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The Distribution of Landslides on Lantau Island, Hong Kong

Bachelor of Arts Dissertation

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12 Courses in Geography

Department of Geography and Geology
University of Hong Kong
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Appendices

ABSTRACT

A study was carried out on the distribution of landslides on Lantau Island in Hong Kong concerning its characteristics, and distribution pattern in relation to 5 landslide-governing factors known as (1)geology, (2)slope gradient, (3)vegetation, (4)annual rainfall and (5)human influence over the island in the year 1995. Aerial photo interpretation, landslides mapping, statistical methods and field observation were adopted in this research to test the degree of relationship between the landslide distribution pattern with each independent factor. Results of the study revealed that landslide distribution in 1995 was highly correlated with geology, slope gradient and annual rainfall of the island, while vegetation (woodland) and human impact were relatively less significant. The recurring landslide distribution pattern of the year 1995 was the result of the combined contribution of the 5 factors with different degree of relationships.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my supervisor, Dr. D.D. Zhang, who has devoted so much time answering my endless questions patiently and gives me lots of support and encouragement; Dr. M.R. Peart, who kindly helped me get permission to have access to the Natural Terrain Landslide Inventory from the Geotechnical Engineering Office Library.

Grateful thanks to Mrs. P. Chan and Miss J. Mui of the Map Library of the Department of Geography & Geology, who have helped me greatly in dealing with technical problems faced during the mapping work; and the staff of the Photographic and Cartographic Units of the Department for their generous help.

Thanks are extended to my friends, who gave me warmth and support throughout the process, especially Miss Y. M. Lai, Miss H. Y. Ng and Miss C. M. Liu, who went with me "discovering" landslides over Lantau Island.

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CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

Slopes occupy most of the earth's land surface, ranging from steep mountains to gentle plains, which are made up of rock or soil materials. The study of slopes has been a major issue in geomorphology. Scientific study on slopes can be mainly divided into three stages.

In the first half of the twentieth century, slope researches were concerned with the long-term landscape development. Various classical models of slope evolution ~~which~~ based upon changing slope morphology were proposed aiming to reconstruct the landform history, notably by W. M. Davis, W. Penck and L. C. King. Since the 1950s, more attention has been paid to the processes of hillslope denudation. From the 1970s onwards, geomorphic processes and the strength of hillslope materials have been widely recognised as determinants of the slope form changes. The morphology of hillslope is dependent or responds to the processes acting upon it. Hillslopes are therefore viewed as process-response systems which are largely applied in much of the current slope research concerning slope stability problems (Selby, 1985; Summerfield, 1991; Selby, 1993).

Mass movement processes are largely responsible for slope instability involving the movement of slope materials downslope under the force of gravity, which occur when shear stress on slopes (the downslope pull that disturbs slope materials causing mass movements) exceeding shear strength (the inherent resistance of slope materials to movement or deformation by stress).

Landslides are the most common known type of mass movement that have affected many countries and have caused disastrous consequences around the world, including Hong Kong. Understanding of landslides occurrence is therefore important, particularly in hilly regions with increasing urban development.

Lantau Island, which is located in the southwest part of Hong Kong, was chosen in this landslide study. The island was largely an undeveloped hilly area in year 1995 but rapid urban development had been taking place. Natural hillslopes were increasingly affected by man which might cause slope instability problems.

This research attempted to provide a general perspective on landslide using the geomorphological approach through investigating its spatial relationships with landslide governing factors including geology, slope gradient, vegetation, annual rainfall and human influence. The scope of this study was limited to landslides identified on Lantau Island in the year 1995. In short, the purpose of this study were:

a) to identify the landslide locations and the general landslide distribution characteristics over Lantau Island in the year 1995 and compare them with those between 1973-1994 respectively.

b) to analyse the relationship between landslide distribution with each landslide controlling factor including geology, slope gradient, vegetation, annual rainfall and human influence on Lantau Island of the year 1995.

c) attempt to find out the dominant landslide distribution controlling factors in respect to Lantau area in the year 1995.

The research problem in this study was, "Why landslide distribution of the year 1995 arranged in ~~such a particular~~ pattern?". It carried the hypothesis that the landslide distribution of the year 1995 (dependent variable) was correlated with 5 landslide-governing factors (independent variables), namely (1)geology, (2)slope gradient, (3)vegetation, (4)annual rainfall and (5)human influence, formulated from the literature review. Aerial photo interpretation, landslides mapping, statistical methods and field observation were adopted to test the hypothesis.

It should be noted that detailed investigation in any particular landslide location with its related factors would be subjected to error due to the general nature of this study.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

2.1. Definition of landslide

Regarding to the terminology of "landslide" in literature, "landslide" was considered as a popular "non-technical" (Tarbuck & Lutgens, 1993), "general" (Skinner & Porter, 1987) (Plummer & McGeary, 1993), "non-specific" (Montgomery, 1995) or "collective" (Crozier, 1986) term for describing the process of rapid downward movement and topographic forms of mass wasting of rock or soil materials, under the influence of gravity without direct aid of erosional agent or transporting medium such as water, wind or ice (Terzaghi, 1958; Tarbuck & Lutgens, 1993; Plummer & McGeary, 1993; Selby, 1993). The term covered all slope movements, including falling, flowing as well as sliding types of earth materials (Coates, 1985). Hence, the definition was fairly vague and broad. Tarbuck & Lutgens (1993) even stated that landslide did not have any specific definition in geology. Nevertheless, a more specific definition for landslides was attempted by Varnes (1975) and Selby (1993), who excluded creep in the definition of landslide, while Selby excluded falls and topples altogether.

The definition of landslide could be confined by its distinctive features from other mass movements, particularly in its topographic form. Landslide, according to Selby (1993), occurred along a well-defined surface or plane. The slipped materials involved were fair coherent (Coates, 1985; Tarbuck & Lutgens, 1993; Plummer & McGeary, 1993). In terms of movement direction, Coates (1985) pointed out that landslides involved a "down and out" motion differed from other "vertical" ground movements such as subsidence and collapse.

In this research, landslide referred to any rapid downward sloping movement or displacement of loosen soil along a well-defined sliding plane influenced by gravity, recognised by topographic form such as scars or tongues. Soil creep and rockfall were excluded.

2.2. Landslide studies in Hong Kong

Extensive literature on landslides of Hong Kong revealed some characteristics of previous landslide studies over the territory. Firstly, landslides in Hong Kong were mostly studied as case studies in small-scale, focusing on particular landslide sites. There was lack information concerning landslide distribution over the territory to enable landslide study in a geographical perspective. Secondly, detailed landslide investigation and records were limited to the landslides which had affected human beings or urban areas. As Lumb (1975) remarked, "many slips in remote parts of Hong Kong remain unrecorded, unless they caused loss of life or serious damage to property". A number of landslides occurred on natural hillslopes in non-urban area was not recorded due to their remoteness.

Documentation of landslides through systematic terrain classification mapping started under the initiation of the Geotechnical Area Studies Programme (GASP) in September 1978 (Burnett, A.D. et al, 1985). The Terrain Classification Map (TCM) recorded the slope angle, terrain component, erosion and instability but did not plot the exact location of landslides. It was not until early 1995, the Hong Kong Government decided to establish a catalogue for landslides (renamed the Natural Terrain Landslide Inventory in 1996) over the territory, paying special attention to landslide distribution and landslides that occurred on hillslopes of non-urban areas. A Natural Terrain Landslide Study (King, 1999) was carried out by the Geotechnical Engineering Office (known as Geotechnical Control Office before 1991). Risk guidelines for landslides and boulder falls from natural terrain were also developed (ERM-HK Ltd, 1998).

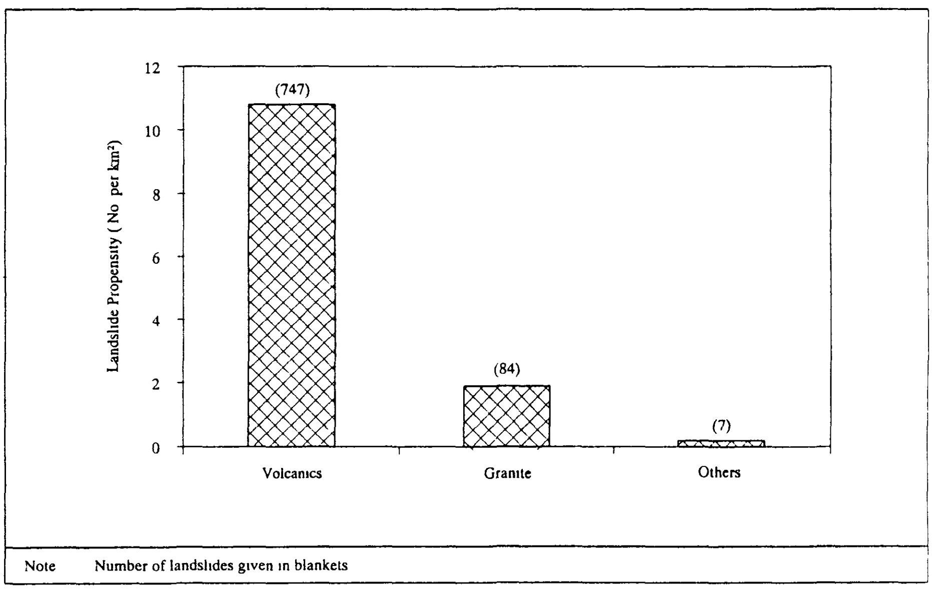
2.3. Previous studies on significance of landslide-governing factors in Hong Kong

Few synthetic studies have been done in Hong Kong regarding the landslide distribution pattern with the degree of relationship among various landslide governing factors. However, numerous studies made contribution to the understanding of landslides in Hong Kong by revealing the relationship with each of the following factors:

2.3.1. Geology

Some literature studied the relationship between landslide occurrence with respect to the underlying solid geology in terms of their number (or frequency) of occurrence, instability index, and location.

Higher number of landslides on volcanics in compare with other geological types in Hong Kong, such as granite, was reported in So (1971, 1978a, 1978b) and Peng (1986). Allen (1971) observed the high landslide frequency on volcanics of Lantau and reported that "a valley in volcanic rock in Southwest Lantau contained 21 recognisable landslide scars within a distance of 100m long one side". In a recent landslide study carried on Lantau Island (Wong et al, 1998), landslides on solid geology of volcanics was reported six times more than on granitic terrain and with the highest landslide density (no. of landslides / km^2) (Figure 2.1). But landslides on intrusive igneous rocks were also common (GCO, 1989). The recent study by Wong et al (1998) pointed out the significance of colluvium in relation to landslides in which 84% of landslides examined occurred on a thin layer of bouldery colluvium. The above observation was also reflected by the Area Instability Index (AII) in the GASP report (GCO, 1989), in which the volcanic terrain had the highest AII of 0.34, followed by sedimentary of 0.27, while granitic rocks had just 0.22. However, opposite view was found in GCO (1989), in which concluded form the landslide incidence after severe rainstorm of May 1982 that the "susceptibility to landslides on the various rock types is not greatly different".



Source Wong et al (1998)

Figure 2.1. Correlation of landslide propensity with geological units of 838 rainfall-induced landslides on Lantau Island on November 4-5, 1993

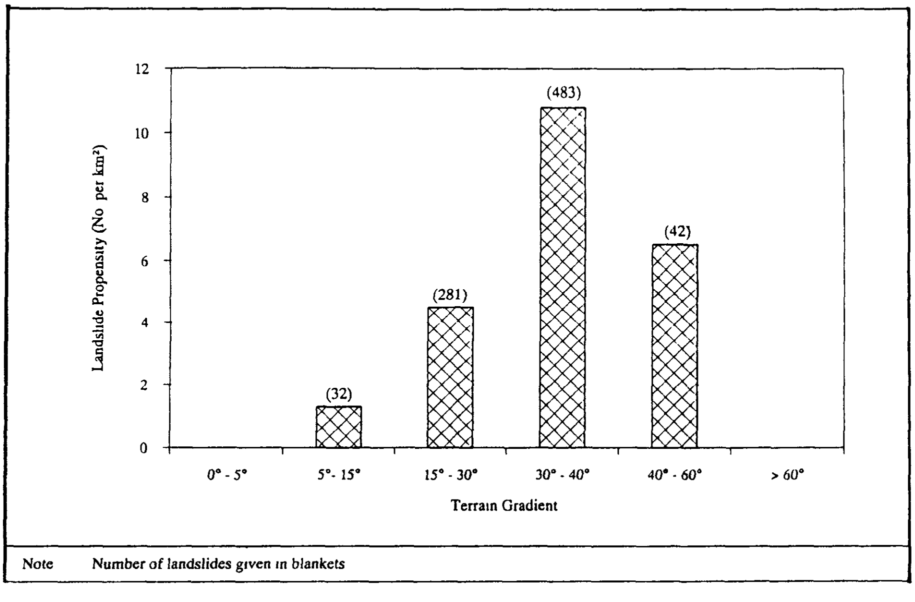
Regarding to landslide locations, So (1971) reported most landslides located at the contact zones between major rock types, especially in the zone of colluvium between granite and volcanics (So, 1978a) (Peng, 1986).

2.3.2 Slope gradient

Previous studies on the relationship between landslide occurrence and slope gradient on Lantau area were mainly taken under the Geotechnical Area Studies Programme (GASP) (GCO, 1988a) and the recent study by Wong et al (1998).

According to the GASP reports (GCO, 1988a, 1988b), many landslides occurred commonly over the steep terrain throughout Lantau area. With particular reference to North Lantau (GCO, 1988a), it was reported that the Area Instability Index (AII) tended to increase with increasing gradient form 0°-15° (AII: 0.23), 15°-30° (AII: 0.29) to 30°-40° (AII: 0.46) and had a slightly drop in AII value at slope gradient over 40° (AII: 0.45). Hence, greater slope angle with higher incidence of slope failure was concluded.

The results of a recent study by Wong et al (1998) on landslide propensity with different range of terrain gradients on Lantau Island after a severe rainstorm of November, 1993 had similar findings (Figure 2.2). Landslide propensity was reported highest at moderately steep slopes with gradient ranging from 30°-40°, about 7 times larger than the gradient between 5°-15°. Decreasing landslide propensity was found from slope gradient of 40°-60°, 15°-30°, 5°-15° to the lowest 0°-5°.



Source Wong et al (1998)

Figure 2.2. Correlation of landslide propensity with terrain gradient

2.3.3. Vegetation

In Hong Kong, there were few studies concerning the relationship between vegetation cover and landslide occurrence. As noted by Lee (1985) in his review of vegetative slope stablisation, Hong Kong was "lack of information, knowledge and experience in the study of interrelationship between vegetation and slope stability". Within those previous studies (So, 1971; Greenway, 1984), the role of vegetation on slope stability remained controversial.

Positive correlation between landslide occurrence and vegetation coverage (especially woodland) was revealed by So (1971), after his investigation followed a severe rainstorm of June 1966 over the territory. In his study which taken place on Hong Kong Island (So, 1971), he reported that landslides occurred in areas both with or without vegetation cover. Besides, woodland suffered the highest landslide density, followed by bare slopes, scrubland and grassland. Based on the observation, it was advocated that "vegetation plays only a limited part in stablising slopes" and could only be served as a "temporary measure of stability" (So, 1971).

However Greenway et al (1984) put forward a different point of view after investigating the mechanical reinforcement effect of tree roots. The root study, as reported by Greenway et al (1984), confirmed that "tree roots provide effective resistance against the relatively shallow failures that are common in Hong Kong". In addition, Lee (1985) concluded from his review of vegetative slope stablisation that vegetation was "highly effective and advantageous" and in stablising slopes. Besides, Lee (1985) also emphasised that the adverse effects imposed by vegetation was "comparatively small". Hence, vegetation could minimise the occurrence of landslides to a certain extent.

2.3.4. Rainfall

In Hong Kong, relationship between rainfall and landslides has been received most attention. Rainfall-induced landslides between 1972 to 1992 was detailly described in Premchitt et al (1994). The earliest work concerning the rainfall-landslide correlation for Hong Kong was taken by Lumb (1975) in which the antecedent rainfall was regarded crucial to cause major landslide events. Based on the analysis on slope failures occurred in 1950 to 1973, Lumb (1975) noted that landslide occurrence was related to the daily rainfall and the previous 15-day rainfall (Figure 2.3).

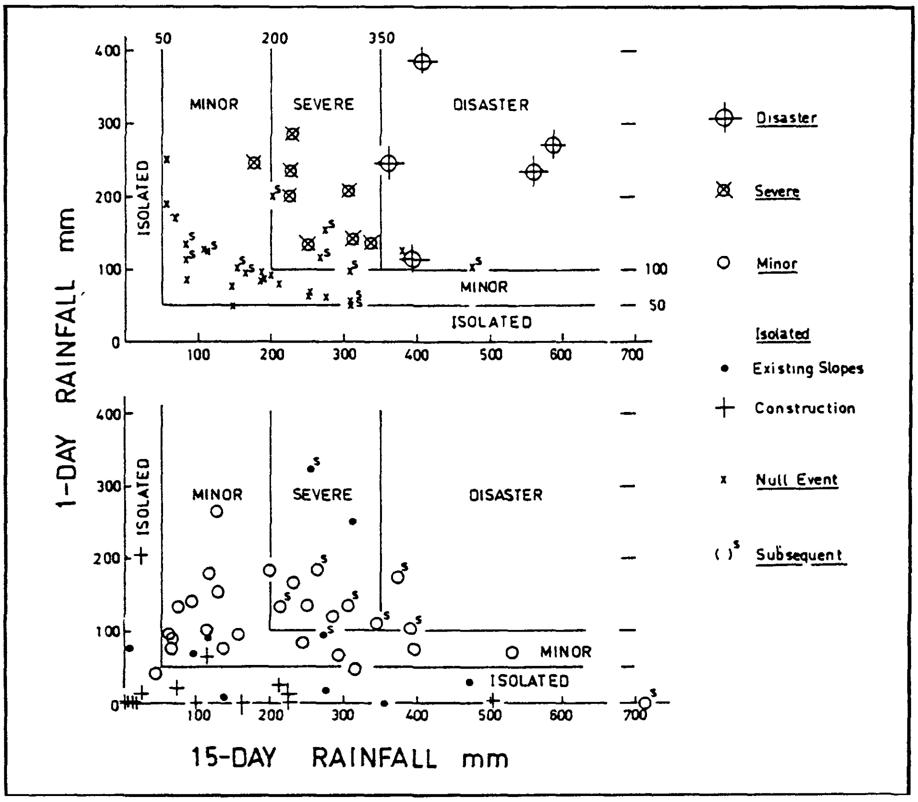


Figure 2.3. Rainfall-landslide relationship after Lumb (1975)

But Brand et al (1984) found that the antecedent rainfall was only significant for minor landslide events. Rather, landslides in Hong Kong were mostly triggered by high rainfall intensity of a short period, depending on the peak hourly rainfall (Brand et al, 1984). This finding was supported by the analyses on landslide records and rainfall data in the years 1963 to 1982 in Hong Kong, where majority of reported landslides occurred within four hours of peak rainfall intensities (Brand et al, 1984).

Brand et al (1984) established a quantified relationship between rainfall and landslides occurrence for Hong Kong based on the 20 years data and concluded that: (1) Local hourly rainfall of 70 millimetres or more was the "threshold value" of landsliding. (2) Landslides were unlikely to occur with a 24-hour rainfall of less than 100 millimetres.

The latter correlation was adopted and operated as Hong Kong's Landslide Warning System since 1984 (Premchitt et al, 1994).

Rainfall-landslide relationship was studied in terms of 24 severe rainstorms from 1982 to 1989 by Au (1993). It was reported that slope failures occurred when 24-hour rainfall was more than 70 millimetres and sometimes even as low as 50 millimetres (Au, 1993), in which the findings were contradicted with Brand et al (1994).

More recent study on rainfall-landslide relationship in Hong Kong was taken by Kay & Chen (1995) which correlated the 1-hour rainfall and 24-hour rainfall with landslides occurrence based on 1984-1992 GEO data (Figure 2.4).

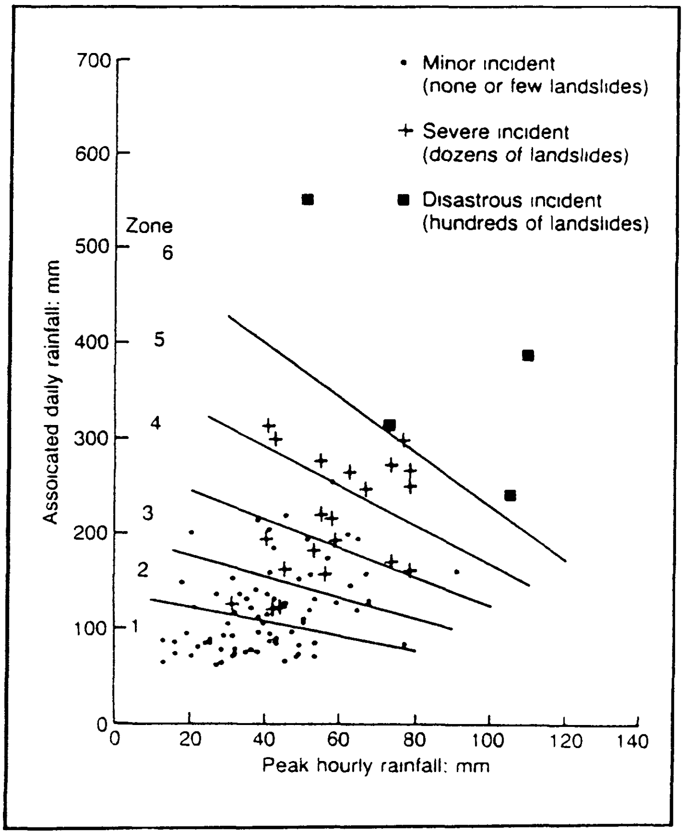
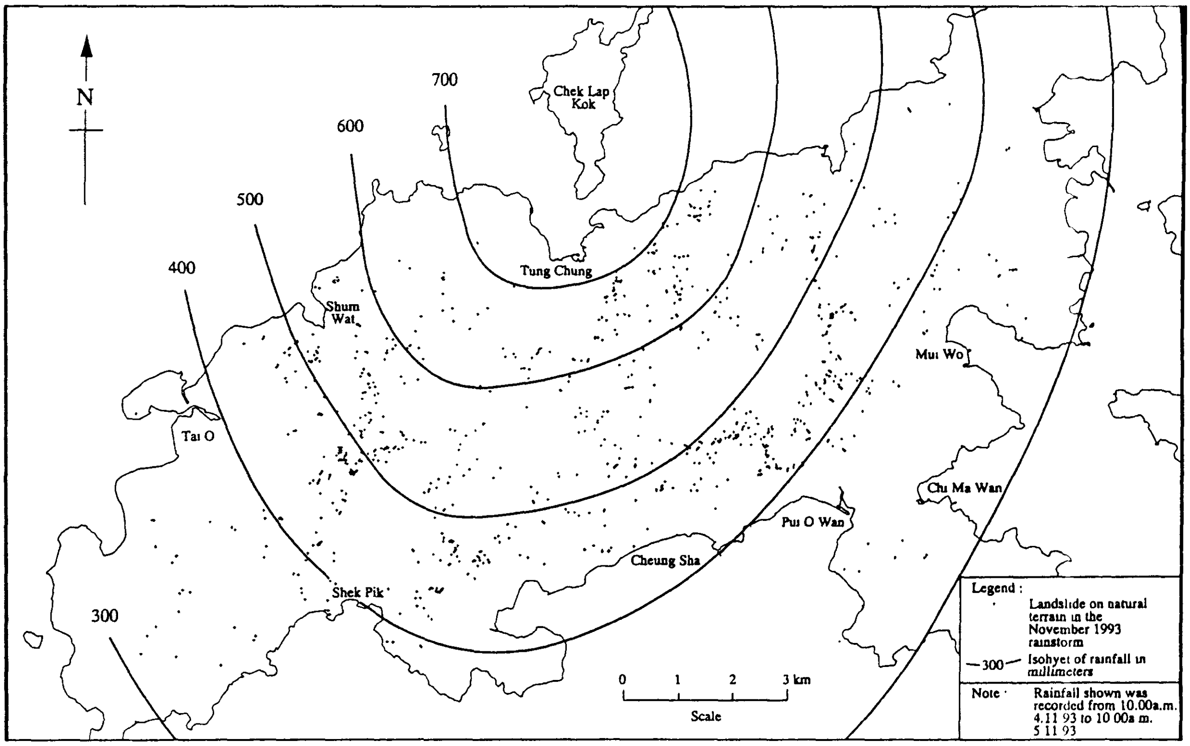


Figure 2.4. Rainfall-landslide relationship after Kay & Chen (1995)

On Lantau Island, landslides caused by a severe rainstorm on November 4 and 5, 1993 was studied in terms of their characteristics and mechanisms by Wong et al (1996, 1998) (Figure 2.5). However, the effects of rainfall intensity on landslide propensity were not assessed due to insufficient reliable data. Nevertheless, the locations of landslides on November 4 and 5 were found to be closely correlated with the 24-hour isohyets (Brand, 1994).



