DETAILED STUDY OF THE COASTAL LANDSLIDE AT SHEK KOK TSUI, LAMMA ISLAND

GEO REPORT No. 173

MAUNSELL GEOTECHNICAL SERVICES LIMITED

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG

SPECIAL ADMINISTRATIVE REGION

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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.

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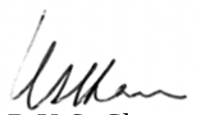

R.K.S. Chan
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December 2005

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FOREWORD

This report presents the findings of an investigation into the history of instability of a massive coastal landslide at Shek Kok Tsui, Lamma Island. The estimated total volume of detached material from several episodes of instability is about 25,000 m^3. Debris derived from the landslide complex, much of which has been deposited in the sea, has a travel angle of approximately 25°.

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

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

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

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1. INTRODUCTION

Geomorphological evidence suggests that a massive coastal landslide with a history of retrogressive instability had affected the natural terrain on the northwest-facing coastal hillside of Shek Kok Tsui, which forms a small headland on the northwest of Lamma Island (Figure 1 and Plate 1). Possible relict coastal landslides may have played a role in recent significant landslide incidents such as the 1999 Shek Kip Mei landslide. To enhance the understanding of the causes and mechanisms of sizeable relict landslides on natural terrain in a coastal setting, this landslide was selected for the present study because of its substantial size and signs of recent movement.

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

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

(a) reviewing relevant background information and previous studies relating to landsliding within the site,

(b) aerial photograph interpretation (API),

(c) detailed geomorphological and engineering geological mapping,

(d) limited ground investigation, and

(e) establishing the probable sequence of landsliding and diagnosis of the probable mechanisms and causes of the sizeable landslides on natural terrain in a coastal setting.

2. THE SITE

2.1 Site Description

The site is located on the northwest-facing coastal hillside of Shek Kok Tsui at the northwest corner of Lamma Island (Figure 1 and Plate 1). Shek Kok Tsui, which has a maximum elevation of approximately 61 mPD, forms a small headland bounded by northwest-facing and southwest-facing coastlines, approximately 25 m above the main scarp of the subject landslide.

The hillside adjacent to the landslide scar has gradients that range between approximately 32° and 50°. The hillside, with intermittent areas of rock outcrop, is vegetated with grass, ferns and bushes and is strewn with numerous large corestones.

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The coastline facing southwest comprises wave-cut rock platforms, whereas the coastline facing northwest, which also has wave cut platforms, comprises a succession of boulder accumulations, cliffs and small beaches.

2.2 Regional Geology

Sheet 14 of the HKGS 1:20,000 scale solid and superficial geology map of Cheung Chau (GEO, 1995) indicates that the landslide site is underlain by ‘debris flow deposits’ (Qd) with a boundary that is similar in shape to the outline of the landslide scar (Figure 2). Fine-grained granite is shown as the parent rock, but a contact with medium-grained granite is shown just behind the main scarp of the landslide. Medium-grained quartz syenite and coarse ash crystal tuff outcrop about 200 m to the east of the landslide site. A cluster of north-northwest trending faults and similarly trending sub-vertical joints are shown to cut the coarse ash crystal tuff near Pak Kok San Tsuen, about 700 m to the east of the site.

2.3 Geological Area Studies Programme

The Geotechnical Area Studies Programme (GASP) Report No. X (1988) - Islands, provides the geotechnical information within the study area, relating to planning and land use management. GASP Report No. X indicates that the site falls within a zone of general instability. The solid geology is identified as coarse ash tuff although as shown on HKGS Map Sheet 14 and confirmed by site inspection (see Section 4.4) the solid geology within the landslide site mostly comprises fine-and medium-grained granite.

3. SITE DEVELOPMENT HISTORY AND PAST INSTABILITY

3.1 General

The history and past instability of the site have been determined from aerial photograph interpretation (API) together with a review of relevant existing documentary information. Details of the findings of the API review are given in Appendix A.

3.2 Site Development

The landslide scar at the current location of the landslide site can be seen in the 1945 aerial photographs, although the extent of the landslide scar at that time was smaller. The earliest low-altitude aerial photographs with good resolution, viz. the 1963 photographs, show only a few apparent anthropogenic features within the general area of Shek Kok Tsui headland, including unpaved footpaths to the southeast of the landslide site and occasional graves to the west of the study area. No evidence of any human influence can be seen within the landslide site itself. The landslide site at this time was sparsely vegetated with mainly low grasses. After 1963, the aerial photographic records show no further human influence within or adjacent to the landslide site. By the early 1990s, bushes and small trees had established within the area of the landslide site. No evidence of hillfires within, or in the vicinity of, the landslide site can be observed from API.

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3.3 Natural Terrain Landslide Inventory and Large Landslide Database

The subject landslide is recorded in the GEO's Natural Terrain Landslide Inventory, which was based on the high altitude (20,000 feet) aerial photographs, as tag No. 0075 on map sheet No. 14NE-B. The records indicate that the landslide was first observed on the 1975 high altitude aerial photographs. The width of the landslide scar at the widest point was classified as '2', i.e. greater than 20 m, and the landslide source was recorded as being totally bare of vegetation. Also included in the NTLI record is the ground slope angle of 45° at the crown, also based on the API.

The subject landslide is also recorded in the GEO's Large Landslide Inventory as tag No. 075L from the same map sheet. Based on aerial photographs taken in 1963, 1975 and 1996, the scarp was described by the consultant who compiled the Large Landslide Inventory as sharp, dissected and vegetated and the morphology was described as hummocky, angular blocks and disturbed drainage.

3.4 Previous Studies and Ground Investigations

In 2001, the Planning Division of the GEO carried out a preliminary investigation of three large coastal landslides which includes the subject landslide (Appendix B). The study included marine geophysical seismic surveys and marine drillholes. The purpose of the seismic surveys was to investigate the morphology, extent and thickness of the near-shore coastal deposits, to determine if a coastal landslide lobe could be confirmed and locate the bedrock surface. A plan showing the seabed levels and the locations of the drillholes are presented in Figure 3. A cross-section showing the seabed profile and estimated rockhead levels is presented in Figure 4.

In March 2001, two marine drillholes were sunk by Gammon Construction Ltd, under the GEO's Ground Investigation - Marine Works Term Contract. Drillholes Nos. LI1 and LI2, with continuous sampling, were drilled to depths of about 12 m and 10 m below the seabed respectively using cable tool boring techniques at locations some 80 m to the northwest of the toe of the landslide site. There are no other records of any nearby ground investigation works in the Geotechnical Information Unit (GIU) of the CED.

In drillholes Nos. LI1 and LI2, boulder deposits, with an intercalated shelly sand layer were found to overlie thin sand and an unknown thickness of completely decomposed granite (Appendix B). The base of the landslide debris was located at elevations of between about -7.9 mPD and -9.5 mPD.

In January and February 2001, the Institute of Geophysical and Geochemical Exploration (IGGE) carried out the marine geophysical surveys off the coast of the subject landslide site, under the GEO's Geophysical Surveys Term Contract.

The marine vessel used to carry out the geophysical survey was unable to get close enough to the shoreline to define the location of the potential debris lobe. Although the chirp sub-bottom seismic profiling was considered unsatisfactory, the boomer seismic surveys were considered clear and usable. The cross-section based on the geophysical survey (Figure 4) indicates that there is a high point in the rockhead with little superficial deposits (highest point

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at approximately -4 mPD) between about 100 m and 150 m from the shoreline. Between this location and the shoreline at the landslide site, the seabed and rockhead levels drop to approximately -6 mPD and -9 mPD respectively with superficial deposits at a maximum thickness of about 2 m.

Aerial photographs revealed that the landslide occurred prior to 1963 (Appendix B). Initial field reconnaissance identified evidence of faulting and associated shearing on the cliffs to the south of the failure and suggested that the failed material probably included the entire weathering profile, comprising completely weathered granite and some corestones, and rectangular granitic blocks derived directly from the bedrock (Appendix B).

Age dating was attempted using luminescence and radiocarbon methods on samples taken from both drillholes Nos. LI1 and LI2 respectively, within possible debris lobe material from the subject landslide. However, the dating results from these tests were highly variable and proved inconclusive.

3.5 Past Instability Identified from Aerial Photograph Interpretation

3.5.1 General

As part of this detailed landslide study, API using all the available low-level aerial photographs was carried out. Continued instability within the landslide site has been identified. The following sections summarise the retrogressive development of the landslide scar between 1945 and the present day. Detailed API observations are presented in Appendix A. Orthorectified images of the site, which have been prepared using the scanned extracts of the 1963, 1978 and 2002 aerial photographs, are shown in Figures 5, 6 and 7 respectively to illustrate the development of landsliding over time.

3.5.2 1945 Aerial Photographs

In spite of the poor resolution, the 1945 aerial photographs show significant landsliding at the site and an arcuate ‘reef’ of large boulders just offshore of the landslide site (see Plate A1 in Appendix A).

3.5.3 1963 Aerial Photographs

The first available low altitude aerial photographs with good resolution were taken in 1963. The details observed from the 1963 aerial photographs are shown in Plate A2 and an orthorectified plan, which is based on the 1963 photographs, is shown in Figure 5. The 1963 aerial photographs show very clearly large-scale instability within the landslide site. Figure 5 shows that in plan the scar was approximately 60 m wide and 50 m long. Although the shape of the scar in 1963 was similar to that visible on the 1945 photographs, some deterioration (in terms of retrogressive development of instabilities retreating uphill) of the landslide site may have occurred between 1945 and 1963. The high reflectivity of all the materials within the landslide scar on the 1963 photographs suggests relatively recent instability at that time. MGSL estimate from the 1963 aerial photographs, based on photogrammetry, that the landslide scar was about 40 m long by 65 m wide with an estimated depth of about 10 m,

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indicating that the total volume of detached material was in the order of about 18,000 m^3 (Figure 5 and Figure 8).

Based on API, the upper southeast and southwest portions of the landslide scar appeared to have planar and wedge structural release surfaces. Bouldery landslide debris was present in the central portion of the scar with several large boulders (>3 m in size) along the shoreline.

The extent of the present day landslide scar is marked on the overlay to Figure 5, from which it can be seen that most of the detached material from subsequent instability originated in the southeast portion of the landslide site. In this area, three large corestones can be seen above the east flank of the main scarp (denoted as corestones Nos. 1 to 3 in Figure 5). After 1973, these boulders can be seen near the toe of the landslide (Figures 6 and 7) and were probably displaced during renewed instability some time between 1963 - 1973. Also, there is a distinct steep depression in this area with possible tension cracks defining approximately the extent of the landslide scar as a result of subsequent instability. The area below the large tors (very large granite corestones about 10 m in size) in the southwest part of the main scarp appears to be very similar to its present-day condition.

3.5.4 1973 and 1978 Aerial Photographs

By 1973, high altitude aerial photographs indicate a significant enlargement of the 1963 landslide scar plan area by approximately 20%. The July 1978 aerial photographs are the first subsequently available low altitude photographs (although the colour tone of the photographs is poor), from which further significant deterioration of the landslide scar is clearly visible (Figure 6).

Most of the detached and displaced ground mass came from the southeast portion of the landslide site and involved about 7,000 m^3 of material, which MGSL has estimated using photogrammetry by comparing the difference between the total volume of detached material from the 1963 and 1978 aerial photographs. Much of the material had detached completely and either remained within the scar as debris or has been deposited in the sea. Some displaced material can be seen within the upper central portion of the scar where an intact raft of material can clearly be seen close to the main scarp. Adjacent to this area, some large displaced boulders (denoted as large toppled boulders in Figure 6) could be observed in an overhanging position. The source of these boulders is difficult to ascertain from the 1963 photographs, since they were originally probably unexposed corestones prior to being affected by retrogressive failure of the landslide backscarp. The extent of the landslide scar in 1978 was much the same as it was in 1973 although minor degradation and erosion of the scar probably continued during this period.

3.5.5 2002 Aerial Photographs

The 2002 aerial photographs show the present-day extent of the landslide scar (Figure 7). Apart from changes in the vegetation and perhaps some minor degradation and erosion, there is little change from the 1978 photographs. A detailed description of the landslide site is given in Section 4.

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4. DESCRIPTION OF THE LANDSLIDE SITE

4.1 General

The following description of the landslide site is based on API, orthorectified images and field mapping. The API observations are detailed in Appendix A, and Figure 7 presents a 2002 orthorectified image with an overlay showing the field mapping results and the geomorphological interpretation. Figure 8 shows a cross-section through the landslide site. Descriptions of materials encountered during field mapping are given in Section 4.5

4.2 Landslide Geometry and Morphology

The landslide scar is approximately 75 m wide and 60 m long (in plan) and is about 50 m high, extending between the shoreline and close to the crest of the Shek Kok Tsui headland above (Figure 7 and Plates 2 and 3). The landslide morphology comprises spurs of displaced masses of 'intact' material, landslide debris, boulders, etc. bounded by the main scarp. The main scarp, which is generally inclined at between approximately 60° and 80°, is on average about 10 m high with sub-vertical to overhanging tors, extending to a height of some 15 m in the west portion of the main scarp. The east flank of the main scarp, which is very angular and steeply inclined at about 80°, comprises mainly yellowish brown completely and highly decomposed granite soil with little vegetation (Plate 4). The main scarp appears to be geometrically defined by several main joint sets (see Section 4.4), suggesting that the landslide geometry and morphology are probably structurally controlled.

Although the morphology of the floor of the landslide scar is quite variable, the floor is inclined at an average gradient of approximately 40°. The main morphological landforms include four semi-angular spur-like features (spurs Nos. 1 to 4) which are between about 15 m and 30 m long and 10 m wide and are situated approximately 15 m from the base of the main scarp (Figure 7 and Plate 5). These spurs comprise completely and locally highly decomposed medium-grained granite (see Section 4.5) and have average face angles of between 40° and 45° and are distinctive due to their light grey colour and lack of vegetation.

Between the spurs, the floor of the landslide scar consists of undulating, bouldery, thickly vegetated ground inclined between 35° and 40°. Above the spurs and particularly spur No. 2 (Figure 7), the ground surface between the spur crests and the base of the main scarp is more gently inclined at about 10° to 20°.

An arcuate 'reef' of large boulders is visible just below sea level at low tide approximately 40 m from the shoreline and probably represents the coarse remnants of a debris front from one or more large landslide events involving the toppling and rolling of large corestones and tors (Figure 8 and Plate 6).

The profile of the seabed, according to the marine geophysical survey data and hydrographic data, has been correlated with that obtained using land photogrammetry to construct a continuous profile through the landslide site (Figures 3 and 4). The plan and section indicate that the seabed profile drops uniformly to about -5 mPD to -6 mPD before increasing to -4 mPD. Rockhead contours, derived from seismic reflection profiles, are also given in the marine geophysical survey data and rise to a local high point at the location of a lighthouse, which is situated about 120 m offshore. About 80 m offshore, there is an apparent

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increase in the thickness of the 'superficial' deposits associated with a depression in the rockhead. The distribution of the offshore 'reef' of boulders, which was probably derived from past landsliding, could not be accurately defined from the geophysical survey.

The total volume of material that has been detached and displaced at the landslide site has been estimated to be in the order of 25,000 m^3 (comprising about 18,000 m^3 prior to 1964 and 7,000 m^3 between 1964 and 1973) using field measurements and photogrammetry based on the 2002 aerial photographs and an assumed pre-failure slope profile based on extrapolation from the adjacent hillside.

4.3 Ground Investigation

In February and March 2003, a limited ground investigation comprising two surface strips (Nos. SS1 and SS2) and four vegetation clearance strips (Nos. VC1 to VC4) were carried out by Gammon Skanska Ltd., under the supervision of MGSL, for general characterisation of the materials and identification of the locations of possible instability or distress. It was not possible to carry out any drilling owing to the GI Contractor's concerns about safety. The locations of the surface strips were selected to primarily investigate the presence of potential tension cracks or other forms of distress within the ground slope above the crown of the main scarp, and also to characterise the nature of surface materials exposed. The vegetation clearance strips were located above the east flank, along the base of the main scarp and up the central portion of the landslide site, in order to facilitate investigation of inferred recent instability. The locations of the surface strips and vegetation clearance strips are shown in Figure 7.

Surface strips Nos. SS1 and SS2 did not reveal any evidence of potential instability such as tension cracks, back scarps or subsidence above the main scarp area. Within the main scarp, a minor scarp (approximately 0.5 m in height) was observed along surface strip No. SS1, approximately 5 m from the base of the main scarp (Plates 7 and 8). This is located in an area of the main scarp that is relatively shallow at approximately 50° and may be a localised feature since it could not be traced laterally for more than 10 m. The materials encountered along both surface strips consisted predominantly of granitic topsoil and slopewash material.

4.4 Geology and Hydrogeology of the Landslide Site

Although the published geological map (Figure 2) indicates that the solid geology comprises fine-grained granite (Plates 9 and 10) within the landslide site and medium-grained granite above, observations made during the site mapping indicate that dark coloured megacrystic medium-grained granite (Plate 11) is located within the scar and that a boundary between the two granite types is located along the east flank of the main scarp (Plate 12). The fine-grained granite is generally light in colour and locally is very light with the grain size reducing towards that of an aplitic texture. There is a similar transition near the west flank of the landslide scar. Plate 12 shows the boundary between the two main granitic rock types inferred from API and site mapping. The area of medium-grained granite coincides with an area where many large corestones are exposed on the hillside. The published geological map

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indicates that in addition to the fine-grained and medium-grained granite, quartz syenite and coarse ash crystal tuff outcrop about 200 m to the east of the landslide site.

An annotated 1993 aerial photograph, which shows the underlying structure and the main photogeological lineaments within the Shek Kok Tsui headland area, is presented in Plate 12. It can be seen from Plate 12 that there is a strong pattern of major discontinuity sets across the Shek Kok Tsui area. The geometrical lines defining the coastline, the subject landslide scar and adjacent relict scars, closely follow these discontinuity sets and therefore suggests that there are structural geological controls affecting coastal erosion and instability. A similarly sized but more degraded landslide scar can be seen just to the east of the study landslide site, and again there are strong geometrical lines defining the landslide scar outline suggesting structural control associated with its formation. Two faults, striking approximately north-south, have been inferred within the headland area. The orientation of these faults is consistent with field observations by MGSL and observations of faulting noted in the file report (see Appendix B). Within the landslide scar itself, no evidence of faulting was found, although some of the fine-grained granite exposed at the lower east and west corners of the landslide site show signs of local shearing.

The background groundwater table was inferred to be relatively low (i.e. >5 m below ground level) as no seepage could be observed anywhere within the landslide scar during the site visits in both winter and summer months (Figure 8). Although no site visits were made immediately after heavy rainfall it is possible that at such times transient elevation of groundwater levels could occur within the saprolite above rockhead or a more complicated groundwater regime (with possible perching or damming) may exist in the southwest portion of the main scarp due the effects of very large corestones within a saprolite matrix. The catchment above the main scarp is relatively small with an area of approximately 1,500 m^2.

4.5 Ground Conditions

The material within the main scarp generally comprises corestone-bearing completely decomposed granite. In the south portion of the main scarp, larger corestones are apparent when traversing from east to west, and the material in this portion of the main scarp comprises mostly juxtaposed large individual corestones within a medium-grained, megacrystic, completely decomposed granite matrix. Some of these corestones, especially in the southwest portion of the main scarp are very sizeable with dimensions up to approximately 15 m in height and 10 m in width, and are more appropriately described as ‘tors’. Most of the individual corestones and tors are orthogonal with sharply defined joint faces which generally define the morphology of the main scarp. The major joint sets defining the main scarp in this area have an orientation of about 80°/179° (joint set No. 5 in Figure 9) and 86°/119° (joint set No. 4 in Figure 9). A shallow-angle tectonic joint set orientated at about 16°/357° (joint set No. 1 in Figure 9) occasionally forms a basal shear surface within completely decomposed granite or a toppling/sliding plane for the large tors. Sheeting or stress-relief joints were not apparent within the landslide or the adjacent hillside. The bases of some of the tors, especially tor No. 2 (Plate 3), are exposed within completely decomposed granite, which is being actively eroded. The southwest portion of the main scarp dates from failure prior to 1963 and the south portion of the main scarp was formed some time between 1964 and 1973.

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Within the east flank of the main scarp, a layer (average thickness approximately 1.5 m) of bouldery colluvium overlies yellowish brown completely decomposed and locally highly decomposed fine-grained granite with relatively few corestones (Plates 4 and 5). Along some relict joints and exposed corestones, sub-vertical structural release surfaces with an orientation of 85°/250° (close to joint set No. 3 in Figure 9) can be seen in upper areas of the eastern flank of the main scarp (where retrogressive failure occurred between 1964 and 1973). The orientation is approximately parallel to the eastern flank suggesting some structural control on the failure by the presence of relict joints. However, where no such structural features are present failure in the east flank appears to be the result of shearing through insitu weathered granite.

The distinctive yellowish brown weathered fine-grained granite material of the east flank of the main scarp is in stark contrast to the light grey colour of the completely and locally highly decomposed medium-grained granite forming the four spurs within the scar (Plates 2 to 5). Relict joints are common within these spurs and signs of significant internal deformation and dilation of relict joints were found in several areas (Plates 13 and 14), with voids and kaolin coated joints being common. Occasional slickensides were observed on the kaolin-coated relict joint faces within the deformed weathered granite of the spurs but were not observed elsewhere. Based on API (see Section 3.5), and the field mapping results, the internal deformation of the spurs appeared to have increased during the most recent failure that occurred some time between 1964 and 1973. Due to the limitations of field mapping of surface expressions under the current study, no evidence of a basal shear surface could be found within the scar.

The area directly above spur No. 1 (where retrogressive failure occurred some time between 1964 and 1973) consists of completely disturbed material derived from granitic saprolite, which appears to have slumped down from the main scarp together with two very large tabular boulders that appear to have rotated and come to rest in a marginally stable overhanging arrangement (Figures 5 and 7 and Plate 5). Exposed corestones and occasional relict joints in the main scarp above this area suggest some structural control on the failure, although a fairly flat vegetated area above spur No. 2 is possibly a relatively intact mass of material which has either rotated or slumped down from the main scarp.

