FACTUAL REPORT ON THE NOVEMBER 1993 NATURAL TERRAIN LANDSLIDES IN THREE STUDY AREAS ON LANTAU ISLAND

GEO REPORT No. 61

H.N. Wong, Y.M. Chen & K.C. Lam

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

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PREFACE

In keeping with our policy of releasing information of general technical interest, we make available some of our internal reports in a series of publications termed the GEO Report series. The reports in this series, of which this is one, are selected from a wide range of reports produced by the staff of the Office and our consultants. A charge is made to cover the cost of printing.

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

A.W. Malone
Principal Government Geotechnical Engineer
August 1997

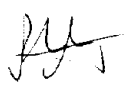
FOREWORD

Over 800 landslides occurred on the natural terrain on Lantau Island during the severe rainstorm of 4 and 5 November 1993. Thirty-three groups of a total of 56 landslides in three selected areas were studied by the Geotechnical Engineering Office (GEO) in early 1994. The study serves to identify and document the key characteristics of the landslides and to develop suitable methodologies for a systematic study of failures on natural terrain in Hong Kong.

This report is a factual documentation of the investigations and observations of the landslides in the three study areas. It provides data which could be used for further research and analyses. A diagnosis of the landslides, including analyses of the data collected, is the subject of a separate report.

The study was conducted by an investigation team in the Special Projects Division led by Mr H.N. Wong. The team included Dr P.Y.M. Chen and Dr A.C.O. Li, who carried out the field study between March and June 1994, and Mr K.C. Lam and Mr A.C.W. Wong, who carried out supplementary field work and desk study between October and December 1995. Mr J. King of the Planning Division offered useful suggestions during the study. Dr R.P. Martin and Mr S.W.C. Au reviewed the report and provided valuable comments.

This report was prepared by Mr H.N. Wong, Dr P.Y.M. Chen and Mr K.C. Lam.



P.L.R. Pang
Chief Geotechnical Engineer/Special Projects

ABSTRACT

In the severe rainstorm of 4 and 5 November 1993, which principally affected the western part of Hong Kong, over 800 landslides occurred on the natural terrain on Lantau Island. A systematic study of the natural terrain failures in three selected areas on Lantau was carried out by the Geotechnical Engineering Office, as part of the research and development work on natural terrain landslides in Hong Kong. The initial phase of the field work was conducted between March and June 1994, and supplementary field work and desk study were carried out between October and December 1995.

This report contains factual records, which include sketches, photographs and descriptions, of the thirty-three groups of a total of 56 landslides investigated in the three study areas. Also included in the records is an appraisal of the nature of debris movement, based on the use of a simplified classification. The majority of the landslides were shallow failure involving loose bouldery colluvium. The mobility of the landslide debris varied and was affected by the mechanisms of the debris movement.

The study has contributed to the improvement of understanding of natural terrain landslides in Hong Kong. It has also provided useful information for the development of suitable methodologies for studying landslides on natural terrain. The data given in the report could be used for further research and analyses.

CONTENTS

* Only the text of the Appendices is contained in this Report. Figures and Plates of the Appendices are provided in Volumes II and III of the study report, a set of which is available in the Civil Engineering Library on the First Lower Ground Floor of the Civil Engineering Building for viewing.

1. INTRODUCTION

Lantau Island was subjected to a severe rainstorm on 4 and 5 November 1993, which resulted in over 800 landslides on the natural terrain there (Figure 1). These landslides have provided valuable data for a systematic examination of the characteristics and mechanisms of natural terrain failures in Hong Kong.

In early 1994, a three-month programme of field study was carried out by the Geotechnical Engineering Office (GEO) on the natural terrain landslides in three selected areas on Lantau. The purpose of this investigation was to compile records of the landslides which could be used for further research and analyses, and to diagnose the key features of the landslides. The study forms part of GEO's research and development work on landslides on natural terrain. It serves to provide data, enhance the understanding of natural terrain failures, and develop suitable methodologies for a systematic study of landslides on the natural terrain of Hong Kong.

This report is a factual documentation of the investigations and observations of the landslides in the three selected study areas.

A diagnosis of the landslides, including analyses of the data collected, is the subject of a separate report.

2. STUDY AREAS

The locations of the three selected study areas, viz. Areas A, B and C, are shown in Figure 2. The three study areas were selected during GEO's field study on the November 1993 man-made slope landslides on Lantau (Wong & Ho, 1994), based on the following considerations :

(a) a large number of natural terrain landslides were observed to have taken place in the areas (except for Area C), and

(b) hiking trails were present across the areas and hence facilitating access to the landslide sites.

Area A comprises eighteen groups of 28 landslides along a two-kilometre stretch of hiking trail between Tung Chung Au and Nam Shan. An aerial photograph of the area is given in Plate 1. The locations of the landslides are shown in Figure 3.

Fourteen groups of 27 landslides in Area B were studied. They are located along a one-kilometre stretch of hiking trail to the east of Keung Shan Road along the northern side of Shek Pik Reservoir (Figure 4). An aerial photograph of the sites is given in Plate 2.

A landslide in Area C, located about 400 m southwest of Tung Chung Au, was studied (Plate 3 and Figure 5). This landslide was selected because of its unusual debris mobility.

The solid geology of the areas, which is based on GEO (1994 & 1995), is shown in Figures 6 and 7. The landslides in Areas A and C occurred in an area where the solid

geology is essentially the volcanic rocks of the Lantau Formation, viz. rhyolite lava and tuff. The two-kilometre hiking trail leading to Area A crosses many stretches of slope debris deposits, which consist of "sand, gravel, cobbles and boulders in a silt matrix". The solid geology in Area B includes metamorphosed rhyolite lava, tuff and tuffite.

3. NOMENCLATURE SYSTEM FOR RECORDING LANDSLIDES

3.1 Terminology

In this report, "natural terrain" refers to land that is principally in a natural state, with negligible influence from human activities on its stability.

In the study, soil and rock were described in accordance with Geoguide 3 (GCO, 1988). The nomenclature recommended by the International Association of Engineering Geology (IAEG) Commission on Landslides and other Mass Movements on Slopes (IAEG, 1990) was adopted to describe features of the landslides.

The concept of rheological classification suggested by Pierson & Costa (1987) was followed in describing the nature of debris movement. To apply this rheological classification system, detailed information on the velocity of debris movement and the sediment-water state of the debris is required. Such information was not available for many of the landslides due to the limited data. For the purposes of a factual documentation of the landslides, the following simplified classification of the nature of debris movement, based on the likely extent of influence by surface water, was adopted in this report :

(a) 'Gravitational' movement - this refers to debris movement which has arisen principally by virtue of its self weight without any significant influence from or action of surface water. The debris downslope movement may involve sliding, disintegration of the soil/rock mass, collision, bouncing and rolling. Minor erosion and wash-out action may also occur, particularly subsequent to the deposition of the bulk of the debris. This typically occurs where the amount of surface water which could reach or mix with the debris is insignificant, e.g. landslides on essentially planar sloping terrain associated with a small catchment.

(b) 'Hydraulic' movement - this refers to debris movement which has arisen principally as a result of action of surface running water. This typically occurs where the debris is fed by a large amount of water which drives the debris downslope under a state of low solid content, e.g. debris movement along a major stream course with a large amount of running water.

(c) 'Mixed' movement - this refers to debris movement which is intermediate between 'Gravitational' and 'Hydraulic', i.e. both the self weight of the material and the effects of

surface water might have considerable contribution to debris movement. This typically occurs where the landslide debris is mixed by a fair amount of surface water but the solid content still has an appreciable influence on debris movement, e.g. debris movement along a local stream course with a fair amount of surface running water. In practice, where debris movement cannot be clearly identified as 'Gravitational' or 'Hydraulic', it would be grouped under the 'Mixed' category.

The type of debris movement may be further classified as 'channelised' or 'non-channelised'. The term 'channelised' refers to the channelised transport of a significant load of debris.

3.2 Numbering System for Landslides

The following numbering system was used to identify the landslides :

(a) Where there is more than one landslide in the study area, the landslides in the area are numbered from east to west.

(b) Each landslide number is prefixed by a letter which denotes the study area, e.g. landslide A2 is the second landslide from the eastern boundary of Area A.

(c) Occasionally the debris trails of several landslides that are close to each other merge, and it is not practical to separate the debris trails further downhill. In such cases, the landslides are assigned a group number, e.g. A5, and the individual scarps are numbered according to this group number with a suffix added to distinguish between different scarps, e.g. A5A and A5B.

4. DESCRIPTION OF THE FIELD STUDIES

Field studies on the landslides in the three study areas were carried out by a team of professional staff of the GEO between March and June 1994. Supplementary field work was carried out in October and November 1995. The field studies included systematic identification and measurement of the extent of failure, mapping of the landslide scar and debris trail, description of the materials involved in the landslides, observation of relevant features (e.g. types of vegetation and presence of soil pipes), and an appraisal of the nature of debris movement.

Apart from photographs taken during field inspections of the landslides, two sets of aerial photographs were used to facilitate the study. These included a set of vertical aerial photographs of Lantau Island taken from 6 000 feet on 5 December 1993, and a set of oblique aerial photographs taken from helicopter flights in June 1994. Selected photographs of the

landslides are given in Appendices A to C.

The landslide (No. C1) in Area C involved a more mobile debris than landslides observed in other areas. Field topographic surveys were carried out on this landslide in June 1994. Ground investigations, which included excavation of ten trial pits and retrieval of bulk and block samples, were conducted in July and August 1994 (Lam Geotechnics limited, 1994).

5. DESCRIPTION OF THE LANDSLIDES

Records of the landslides, including sketches, photographs and descriptions, are given in Appendices A, B and C in Volumes 2 and 3 of this report. A brief summary of the key features of the landslides is given below.

The landslides in the three study areas displayed many similar characteristics. All landslides had at least one scarp from which the failed material originated. Most of the landslides were found, from field inspections, to have taken place in loose bouldery colluvium. None of the rupture surfaces appeared deep-seated (i.e. they all involved only the surface few metres of the sloping terrain). In many instances, it was apparent that the failed material was different in nature and age from the underlying material, e.g. a young colluvium overlying an old colluvium or a saprolitic soil.