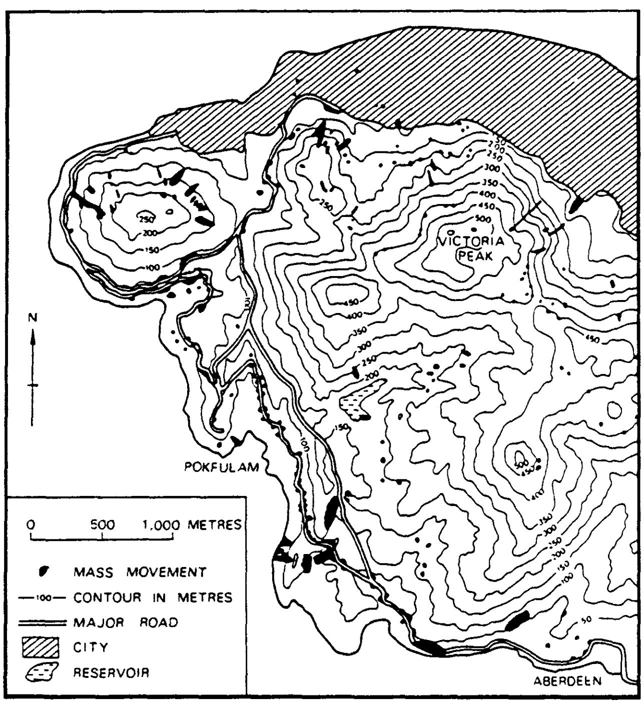
Source Wong et al (1996)

Figure 2.5. Rainfall-induced landslides on November 4-5, 1993 rainstorm on Lantau Island

2.3.5. Human Influence

Adverse effects on slope stability caused by human activities were noted in many previous studies. Many landslides in Hong Kong were said to be human-induced or accelerated by the expanding urban development on steep hillslopes due to limited flat, low-lying land and dense population. As Harris (1984) concluded, "the anthropogenic factors are major inducers of landsliding in Hong Kong". Based on the historical records on severe landslide events since 1889, it was noted that there was an increase in the number and severity of landslide events with the intensive urban development on slopes since 1950, associated with increased hillslope cuttings (Lumb, 1979; Premchitt et al, 1994; Brand, 1985).

The majority of mass movements, according to Brand (1984, 1985, 1989) and Premchitt et al (1994), was associated with man-made features, particularly at soil cut slopes which usually caused severe consequence. The most significant and hazardous landslide events which caused considerable loss of life and property, occurred in urban areas involving man-made cut and fill slopes (So, 1971; Hong Kong Government, 1972a, 1972b, 1977) (Figure 2.6).



Source So (1971)

Figure 2.6. Distribution of landslides associated with a rainstorm of June 1966, west part of HK Island, mainly found at artificial roadcuts (after So, 1971)

Examples of human-induced landslides were given by Brand (1985), who noted that slope instability were caused by the improper slope stabilising measures after cutting and filling, and uncontrolled cuttings on steep slopes in squatter areas without adequate surface drainage systems. A recent study carried by Wong & Ho (1995) revealed that inadequate slope protective measure was the major cause for causing over 250 man-made slope failures on Lantau Island, triggered by a severe rainstorm on November 4 and 5 in the year 1993.

CHAPTER 3

RESEARCH AREA AND METHODOLOGY

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RESEARCH AREA AND METHODOLOGY

3.1. Geographical location of research area

Lantau Island is the largest island located in the Southwestern part of Hong Kong Territory (Figure 3.1). Most part of the island is unaffected by urban development and uninhibited because of the steep hilly terrain (Figure 3.2). The total land area is about 165 square kilometres (Langford, 1995), consisting 13.28% of the territory (GCO, 1989). The island is mountainous, dominated by east-northeast trending ridges with steep slopes. Highest relief is located in the central part of Lantau (Plate 3.1) where the second and third highest peaks of Hong Kong---Fung Wong Shan (Lantau Peak, 934 metres) and Tai Tung Shan (Sunset Peak, 869 metres) are located. Lowlands are limited, mainly found along the coastline which is indented by narrow deep bays (Langford, 1995) (Plate 3.2).

It should be noted that the study area does not include Chek Lap Kok and Ma Wan.

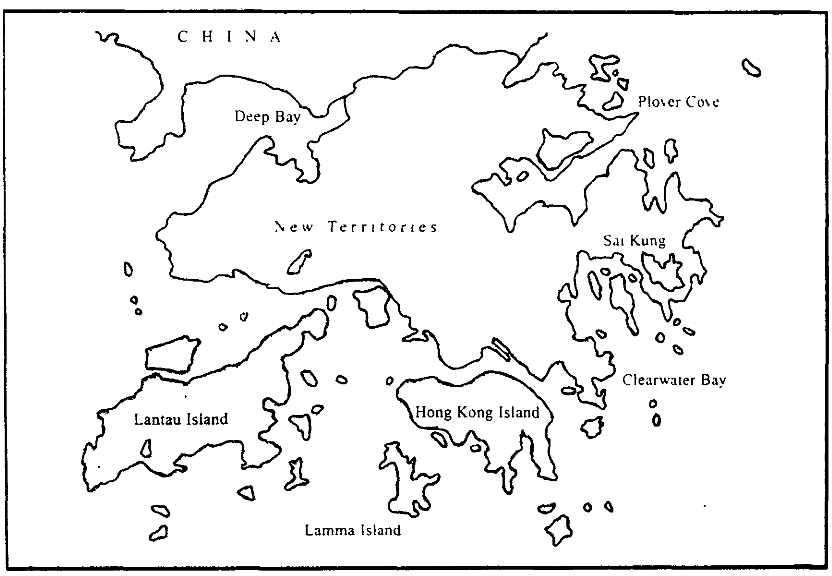


Figure 3.1 . Geographical location of Lantau Island, Hong Kong

RELIEF OF LANTAU ISLAND

Source: Survey & Mapping Office (1990)

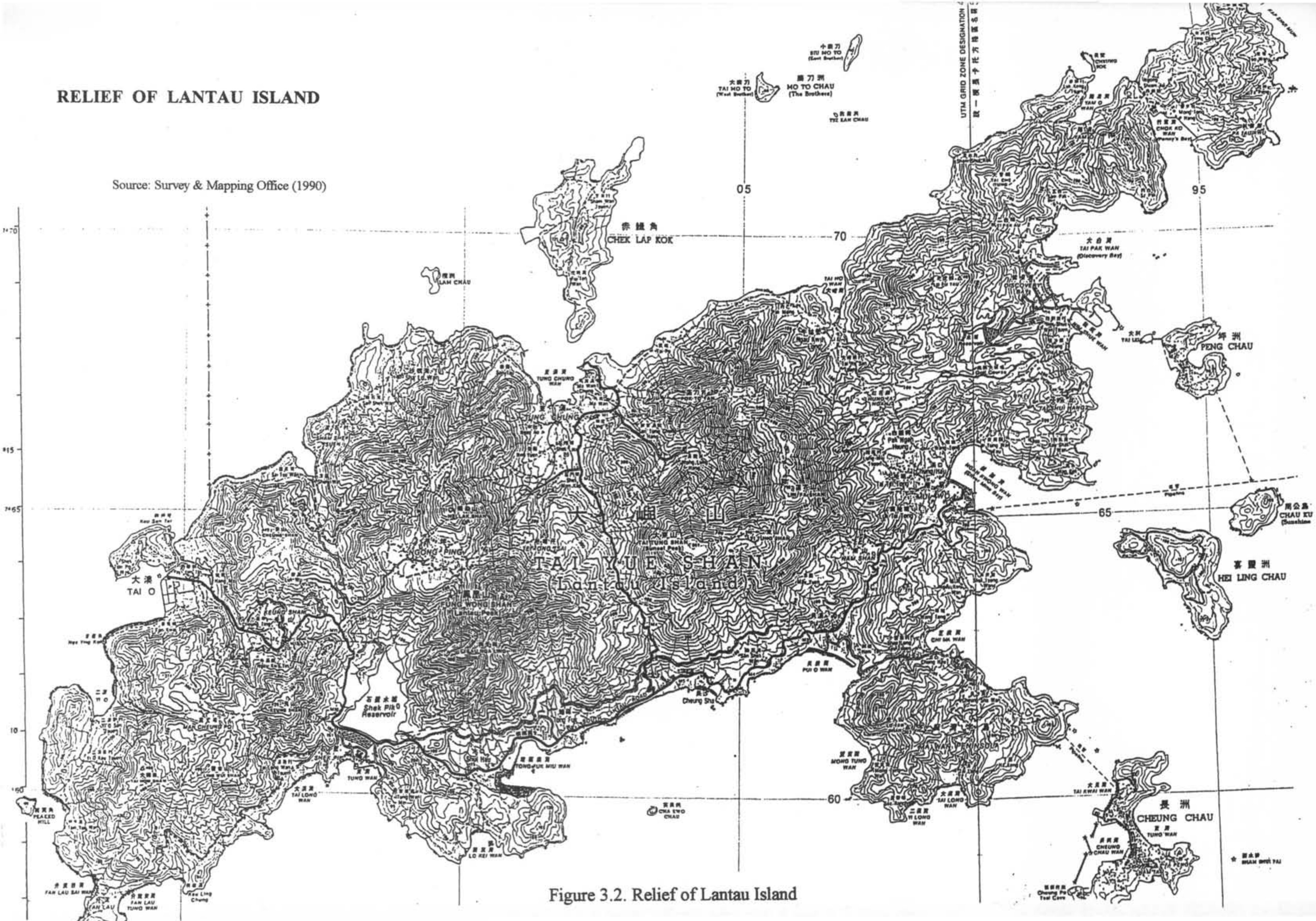


Figure 3.2. Relief of Lantau Island

Plate 3.1. High relief with steep slopes at Central Lantau

Plate 3.2. Flat low-lying alluvial plain at Mui Wo, East Lantau

3.2. Research methodology

The definition of landslide (refer to Chapter 2.1) applied throughout the methodology. Several methods were adopted to test the hypotheses about the correlation between landslide distribution with each landslide-governing variable.

3.2.1. Aerial photo viewing and interpretation

46 pieces of vertical aerial photographs (Survey & Mapping Office, 1995) taken from 10 000 feet dated on November 23, 1995 covering the whole Lantau Island, were used to identify landslides 3-dimensionally with their locations on the island. Serial number of aerial photographs used are shown in Table 3.1 and the aerial photo index map is attached in Appendix A.

Date of Aerial Photographs	**Photograph Serial Number**	**No. of Photos**
23.11.1995	CN 12262-64	3
	CN 12238-42	5
	CN 12171-79	9
	CN 12154-68	15
	CN 12178-88	11
	CN 12074-76	3
	Total	**46**

Table 3.1. List of aerial photographs used

Regarding ~~to~~ the procedure of aerial photo interpretation, the aerial photographs were placed side by side in correct orientation, two at each time. They were then studied stereoscopically by overlapping a stereopair of aerial photos with the help of a stereoscope.

Landslides were recognised by the following topographic features:

a) disturbed vegetation

b) unique landslide features -- scar, tongue

c) Colour -- light brown for recent landslides

d) disturbed topography

Aerial photos were valuable for identifying the location of landslides over Lantau Island. Firstly, aerial photos provided the quickest way of obtaining a complete and reliable information record of landslides over the island. The information in turn was used as a basis for landslide mapping which was required for further investigation and analysis with other landslide governing factors in this research. Secondly, "overlooking" of landslides in the field, which was caused by its small scale, vegetation obstruction and inaccessibility, was minimised.

3.2.2. <u>Landslides mapping</u>

Mapping of landslides of 1995 and 1973-1994 (data obtained from Geotechnical Engineering Office, 1997) by ploting landslides location on topographic map, was done respectively for 3 purposes:

a) to identify landslide distribution in the year 1995 and years 1973-1994

b) to compare landslide distribution pattern between the two periods in terms of location and ~~in~~ number.

c) to analyse the relationship between landslide distribution and its controlling factors including geology, slope angle, vegetation (woodland), annual rainfall and human influence on Lantau Island, with reference to the year 1995.

Natural terrain features such as river, relief (e.g. spurs, valleys) and man-made features (e.g. footpaths, villages) played an important assisting role in locating landslides on the topographic map.

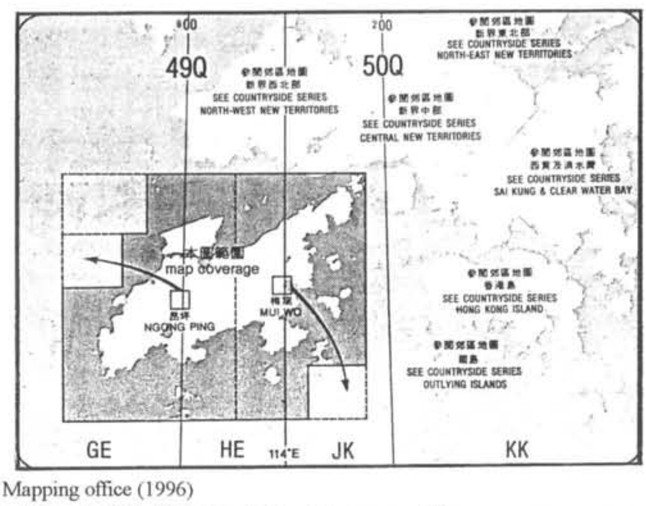
Legend used in mapping:

Landslide {


All the maps produced are contained in the Map Folder.

a) Mapping landslides of the year 1995

Landslide locations identified from the aerial photographs (Table 3.1), were mapped on a transparency laid on a Lantau Island topographic map (the base map) on a scale of 1:25 000 (Survey & Mapping Office, 1996). (Figure 3.3)



Source: Survey & Mapping office (1996)

Figure 3.3. Lantau Island topographic map coverage

b) Mapping of landslides of years 1973-1994

Landslide distribution data (1973-1994), which was classified as "recent landslides" by the Geotechnical Engineering Office, was obtained from the Natural Terrain Landslide Inventory (NTLI) at the GEO library with permission. Hence, the landslide positions were not controlled by the author. Limitations of the NTLI were ~~detailly~~ detail is described in King (1999).

The main purposes of using the NTLI were as follows:

a) to have a more complete picture on finding the correlation between invariable landslide-control factors, such as geology and slope angle, and landslide distribution.

b) to serve as a comparison between landslides of year 1995 and years 1973-1994 in terms of number and geographic locations.

c) to be used as a "counter-check" for landslide mapping of year 1995.

Landslide location data in Sheet 9, 10, 13 and 14 (Scale: 1:20 000) (Figure 3.4) of the NTLI covering Lantau Island was copied. According to the map note (GEO, 1997), landslide data was compiled from the interpretation of high-altitude (over 10 000 feet) aerial photographs, carried out by a team of aerial photograph specialists from the Department of Lands and Water Conservation of New South Wales.

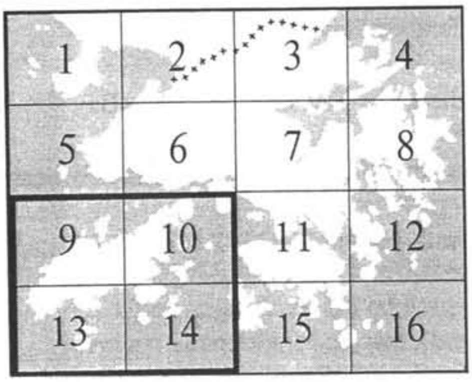


Figure 3.4. Map sheets index

3.2.3. Mapping of landslide distribution governing factors

The aim of mapping landslide distribution with each governing factor including geology, slope gradient, vegetation (woodland), annual rainfall and human influence, is to find out the degree of correlation between landslide occurrence among different factors for later analysis. This was done by overlapping the landslide distribution (1995) map with each landslide-governing factor map produced.

a) Geology map

Geology map of Lantau Island was combined from 4 sheets (Table 3.2) and was simplified by re-grouping into 4 major geological types: "volcanic rock", "granitic rock", "sedimentary rock" and "superficial deposits" (Appendix B). New legend and colours representing each geology type were added.

Geology map used	**Map title**	**Publication year**	**Latest edition**	**Map series**
Sheet 9	Tung Chung	1994	1	HGM20
Sheet 10	Silver Mine Bay	1991	1	HGM20
Sheet 13	Shek Pik	1995	1	HGM20
Sheet 14	Cheung Chau	1995	1	HGM20

Table 3.2. List of solid and superficial geology maps used (GEO, 1991, 1994, 1995a, 1995b)

b) Slope gradient map

Computer-generated GEOTECS slope gradient maps of North Lantau (GCO, 1988a) and South Lantau (1988b) produced by the Geotechnical Control Office, were used after map combination and map scale enlargement to 1:58 824. The slope gradient map presented the general distribution of slope gradient of Lantau Island. Slope gradients were divided into 5 slope class-units: 0°-5°, 5°-15°, 15°-30°, 30°-40° and over 40°.

The original GEOTECS maps of slope gradient were at a scale of 1:100 000, which were compiled from the 1:20 000 scale regional Terrain Classification Maps (GCO, 1989).

c) Vegetation map

Woodland areas, defined by the legend of the Lantau Island topographic map (Survey & Mapping Office, 1996) were encircled and mapped.

d) Annual rainfall map

The annual rainfall map of year 1995 produced by the Hong Kong Observatory (Royal Observatory, 1995) was used after enlarging the map scale from 1:250 000 to 1:58 824. Three class-units with equal rainfall interval (200 millimetres) were noted: 2000-2200mm, 2200-2400mm and over 2400mm.

e) Human influence map

Human influence on Lantau Island was classified into 5 types: "main road", "road cuts", "human settlements", "reclaimed land" and "reservoir". All man-made features were identified and mapped on a transparency laid on Lantau Island topographic map (Survey & Mapping Office, 1996).

3.2.4. Map re-scaling

Owing to different scale of original maps used (Table 3.3), the scale of maps were reduced or enlarged into same scale (1:58 824) by photocopying machine to fit into A3 size (attached in the Map Folder) for data analysis by overlaying and A4 size on a scale of 1: 83 320 (sample maps) to put into this dissertation. Further reduction of maps was made to minimise the "displacement" with the base map (details can be referred to Chapter 3.3.2.).

Maps Presented	**Original Map Scale**	**Reduction (R) or Enlargement (E)**	**Reduction or Enlargement procedures**	**Correction Error**
Landslide locations (1995) [Base map]	1:25 000	R	Original map scale x 0.5 x 0.85	
Landslide locations (1973-1994)	1:20 000 (4 sheets)	R	Original maps scale x 0.8 x 0.5 x 0.85	x 0.993
Geology	1:20 000 (4 sheets)	R	Original maps scale x 0.8 x 0.5 x 0.85	x 0.993
Slope gradient	1:100 000	E	Original map scale x 1.70	x 0.993
Vegetation (woodland)	1:25 000	R	Original map scale x 0.5 x 0.85	x 0.993
Annual rainfall (1995)	1:250 000	E	Original map scale x 4.25	x 0.993
Human influence	1:20 000	R	Original map scale x 0.5 x 0.85	x 0.993

Table 3.3. Map-rescaling procedures

3.2.5. Quantification and statistical methods

a) Landslides records

The purpose of making landslide record sheets (Appendix C) was to quantify the total number and percentage of landslides occurred on each landslide controlling factor.

All landslides identified from the aerial photographs (year 1995) were numbered (Appendix D). Geology, slope angle, vegetation, annual rainfall and human influence of each landslide identified were all recorded (Appendix C).

Formula used to calculate the percentage (%) of landslides occurred at a particular factor:

$$\text{Percentage of landslides occurred at a particular factor (e.g. volcanics)} = \frac{\text{No. of landslides occurred at the particular factor (e.g. volcanics)}}{\text{Total no. of landslides identified on Lantau Island from aerial photographs (year 1995)}}$$

b) Area measurement

The purpose of areal measurement was to find out the relative percentage of area coverage of each factor over Lantau Island.

Data on the areal extent of geology and slope angle of Lantau Island was summarised from North Lantau (GCO, 1988a) and South Lantau (GCO, 1988b) GASP reports (Appendix E). Data was modified by changing the unit base from hectare to square kilometres (1 ha = $0.01 km^2$).

No available areal data was found for vegetation coverage, varied annual rainfall (2000-2200mm, 2200-2400mm, >2400mm) and different artificial structures (main road,

road cut, settlements, reclaimed land, reservoir) over the island of year 1995. Area was therefore calculated by counting the number of squares in terms of square units from the transparent graph paper (Appendix F).

Formula used to calculate the areal percentage of a specified factor:

$$\text{Percentage of area covered by the specified factor (e.g. volcanics)} = \frac{\text{No. of square units covered by specified factor (e.g. volcanics)}}{\text{Total no. of square units of Lantau Island}}$$

c) Landslide density

Landslide density (number of landslides per square kilometre) is the ratio of the total number of landslides occurred on a particular factor (e.g. no. of landslides on volcanics) to the total area of that specific factor (e.g. total areal extent of volcanics). It was used to eliminate the biased results caused by the different areal extent involved in different factors to enable their comparison.

This method only applied to measure landslide density in respect to the geology and slope gradient factors as they had dependable areal data from the GCO (1988a, 1988b).

d) Location quotient

Location quotient (Burt & Barber, 1996) is another statistical method used to measure concentration (or density) of landslides for each factor, by calculating the ratio of percentage of landslides occur on a particular factor to the areal percentage of that factor over Lantau Island. The following is an example which calculate the LQ of volcanics:

% of Lantau Island covered by volcanics : 41.2

% of landslides occurred on volcanics : 78.9

Locational Quotient (LQ) : 78.9 / 41.2 = 1.92

The above "more than proportionate" result (LQ > 1) showed a very high concentration or density of landslide occurrence on volcanics since 78.9% of landslides occurred on volcanic area, which only consisted 41.2% of Lantau Island. The interpretation of LQ is summarised in Table 3.4:

Location Quotient	**Interpretation**
LQ > 1	The distribution of landslides occurred on a particular factor (in %) is greater than the areal distribution at that particular factor over Lantau Island (in %), indicates a relative high concentration (or higher density) of landslides over the particular factor in areal base.
LQ = 1	The distribution of landslides occurred on a particular factor (in %) is same as the areal distribution at that particular factor over Lantau Island (in %), indicates an equal proportion of landslides over the particular factor in areal base.
LQ < 1	The distribution of landslides occurred on a particular factor (in %) is smaller than the areal distribution at that particular factor over Lantau Island (in %), indicates a relative low concentration (or lower density) of landslides over the particular factor in areal base.

Table 3.4. Interpretation of location quotient

LQ enables comparison of landslide density among the 5 factors by using the same base even though three of the factors (vegetation, annual rainfall and human influence) without available numerical areal data. LQ considers the percentages rather than the absolute numerical value.

3.2.6. <u>Field visits</u>

Four field trips were taken along hiking trails or roads on Lantau Island to observe landslides with respect to its distribution characteristics and geology, slope angle, vegetation and human influence. Ground-truthing also provided the author first-hand field experience about landslide form (e.g. shape, size) and location (e.g. height, orientation) characteristics on Lantau Island. Photos were taken in the field. Visit records and route map were attached in Appendix G.

3.3. Research limitations

3.3.1. <u>Aerial photo interpretation</u>

Underestimation of landslides might be resulted because some landslides might be missed due to their small size, hidden by dense vegetation cover or the scale of photographs (high-altitude aerial photos were used).

Only "well-defined" landslides (those with a scar or scar with a tongue) were mapped. Landslides mixed with badlands were ignored to minimise identification problems.

Errors might have been made in the process of locating landslides on a topographic map, especially on a natural terrain like Lantau Island. To improve accuracy of landslide locating, natural features (e.g. rivers, relief) and man-made structures (e.g.

roads, footpaths, villages) played an assisting role. But for areas with dense vegetation, especially woodland, such as Chi Ma Wan Peninsula, where all the "assisting" features were covered, landslide locations could only be mapped approximately.

It should be noted that landslides identified from aerial photos of year 1995 were not necessarily occurred in 1995. Some "old" landslides occurred in previous years could also be identified because of slow growth rate of vegetation (King, 1999).

3.3.2. Re-scaling maps

Though all the maps (with different scales before re-scaling) were reduced or enlarged into same scale (1:58 824) by mathematics calculations to fit into A3 size, they still could not be overlaid with exact size. Slight "displacement" between maps was noted during overlapping.

"Displacement" error might be caused by copying machine during the process of map reduction or enlargement, or during the map-making process since the original maps were in different scales. To minimise the displacement error, a "correction" was made by reducing map size to 0.993 to fit into the base map.

3.3.3. Field visits

Most landslides found during the field trips were not accessible by hiking trails or roads. Observation or photo-taking could only be made at a distance. Besides, many landslides were not seen clearly at the site since the view was sometimes obstructed by luxuriant vegetation.