Also between and below the spurs within the landslide scar are extensive thickly vegetated colluvial debris deposits, which were probably derived from previous landslide events (Plate 15). Most of this material, which is relatively recent and above an elevation of approximately 15 mPD, comprises loose, silty sand with much gravel, cobbles and small boulders derived from a completely decomposed granitic matrix. Below 15 mPD, the debris attains a thickness of more than 2 m and contains granite boulders up to 7 m across, especially within the tidal and wave affected shoreline, where the matrix has been totally eroded to leave a beach strewn with boulders, with a large variation in sizes (Plate 6). For the same reasons, landslide debris can only be observed in the sea for about 5 m to 10 m offshore and comprises mainly boulders. Further out, at about 40 m offshore, an arcuate ring of large boulders can be seen just below the surface of the sea and probably represents the maximum runout of the coarse debris front during previous landslides.

Adjacent to this bouldery beach, and possibly protected by it, are local remnants of ‘relict’ landslide debris characterised by completely weathered clasts within a stiff silty sand

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matrix in isolated areas below some of the larger boulders near the toe of the landslide (Plate 16).

Virtually no insitu material is visible towards the toe of the landslide scar, due to the extensive bouldery landslide debris cover.

Extensive tension cracks over a distance of about 70 m were observed along the base of the central and western portions of the main scarp, at the base of tors Nos. 2, 3, 4 and 5, and along the base of the main scarp above spurs Nos. 1 and 2 (Figure 7 and Plates 17 and 18). The tension cracks are up to about 0.3 m wide and displaced vertically by up to approximately 0.5 m. In most cases they appear to be relatively recent from the fresh appearance of the soil within the tension crack and lack of degradation. Incised 'gully' features, up to about 0.2 m wide and 0.5 m deep, were found adjacent to vegetation clearance strips Nos. VC2 and VC3, descending the landslide scar on either flank of spurs Nos. 1 and 2.

Although signs of 'recent' movement and possible distress were observed within the landslide scar based on the observed tension cracks and deformation of the weathered granite spurs, no obvious signs of heave or toe displacement can be seen within the scar.

5 DIAGNOSIS OF THE LANDSLIDE

5.1 Geological and Geomorphological Setting

Plate 12 shows the solid geology boundaries of Shek Kok Tsui headland based on API and field mapping. The boundary between the fine-grained granite and the megacrystic medium-grained granite was observed during field mapping at the east flank of the main scarp and near the west flank of the main scarp. An inferred extension of this boundary, which covers the upper headland area and follows closely the occurrence of large corestone development, is shown in Plate 12. The difference in grain size may be a result of local variations in the crystallisation/cooling time of the magma that formed the granite in the area. The observed difference in grain size of the granite also correlates strongly with observed increases in joint spacing that has resulted in the local development of large corestones and tors within and above the central and west portions of the landslide site.

Based on API alone, the morphology of the landslide site initially suggests that the instability involved a deep-seated failure. However, the apparent structural geological control defining the coastline and the landslide main scarp (Plate 12), together with structural release surfaces observed in the field, actually suggests that the landslide scar was developed from a series of structurally controlled failures. Field mapping including joint measurements, supported by kinematic analysis outlined in Section 5.2 below, suggest that planar and wedge failures have occurred, mainly within completely to highly decomposed medium-grained megacrystic granite prevalent within most of the landslide scar. Toppling failure was most common within the areas of large juxtaposed moderately to slightly decomposed medium-grained megacrystic granite corestones and tors (such as the south and southwest portion of the main scarp) which were marginally supported by surrounding saprolite matrix. A group of such tors, situated in the upper part of the hillside, appear to have toppled down into the landslide scar and the sea due to undermining as a result of retrogressive failure of its supporting soil matrix.

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The presence of pockets of relatively old colluvium (containing completely to highly decomposed clasts) near the toe of the landslide site suggests a long history of instability. The diversity of materials within the 'old' colluvium (i.e. fine-grained granite or medium-grained granite) was apparently derived from different saprolite sources.

The relatively flat-lying ground forming a convex break in slope between spur No. 2 and the base of the main scarp appears to have moved as a relatively intact mass. However, no related shear surfaces were observed. The gully features observed between spurs Nos. 2 and 3 and the east of spur No. 1 cannot be traced for more than 20 m because they are obscured by vegetation and colluvial boulders downslope. It is not possible to establish whether they are simply erosional features or features related to the movement.

The tension cracks observed behind the relatively-flat lying ground, around the base of the main scarp do not appear to be associated with movements that occurred some time between 1963 and 1973, since the tension cracks, despite being extensive, are relatively small compared with the dimensions of the main scarp of the landslide. It is considered that the tension cracks are probably the result of post-1973 instability and intermittent movement (e.g. during rainstorms) in the marginally stable slope.

As no exposed shear surfaces can be seen within the landslide scar, it is possible that the movement observed within the tension cracks could be associated with the local deformation observed within the weathered granitic rock mass of spurs Nos. 1 and 2.

A similar situation exists where tension cracks are found at the base of the main scarp below tors Nos. 2, 3 and 4. Here there is a tension crack of similar size (i.e. about 0.3 m wide and 0.5 m deep) and deformation in the weathered granite spurs below. However, below tor No. 3 an approximately 1 m wide strip has subsided by up to about 0.5 m to produce a graben-like feature.

5.2 Kinematic Analysis

During the field mapping, joint measurements were taken from exposures around the landslide site (i.e. the fine-grained and medium-grained megacrystic granite types). The field observations and measurements indicated that there were differences in the sub-vertical joint orientations and significant increases in the joint spacing between the two granite types (i.e. different structural domains). Also, most of the structurally controlled failure had taken place within discontinuities of the medium-grained megacrystic granite (see Section 4.5) comprising relict joints within completely to highly decomposed granite. Thus, an analysis of the joints within this material was undertaken to assess whether failure would have been kinematically feasible (Figure 9) and what type of initial failure was likely to have occurred in the estimated pre-failure hillside (Figure 8) and during later retrogressive landslides.

The analysis indicates the possibility of both planar and wedge type failures (Figure 9). Some of the major joint sets define back-release surfaces of the main scarp such as joint set No. 5 (80°/179°) and joint set No. 4 (86°/119°) as shown in Figure 9. Within the medium-grained granite, a shallow-angle joint set (joint set No. 1) orientated at about 16°/357° forms a planar failure surface, and joint set No. 3 (79°/078°) forms a side-release surface. Instability of large corestones and tors has occurred in the upper scar area, possibly

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induced by unloading from prior failures below. Potential failure surfaces may have first daylighted as a result of a combination of the hillside geometry and aspect together with undercutting of the toe of the coastal hillside, resulting in the early landslide development.

5.3 Probable Mechanisms and Sequence of Failure

The exact time of the initial landslide is not known. Although the resolution of the 1945 aerial photographs is poor, a relatively large landslide scar is apparent at the location of the landslide under study. The 1963 aerial photographs have good resolution and show a large landslide at the same location that appears relatively fresh, suggesting some recent instability. Subsequent further instability between 1964 and 1973, led to retrogressive development of the back scarp and hence the present landslide scar appears to be the result of instability, which over the past 60 years has been, in geological terms, fairly active.

Based on the geological model that has been developed for the landslide site, it is postulated that the first phase of landsliding (before 1945) was structurally controlled and probably triggered by rainfall, with the hillside being predisposed to failure due to ongoing coastal erosion and undercutting of the toe. The instability observed in the 1963 photograph strongly suggests primary structural control due to the geometric angularity of the main scarp with exposed joint-controlled release surfaces. The depth of failure estimated from the 1963 photographs is relatively deep (between 5 m and 10 m perpendicular to the ground surface). The substantial depth of failure surface was probably controlled by a combination of extremely widely spaced joint sets and a deeply weathered profile within the landslide site, which is estimated to be between 10 m in the lower hillside areas and up to 20 m (including corestones) in the upper hillside area.

Apparent tension cracks can be seen in the 1963 photographs at the approximate location of the present main scarp. This indicates that this portion of the hillside was probably only marginally stable in 1963 due to loss of lateral and toe support as a result of the previous landsliding. The 1978 photographs indicate further instability along the line of the present-day main scarp and some areas above spur No. 2 appear to have slid down as intact rafts or slumping of material based on the presence of areas of vegetation within the scar. The depth of failure estimated from the 1978 photographs is still fairly deep at about 5 m perpendicular to the ground surface. The depth of failure surface was probably controlled by a combination of extremely widely spaced joint sets and the deeply weathered profile within the landslide site, together with the significant loss of toe support.

Much of the slope distress, which is concentrated in the central part of the feature and was observed during field mapping and the GI for the present study, probably reflects recent slope movement that has occurred since 1973. The amount of movement is relatively small and has resulted in tension crack formation and local deformation of the disturbed weathered granite. No signs of distress or instability were observed beyond the crown of the landslide scar and hence imminent retrogressive failure of the hillside above the scar is unlikely. However, there are signs of instability (tension cracks and deformed weathered granite) within the landslide scar and it is inferred that this relatively small movement has taken place since the last major instability (i.e. prior to 1973). There is active erosion taking place in the granitic saprolite supporting some of the very large tors within the main scarp. Detachment of

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such large blocks may instigate further small-scale landsliding due to the exposure of steep saprolite profiles behind the tors.

The area inferred as a ‘relict’ (i.e. occurring prior to the earliest aerial photograph in 1945) landslide observed just to the east of the landslide under study, and is about the same size (see Plate 12). The feature is more degraded than the subject landslide with a rounded main scarp and a fully vegetated scar and it has shown no signs of major instability in recent time, although it may be vulnerable to disturbance such as cutting or unloading near the slope toe. The crown of this adjacent landslide is almost at the top of the hillside ridge and hence the landslide has probably reached a state of equilibrium in contrast to the subject landslide that has not yet regressed as far as the top of the hillside ridge. The difference in behaviour of the adjacent landslide sites may be a result of differences in the geomorphological setting, (with the subject landslide being topographically higher than the relict landslide), and the geology (with the variation in grain size and joint spacing/orientation of the bedrock) probably affecting the rate, depth and type of weathering. Thus these factors may not have affected the ultimate size of the landslide (they are of similar size and aspect) although they may have affected the rate of activity.

The many boulders along the shoreline at the toe of the scar of the subject landslide would provide a natural breakwater that may reduce the effect of wave erosion of the shoreline in this case. The estimated travel angle of the debris (25º) given in Figure 8 is based on the furthest extent of debris that can be observed in the sea (viz. the arcuate ring of large boulders forming a ‘reef’ approximately 35 m offshore). The travel angle as deduced by these means, is subject to uncertainty due to the retarding action of the sea and the likelihood that finer material, which could have travelled further, was subsequently eroded by sea currents. The overall history of instability of the subject landslide site is likely to be related to the marginal stability state of the hillside caused by a combination of geological (particularly variations in grain size resulting in variations in joint spacing and thus weathering) and topographical factors, together with destabilisation action involving progressive wave erosion at the toe of the hillside.

6. DISCUSSION

The current study, based on detailed API, field mapping and limited shallow GI, has provided additional information on the nature, development and likely relative age of the subject landslide. The detailed study has confirmed that the hillside was subject to the development of retrogressive landsliding as opposed to a single massive landslide event in recent time. The nature of the landslide site has been further related to materials with variations in grain size of the granite, joint spacing and weathering, and in terms of processes with structural control of failure being dominant. The evolution of the subject landslide has been shown to be influenced by several episodes of recent retrogressive failures over at least the past 60 years. Despite the observed relatively recent activity, the age of the landslide site as a whole is considered to be much older than that suggested by the aerial photographs, based on the presence of relatively old colluvium at the toe of the landslide site and the adjacent, much more degraded landslide site (with a similar aspect) to the east which has essentially reached equilibrium with its geological and geomorphological setting.

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Notwithstanding the above, the absolute age of landsliding within the subject landslide site remains uncertain. Age dating has been tried on possible landslide debris offshore but the results are not definitive. On land, age dating would require material from early landslide events which is not easy to identify. One possibility is the small area of relatively old colluvium at the toe of the landslide site but upon observation, no organic material could be found leaving possibly only luminescence methods as applicable.

The setting of the subject landslide, with variations in topography (a higher ridge line) and geology (particularly with respect to the grain size and joint spacing of the granite) leading to adverse relict joint orientations, differential weathering and tor development, is such that overall equilibrium has not yet been reached and hence further instability is probable.

7. CONCLUSIONS

The substantial size of the subject landslide is mainly the result of retrogressive development of structurally controlled failures over the past 60 years. However, the exact time of the initial landslide is not known. Recent debris and relatively old colluvium (containing completely to highly decomposed clasts) have been identified at the landslide site, suggesting a long history of instability.

The significant depth of the failure surface, which is estimated to be between 5 m and 10 m, is probably controlled by the extremely widely spaced joints and the significant depth of weathering of the medium grained granite. No obvious signs of a conventional deep-seated failure were found. The development of the subject landslide is complex with probable initial structurally controlled failure due to coastal erosion and undercutting followed by further structurally controlled and retrogressive failure by over-steepening and removal of lateral and toe material. Prior to 1964 the estimated volume of detached material is about 18,000 m^3, based on photogrammetry. The retrogressive failure, which can be observed from the aerial photographic record, has been fairly active with the last significant detachment and displacement of an estimated 7,000 m^3 of material possibly occurring within the last 30 years.

The debris was not very mobile with significant amounts of bouldery landslide debris still within the landslide scar. The travel angle is estimated to be about 25° from the bouldery debris that could be mapped in the sea although fine material that could have travelled further may have been subsequently eroded by wave action. There are still signs of relatively recent and possibly ongoing instability, in the form of translational movement within the landslide scar, albeit on a smaller scale. The possible ongoing movement may be the result of marginal stability within the landslide scar due to local over-steepening during previous phases of landsliding.

8. REFERENCES

Geotechnical Control Office (1988). Geotechnical Area Study Programme Report X - Islands. Geotechnical Control Office, Hong Kong, 142 p. plus 3 maps.

Geotechnical Engineering Office (1995). Cheung Chau: Solid and Superficial Geology, Hong Kong Geology Survey, Map Series HGM20, Sheet 14, 1:20 000 scale. Geotechnical

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Engineering Office, Hong Kong Government.

Strange, P.J. & Shaw, R. (1986). Geology of Hong Kong Island and Kowloon. Geotechnical Control Office, Hong Kong, 134 p. (Hong Kong Geological Survey Memoir No. 2)

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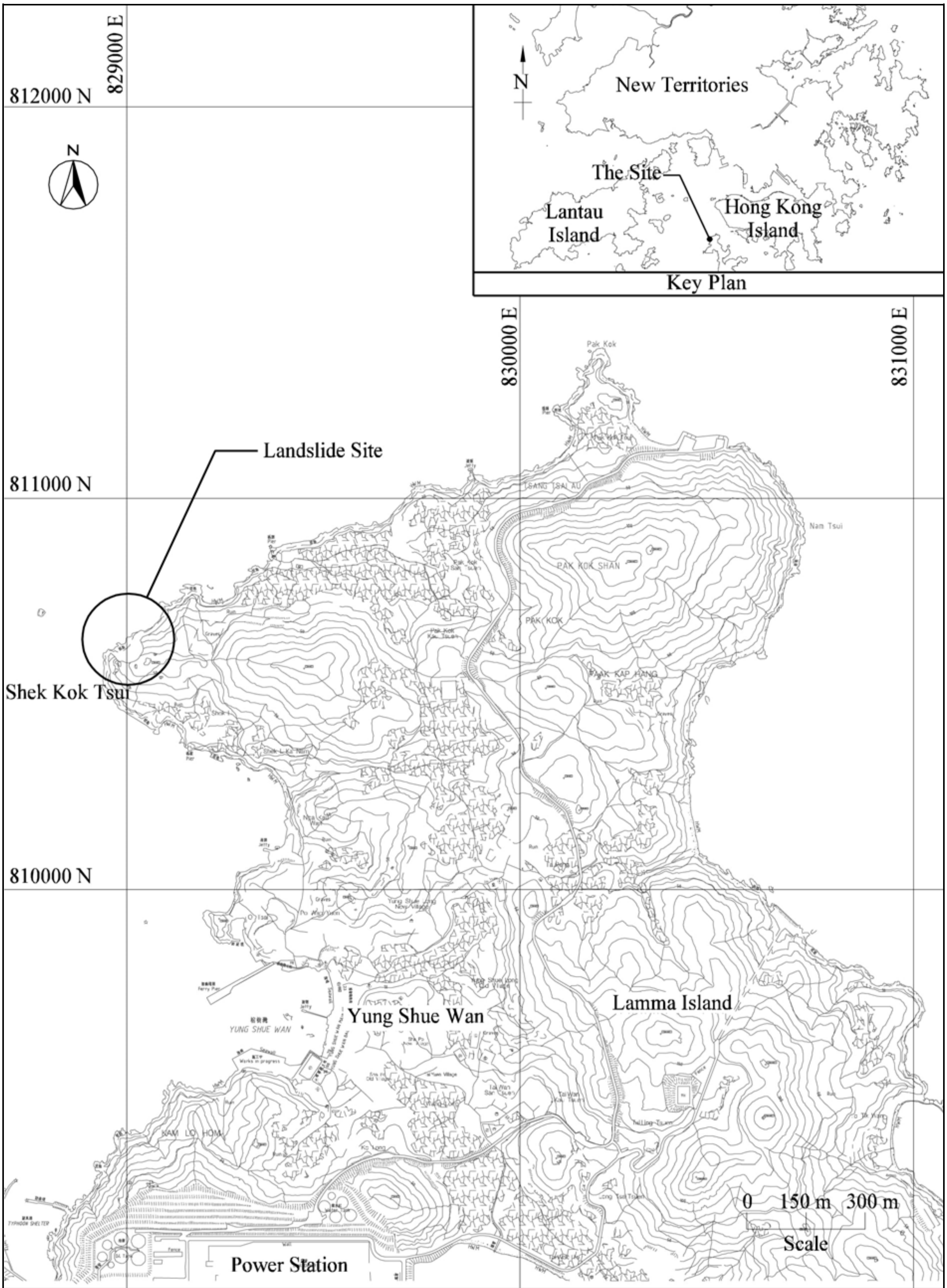

Note : Base plan is extracted from 1 : 5000 survey sheets Nos. 14NE-B and 15NW-A dated March 2001.

Figure 1 - Site Location Plan

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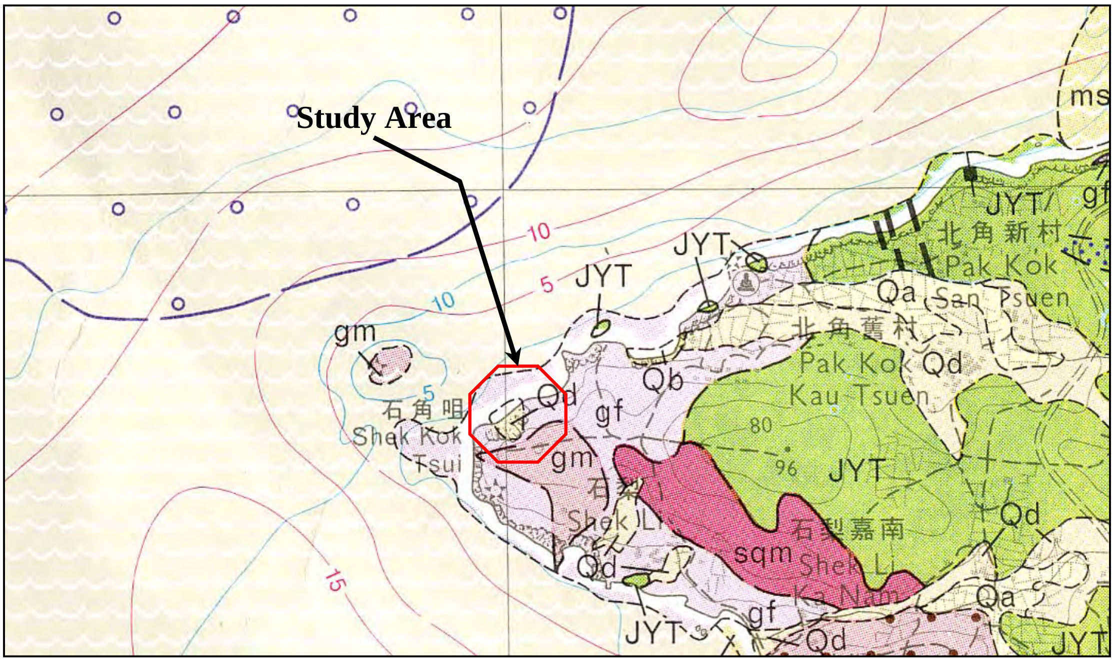

0m 1000 m

LEGEND:

SUPERFICIAL DEPOSITS

Qa	Silt, sand and gravel (Alluvium)	Qb	Sand (Beach deposits)
Qd	Sand, gravel, cobbles and boulders in silt matrix (Slope debris)	QHH	Soft to very soft mud; some sand (Marine mud)
ms	Sand, part silty (Marine sand)		Fill
	Mud showing acoustic turbidity at depth caused by gas		

SOLID GEOLOGY

gf	Fine-grained granite, <2mm	JYT	Coarse ash crystal tuff (Tsuen Wan Volcanic Group)
gfm	Medium-grained granite, 2-6mm		Metamorphosed
sqm	Medium-grained quartz syenite, 2-6mm		

GEOLOGICAL LINES

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

STRUCTURAL SYMBOLS

Jointing for vertical

Note: Extracted from Hong Kong Geological Survey, Map Series HGM20, Sheet No. 14, 1:20 000 Scale (GEO, 1995).