Water undoubtedly played an important role in the landslides, contributing to both the initiation of the landslides as well as the transportation of the debris. Soil pipes were observed at the scarp in nearly all cases.

The size of the landslides, in terms of the unbulked volume, varied from within several tens of cubic metres to over one thousand cubic metres. Some landslides were large groups of several landslides, e.g. landslide group B7, while others were small isolated events, e.g. landslides A11 and B6. The crowns and scarps of the landslides were usually concave but some exceptions were also noted, e.g. the comparatively planar scarp of landslide A4.

The mobility of the debris varied considerably. Generally, the debris from landslides which occurred near stream courses travelled the furthest. This was probably primarily due to the debris having fallen into the stream courses and being transported by mixing with water within the stream courses at the time of heavy rain (i.e. 'hydraulic' movement), e.g. landslides A18, B1 and B2. Hydraulic action was usually accompanied by significant erosion of pre-existing channels and large boulders (e.g. over 10 m^3 in volume) were sometimes deposited at a considerable distance (e.g. several hundred metres) downhill from the source of the landslide.

In some cases, where the landslide had occurred at some distance away from the stream course, the debris travelled a comparatively short distance by virtue of its self weight and then stopped (i.e. 'gravitational' movement), e.g. landslides A8, A9 and A14. Post-depositional erosion sometimes occurred, which resulted in the formation of erosion channels in the deposited soil mass and further washing-out of the debris downslope.

Landslide C1 appears to be an exception to the observations of landslides involving

'gravitational' movement, in that the debris of the landslide travelled a long distance of about 120 m along a comparatively gentle sloping surface (about 20° to the horizontal). In this landslide, the debris slid along the ground surface downslope of the source of the failure, stripping only the vegetation and leaving the top soil more or less intact. There were no signs of any significant hydraulic action from surface running water affecting the pre-deposition debris movement.

6. SUMMARY

The rainstorm over Lantau on 4 and 5 November 1993 has resulted in numerous landslides on the natural terrain. Factual records of the landslides in three selected study areas have been collated and presented in this report. These could be used for further research on the characteristics and mechanisms of natural terrain failures in Hong Kong.

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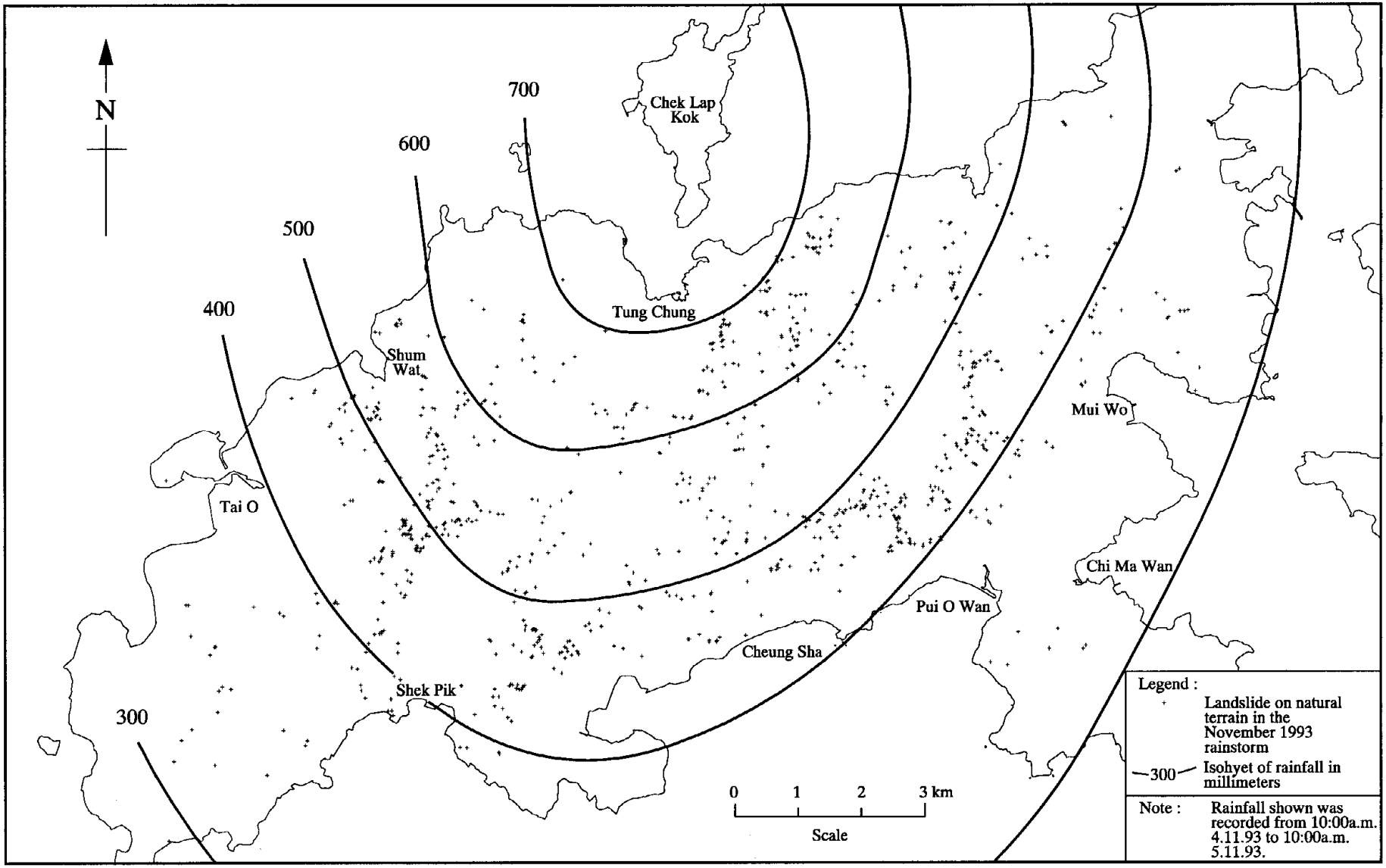