CHAPTER 4

GENERAL DESCRIPTION ON THE DISTRIBUTION AND CHARACTERISTICS OF LANDSLIDES ON LANTAU ISLAND

CHAPTER 4

GENERAL DESCRIPTION ON THE DISTRIBUTION AND CHARACTERISTICS OF LANDSLIDES ON LANTAU ISLAND

4.1. Distribution of landslides

4.1.1. Landslide distribution in the year 1995

The spatial distribution of landslides on Lantau Island in 1995 was unevenly distributed (Figure 4.1). In the northeast and eastern part of the island, landslides were sparsely distributed, showing a dispersed spatial distribution pattern. In contrast, the number and density of landslides in the central and western part of the island were much higher where a clustered spatial distribution pattern was shown. It was also noted that most landslides occurred at the interior part of the island. Very few landslides found along the coastline.

Several areas had a much higher density of landslides (where there were high number of landslides within a small area), relative to other areas of the island. These areas included Ngong Ping (Area A) (Plate 4.1), eastern part of Shek Pik Reservoir (Area B), western part of Mui Wo (Area C) and eastern part of Tung Chung (Area D) (Plate 4.2) (Figure 4.2).

Plate 4.1. High landslide density at the junction of Sham Wat Road and Ngong Ping Road, Ngong Ping

Plate 4.2. A number of small-sized landslides on volcanic hillslopes, near Tung Chung New Town

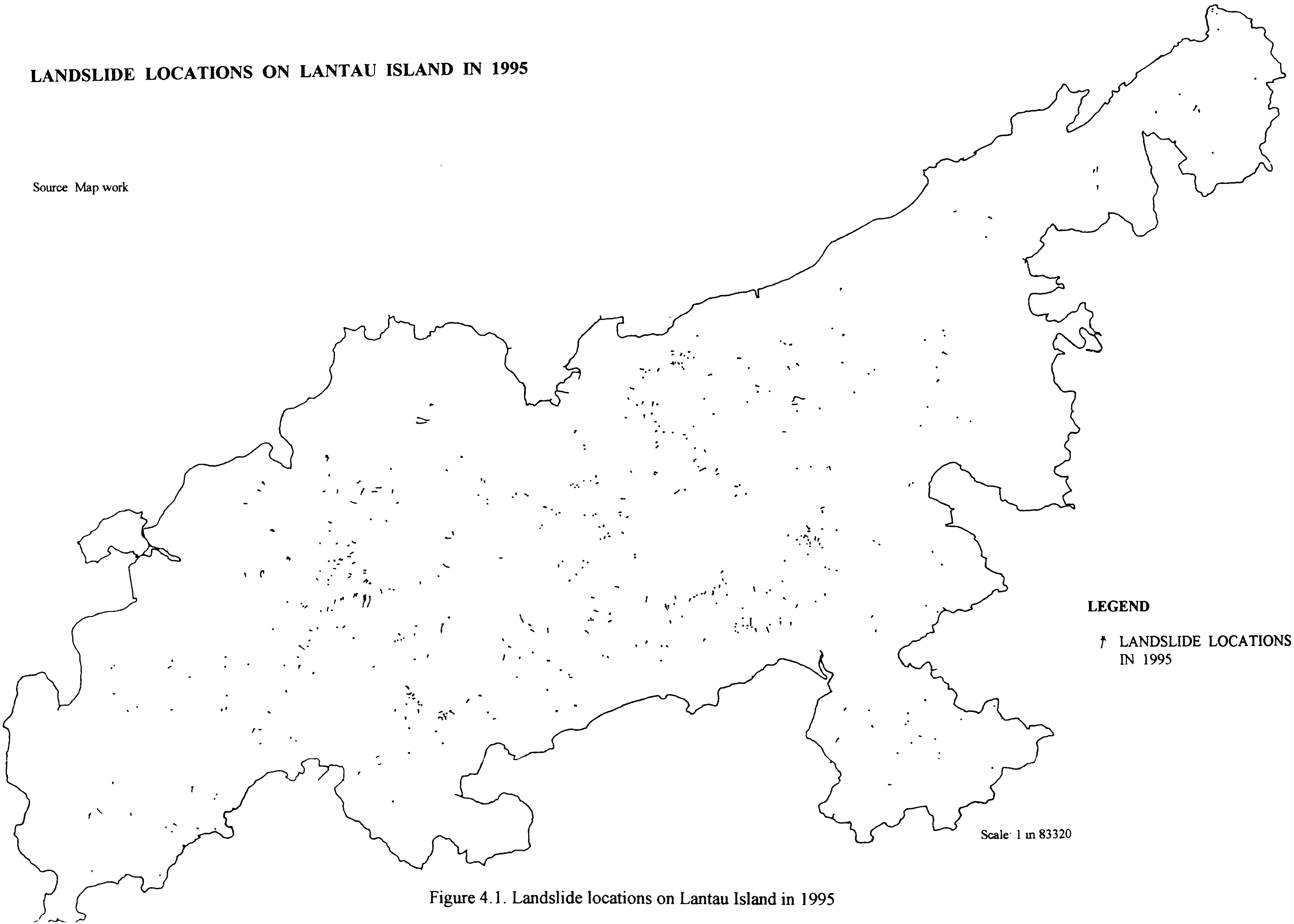


Figure 4.1. Landslide locations on Lantau Island in 1995

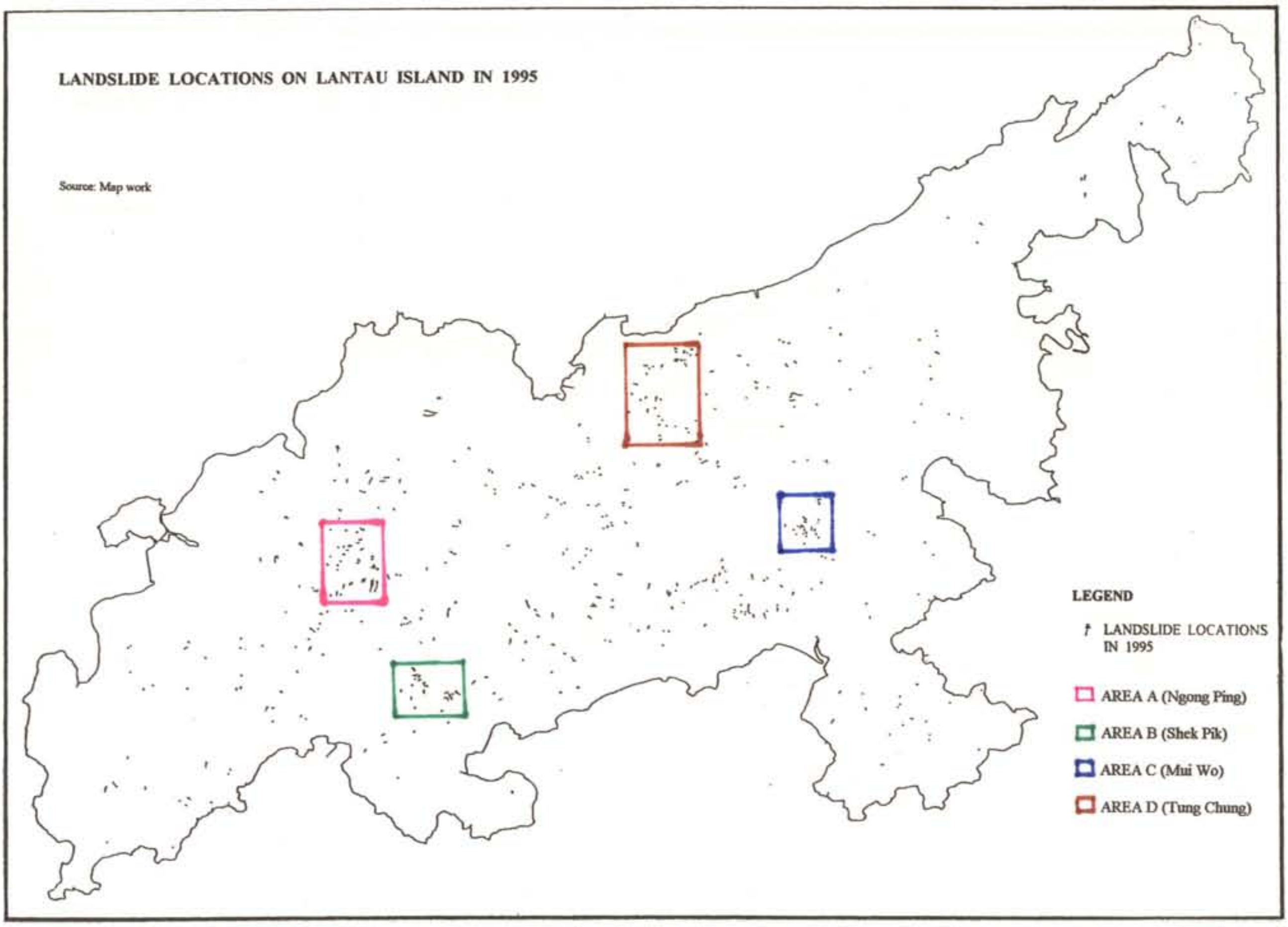


Figure 4.2. Areas with high landslide density in 1995

It was also noted that the distribution of landslides was influenced by relief (Figure 3.2). Circular distribution pattern of landslides was found (Figure 4.3). Landslides distributed at the mid-slopes surrounding the mountain ranges on the island, forming a "circular" distribution pattern. The "circled" areas were usually corresponded with mountain peaks..

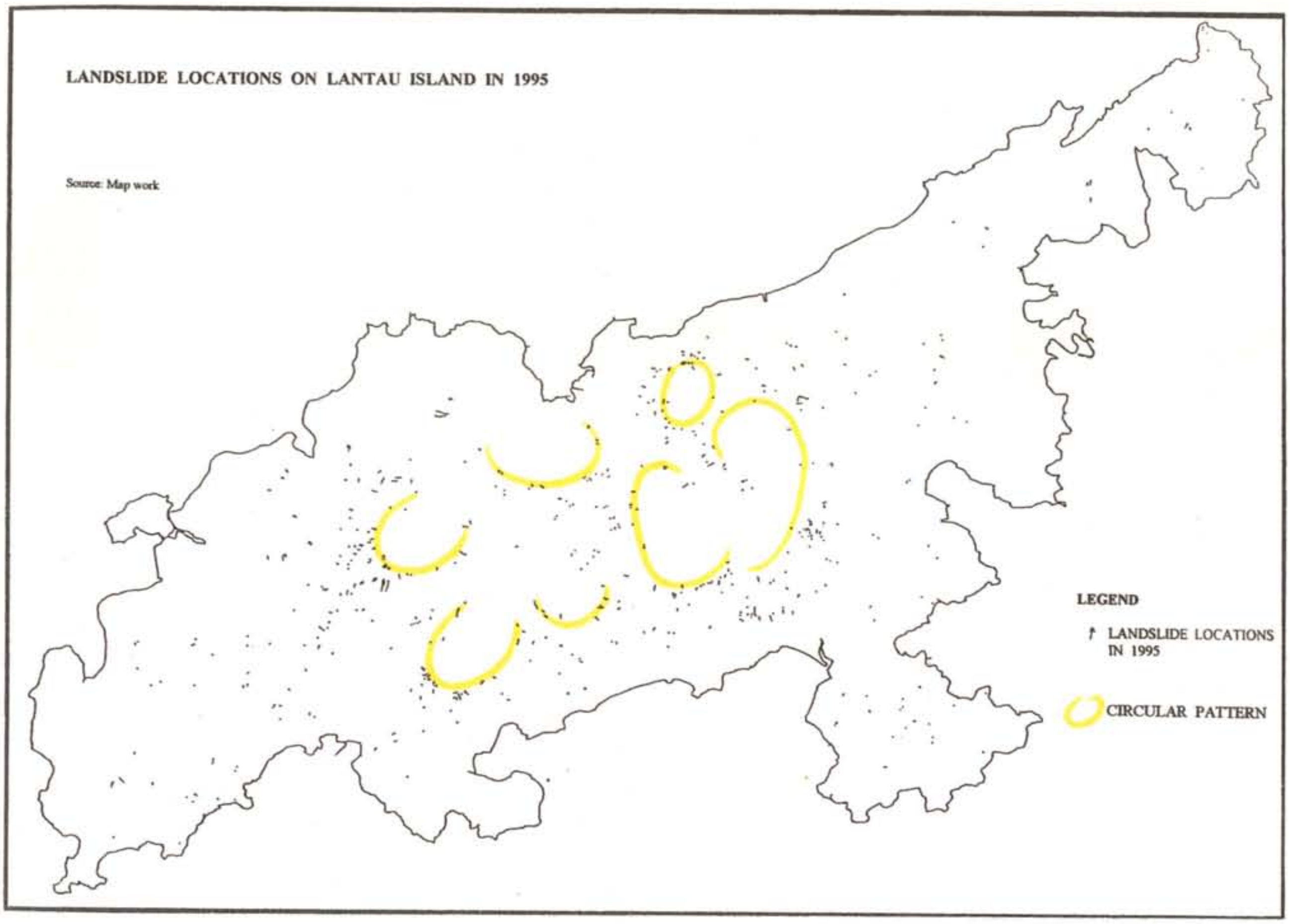


Figure 4.3. Circular distribution pattern of landslides in 1995

4.1.2. Landslide distribution in the years 1973-1994

Comparing with landslide distribution in 1995, landslides in 1973-1994 showed similar distribution characteristics mentioned in Chapter 4.1.1., but in a more obvious way in terms of the spatial pattern and locations (Figure 4.4). The similarities were as follows:

a) an uneven spatial distribution pattern over the island was shown.

b) similar high-density and low-density landslide locations found.

c) obvious circular pattern of landslides was noticed.

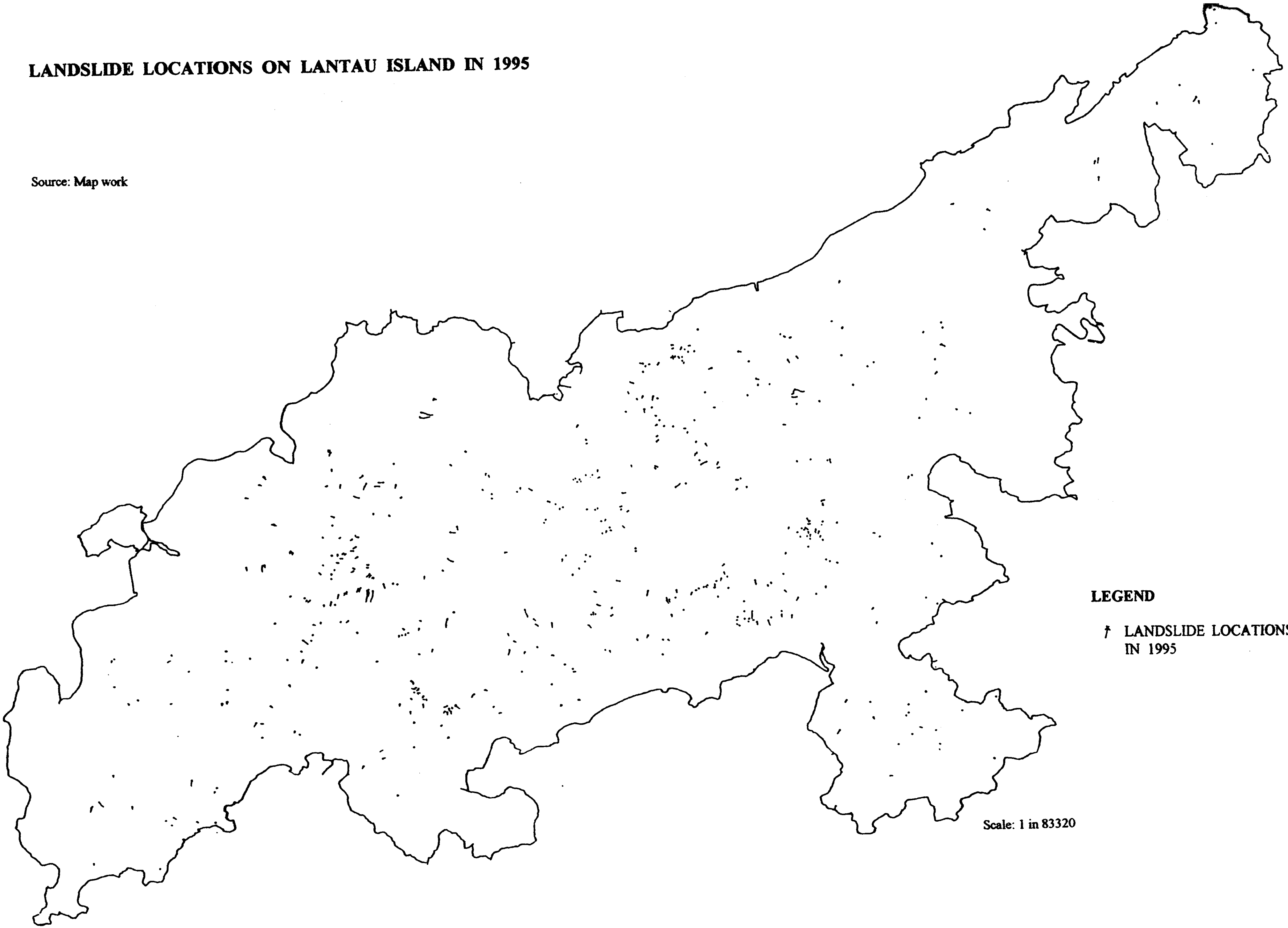
However, much more landslides of 1973-1994 were located near the coastline of the island, which made a difference with landslide distribution pattern of 1995.

4.1.3. Implication

Similarity of landslide distribution between years 1973-1994, and the year 1995 showed that landslides did not occur randomly. As many landslides occurred in the same area where previous slope movements had taken place, there might have some landslide-control factors behind that governing its distribution. These governing factors would be discussed in more detail in Chapter 5 to Chapter 9.

LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1995

Source: Map work



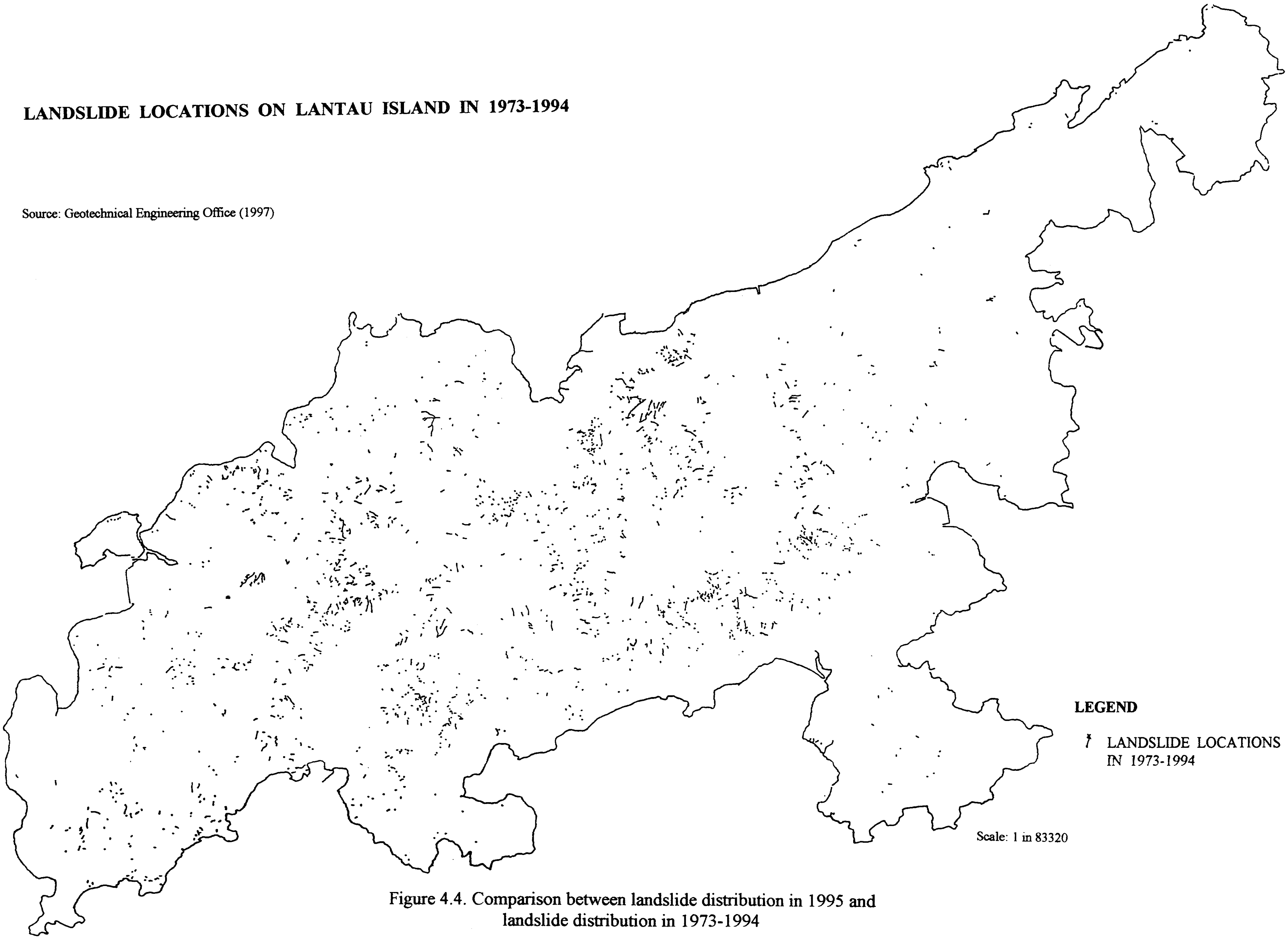


Figure 4.4. Comparison between landslide distribution in 1995 and landslide distribution in 1973-1994

LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1995

LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1973-1994

Source: Map work

Source: Geotechnical Engineering Office (1997)

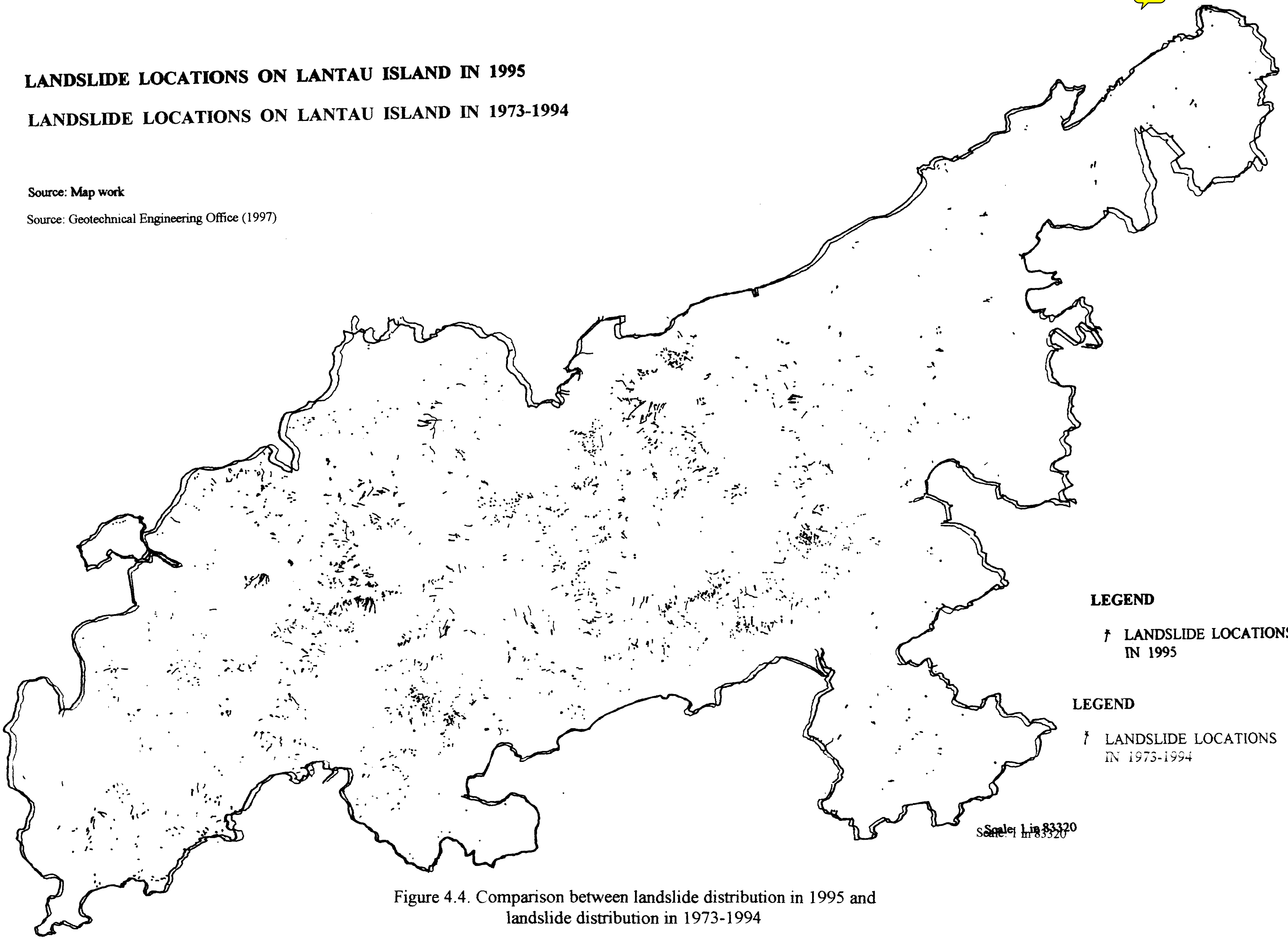
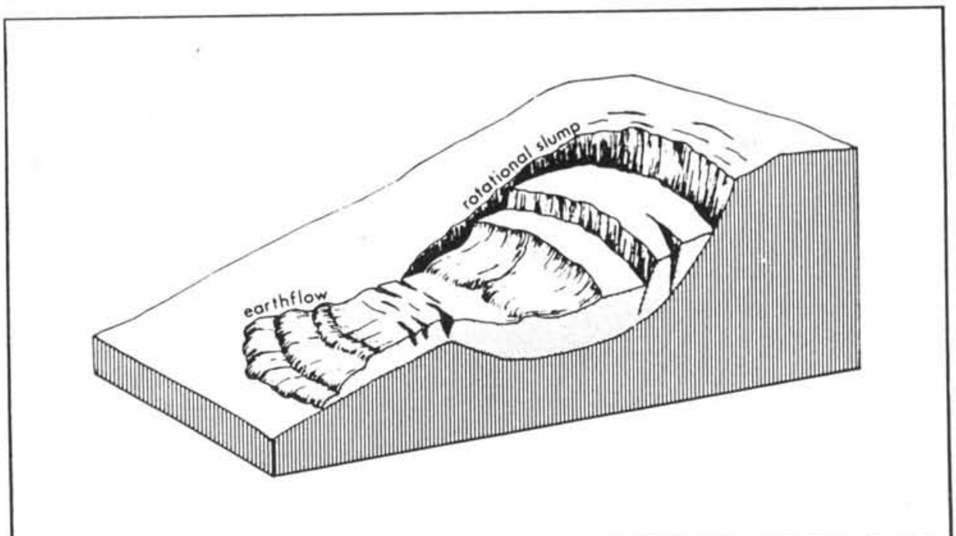


Figure 4.4. Comparison between landslide distribution in 1995 and landslide distribution in 1973-1994

4.2. Characteristics of landslides on Lantau Island

The following characteristics of landslides on Lantau Island were recognised from the study of aerial photographs (Survey & Mapping Office, 1995) and during field visits.