Figure 2 - Regional Geological Map

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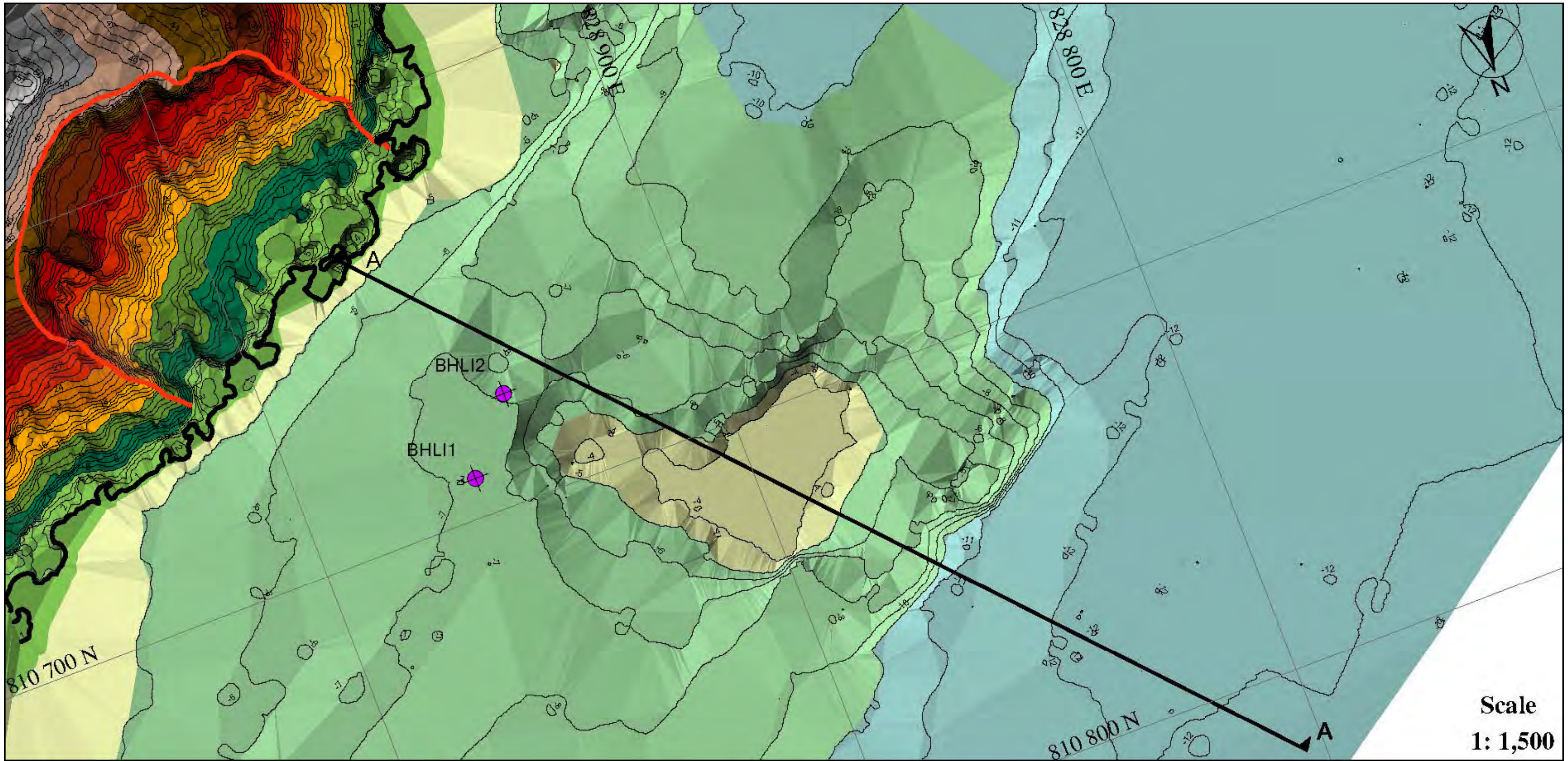

Legend:

Landslide site boundary — Cross section line — Borehole location (2001)

Elevation (mPD): 60 - 65, 55 - 60, 50 - 55, 45 - 50, 40 - 45, 35 - 40, 30 - 35, 25 - 30, 20 - 25, 15 - 20, 10 - 15, 5 - 10, 0 - 5, -5 - 0, -10 - -5, -12 - -10

Note:
1. Land base plan generated from photogrammetric survey carried by MGSL (2002).
2. Marine base plan generated from geophysical survey carried out by IGGE (2001).
3. See Figure 4 for section A - A.

Figure 3 - Marine Geophysical Surveying Plan

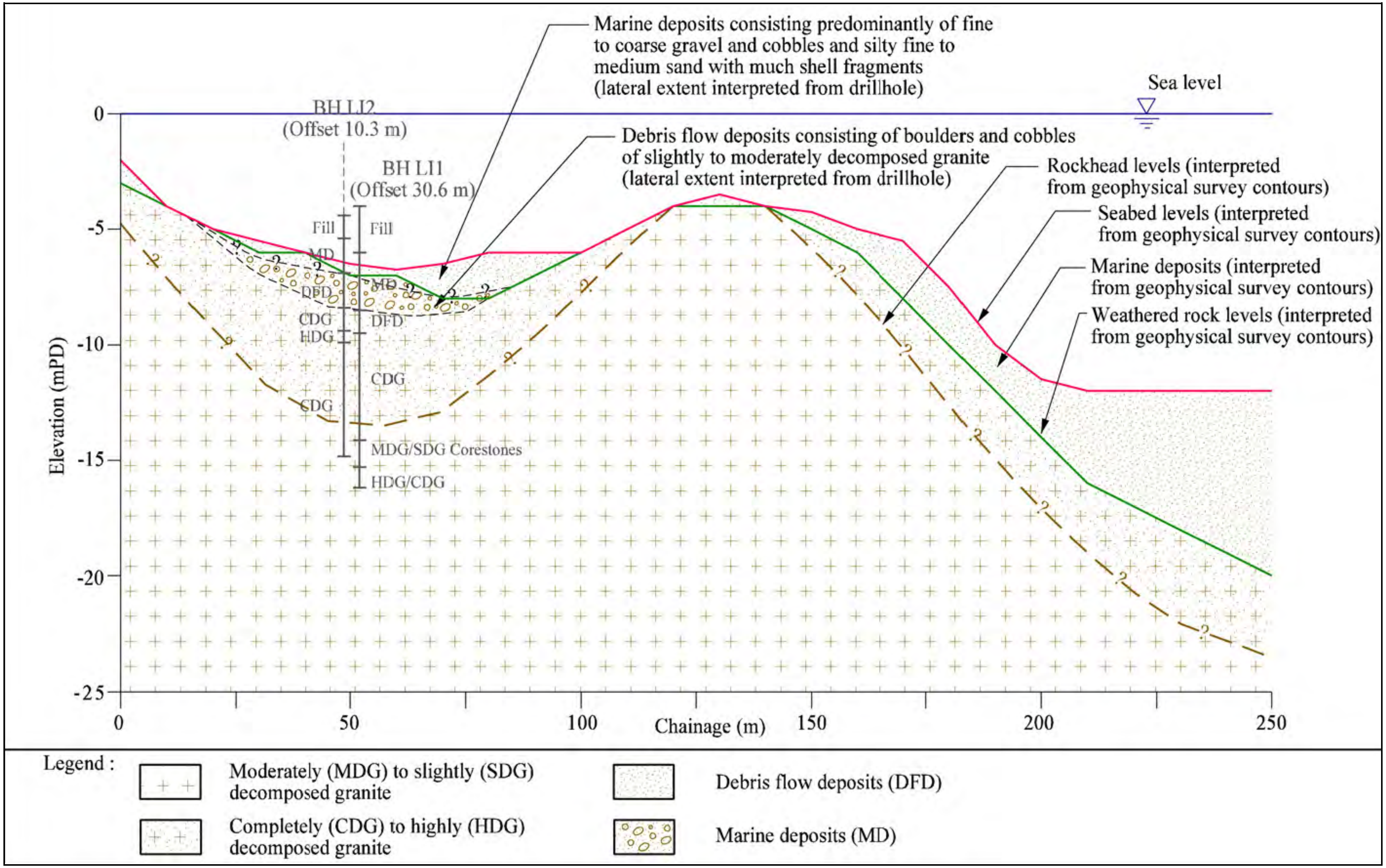

Figure 4 - Section A-A Offshore of Landslide Site

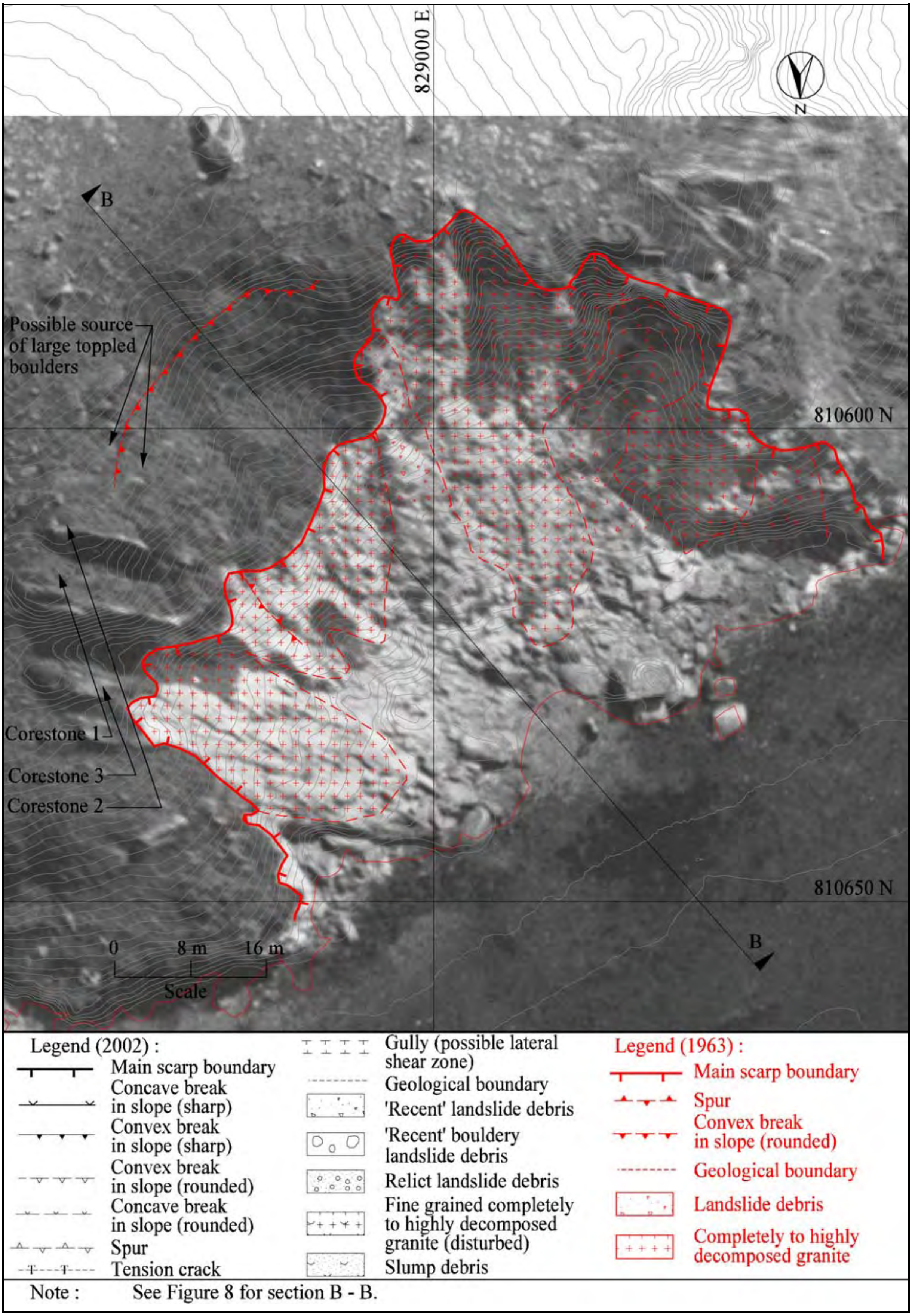

Figure 5 - Orthorectified Image (1963)

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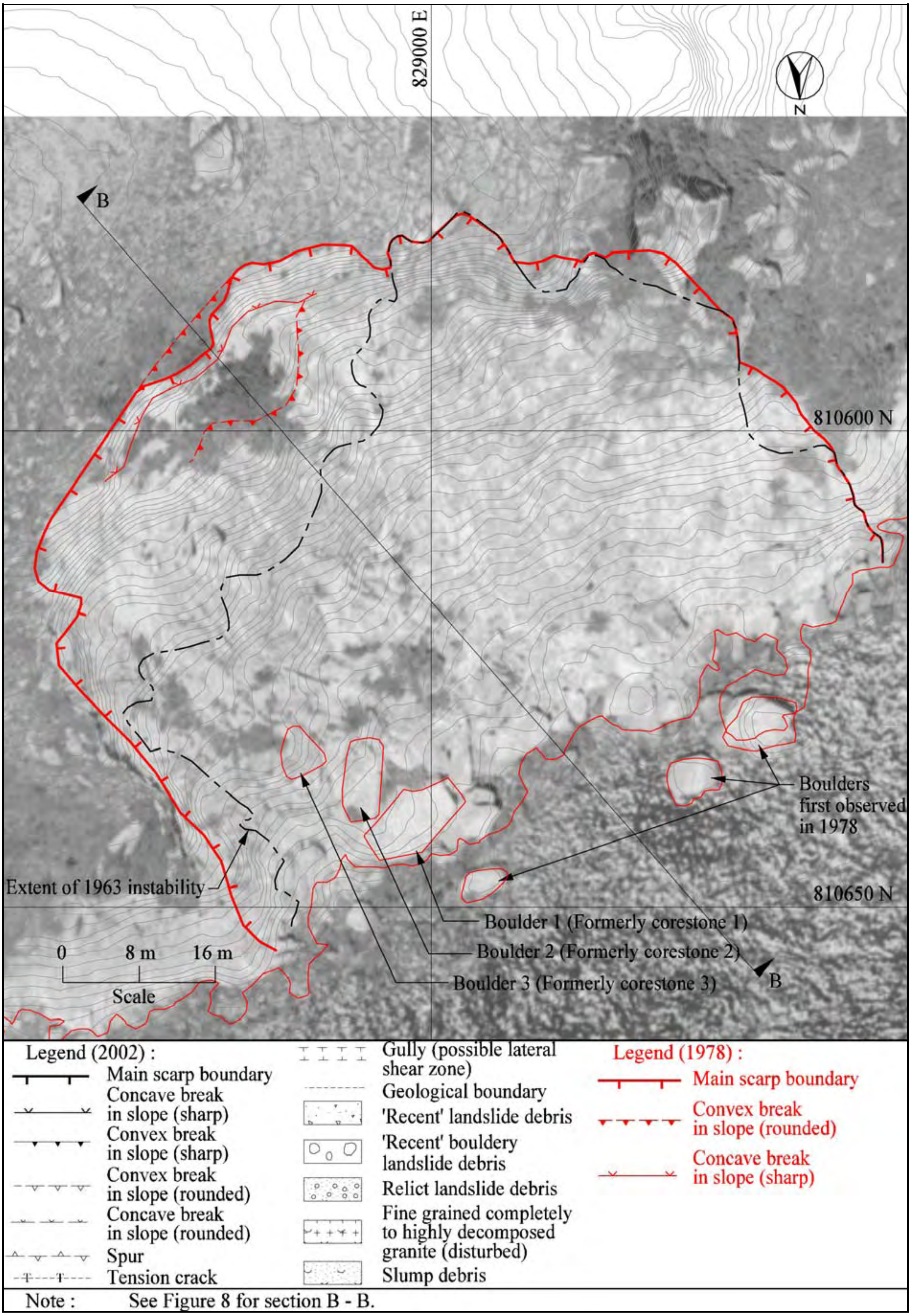

Figure 6 - Orthorectified Image (1978)

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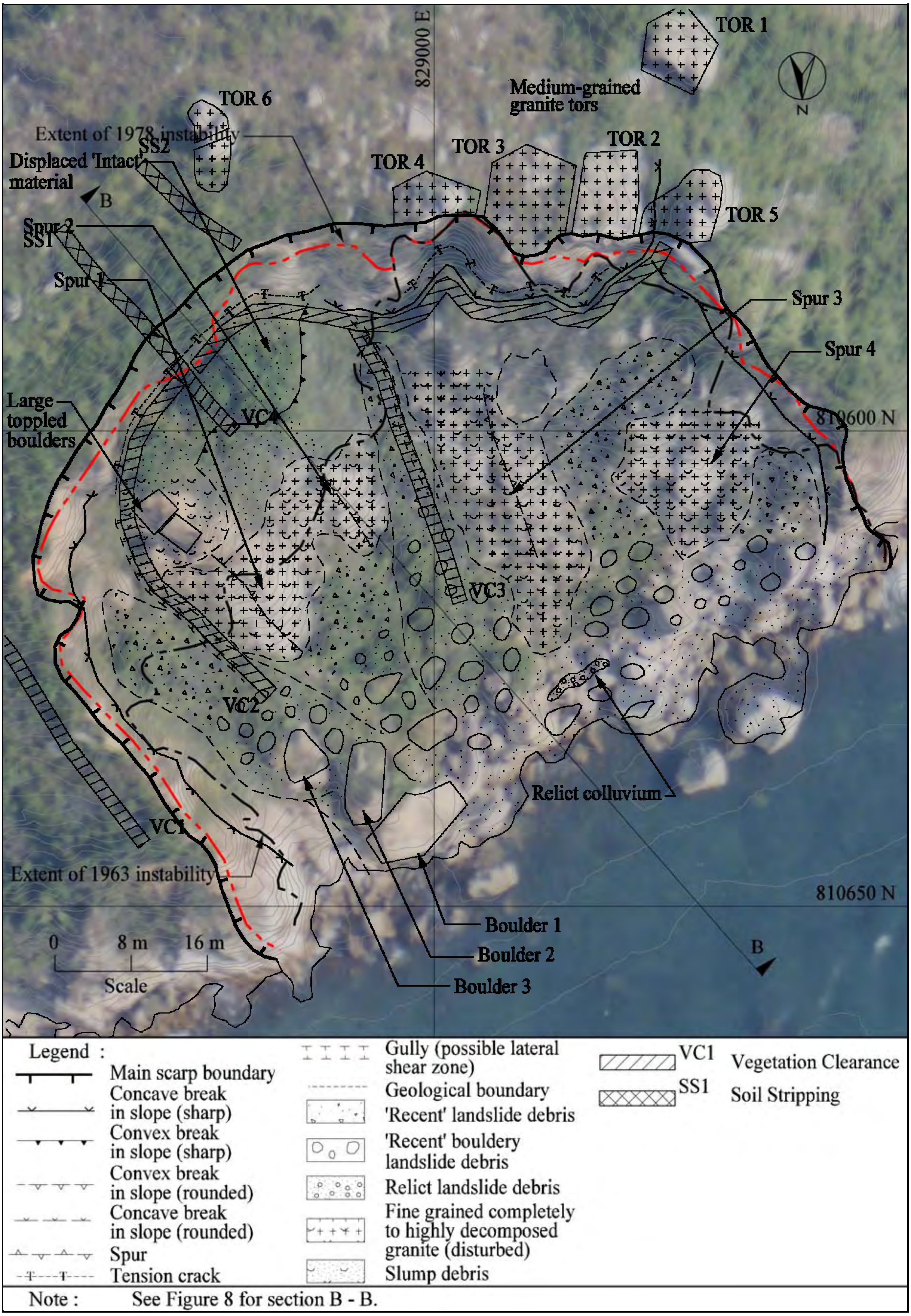

Figure 7 - Orthorectified Image (2002)

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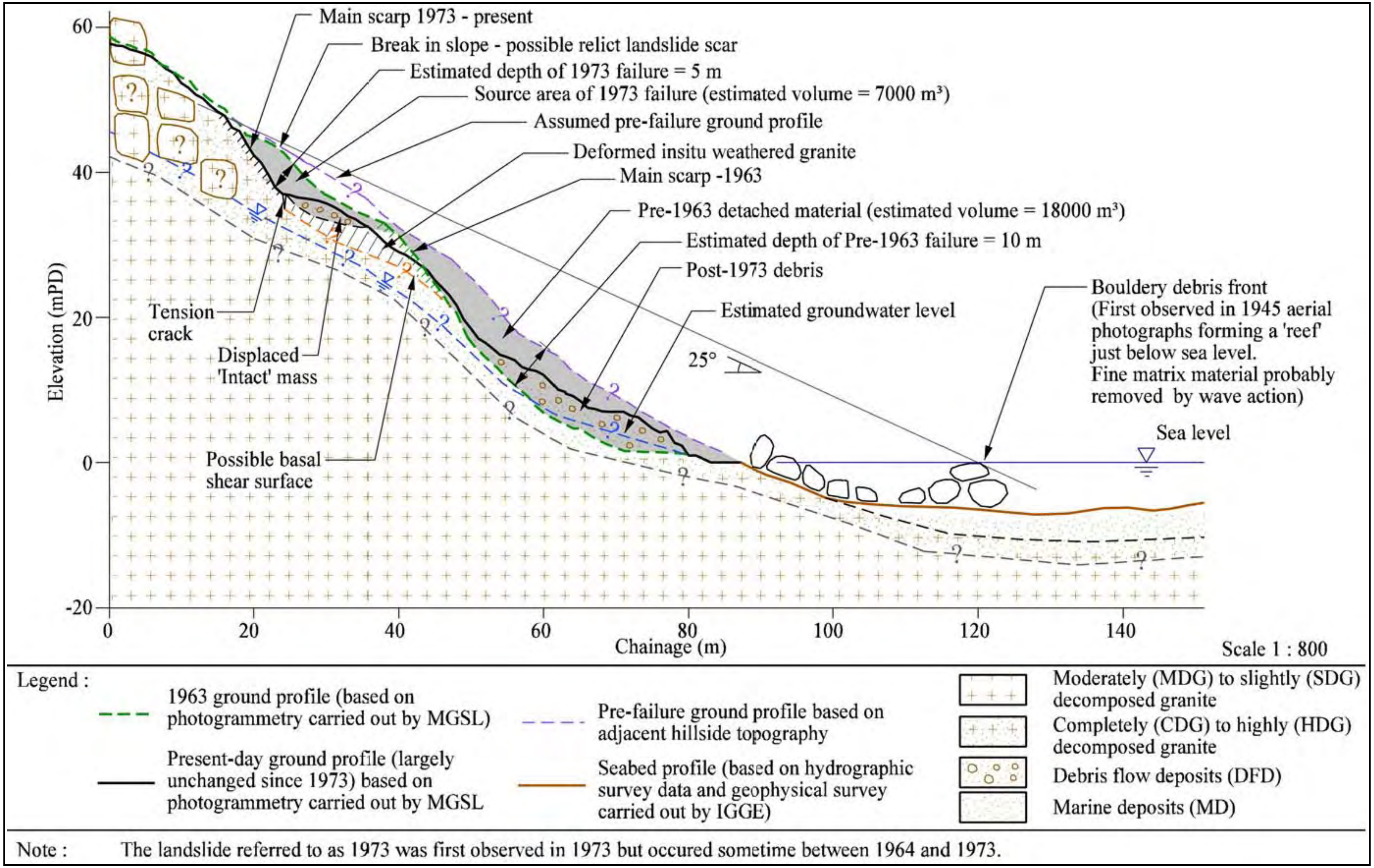