Figure 1 - Location Plan of Landslides on Natural Terrain

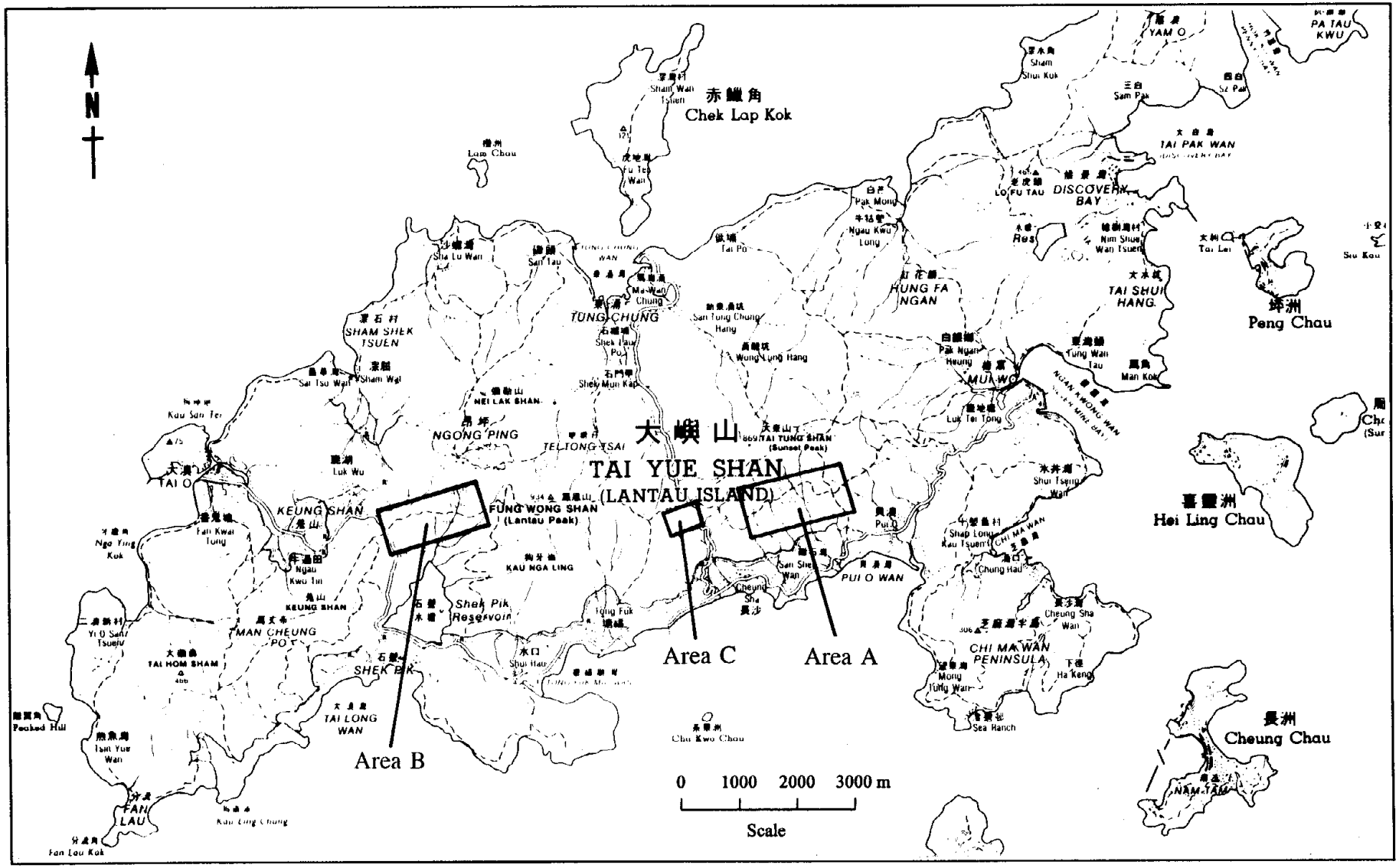


Figure 2 - Study Areas A, B and C

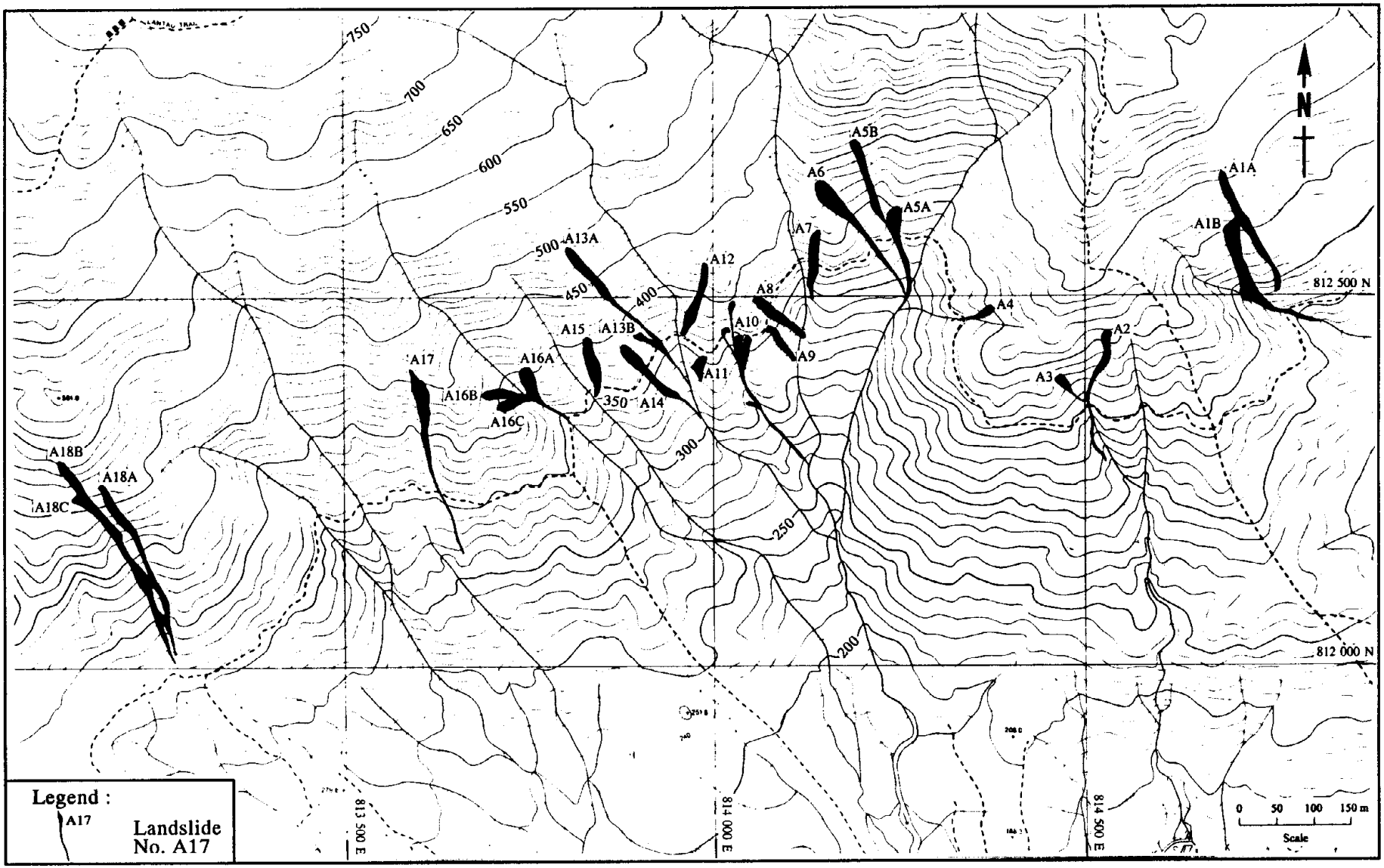


Figure 3 - Landslides in Study Area A

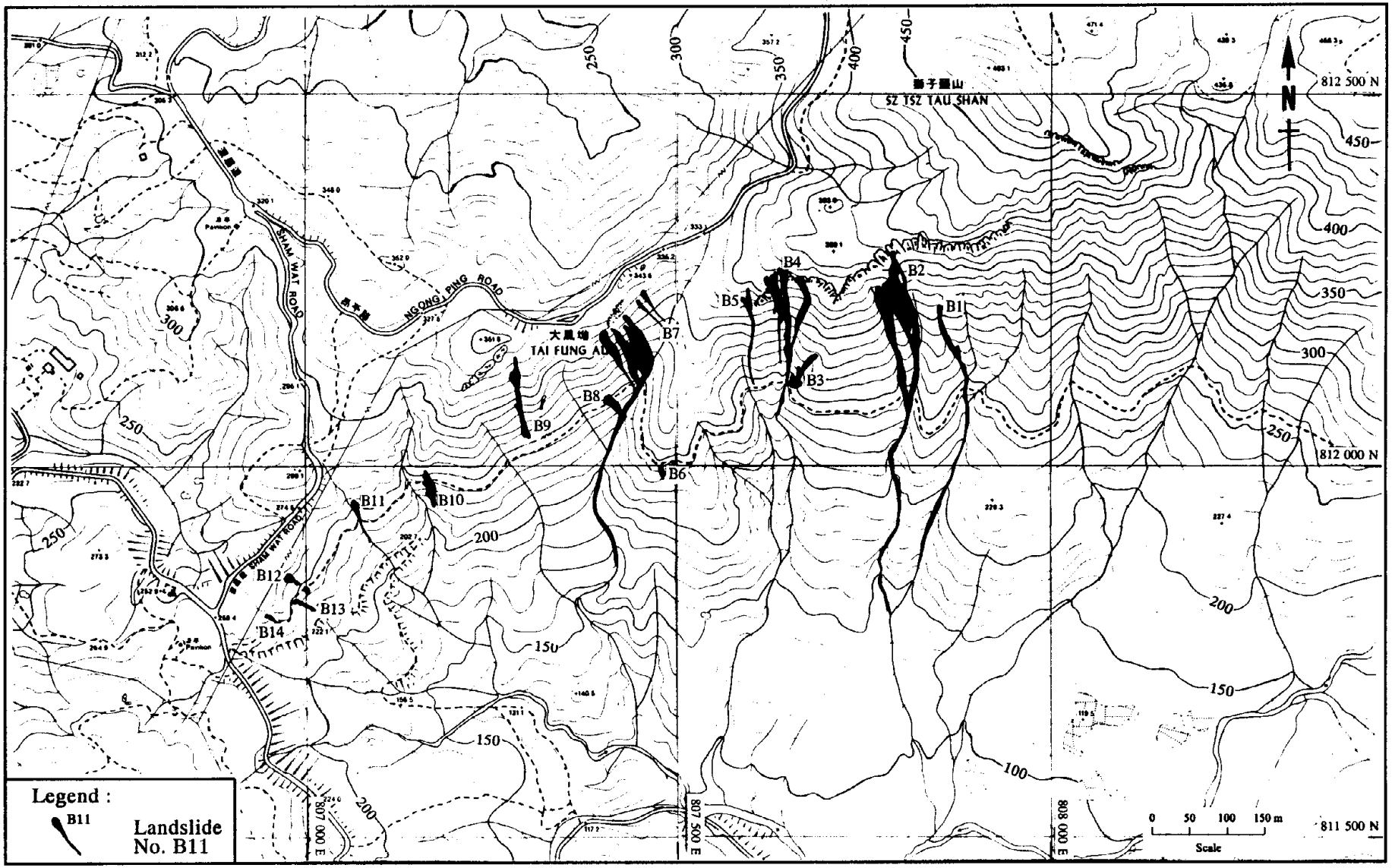


Figure 4 - Landslides in Study Area B

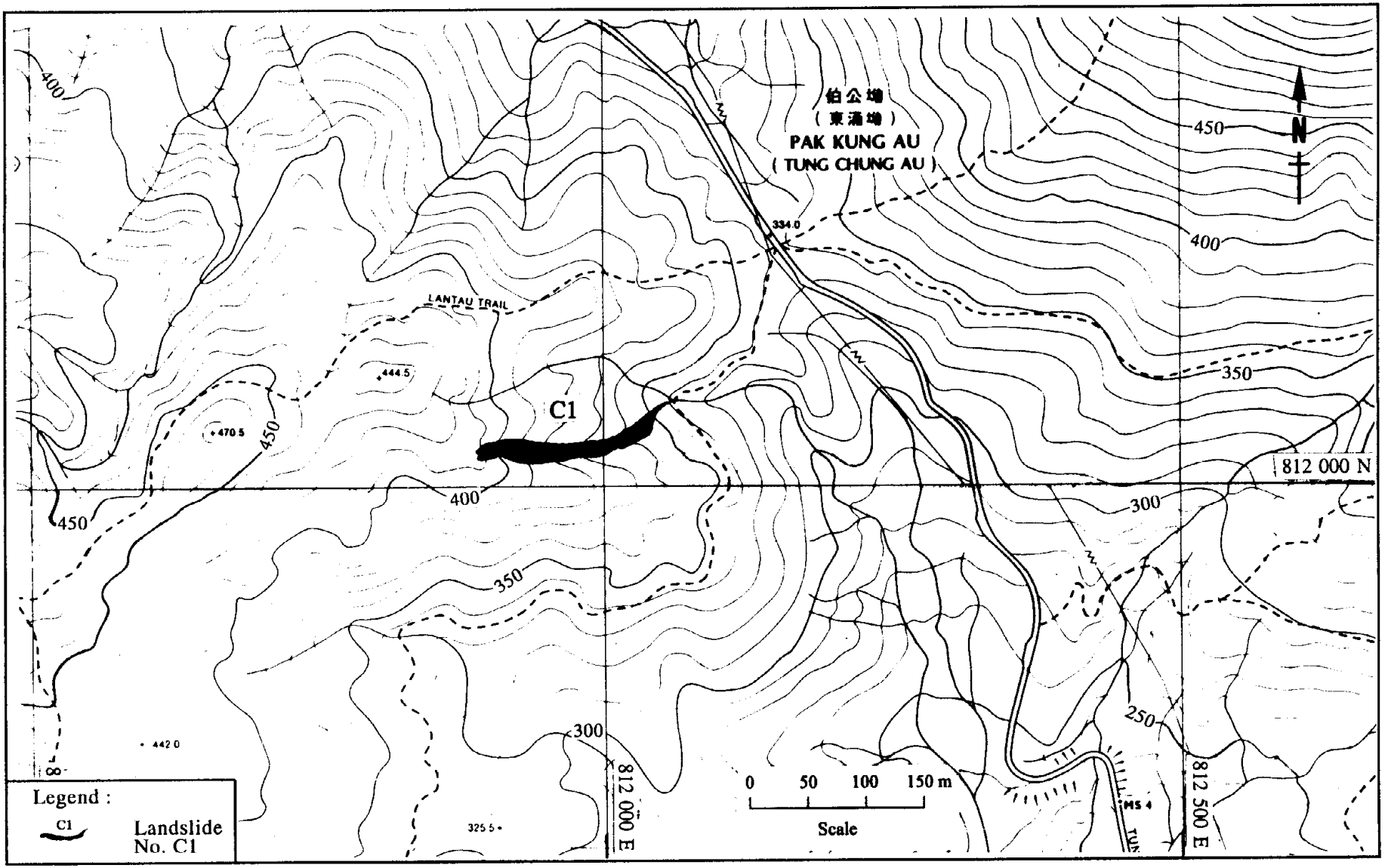
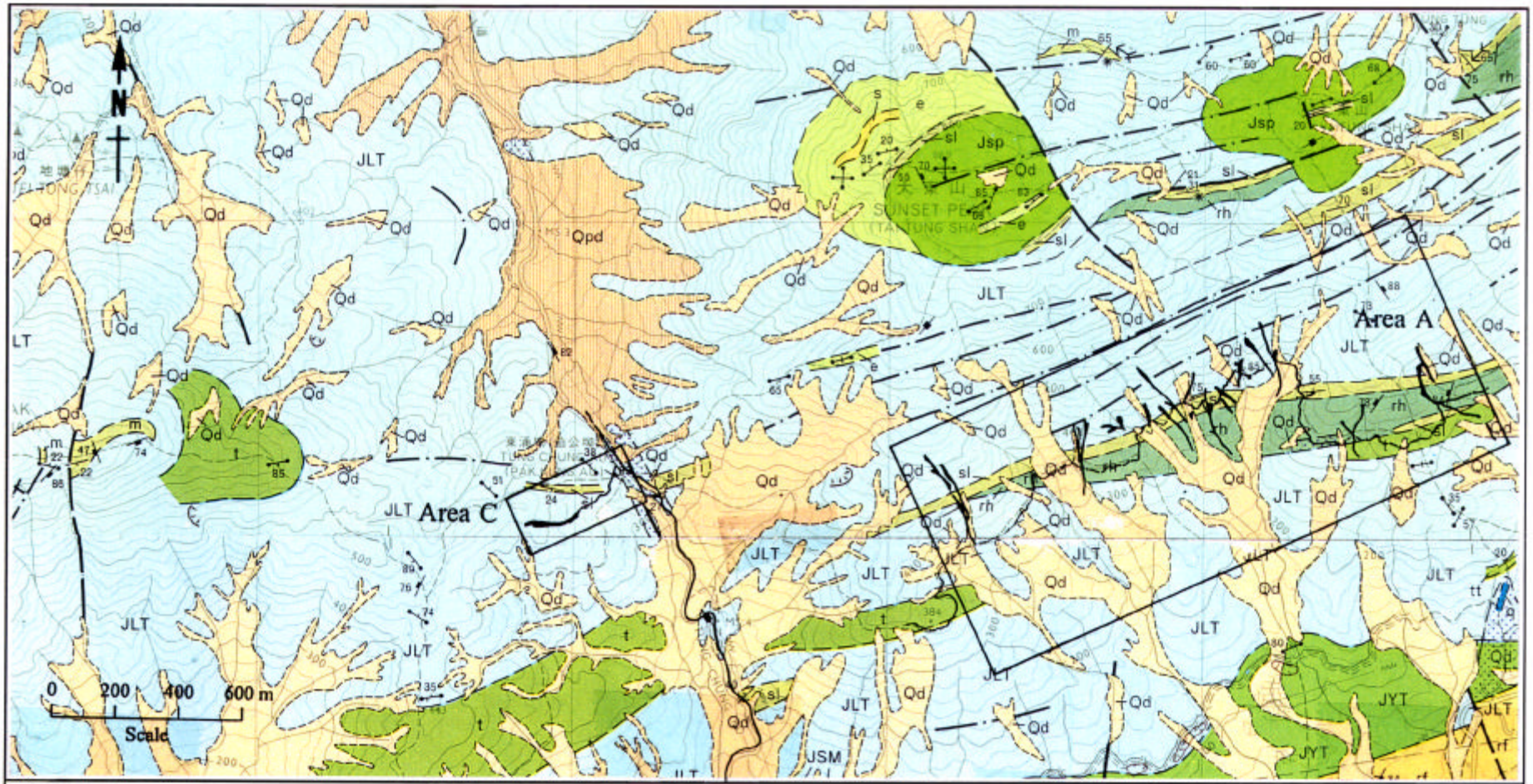


Figure 5 - Landslide in Study Area C

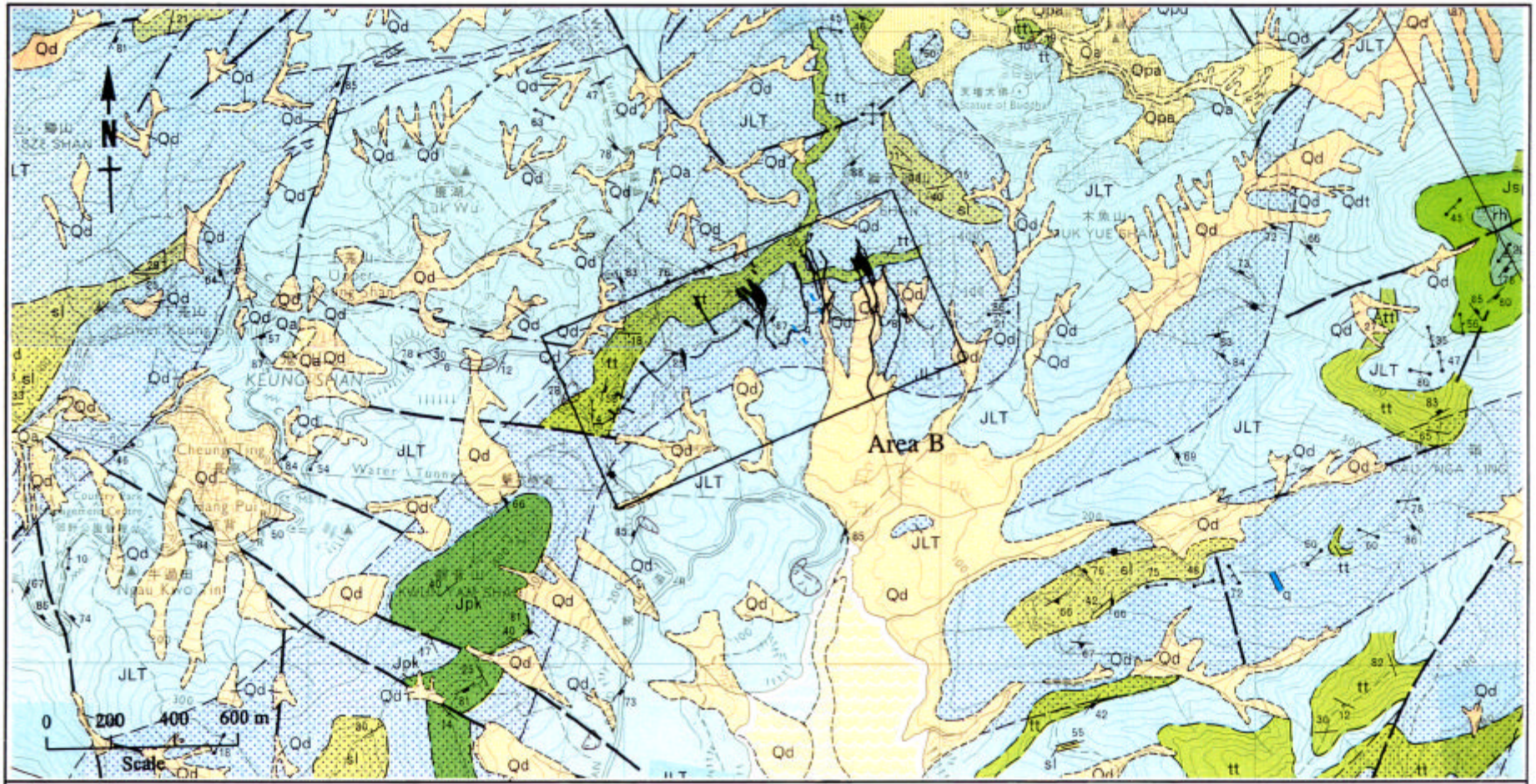


Legend :

Qd	Sand, gravel, cobbles and boulders in silt matrix (slope debris)	JLT	Rhyolite lava and tuff	rh	Rhyolite lava
sl	Siltstone		Metamorphosed		

Note : For other legends, refer to Sheets 9 and 13, Series HGM20, GEO (1994 & 1995).

Figure 6 - Solid Geology of Study Areas A and C



Legend :					
Qd	Sand, gravel, cobbles and boulders in silt matrix (slope debris)	JLT	Rhyolite lava and tuff	tt	Tuff and tuffite
q	Quartz vein		Metamorphosed		

Note : For other legends, refer to Sheets 9 and 13, Series HGM20, GEO (1994 & 1995).