Regarding to the shape, size and colour of landslides, the scars recognised had well-defined sliding plane and were mostly circular in shape and concave-upward. Some had elongated tongues, with slope debris extending out downslope from the base of the scar to a certain distance. Size of landslides on Lantau was small with shallow depth. Colour of most recent landslides was light reddish brown (deeply weathered soil) while dull in colour for the "older" ones that occurred in previous years. The landslide scars recognised were mostly bare of vegetation cover. Concluding from the above characteristics, landslides on Lantau could be classified as rotational slips or "earthflows" (Figure 4.5) which are commonly found on hillsides in humid areas (Tarbuck & Lutgens, 1993). Compared with landslides, badlands (Plate 4.3) (some mixed with landslides) on Lantau were in irregular-shaped and mostly found on the ridgecrest of granitic terrain.



Source: Selby (1993)

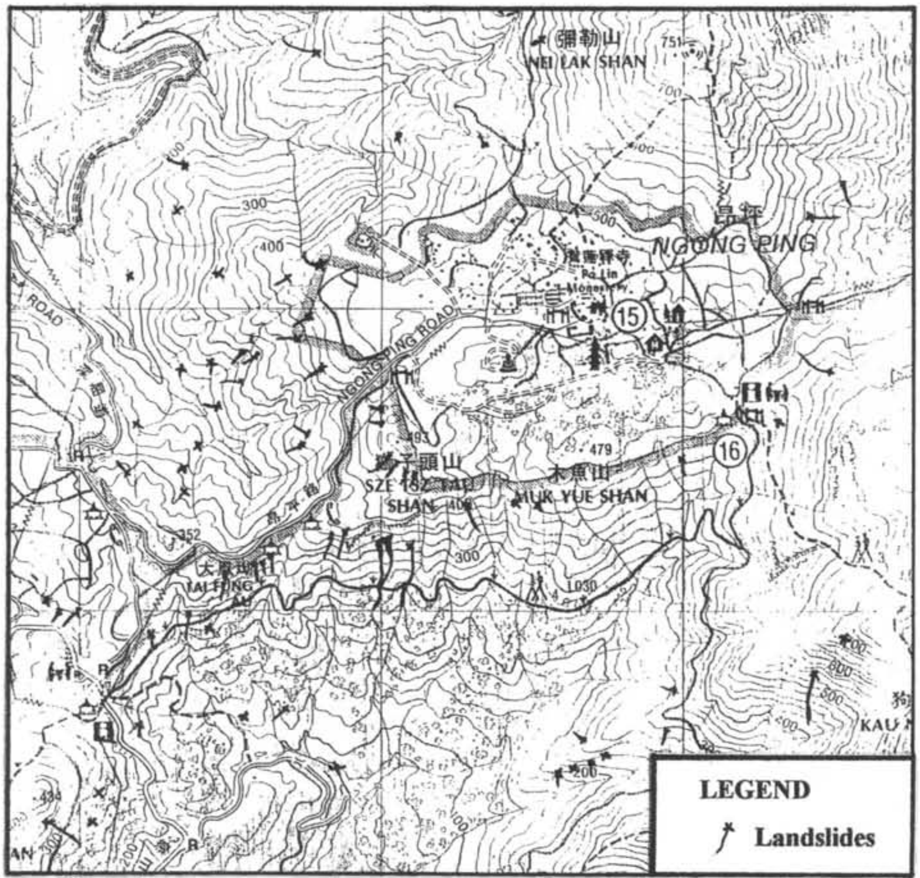
Figure 4.5. The most common type of mass wasting found on Lantau Island

Plate 4.3. Severe soil erosion at ridgecrest of granitic terrain, East Lantau

In geographical location, most landslide scars were found at the upper part of valley slopes, just below the crest of the spurs (Plate 4.4). Also, most landslides occurred on natural hillslopes of the island -- areas without much human impact or development.

Landslides identified showed an "orientation". The tongues of landslides mostly run at right angles to contours down the valley slopes in the direction of the valley floor to the upper part of streamlines (Plate 4.4) (Figure 4.6).

Plate 4.4. A number of small-sized landslides at upper hillslopes of Lantau Peak, showing orientation



Source: Map work

Figure 4.6. Landslide orientation shown on topographic map

CHAPTER 5

DISTRIBUTION OF LANDSLIDES IN RELATION TO GEOLOGY

CHAPTER 5

DISTRIBUTION OF LANDSLIDES IN RELATION TO GEOLOGY

5.1. Geology of Lantau Island

Based on the areal data combined and summarised from North Lantau (GCO, 1988a) and South Lantau (GCO, 1988b) Geotechnical Area Studies Programme (GASP) reports (Table 5.1) (Appendix E), volcanics and granites are the dominant rock types, consist 46.7% (69.42 km^2) and 30.5% (45.36 km^2) of Lantau Island respectively. Sedimentary rocks are less significant, consist only 0.8 % (1.23 km^2). Superficial deposits cover 21.9% (32.54 km^2) of the island.

Geology type	**Geology areal extent**	
	Area (km^2)*	**% of specified geology over Lantau Island**
Volcanics	69.42	46.7
Granites	45.36	30.5
Sedimentary	1.23	0.8
Superficial deposits	32.54	21.9
Total	**148.55**	**99.9**

*Source: Data combined and modified from North Lantau (GCO, 1988a) and South Lantau (GCO, 1988b) GASP reports

Table 5.1. Areal extent of different geology types over Lantau Island in year 1995

Regarding to the general location (Figure 5.1) and the age of different solid geology over the district, volcanic rocks (Plate 5.1) are widespread over the central and western part of Lantau Island, with small outcrops at the Northeastern tip. These are Mesozoic volcanics and are classified as Repulse Bay Formation, which comprise tuffs and lavas (Lands & Survey Dept., 1979; Langford, 1995). Some parts have been severely folded and metamorphosed as a result of granitic intrusion. Volcanics are well-jointed with joint-spacing varies from narrow to wide of less than 10 metres. Its weathering depth is about 8-10 metres, in which weathered materials are mainly clayey silt with minor sand (GEO, 1988a, 1988b).

Plate 5.1. Jointed volcanic rock exposed after roadcutting at Keung Shan Road

Granite is another major type of intrusive igneous rock found on Lantau, which exposes extensively on eastern part of the island (Plate 5.2), with isolated outcrops at the Northern coast west of Tung Chung and Southwest coast at Shui Hau and Fan Lau (Figure 5.1). Granites of Lantau Island are mostly classified as Cheung Chau Granite of Upper Jurassic age, characterised by its pinkish colour, porphyritic texture, with medium to coarse-grained size between 3-5mm (Lands & Survey Dept., 1979; GCO, 1988a, 1988b). Granites have medium to very widely-spaced sheeting and tectonic joints. Its weathering depths is usually nearly twice the depth of volcanic rocks, composed of silty clayey sand (GCO, 1988a, 1988b).

Plate 5.2. Well-jointed granite outcrops at Chi Ma Wan Peninsula

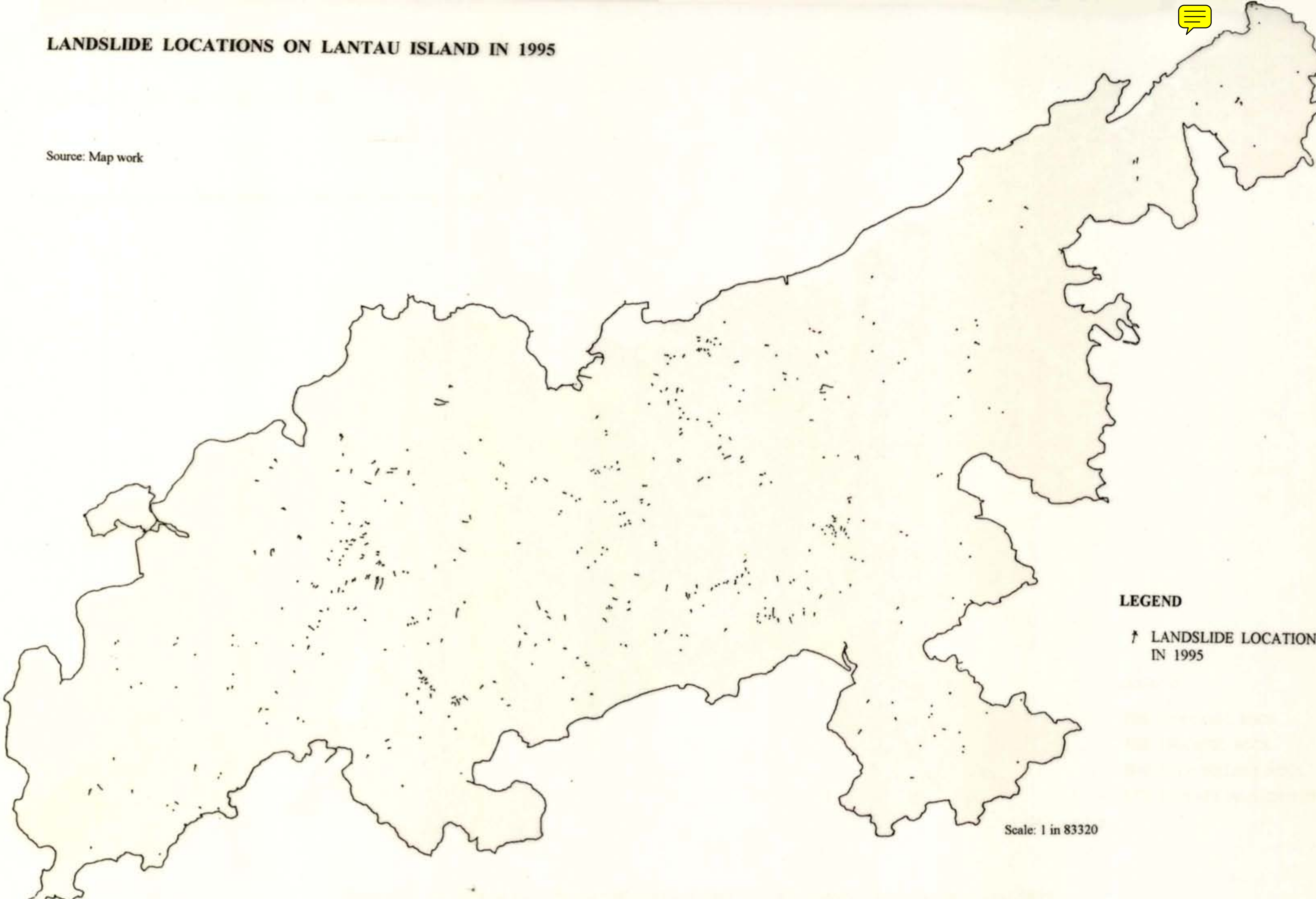
Sedimentary rocks are limited to the Northwest coast of the island between Tai O and San Shek Wan (Figure 5.1). Its geological age is of Middle to Lower Jurassic, known as Tai O Formation. They are composed of thinly bedded siltstones, black silty shales and sandstones, which are folded, faulted and metamorphosed (Lands & Survey Dept., 1979; GCO, 1988a, 1988b).

Superficial deposits distribute extensively as isolated groups over the island, found on hillslopes inland (colluvium) and along the coastline (alluvium and beach deposits) (Figure 5.1). Superficial deposits on Lantau Island are of Quaternary age. They are unconsolidated loose materials covering bedrock (Langford, 1995). The most extensive superficial deposits are found at Mui Wo (East Lantau), Pui O (Southeast

Lantau), Tung Chung (North Lantau) and Tai O (Northwest Lantau). Colluvium of Lantau area comprises poorly-sorted mass movement debris deposits and alluvium is composed of locally developed well-sorted to semi-sorted clays, silts, sands and gravels (Langford, 1995).

LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1995

Source: Map work



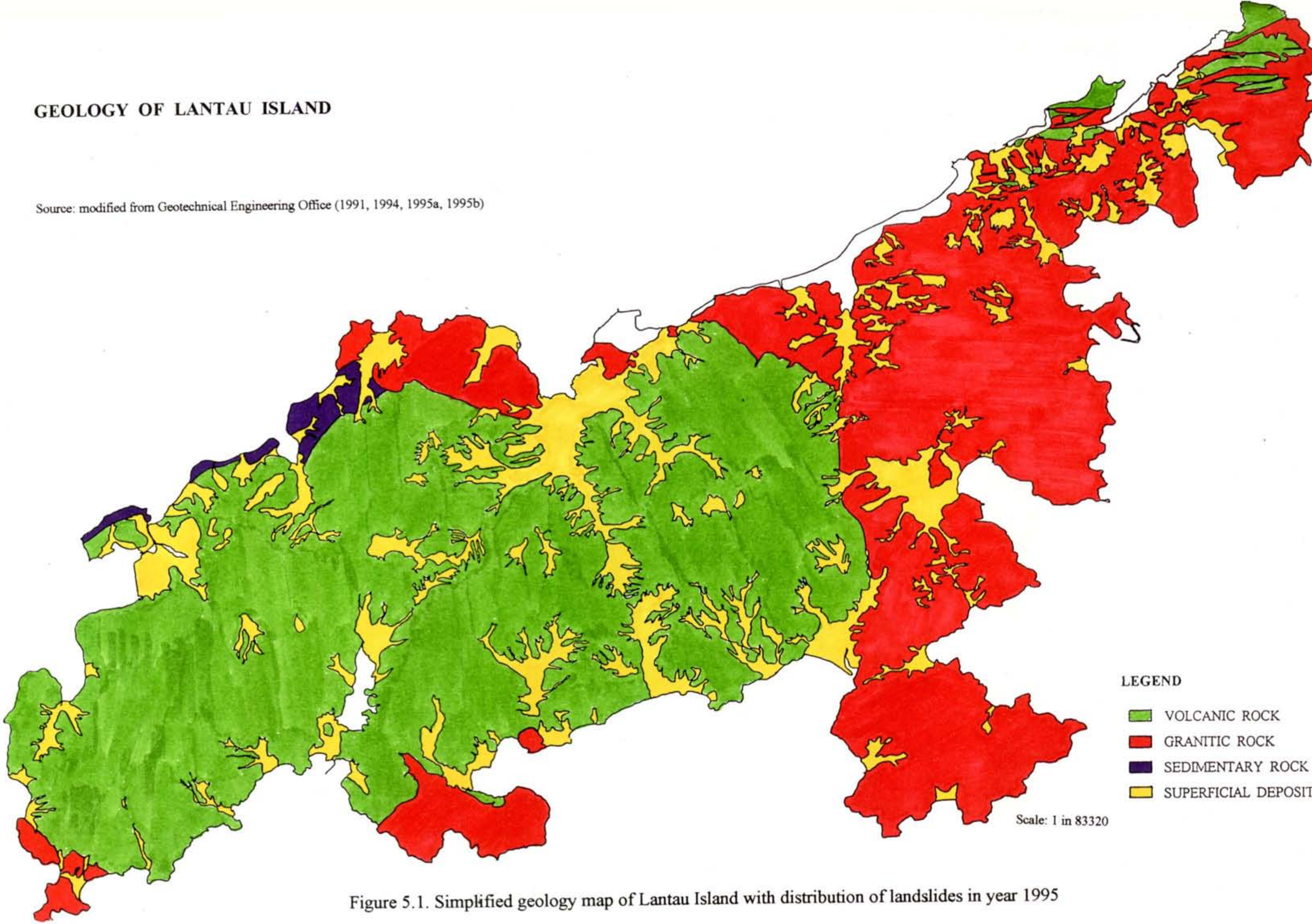


Figure 5.1. Simplified geology map of Lantau Island with distribution of landslides in year 1995

LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1995

GEOLOGY OF LANTAU ISLAND

Source: Map work

Source: modified from Geotechnical Engineering Office (1991, 1994, 1995a, 1995b)

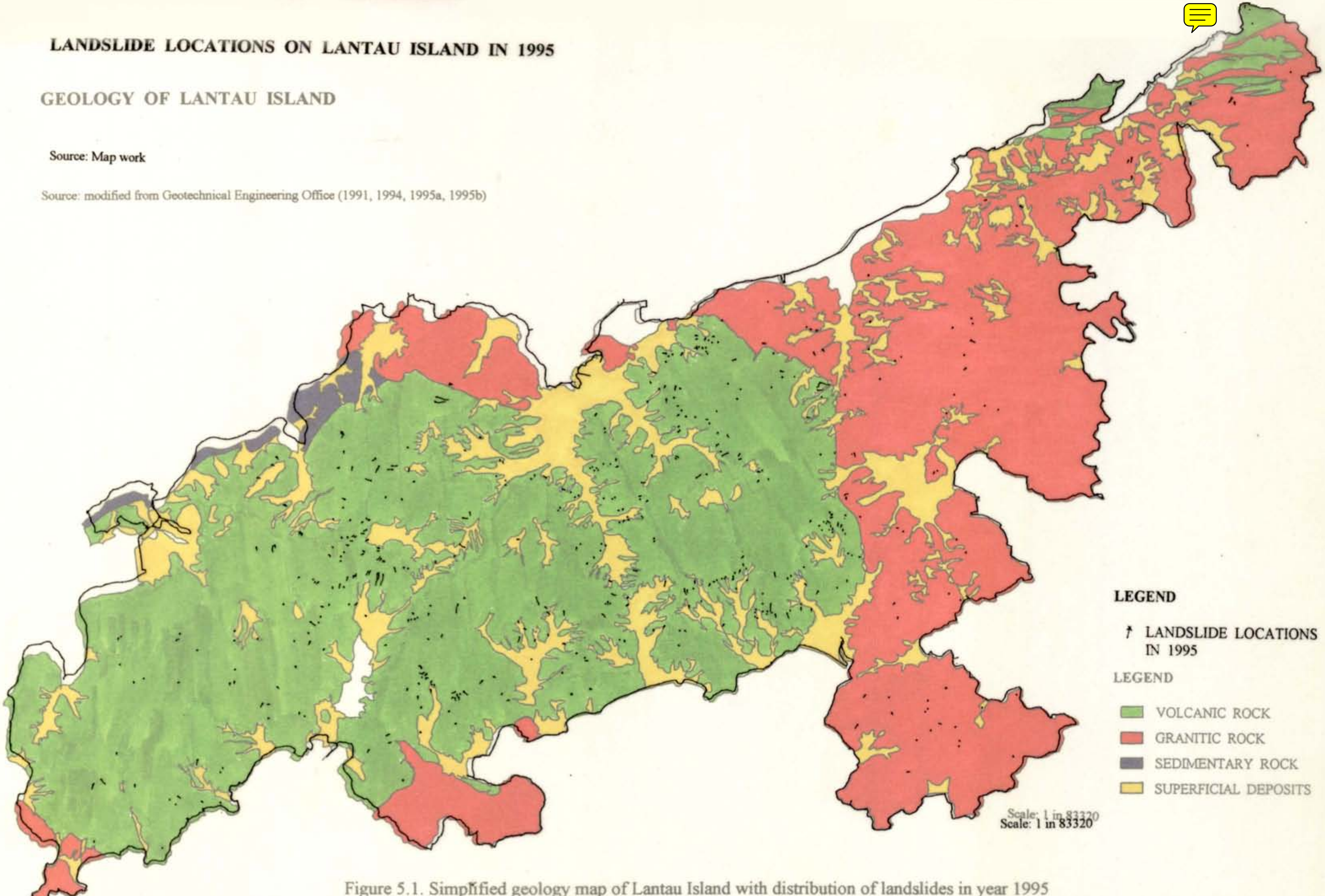


Figure 5.1. Simplified geology map of Lantau Island with distribution of landslides in year 1995

5.2. Distribution of landslides on different geology types

The spatial distribution of landslide locations over Lantau Island in the year 1995 with respect to different geology types was analysed by statistical methods (calculation details ~~refer to~~ Chapter 3.2.5) and map observation (Figure 5.1). The results are presented as follows:

5.2.1. Statistical analysis

~~Regarding to~~ 502 landslides identified, 396 landslides (78.9%) occurred on volcanic terrain, 65 (12.9%) landslides occurred on granitic terrain, followed by 41 (8.2%) landslides ~~occurred~~ on superficial deposits. No landslide found on sedimentary solid geology. Hence, highest number of landslides occurred on volcanics which was 6.1 times more than on granites, 9.7 times more than superficial deposits, and 3.7 times outweighed all other rock types combined. (Table 5.2)

Landslide density (number of landslides per square kilometre) was also highest on volcanics (6.46 landslides/km^2) (LQ=1.69), several times more than granites (1.43 landslides/km^2) (LQ=0.42) and superficial deposits (1.26 landslides/km^2) (LQ=0.37). Hence, landslide density of volcanics was extraordinary high in compare with other geology types over Lantau Island.

Geology type	Geology areal extent		Landslide occurrence (year 1995)		Landslide Density (no. of landslides/ km^2)	Location Quotient
	Area (km^2)*	% of specified geology on Lantau Island	No. of landslides	% of landslides on specified geology		
Volcanics	69.42	46.7	396	78.9	6.46	1.69
Granite	45.36	30.5	65	12.9	1.43	0.42
Sedimentary	1.23	0.8	0	0.0	0.00	0.00
Superficial deposits	32.54	21.9	41	8.2	1.26	0.37
Total	**148.55**	**99.9**	**502**	**100.0**		

*Source. Data combined and summarised from North Lantau (GCO, 1988a) and South Lantau (GCO, 1988b) GASP reports

Table 5.2. Landslide distribution on different rock types in year 1995

5.2.2. Map observation analysis

Landslides were not evenly distributed on different types of geology (Figure 5.1). In volcanic terrain, landslide distribution showed a clustered pattern with high landslide density (Plate 5.3). In contrast, landslides on granitic rocks showed a sparse or dispersed distribution pattern (Plate 5.4).

Plate 5.3. High landslide density on steep volcanic hillslopes, Pui O

Plate 5.4. Low landslide density on gentle granitic hillslopes, Chi Ma Wan Peninsula

Change in landslide number and density was very obvious between volcanics and superficial deposits, where volcanics had a much higher landslide density. In contrast, very few landslides occurred on superficial deposits. No landslide was found on sedimentary terrain.

The significant change in landslide density in response to different types of geology, especially between volcanics and granites, indicated high correlation between landslide distribution pattern with different geology types.

