay, revealed a surface layer of colluvium (referred to as young colluvium) of composition similar to that noted in the lower part of the landslide scar (see Section 4.2 above) and of thickness ranging from 0.5 m to 1.3 m. The young colluvium is underlain by a layer of old top soil (maximum 0.3 m thick) comprising firm, dark grey, very silty, sandy clay, similar to that observed in the surface strips. A few isolated tree roots were found in the young colluvium and old top soil. The old top soil is underlain by another layer of colluvium (referred to as old colluvium), approximately 0.5 m thick and composed of firm, mottled brown, very silty, sandy clay with some angular gravel and cobble-sized rock fragments. The subsoil profile exposed in TP1 is shown in Plate 7. Trial pit TP2, which was excavated approximately 7 m downslope from TP1, revealed a similar sequence of colluvial layers divided by a layer of top soil as found in TP1. In TP2, the surface layer of colluvium (i.e. young colluvium) is approximately 0.2 m thick.

In both TP1 and TP2, the young colluvium was noted to contain a relatively higher content of gravels and cobbles than the old colluvium. As the permeability of a soil stratum is related to its particle size distribution, the young colluvium is therefore likely to be more permeable than the old colluvium.

Based on the results of geological mapping and ground investigation works, an inferred geological profile of the landslide site is presented in Figure 7. The geological mapping and ground investigation results indicate that the landslide occurred mainly in the young colluvium.

4.4 Materials' Properties

A total of eight undisturbed U100 and seven disturbed bulk soil samples of the young colluvium and old colluvium were obtained from the trial pits for laboratory testing to determine the engineering properties of the colluvium at the landslide site. As the maximum thickness of the old top soil in the trial pits is only 0.3 m, no undisturbed samples could be obtained from this stratum. The laboratory testing was carried out by Gammon Construction Limited. Tests included classification and index tests, which were carried out in accordance with the methods described in GEO Report No. 36, and consolidated undrained triaxial compression tests.

The results of the classification tests are summarized in Table 1. The average fines (i.e. clay and silt) content of the young colluvium was 57%, whilst that of the old colluvium was 63%. The fact that the young colluvium has a lower fines content suggests that it is comparatively more coarse grained than the old colluvium and generally more permeable than the old colluvium.

The ranges of permeability of the young colluvium and old colluvium derived from the consolidation phase of triaxial compression tests are 3.4×10^{-6} m/s to 2.5×10^{-9} m/s and 6.2×10^{-7} m/s to 7.8×10^{-11} m/s respectively. These results further support that the young colluvium is generally more permeable than the old colluvium.

The shear strength properties of the matrix material of the young colluvium and old colluvium were assessed by triaxial compression tests on eight U100 samples. Results of the triaxial compression tests are summarized in Table 2 and presented in the form of p′-q plots in Figures 9 and 10. The shear strength of the tested soils are found to be typical for similar materials in Hong Kong. The presence of coarse fractions such as boulder-sized material will, however, increase the mass shear strength.

4.5 Groundwater Conditions

No seepage was observed from the landslide scar and the adjacent hillside by FSW during the inspection of the landslide site in the afternoon of 11 June 1998 and the frequent site inspections during field mapping and ground investigation works. The gardener of Bowen Mansion, who has worked at Bowen Mansion for 7 years, advised that he had never observed muddy water flowing down the slope behind Bowen Mansion, except for the period shortly before the landslide (Section 3.2). The temporal coincidence of muddy water flowing down the hillside shortly before the landslide during a period of light rainfall and the observation of significant leakage from the ‘simple joint’ of the 40-mm diameter water main suggests that the muddy water was probably due to leakage rather than groundwater issuing from the hillside.

In order to further assess the prevailing groundwater level and the storm response of the groundwater table in the landslide area, the site was visited by FSW during a heavy rainfall on 23 June 1998, when 49 mm of rain was recorded over a 2 hours period at the nearest GEO automatic raingauge No. H17. During the site visit, no seepage was observed from either the weepholes of the landslide scar, the adjacent hillside or the cut slope above the access road. Also, no overflow of surface water from the access road onto the hillside below was noted.

The above observations indicate that the main groundwater table was below the failure surface at the time of the landslide. This is consistent with the results of groundwater monitoring at standpipes installed in the two trial pits at the landslide scar, where no groundwater was encountered at about 3 m below the post-failure slope surface during September to November 1998.

5. ANALYSIS OF RAINFALL RECORDS

The nearest GEO automatic raingauge (No. H17) is located at 25 Borrett Road, about 230 m to the southeast of the landslide area (Figure 1). According to the records from this raingauge, a total of 756 mm rainfall was recorded in the 31-day period before the landslide. The hourly and daily rainfall recorded by the raingauge before the landslide are shown on Figures 11a and 11b respectively. It can be seen from Figure 11 that rain was quite heavy in the early morning of the day of the landslide, especially between 3:45 a.m. and 6:45 a.m.

Within this period, a total of 58 mm rainfall was recorded. However, only 8 mm rainfall was recorded between 6:45 a.m. and the time of the landslide (i.e. at about 9:40 a.m.).

Figure 12 presents a comparison of the pattern of the rainfall prior to the 11 June 1998 landslide with those of previous major rainstorms recorded at GEO raingauge No. H17 since its installation in 1978. It can be seen that the rainfall prior to the landslide was less severe than that experienced before by the raingauge.

Table 3 presents the maximum rolling rainfall recorded at GEO raingauge No. H17 before the landslide for selected durations. The table also shows the corresponding estimated return periods for maximum rolling rainfalls of different durations. The 12-hour rainfall ending at 16:50 on 9 June 1998 was the most severe of that rainstorm, with a corresponding estimated return period of about 8 years.

6. THEORETICAL ENGINEERING ANALYSES

Theoretical stability analyses were performed to assist in the diagnosis of the probable triggering factors and causes of the landslide. The slope stability analyses were carried out using the rigorous solution of Morgenstern & Price (1965).

Results of the post-failure ground investigation, laboratory testing and site observations were used in the stability analyses. The geological mapping and ground investigation results indicate that the landslide occurred mainly in the young colluvium. A representative cross-section of the landslide site and the soil parameters adopted in the analyses are shown in Figure 13. In view of the fact that the tree roots exposed in the landslide scar are largely shallow (see Plate 5 and Section 3.3(d)), the reinforcing effect due to tree roots has not been taken into account in the soil shear strength parameters.

The observation by FSW that the young colluvium is more coarse grained than the underlying old top soil and old colluvium suggests that the young colluvium is generally more permeable (see Section 4.3), which is corroborated by the laboratory tests (Section 4.4). The hydrogeological setting of the landslide site was therefore favourable for the development of perched water table in the young colluvium when a large amount of water has infiltrated into it.

The results of stability analyses are summarized in Figure 13. When the near-surface material is not fully saturated with a nominal suction prevailing in the young colluvium, the theoretical factor of safety for the failure surface is much greater than unity. The results also indicate that when the young colluvium becomes fully saturated with a perched water table at about 1 m above its base, the factor of safety of the failure surface would be below unity (i.e. failure will theoretically occur).

7. DIAGNOSIS OF THE PROBABLE CAUSES OF THE LANDSLIDE

7.1 The Mode of the Landslide

Based on the information collected, the shallow landslide occurred suddenly with wet and fast-moving debris and failure was observed to be initiated at the edge of the passing bay. Based on the field mapping, the predominant mode of landslide involves a sliding failure rather than major wash-out by concentrated surface water flow.

7.2 Probable Causes of the Landslide

Field observations of the landslide together with results of supporting theoretical analyses suggest that the failure was most likely triggered by the ingress of a large amount of water into the hillside immediately below the passing bay, resulting in saturation of the young colluvium, development of transient elevated water pressure and reduction in shear strength. The possible sources of water ingress into the hillside include the following:

(a) subsurface groundwater flow from the uphill area,

(b) overflow of surface water from the access road,

(c) direct infiltration of rainfall, and

(d) leakage from the 40-mm diameter water main.

Given the absence of signs of seepage or high groundwater table in the landslide site on old aerial photographs and the observation of no seepage or erosion pipes in the landslide scar during the various visits of the FSW's field mapping work, it is considered unlikely that subsurface groundwater flow was a significant source of water into the colluvium.

The landslide occurred below a road bend. Overspilling from roads, particularly at vulnerable locations such as road bends, has been known to be a fairly common cause of downhill slope failures. Overflow of surface water from the access road onto the hillside below could have resulted from the 300-mm surface U-channel, or directly from the road surface, either due to inadequate or blockage of the drainage provisions. However, the evidence collected during this landslide study suggests that this source of water to the landslide site is unlikely for the following reasons:

(a) observations by two witnesses from the building of Nos. 8 and 9 Bowen Road and the gardener of No. 7C Bowen Road, corroborated by the surveillance video tape, confirm that the rainfall at the time of the landslide was not heavy (Sections 3.1 and 3.2),

(b) the rainfall recorded by the nearest raingauge within a few hours before the landslide was very small (8 mm in 3 hours prior to the landslide),

(c) although the 300-mm U-channel had previously been observed to be blocked at times of heavy rainfall with water overflowing onto the access road, surface water overspilling onto the hillside below has never been observed. The topographic surveys carried out in July 1998 indicate that the road surface is dipping towards the uphill side of the access road with a level difference of 300 mm between the outward side and inward side of the road. In addition to this level difference is the 100-mm high upstand kerb along the outward edge of the passing bay. Hence, there is a total level difference of 400 mm which would have served to mitigate against surface water overflowing onto the hillside below, and

(d) the fireman who first arrived at the passing bay about 30 minutes after the landslide reported that no overflow of surface water from the passing bay onto the hillside below was observed.

The rainfall on the hillside had probably been a source of water into the ground via direct infiltration. The rainfall recorded by the nearest GEO raingauge No. H17 prior to the landslide was less than that during previous severe rainstorms in 1993, 1994 and 1997. Thus, the hillside where the landslide occurred had experienced in the recent past more severe rainfall without failures or obvious signs of distress.

It is noted that the visual inspection by WSD in the morning of 8 June 1998 did not observe leakage from the exposed water main. A number of witnesses observed leakage from the exposed water main in the "few days" before the landslide which occurred on 11 June 1998. A strong water spray with a radius of about 1 m to 2 m from the 'simple joint' at the landslide crest was observed by a witness about two hours before the landslide. The amount of leakage apparently increased with time according to witnesses' accounts, particularly within at least about two hours prior to the landslide.

Infiltration from the heavy rainfall during the period 9 to 11 June 1998 prior to the landslide coupled with significant leakage from the water main within the period probably resulted in the ingress of a large amount of water into the hillside directly below the passing bay. This had probably been further promoted by localised erosion caused by concentrated flow from the leak, as suggested by the observation of muddy water flowing down the slope shortly before the failure when the rainfall was very light at the time (Sections 3.2 and 4.5). Such infiltration would increase the degree of saturation of the young colluvium and reduce or eliminate any suction. The presence of the underlying steeply-sloping, less permeable old colluvium was likely to have resulted in the formation of a perched water table in the young colluvium reducing its shear strength.

Based on the detailed eye-witness accounts, water ingress resulting from leakage of the water main could be comparable to that from rainfall. The source of water ingress triggering the landslide could probably be the combined effect of direct infiltration of rainfall and leakage from the 40-mm diameter water main.

A summary of observations by witnesses and events preceding the landslide is given in Appendix B. The probable sequence of the landslide event has been re-constructed and is illustrated in Figure 14.

Regarding the cause of leakage of the water main, it is not certain as to whether the leakage was caused by ground movement prior to the landslide resulting in distress to the water main, or whether the leakage occurred in the absence of adverse effect on the water main due to any ground movement prior to the landslide.

8. OTHER FACTORS RELEVANT TO THE LANDSLIDE

Apart from the combined effect of heavy rainfall and significant leakage from the 'simple joint' of the water main, the following factors are also considered relevant to the landslide:

(a) Hydrogeological conditions of the landslide site

The vegetated hillside with a surface layer of more permeable young colluvium above the old top soil and old colluvium provided hydrogeological conditions favourable to surface infiltration and development of a perched water table which adversely affects slope stability.

(b) The nature of the 'simple joint' of the water main

The leakage occurred at a 'simple joint' of the water main along the outward edge of the access road. Such joints do not require threads to be formed at the end of pipes to be joined, and the pipe sections are fixed in position by squeezing a rubber wedge ring to clamp them together (Plate 6). In comparison with a screw joint, this type of joint is more vulnerable to leakage when it is subjected to localised ground movement, or repeated tension/bending forces, particularly in the absence of adequate anchoring resistance from the support to take up the surge loading acting on the bend.

The WSD advised that the 'simple joint' was "an expansion joint for that water main" and that "It was not designed to take tension or bending force. These forces were taken up by anchors at suitable interval and at bends". The WSD further advised that "the nearby bend with anchor was only about 1 metre from the concerned expansion joint" but that the as-constructed details of the anchors could not be traced.

9. CONCLUSIONS

It is concluded that the landslide which occurred on 11 June 1998 at the vegetated hillside above 7C Bowen Road was most likely triggered by the ingress of a large amount of water into the area below the passing bay. Water ingress resulted in wetting and reduction in shear strength of the near surface material and the development of transient elevated water pressures, leading to the failure.

The large amount of water ingress was probably brought about by the heavy rainfall and was probably aggravated by leakage from the exposed 40 mm diameter water main.

Based on the information collected, the exposed 40 mm diameter water main located above the landslide site was leaking prior to the landslide. It is not certain as to whether the leakage was caused by ground movement prior to the landslide resulting in distress to the water main, or whether the leakage occurred in the absence of adverse effect on the water main due to any ground movement prior to the landslide.

10. REFERENCES

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LIST OF TABLES

Table 1 - Summary of Classification Test Results

Material Type	Sample Type & No	Trial Pit No.	Depth (m)	Particle Size Disturbution			Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Water Content (%)
				Gravel (%)	Sand (%)	Fine (Silt + Clay) (%)			
Colluvium (Young)	U100	TP1	0.3	-	-	-	1.72	1.41	22
Colluvium (Young)	U100	TP1	0.5	-	-	-	1.84	1.58	17
Colluvium (Young)	U100	TP1	0.6	-	-	-	1.77	1.56	14
Colluvium (Old)	U100	TP1	1.5	-	-	-	1.75	1.47	19
Colluvium (Old)	U100	TP1	1.7	-	-	-	1.86	1.51	24
Colluvium (Old)	U100	TP2	1.3	-	-	-	1.87	1.55	20
Colluvium (Old)	U100	TP2	1.5	-	-	-	2.15	1.92	12
Colluvium (Old)	U100	TP2	1.6	-	-	-	2.15	1.91	12
Colluvium (Young)	Bulk	TP1	0.5	9	30	61	-	-	-
Colluvium (Young)	Bulk	TP1	0.5	16	26	58	-	-	-
Colluvium (Young)	Bulk	TP2	0.1	13	31	56	-	-	-
Colluvium (Young)	Bulk	TP2	0.1	14	32	54	-	-	-
Colluvium (Old)	Bulk	TP1	1.5	7	32	61	-	-	-
Colluvium (Old)	Bulk	TP1	1.5	5	32	63	-	-	-
Colluvium (Old)	Bulk	TP1	2.5	9	34	57	-	-	-
Colluvium (Old)	Bulk	TP2	1.5	17	20	63	-	-	-
Colluvium (Old)	Bulk	TP2	1.5	8	24	68	-	-	-
Colluvium (Old)	Bulk	TP2	2.5	12	25	63	-	-	-

Table 2 - Summary of Triaxial Compression Test Results

Material Type	Sample Type & No.	Sample Location	Depth (m)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)	Stage	Permeability, k (m/s)	p' (kPa)	q (kPa)
Colluvium (Young)	U100	TP1	0.3	1.72	1.41	22	1	$2.98x10^{-8}$	19.6	9.6
							2	$1.25x10^{-8}$	25.9	12.9
							3	$2.52x10^{-9}$	41.5	20.5
Colluvium (Young)	U100	TP1	0.5	1.84	1.58	17	1	$4.48x10^{-8}$	29.1	14.1
							2	$6.04x10^{-8}$	41.8	19.8
							3	$1.2x10^{-8}$	76.8	36.8
Colluvium (Young)	U100	TP1	0.6	1.77	1.56	14	1	$3.43x10^{-6}$	36.2	21.2
							2	$1.52x10^{-7}$	85.8	51.8
							3	$1.71x10^{-8}$	195.9	116.9
Colluvium (Old)	U100	TP1	1.5	1.75	1.47	19	1	$1.96x10^{-9}$	17.4	9.4
							2	$4.57x10^{-10}$	35.1	18.4
							3	$5.67x10^{-10}$	83.5	43.5
Colluvium (Old)	U100	TP1	1.7	1.86	1.51	24	1	$2.17x10^{-8}$	58.8	35.8
							2	$1.35x10^{-8}$	106.8	61.8
							3	$8.48x10^{-9}$	168.3	94.3
Colluvium (Old)	U100	TP2	1.3	1.87	1.55	20	1	$6.23x10^{-7}$	28.0	17.0
							2	$8.07x10^{-9}$	48.8	27.8
							3	$3.17x10^{-8}$	69.6	39.6
Colluvium (Old)	U100	TP2	1.5	2.15	1.92	12	1	$2.68x10^{-7}$	61.7	36.7
							2	$4.33x10^{-8}$	107.2	61.2
							3	$2.08x10^{-8}$	212.0	123.0
Colluvium (Old)	U100	TP2	1.6	2.15	1.91	12	1	$6.83x10^{-9}$	73.8	48.8
							2	$9.34x10^{-10}$	118.0	71.0
							3	$7.76x10^{-11}$	265.5	162.5

Legend:

$p' = 0.5 (\sigma'_1 + \sigma'_3)$, where σ'_1 and σ'_3 are the major and minor principal effective stresses respectively.