Figure 7 - Solid Geology of Study Area B

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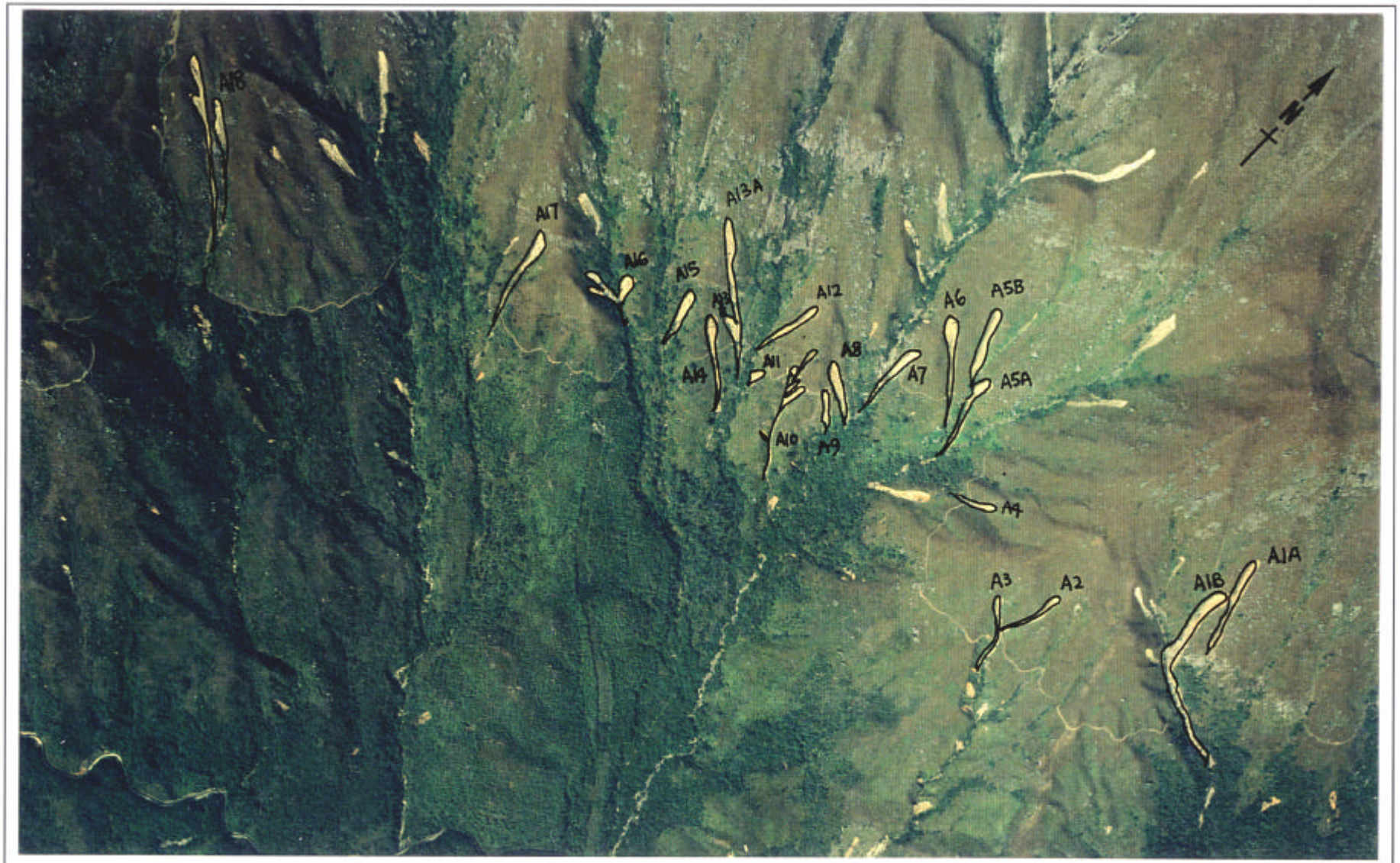

Plate 1 - Aerial Photograph of Site A (Date : 5.12.1993 Height : 6 000 feet)

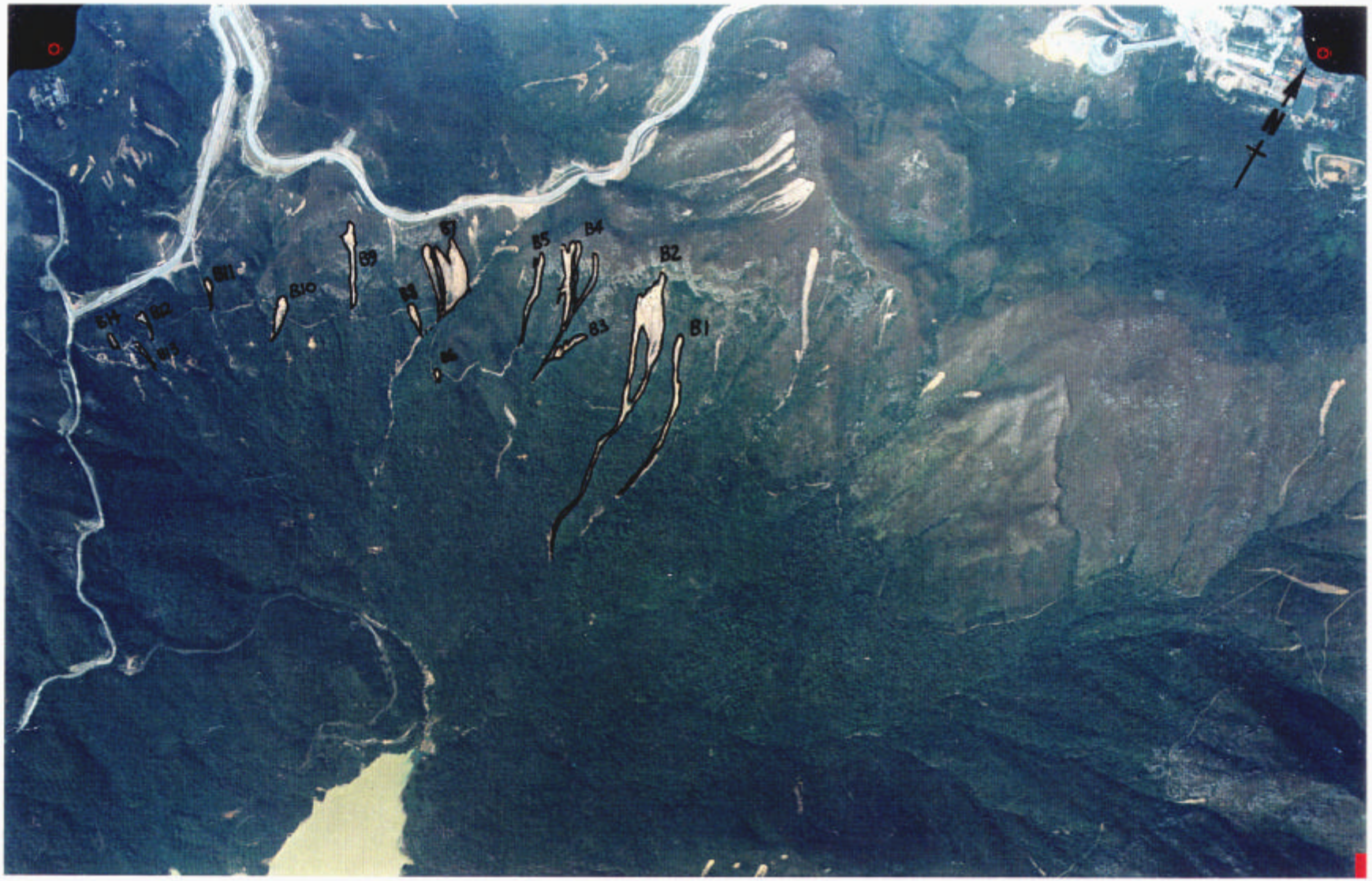

Plate 2 - Aerial Photograph of Site B (Date : 5.12.1993 Height : 6 000 feet)

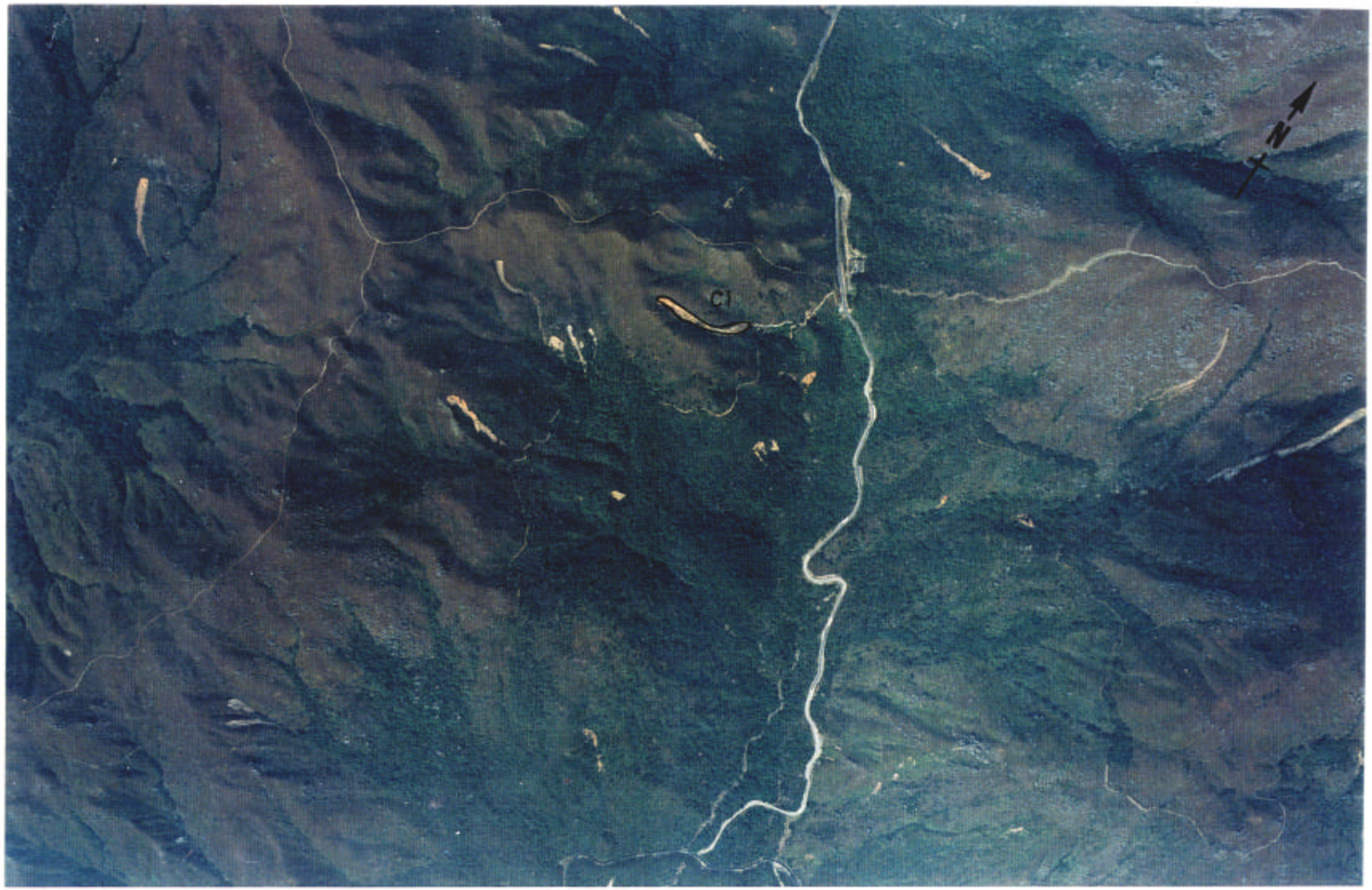

Plate 3 - Aerial Photograph of Site C (Date : 5.12.1993 Height : 6 000 feet)

APPENDIX A

LANDSLIDES IN STUDY AREA A

CONTENTS

A.1 INTRODUCTION

This Appendix contains factual records of eighteen groups of landslides in Area A, which were inspected and logged during the period from 30 March 1994 to 11 June 1994. Supplementary inspections and logging were carried out in October and November 1995. The aerial photographs shown in this Appendix, with enlargements made, were taken on 5 December 1993 from a height of 6 000 feet. Additional oblique photographs of the landslides were taken from helicopter flights in June 1994.