Figure 8 - S Section B-B Through Landslide Site

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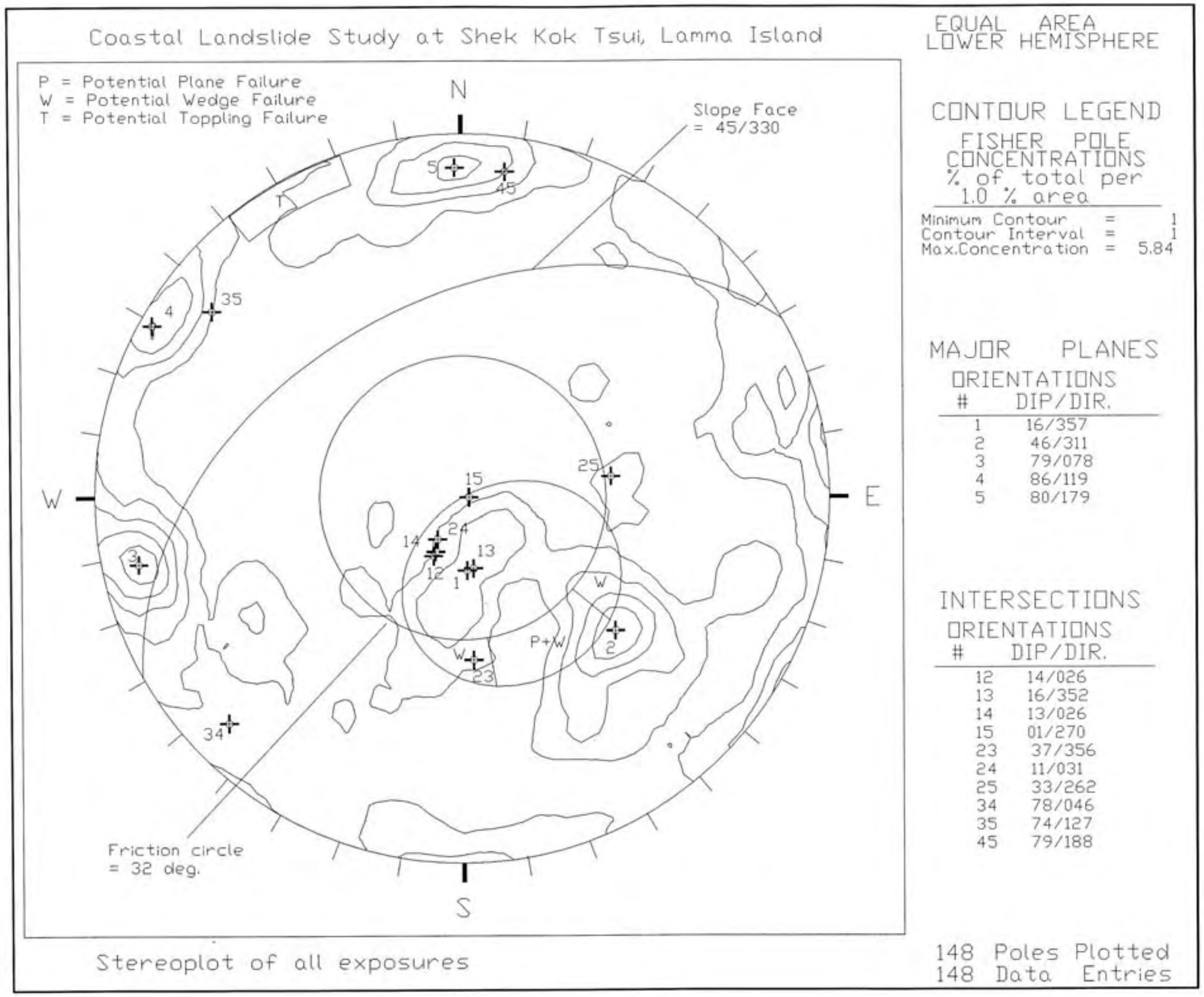

Note: Joint data taken from medium-grained granite outcrops

Figure 9 - Kinematic Analysis

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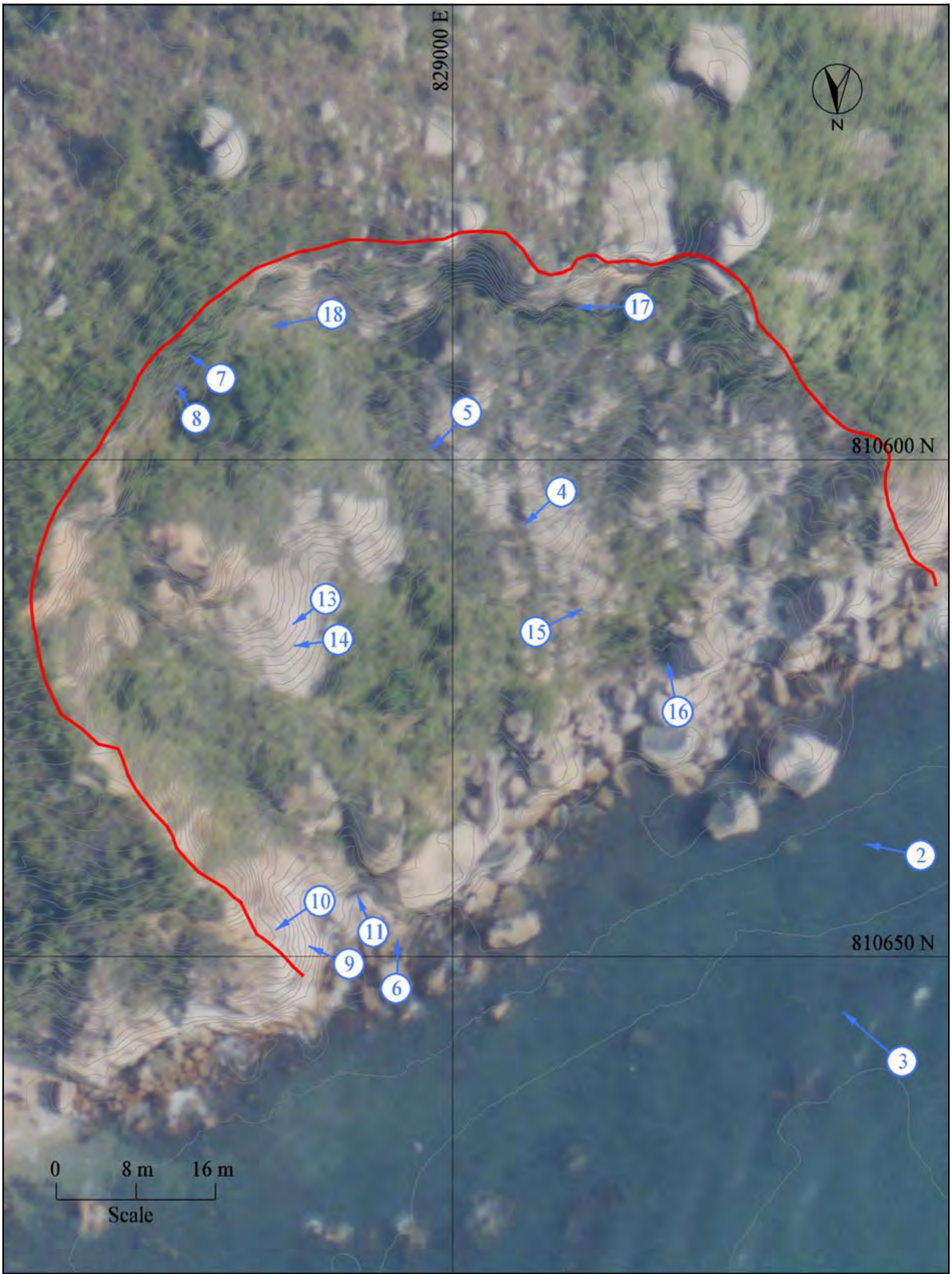

Legend : Extent of landslide; (10) Location and direction of photograph

Note : Ortho-image produced from 2002 aerial photograph.

Figure 10 - Locations and Directions of Photographs

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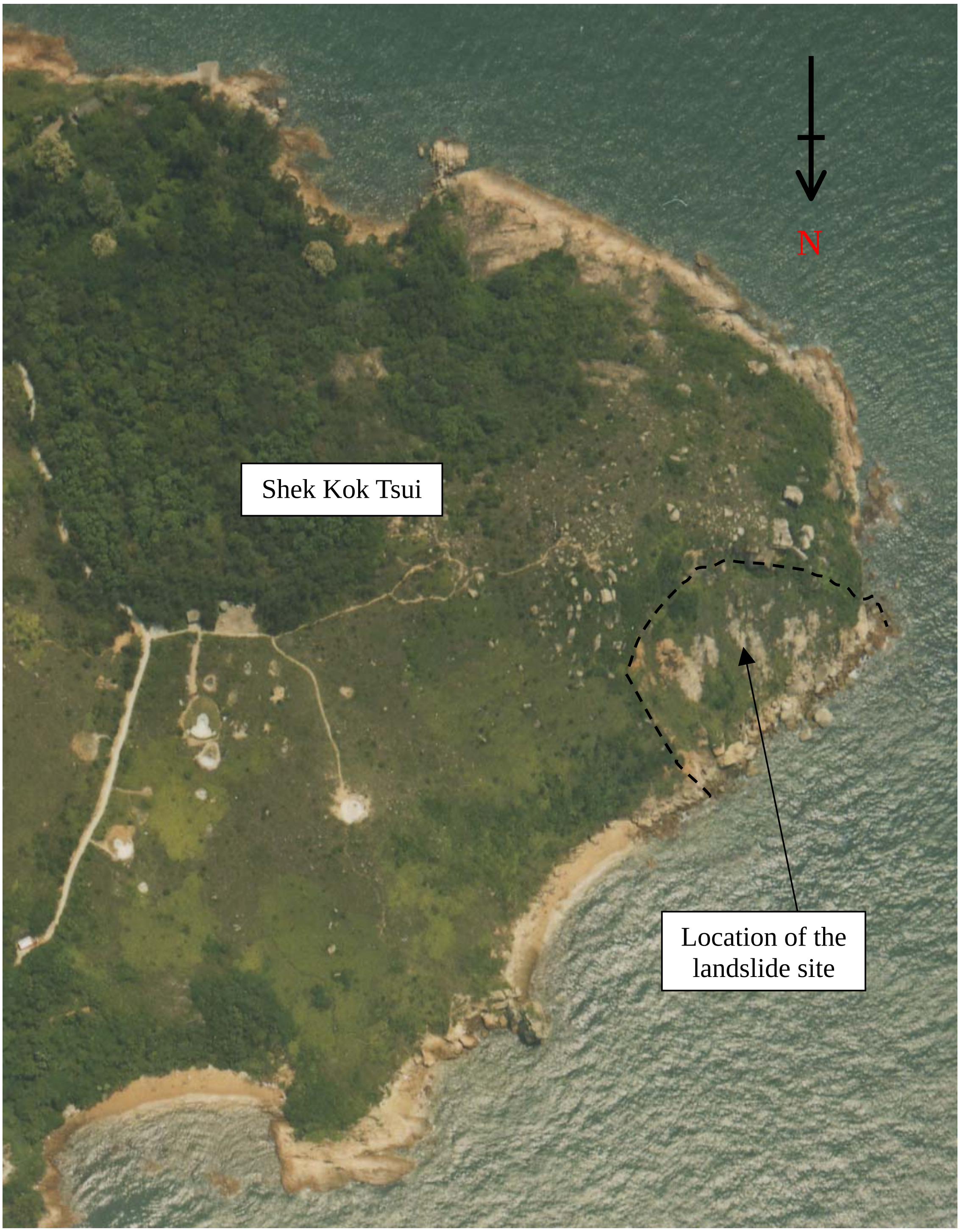

Plate 1 - Aerial Photograph of Shek Kok Tsui and the Landslide Site
(Photograph taken on 25 May 2001)

Notes: See Figure 10 for location and direction of photograph.

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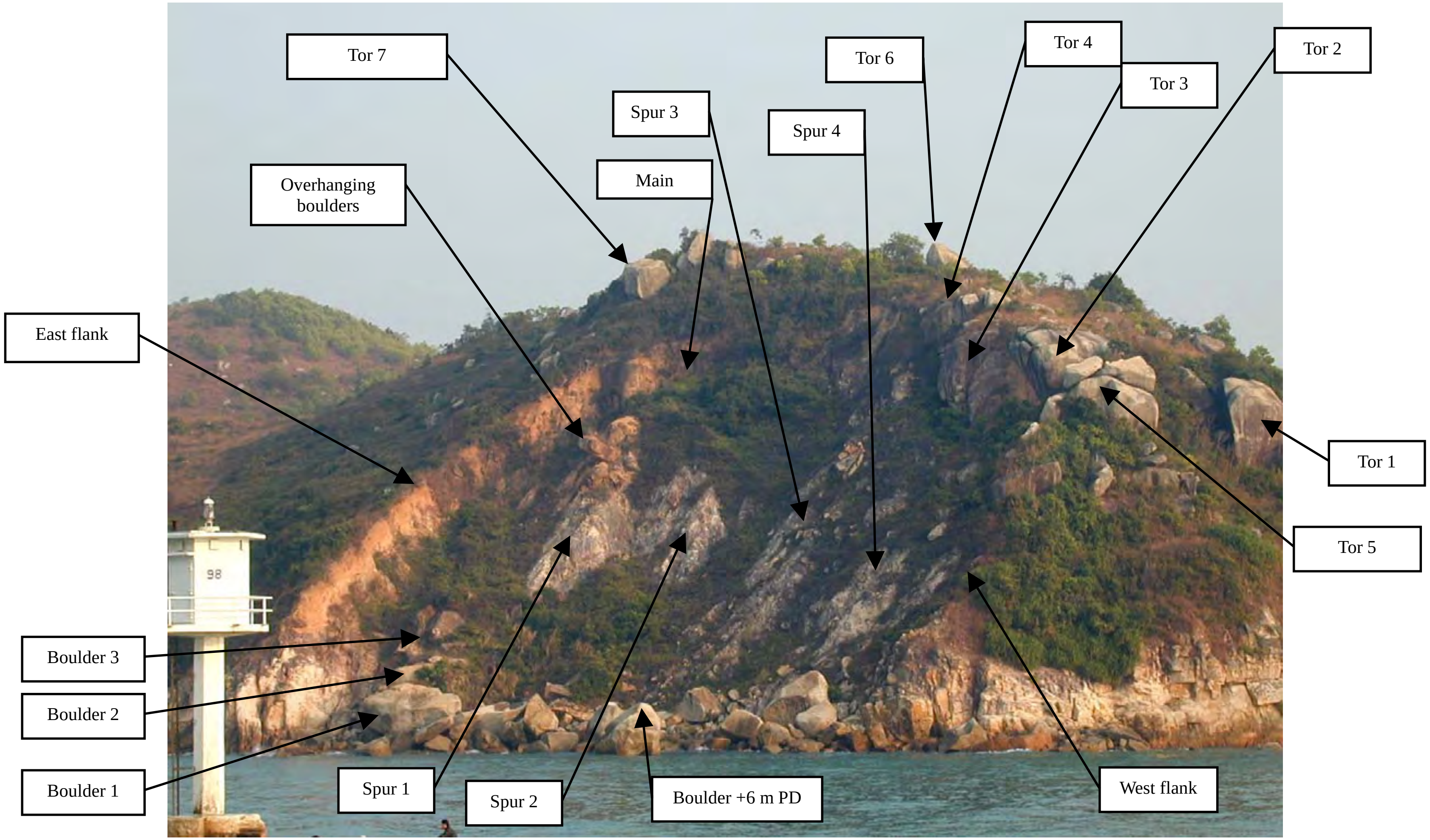

Plate 2 - Oblique View of Landslide Site (Photograph taken on 11 January 2002)

Note: See Figure 10 for location and direction of photograph.

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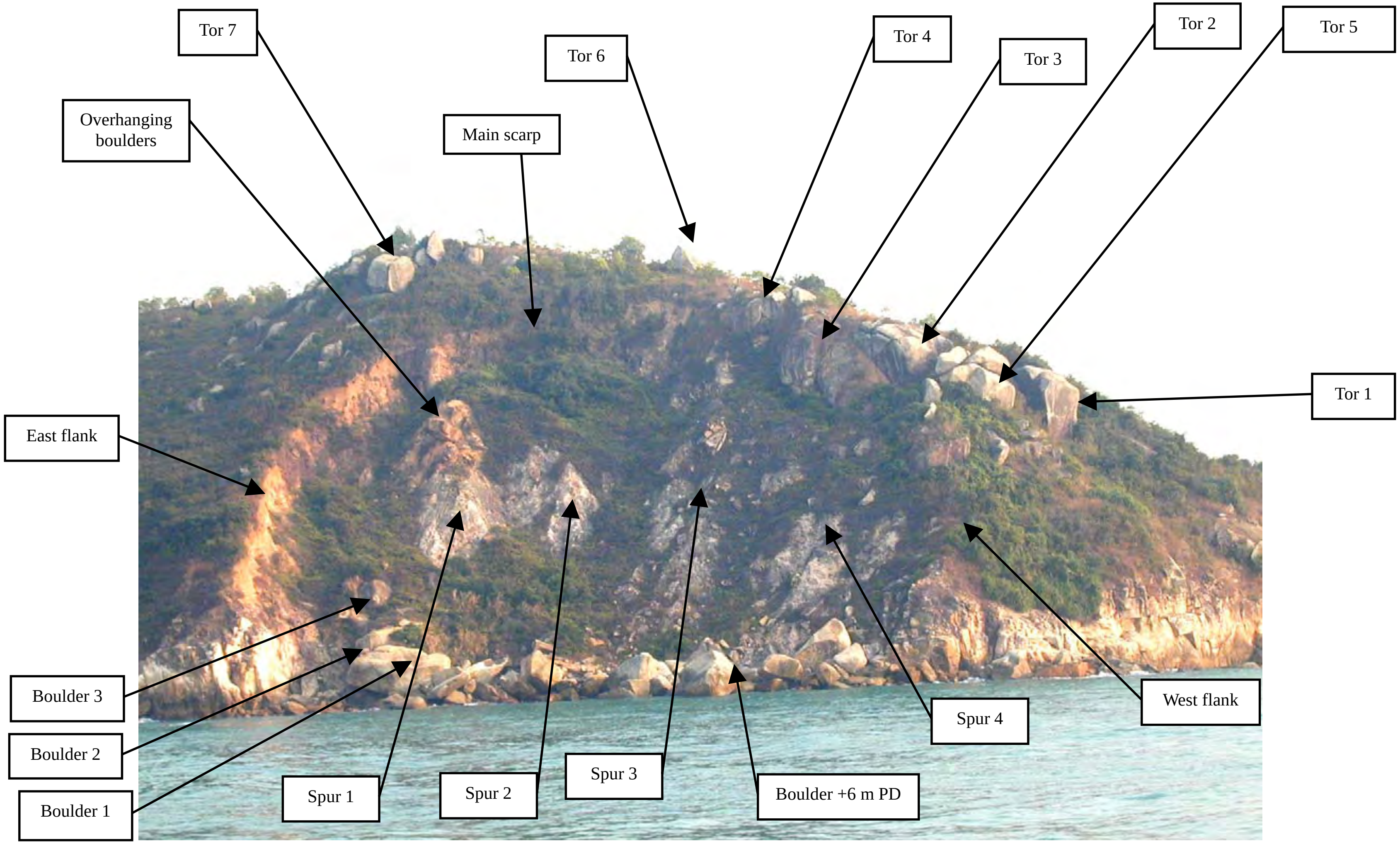

Plate 3 - View Looking Southeast of Landslide Site (Photograph taken on 11 January 200)

Note: See Figure 10 for location and direction of photograph.

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Plate 4 - Lower East Flank of Landslide (Photograph taken on 5 December 2001)

Note: See Figure 10 for location and direction of photograph.

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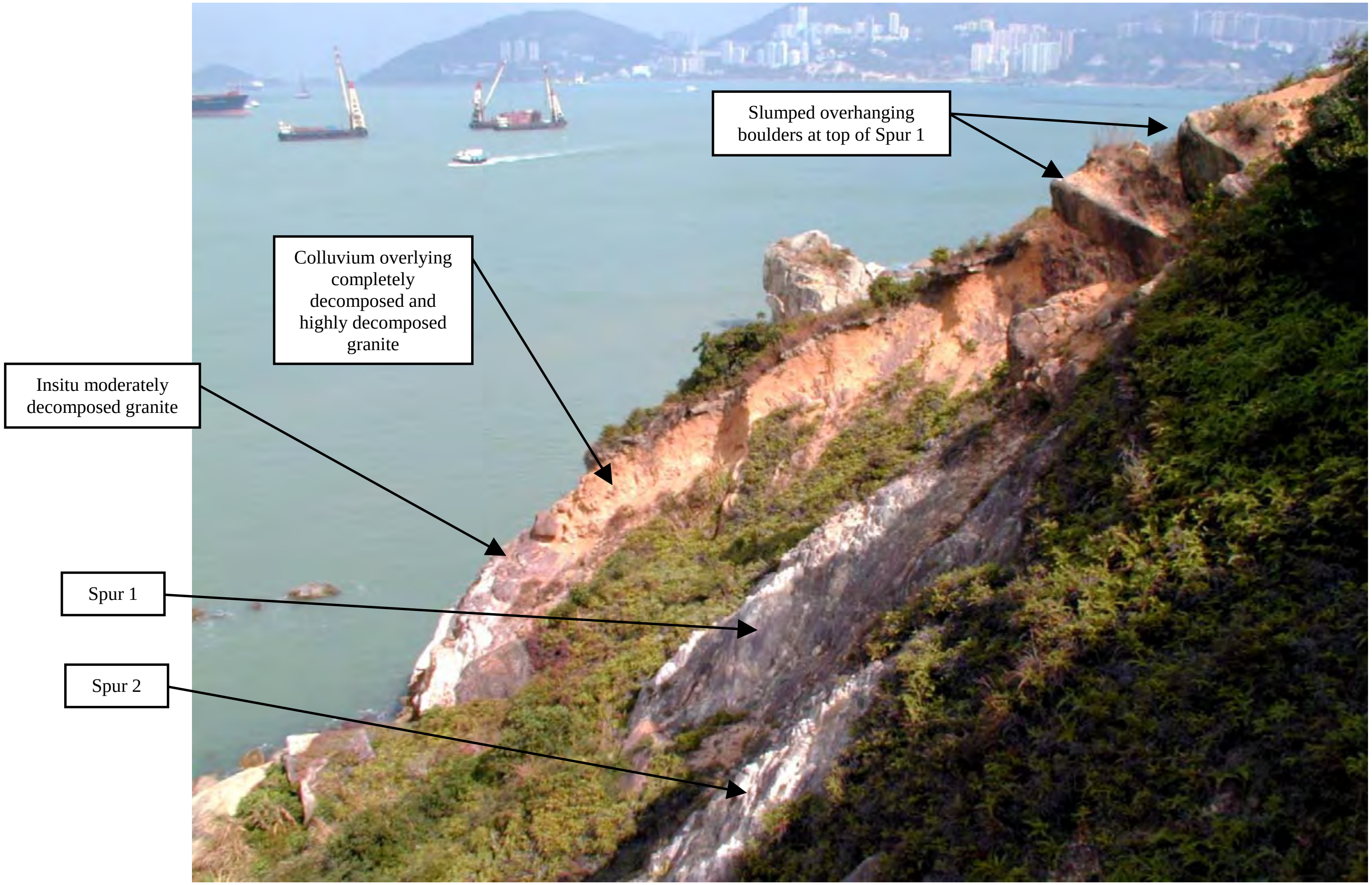

Plate 5 - Middle Section of Landslide From Crest of Spur No. 3 (Photograph taken on 5 December 2001)

Note: See Figure 10 for location and direction of photograph.