5.3. Relations between geology and landslide occurrence

The results showed a high correlation between landslide distribution and different geological types of Lantau Island in year 1995, revealing its importance as a landslide governing factor. This finding was largely consistent with the previous studies (So, 1971, 1978a, 1978b; Peng, 1986), especially in the comparison of the number of landslides regarding to solid geology of volcanics and granites (Wong et al, 1998). But difference was noted regarding to landslide locations. As revealed by map work (Figure 5.1), most landslides were located near the "contact zone" between superficial deposits and volcanics, instead of between granites and volcanics as reported by So (1978a) and Peng (1986).

Some studies were done by other researchers on comparing the physical properties and behaviour between weathered volcanic and granitic soil, which might offer explanations for such a contrasted spatial landslide distribution pattern on volcanic (high landslide density) and granitic (low landslide density) areas. It should be noted that the geology studies involved the weathering mantle of different rock types rather than bedrock since it was the former provided landslide materials.

According to the report on the general nature of soils of Hong Kong (Lumb, 1962a), decomposed volcanics have sand and gravel content less than 50% with clay content less than 20%; while decomposed granite has a higher sand and gravel content of 50-80%. Grain size composition can affect the angle of repose of soil, which is defined as "the maximum slope angle at which the material is stable" (Montgomery, 1995). Since weathered granitic soil contains much coarser, angular sandy materials, it can maintain a steeper stable slope angle or higher angle of repose than volcanics (Figure 5.2). This is supported by the findings of Lumb (1965) who found a higher value of angle of shearing resistance with 35° for decomposed granite and lower value of 30° for decomposed volcanics when fully drained. This may provide an explanation for fewer landslides occurring on granites but more on volcanics.

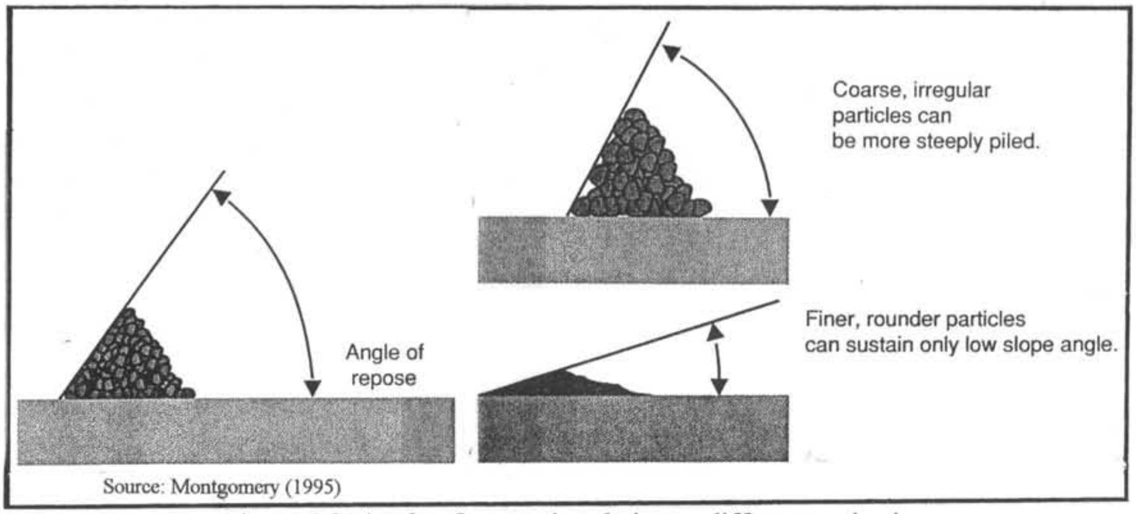


Figure 5.2. Angle of repose in relation to different grain size

Besides, grain size composition can also affect soil response to the degree of saturation. Lumb (1965) reported that the decomposed volcanics (which have a higher clay content) were "extremely sensitive to changes in degree of saturation". This indicates that volcanics may have a higher possibility of landsliding after water infiltration because of this more significant drop in cohesion, which rapidly decreases the shear strength derived from the electro-chemical bonds operating between the fine particles and the surface tension effects of films contained in the pore spaces (Briggs & Smithson, 1995). In addition, pore-water tension in unsaturated volcanics was greater because of its finer grain size (Lumb, 1965). On the other hand, lower landslide density in granite may be explained by its well-jointed structure and coarse grain size. As reported by Lumb (1962a, 1965), decomposed granite were "free-draining" in which the excess pore-water pressure could be dissipated very rapidly, especially in unsaturated soil.

The "significantly large" void ratio of decomposed volcanics than decomposed granite reported by Lumb (1965), may also help explaining the higher landslide density found on volcanics on Lantau Island; since high void ratio will lower the strength of materials (Selby, 1993).

Regarding to the weathering layer, Lumb (1962b) pointed out that an oxidation layer (known as "red soil") developed on granites which caused by the compaction during the iron oxidation process on mica and other dark minerals, was effective to limit the infiltration of rainwater. The red earth layer was relatively impermeable, found at the uppermost zone of weathering granites (Ruxton, 1980). In contrast, effect of oxidation on surface layers in decomposed volcanics was not so significant (Lumb, 1962a). In addition, Irfan (1994) also reported that the presence of sesquioxide minerals in granitic soils gave a "true cohesion" to its soil by coating the surface of individual soil particles to form aggregates, which reduced the ability of clay minerals to absorb water and physically cement adjacent grains. Hence, it was noted that deeper weathering layer (which provided more weakened materials) of granite did not necessarily cause higher number of landslides.

Above all, the geology data alone is insufficient to explain effectively the spatial distribution pattern of landslides of year 1995. Firstly, it was noted that landslide density varied within the same geology type (Figure 5.1). Secondly, higher landslide density found on volcanics might also be caused by its steep relief. On gentle granitic terrain, few landslides were found (Figure 3.2, Figure 5.1). Thirdly, So (1971) reported that volcanics experienced more landslides because it supported a better vegetation cover which had contributed to slope instability. Hence, other factors also played a role in controlling the landslide distribution.

5.4. Limitations

In this research, although correlation between landslides distribution with geology was highly significant, it should be noted that the statistical results on the number of landslides which occurred on the granitic terrain might have been underestimated due to two reasons: (1) Some of these landslides mixed with badlands on granitic terrain were not mapped due to identification problems. (2) Longevity of identifiable landslide scars on granitic terrain was shorter due to higher erodibilty of the granitic soil (GCO, 1989).

CHAPTER 6

DISTRIBUTION OF LANDSLIDES IN RELATION TO SLOPE ANGLE

CHAPTER 6

DISTRIBUTION OF LANDSLIDES IN RELATION TO SLOPE ANGLE

6.1. Slope angle distribution on Lantau Island

Based on the combined and summarised data from North Lantau (GCO, 1988a) and South Lantau (GCO, 1988b) Geotechnical Area Studies Programme (GASP) reports (Table 6.1) (Appendix E), 41.4% (62.12 km^2) of Lantau Island has slope gradient between 15°-30°; 29.9% (44.86 km^2) of land with slope angle of 30°-40°; 16.0% (24.01 km^2) has slope angle of 5°-15°. Low angle slope of 0°-5° consist 8.2 % (12.26 km^2) of the island. Steep terrain with slope angle over 40° consists 4.4% (6.67 km^2) over Lantau Island.

Slope gradient	Areal extent	
	Area (km^2)*	% of specified gradient over Lantau Island
0° -5°	12.26	8.2
5° -15°	24.01	16.0
15° -30°	62.12	41.4
30° -40°	44.86	29.9
> 40°	6.67	4.4
Total	**149.92**	**99.9**

*Source Data combined and summarised from North Lantau (GCO, 1988a) and South Lantau (GCO, 1988b) GASP reports

Table 6.1. Areal extent of different slope angle range over Lantau Island in year 1995

Regarding to the general slope angle distribution (Figure 6.1), the steepest terrain of slope gradient over 40° is found mainly at the highest peaks of Lantau Island, namely Lantau Peak (at central west Lantau) and Sunset Peak (at central east Lantau), Southwest tip of the island, and eastern part of Tung Chung. The lowest slope gradient areas of 0°-5° are usually found at the bay areas of the indented coastline associated with lowlands, such as Tung Chung, Tai O, Pui O and Mui Wo. Low angle slope can also be found inland such as Ngong Ping (Plate 6.1). For other slope gradient ranges, they are widely distributed over the island without specific spatial pattern.

The result revealed the steep hilly relief of the island since 34.3% of the area has slope gradient of more than 30°, where over 75% of the island with slope gradient greater than 15° (Table 6.1). Lowland areas are limited.

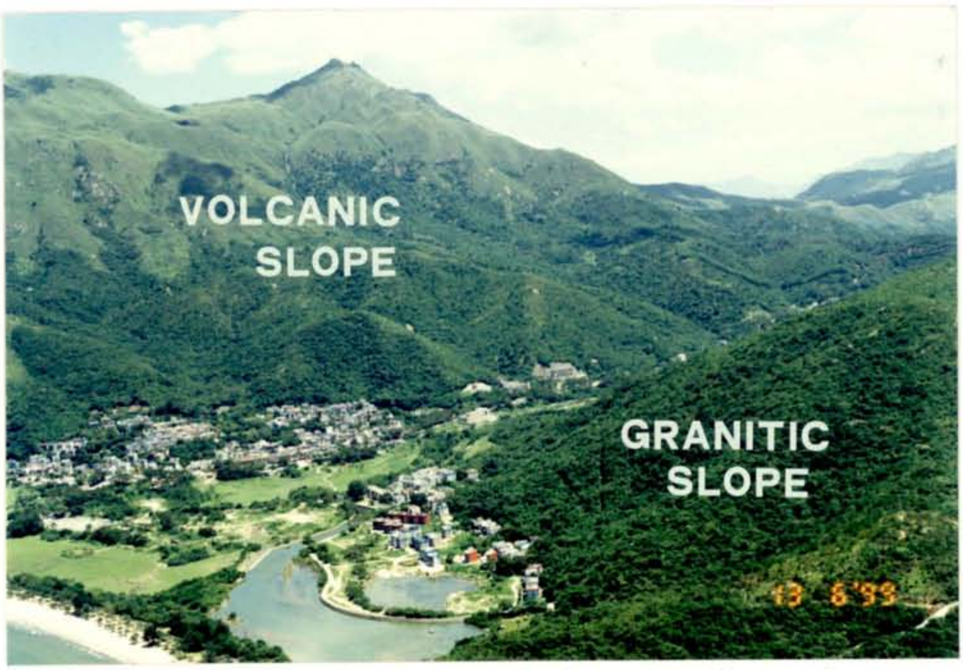
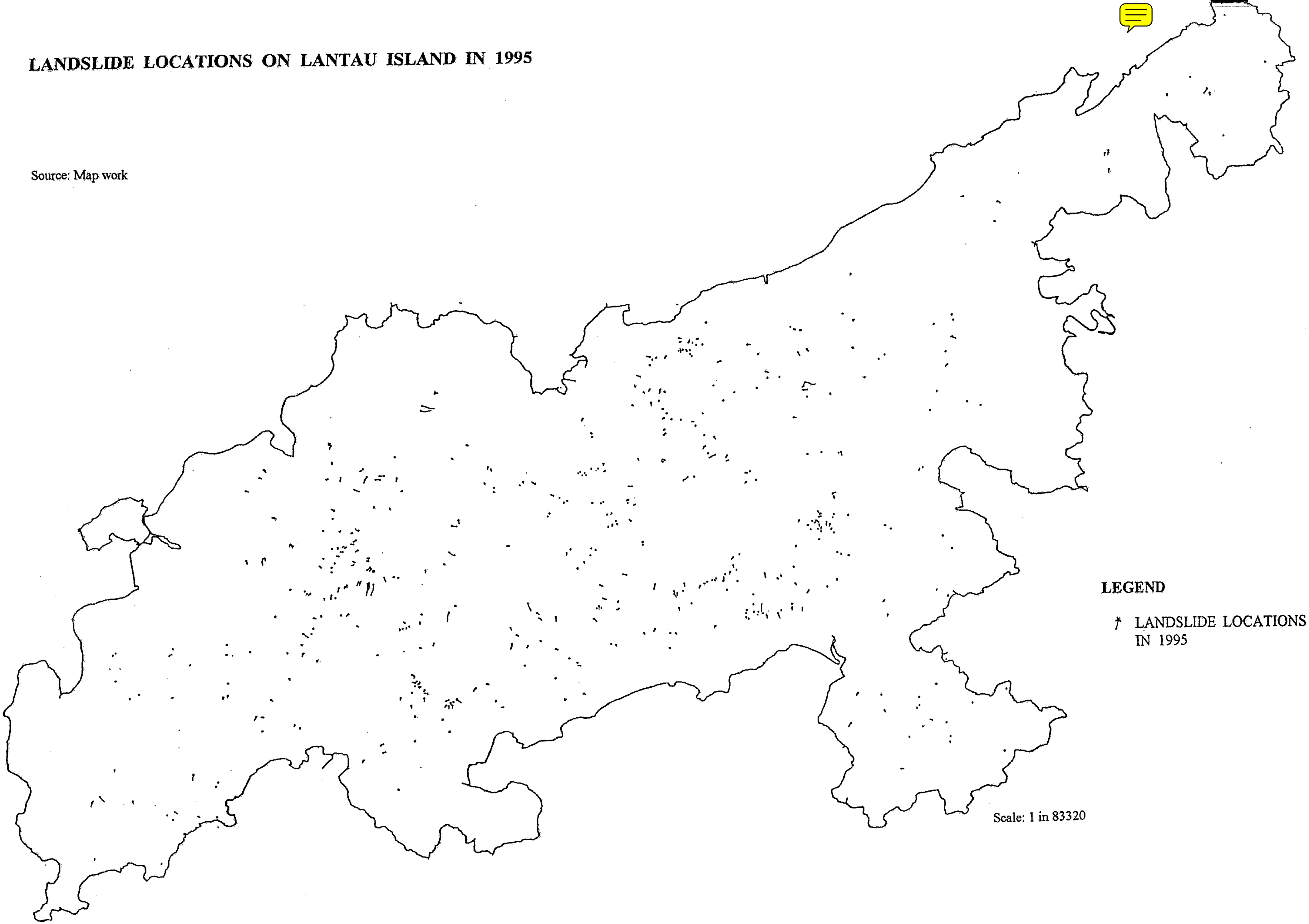


Plate 6.1. Boundary of high-steep volcanic terrain and low-gentle granitic terrain, at Pui O

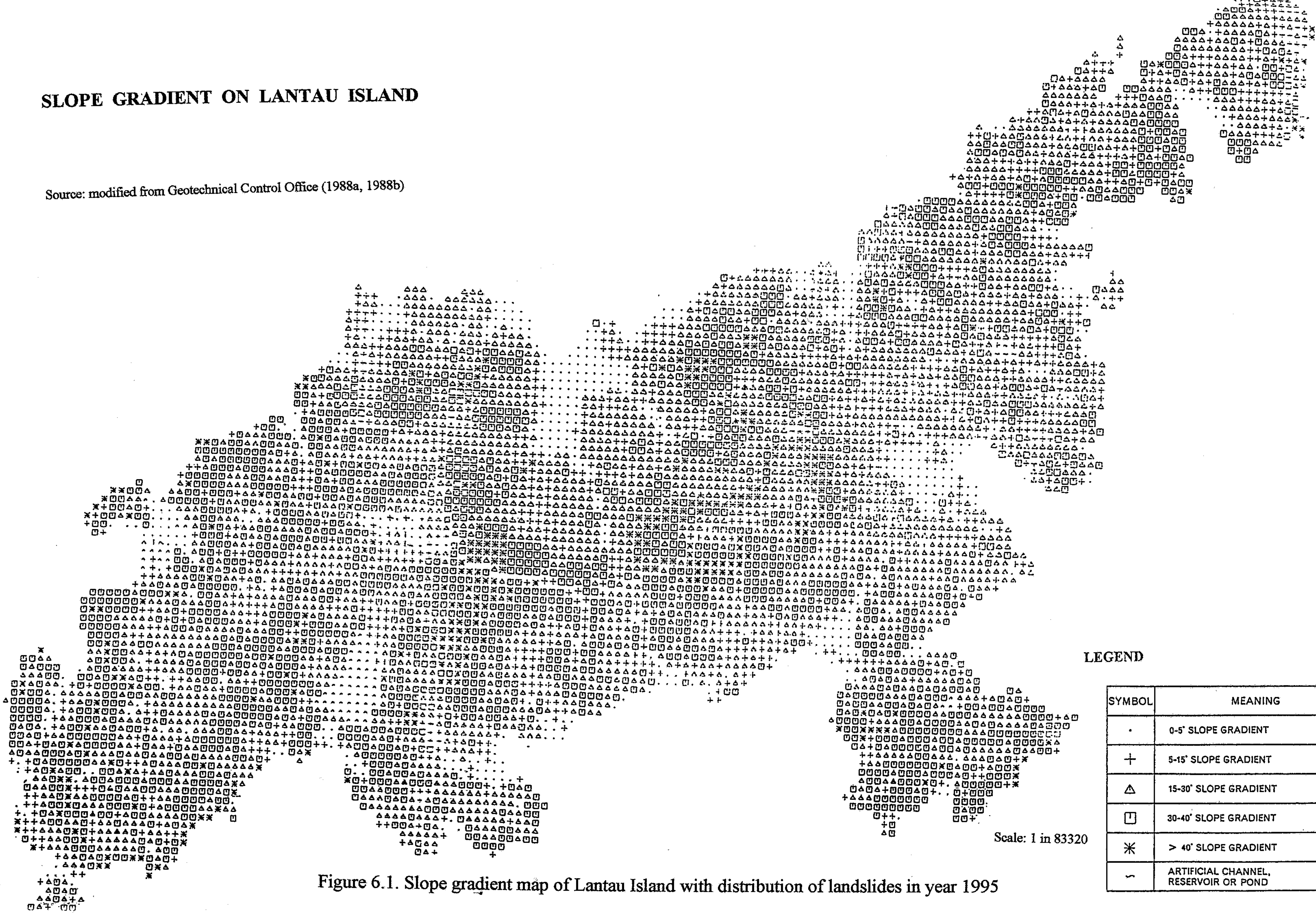
LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1995

Source: Map work



SLOPE GRADIENT ON LANTAU ISLAND

Source: modified from Geotechnical Control Office (1988a, 1988b)



LEGEND

SYMBOL	MEANING
·	0-5° SLOPE GRADIENT
+	5-15° SLOPE GRADIENT
△	15-30° SLOPE GRADIENT
⊡	30-40° SLOPE GRADIENT
✳	> 40° SLOPE GRADIENT
~	ARTIFICIAL CHANNEL, RESERVOIR OR POND

Scale: 1 in 83320

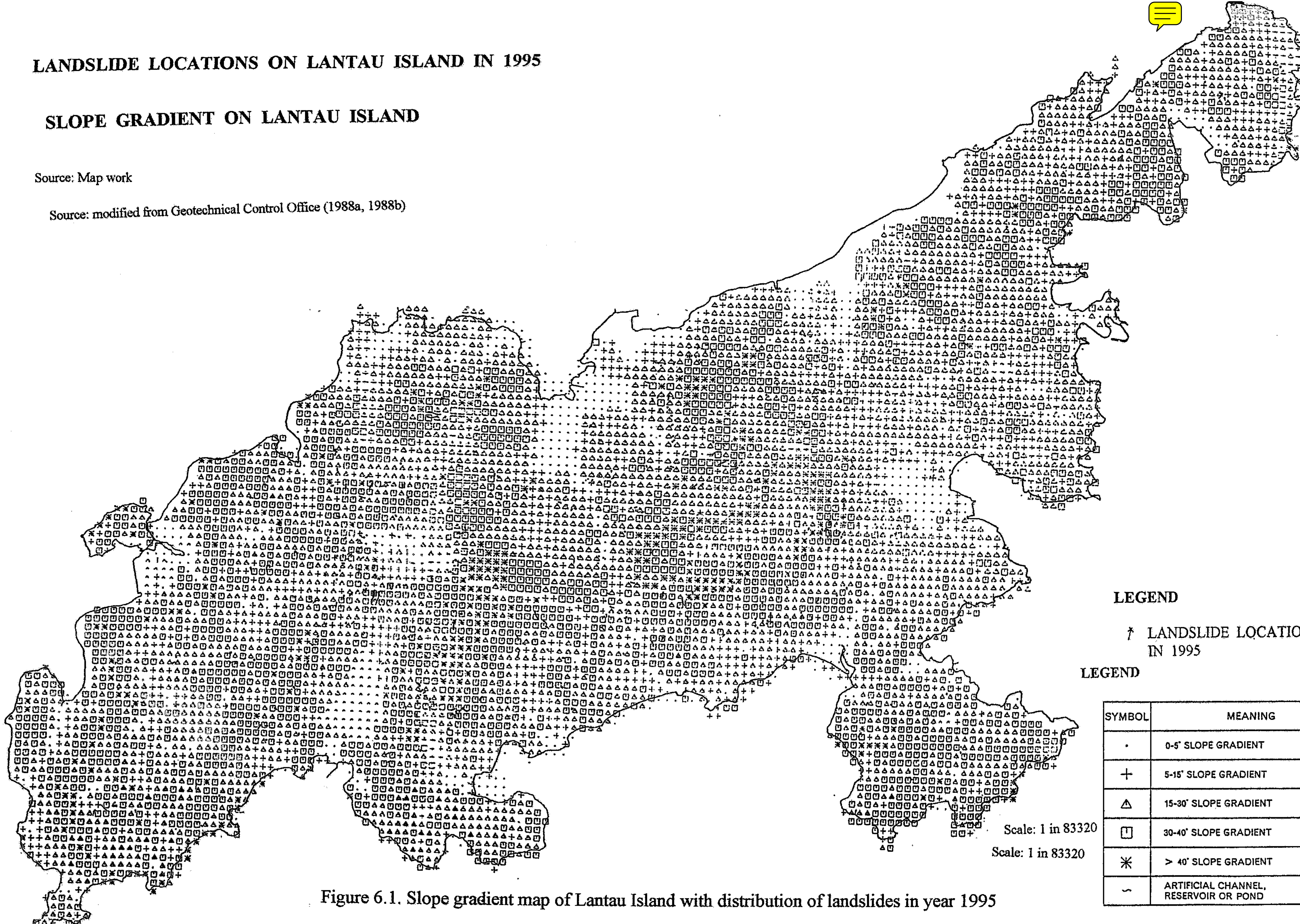
Figure 6.1. Slope gradient map of Lantau Island with distribution of landslides in year 1995

LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1995

SLOPE GRADIENT ON LANTAU ISLAND

Source: Map work

Source: modified from Geotechnical Control Office (1988a, 1988b)



Scale: 1 in 83320

Scale: 1 in 83320

LEGEND

† LANDSLIDE LOCATIONS IN 1995

LEGEND

SYMBOL	MEANING
·	0-5° SLOPE GRADIENT
+	5-15° SLOPE GRADIENT
△	15-30° SLOPE GRADIENT
□	30-40° SLOPE GRADIENT
✳	> 40° SLOPE GRADIENT
~	ARTIFICIAL CHANNEL, RESERVOIR OR POND

Figure 6.1. Slope gradient map of Lantau Island with distribution of landslides in year 1995

6.2. Distribution of landslides on different slope gradient

The spatial distribution of landslide locations over Lantau Island in the year 1995 with respect to different slope gradient range was analysed by statistical methods (calculation details refer to Chapter 3.2.5) and map observations (Figure 6.1). The results are presented as follows:

6.2.1. Statistical analysis

Regarding to 502 landslides identified, 229 landslides (45.6%) occurred on slope gradient between 15°-30°, which was the highest in terms of total number. 211 landslides (42.0%) occurred on slope gradient of 30°-40°. 32 landslides (6.4%) occurred at slope of 5°-15°. 30 landslides (6.0%) occurred on steep slopes over 40°. No landslide found at 0°-5°. It was noted that 87.6% landslides on Lantau Island occurred at moderate slopes with angles between 15°-40° (Table 6.2). The results also showed an increasing number of landslides with increasing slope gradient from 0°-5° to 15°-30° but a decrease from 30° onwards.

However, the results of landslide density (no. of landslides/ km^2) (Table 6.2) showed that slope gradient of 30°-40° experienced highest number of landslides per square kilometre, which was, 4.7 landslides/km^2. LQ was also the highest, at 1.40. High landslide density of 4.5 landslides/km^2 with LQ = 1.36 also found at slopes of more than 40°. On slopes with gradient between 15°-30°, 3.69 landslides/km^2 was found (LQ = 1.10). Gentle slope between 5°-15° had a much lower landslide density of (1.33 landslides/km^2) (LQ = 0.40). Landslide density of slope between 0°-5° was zero because no landslide occurred at that low angle slope. It was noted that the value of landslide density and location quotient showed a general increase from 0°-5° to 30°-40°, with a significant increase starting at slope gradient range of 15°-30° but dropped at slope gradient range over 40°. Moreover, their rate of increase dropped with increasing slope gradient (from slope gradient range of 15°-30° to over 40°) (Table 6.2).