An assessment of the nature of debris movement in the landslides is included. 'G', 'M' and 'H' denote 'gravitational', 'mixed' and 'hydraulic' movement respectively. The debris mobility angle, i.e. the inclination (θ) of the line joining the crest of the failure scarp and the distal end of the debris, was used to denote the mobility of the debris.

"CH" is the prefix given to the chainage in metres measured along the inclined surface of the original sloping terrain from the crest of the landslide.

A.2 LANDSLIDES A1A AND A1B

This group consists of two landslides located close to each other (Plate A1.1). Landslide A1A, with the crown of the scarp at about 460 mPD, has a visible debris trail length of about 170 m (Figure A1). The debris might have travelled even further over the rock cliff but it was not possible to determine the origin of the material in the natural stream course below the cliff. It can be seen from Plate A1.2 that some debris has remained on the natural ground with signs of post-depositional erosion. Plates A1.3 to A1.5 show the scarp of landslide A1A. Many 'pipe holes' were observed at the scarp (Plate A1.6).

Figure A2 is a cross-section of landslide A1B. The crown of A1B was at about 413 mPD. The length of the debris trail, from the crown to where it joined the natural stream course, was about 140 m. Plates A1.7 to A1.14 follow the trail from the footpath (i.e. the Lantau hiking trail) to the scarp. Plates A1.15 to A1.19 show the scarp of landslide A1B.

Plates A1.20 to A1.23 follow the debris trail and the natural stream course downhill from the rocky cliff below landslide A1B.

Along the debris trail of A1A, some debris was deposited between CH10 and CH65. At CH88, $\theta=33°$ for 'G' non-channelised debris movement. Subsequent movement up to CH154 was classified as 'M'. At CH154, $\theta=32°$ for 'M' non-channelised debris movement.

For landslide A1B, the main body of the debris was deposited along CH15-60. At CH84, $\theta=32°$ for 'G' non-channelised debris movement. The debris mixed with surface water after reaching the stream course at CH84. At CH176, $\theta<31°$ for 'H' channelised debris movement.

A.3 LANDSLIDES A2 AND A3

Landslides A2 and A3 started at different points but their debris trails met at the

footpath (Plates A2.1 and A2.2). Landslide A2 was about 120 m long from the crown to the footpath (Figure A3). Plates A2.3 to A2.6 show the debris trail of landslide A2. Plates A2.7 and A2.8 show its scarp. 'Pipe holes' were observed at the scarp of landslide A2.

Landslide A3 was of about half the length of landslide A2 (Figure A4). Views of the debris trail are shown in Plates A3.1 to A3.3, and the scarp in Plates A3.4 and A3.5.

For landslide A2, scattered angular and subangular cobbles and boulders were deposited along CH12-142. Fines of the debris were believed to have been washed away by surface water. At CH142, $\theta=30°$ for 'M' non-channelised debris movement.

For landslide A3, scattered angular and subangular cobbles and boulders were deposited by 'gravitational' movement along CH12-35. Fines of the debris were believed to have been subsequently washed away by surface water. At CH35, $\theta=31°$ for 'G' non-channelised debris movement.

A.4 LANDSLIDE A4

Landslide A4 was one of the smallest landslides in the Area. As shown in Plate A4.1 and Figure A5, the full length of the debris trail was about 100 metres. Plates A4.2 to A4.4 show various views of the landslide. Plates A4.5 to A4.7 show the scarp. The thickness of the colluvium ranged from 0.5 m to 1 m.

The main body of debris was deposited along CH10-20. Scattered lumps of soil and angular/subangular cobbles and boulders were deposited along CH20-55. At CH55, $\theta=29°$ for 'G' non-channelised debris movement. At CH100, $\theta=26°$ for 'M' non-channelised debris movement.

A.5 LANDSLIDES A5A, A5B AND A6

These three landslides occurred very close to each other (Plates A5.1 and A5.2). Figure A6 shows a cross-section of landslide A5A. It was smaller than A5B and the debris only travelled some 35 metres (Plates A5.3 to A5.5) before it reached a natural channel near the footpath (Plates A5.6 to A5.8). 'Pipe holes' were present at the scarp of landslide A5A.

Figure A7 is a cross-section of landslide A5B. The full length of the landslide was about 130 metres. Plates A5.9 to A5.12 show the debris trail. The scarp is shown in Plate A5.13.

Landslide A6 was not geographically connected to landslides A5A and A5B (Plate A6.1). Unlike landslides A1A to A5B, the debris of landslide A6 was deposited and spread over the surface of a planar slope (Plate A6.2 and Figure A8). Plates A6.3 and A6.4 give different views of the landslide. The ground topography suggests that previous landslides might have had occurred at this location (Plate A6.4). The scarp of A6 is shown in Plates A6.5 to A6.7.

For landslide A5A, the main body of the debris was deposited along CH10-45. At

CH45, the debris would probably have started to mix with the stream water. $\theta < 40°$ for 'G' non-channelised debris movement up to CH45. At CH120. $\theta = 31°$ for 'M' channelised debris movement.

For landslide A5B, a debris comprised of cobbles and boulders was deposited along CH12-122, before reaching a stream course. At CH122, $\theta = 35°$ for 'G' non-channelised debris movement.

For landslide A6, the main body of debris was deposited along CH10-40. At CH122, $\theta = 31°$ for 'G' non-channelised debris movement.

A.6 LANDSLIDES A7, A8 AND A9

Plate A7.1 shows the three landslides, which were close to each other. A cross-section of landslide A7 is shown in Figure A9. Plate A7.2 shows an uphill view of the landslide. Plate A7.3 is a view downhill from landslide A7. Plate A7.4 shows the debris trail at the level of the footpath. Plate A7.5 is an oblique view of the landslide showing the landslide scar and debris trail. Plate A7.6 is a close-up of the scarp. The colluvium that covered the slope was generally within 0.5 m thick. The landslide was mainly through Grades IV to V volcanic rock.

Figure A10 is a cross-section of landslide A8. Plate A8.1 is an oblique view of the landslide showing the debris trail. This landslide originated a short distance above the footpath and some of the debris was deposited on the footpath after the landslide (Plate A8.2).

Figure A11 is a cross-section of landslide A9. Plate A9.1 is an oblique view of the debris trail. A minor landslide occurred on the sloping ground alongside the footpath just above the scarp of landslide A9 (Plate A9.2, A9.3 and A9.4).

For landslide A7, debris movement was assessed to be 'G' non-channelised up to CH80, with $\theta < 40°$.

For landslide A8, the debris was deposited in a blanket form. $\theta = 39°$ for 'G' non-channelised debris movement.

For landslide A9, the slope below the footpath probably failed as a result of concentrated flow of surface water diverted by the debris of the small landslide which blocked the footpath. The debris moved downslope by gravity. $\theta < 42°$ for 'G' non-channelised debris movement.

A.7 LANDSLIDE GROUP A10

This is a group of landslides in close proximity to each other and their debris trails followed the same natural gulley. Plate A10.1 shows the scarps of A10A to A10E. Plate A10.2 is an oblique view, and Plates A10.3 and A10.4 are a continuation from Plate A10.2 showing the downhill debris trail.

Figures A12 and A13 are cross-sections of landslides A10A and A10B respectively. An oblique view of the scarps of the two landslides are shown in Plate A10.5. The main scarp of landslide A10A is the largest in the group (Plates A10.6 and A10.7). Plate A10.8 shows the volcanic rock underlying the landslides in this group. The colluvium had an average thickness of about 0.5 m, and consists of light brown gravelly sand/sandy gravel with sub-angular to angular cobbles of Grade II/III volcanic rock.

Figures A14 and A15 show cross-sections of landslides A10C and A10D respectively. Plates A10.9 to A10.13 shows the two landslides.

For landslide A10B, a small amount of debris was deposited along CH0-85. Vegetation was stripped away from CH20 to CH85. The debris was washed away by stream water after CH85. $\theta < 37°$ for 'G' non-channelised debris movement. $\theta < 28°$ for 'H' non-channelised debris movement.

For landslide A10D, some debris was deposited along CH10-50. The debris moved further downslope after reaching the stream course at CH50. $\theta < 41°$ for 'G' non-channelised debris movement.

A.8 LANDSLIDE A11

The landslide is shown in Plate A10.1. Oblique views are shown in Plates A11.1 and A11.2. A cross-section is given in Figure A16.

The debris stopped before reaching the stream course. At CH50, $\theta = 35°$ for 'G' non-channelised debris movement.

A.9 LANDSLIDES A12, A13A, A13B AND A14

These four landslides occurred very close to each other (Plate A12.1). Plate A12.2 is a an uphill view of landslide A12. Figure A17 is a cross-section of the landslide. The scarp of landslide A12 are shown in Plates A12.3 and A12.4.