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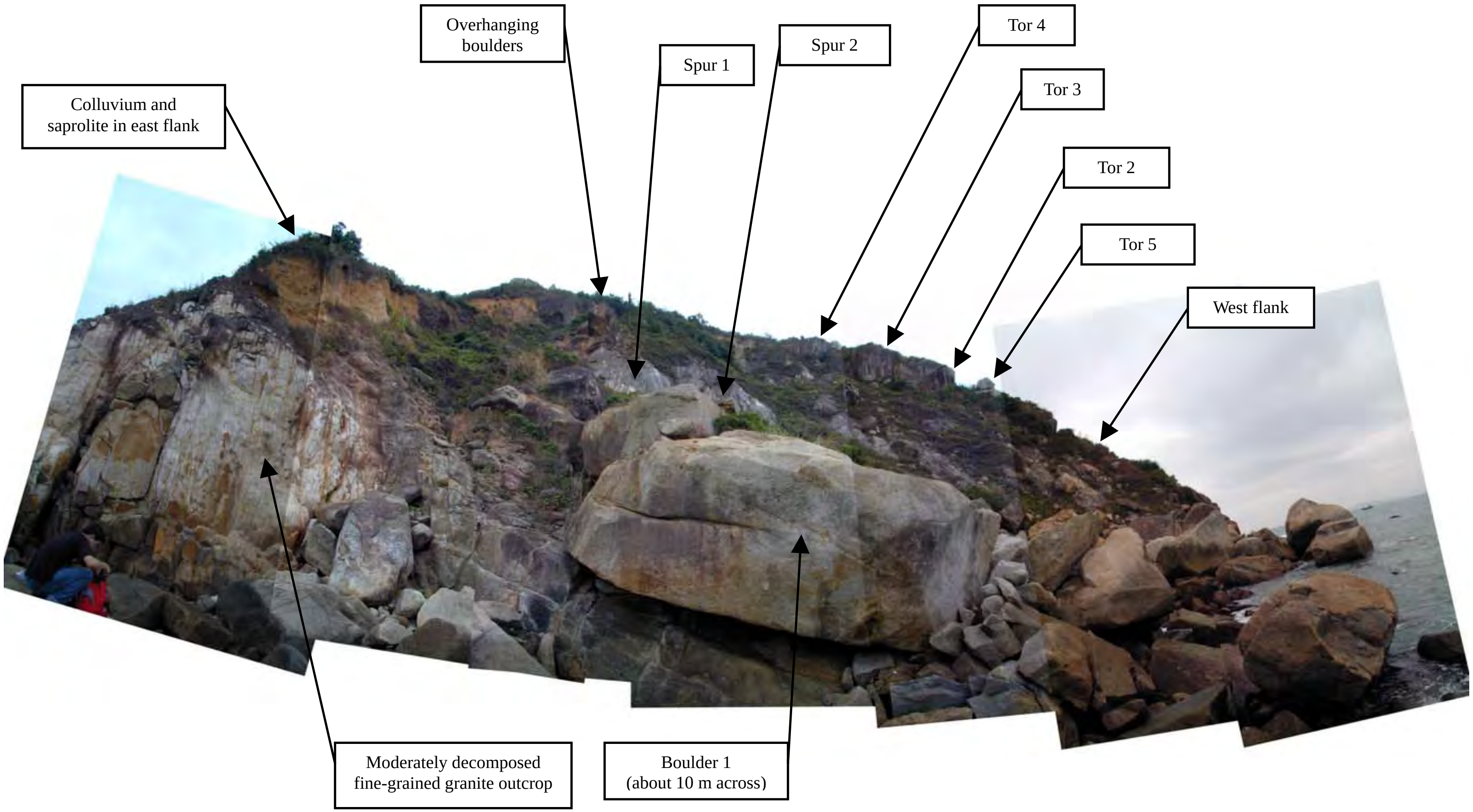

Plate 6 - View of Landslide from Shoreline (Photograph taken on 5 December 2001)

Note: See Figure 10 for location and direction of photograph.

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Plate 7 - View of a Minor Scarp (0.5 m in Height) Immediately above the Main Scarp Along Surface Strip SS1 (Photograph taken on 11 March 2003)

Plate 8 - View Upslope of Surface Strip SS1 from the Base of the Main Scarp Towards the Minor Scarp shown in Plate 7 (Photograph taken on 11 March 2003)

Note: See Figure 10 for location and direction of photograph.

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Plate 9 - View of Insitu Fine-grained Granite at the Lower Eastern Flank of the Main Scarp (Photograph taken on 10 March 2003)

Plate 10 - Close-up View of Insitu Fine-grained Granite as Shown in Plate 9 (Photograph taken on 10 March 2003)

Note: See Figure 10 for location and direction of photograph.

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Plate 11 - Close-up View of Insitu Megacrystic Granite at the Lower Eastern Flank of the Main Scarp (Photograph taken on 10 March 2003)

Note: See Figure 10 for location and direction of photograph.

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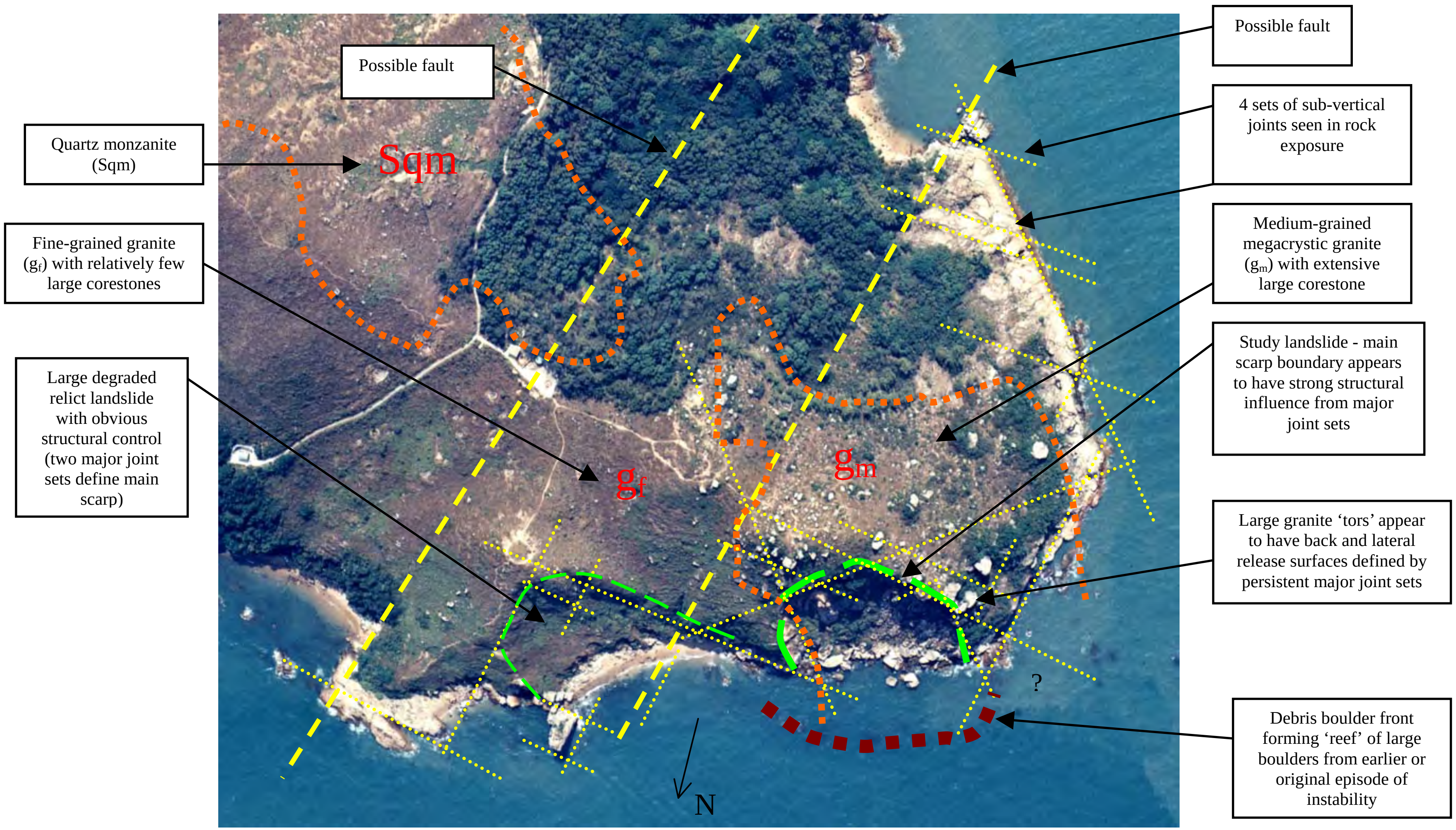

Plate 12 - Inferred Photo-geological Lineaments, Geology and Areas of Relict and Recent Instability Identified From Aerial Photographs taken on 2 November 1993

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Plate 13 - View of Deformed Rock Mass Within Spur No. 1. Showing Dilation and Voids (Photograph taken on 18 March 2003)

Plate 14 - Close-up View of Deformed Rock Mass with Voids and Kaolin Coated Joint Surfaces (Photograph taken on 18 March 2003)

Note: See Figure 10 for location and direction of photograph.

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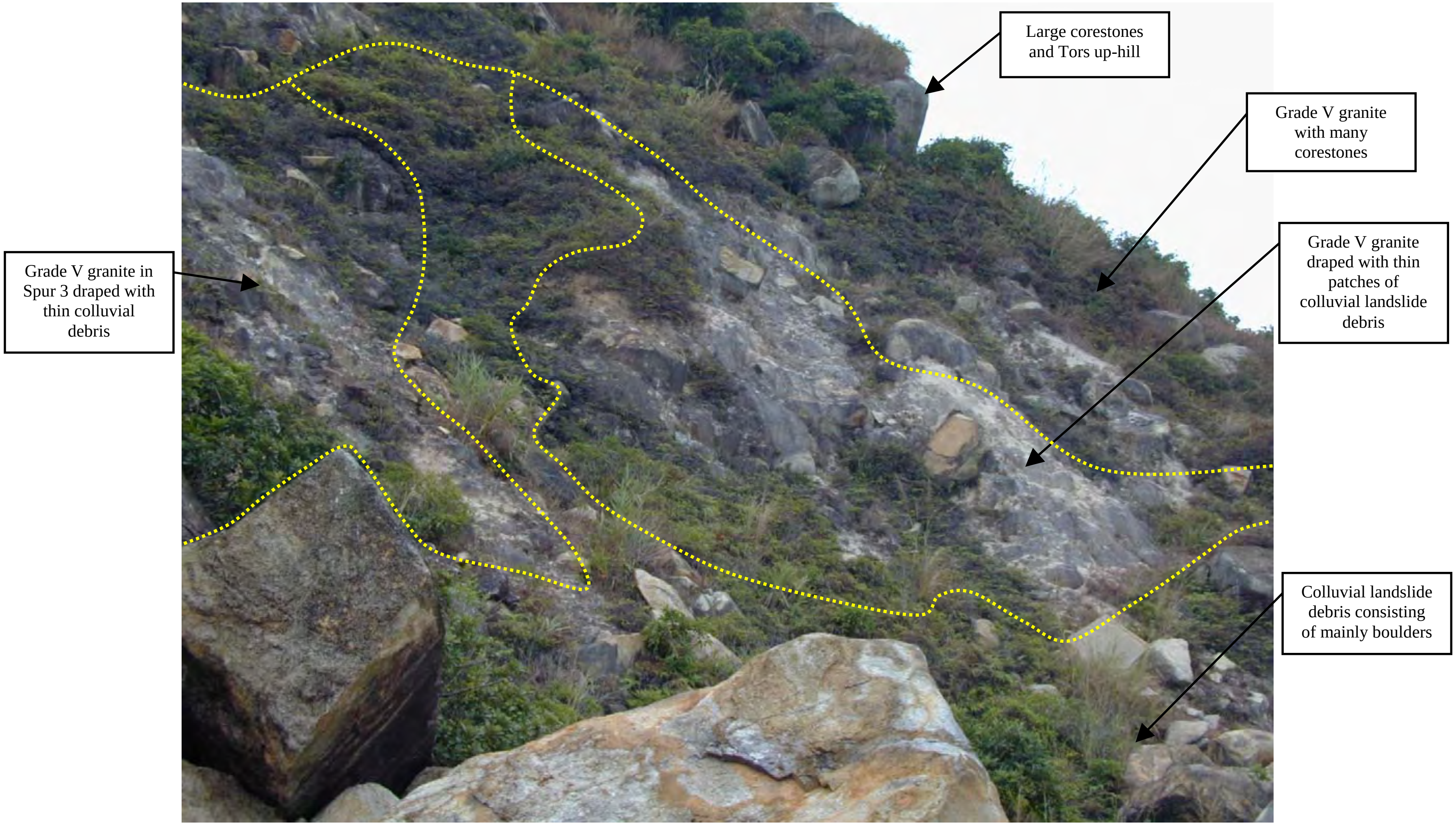

Plate 15 - View Looking Towards West Flank of Landslide Main Scarp (Photograph taken on 5 December 2001)

Note: See Figure 10 for location and direction of photograph.

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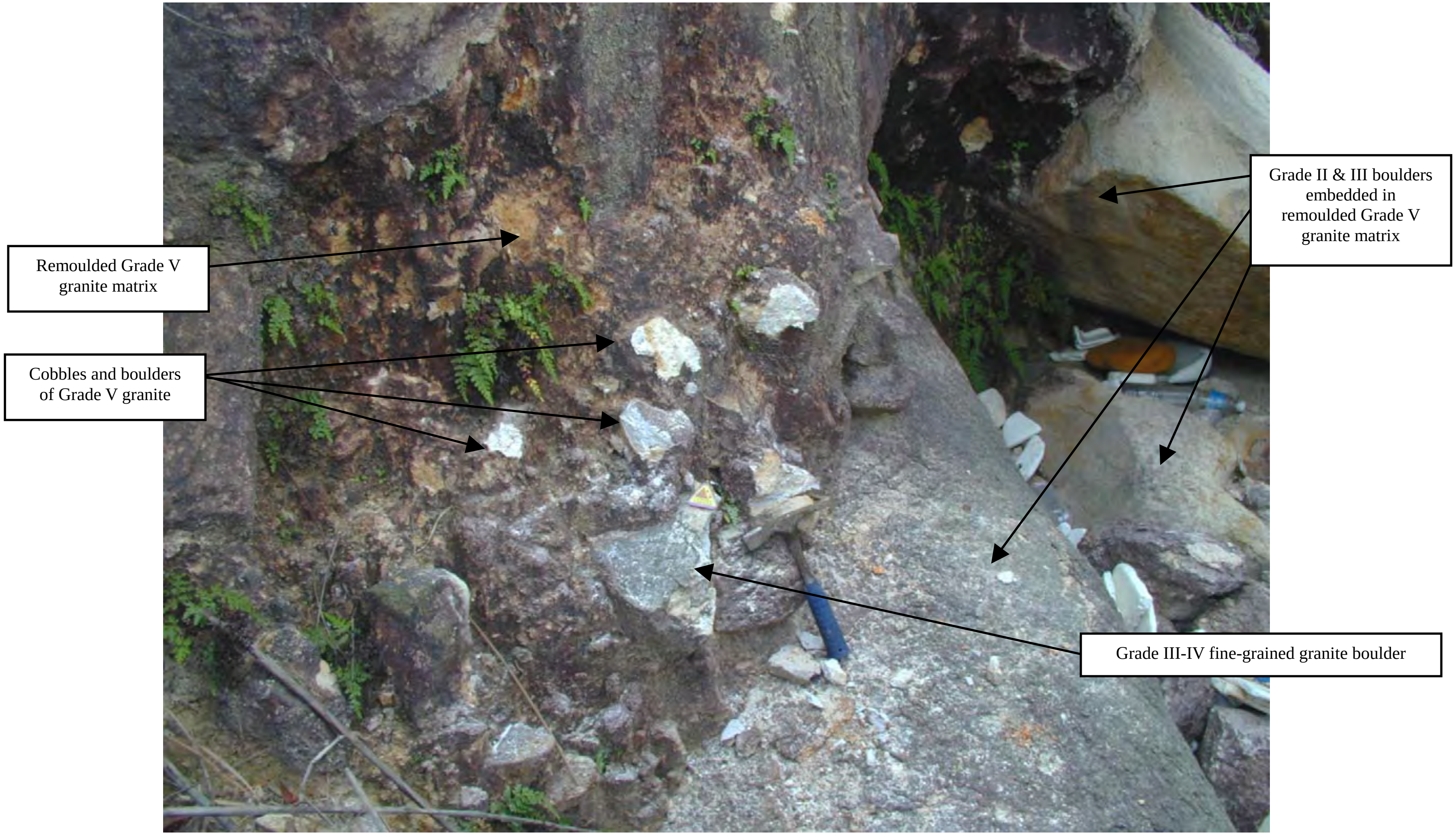

Plate 16 - Relict Colluvium Near the Toe of the Landslide Scar (Photograph taken on 5 December 2001)

Note: See Figure 10 for location and direction of photograph.

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Plate 17 - Tension Crack Along the Base of the Main Scarp below Tor No. 3 (Photograph taken on 5 December 2001)

Plate 18 - Tension Crack Along the Base of the Main Scarp below Surface Strip SS1 (Photograph taken on 5 December 2001)

Note: See Figure 10 for location and direction of photograph.

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

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CONTENTS

A1. DETAILED OBSERVATIONS

The following comprises a summary of all site history findings for the study area. The findings of the aerial photograph interpretation are shown in Plates A1 to A4.

YEAR	OBSERVATIONS
1945	The study area comprises undeveloped natural terrain hillside. 'Recent' instability (indicated by a light tone area) can be seen within the landslide site on 11 November 1945, which are the earliest photographs available (Plate A1). Although the photographs are high level (20,000 ft), and poor resolution, the outline of a fairly large landslide scar (>30 m wide) can be identified at the location of the study landslide site. Also, an arcuate 'reef' of boulders can be seen in the sea around the toe of the scar, probably representing a boulder debris front from an earlier, or original episode of instability. The landslide appears to be similar in shape although smaller in extent to the 1963 landslide scar.
1963	By 1963 details of the main scarp can be seen clearly (Plate A2). The visible main scarp was smaller in extent than can be seen on the next aerial photographs taken on 20 December 1973. However, two apparent tension cracks can be seen on the 1963 photographs that appear to follow the outline of the 1973 and present-day main scarp. The landslide scar morphology in the western part of the main scarp indicates possible wedge failure with a geometrically shaped crown. This suggests a probable structural control to the instability. Very large boulders accumulated at the toe of the scar suggest failure of corestone/coreslabs or failure of a saprolite mass supporting the corestones. The orthogonal shape of the boulders again suggests a structural control element to the failure. A distinctive break in slope is apparent above the main scarp which could be due to possible relict instability extending beyond the tension cracks.
1964	No observable changes.
1973	The next set of photographs taken in 1973 are high level but indicate that the study landslide main scarp has enlarged by approximately 20%, by regressing back up the hillside to form the general shape of the present-day landslide.
1974	No observable changes.
1975	No observable changes.

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YEAR	OBSERVATIONS
1976	No observable changes.
1978	The 5 July 1978 photographs are low level and confirm the extent of the main scarp enlargement being similar to the present-day outline (Plate A3). The ground between the 1963 main scarp and the present-day main scarp (tension cracks of 1963) has apparently slumped vertically several metres. This area is relatively flat-lying, thickly vegetated and was observed on site to lie between the crest of Spur 2 and the base of the main scarp. A vegetated mass, surrounded by bare soil, in a similar position can be seen on the 1978 photographs. The large intact spurs of apparently insitu decomposed granite appear to be undisturbed with no bulging, cracking or distortion, suggesting little possibility of deep seated movement taking place underneath.
1979	No observable changes.
1984	No observable changes.
1993	The 2 November 1993 photograph indicates very strongly that there is a structural geological control on the instability of the hillside. The main scarp of the landslide is shown clearly to follow three main structural trends of sub-vertical discontinuities, one of which (striking E-W) forms the back release surface for the large granite tors within the western flank. Other main structural trends (striking N-S) shown in the photograph indicate side release surfaces for the tors. Similar structural trends are repeated within the degraded large relict landslide scar approximately 70 m to the west, and within a small degraded landslide scar 30 m to the southwest. Other lower angle joint sets were observed from the site reconnaissance visit which initially indicate possible toppling or wedge sliding failure possibilities. The hillside to the south of the present-day main scarp contains distinctly more large corestone-bearing ground than that to the west, which generally coincides with the area of medium grained granite as shown in the published 1:20 000 geological map (HKGS Map Sheet 14). It is possible that the conditions of placement of this granite, including cooling and crystal growth, may have been favourable for the very wide, persistent, orthogonal joint development leading to the eventual formation of the large corestones. The dominant discontinuity trends are N-S, E-W, and NW-SE. A number of lineations that may represent major, sub-vertical discontinuities and/or tension cracks can be seen striking across the slope and through the East and West flanks, extending across the natural hillside on either side. A N-S trending fault is inferred passing within 30 m of the east flank of the landslide.
1995	No observable changes.