Slope gradient	**Areal extent**		**Landslides occurrence (year 1995)**		**Landslide density (no. of landslides / km^2)**	**Location Quotient**
	Area (km^2)*	**% of specified gradient on Lantau Island**	**No. of landslides**	**% of landslides on specified gradient**		
0°-5°	12.26	8.2	0	0.0	0.00	0.00
5°-15°	24.01	16.0	32	6.4	1.33	0.40
15°-30°	62.12	41.4	229	45.6	3.69	1.10
30°-40°	44.86	29.9	211	42.0	4.70	1.40
> 40°	6.67	4.4	30	6.0	4.50	1.36
Total	**149.92**	**99.9**	**502**	**100.0**		

*Source Data combined and summarised from North Lantau (GCO, 1988a) and South Lantau (GCO, 1988b) GASP reports

Table 6.2. Landslide distribution on different slope gradient in year 1995

6.2.2. Map observation analysis

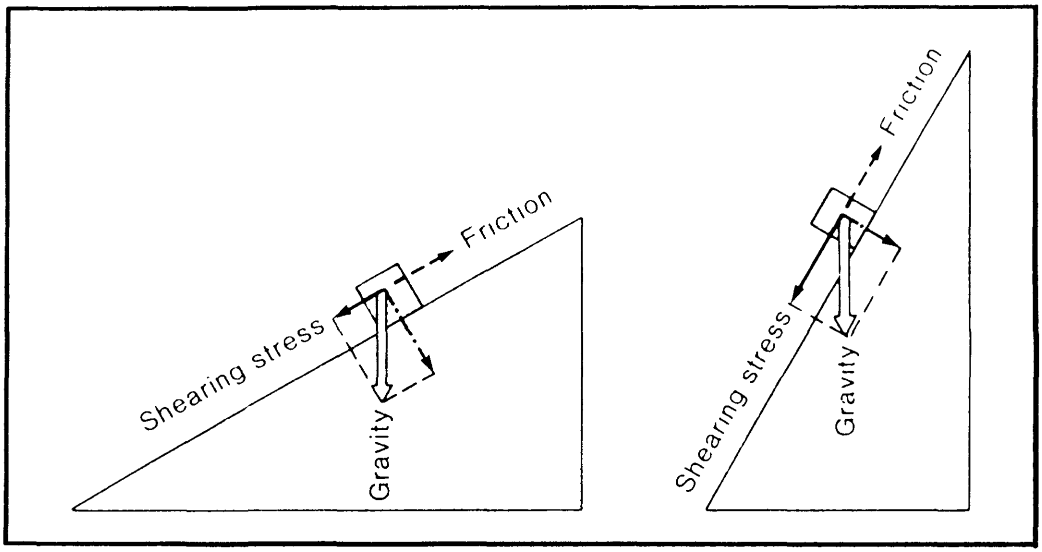
Landslides were not evenly distributed on different slope gradient range (Figure 6.1). Most of the landslides took place at slope gradient between 15°-40°. Only small number of landslides occurred at slope gradient of 5°-15° or over 40°. No landslide found at 0°-5°. Change in landslide density was obvious at Tung Chung (North Lantau), Pui O and Ngong Ping (Central west Lantau), where high landslide density at the gradient range of 15°-30° but no landslide found at slope angle 0°-5° (Figure 6.1).

Hence, the clustered and dispersed landslide distribution pattern showed correlation with the slope gradient distribution pattern, because the landslide distribution pattern responded to the slope gradient changes. But the response to gradient change was rather less significant between 15°-30° and 30°-40° slopes, as shown by similar landslide density within 15°-40°.

6.3. Relations between slope angle and landslide occurrence

The results revealed a high correlation between landslide occurrence and slope gradient range of Lantau Island, though the changes in landslide density among slope gradient ranges was relatively less significant (as reflected by LQ) in compare with the different geology types. Nevertheless, the results on the landslide frequency with different ranges of slope gradient was similar to the previous studies (GCO, 1988a) (Wong et al, 1998), in which the highest landslide frequency in this study was also found at the slope gradient range of 30°-40° with a same decreasing order in terms of landslide density and Area Instability Index (AII) among the other slope angle ranges.

Slope gradient did contribute as one of the controlling factors to the landslide distribution of Lantau Island in the year 1995. As reflected by the results (Table 6.2), landslides increase (both in number and in density) with slope gradients from 0°-5° to 15°-30°. It was because higher-angle slopes imposed a greater shearing stress which caused downward movement of slope materials (Figure 6.2).



Source: Montgomery (1995)

Figure 6.2. Effects of slope geometry on slide potential. Note the greater shearing stress on the steeper slope

However, the above positive relationship between slope gradient and slope instability failed to explain the decreased total number of landslides at slope gradients 30°-40° and over 40°; and the decreased landslide density from slope gradient over 40° (Table 6.2), since they revealed the opposite phenomenon (i.e. steeper slopes with fewer landslides). Besides, it was doubtful whether the slope gradient alone could fully explain the significant increase of the total number of landslides and landslide density found at slope gradient between 15°-40° (Table 6.2).

Nevertheless, the reason for such an uneven distribution of landslides on different slope gradients was suggested by Wong et al (1998), whose explanation combined the slope gradient with the geology factor.

Lower landslide propensity for steep slopes over 40° was probably caused by the presence of stronger soil or less-weathered rock (Wong et al, 1998). In addition, most slope materials, which provided the "material source" for landslides, could not accumulate thick on steep slopes over 40°.

High landslide propensity revealed by the highest landslide density at moderate steep slope gradient of 30°-40° could be explained by the findings of Lumb (1962b, 1965). Slope gradient range of 30°-40° was most likely to occur landslides as these slopes angles were greater than the maximum frictional angle of the volcanic and granitic slope materials. Also, slope gradient range of 30°-40° had a thicker layer of less stable colluvium (loose unconsolidated material) which probably caused the highest landslide propensity (Wong et al, 1998).

This significant increase of landslide number and density from slope gradient range 5°-15° to 15°-30° may probably caused by the increase of slope gradient (increasing shear stress) as well as geology. Volcanics, which was more vulnerable to landslides (details refer to Chapter 5), occupied higher slope gradients than granite on Lantau Island. But this was not detailly investigated due to the general nature of this study.

6.4. Limitations

It should be noted that the statistical results might have been affected by the 5 predetermined slope gradient classes in which its class intervals were different. For example, at the class of 0°-5°, the range of value was 5°; but at class of 5°-15°, the range of value was 10°.

CHAPTER 7

DISTRIBUTION OF LANDSLIDES IN RELATION TO VEGETATION

CHAPTER 7

DISTRIBUTION OF LANDSLIDES IN RELATION TO VEGETATION

7.1. Woodland distribution on Lantau Island

Based on the areal data calculated by counting square units (refer to Chapter 3.2.5b), out of 41788 square units of Lantau Island, woodland consisted of 6165 square units (14.8%), while non-woodland areas (including grassland and undeveloped areas) consisted of the remaining 35623 square units (85.2%) (Table 7.1).

Vegetation type	**% over Lantau Island**	
	Area (in sq. units)*	**% over Lantau Island**
Woodland #	6165	14.8
Non-woodland	35623	85.2
Total	41788	100.0

*Source map work
#Woodland is defined by legend of Lantau Island topographic map (Survey & Mapping Office, 1996)

Table 7.1. Areal extent of woodlands over Lantau Island

The spatial distribution of woodland over the island was not evenly distributed (Figure 7.1). Woodland was mainly found at Nam Shan and extensively covered Chi Ma Wan Peninsula (Southeast Lantau). Large woodland coverage was also found around Shek Pik Reservoir (Plate 7.1). They were mainly the result of the government's reafforestation programmes since the 1950s, particularly during the 1960s and 1970s, for environmental conservation and preservation (Catt, 1986). As reported by GCO (1988a, 1988b), the natural vegetation of Lantau Island was largely modified by man.

Plate 7.1. Luxuriant woodlands around Shek Pik Reservoir due to afforestation, for protecting water catchment

Scattered vegetation pattern was shown in the Northern part (west of Tung Chung) and Northeast part of the island. By map (Survey & Mapping Office, 1996) and field observation (Plate 7.2, 7.3), it was noted that woodlands were usually most intensive at the lower and middle slopes of river drainage basin, extending "narrowly" to the upper slope near ridgecrest.

Plate 7.2. Woodland distribution pattern at low and mid-slopes, Pui O

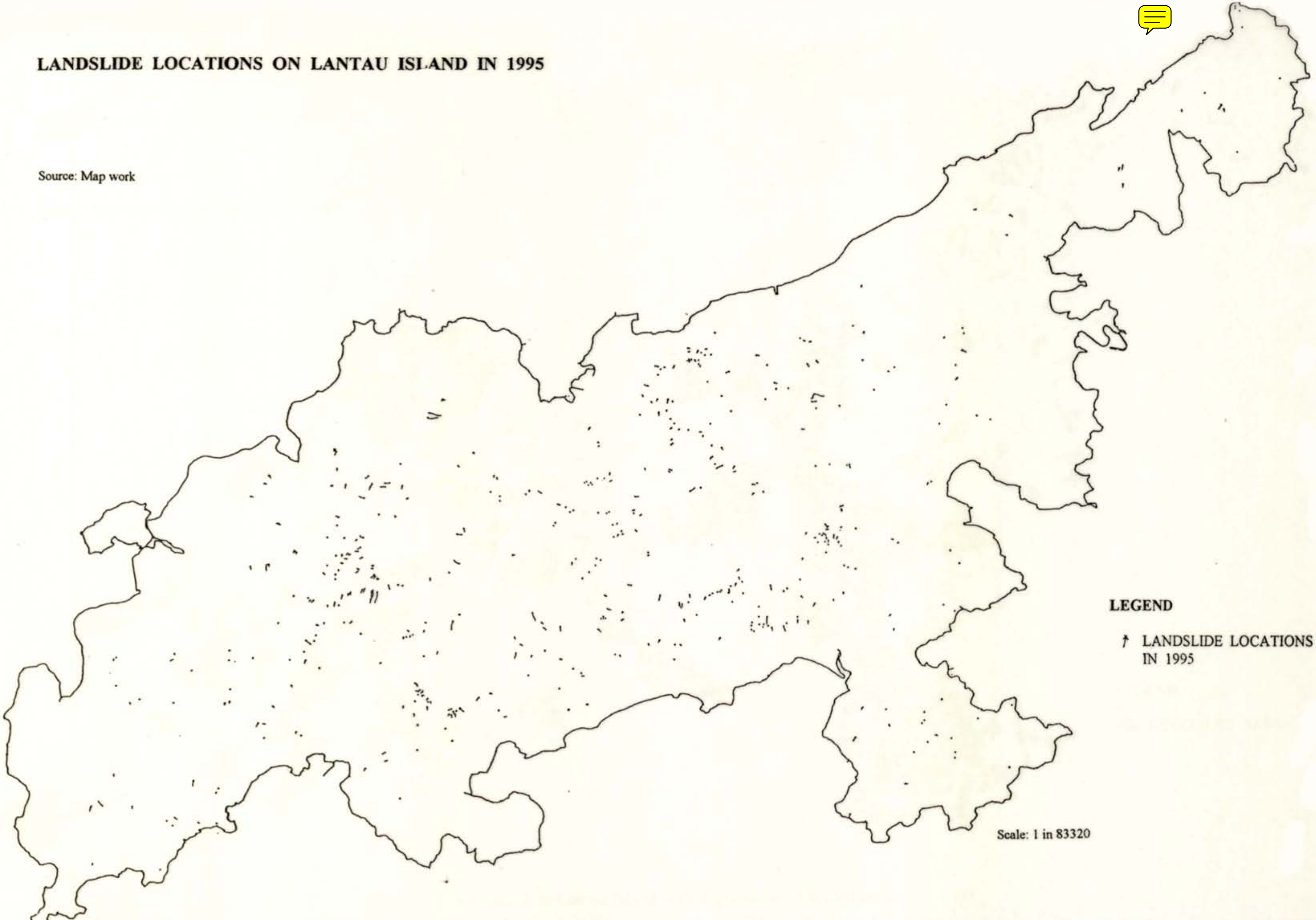
Plate 7.3. Woodlands follow drainage lines stretching upslope, Lin Fa Shan

Non-woodland areas (85.2 % of Lantau) were mainly grasslands (observed from air photos of 1995 and during field visits) (Plate 7.4), usually found at the higher slopes and crest slopes. This was caused by the clearing of shrub and woodland by hillfires and strong prevailing winds (GCO, 1988b).

Plate 7.4. Most of Lantau Island is covered by grassland
(photo taken at Ngong Ping)

LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1995

Source: Map work



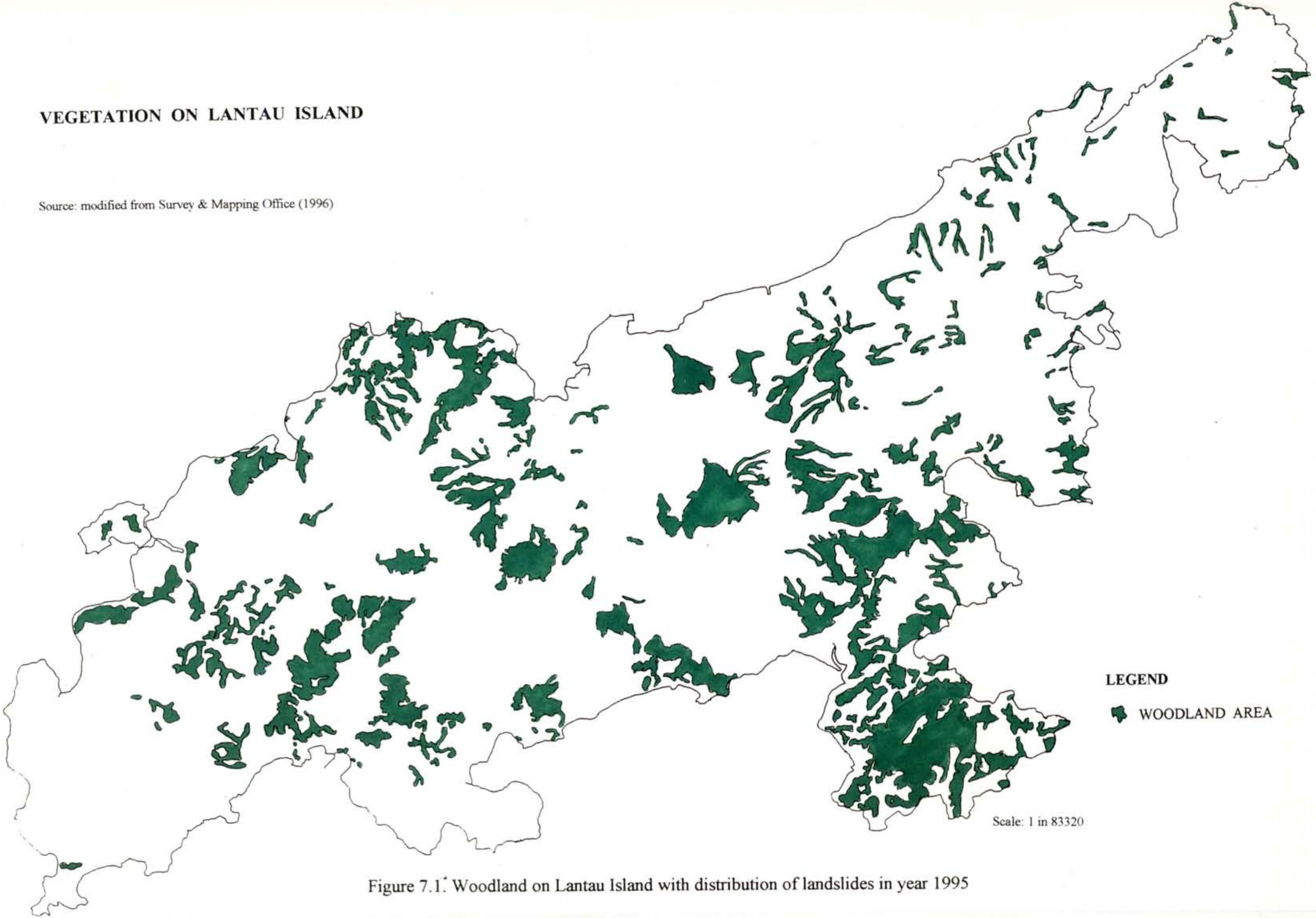


Figure 7.1.* Woodland on Lantau Island with distribution of landslides in year 1995

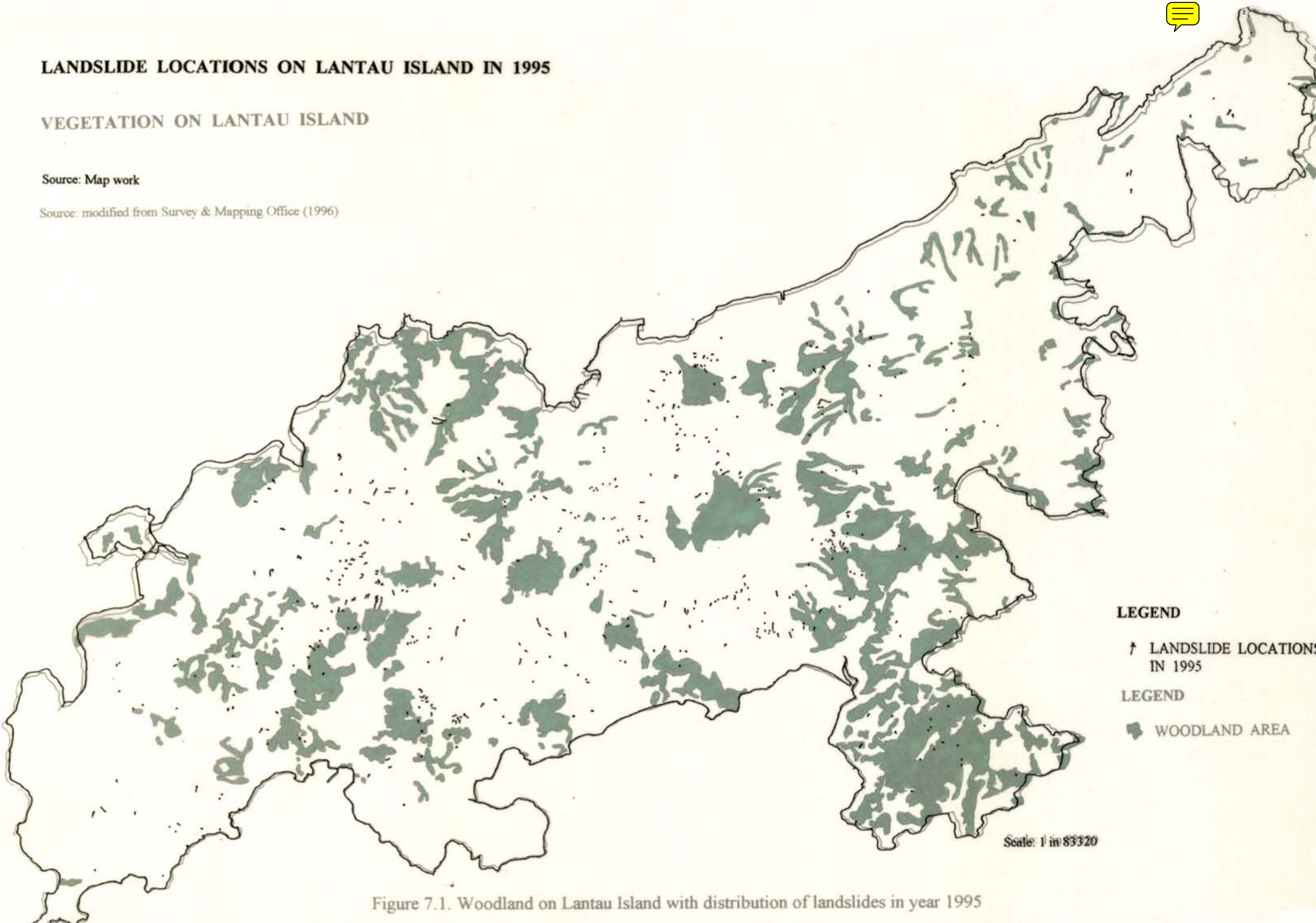


Figure 7.1. Woodland on Lantau Island with distribution of landslides in year 1995

7.2. Distribution of landslides on woodland and non-woodland areas

The spatial distribution of landslide locations over Lantau Island in the year 1995 with respect to vegetation (woodlands) was analysed by statistical methods (calculation details refer to Chapter 3.2.5) and map observation (Figure 7.1) (Survey & Mapping Office, 1996). The results are presented as follows:

7.2.1. Statistical analysis

Regarding ~~to~~ the 502 landslides identified, 421 landslides (83.9%) occurred on non-woodland areas. Only 81 landslides (16.1%) occurred on woodland area. In absolute value, without considering landslide density, landslide number occurred on non-woodland area was 5 times more than in woodland area. But this result was biased, because of the small woodland coverage over the island. (Table 7.2)

Vegetation Type	**Areal extent**		**Landslides occurrence (year 1995)**		**Location Quotient**
	Area (in sq. units)*	**% over Lantau Island**	**No. of landslides**	**% of landslides**	
Woodland	6165	14.8	81	16.1	1.09
Non-woodland	35623	85.2	421	83.9	0.98
Total	**41788**	**100.0**	**502**	**100.0**	

*Source map work
#Woodland is defined by legend of Lantau Island topographic map (Survey & Mapping Office, 1996)

Table 7.2. Landslide distribution on woodland and non-woodland areas in year 1995

Revealed by the result of the location quotient, woodland had a slightly higher landslide concentration value (LQ = 1.09) when compared with non-woodland area (LQ

= 0.98). This indicated that landslide occurrence had a slight tendency to concentrate on woodland areas. It was noted that 16.1% landslides occurred over the island took place at woodland area, which consisted 14.8% of Lantau Island. However, as the LQ of woodland and non-woodland areas (Plate 7.5, 7.6) was approximately near the value of 1, this indicated that the distribution of landslide on woodland and non-woodland areas was in equal proportion with their areal extent. In short, landslide distribution had insignificant relationship with woodland.

Plate 7.5. Landslides occurred on grassland upslope and woodland areas at foothill of Lantau Peak

Plate 7.6. Landslide at shrubland under revegetation, the biggest landslide found beside Tung Chung Road

7.2.2. Map observation analysis

The spatial distribution pattern of landslides seemed randomly distributed on woodland area or simply did not follow the changes (existence or non-existence) of woodland distribution (Figure 7.1).

Some woodland areas such as those at North Lantau and Northeast Lantau occurred isolatedly or even without landslides. But relatively high landslide density found at the woodlands on Chi Ma Wan Peninsula. At Shek Pik and west of Mui Wo, landslides with similar density occurred at the "edges" of woodland areas, only about 50% landslides (in per unit area) occurred at woodlands. Nevertheless, large number of landslides were mainly located on the natural grass hillslopes of the island (noted by aerial photo interpretation).

7.3. Relations between woodland and landslide occurrence

The data drawn in this research was different from So (1971) concerning the correlation between landslide distribution with vegetation (woodland). Regarding ~~to~~ this research, only 16.1% of landslides occurred on woodland, which covered 14.8% of Lantau Island, reflected by a slight concentration value of LQ = 1.09 (Table 7.2). In contrast, high significant relationship between landslides and woodland was reported by So (1971) in which 34.8% landslides occurred in the 8.4% woodland coverage of Hong Kong Island. The relative concentration value (LQ) was much higher at 4.14. Nevertheless, both So (1971) and this study found that landslides occurred at areas both with and without vegetation cover. However, based on statistical and map observation analyses, landslides on Lantau Island did not have a strong preferred location in woodland areas, but were rather randomly distributed. Landslide density (reflected by LQ) on woodland and non-woodland areas were similar. Hence, the role played by woodland on Lantau in relation to landslides was not so significant.

The "evenly" distribution of landslides on woodlands and non-woodland areas (Table 7.2) might be the result of the combined positive and negative effects of vegetation on slope stability.

Positive effects of vegetation on slope stability by increasing soil strength are mainly asserted by its root reinforcement and soil moisture modification. The root system of plants increases soil shear strength by binding the unconsolidated soil or materials together, which enhances slope stability and reduces shallow slope failures (Carson &

Kirkby, 1972). Besides, the interlocking root networks provide an apparent cohesion to the soil (Selby, 1993).

In addition, vegetation can increase soil shear strength by reducing soil moisture content of slope materials and decreases shear stress by lowering the water table through interception of rainfall by leaves and transpiration processes through its roots. Soil suction can be created (Lee, 1985; Selby, 1993). The drier soil condition promoted by vegetation can delay or minimise soil saturation which can ultimately improve slope stability and increase tolerance to rainstorm (Lee, 1985).

However, vegetation can also have destabilising effect on slopes. Firstly, vegetation, especially trees, can transmit wind drag force from wind vibrations (known as the "wind throwing" effect) through its stem and root system to disturb the soil. This mechanism is most effective in strong winds and is most noticeable on steep slopes (Lee, 1985; Crozier, 1986; Selby, 1993). Secondly, vegetation (especially trees) can increase shear stress by adding weight to the slope, particularly on steep slope of over 30° with thick soil (Lee, 1985). Thirdly, trees or well-developed vegetation cover promote rapid infiltration which may adversely affect slope stability (GCO, 1988a, 1988b; Styles & Hansen, 1989) as they promote higher water table and positive pore-water pressure.