Plate A13.1 is an oblique view of landslide A13A showing the debris trail. A cross-section of the landslide is shown in Figure A18. Plate A13.2 is an uphill view of the debris trail and Plates A13.3 and A13.4 show accumulations of debris at the base of some trees located along the debris trail. Plates A13.5, A13.7, A13.8 and A13.9 are closer views of the scarp of landslide A13A. Plate A13.6 shows signs of action of surface water, viz. grass which has been swept flat.

Plate A13.10 is an oblique view of landslide A13B. The cross-section of this landslide is shown in Figure A19. Plate A13.11 is a downhill view of the debris trail. Plates A13.12, A13.13 and A13.14 are close-ups of the scarp of landslide A13B. The colluvium was about 1 m thick. It consisted of medium dense brown to greyish brown sandy gravel with angular cobbles of Grade II/III volcanic rock. Some small 'pipe holes' were present in the colluvium.

Plate A14.1 is an oblique view of landslides A13B and A14. Figure A20 shows a

cross-section of landslide A14. Plate A14.2 shows a full view of landslide A14. A downhill view of the debris trail is shown in Plate A14.3. Plate A14.4 is a close-up view of landslide A14. Plates A14.5 and A14.6 are continuation of Plate A14.4, showing the downhill views of the debris trail. A close-up of the scarp of landslide A14 is shown in Plate A14.7.

For landslide A12, some blocks of the slipped soil remained on the scarp. Patches of sand, gravels, and cobbles were deposited along CH15-101. Trees at CH56 were not damaged by the debris. At CH101, $\theta=31°$ for 'G' type non-channelised debris movement.

For landslide A13A, the debris was deposited along CH16-90. At CH90, some debris was trapped by shrubs. At CH90, $\theta<28°$ for 'G' non-channelised debris movement.

For landslide A13B, the debris was deposited along CH17-57 before reaching a stream course. At CH57, $\theta=31°$ for 'G' non-channelised debris movement.

For landslide A14, the debris was deposited mainly along CH20-60. At CH110, $\theta=32°$ for 'G' non-channelised debris movement.

A.10 LANDSLIDE A15

Plate A15.1 is an enlarged aerial photograph of landslide A15. Plate A15.2 is an uphill view of landslide A15, taken from the footpath. Plate A15.3 is a downhill view of the landslide. Figure A21 is a cross-section of the landslide. An oblique view of the landslide is shown in Plate A15.4. A close-up of the scarp is shown in Plate A15.5.

The debris was deposited along CH20-95. At CH70, the debris was partially blocked by trees. At CH95, $\theta=33°$ for 'G' type non-channelised debris movement.

A.11 LANDSLIDE GROUP A16

This is a group of three landslides (Plate A16.1), the debris trails of which met at a natural stream course. Plate A16.2 is an oblique view of the scarp of A16A. A cross-section of the landslide is shown in Figure A22. Plate A16.3 is an uphill view of the debris trail from the footpath. Plates A16.4 to A16.6 are different views of landslide A16A.

Plate A16.7 shows landslides A16B and A16C. A cross-section of landslide A16B is shown in Figure A23. The scarp of landslide A16B is shown in Plates A16.8 and A16.9.

A cross-section of landslide A16C is shown in Figure A24. Plate A16.10 is an oblique view of landslides A16B and A16C. The scarp of landslide A16C is shown in Plate A16.11.

Plates A16.12 and A16.13 show soil pipes at the scarp of landslides A16A and A16B respectively.

The debris stopped before reaching a stream course at CH60. $\theta=37°$ for 'G' non-channelised debris movement.

A.12 LANDSLIDE A17

The landslide is shown in an enlarged aerial photograph in Plate A17.1. A cross-section of the landslide is shown in Figure A25. Plates A17.2 and A17.3 are uphill views showing the extensive erosion along the debris trail. Plate A17.4 is a downhill view of the debris trail. Plate A17.5 is an oblique view of the landslide showing various parts of the debris trail. Plates A17.6 and A17.7 show the scarp of A17A and A17B respectively.

The colluvium that failed in the landslide was generally within 0.5 m thick. It consisted of brownish grey/greyish brown sandy gravel with sub-angular to angular cobbles of volcanic rock.

Debris was deposited along CH20-50. Patches of debris comprising silty sand, gravels and cobbles were present along CH50-104. At CH104, $\theta=32°$ for 'G' non-channelised debris movement. Some debris was also trapped by trees along CH100-150, and it piled up against the trees to a thickness up to 1.5 m. At CH270, $\theta<27°$ for 'H' non-channelised debris movement.

A.13 LANDSLIDE GROUP A18

There are three main scarps in this group of landslides (Plate A18.1). The cross-section of landslide A18A is shown in Figure A26. Downhill and uphill views of the debris trail of landslide A18A are shown in Plates A18.2 to A18.4. An oblique view of the scarp of A18A is shown in Plate A18.5, and a close-up in Plate A18.6. The colluvium was generally within about 0.5 m thick. It consisted of medium dense brownish grey gravelly sand with some angular cobbles of volcanic rock.

Figure A27 shows the cross-section of landslides A18B and A18C. Plate A18.7 is a view from the footpath showing an accumulation of large boulders. Plates A18.8 and A18.9 show signs of hydraulic action along the debris trail. Plate A18.10 is a downhill view from where the debris from landslides A18B and A18C met. Plate A18.11 is a downhill view of the debris trail from landslide A18B. Plates A18.12 to A18.14 show the scarps of A18B and A18C.

For landslide A18A, the debris was mainly deposited between CH5-38. At CH98, $\theta=32°$ for 'G' non-channelised debris movement. A large amount of surface water brought the debris further downslope. At CH320, $\theta<26°$ for 'H' non-channelised debris movement.

For landslide A18B, the debris was deposited along CH5-60. At CH117, $\theta=31°$ for a 'G' type non-channelised debris movement. Beyond CH117, a large amount of surface water probably brought the debris further downslope. Boulders up to 2.5 m diameter were stopped by trees at CH360. $\theta<28°$ for a 'H' type non-channelised debris movement.

APPENDIX B

LANDSLIDES IN STUDY AREA B

CONTENTS

B.1 INTRODUCTION

This Appendix contains factual records of 14 groups of landslides in Area B, which were inspected and logged during the period from 30 March 1994 to 11 June 1994. The aerial photographs shown in this Appendix, with enlargement made, were taken on 5 December 1993 from a height of 6 000 feet. Additional oblique photographs of the landslides were taken from helicopter flights in June 1994.

An assessment of the nature of debris movement of the landslides in Area B is also included below.

B.2 LANDSLIDE B1

Plate B1.1 shows the scarps of landslides B1 and B2. Plate B1.2 is an oblique view of the upper part of landslide B1. A cross-section of landslide B1 is shown in Figure B1. Plates B1.3 to B1.8 show different views, uphill and downhill, of landslide B1. Cross-sections through the scarps of B1B and B1A are shown in Figures B2 and B3 respectively. Plates B1.9 to B1.12 follow the debris trail of landslide B1, downhill from the scarps.

A large lump of debris was deposited at CH227-277. Fines of the debris had been washed away by surface water. At CH277, $\theta=25°$ for 'M' channelised debris movement. Vegetation was stripped off along the debris trail up to CH307. At CH307, $\theta<22°$ for 'H' channelised debris movement.

B.3 LANDSLIDE B2

Plate B2.1 shows landslides B1 and B2. Cross-sections B2A-B2A and B2B-B2B are given in Figures B4 and B5 respectively. Plate B2.2 is an uphill view of the rock cliff above the scarps. Plate B2.3 show various parts of the scarp. The debris trail is shown in Plates B2.4 to B2.10.

The colluvium that failed was generally within 1 m thick (Plates 2.19 and 2.20). It comprised medium dense light yellowish brown gravelly sand with many cobbles and boulders of Grade II/III volcanic rock. An older colluvium was exposed along the debris trail (Plates 2.21 and 2.22). It consisted of stiff reddish brown mottled yellow sandy silt with many cobbles and boulders of Grade III/IV volcanic rock.

Big boulders were deposited along the debris trail above the footpath level (Plate 2.23). No debris was deposited on the footpath (Plate 2.24). Below the footpath, boulders of a wide range of sizes and soil debris were deposited in heaps in the eroded channel. Rock joints in the rock outcrop oriented favourably (77°/261°, 89°/252°, 85°/055°, 30°/195°, 76°/343°,80°/235°, 18°/070° & 25°/164°) for the dislodgement of rock blocks in the valley trending 204°. Further views of the debris trail are given in Plates B2.25 to B2.31.

Some debris was deposited at CH86-130 along Section B-B. At CH130, $\theta=32.5°$ for 'G' non-channelised debris movement. No significant amount of debris was found along subsequent parts of the debris trail. Vegetation was stripped off up to CH550. At CH550,

$\theta < 24°$ for 'H' channelised debris movement.

B.4 LANDSLIDE GROUP B3

The scarps of this group are shown in Plates B3.1 and B3.2. Figure B6 shows a cross-section and a plan of landslide B3A. Plates B3.2 to B3.9 show different views of landslide B3A. Figure B7 shows a cross-section of landslide B3B. Plates B3.10 and B3.11 show this landslide. Cross-sections of landslides B3C and B3D are given in Figures B8 and B9 respectively. Views of landslide B3D are shown in Plates B3.12 to B3.17.

For landslide B3B, $\theta = 40°$ for 'G' non-channelised debris movement.

For landslide B3A, $\theta < 45°$ for 'G' non-channelised debris movement. The debris trail met the stream course beyond CH22.

B.5 LANDSLIDE GROUP B4

Plates B4.1 and B4.2 show this group of landslides. Plates B4.3 to B4.5 show the scarps and debris trails. Figure B10 shows a cross-section of landslide B4E. Plates B4.6 and B4.7 show the scarp of B4E.

The valley along which the landslide debris travelled was very narrow above the footpath level (Plate B4.16). Some big boulders were found wedging on the sides of the narrow valley and damming other debris (Plate 4.17). Erosion of the narrow stretch of the valley exposed the colluvium. In the upper stretch, partly weathered porphyritic volcanic rock was exposed. Many medium-sized boulders were present along the part of the valley below the footpath. They appeared to have been left by erosion which removed the soil matrix of the original colluvial deposits in the valley.