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YEAR	OBSERVATIONS
1996	No observable changes.
1997	No observable changes.
1998	No observable changes.
1999	No observable changes.
2001	No observable changes.

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Table A1 - List of Aerial Photographs

Date taken	Altitude (ft)	Photograph Number
11 November 1945	20,000	Y00329-30
13 February 1963	3,900	Y06496-98
1964	12,500	Y12795-96
20 December 1973	12,500	8063-64
21 November 1974	12,500	9657-58
19 December 1975	12,500	11656-57
4 November1976	12,500	15867, 69
10 January1978	12,500	20825-26
5 July 1978	4,000	22174-75
25 January 1979	12,500	24613-14
28 November 1979	10,000	27965-66
22 November 1984	5,000	57318-19
2 November 1993	3,000	CN5169*
19 July 1995	3,500	CN10092-93*
9 January 1995	3,500	A40377
31 October 1995	4,000	CN11709-10*
23 October 1996	4,000	CN15448-49*
21 May 1996	4,000	CN13742*
23 June 1997	4,000	CN17505-06*
23 October 1998	4,000	CN21016-17*
8 February 1999	4,000	CN22743-44*
16 February 2000	20,000	CN25959-60*
24 May 2001	4,500	CW31125-26*
22 August 2001	4,000	AW52492-93

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

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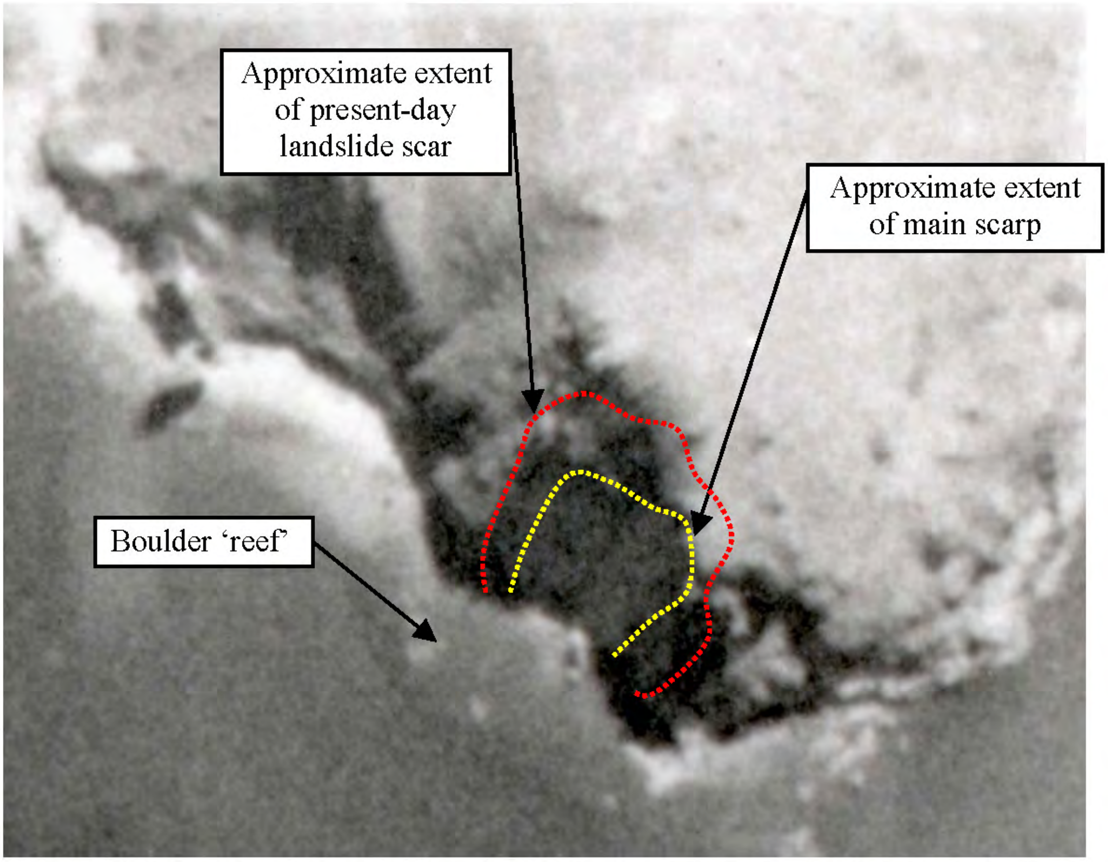

Plate A1 - API Observations of Landslide Area From 13 February 1945 Stereo-photographs

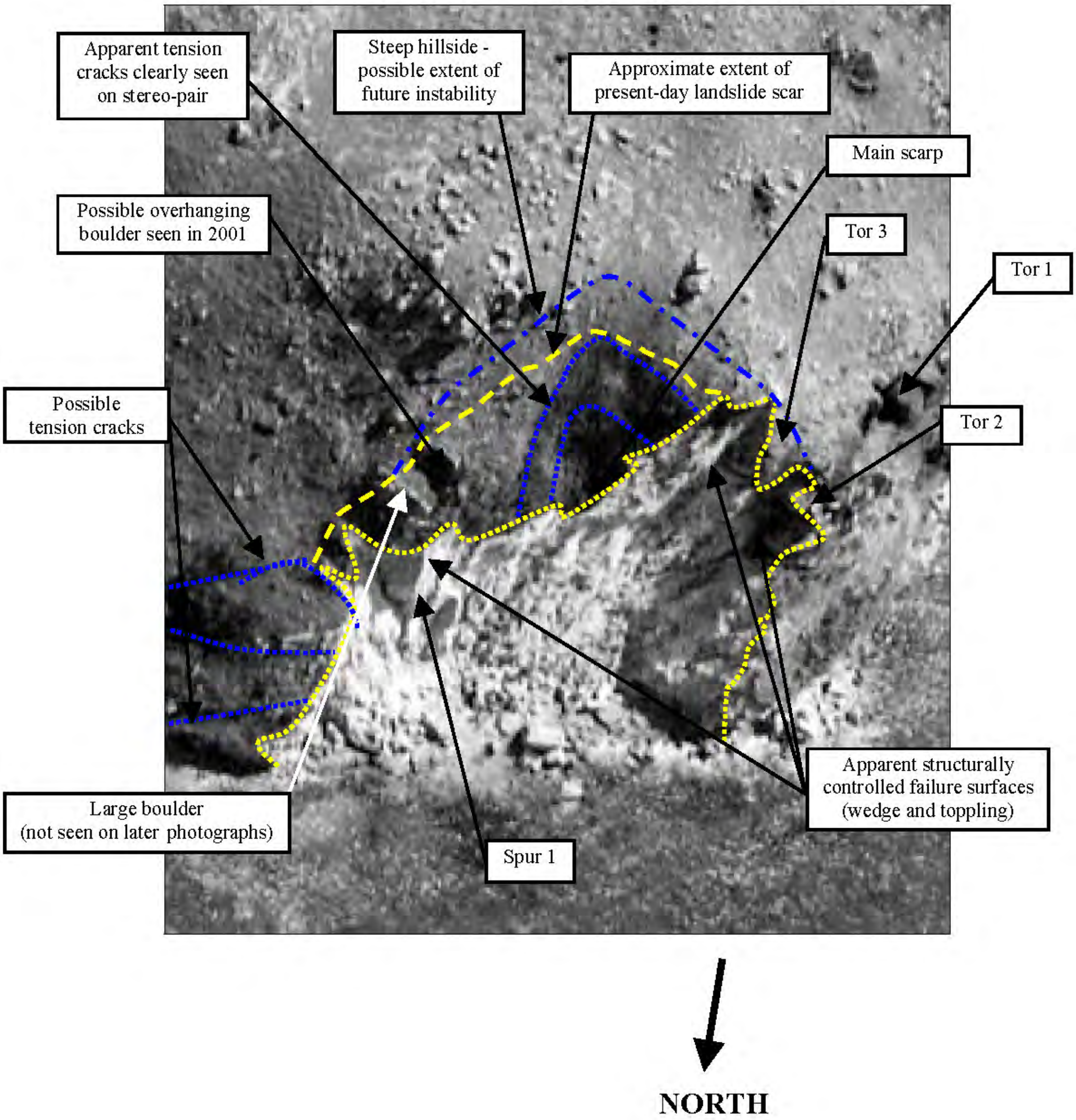

Plate A2 - API Observations of Landslide Area From 13 February 1963 Stereo-photographs

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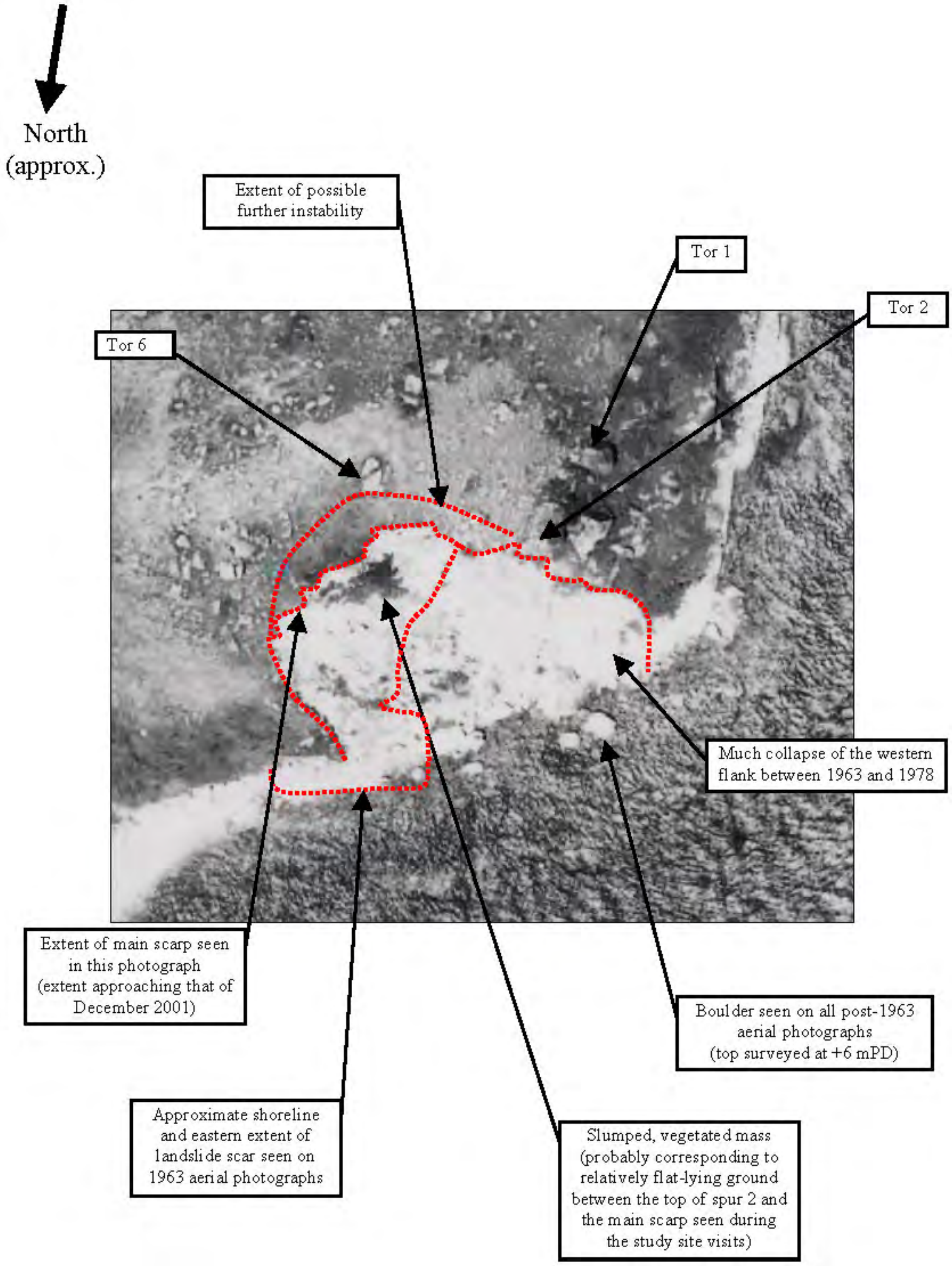

Plate A3 - API Observations of Landslide Area From 5 July 1978 Stereo-photographs

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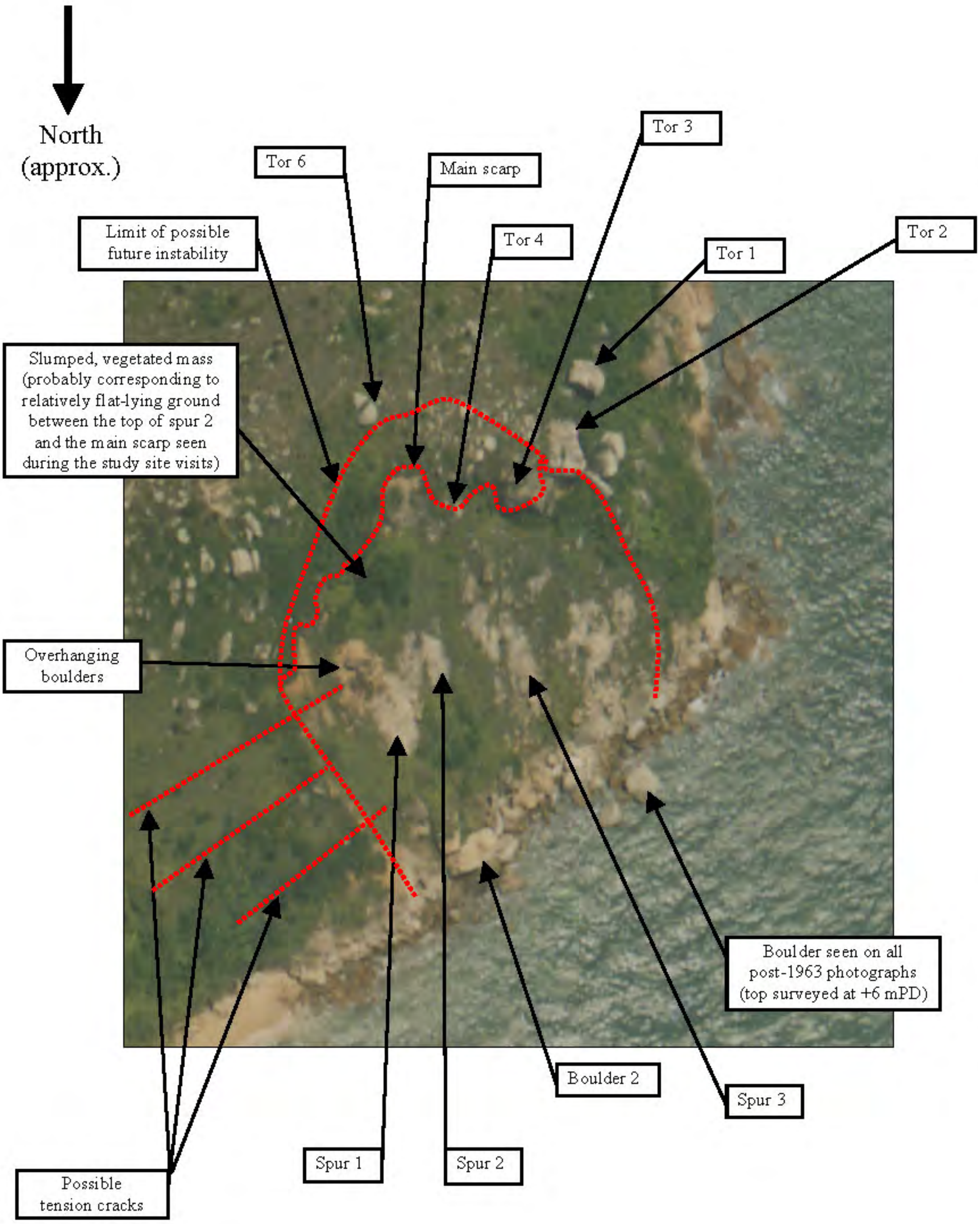

Plate A4 - API Observations of Landslide Area From 24 May 2001
Stereo-photographs

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APPENDIX B

REPORT ON LARGE COASTAL LANDSLIDES
BY PLANNING DIVISION OF GEO

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LARGE COASTAL LANDSLIDES

A Preliminary Investigation of Three Landslides at Lamma Island, Sham Wat and Nam She Wan

Planning Division
October 2001

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LARGE COASTAL LANDSLIDES

A Preliminary Investigation of Three Landslides at Lamma Island, Sham Wat and Nam She Wan

LARGE COASTAL LANDSLIDES

A Preliminary Investigation of Three Landslides at Lamma Island, Sham Wat and Nam She Wan

1. Introduction

Through the systematic mapping of natural terrain landslides in Hong Kong, the Geotechnical Engineering Office has identified a broad spectrum of commonly occurring landslide types and is now carrying out studies to develop an understanding of their characteristics. However, several types have not been closely studied, in particular coastal landslides. Landslides that occur adjacent to actively undercutting river channels constitute a similar category.

Coastal cliffs are geologically recent features, natural excavations into the landscape around the margins of the landmass. Active erosion at the base of the coastal cliffs oversteepens the coastal slopes (creating metastable faces in the exposed lithologies) and removes toe support. The freshly exposed lithologies in the cliffs comprise transported superficial deposits (colluvium and alluvium), *in situ* weathering profiles (Grades IV to VI material), and bedrock (Grades I to III material). Also exposed are geological structures within the bedrock, relict structures within the weathering profiles, and lithological contacts (especially the base of the superficial deposits or the weathering front). In addition, ground water discharges from these daylighting discontinuities may be important. Therefore, coastal slopes should perhaps be more prone to landslides than hillslopes inland, and the failed masses potentially larger.

In general, coastal slopes commonly have the following characteristics:

(i) they are relatively more accessible than their densely vegetated inland counterparts;

(ii) they are located in an actively eroding environment;

(iii) they have the potential for employing continuous seismic profiling using marine survey techniques; and

(iv) they present increased opportunities for absolute age dating, especially if the debris is interdigitated with shell-bearing marine deposits.

Hong Kong is fringed by large areas of coastal reclamation. As a result, many steep natural slopes that parallel the present reclamation coastline were steep coastal cliffs prior to reclamation. The former sea cliffs are now located up to several hundred metres inland, and wave action at their base has now been removed. These facts are important antecedent conditions for several slope failures in Hong Kong. Current mass movements on these abandoned marine cliffs may reflect, either the reactivation of earlier coastal instability, or the natural degradation of an oversteepened slope profile to produce a more stable geometry.

2. Site Selection

The aim of the project was to study the potential for:

(i) identifying coastal landslide deposits using seabed bathymetry and seismic profiling techniques;

(ii) investigating the thickness and extent of landslide deposits using seismic profiling and marine drilling; and

(iii) examining the feasibility of dating the deposits.

These studies were designed to broaden the understanding of natural terrain landslides in Hong Kong, and also to gather valuable information that would assist with improving the procedures for Natural Terrain Hazard Studies.

Following a detailed examination of both the Natural Terrain Landslide Inventory (NTLI) and the Large Landslide Dataset, and discussions with colleagues in Planning Division, three study sites were selected, namely Lamma Island, Sham Wat, and Nam She Wan (Figure 1). Each site exhibits distinctive coastal geomorphology that would allow a range of features and their associated deposits to be examined.

Having selected the three study sites, an examination of the historical aerial photographs and the bathymetric charts was conducted to assess the geomorphological characteristics of the selected features and their associated offshore depositional zone. Limited field work was also carried out. Background information about the three sites, including the location, topography, access conditions and geology, is described below.

2.1 Lamma Island

Location: The site is located on a northwesterly-facing hillside on the northern coastline of Lamma Island. Steep rocky cliffs, with boulder strewn littoral and beach zones, fringe sections of the coast, interspersed with narrow sandy bays (Figures 2, 3 and 4).

Topography: This feature is a distinct landslide scar that originates on the convex crest slope above the cliffline and terminates in the sea (Figure 5). A steep scarp and sidescarps surround three sides of a seaward-inclined bedrock surface, which is developed along structural discontinuities in the granite bedrock. The scar is clearly discernible on aerial photographs. Boulder debris forms a distinctive arcuate deposit in the sea around the foot of the cliff.

Access: The crest of the site can be easily reached along well-defined footpaths. A low-growing, dominantly grassy vegetation with scattered stands of low bushes covers the slopes. However, access to the failure scar is more difficult, requiring a coastal traverse along the rocks and cliffs that is difficult at higher tides.

Water Depths: Water depth ranged from about -3 m near the coast to about -10 m approximately 100 metres offshore. The seabed higher directly offshore from the

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landslide feature, forming a low ridge that probably reflects the submarine extension of the debris deposits.

Geology: HKGS Map Sheet 14 (Figure 5) shows the bedrock as fine-grained granite, although a contact with medium-grained granite is mapped near the head of the failure.

2.2 Sham Wat

Location: The site is located on a northwesterly-facing hillside that runs parallel to the northern coastline of Lantau Island (Figures 6, 7 and 8).

Topography: This feature is a degraded, bowl-shaped, colluvium-filled depression located on the northwestern face of a prominent ridgeline (Figure 9). On the southeastern slopes of the ridge is a large landslide lobe, the Sham Wat debris lobe, that has been studied by GEO. The depression, which forms a large scallop in the hillside, is about 300 m wide and 500 m long and encloses a discrete drainage basin with a restricted outlet, through a low coastal ridge, to the sea. At the mouth of the outlet is a distinctive seaward bulge along an otherwise straight coastline. The seaward bulge is also reflected in the bathymetric contours. This appears to be a lobe of debris, probably a colluvial lobe or an alluvial fan.

Access: A dense cover of trees and bushes mantles the slopes, making access extremely difficult.

Water Depths: Water depth ranged from about -2 m near the coast to about -4.6 m approximately 450 metres offshore. The seabed higher directly offshore from the landslide feature, forming a low ridge that probably reflects the submarine extension of the debris deposits.

Geology: HKGS Map Sheet 9 (Figure 9) shows that the main ridge is formed in eutaxites, volcanic rocks with a well-developed planar fabric. A single dip measurement taken at a point about 600m to the southeast of the site shows the eutaxitic foliation dipping to the south at about 50º. The low coastal ridge is formed in metasiltstones and metasandstones.

2.3 Nam She Wan

Location: This site is located on the northern slopes of Nam She Tsim (Sharp Peak), summit height 468 mPD, above an unnamed bay to the east of Nam She Wan (Figure 10).