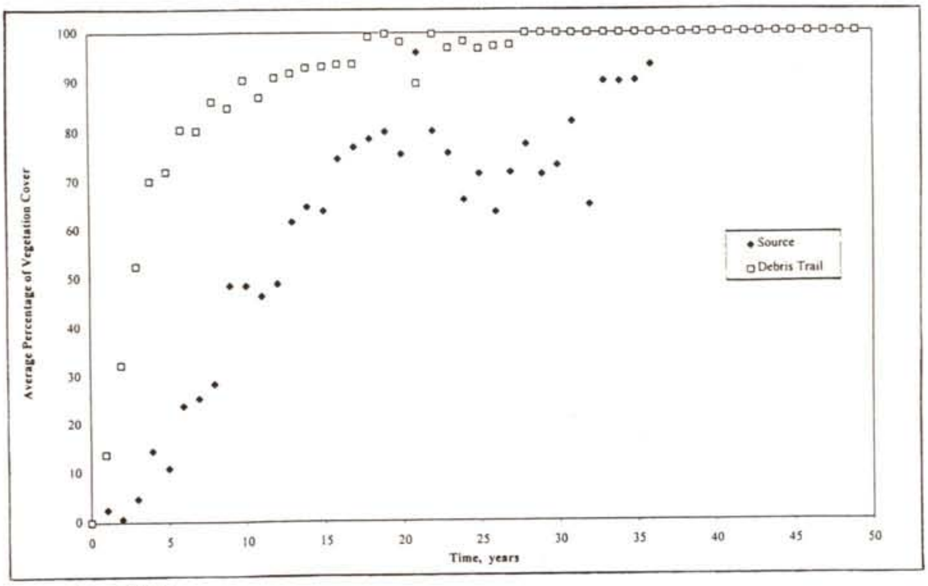
Nevertheless, the slight difference of landslide density (reflected by LQ) could be explained by considering the soil cover (Zhang, personal communication). Woodland areas indicated a thicker soil cover (thick soil is needed to support luxuriant tree cover), which might increase landslide potential by providing more unconsolidated slope materials. In contrast, lower landslide density at non-woodland areas such as grassland

and rock surfaces would be relatively more stable because of less soil cover. Bedrock outcrops, which were also included in the "non-woodland" category because of bare vegetation cover, caused the lower landslide density because no landslide (which involved loosen soil) would probably occur.

Above all, the vegetation factor was inadequate to explain the landslide distribution on Lantau Island in 1995 because of the insignificant relationship revealed in controlling the landslide occurrence.

7.4. Limitations

It should be noted that landslides occurred on woodland areas might have been underestimated during the aerial photo interpretation process of this study, due to the thick luxuriant woodland cover in parts of Lantau Island. In addition, because of the slow revegetation rate on natural slope landslides (King, 1999) (Figure 7.2) (Plate 7.7), landslides occurred 5 or up to 23 years ago might have been appeared on the landslide location map of year 1995. As reported by King (1999), "landslides trail needs 5-8 years to be recovered by vegetation, while landslide head and crown need 10-15 years longer". The research results would be greatly affected if there was significant change of woodland areal coverage in the past 20 years, which could not be detected from the woodland coverage map of year 1995.



Source: King (1999)

Figure 7.2. Revegetation rate of landslide scars

Plate 7.7. Landslide scar under revegetation on a steep slope beside Tung Chung Road

Due to unavailable data on the coverage of other vegetation types on Lantau Island of year 1995, only woodlands (defined by Survey & Mapping Office, 1996) were mapped and analysed in this study.

CHAPTER 8

DISTRIBUTION OF LANDSLIDES IN RELATION TO ANNUAL RAINFALL

CHAPTER 8

DISTRIBUTION OF LANDSLIDES IN RELATION TO ANNUAL RAINFALL

8.1. Annual rainfall distribution on Lantau Island of year 1995

Based on the areal data calculated by counting square units (refer to Chapter 3.2.5), out of 41788 square units of Lantau Island, 23682 square unit area (56.7%) experienced annual rainfall of 2200-2400 millimetres (mm) in 1995. 10931 square unit area (26.2%) recorded 2000-2200mm of rainfall. 7175 square unit area (17.2%) received over 2400mm. (Table 8.1)

Annual Rainfall # (in mm)	**Areal Extent**	
	Area (in square units)*	**% of specified rainfall over Lantau Island**
2000-2200mm	10931	26.2
2200-2400mm	23682	56.7
> 2400mm	7175	17.2
Total	**41788**	**29.9**

Data source HK Royal Observatory (1995)
* Source Map work

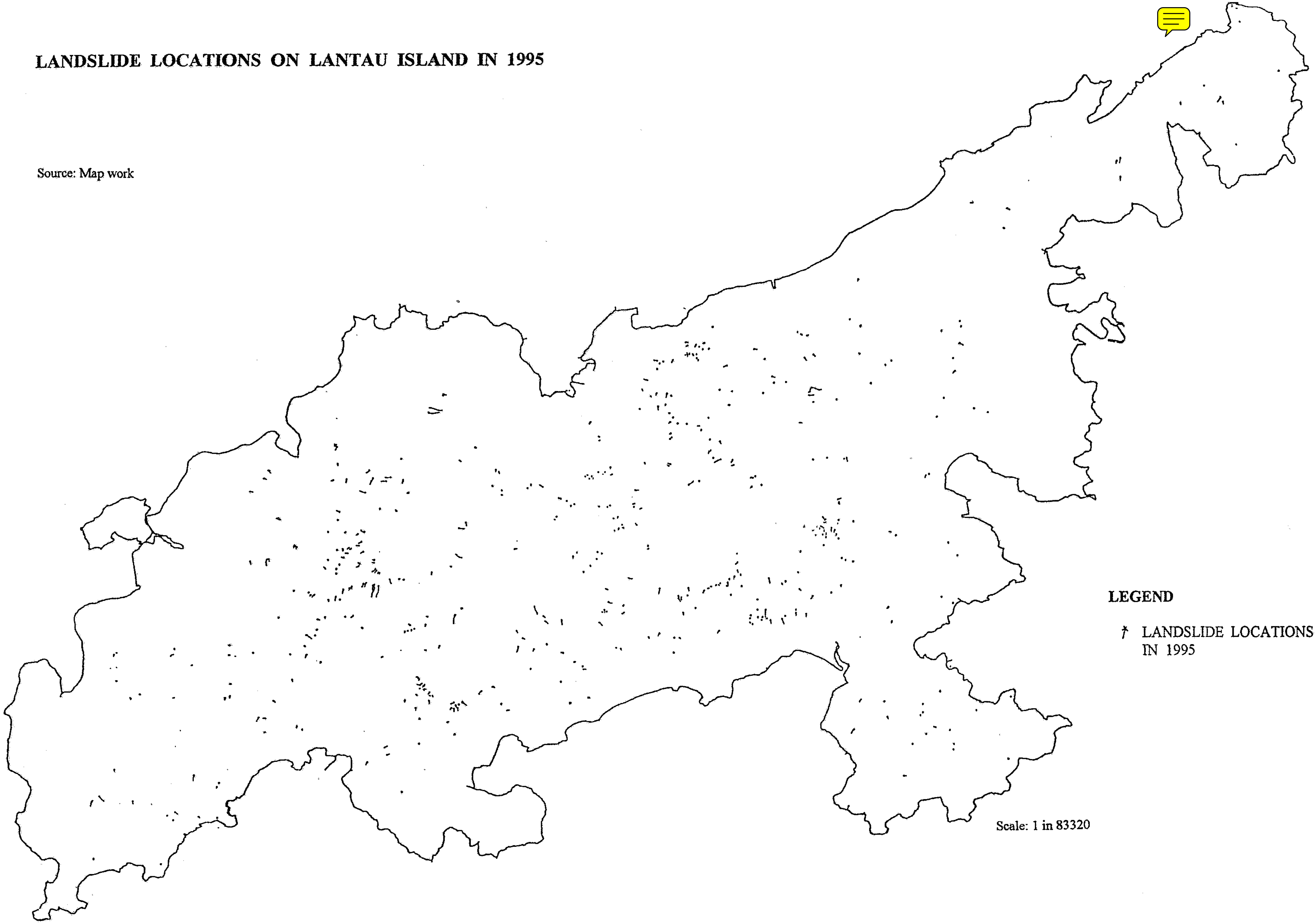
Table 8.1. Areal extent of rainfall distribution over Lantau Island in year 1995

The spatial distribution of annual rainfall over the island was not evenly distributed (Figure 8.1). The highest annual rainfall was concentrated at the central part of the island in a limited areal extent. Most of the island, except the Northeast and the Southwest parts, received the "medium" range of rainfall of 2200-2400mm. The rest of the island had 2000-2200mm rainfall over the year 1995. It was noted that the rainfall distribution pattern over Lantau had a characteristic --- radiating outwards from the centre of the island, probably caused by relief (Figure 3.2).

According to the Hong Kong Royal Observatory (1995) (renamed Hong Kong Observatory after July 1997), the annual rainfall record in 1995 at the Observatory was 2754.4 millimetres, which was 24 % above the annual mean.

LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1995

Source: Map work



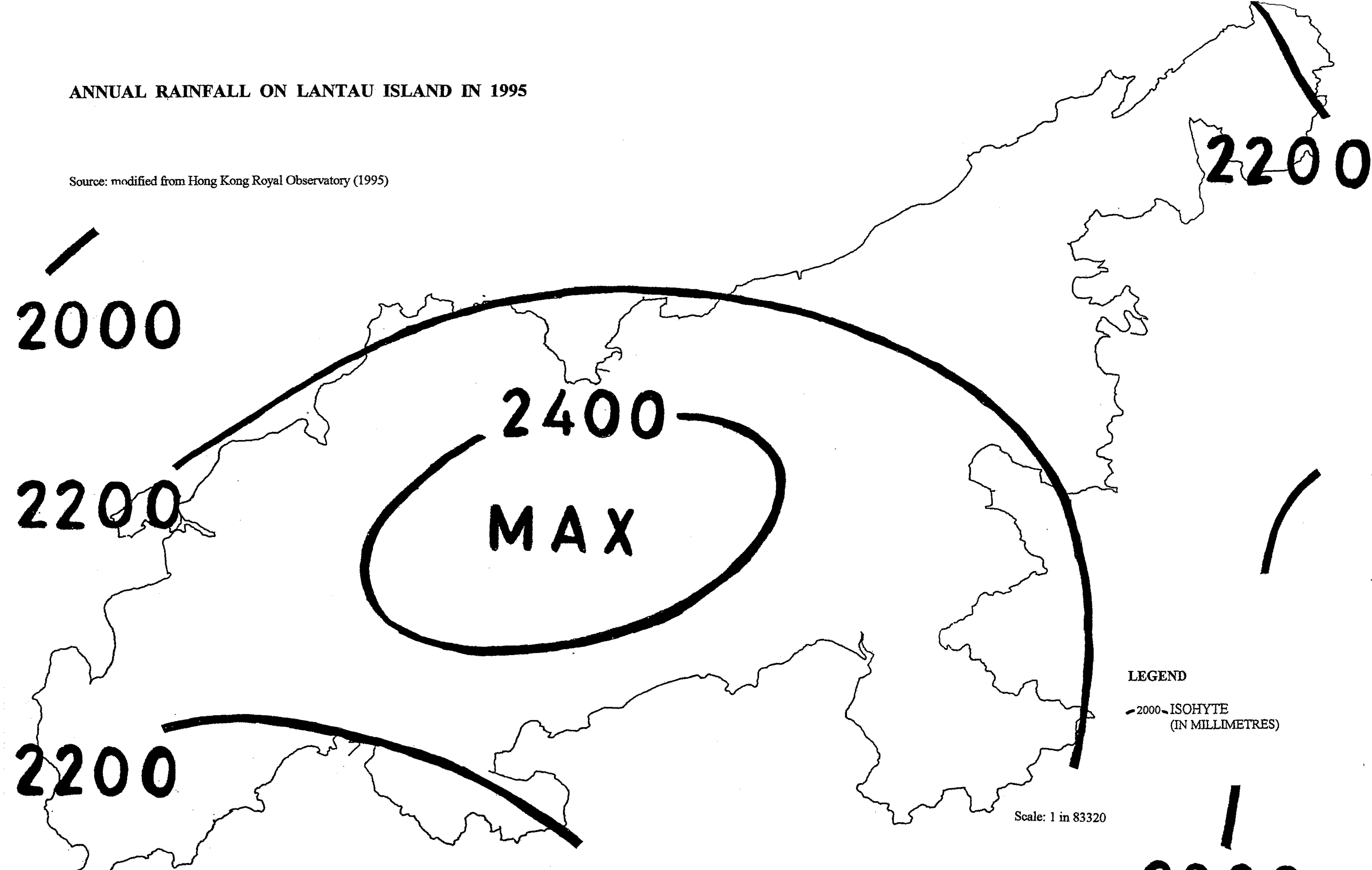


Figure 8.1. Annual rainfall map of Lantau Island with distribution of landslides in year 1995

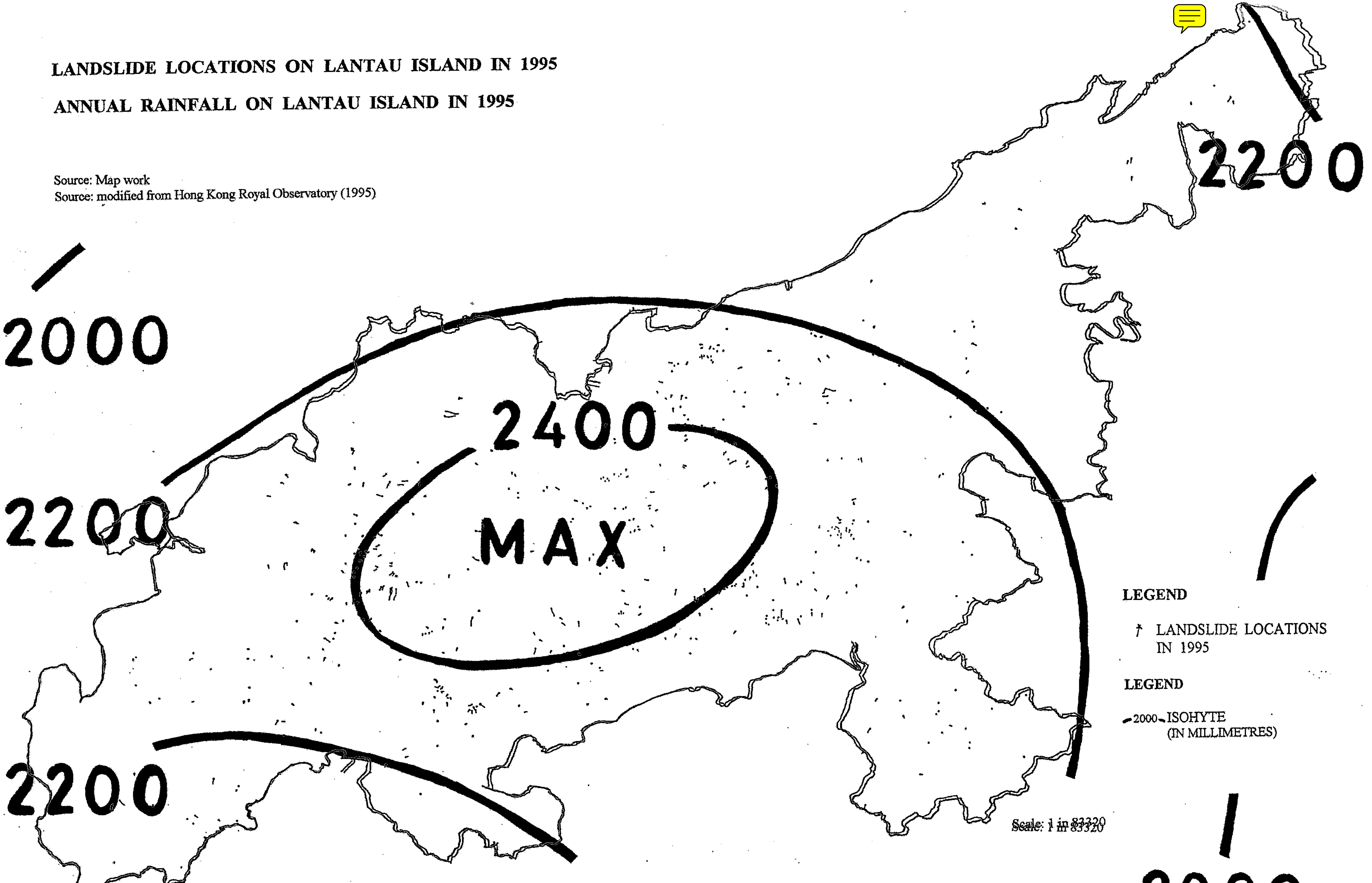


Figure 8.1. Annual rainfall map of Lantau Island with distribution of landslides in year 1995

8.2. Distribution of landslides on different rainfall range

The spatial distribution of landslides locations over Lantau Island in the year 1995 with respect to annual rainfall was analysed by statistical methods (calculation details refer to Chapter 3.2.5) and map observation (Figure 8.1). The results are as follows:

8.2.1. Statistical analysis

Regarding ~~to~~ the 502 landslides identified, 298 landslides (59.4%) occurred at annual rainfall range of 2200-2400mm. 164 landslides (32.7%) located ~~where~~ experienced the highest annual rainfall of over 2400mm. The remaining 40 landslides (8.0%) were found at annual rainfall range of 2000-2200mm. (Table 8.2)

Annual Rainfall (in mm)#	**Areal extent**		**Landslides occurrence (year 1995)**		**Location Quotient**
	Area (in sq. units)*	**% of specified rainfall over Lantau Island**	**No. of landslides**	**% of landslides on specified rainfall**	
2000-2200mm	10931	26.2	40	8.0	0.31
2200-2400mm	23682	56.7	298	59.4	1.05
> 2400mm	7175	17.2	164	32.7	1.90
Total	**41788**	**29.9**	**502**	**100.1**	

Source Hong Kong Royal Observatory (1995)
* Source Map work

Table 8.2. Landslide distribution on different annual rainfall range in year 1995

Revealed by the result of the location quotient, highest landslide density was found ~~at~~ in areas with annual rainfall over 2400mm (LQ = 1.90). 32.7% landslides of Lantau Island concentrated in just 17.2% of area which received the greatest amount of rainfall, nearly two times. Although highest number of landslides occurred at rainfall range between 2200-2400mm, LQ of 1.05 reflected that its landslide distribution was rather proportional within that rainfall areal extent. Lowest landslide density was found at 2000-2200mm rainfall range. Only 8% of landslides occurred within this 26.2% of relatively low annual rainfall range (2000-2200mm), resulted in low LQ value of 0.31.

The increasing (or decreasing) LQ with increasing (or decreasing) amount of annual rainfall revealed that the landslide distribution had correlation with the annual rainfall distribution pattern. Landslide density corresponded (with positive relationships) to changes of the annual rainfall, especially significant between rainfall range of 2000-2200mm and 2200-2400mm. However, the rate of increase in LQ dropped with increasing annual rainfall amount.

8.2.2. Map observation analysis

The spatial distribution pattern of landslides over Lantau was unevenly distributed (Figure 8.1). There was a marked difference in landslide density at the rainfall range between 2000-2200mm (Northwest Lantau) and those above 2200mm (in the centre and western part of Lantau). However, landslide density was rather similar in annual rainfall range between 2200-2400mm and above 2400mm. Nevertheless, landslide density on the island correlated rather closely with the isohyets.

8.3. Relations between rainfall distribution and landslide occurrence

The geographical distribution of landslides (Figure 8.1) and the statistics (Table 8.2) revealed a significant positive rainfall-landslide correlation. Annual rainfall isohyets coincided well with landslide density. Wong (1997) also had similar findings on rainfall-landslide relationship of the year 1995. It was reported that "geographical distribution of rainfall had a considerable influence on the occurrence of landslides". Hence, annual rainfall distribution contributed in controlling landslide occurrence. Rainfall increased slope instability by increasing shear stress through adding weight and decreasing soil shear strength through eliminating soil cohesion and increasing pore water pressure (Plummer & McGeary, 1993; Selby, 1993; Montgomery, 1995).

Nevertheless, the importance of rainfall distribution on landslide occurrence should not be over-exaggerated because the annual rainfall could only partially explain the distribution pattern of landslides. Firstly, it was doubtful whether an increase of 200 millimetres of annual rainfall could fully explain the significant rise in landslide density (from LQ = 0.31 to LQ = 1.05). Secondly, the rate of increase in landslide density dropped with increasing annual rainfall from 2200-2400mm (LQ = 1.05) to over 2400mm (LQ = 1.90).

The topography combined with geology of Lantau Island might help explaining the changing rate of increase of landslide density in different annual rainfall ranges. It was noted that the topography of Lantau Island (Figure 3.2) also had some control over the rainfall distribution, which in turn might have affected the landslide distribution. Maximum annual rainfall was found in hilly Central Lantau, where the highest peaks ---

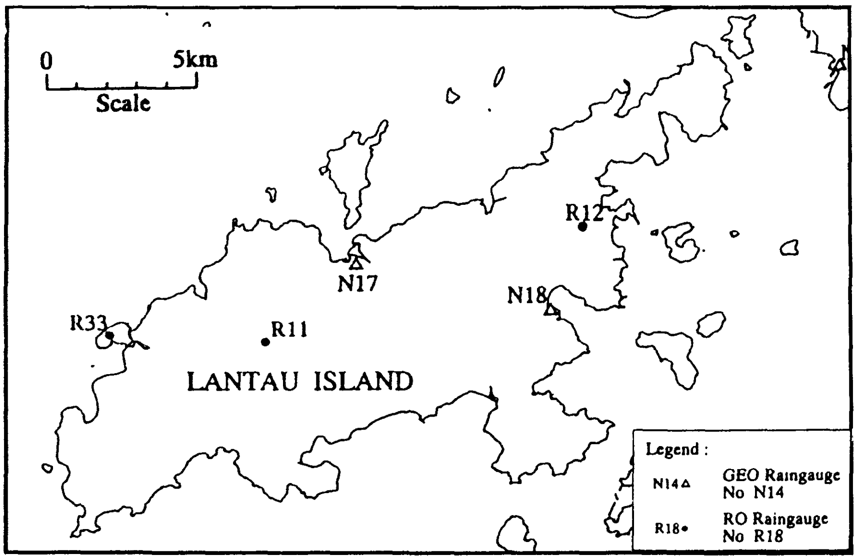
Lantau Peak (934 metres) and Sunset Peak (869 metres) were located. The annual rainfall isohyets followed the contour lines. At the same time, the high relief of the Lantau Island mostly corresponded to volcanic terrain which had a higher landslide propensity (details refer to Chapter 5).

Hence, low landslide density (LQ = 0.31) at annual rainfall range of 2000-2200mm (Figure 8.1) was probably also influenced by the gentle and low granitic terrain (Figure 3.2, 5.1) in addition to the lower amount of annual rainfall. In contrast, the significant rise in landslide density (LQ increased from 0.31 to 1.05) at areas experienced 2200-2400mm annual rainfall was largely laid on steeper volcanic terrain which were found to be highly unstable (details refer to Chapter 5-6).

The drop in the increasing rate of LQ might be explained with topography and slope angle characteristics. Referring to Figure 3.2, 6.1 and 8.1, it was noted that the area receiving over 2400mm annual rainfall was coincided with the highest relief with mainly the steepest slope gradient. All these factors caused the highest landslide density (LQ = 1.90). But since the steepest gradient did not result in highest landslide propensity (details refer to Chapter 6), the rate of increase in LQ dropped.

8.4. Limitations

The distribution of annual rainfall over Lantau should be viewed critically since the few number of rain gauges (Figure 8.2) might not sufficient to represent the highly variable spatial rainfall pattern on such a hilly topography. Lantau Island had only 5 rain gauges (R12, N18, N17, R11 and R33) despite its large area. Four of them were located along coastal area and only one located at the hilly regions (R11) (Figure 8.2). Underestimation or overgeneralisation of spatial rainfall variation might have affected the analysis of rainfall-landslide correlation as the rainfall variation of some localised areas could not be accurately and fully revealed.



Source modified from Wong et al (1997)

Figure 8.2. Locations of GEO and RO Automatic Rain gauges

It is important to note that the landslides identified (Figure 8.1) might not necessarily triggered by rainfalls in the year 1995, because landslides occurred in previous years might have been mapped due to slow rate of revegetation of landslide scars (details refer to Chapter 7.4).

Effects of antecedent rainfall and rainfall intensity on landslide distribution were not investigated due to the general nature of this research.