For landslide B4E, pieces of rock were deposited along CH0-69. At CH69, $\theta < 40°$ for 'G' non-channelised debris movement. Large lumps of debris were deposited before CH189. At CH189, $\theta < 39°$ for 'M' channelised debris movement. Along CH189-244, it is likely that a large amount of surface running water had brought the debris further downslope. Vegetation was stripped off up to CH244. At CH244, $\theta < 36°$ for 'H' channelised debris movement.

B.6 LANDSLIDE GROUP B5

Plates B5.1 and B5.2 show the landslide group B5 in relation to landslide group B4. Figure B11 is a cross-section of the landslide from the crown of the highest scarp (B5A) to the footpath. Plate B5.3 is an uphill view of the debris trail of the landslide, as seen from the footpath. Plate B5.4 is an uphill view further up this debris trail. Plate B5.5 show the debris trail. This landslide group consists of three scarps (B5A, B5B and B5C as marked in Plate B5.6). Plate B5.7 is a close-up of the scarp of B5A, taken from the scarp of B5C. Plate B5.8 is a downhill view from the scarp of B5A. Further close-up views of the scarp of B5A are given in Plates B5.9 to B5.11. Plate B5.12 shows the scarp of B5B. The

material exposed at this scarp is shown in Plates B5.13 and B5.14.

Bouldery debris stopped shortly below the footpath. Signs of erosion and surface water flow were observed in the valley below the footpath (Plate B5.15).

For landslide B5B, the debris stopped before reaching the stream course. At CH25, $\theta=37°$ for 'G' non-channelised debris movement.

For landslides B5A and B5C, a 'gravitational' deposit was found up to CH66, and $\theta<39°$ for 'G' debris movement. There was 'mixed' debris movement up to about CH171, and $\theta<37°$ for 'M' channelised debris movement.

B.7 LANDSLIDE B6

Landslide B6 is a small landslide which occurred at a section of the footpath. Plate B6.1 is an enlargement of an aerial photograph showing the landslide in relation to other landslides in the area. Plates B6.2 and B6.3 are oblique views. The scarp and debris trail are shown in Plates B6.4 to B6.8. A small separate landslide (Plate B6.9) also occurred above the footpath at this location.

The slope below the footpath probably failed due to concentrated flow of surface water diverted by the debris of the small landslide that blocked the footpath. Debris movement was principally 'G', with $\theta=30°$.

B.8 LANDSLIDE GROUP B7

This was the largest group of landslides in this study area. Plates B7.1 to B7.4 show the scarps. A cross-section of landslide B7A is given in Figure B12. A close-up of the scarp of B7A is given in Plate B7.5. A cross-section of landslide B7B is shown in Figure B13. The scarp is shown in Plates B7.6 and B7.7. Plate B7.8 is a downhill view of the debris trail from the natural stream course. Plate B7.9 shows the debris trail as seen from the footpath. A cross-section of landslide B7C is shown in Figure B14, and a close-up of the scarp in Plate B7.10. The scarp of landslide B7D is shown in Plates B7.11 and B7.12. Figure B15 is a cross-section of landslide B7F. The scarps of B7E and B7F are shown in Plates B7.13 to B7.17. The scarp of B7I is shown in Figure B16 and Plate B7.18. Plates B7.19 and B7.20 show the stream course along which the debris travelled.

At the scarp of B7A, the colluvium was about 0.5 m thick. It comprised medium dense light yellowish brown gravelly sand with many sub-angular to angular cobbles of Grade III/IV volcanic rock. Small 'pipe holes' were present. At the scarp of B7B, the colluvium ranged from 0.5 m to 0.8 m thick. It consisted of firm to stiff light yellowish brown very sandy silt/silty sand with some sub-angular to angular gravels and cobbles of Grade III/IV volcanic rock. 'Pipe holes' were present in the colluvium.

For landslide B7A, a 'gravitational' deposit was found along CH0-63, with $\theta=33°$. Secondary deposition due to action of surface water was found along CH53-100. Vegetation were disturbed up to CH100, $\theta<28°$ for 'H' non-channelised debris movement.

For landslides B7C to B7E, 'gravitational' deposit was found up to CH61, with θ = 37° for 'G' non-channelised debris movement. No field inspection data were available between CH61-368. Debris movement was channelised and was assessed to be 'H' in view of the large catchment area, with $\theta < 24°$.

B.9 LANDSLIDE B8

Plate B8.1 is an enlarged aerial photograph showing the debris trail of landslide B8. A close-up is shown in Plate B8.2. Plate B8.3 shows the debris trail. Plates B8.4 to B8.6 show details of the scarp. Plate B8.7 is a downhill view from the scarp.

The debris travelled downslope on a relatively planar surface, with $\theta = 38°$ for 'G' movement.

B.10 LANDSLIDE B9

Landslide B9 is shown in the enlarged aerial photograph in Plate B9.1. Oblique views are shown in Plates B9.2 and B9.3. A cross-section of the landslide is given in Figure B17. The scarp is shown in Plate B9.4. 'Pipe holes' were present in the colluvium exposed (Plates B9.5 and B9.6). The debris trail is shown in Plates B9.7 to B9.10.

Boulders were thinly scattered on the slope. A piece of boulder was found wedging between the trunks of a group of small trees (Plate B9.11 & B9.12). The boulder would probably have been bouncing and rolling downslope before being caught by the trees.

The limit of the bulk of the 'gravitational' deposit was at about CH26, with $\theta = 33°$ for 'G' non-channelised debris movement. Debris was deposited on the footpath at CH150, and $\theta < 36°$ for 'M' non-channelised debris movement. The catchment area was still comparative small at this location. Type 'H' non-channelised deposit was found at CH245 and beyond, with $\theta < 33°$.

B.11 LANDSLIDE B10

Plate B10.1 is an enlarged aerial photograph of landslide B10. The debris trail crossed the footpath (Plate B10.2). The various parts of this landslide are shown in Plates B10.3 and B10.4. A view of the debris trail, where it crossed the footpath, is shown in Plate B10.5. The scarp is shown in Plates B10.6 and B10.7.

The slope above the footpath at the flank of a spur failed. The debris crossed the footpath and deposited on the slope below.

Debris was deposited in a blanket form, with $\theta = 35°$ for 'G' non-channelised debris movement.

B.12 LANDSLIDE B11

Landslide B11 is shown in Plates B11.1 to B11.4. Cross-sections of the landslide are given in Figures B18 and B19. Plate B11.5 shows details of the scarp of B11B. The debris trail is shown in Plates B11.6 to B11.8.

The landslide released bouldery debris which was deposited mainly above the level of the footpath. Erosion was observed along the trail below the footpath.

Debris was deposited before reaching the stream course at CH50. $\theta = 34°$ for 'G' non-channelised debris movement. Debris went downslope along a small stream course, with $\theta < 32°$ for 'M' non-channelised debris movement.

B.13 LANDSLIDE B12

The landslide B12 is shown in Plate B12.1 to Plate B12.3. A cross-section of the landslide is given in Figure B20. The scarp is shown in Plates B12.4 and B12.5, and details of the debris trail in Plates B12.6 and B12.7.

The scarp appeared to have been formed as a result of two adjacent slips. Debris from the western slip stopped at the footpath level. Debris from the eastern slip crossed the footpath and came to rest in the form of a debris fan with a relatively steep front.

Primary deposition was found up to CH24, with $\theta = 31°$ for 'G' non-channelised debris movement. From CH24 onward, secondary deposition due to action of surface water was noticed, with $\theta < 29°$ for 'M' non-channelised debris movement.

B.14 LANDSLIDE B13

Landslide B13 is shown in Plate B13.1. A cross-section of the landslide is given in Figure B21. The debris trail and the scarp are shown in Plates B13.2 to B13.8. The landslide occurred between two branches of the hiking trail, and the debris destroyed a small masonry wall adjacent to the lower of the two footpaths (Plate B13.2).

The landslide involved a thin layer of bouldery colluvium. There was a minor landslide at the toe of the slope above the footpath. The debris blocked about half of the footpath. Below the footpath, a narrow scar (B13A) occurred immediately downslope of the edge of the footpath and was joined by landslide B13B to its west. To the east of B13A, the ground had settled by about 0.5 m, and displaced horizontally by about 0.3 m, resulting in a 8 m long tension crack. The scar was generally rugged on the date of inspection (26.1.94), with no signs of major erosion.

Primary deposition occurred up to CH27, with $\theta = 34°$ for 'G' non-channelised debris movement. Secondary deposition occurred from CH27 to beyond CH48, with $\theta < 32°$ for 'H' non-channelised debris movement.

B.15 LANDSLIDE B14

Landslide B14 occurred on the slope above the footpath (Plate B14.1). The footpath was completely covered by the debris (Plate B14.2). Plates B14.3 shows an uphill view of the debris trail and the scarp of this landslide. A close-up of the scarp is shown in Plates B14.4 and B14.5. Plate B14.6 shows the debris trail.

Colluvium and weathered volcanic were involved in the landslide. The landslide released blocky debris, which did not travelled very far, with $\theta = 34°$ for 'G' non-channelised debris movement.

APPENDIX C

LANDSLIDE IN STUDY AREA C

CONTENTS

C.1 INTRODUCTION

This Appendix contains factual records of a landslide (No. C1) in Area C, which was inspected and logged in June 1994. The aerial photograph in Plate C1 was taken on 5 December 1993 from a height of 6 000 feet. An assessment of the nature of debris movement is also given below.

C.2 LANDSLIDE C1

A cross-section of the landslide is given in Figure C1. Different parts of the landslide were annotated in Plate C2. The scarp is shown in Plates C3 to C5, and the debris trail in Plates C7 to C12.

'Gravitational' debris movement probably occurred up to CH139. The debris that was deposited between CH47 and CH118 remained largely in place and was retained by a large boulder at CH118. However, the primary deposition between CH118 and CH139 were partly removed by surface water. Hydraulic action was evident beyond CH118. At CH139, $\theta = 20°$ for 'G' non-channelised debris movement. At CH183, $\theta < 20°$ for 'H' non-channelised debris movement.