$q = 0.5 (\sigma'_1 - \sigma'_3)$

Table 3 - Maximum Rolling Rainfall at GEO Raingauge No. H17 and Estimated Return Periods for Selected Durations Preceding the Landslide of 11 June 1998

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (years)
5 minutes	8.5	13:05 on 9 June 1998	< 1
15 minutes	21.0	12:10 on 9 June 1998	< 1
1 hour	55.5	07:25 on 9 June 1998	2
2 hours	98.5	08:40 on 9 June 1998	3
4 hours	146.0	09:15 on 9 June 1998	4
12 hours	269.0	16:50 on 9 June 1998	8
24 hours	317.5	17:35 on 9 June 1998	6
48 hours	355.5	10:40 on 10 June 1998	5
4 days	439.0	14:50 on 11 June 1998	5
7 days	484.0	11:30 on 11 June 1998	5
15 days	570.5	14:50 on 11 June 1998	4
31 days	762.5	14:20 on 11 June 1998	4

Notes : (1) Return periods were divided from the Gumbel's equation and data published in Table 3 of Lam & Leung (1994).
(2) Maximum rolling rainfall was calculated from 5-minute data.
(3) The use of 5 minute data for durations between 2 hours and 31 days results in better data resolution, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.

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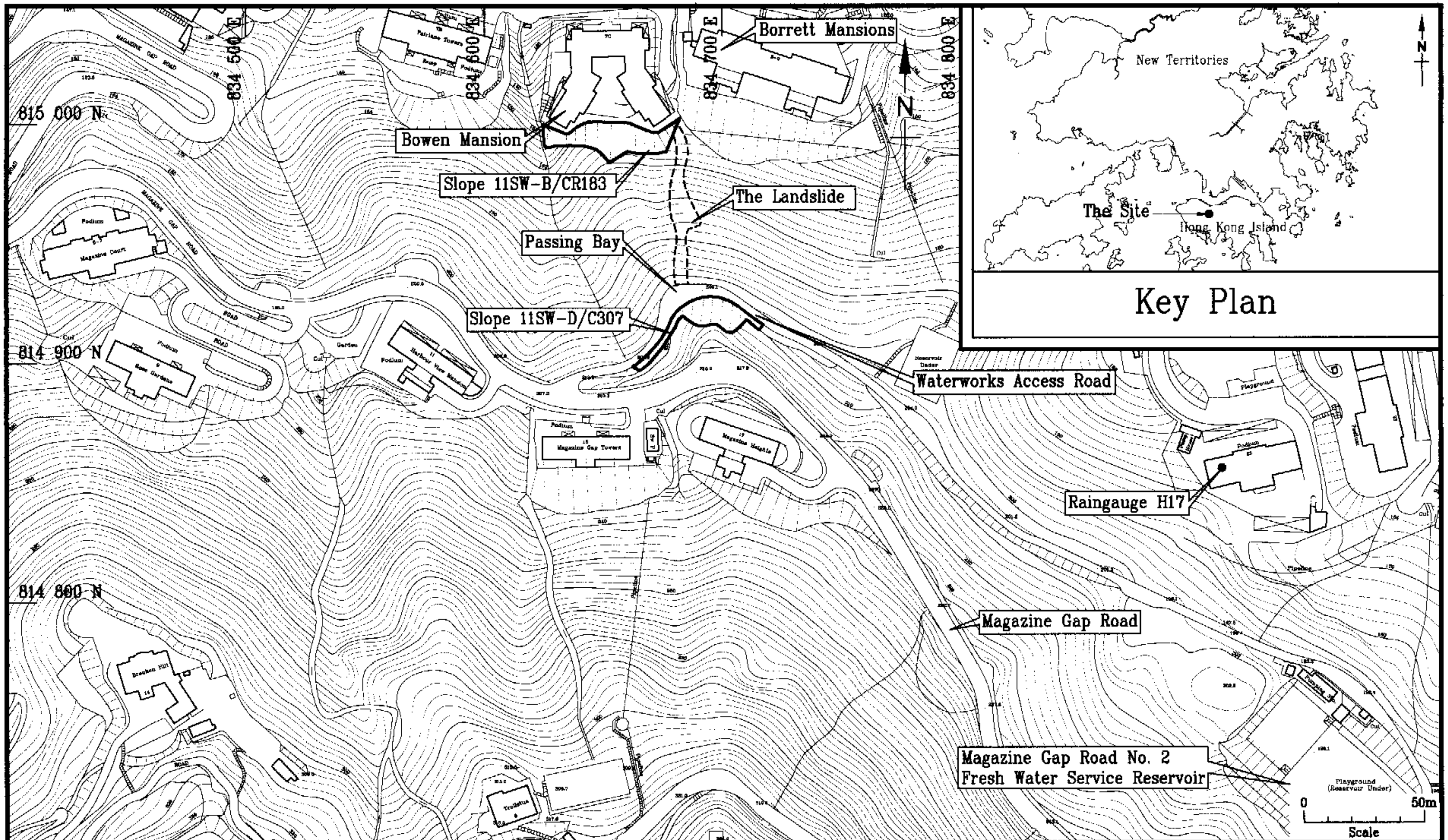
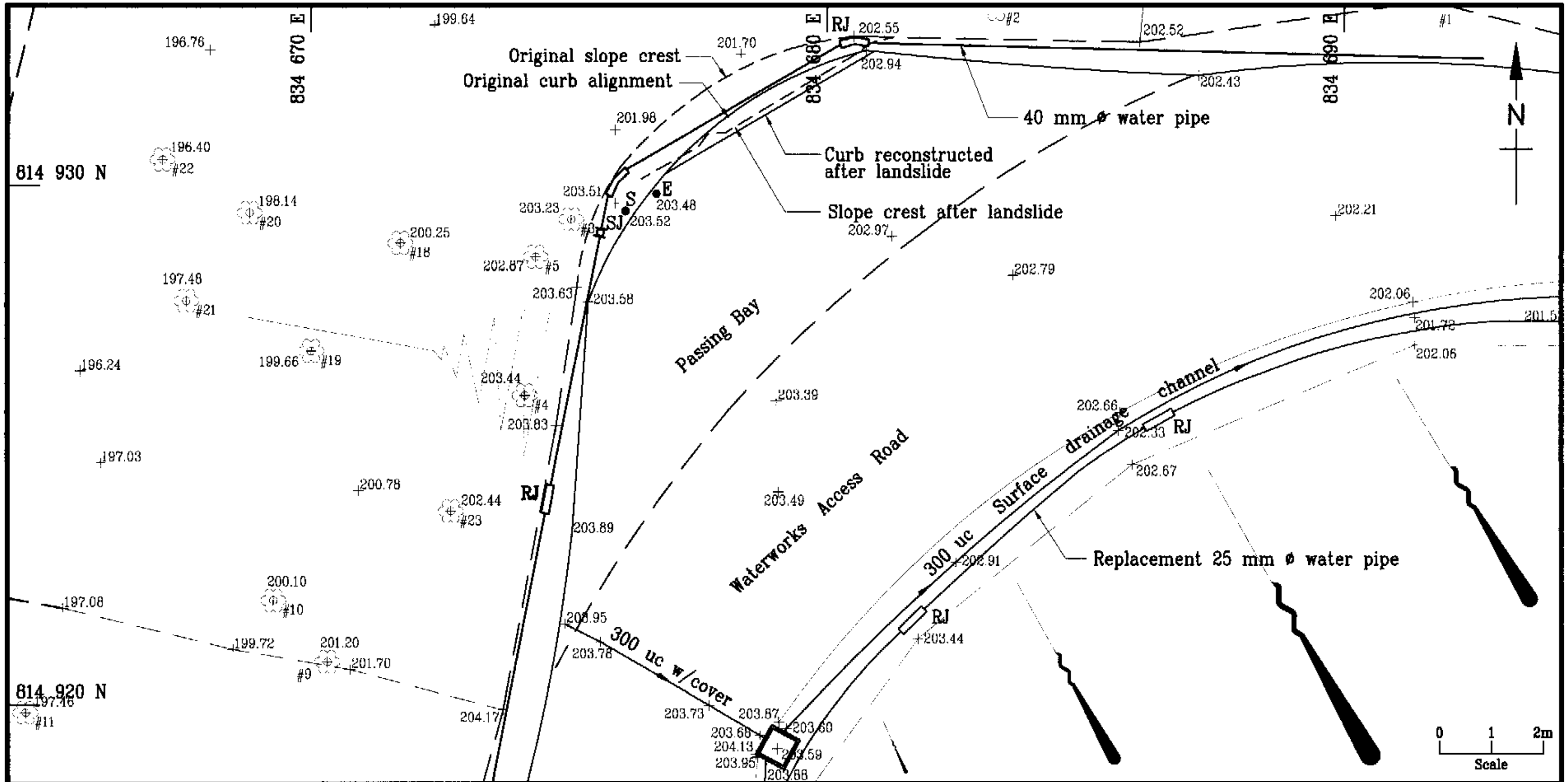


Note: Base map is extracted and reduced from survey sheets no. 11SW-14A and 14C, dated May 92 and Mar 92 respectively, scale 1 : 1000.

Figure 1 - Site Plan

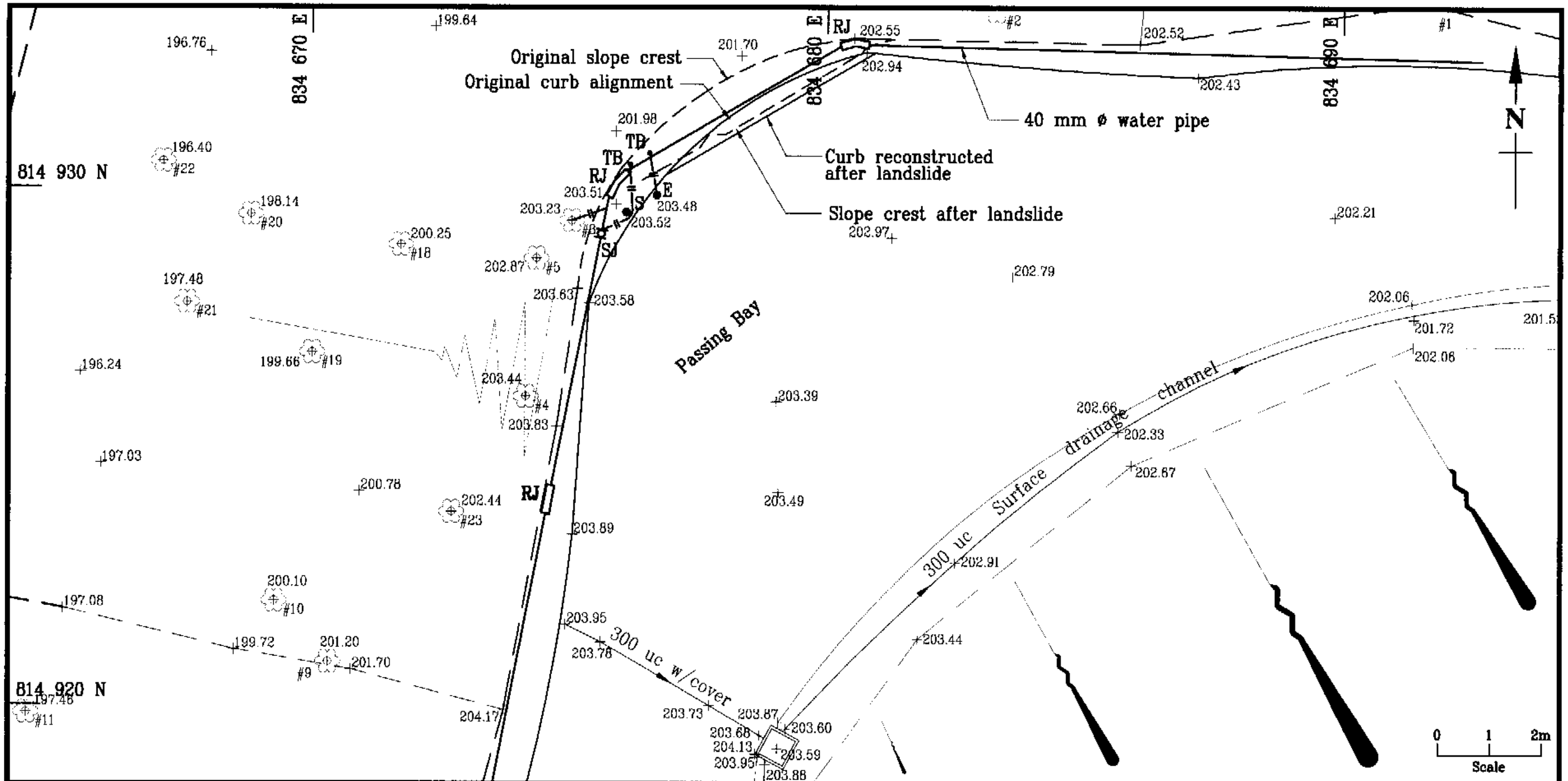


Legend:

•E	Telephone pole	RJ	Screw joint
•S	Sign pole		
SJ	Simple joint		

Note: Information shown on this figure is based on ground investigation and field mapping.

Figure 2 - Layout of Drainage and Water-carrying Services at Waterworks Access Road



Legend:

●E	Telephone pole	RJ	Screw joint
●S	Sign pole	TB	Tie bar
SJ	Simple joint	—ıı—	Tie wire

Note: Information shown on this figure is based on ground investigation and field mapping.