Topography: This feature is a large ampitheatre on the northern slopes of Nam She Tsim (Sharp Peak)(468 mPD), above an unnamed bay to the east of Nam She Wan (Figure 11). The slopes are steep, bouldery and rugged, dissected by deep and narrow stream channels.

Access: The site is very remote. Access is either by sea, or on foot from the ferry piers at Chek Keng or Ko Lau Wan. The slopes are steep and rugged, with a cover of grasses and bushes.

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Water Depths: Water depth ranged from about -2 m near the coast to about -7 m approximately 400 metres offshore, at which point the shelf edge steepened markedly, descending to about -14 m over a distance of about 100 metres.

Geology: HKGS Map Sheet 8 (Figure 11) shows that the Nam She Tsim upland is underlain by trachydacitic and rhyolitic lavas, with geologically younger coarse ash crystal tuffs forming the lower slopes below the 100 mPD contour. A band of intercalated tuffaceous mudstones, siltstones and breccias crop out on the western slopes along the contact, wedging-out eastwards.

3. Ground Investigation

3.1 Geophysical Surveys

Based on the findings of the preliminary review of aerial photographs and site reconnaissance, seismic survey grids were designed to investigate the morphology and extent of the nearshore coastal deposits, to determine if offshore landslide lobe could be identified. Survey lines were laid out at 10 metre, 20 metre, and 50 metre spacings, varying from site to site and across sites (Figures 12, 13 and 14). Echo sounding, Chirp seismic sub-bottom profiling, and boomer seismic reflection profiling were requested (IGGE, 2001a, 2001b).

To achieve maximum results from the study, it was necessary that the surveys were run as close inshore as practically possible, that a boat of very shallow draft was mobilized, and that the surveys were run at the highest tides. For example, the Tide Tables for Hong Kong (Hong Kong Observatory, 2000) showed that tides of from 2.3 m to 2.7 m occured at the Tai O station between the 10^{th} November and the 18^{th} November 2000, progressing from 2100 hours to 0048 hours. This would result in almost 4 m of water to very close inshore at the Sham Wat site, with similar tidal conditions and times prevailing at the other two sites.

Echo sounding of about 105 line kilometres was requested. This technique allowed a detailed sea bed morphology map to be compiled. Chirp seismic sub-bottom profiling was requested to investigate, as far as possible, the thickness, internal structures and boulder content of the near surface deposits. Boomer seismic reflection profiles were used to locate the bedrock surface.

3.2 Drilling

A total of six continuously sampled boreholes were completed, two at each site at Lamma Island, Sham Wat, and Nam She Wan (Gammon, 2001). The locations and total depths of each borehole were estimated from the seismic records as follows (Figure 15):

Lamma Island	BH LI1	828959.523 E	810690.593 N	19 metres
	BH LI2	828946.881 E	810675.182 N	19 metres
Sham Wat	BH SW1	805506.756 E	814683.002 N	20 metres
	BH SW2	805480.396 E	814730.431 N	15 metres
Nam She Wan	BH NS1	857176.417 E	833157.881 N	18 metres
	BH NS2	857378.600 E	833093.301 N	19 metres

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All six boreholes were predominantly in sediments (soils) with no hard bedrock drilling specified. However, drilling was required to penetrate for Completely Decomposed Rock (CDR), sufficient to prove that CDR has been reached. However, rock drilling was required in any boulders that were encountered in the colluvium (landslide deposits)(Figure 15).

4. Results

4.1 Seismic Surveys

In practice, none of the surveys was run as close inshore as had been specified, because a boat of very shallow draft was not mobilized and the surveys were not run at the highest tides. Therefore, work was not carried out at the optimum nearshore locations. The results of the Chirp seismic sub-bottom profiling were unsatisfactory, because the contractor was unable to provide colour printouts of the profiles. However, the boomer seismic surveys provided clear and usable records.

4.2 Drilling

The drilling results proved to be the most valuable aspects of the survey. Satisfactory results were obtained.

4.3 Site Descriptions

4.3.1 Lamma Island

Both boreholes penetrated boulder deposits. Borehole LI2, the closest inshore and the closest to the centre of the possible debris lobe encountered boulders at 3.20 m to 5.50 m below seabed, with an intercalated shelly sand layer at between 3.50 m and 4.50 m (Figure 15). It was concluded that the shelly layer was probably dateable by radiocarbon methods.

Borehole LI1 encountered boulders between 2.50m and 3.50m below seabed, overlying a sand and gravel layer from 3.50m to 4.00m. It was concluded that the sandy layer was probably dateable by luminescence methods.

4.3.2 Sham Wat

One borehole, SW2, the closest to shore, penetrated a boulder layer at 7.50 m to 13.15 m below seabed (Figure 15). It was concluded that an intercalated silty sand layer, at 10.50 m to 11.65 m below seabed, was probably dateable by luminescence methods.

4.3.3 Nam She Wan

One borehole, NS1, penetrated a boulder layer at 1.80 m to 6.50 m below seabed. No, intercalated or underlying, layers of dateable shelly material were drilled (Figure 15). It was

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concluded that luminescence dating of the sandy matrix of the lower colluvial deposit should be attempted.

5. Summary and Conclusions

The study began with several outstanding questions, which are systematically presented and provisionally answered below:

5.1 Lamma Island

Is the feature a landslide?: The feature is clearly a landslide. Preliminary field work revealed evidence of faulting and associated shearing on the cliffs to the south of the failure, a zone that gave rise to a re-entrant in the bay to the south. This evidence suggests that the failure is located along a line of geological weakness. The failed material probably included the entire weathering profile, comprising completely weathered granite and some corestones, and rectangular granitic blocks derived from the bedrock.

Is it a single event or multiple event?: The failure was probably a large single event, modified by subsequent erosion. However, more detailed studies are required to examine this aspect.

What is the age of the feature?: The scar is clearly visible on the 1963 aerial photographs.Therefore, the failure occurred prior to 1963. Subsequent erosion has had only a minimal effect on the scar, which maintains steep scarps formed in the completely decomposed granite of the weathering profile. However, timing of the initial failure event is uncertain. Dateable layers encountered during the drilling may provide information on the age of this feature.

5.2 Sham Wat

Is the feature a landslide?: The degraded feature is interpreted as a landslide based on its morphology and the characteristics of the offshore deposits.

Is it a single event or multiple event?: Evidence, in the form of the bowl-shaped scar and the bouldery offshore deposit, suggests that the feature is possibly a single event. However, prolonged erosion has smoothed and modified the original scar. In addition, the stream has developed an alluvial splay over the seaward lobe that protrudes beyond the coastal ridge.

What is the age of the feature?: The interpreted failure scar is degraded and smoothed, with a mature vegetation cover. This suggests that the failure probably occurred hundreds, if not a few thousand, years ago. One borehole penetrated an intercalated sandy layer that is probably dateable.

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5.3 Nam She Wan

Is the feature a landslide?: Field work revealed thick colluvial deposits that are well-exposed in the banks of the stream channels, and also along the coast where coastal erosion has exposed vertical sections. The whole feature is a steep ampitheatre that is being fluvially dissected, with evidence of lobate masses of colluvium.

Is it a single event or multiple event?: The feature is interpreted as a steep, enclosed mountain flank catchment in which multiple small failures have occurred as individual, fairly localized lobes. These have coalesced to build up an extensive colluvial apron, which is now being dissected by the steeply graded ephemeral streams.

What is the age of the feature?: Mass movement activity has been progressively accumulating colluvial debris as lobes on the northern flanks of Nam She Tsim, some of which has not reached the sea. Most of the colluvium seen in sections was weathered and partially indurated, indicating a considerable age for the deposits. Despite thick colluvial deposits on the hillsides, the coastal and littoral deposits are thin. However, dating of the basal layers of the colluvial deposits may give an indication of the age of one lobe.

6. References

IGGE 2001a. *Investigation of Coastal Landslides at Lamma: Marine Echo Sounding and Seismic Reflection Surveys*. Final Report, March 2001, Institute of Geophysical and Geochemical Exploration, MLR, PRC, 7 p plus 3 Figures, 7 Drawings, and 2 Appendices.

IGGE 2001b. *Investigation of Coastal Landslides at Nam She Wan and Sham Wat: Marine Echo Sounding and Seismic Reflection Surveys*. Final Report, March 2001, Institute of Geophysical and Geochemical Exploration, MLR, PRC, 7 p plus 3 Figures, 14 Drawings, and 2 Appendices.

Gammon 2001. *Investigation of Coastal Landslides at Sham Wat, Lamma Island and Nam She Wan: Marine Ground Investigation*. Final Report, March 2001, Gammon Construction Limited, Hong Kong, 6 p plus 2 Tables and 6 Appendices.

7. Figures

Figure 1 - Locations of the Three Coastal Landslide Study Sites

Figure 2 - Vertical Aerial Photograph of the Lamma Island Feature in 1963 (Photograph No.Y06497 from 3,900 feet on 13/02/1963)

Figure 3 - Vertical Aerial Photograph of the Lamma Island Feature in 1995 (Photograph No.A40376 from 3,500 feet on 09/01/1995)

Figure 4 - Oblique Aerial Photograph of the Lamma Island Feature in 1999 View from the Northwest (Helicopter Photograph No. HK914)

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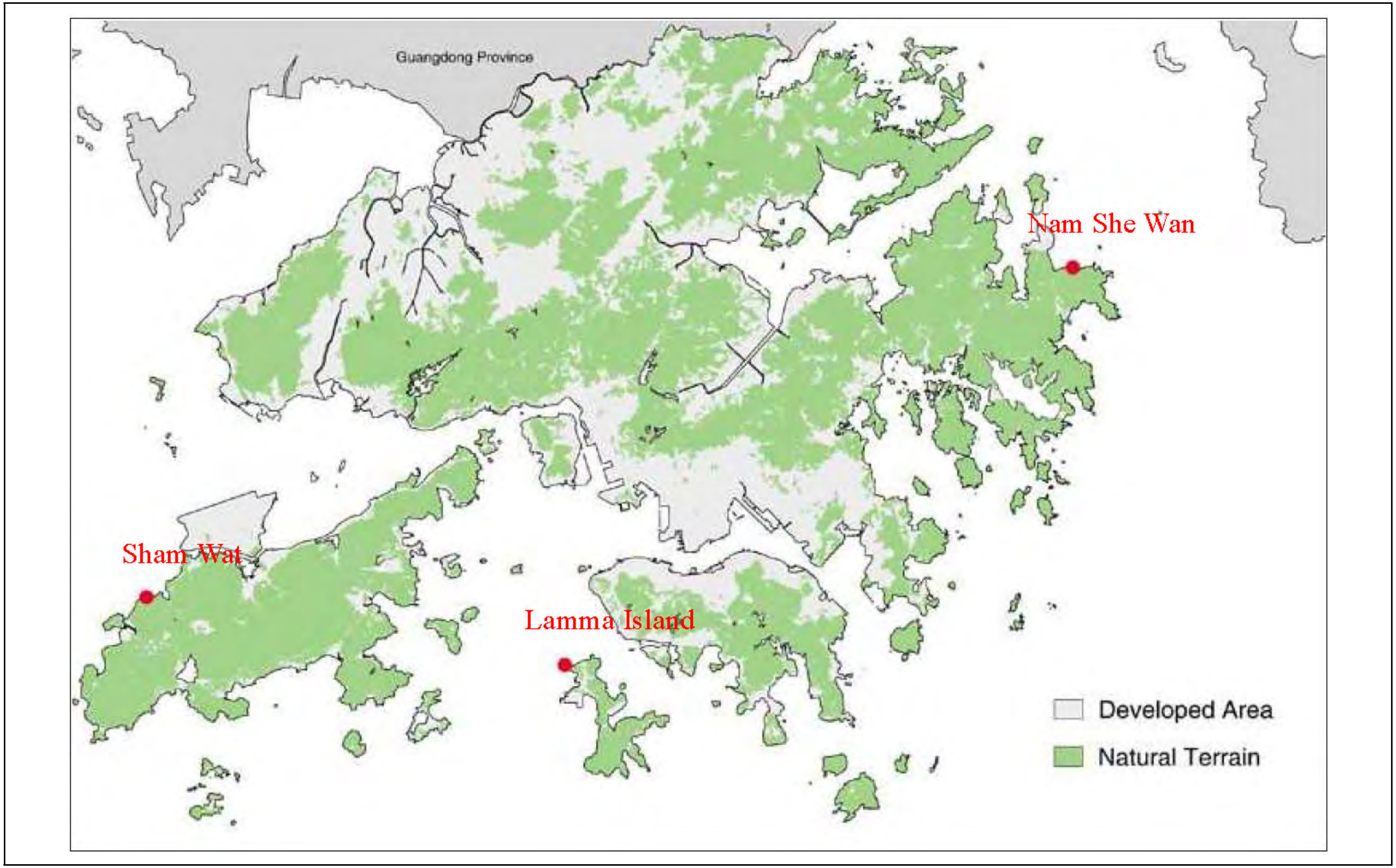

Figure 1 - Locations of the Three Coastal landslide Study Sites

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Figure 2 - Vertical Aerial Photograph of the Lamma Island Feature in 1963
(Photograph No. Y06497 from 3,900 feet on 13/02/1963)

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Figure 3 - Vertical Aerial Photograph of the Lamma Island Feature in 1995
(Photograph No. A40376 from 3,500 feet on 09/01/1995)

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Figure 4 - Oblique Aerial Photograph of the Lamma Island Feature in 1999
View from the Northwest (Helicopter Photograph No. HK914)

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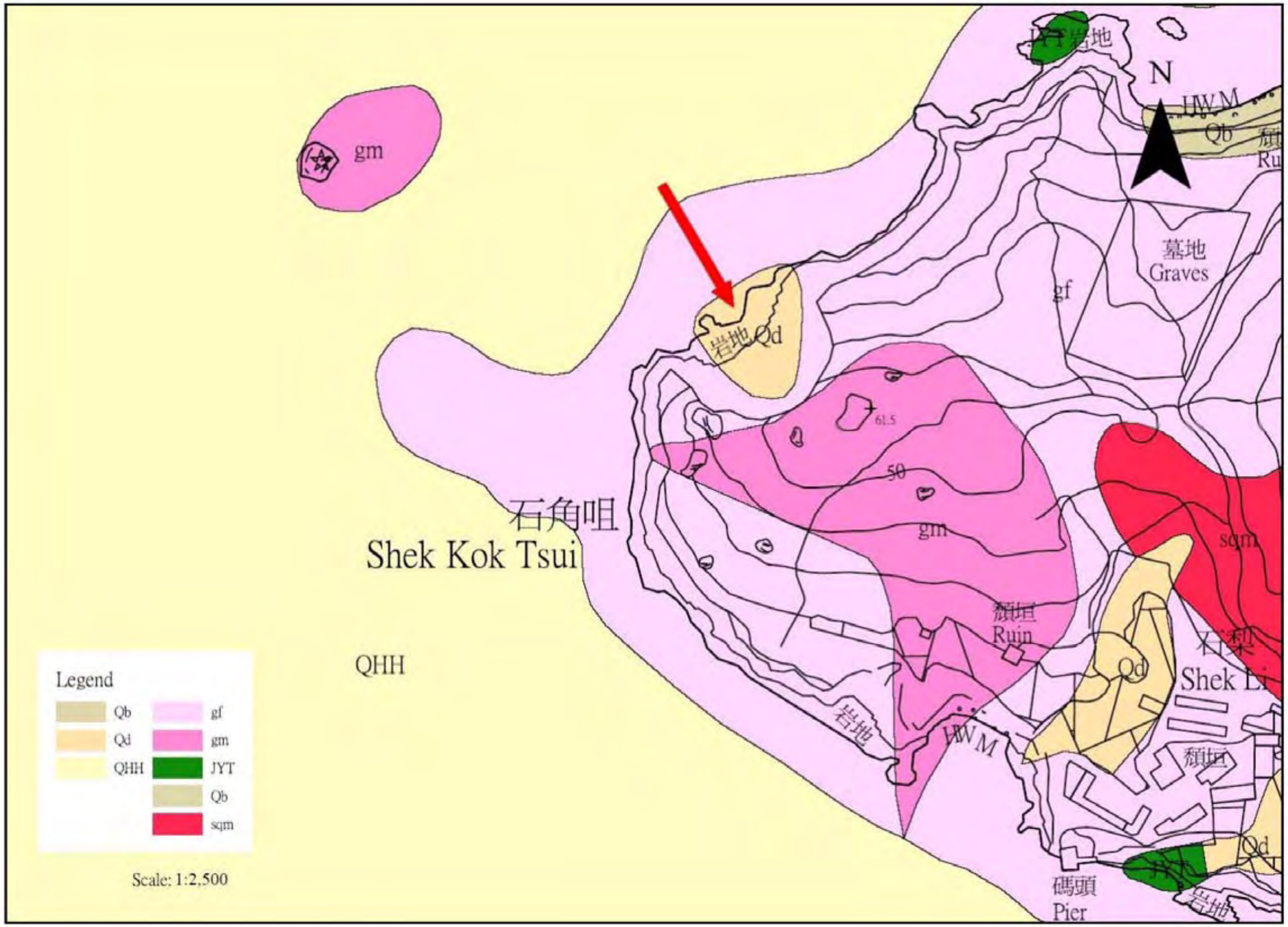

Figure 5 - Topography and Geology of the Lamma Island Study Site

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Figure 6 - Vertical Aerial Photograph of the Sham Wat Feature in 1963
(Photograph No. Y06392 from 7,000 feet on 24/02/1963)

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Figure 7 - Oblique Aerial Photograph of the Sham Wat Island Feature in 1999
View from the North (Helicopter Photograph No. PS1032-11)

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Figure 8 - Oblique Aerial Photograph of the Sham Wat Feature in 1999
View from the West (Helicopter Photograph No. PS1032-5)

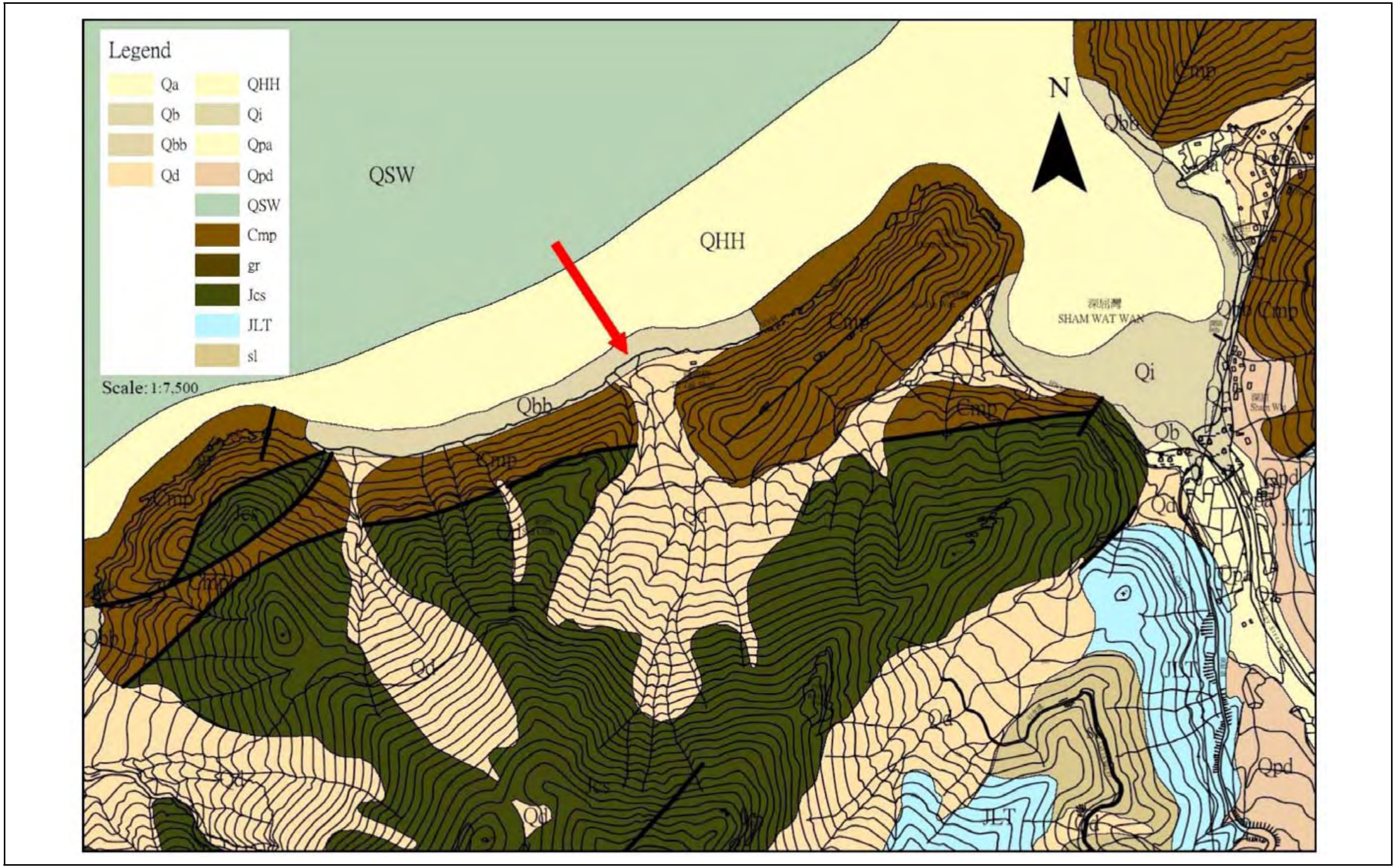

Figure 9 - Topography and Geology of the Sham Wat Study Site

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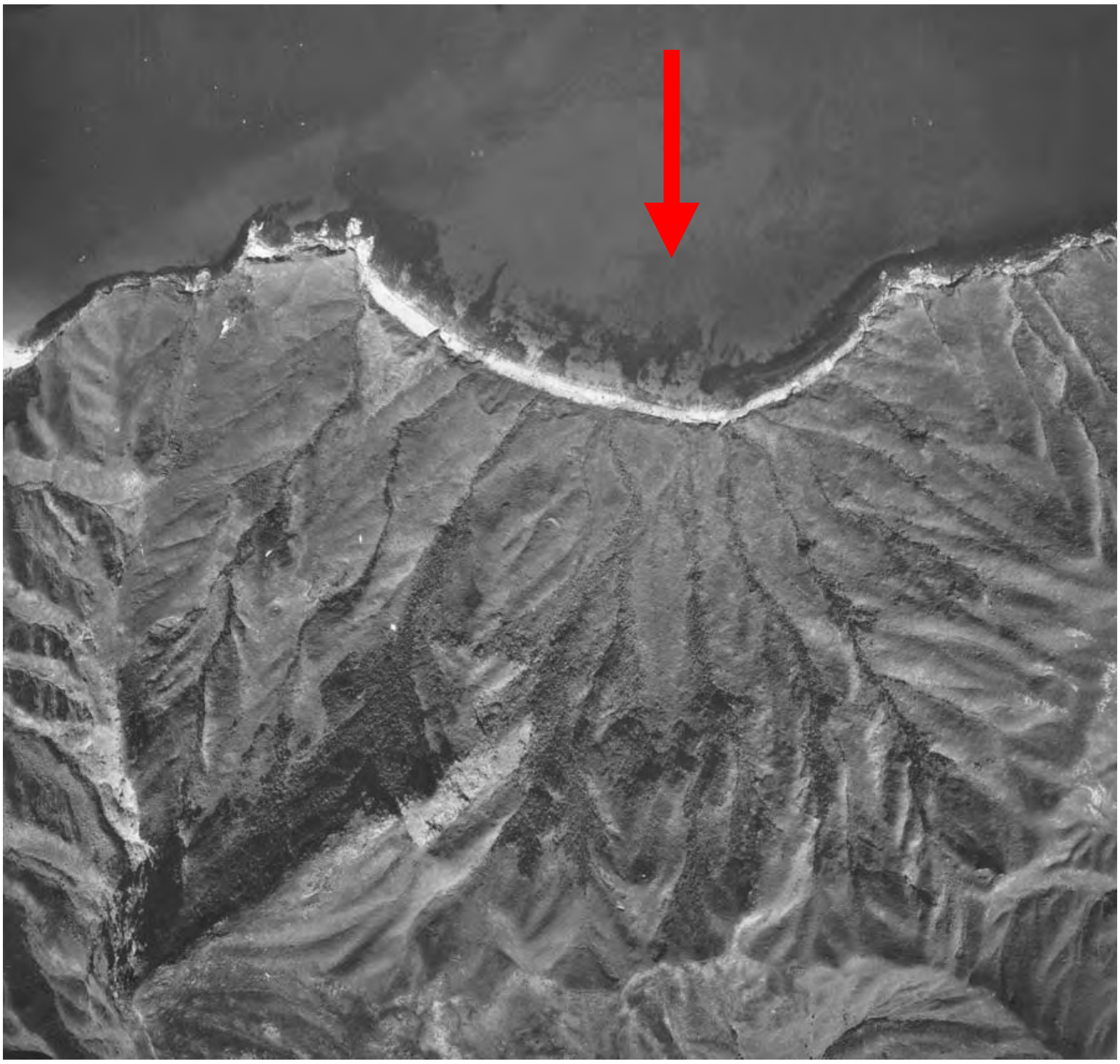