Figure 3 - Approximate Locations of Supports to the Water Pipe at Passing Bay

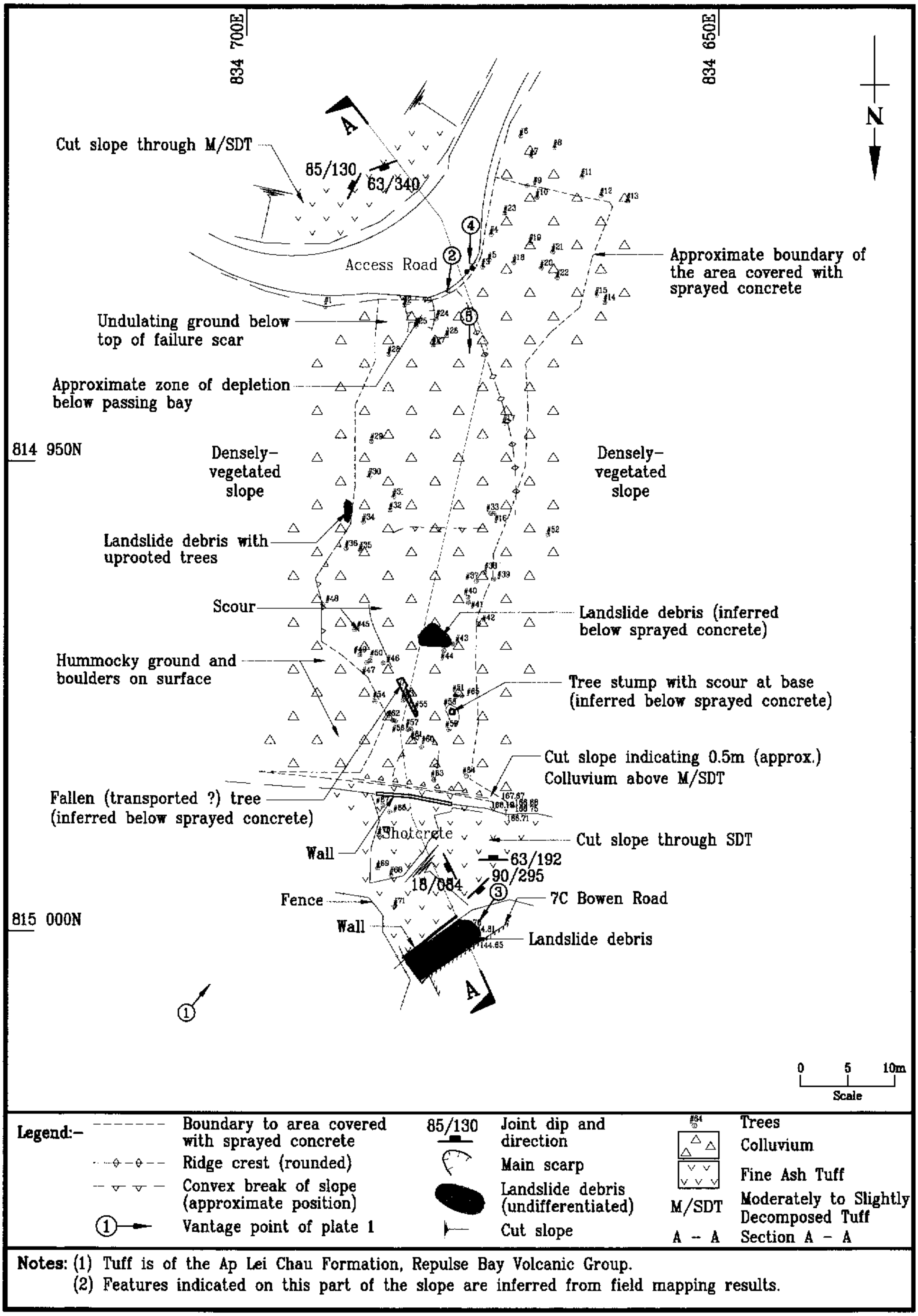
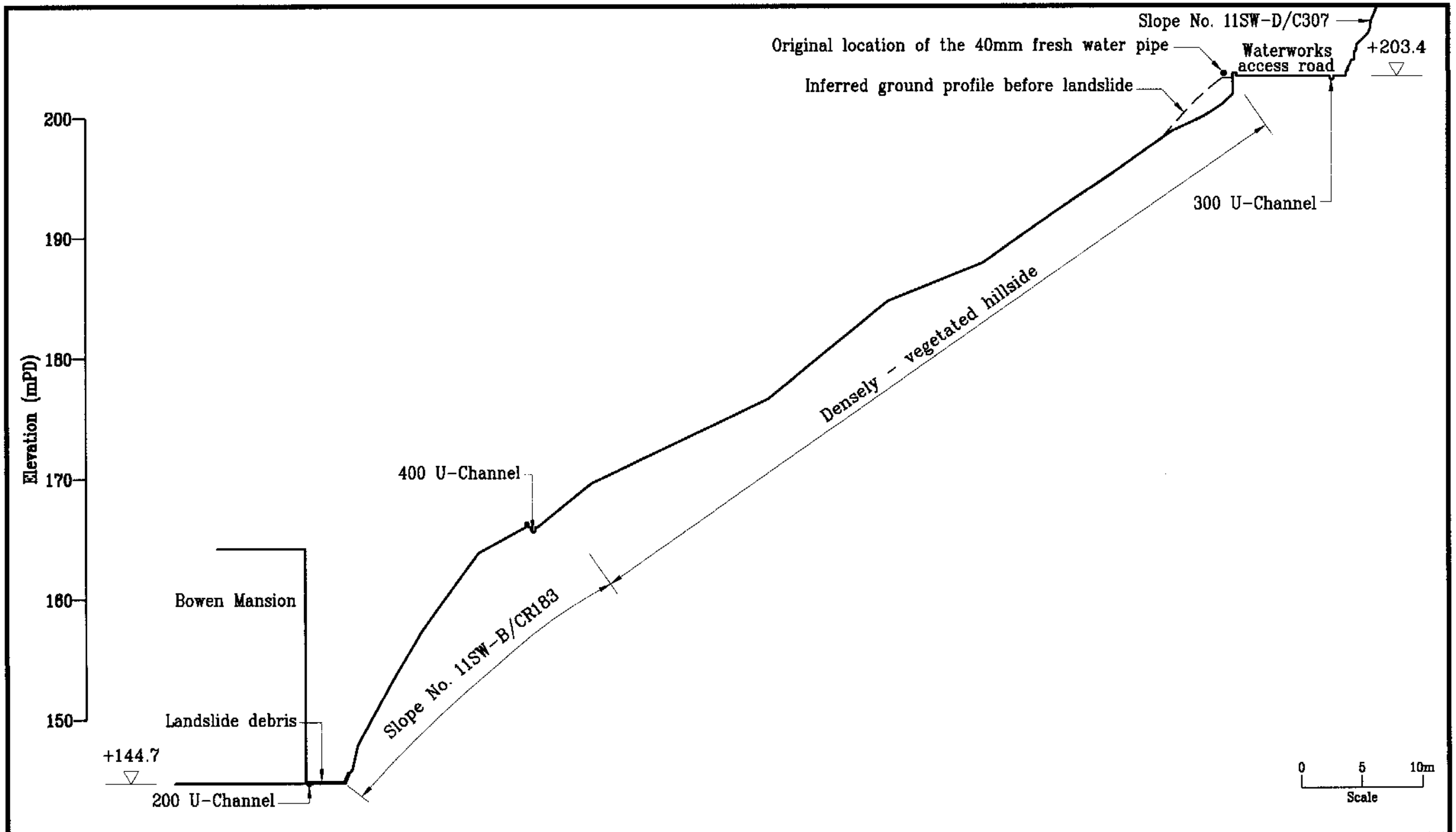
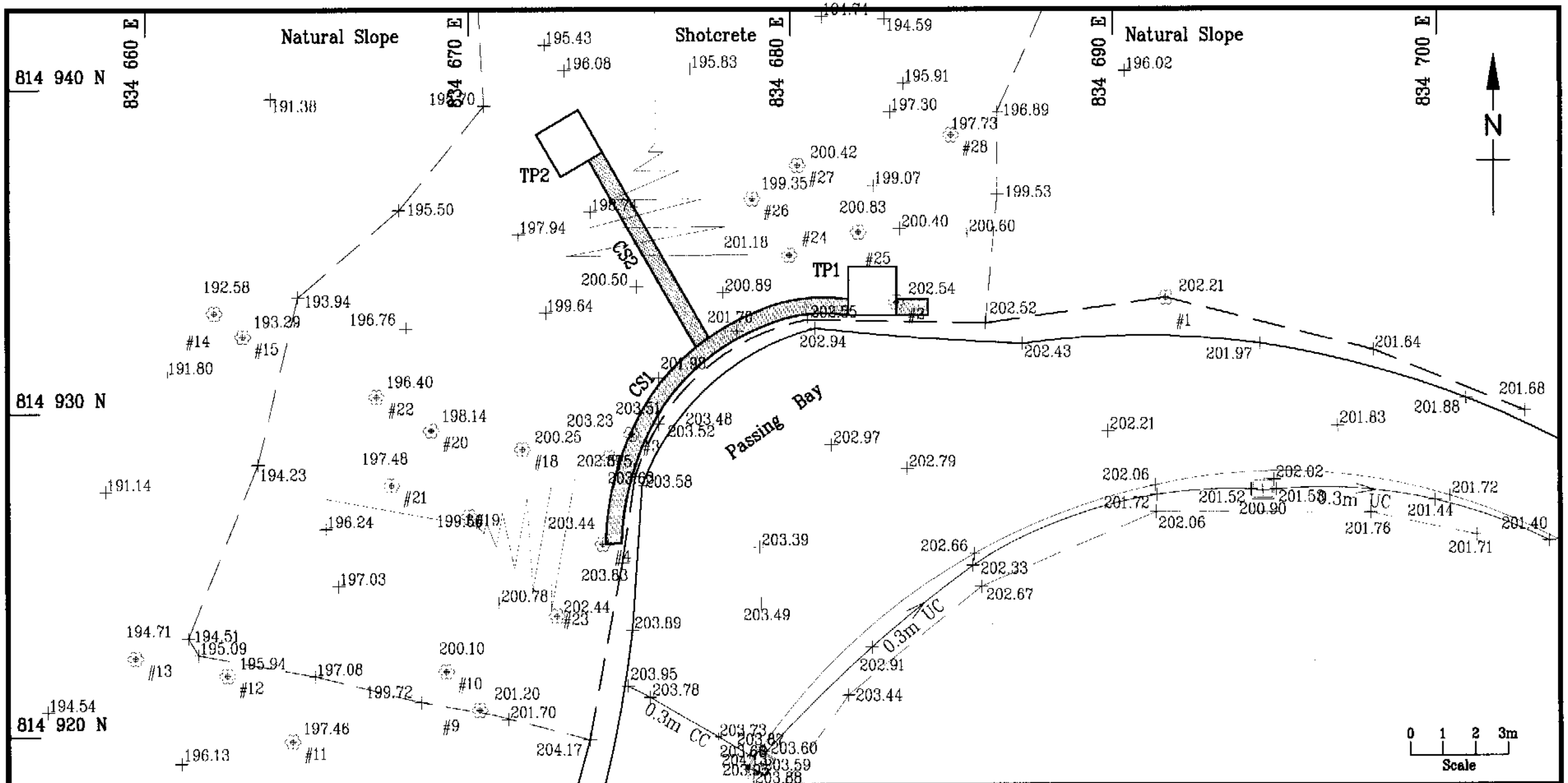


Figure 4 - Plan of the Landslide



Notes: (1) See figure 4 for location of section.
(2) Information shown on this figure is based on topographic survey and field observations.

Figure 5 - Section A - A through the Landslide



Legend:

TP Trial Pit

SC Surface Stripping

Note: Information shown on this figure is based on ground investigation and field mapping.

Figure 6 - Location Plan of Ground Investigation Works

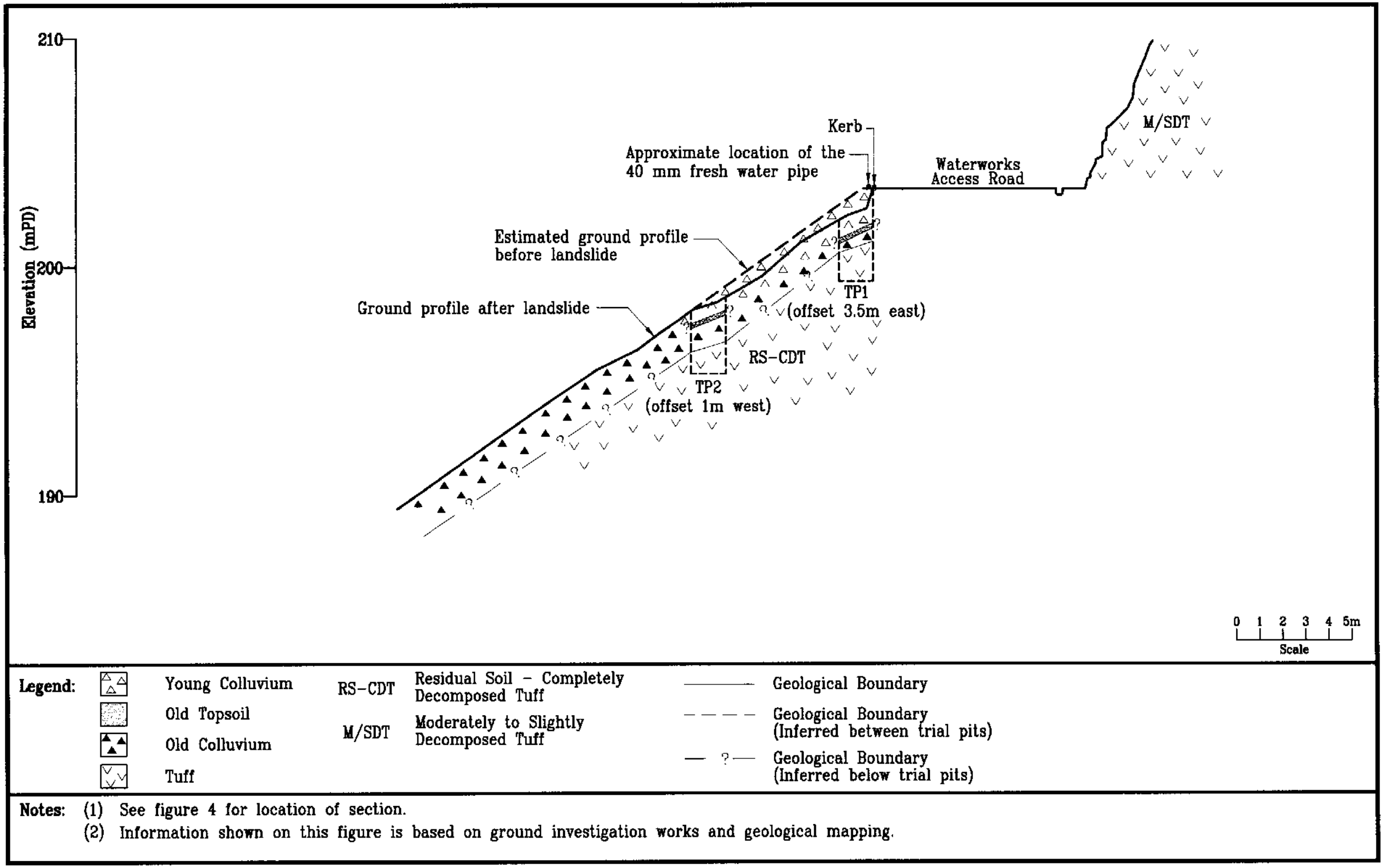
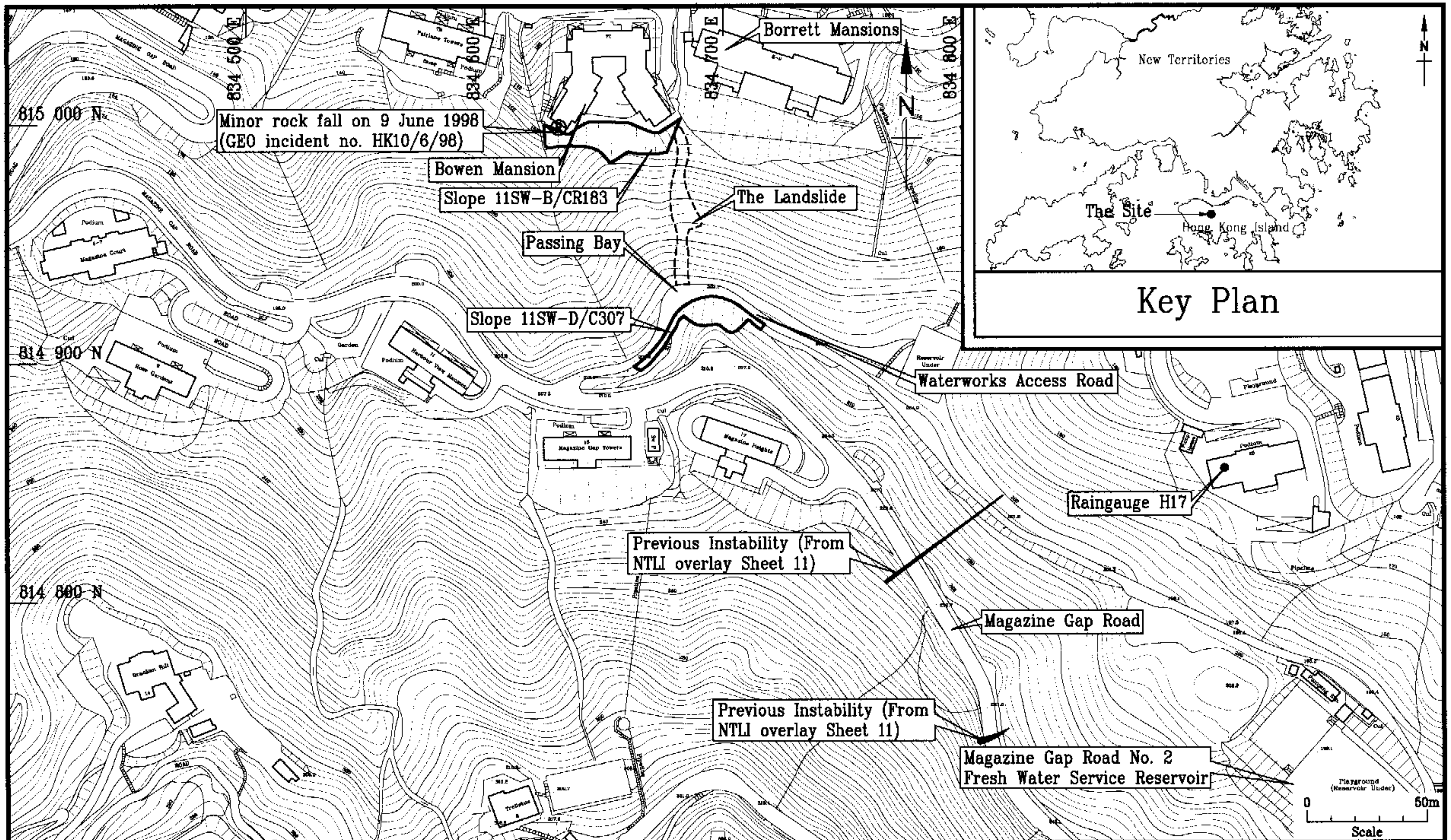
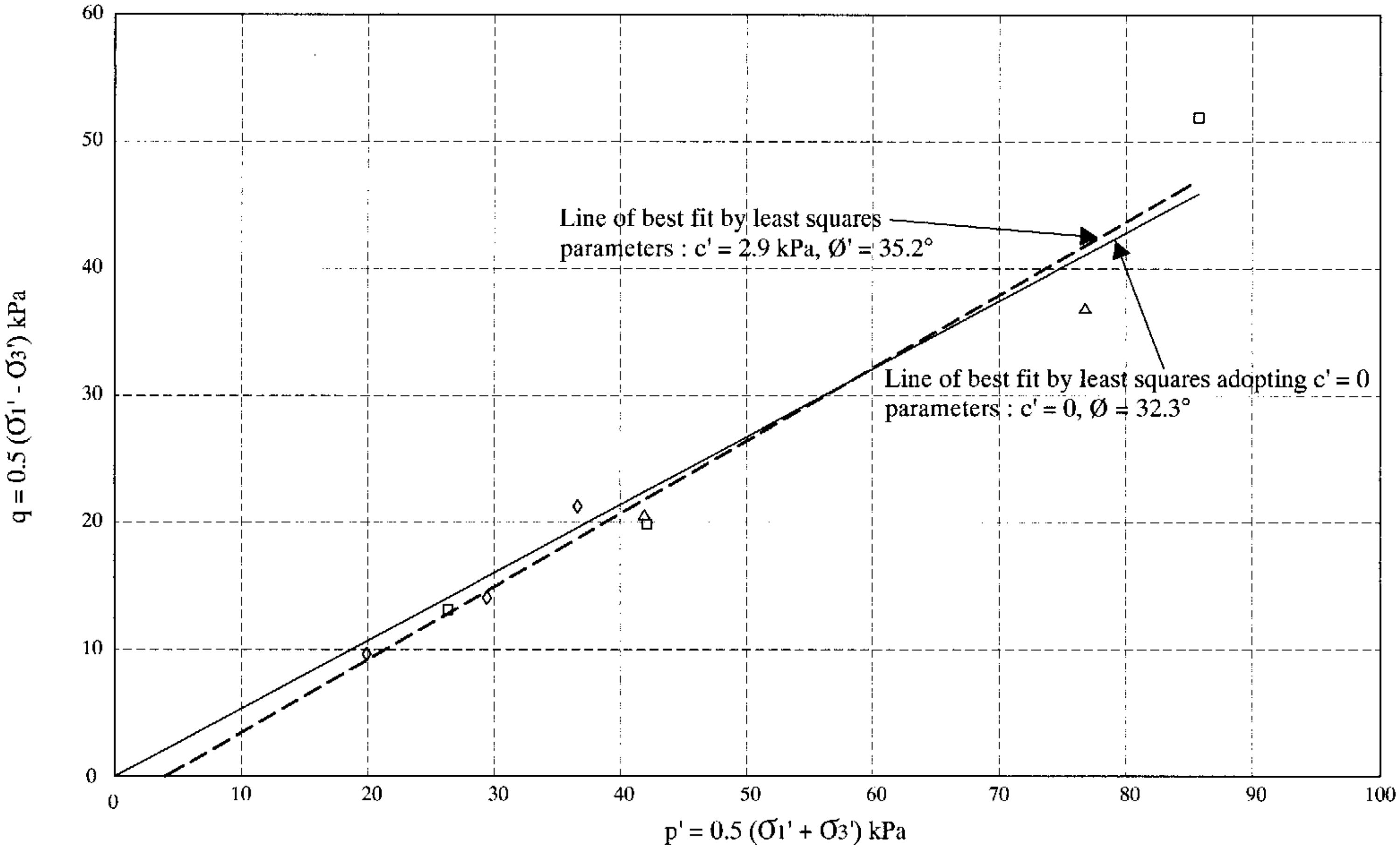


Figure 7 - Geological Section A - A



Note: Base map is extracted and reduced from survey sheets no. 11SW-14A and 14C, dated May 92 and Mar 92 respectively, scale 1 : 1000.

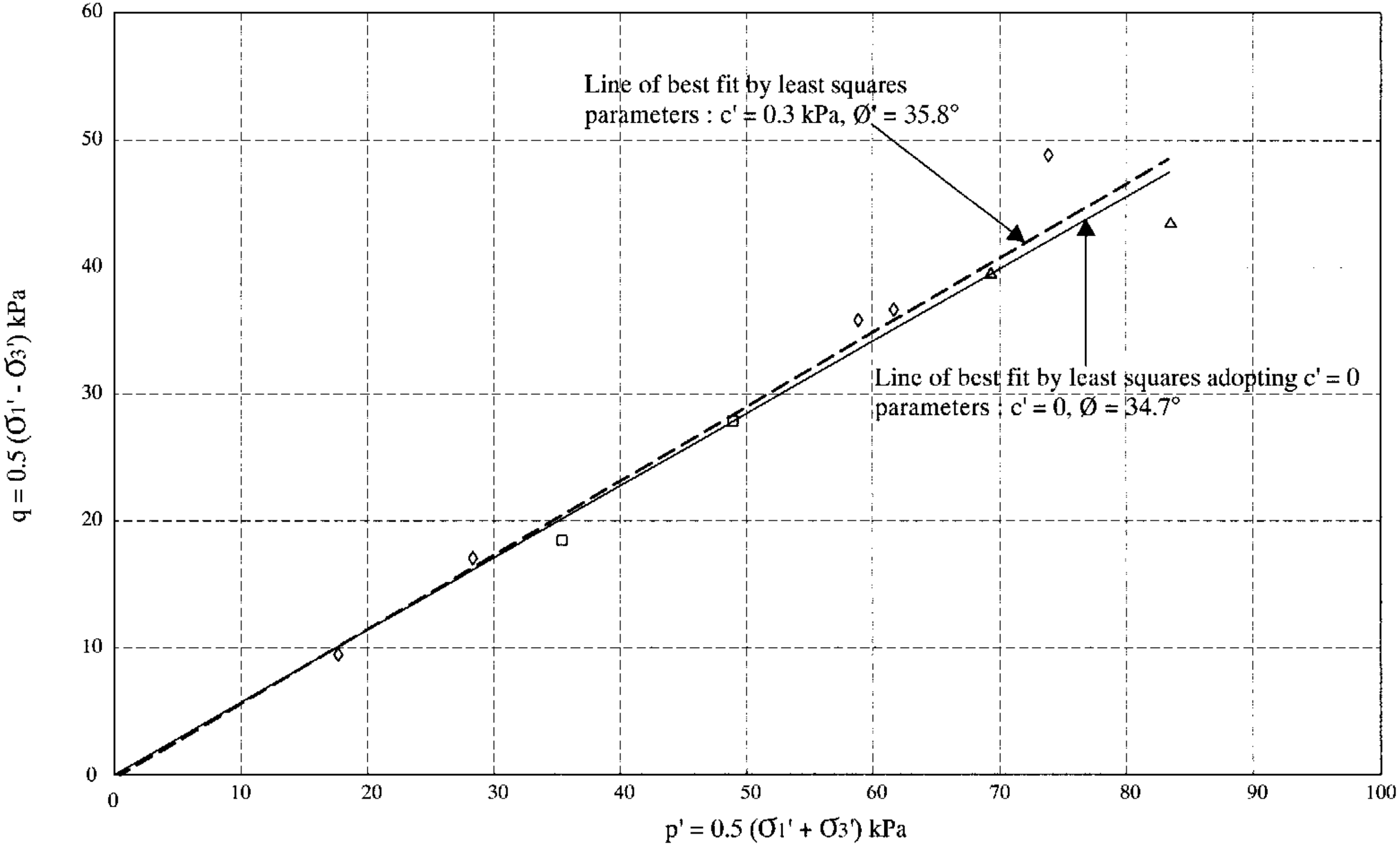
Figure 8 - Locations of Previous Instability



Legend :	◊ Multi-stage test (first stage)	σ_1'	Major principal effective stress	c'	Cohesion
	□ Multi-stage test (second stage)	σ_3'	Minor principal effective stress	Ø'	Angle of shearing resistance
	△ Multi-stage test (third stage)				

Note : Triaxial compression test results (with p' < 100 kPa) correspond to those at the point of maximum deviatoric stress, i.e. $\sigma_1' - \sigma_3'$.

Figure 9 - Triaxial Compression Test Results for Young Colluvium



Legend : ◊ Multi-stage test (first stage) □ Multi-stage test (second stage) △ Multi-stage test (third stage)

σ_1' Major principal effective stress

σ_3' Minor principal effective stress

c' Cohesion

Ø' Angle of shearing resistance

Note : Triaxial compression test results (with p' < 100 kPa) correspond to those at the point of maximum deviatoric stress, i.e. σ_1'-σ_3'.

Figure 10 - Triaxial Compression Test Results for Old Colluvium

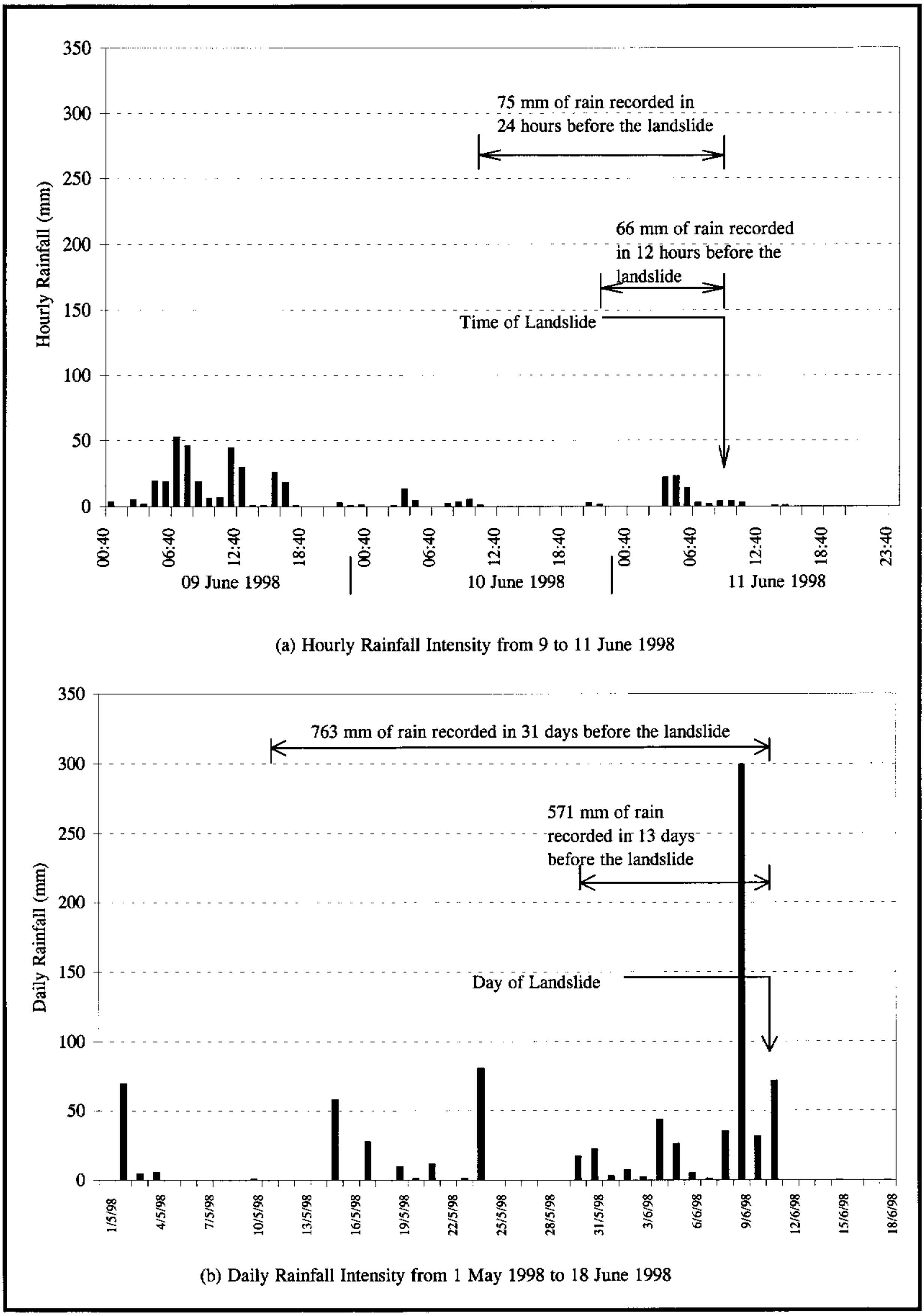
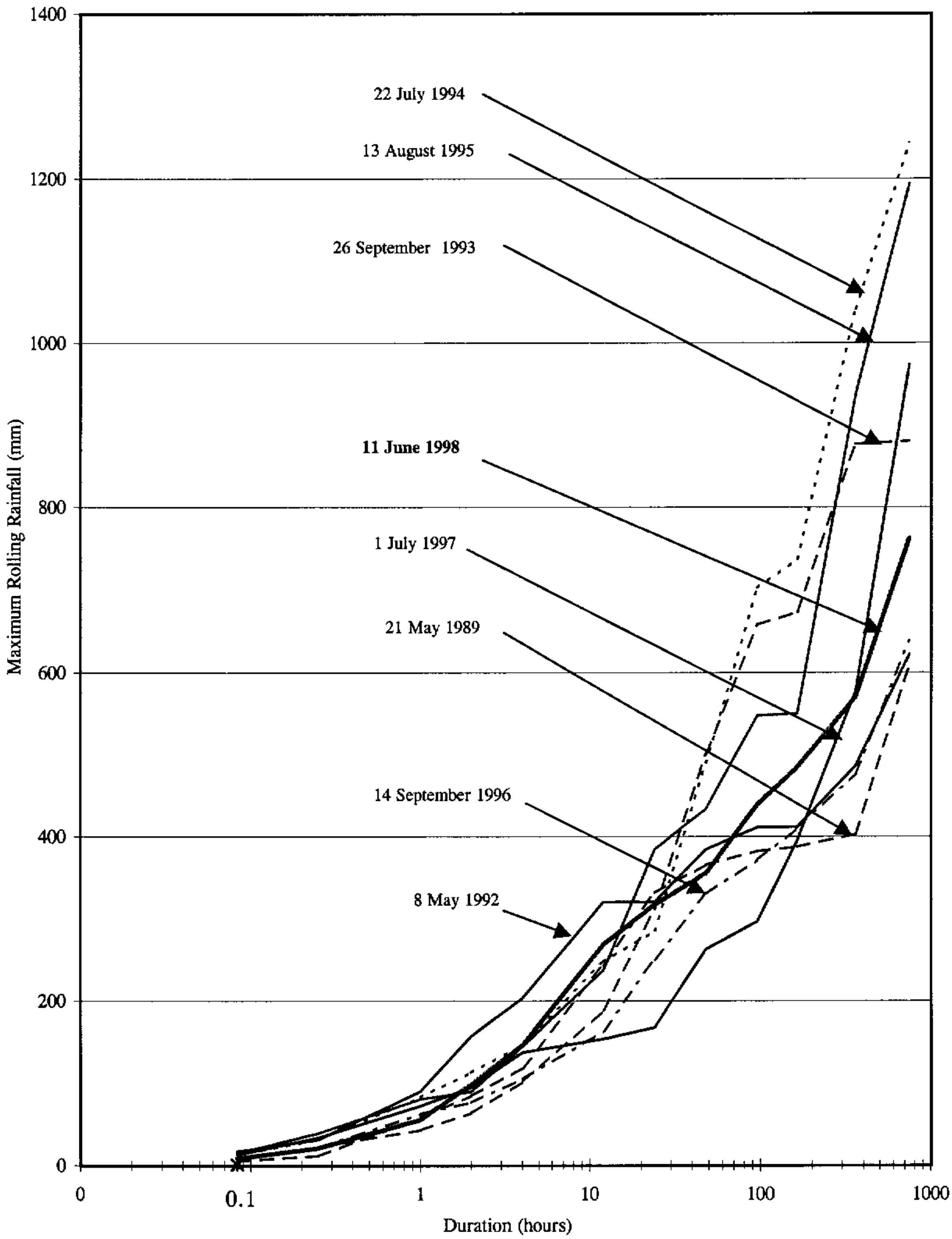