Figure 10 - Vertical Aerial Photograph of the Nam She Wan Feature in 1963
(Photograph No. Y10437 from 3,900 feet on 17/02/1963)

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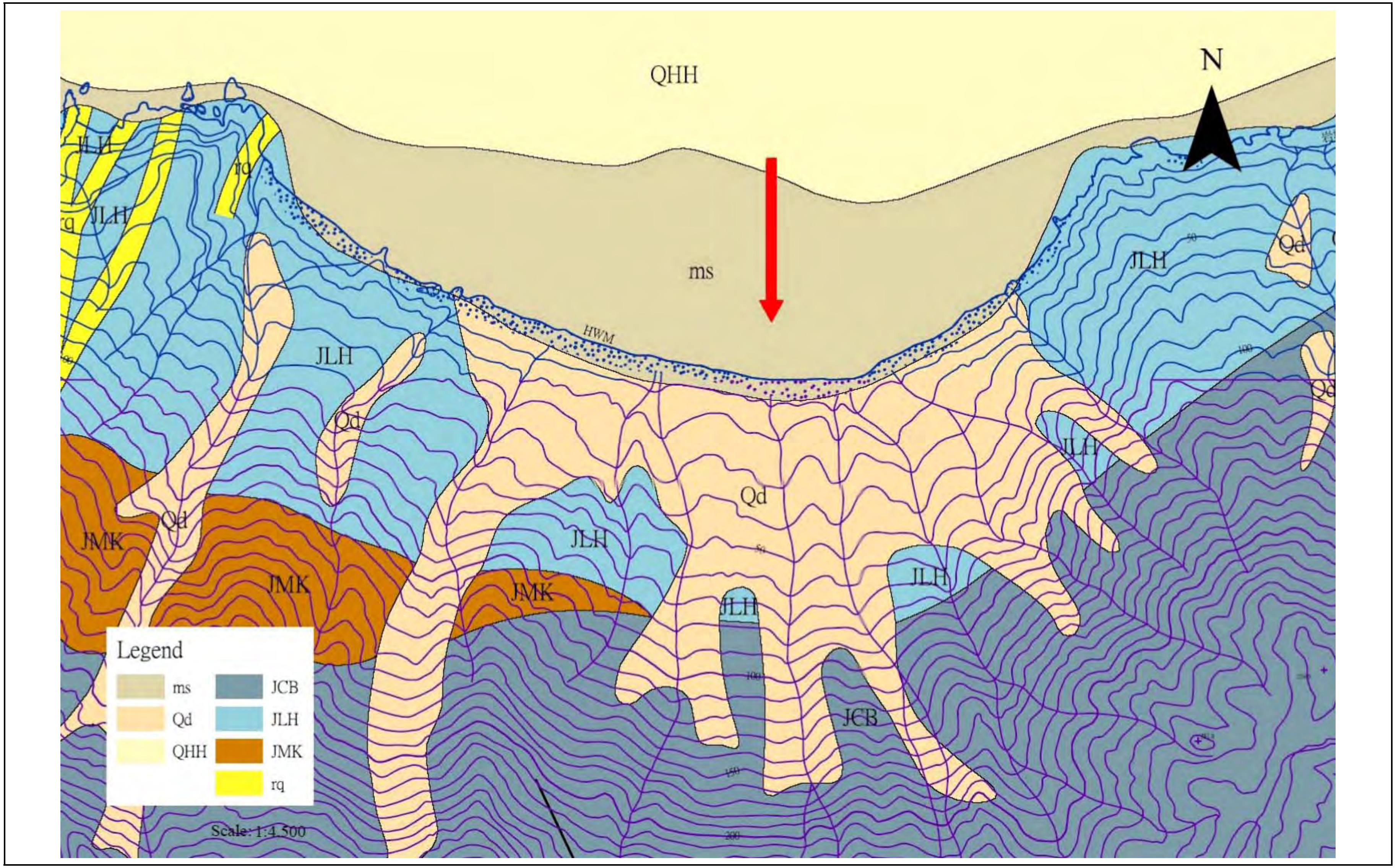

Figure 11 - Topography and Geology of the Nam She Wan Study Site

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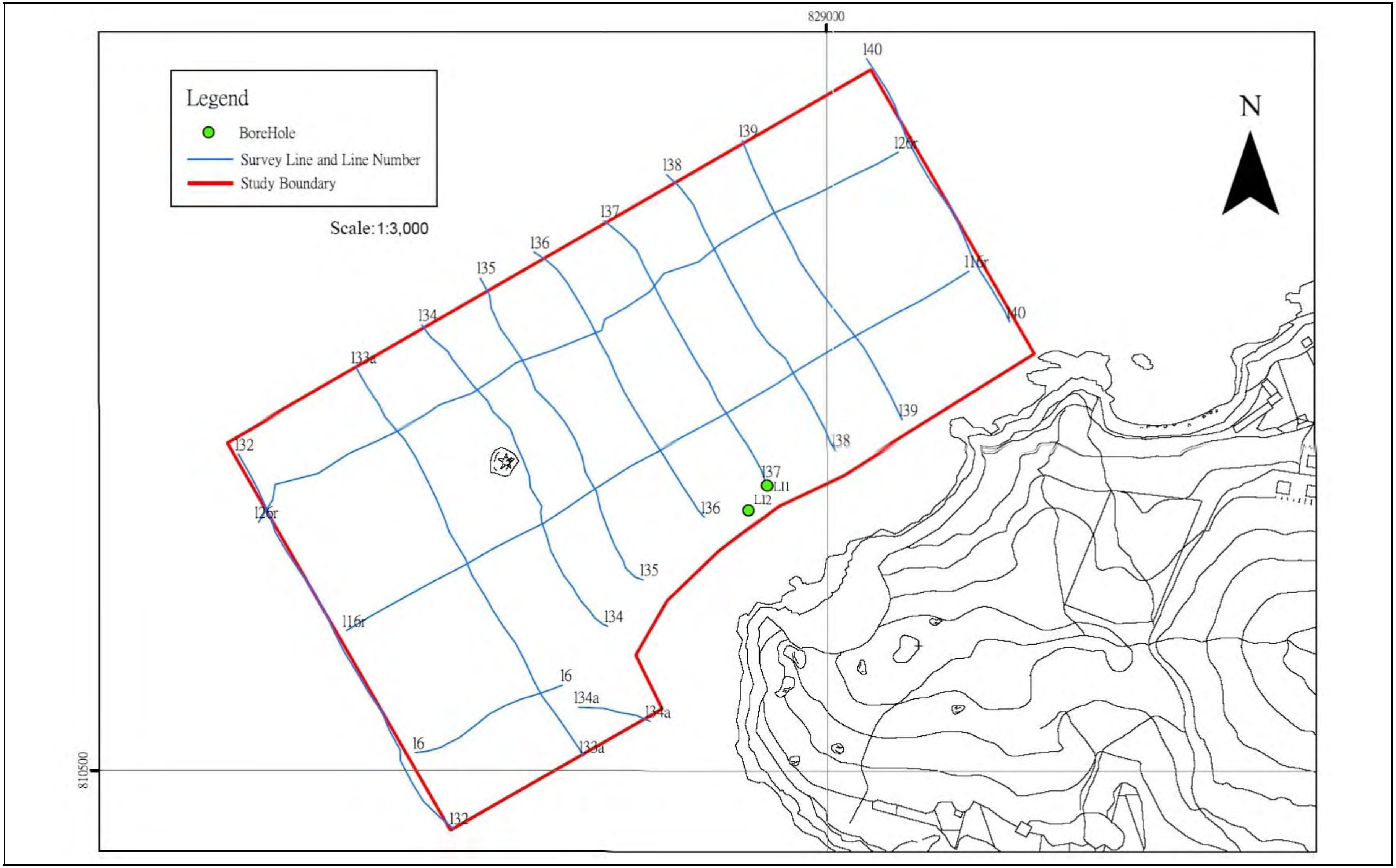

Figure 12 - Seismic Survey Lines and Borehole Locations at the Lamma Island Study Site

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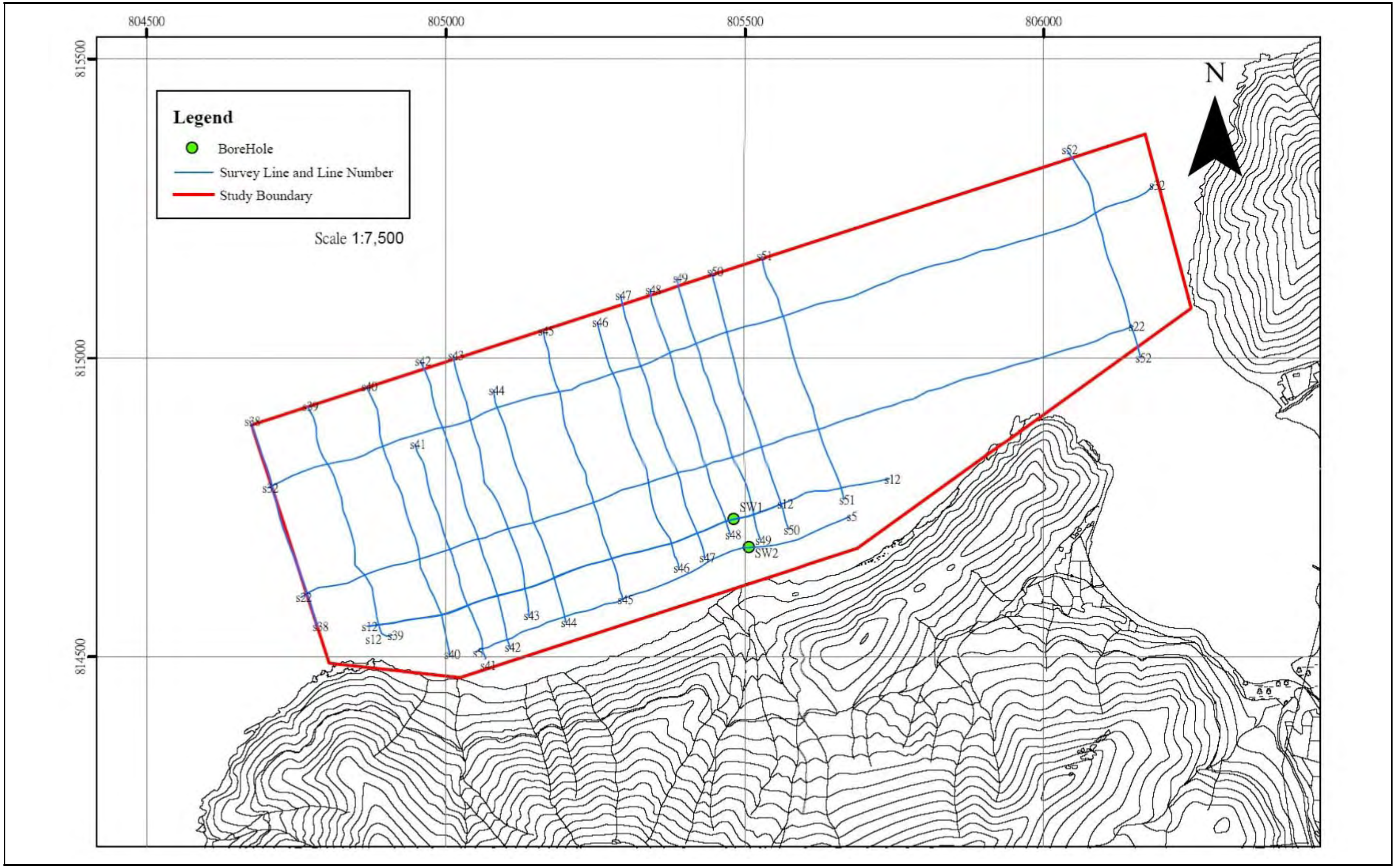

Figure 13 - Seismic Survey Lines and Borehole Locations at the Sham Wat Study Site

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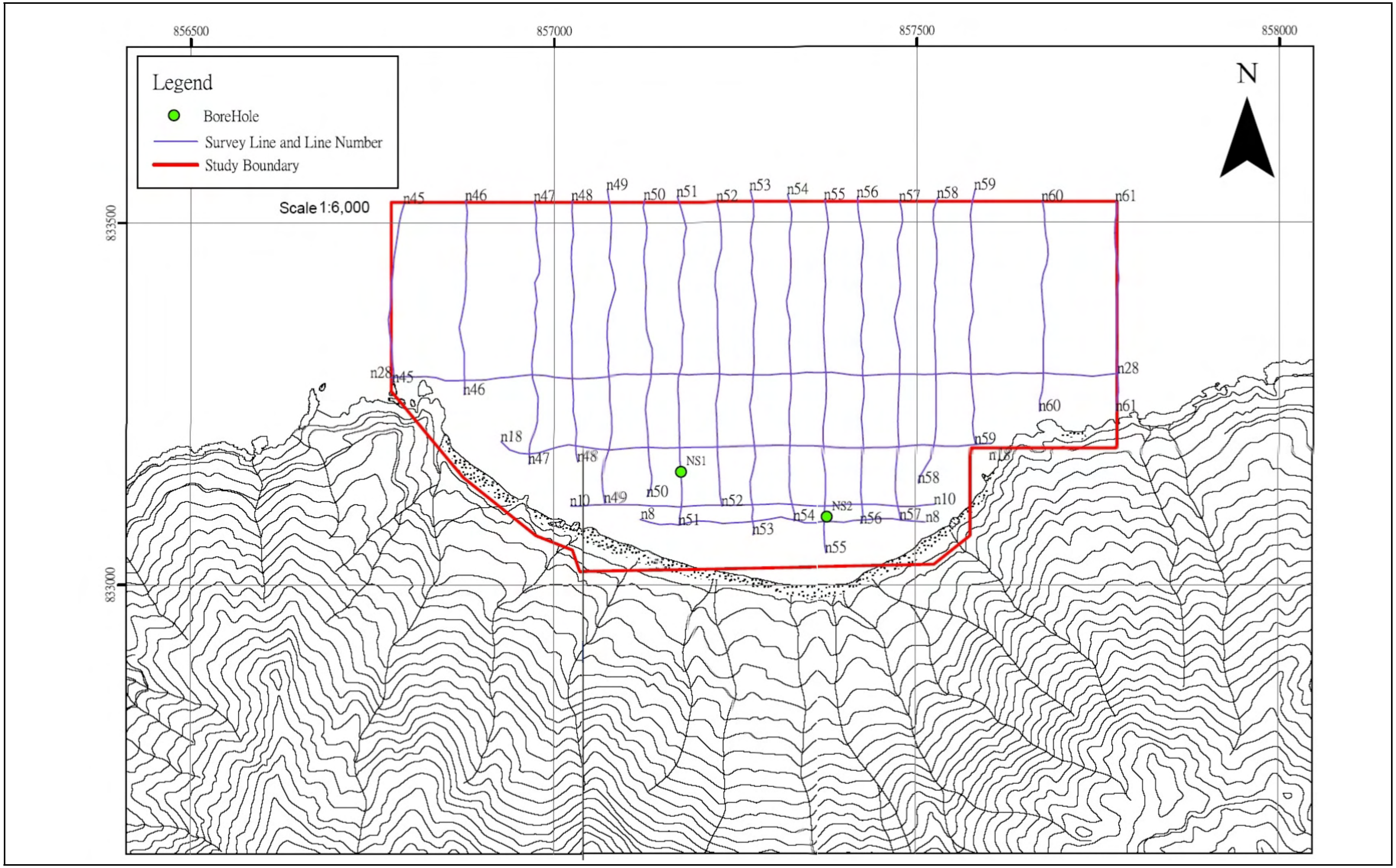

Figure 14 - Seismic Survey Lines and Borehole Locations at the Nam She Wan Study Site

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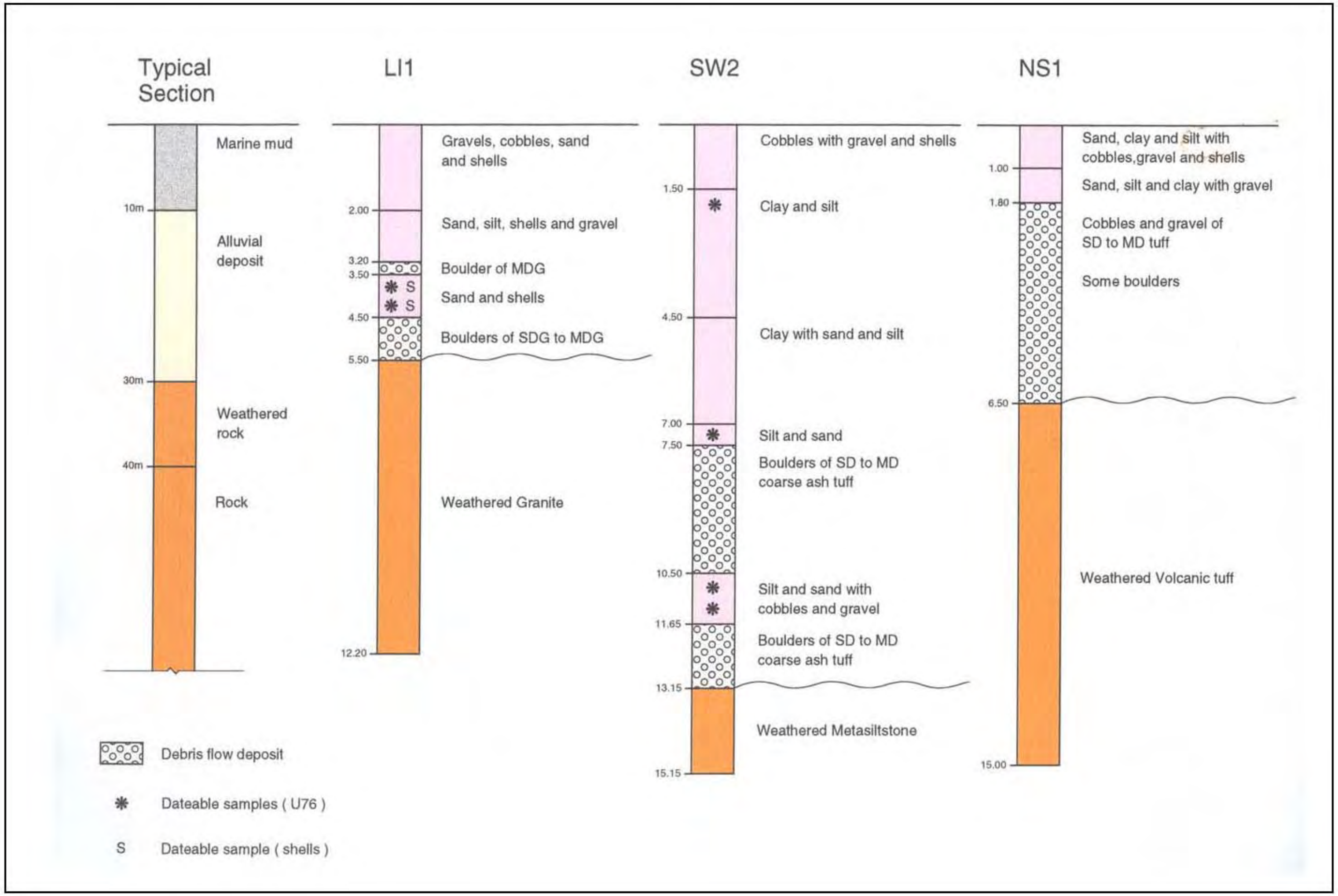

Figure 15 - Generalised Logs of Offshore Boreholes at the Three Study Sites

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土力工程處刊物及訂購資料

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香港九龍何文田公主道101號
土木工程拓展署大樓
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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

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

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