Figure 11 - Rainfall Records of GEO Raingauge No. H17

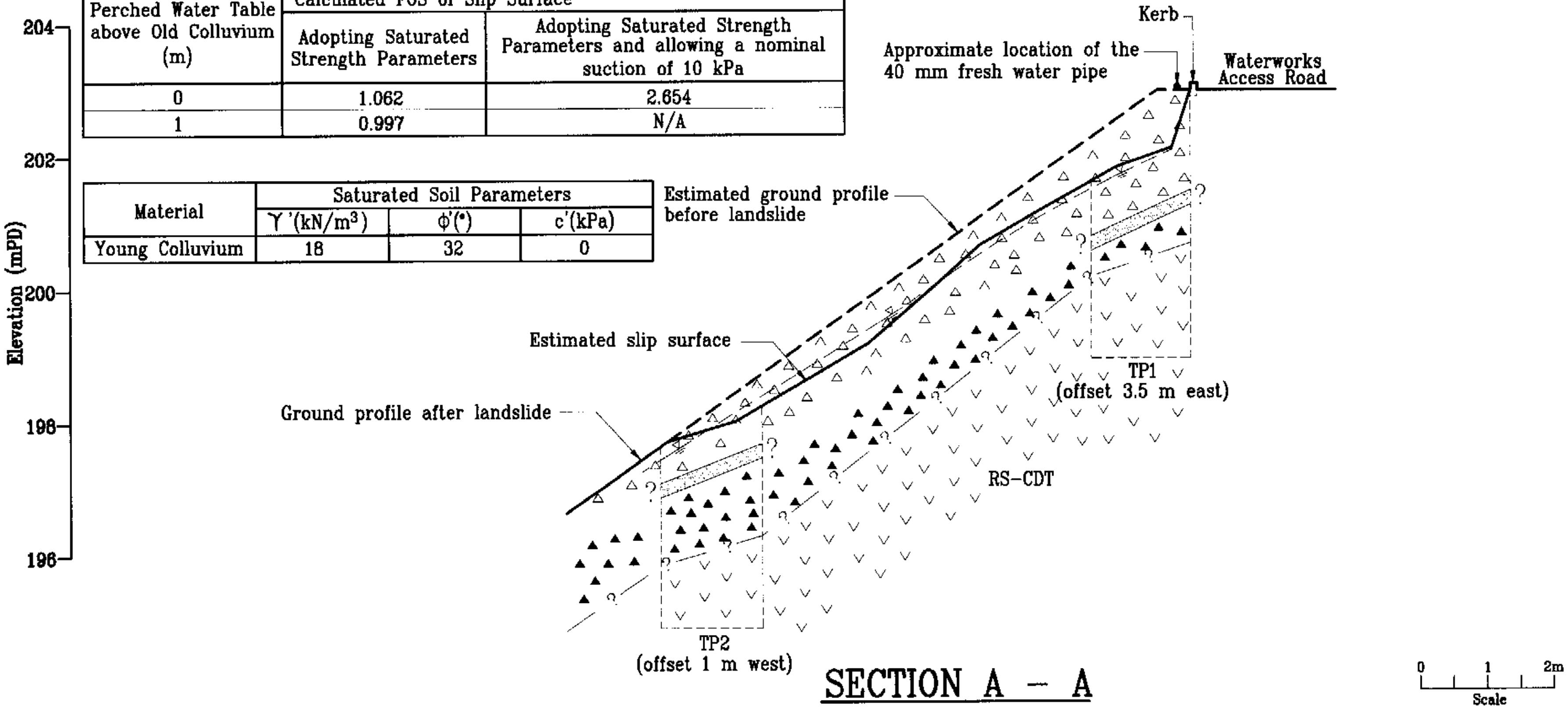


Notes : (1) Rainfall data are 5-minute statistics from GEO raingauge No. H17 except for rainstorm on 13 August 1995.
(2) Due to malfunction of raingauge No. H17 during August 1995, rainfall data from raingauge No. H22, which is at about 270 m north-east of the landslide location, are used for the rainstorm on 13 August 1995.

Figure 12 - Maximum Rolling Rainfalls at Raingauge No. H17 for Major Rainstorms

Perched Water Table above Old Colluvium (m)	Calculated FOS of Slip Surface	
	Adopting Saturated Strength Parameters	Adopting Saturated Strength Parameters and allowing a nominal suction of 10 kPa
0	1.062	2.654
1	0.997	N/A

Material	Saturated Soil Parameters		
	γ'(kN/m³)	φ'(°)	c'(kPa)
Young Colluvium	18	32	0



SECTION A – A

Legend:

△	Young Colluvium	RS-CDT	Residual Soil – Completely Decomposed Tuff	———	Geological Boundary
(stippled)	Old Topsoil	M/SDT	Moderately to Slightly Decomposed Tuff	– – – –	Geological Boundary (Inferred between trial pits)
▲	Old Colluvium			— ? —	Geological Boundary (Inferred below trial pits)
V	Tuff				

Notes:
(1) See figure 4 for location of section.
(2) Information shown on this figure is based on ground investigation works and geological mapping.
(3) Tree root effects have not been taken into account in the soil strength parameters.

Figure 13 - Theoretical Slope Stability Analyses

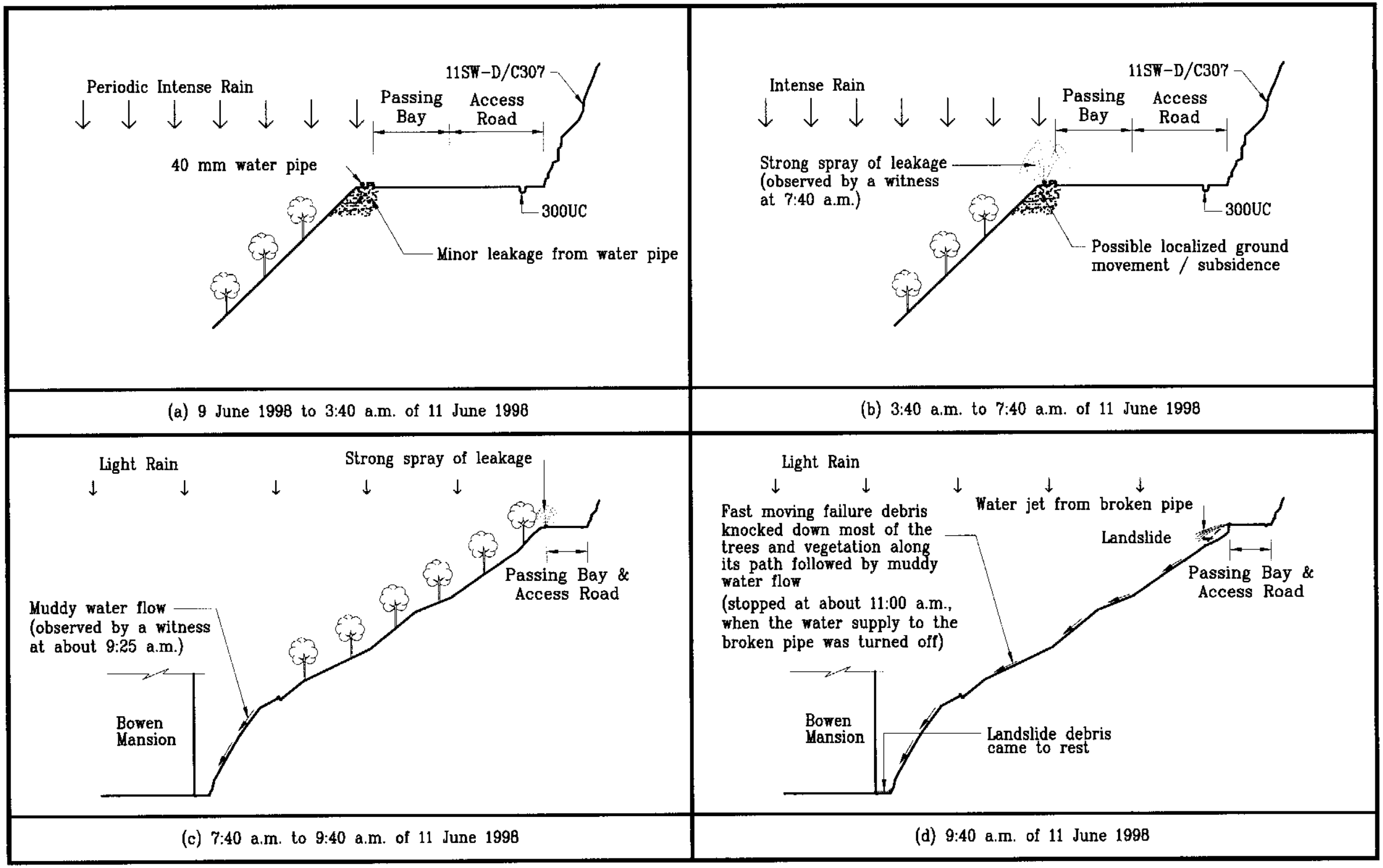


Figure 14 - Probable Sequence of Events

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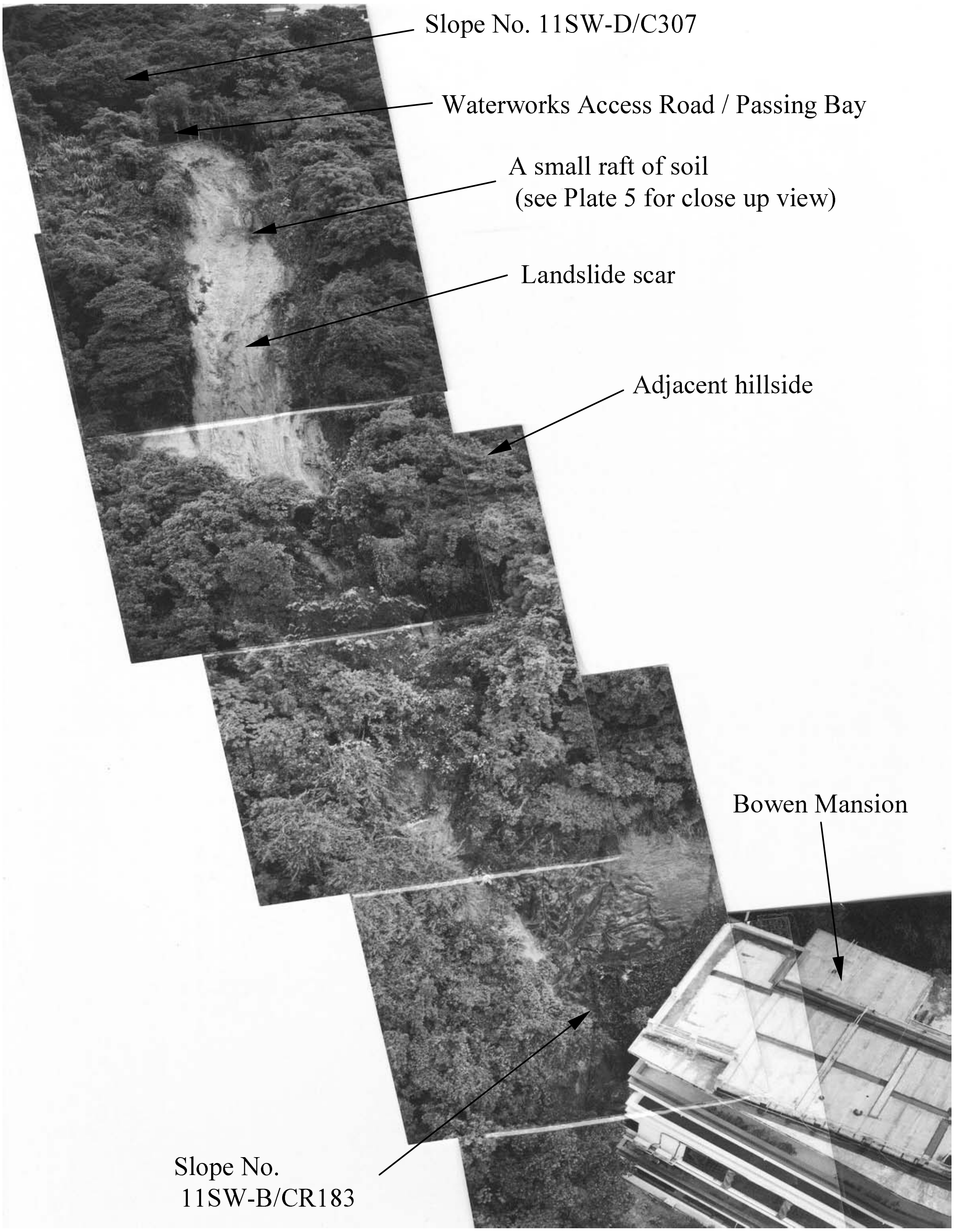


Plate 1 - General View of the Landslide
(Photograph taken on 11 June 1998. See Figure 4 for Location of Photograph)

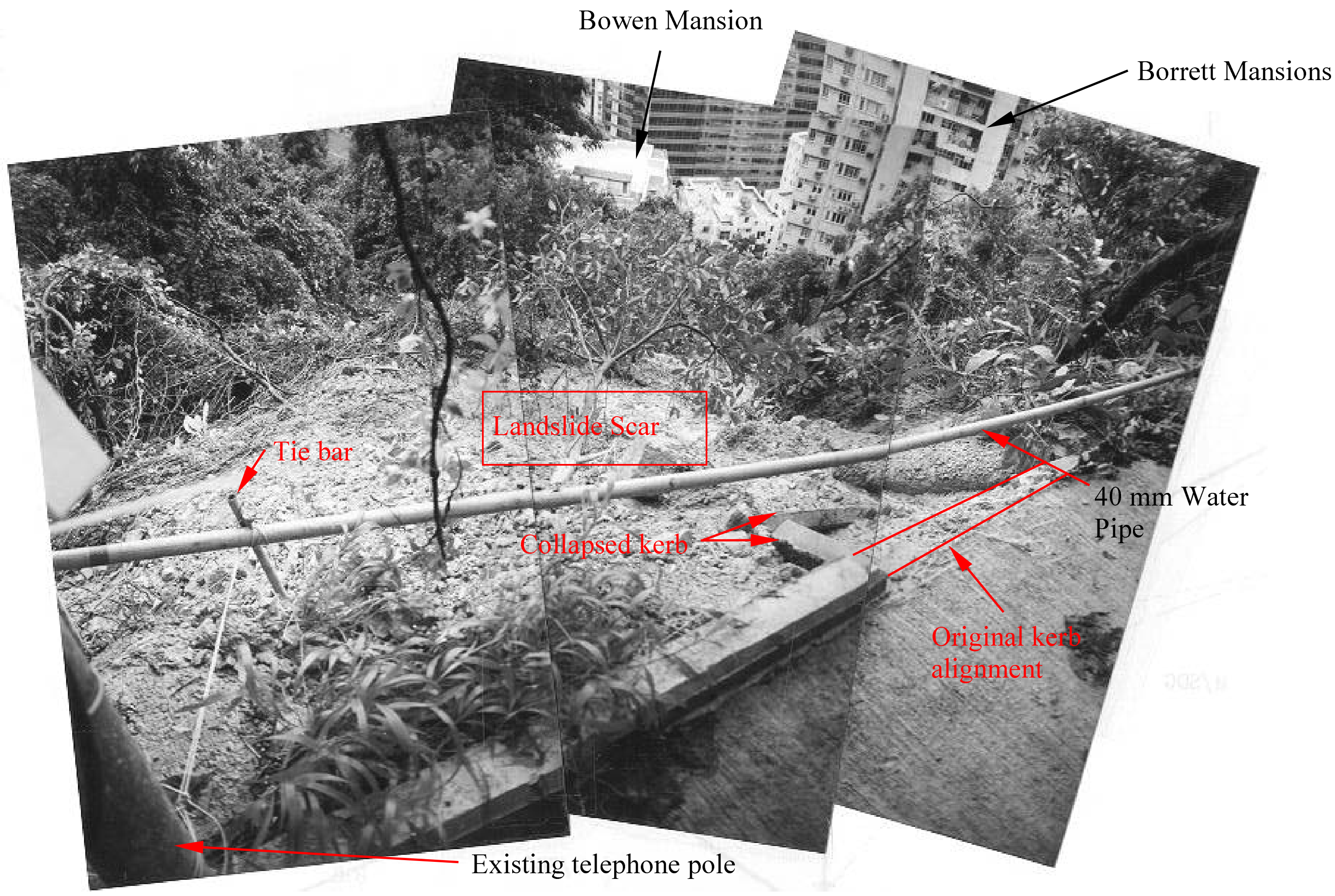


Plate 2 – General View of the Landslide Scar near the Crest
(Photograph taken on 11 June 1998. See Figure 4 for Location of Photograph)

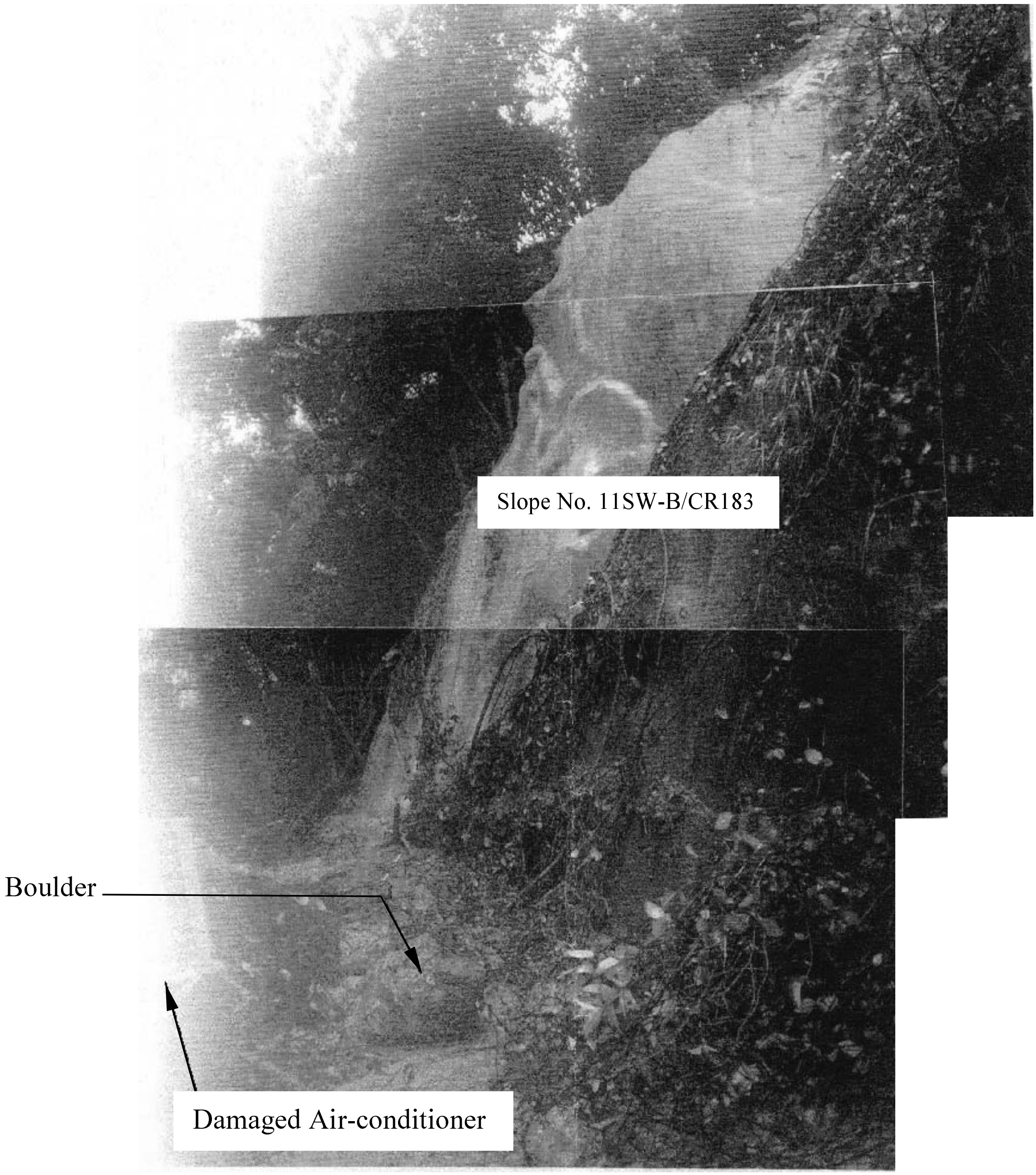


Plate 3 - Landslide Debris deposited at the Rear Yard of Bowen Mansion (Photograph taken on 11 June 1998. See Figure 4 for Location of Photograph)

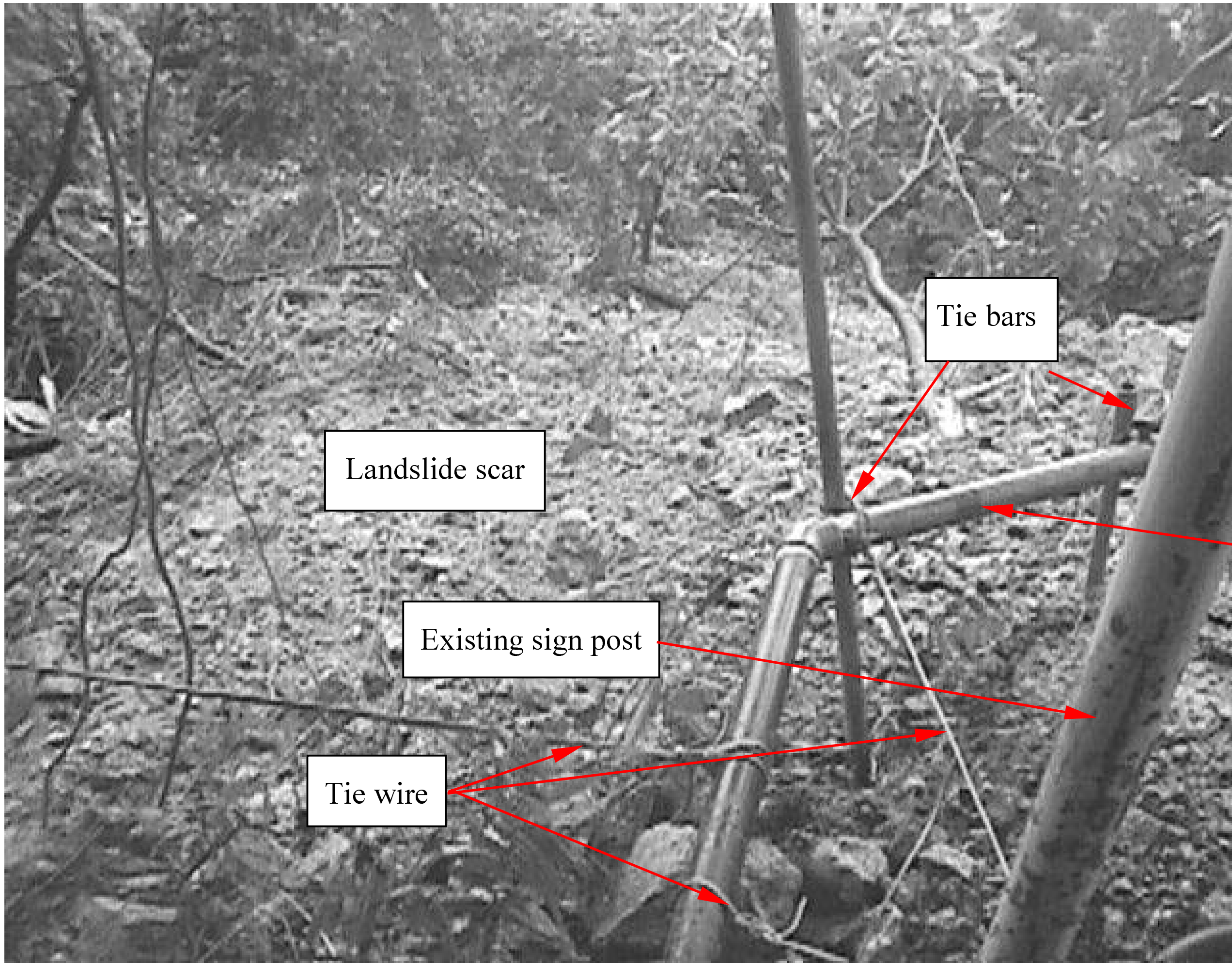


Plate 4 - Large Amount of Cobble-sized Debris Scattered near Slope Crest
(Photograph taken on 11 June 1998. See Figure 4 for Location of Photograph)

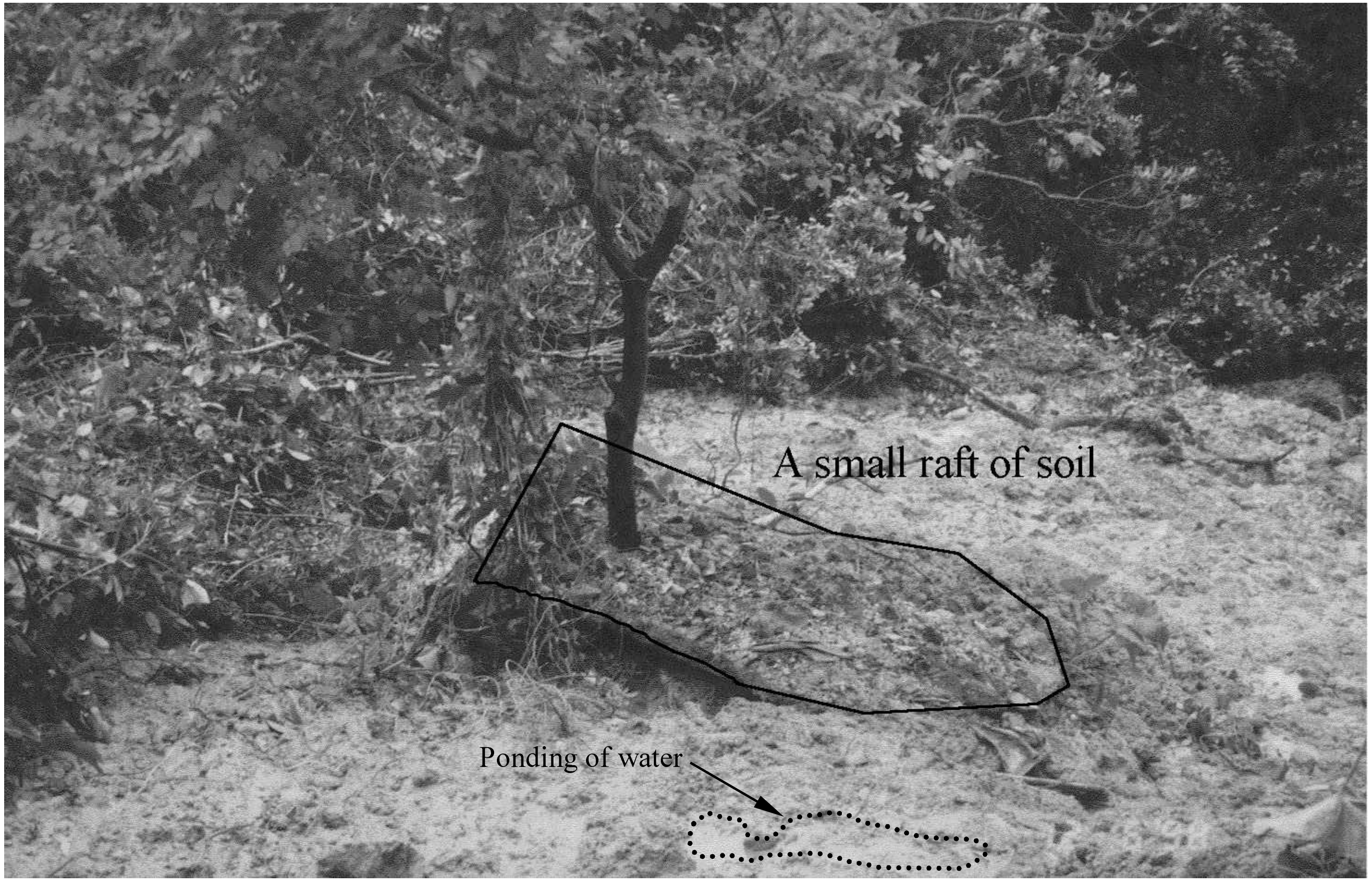


Plate 5 - A small Raft of Soil near Slope Crest
(Photograph taken on 12 June 1998. See Figure 4 for Location of Photograph)

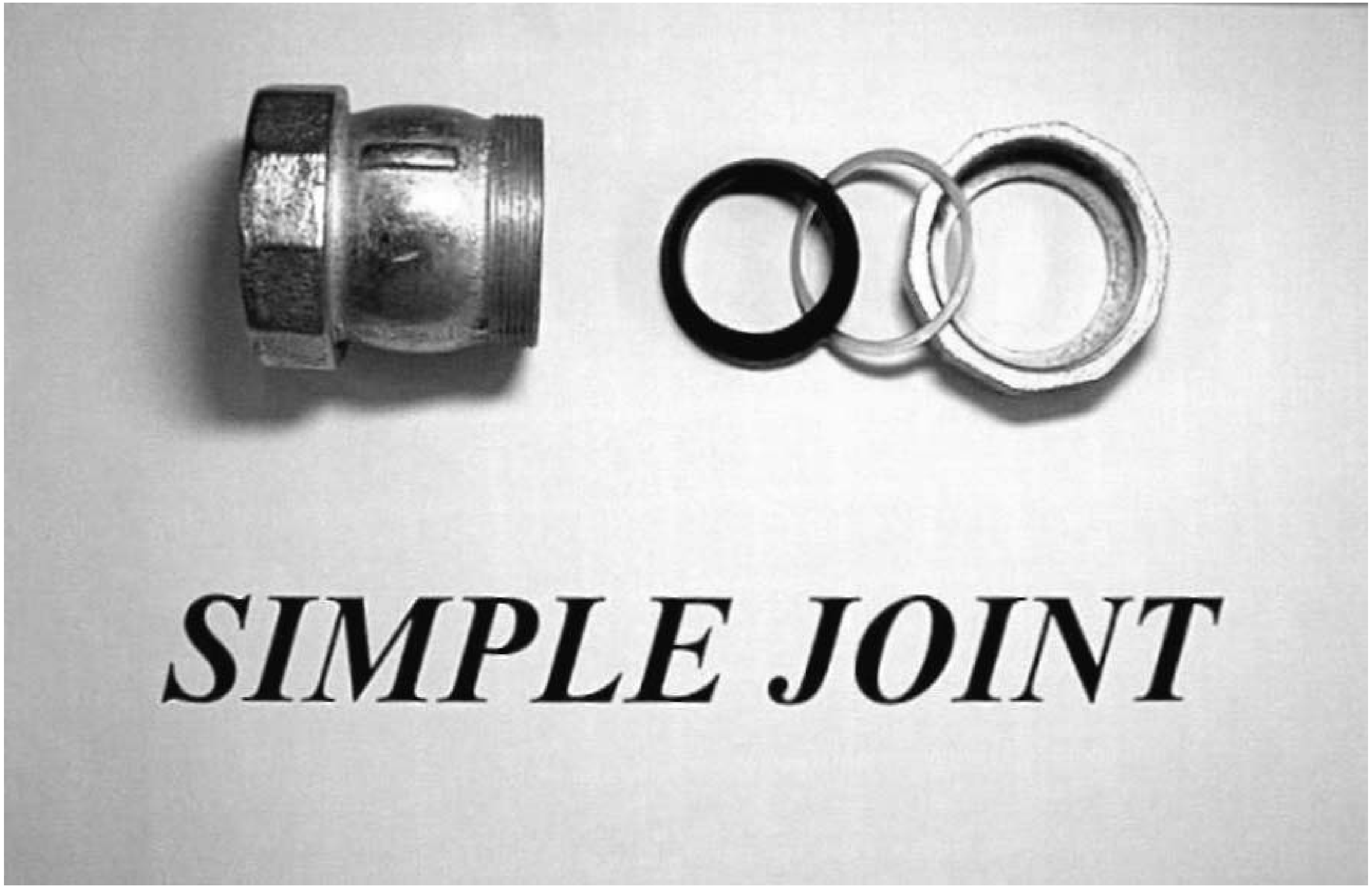


Plate 6 - Details of Simple Joint

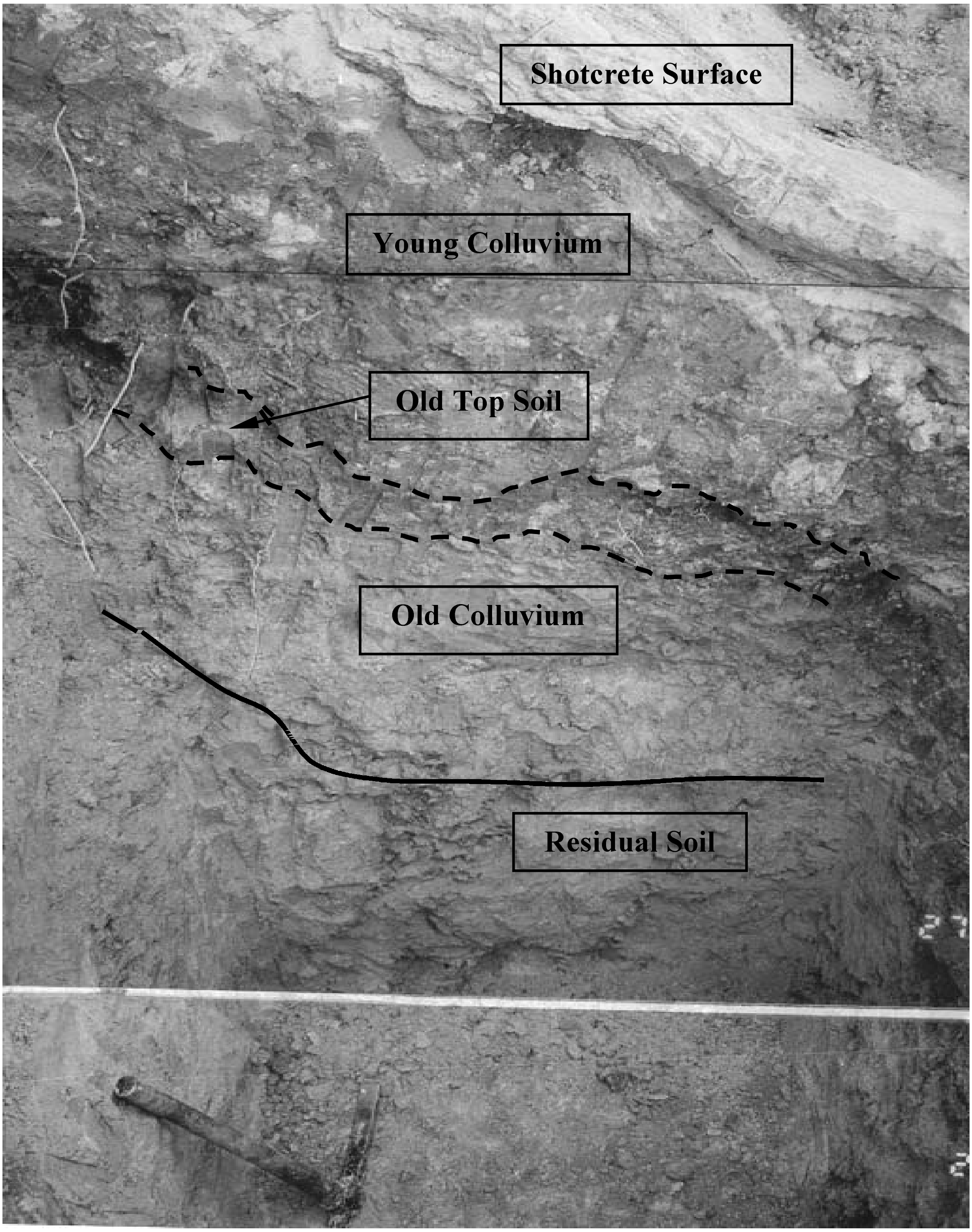


Plate 7 - Subsoil Profile Exposed in Trial Pit TP1
(Photograph taken on 27 August 1998. See Figure 4 for Location of Photograph)

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

CONTENTS

A.1 GEOMORPHOLOGY

The key geomorphological features interpreted from aerial photographs in the immediate area of the landslide site are illustrated in Figure A1.

A.2 SITE HISTORY

The following site history has been interpreted from the aerial photographs taken between 1924 and 1997.

YEAR	**OBSERVATIONS**
1924	Magazine Gap Road has been formed. The landslide location is a natural slope covered by dense vegetation. There is no indication of any footpath or access road on this slope.
1949	A footpath has been formed trending NE for about 70 m from Magazine Gap Road, then SE towards a formed area (Figure A2). From the 1959 Survey Plan of the area it can seen that the footpath follows closely the alignment of the present access road as illustrated in Figure A3. At the point where the footpath turns towards the SE, it traverses a SSE-NNW trending spur. There appears to be a small amount of cutting into this spur but it is uncertain as to whether this is through rock or soil. The footpath also appears to be wider at this point partly as a result of the cutting described above, but also due to the presence of a natural platform on this portion of the spur. This area approximately corresponds to the area currently occupied by the passing bay. The slope below the footpath is mostly densely vegetated with high shrubs and trees. However, one portion of the slope (that which comprises the lower slope at present, to the north of the break in slope gradient identified on the 1963 photographs), is sparsely vegetated suggesting that this area has been subjected to either past instability or tree clearance. However, the former is not supported by any other evidence such as a landslide scarp or scar. The area is illustrated in Figures A1 and A2. The slope below Magazine Gap Road between the footpath and the reservoir has a similar tone and texture to that noted above, and may also have been subjected to vegetation clearance.
1961	The reservoir access road has not yet been constructed.
1963	A vehicular access road joining the Magazine Gap Road Service Reservoir (under construction) and Magazine Gap Road can be clearly seen in the photographs. A passing bay has been constructed where the original path turned SE on the natural platform. The alignment of the northern edge of this access road and the passing bay appears to closely follow that of the original footpath noted in 1949. Although the western and northwestern edges of the passing bay are obscured by

YEAR	OBSERVATIONS
1963 (continue)	tree cover, the east side of the bay is visible and appears to be partly formed with a small vertical feature (Figure A5a). The vertical feature can only be clearly seen on the 1963 photographs. For the subsequent years until 1980 the area is generally obscured by tree cover (with the exception of 1968 – see below). To the east of the vertical feature there appears to be an area formed between the kerb marking the outer edge of the passing bay, and the existing slope, as illustrated in Figure A5a. The formed area is very likely the outer edge of the natural ground covered by a small amount of reworked material (possibly fill related to the pavement construction). It is expected that the kerb was formed in such a position to provide a suitable outer edge to the passing bay on the platform. Therefore, the formed area probably served no particular purpose. The slope to the south of the passing bay (i.e. that below Magazine Gap Road) has been cut through the spur suggesting that the road at the location of the passing bay was formed mainly by cutting rather than filling. A recent site visit confirmed that the cut at this location is through slightly to moderately decomposed volcanic rock. Evidence of spoiling (fill) is seen on the slope below the access road towards the reservoir (at a location approximately 25 m and beyond, to the east of the passing bay), and between the trees downslope of the access road in the valley to the west of the passing bay. It is possible that the spoil to the west of the passing bay is slightly older than that to the east as it has a darker tone and texture. The spoil is likely to be thin as most of the trees appear to have survived the filling process, and is probably from the slope cutting during construction of the access road. Judging from the observed increased density of tree and vegetation growth, and the change in ground topography, it appears that the extent of road construction filling stops about 10 m before the western edge of the passing bay. Below the access road Bowen Mansion has been constructed and a large cut slope formed at the rear of the building. A drainage channel has been formed to the south of the cut slope (Figure A4). The sparsely vegetated area in 1949 is now fully vegetated. A change of slope gradient between the access road and Bowen Mansion, also detected on the 1949 photographs, is noticeable and is illustrated in Figure A3.
1967	Spoiled areas below the road towards the reservoir are now fully vegetated.
1968	The passing bay appears to have the same shape as that in 1963. In these photographs the area was not obscured by vegetation.
1980	The alignment of the passing bay now appears to be continuous suggesting minor filling in the area previously occupied by the vertical feature, i.e. about 5 m to the east of the area involved in the 1998 landslide (Figure A5b).

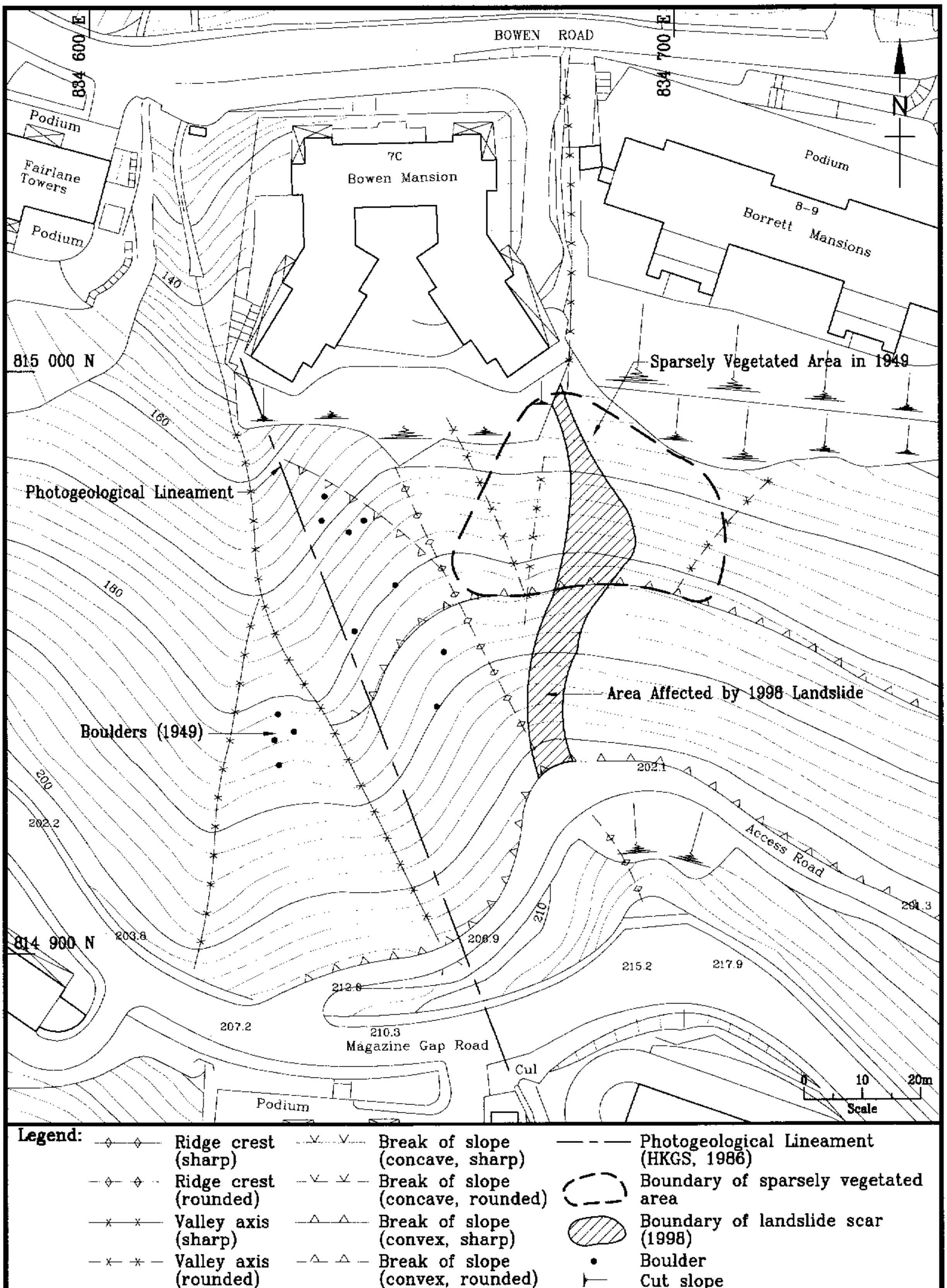
YEAR	**OBSERVATIONS**
1989	The outer edge of the passing bay appears to be covered by shrub vegetation to such an extent that the width of the passing bay is restricted.
1989-97	No major changes are apparent.

A.3 LIST OF PHOTOGRAPHS

A full list of aerial photographs used in this API study is shown below:

YEAR	**PHOTOGRAPHS**			
1924	Y36	Y37		
1949	Y1414 Y1467	Y1415 Y1468	Y1416 Y1469	
1961	High Altitude			
1963	Y7454 Y7512	Y7455 Y7513	Y7456 Y7514	
1967	Y13277 Y13302	Y13278 Y13303	Y13279	
1968	Y14102 (stereopair not available)			
1972	97	98	99	1646 (oblique)
1973	7077	7078	7079	
1976	12647	12648		
1977	19693 18429	19694 18430	 18431	
1978	23872 23898	23873 23899	23874 23900	
1979	26916 27154	26917 27155	 27156	
1980	29832 31967 28986 29815	29833 31968 28987 29816	 31969 28988	
1981	37406	37407		
1982	43062	43063	43064	
1983	48140 (oblique)			
1984	56624 (stereopair not available) 53688 53672	 53689 53673	 53690	
1986	A5956	A5957		
1987	A10311 A9899 (stereopair not available)	A10312		
1988	A14424 CN2101	A14425 CN2102	A12550 (oblique)	

YEAR	PHOTOGRAPHS		
1989	A17647	A17648	
	A16397 (oblique)		A16398 (oblique)
1990	A23759	A23760	
	A23804	A23805	
1991	A27728	A27729	
	A28055	A28056	
1992	A32501	A32502	
1993	CN4716 (stereopair not available)		
	A36995	A36996	
1994	CN8106	CN8107	CN8108
	CN7914	CN7915	CN7916
1995	CN12633	CN12634	CN12635
1997	CN17059	CN17060	CN17061



Note: (1) Information shown on this figure is based on survey sheet nos. 11SW-14A and 11SW-14C, scale 1 : 1000.

Figure A1 - Location Plan

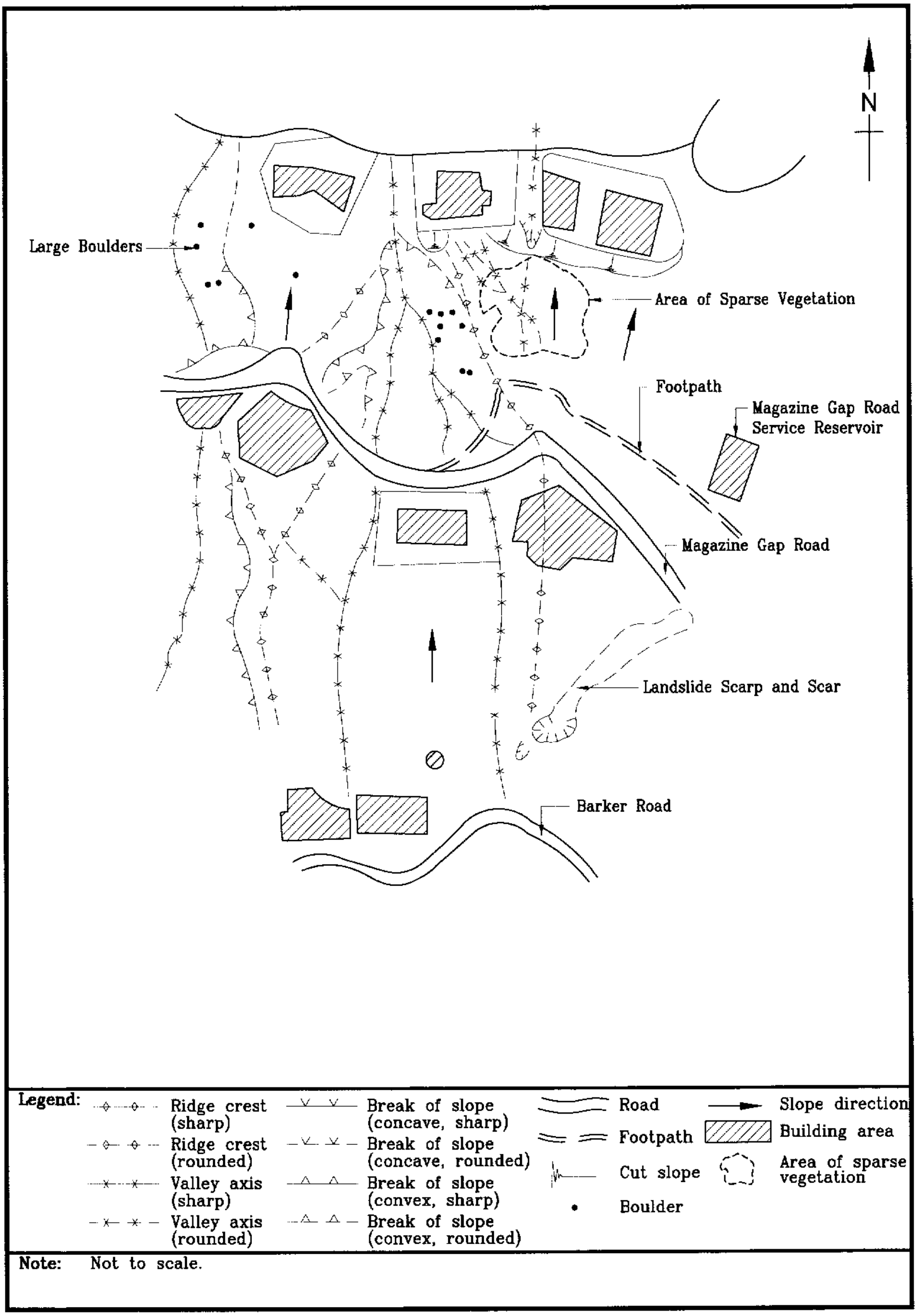
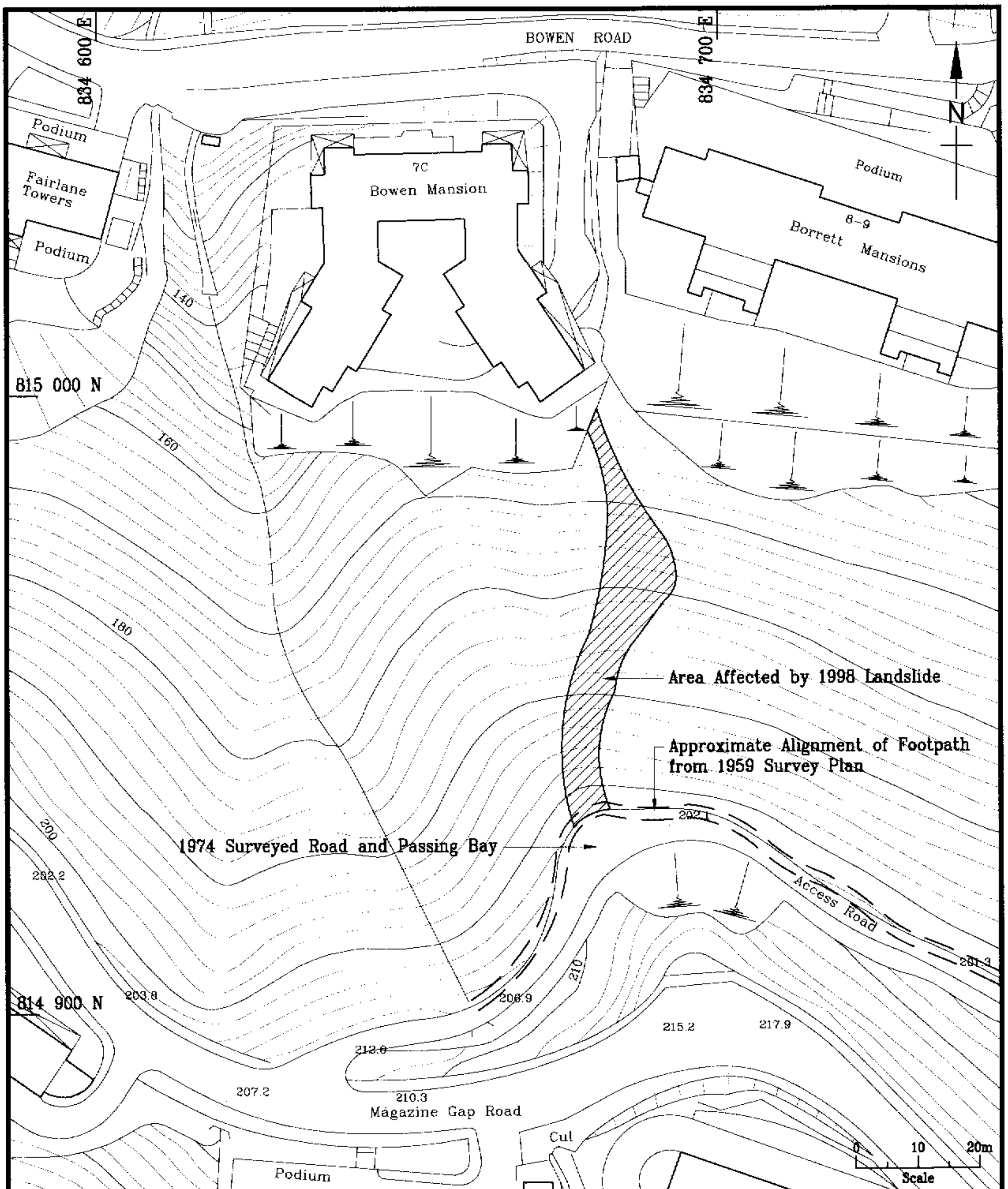


Figure A2 - 1949 Aerial Photograph Interpretation



Legend:

Area affected by 1998 Landslide

Approximate alignment of footpath from 1959 Survey Plan

Cut slope

Note: Information shown on this figure is based on survey sheet nos. 11SW-14A and 11SW-14C, scale 1 : 1000.

Figure A3 - Locations of Present Access Road and Previous Footpath

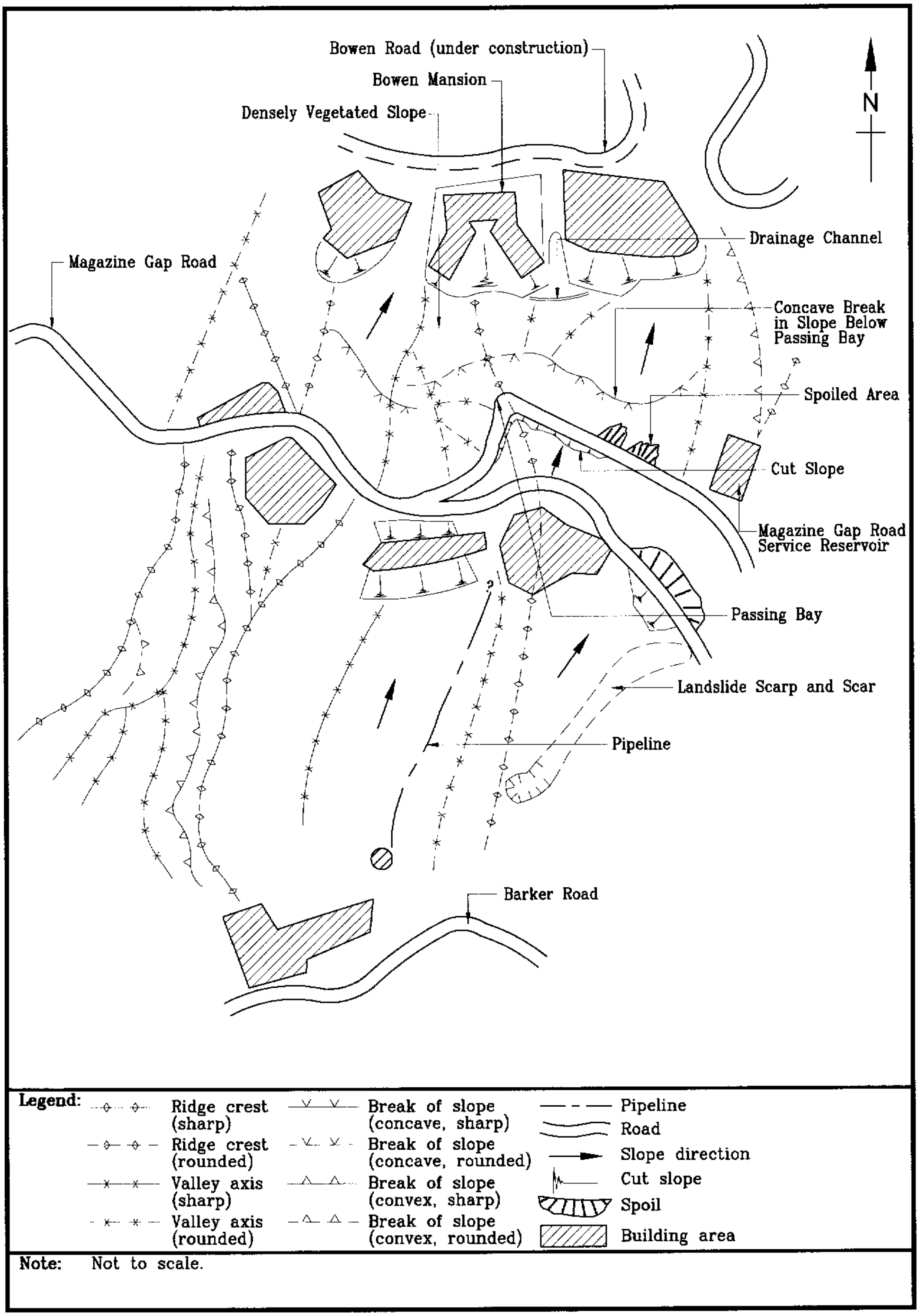


Figure A4 - 1963 Aerial Photograph Interpretation

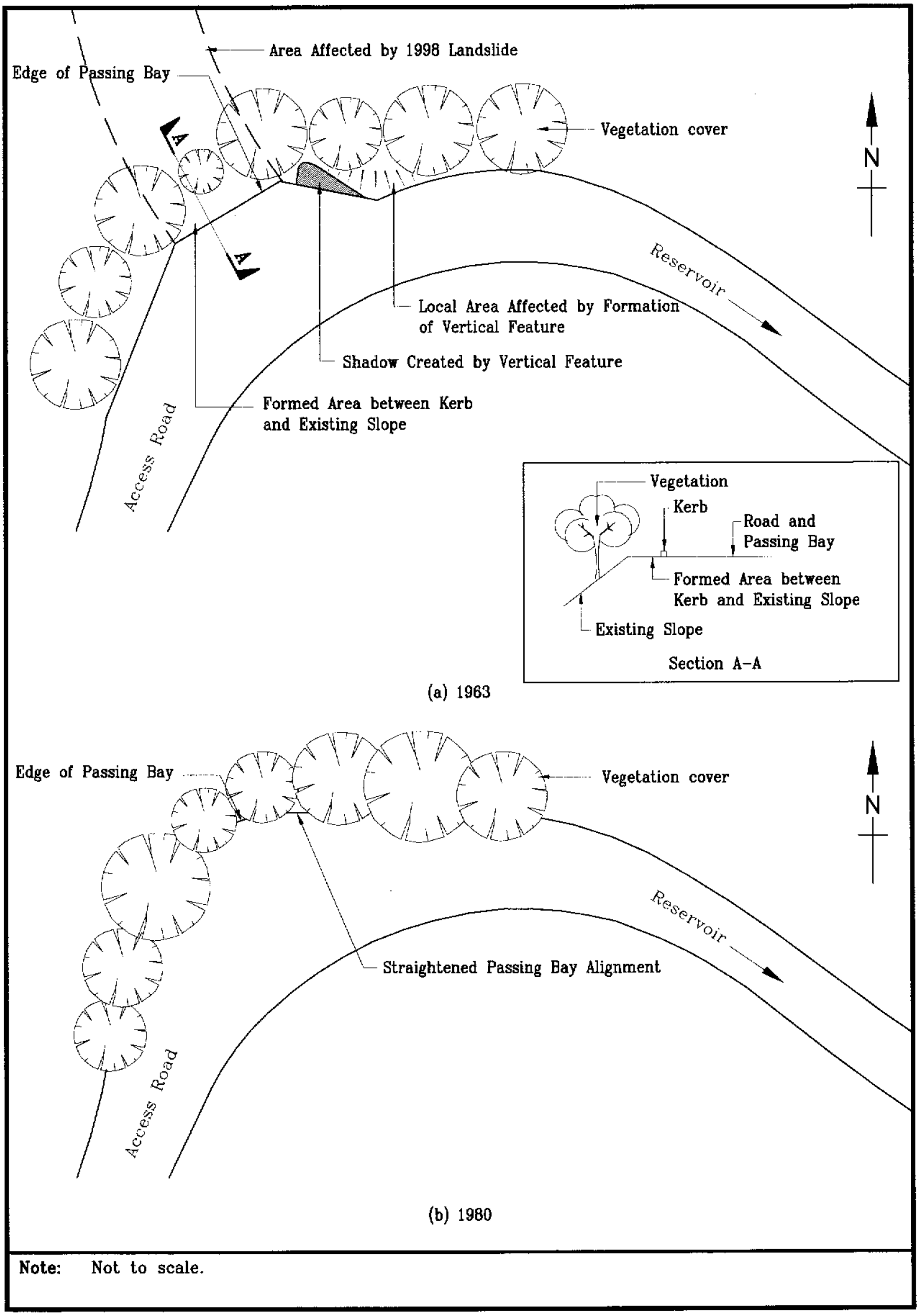


Figure A5 - Sketches of the Passing Bay Area from Aerial Photograph Interpretations

APPENDIX B

BRIEF SUMMARY OF OBSERVATIONS AND EVENTS

CONTENTS

B.1 BRIEF SUMMARY OF EVENTS AND OBSERVATIONS

Time	Events/Observations
Early 1960s	The waterworks access road, together with the passing bay above the landslide site, was formed.
1985	The 40-mm diameter fresh water pipe was installed by WSD along the outward side of the waterworks access road.
January 1997	Concrete pavement of access road and passing bay was constructed by WSD to replace the bituminous surface.
A few weeks prior to landslide	Four pedestrians observed leakage occurring from the 40-mm fresh water pipe at the passing bay.
A few days prior to landslide	Six pedestrians observed leakage occurring from the 40-mm fresh water pipe at the passing bay.
9 to 11 June 1998	Direct infiltration of rainfall into the ground in the hillside below the passing bay due to the rainfall in this period.
11 June 1998 7:40 a.m.	A large amount of water was leaking in the form of a circular spray from a joint in the exposed water pipe at the western of passing bay. Water sprayed onto the access road and the hillside below it.
9:25 a.m.	Muddy water flowed down the hillside behind the east wing of Bowen Mansion (the time that muddy water started flowing down the hillside was not known).
9:35 a.m.	A large amount of water was spraying from the western of the passing bay onto the hillside below.
9:40 a.m.	<u>Occurrence of Landslide</u> Muddy water, soil, boulders and trees suddenly slipped down the hillside initiating at the edge of passing bay. Water jetting out from the western end of the crest of failure scar, apparently discharging from the severed water pipe.
10:20 a.m.	FSD arrived on site. They observed water jetting out from a broken joint at the western end of the severed water pipe onto the landslide scar.
11:00 a.m.	WSD arrived on site. Water supply to the severed water pipe was turned off by WSD staff. Muddy water stopped flowing down the hillside.
11:30 a.m. – 12:30 a.m.	Representatives of GEO, HyD and BD arrived on site.

Time	Events/Observations
A few hours after landslide	Urgent repair works comprising shotcrete applied to failure scar were commenced by HyD’ s contractors.
4:00 p.m.	FSW started inspection of the landslide scar.