CHAPTER 9

DISTRIBUTION OF LANDSLIDES IN RELATION TO HUMAN INFLUENCE

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DISTRIBUTION OF LANDSLIDES IN RELATION TO HUMAN INFLUENCE

9.1. Human influence on Lantau Island

Human influence on Lantau Island was categorised into 5 types (main road, roadcut, settlements, reclaimed land and reservoir) to have a more complete picture about the distribution of those man-made features over the island in relation to landslide distribution.

Artificial Structures #	Areal extent	
	Area (in square units)*	% of specified artificial structures over Lantau Island
Main road	395	0.95
Roadcut	329	0.79
Settlements	3873	9.27
Reclaimed land	1062	2.54
Reservoir	371	0.89
Sub-total (artificial structures)	6030	14.4
Total (Lantau area)	41788	14.4

Source data derived from Lantau topographic map (Survey & Mapping Office, 1996)
* Source · Map work

Table 9.1. Areal extent of different types of artificial structures on Lantau Island

After summing up the areal data calculated by counting square units (refer to 3.2.5) of all artificial structures, human influenced area consisted of 6030 square units

(14.4%) out of 41788 square units of Lantau Island. Majority of areas were undeveloped, especially at Central Lantau (Figure 9.1).

Among all these artificial influences, human settlements consisted the largest amount of area (9.27%), scattering mainly along the coastline (Figure 9.1). Major settlements were located at the Discovery Bay, Mui O, Tung Chung, Tai O and along the Southern coast. They were mostly villages with low-rise residential buildings (Plate 9.1). Large housing estates were located at the Discovery Bay and Tung Chung. The golf course near Tai Shui Hang (Northeast Lantau) was also be grouped in "settlement" category.

Plate 9.1. Typical low-rise village residential buildings on Lantau Island, Shui Hau

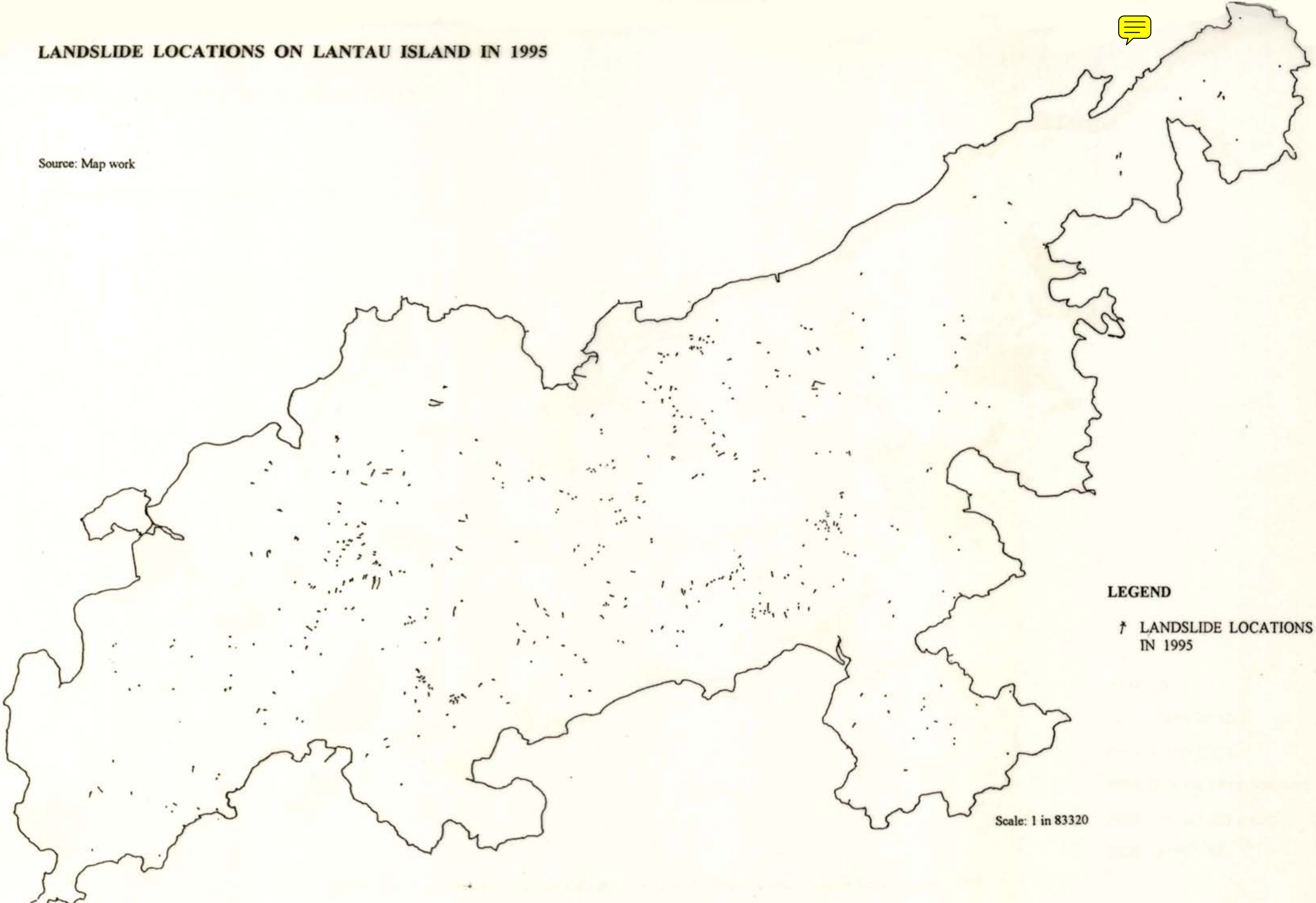
Another major human impact was noted at reclaimed land (consisted 2.54% of Lantau) (Figure 9.1). A long stretch of reclaimed land along the North coast of the island was caused by the construction of the North Lantau Expressway (Plate 9.2) and the airport railway linked with the New International Airport. Reclaimed land was also found at the coast of Penny's Bay associated with a shipyard. Other human structures were less significant in areal terms, including roads, roadcuts (Plate 9.3) and reservoirs.

Plate 9.2. Steep roadcuts along the North Lantau Expressway

Plate 9.3. Roadcuts along Tung Chung Road

LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1995

Source: Map work



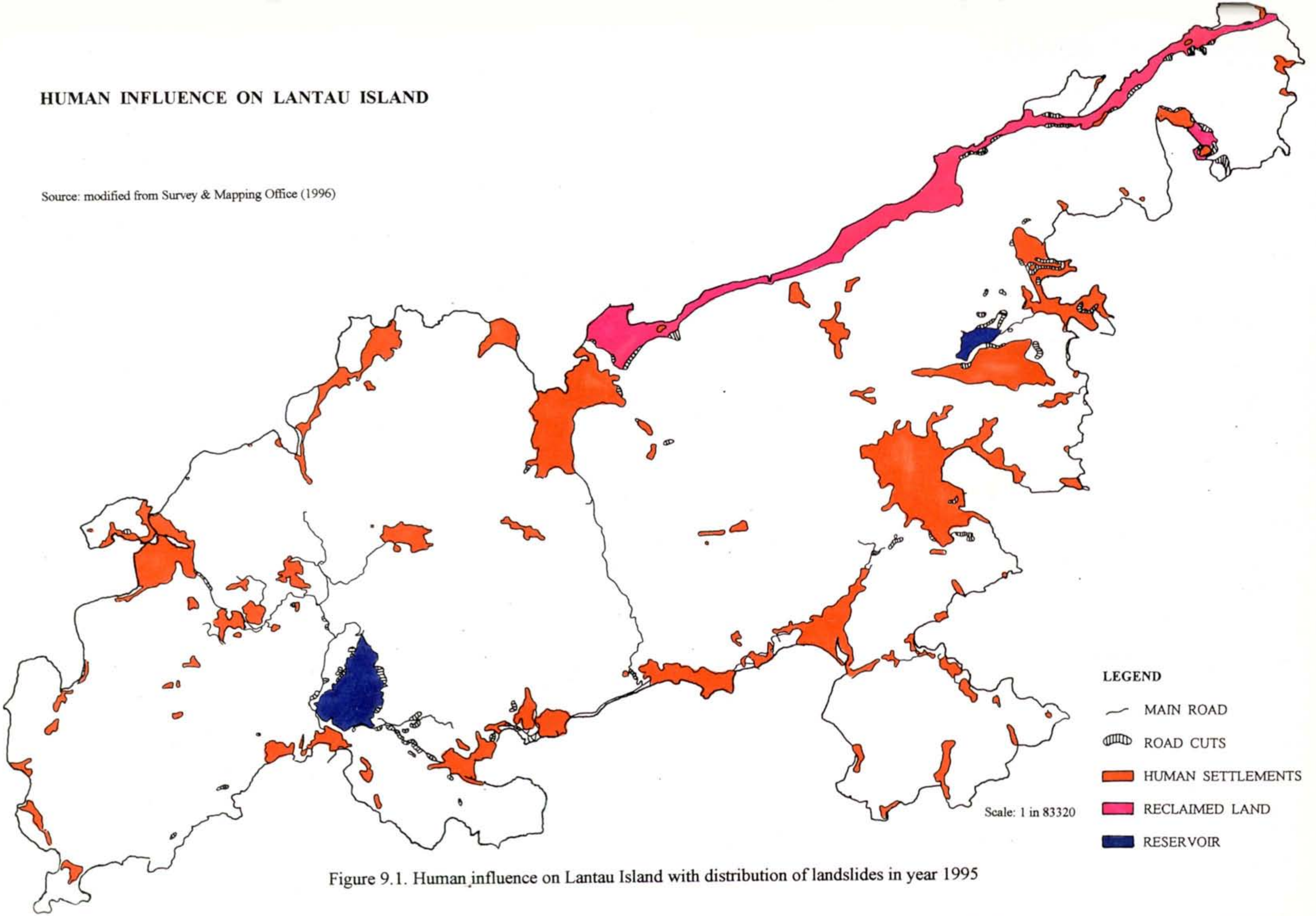


Figure 9.1. Human influence on Lantau Island with distribution of landslides in year 1995

LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1995

HUMAN INFLUENCE ON LANTAU ISLAND

Source: Map work

Source: modified from Survey & Mapping Office (1996)

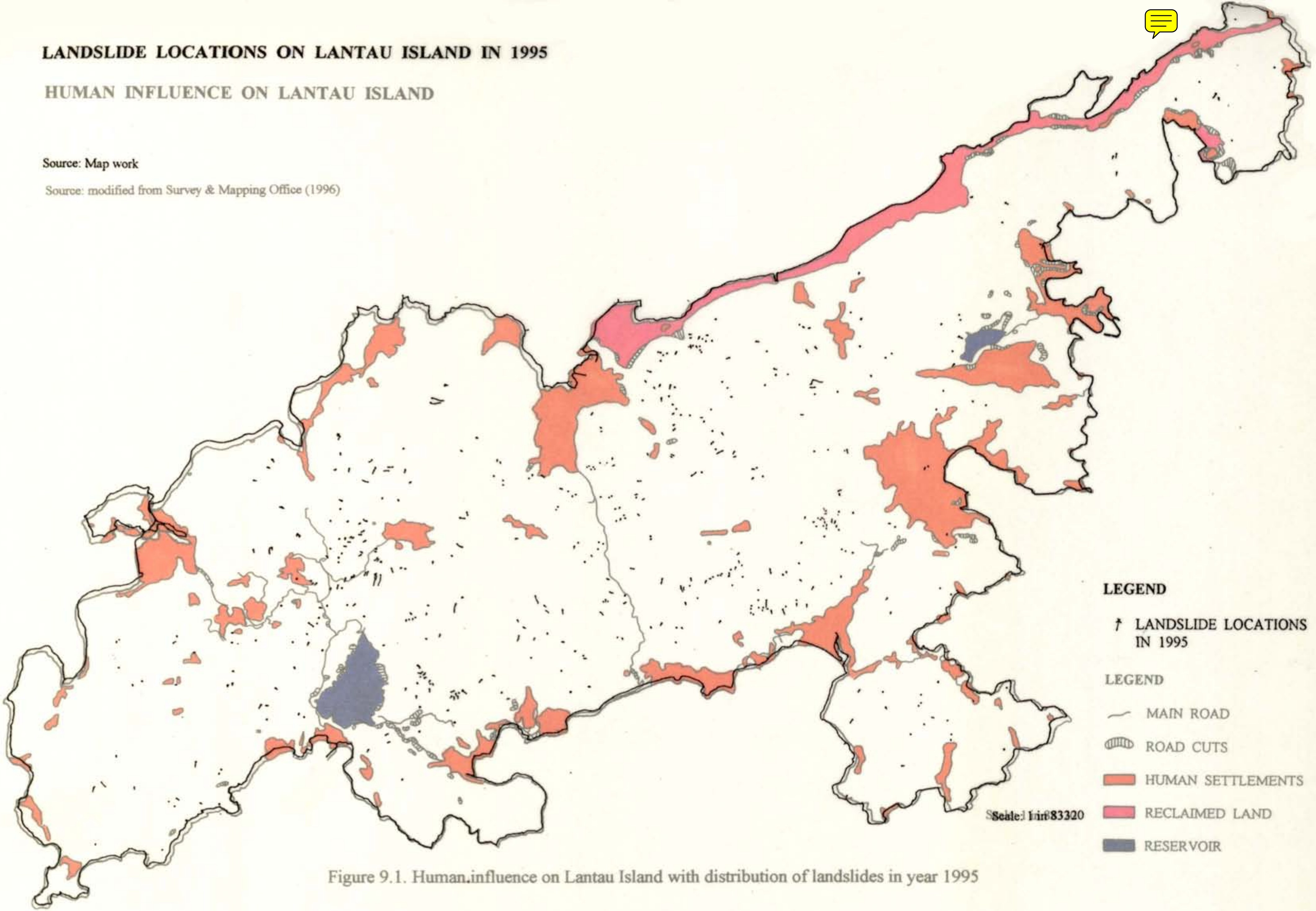


Figure 9.1. Human.influence on Lantau Island with distribution of landslides in year 1995

9.2. Distribution of landslides on artificial structures

The spatial distribution of landslide location over Lantau Island in the year 1995 with respect to "human influence" was analysed by statistical methods (calculation details refers to Chapter 3.2.5) and map observation (Figure 9.1) (Survey & Mapping Office, 1996). The results are presented as follows:

9.2.1. Statistical analysis

Human influence on Lantau Island was analysed after the combination of results of the 5 artificial structures. Regarding to 502 landslides identified, only 16 (3.19%) occurred at the man-made features. (Table 9.2)

Artificial Structures #	Areal extent		Landslides occurrence (year 1995)		Location Quotient
	Area (in sq. units)*	% of specified artificial structures over Lantau Island	No. of landslides	% of landslides on specified artificial structures	
Main Road	395	0.95	8	1.59	1.67
Road Cut	329	0.79	1	0 20	0 25
Settlements	3873	9 27	7	1.39	0.15
Reclaimed Land	1062	2.54	0	0.00	0.00
Reservoir	371	0.89	0	0 00	0 00
Sub-total (artificial structures)	**6030**	**14.4**	**16**		
Total (Lantau Area)	**41788**	**14.4**	**502**	**3.19**	**0.22**

Source Data derived from Lantau Island topographic map (Survey & Mapping Office, 1996)
* Source Map work

Table 9.2. Landslide distribution on human-influenced area on Lantau Island

Revealed by the result of the location quotient, human-influenced area had low LQ value of 0.22. This indicated that concentration degree or landslide density on human influenced area was very low. Only 3.19% landslides occurred on Lantau Island took place on artificial structures (Plate 9.4), which consisted 14.4% of Lantau area. Hence, artificial structures seemed to have little control on governing the landslide distribution of year 1995.

Plate 9.4. Landslide along a roadcut at South Lantau Road exposing deeply-weathered reddish-brown soil.

9.2.2. Map observation

Regarding to the spatial distribution of landslides, it was noted that landslide distribution had very low correlation with human influenced areas. Majority of landslides did not occur on man-made features though many landslides located around those features (Figure 9.1) (Plate 9.5). However, some high landslide density areas did locate near human settlements, such as Tung Chung (Plate 9.6) and Ngong Ping.

Plate 9.5. Landslides on natural hillslopes above a roadcut, Tung Chung

Plate 9.6. Hillslopes near Tung Chung New Town have high landslide density

9.3. Relation between artificial structures and landslides

The spatial relationship between artificial structures and landslide occurrence was not significant on Lantau Island. Compared with the results of previous human-landslide relation studies mainly taken in urban areas of Hong Kong, the results in this study of Lantau Island gave a complete different picture. The negative location quotient (LQ) value of 0.22 indicated that landslides did not concentrate at man-made structures. As shown on Figure 9.1, a large majority of landslides occurred at undeveloped natural hillslopes.

Nevertheless, human activities did increase the risk of landslides in certain areas. It was revealed that the location quotient at main road was particularly high at 1.67. This might probably because majority of road network was built at slope base (due to hilly relief over most parts of Lantau Island) where main roads became "recipient site" for landslide debris from the slopes above. Besides, the passage of heavy vehicles might generate minor shock wave which triggered off slope failure (Briggs & Smithson, 1985).

Roadcut, which was man-made slope alongside roads (Plate 9.2, 9.3), could trigger landslides since this artificial oversteepening of natural slopes by undercutting increased shearing stress by removing the lateral support. Landslide occurrence could also caused by roadcut failures due to poor maintenance and inadequate protective measures (Wong & Ho, 1995) (Plate 9.7). However, this study revealed a low LQ at roadcut places, which might indicate they were under proper maintenance.

Plate 9.7. The roadcut slope was not properly protected by shotcrete, at South Lantau Road

Human settlement contributed to landslides by increasing development on marginal slope. However, it was noted that the LQ was relatively low at 0.15. This was probably because urban development on the island was mainly limited to gentle coastal low-lying areas (Figure 9.1) (Plate 3.2) at the foothill region without intense development on hillslopes (due to its sparse population). Besides, most of the buildings on the island was low-rise village houses, consisting of few storeys (Plate 9.1). The weight added (or shear stress imposed) to slopes would be relatively less in compare with those high-rise commercial buildings on Hong Kong Island and Kowloon. In addition, 78.4 square kilometres (approximately 48% of Lantau Island) was designated as the Lantau North and Lantau South Country Parks (Figure 9.2) for recreational use, where urban development was restricted.

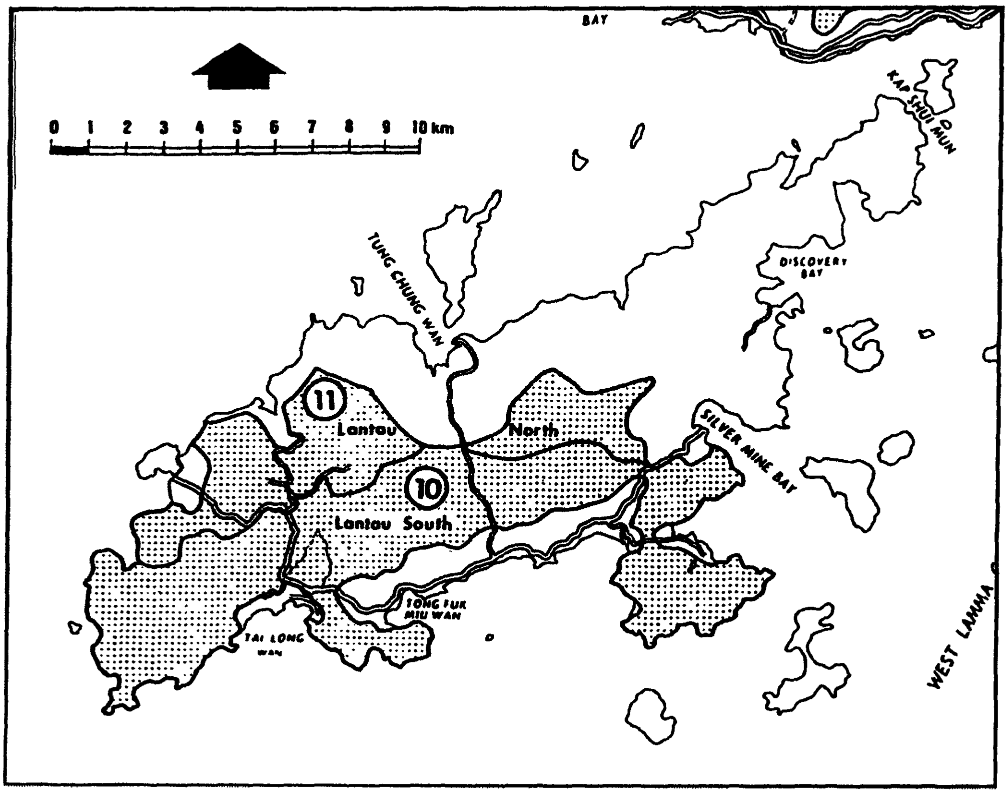


Figure 9.2. Location of Lantau North and Lantau South Country Parks

Although no landslide would have occurred at artificial structures such as reclaimed land (due to its plainness) and reservoir, their influence in controlling landslide occurrence should not be underestimated. Most of the reclaimed land on the island was obtained by cutting natural hillslopes which might increase stress on the slopes above. The best example was the reclaimed land built for the North Lantau Expressway at North Lantau Island (Figure 9.1) (Plate 9.2). Artificial reservoir might cause landslides by increasing pore pressure in rocks along the sides of the reservoir which decreased shear strength of the rocks (Montgomery, 1995).

9.4. Limitations

It should be noted that landslides occurred at man-made structures, especially those affected main roads and roadcuts, might have been underestimated. Landslide debris on main road and roadcut slope failure would be cleared and repaired (Plate 9.8) shortly after failures which could not be revealed during landslide mapping.

Plate 9.8. A newly-repaired roadcut slope with numerous surface drainage, at Tung Chung Road

Besides, human influence on landslide occurrence was not necessarily restricted to these man-made structures. It was the natural slopes above these protective structures that were mostly affected (Plate 9.5) because of increased stress caused by the undercutting. However, only landslides that directly hit the defined artificial structures were recorded due to the difficulties in assessing the areal extent of human influence.

The overall human-landslide relationship was best represented by LQ = 0.22 since area counting (in square units) for all man-made features were done mutually exclusively to avoid double-counting of the total area covered by these structures. For example, the area of main road within settlements was counted as "settlements". However, this might have caused underestimation of results at certain artificial structures.

CHAPTER 10

CONCLUSION

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CONCLUSION

The spatial distribution of landslides on Lantau Island was unevenly distributed, concentrating on the Central and Western part, with some "circular" pattern demonstrated. Most landslides were small-sized, shallow earthflows or rotational slips located at upper natural hillslopes with a specific orientation.

The relationships between the spatial distribution of landslides of year 1995 and landslide governing factors including geology, slope gradient, vegetation, annual rainfall and human influence on Lantau Island were examined by statistical methods and map observation. The contribution of each factor was summarised in Table 10.1.

Landslide governing factors	**Areas of high landslide risk**	**Reasons for high landslide risk**
Geology	volcanics	- lower angle of repose - more prone to positive pore water pressure - larger void ratio - sensitive to saturation
Slope gradient	30°-40°	- exceeded the maximum frictional angle of volcanics (30°) and granite (35°) - accumulation of colluvium
Vegetation	woodland	- thicker unconsolidated materials provided
Annual rainfall	over 2400 millimetres	- adding weight - eliminating soil cohesion - increasing pore water pressure
Human influence	main road	- recipient site for slope debris - triggering effect imposed by passing vehicles - oversteepening of slopes by roadcutting

Table 10.1. Factors that contributed to landslide occurrence on Lantau Island in year 1995

Geology and landslide distribution had a high correlation. Landslide distribution was influenced by the physical properties and behaviour of slope materials derived from different geology types. High landslide density on volcanic terrain was caused by its finer grain size and soil behaviour. Since decomposed volcanics had a higher clay content, its angle of repose was lower than coarser-grained granites, and was more prone to positive pore water pressure. Also, its larger void ratio resulted in lower material strength. The soil behaviour of volcanics was more sensitive to saturation which resulted a significant drop in cohesion and thereby lowered strength.

A high correlation was found between slope gradient and landslide occurrence. Areas with slope gradient at 30°-40° had high landslide propensity because this slope gradient range exceeded the maximum frictional angle of volcanic (30°) and granitic (35°) soil, which covered most of the island. Thick layer of less stable colluvium provided landslide materials.

The role played by vegetation was not so significant. Nevertheless, woodlands contributed to a slight concentration of landslides by providing more unconsolidated slope materials because of its thicker soil cover.

This study revealed a significant positive rainfall landslide correlation. Areas with annual rainfall over 2400mm experienced highest landslide occurrence because rainfall increased shear stress by adding weight and decreased soil shear strength through eliminating soil cohesion and increasing pore water pressure.

The spatial relationship between artificial structures and landslide occurrence was insignificant. However, man-made structure such as main road was found to be mostly affected by landslides on the island. The oversteepening of natural slopes for road network by undercutting removed the lateral support of the slopes above and main roads below became the recipient site for landslide debris. The passage of heavy vehicles also posed a triggering effect for roadside failures.

Among the individual factors, this study found that geology, slope gradient and rainfall were the most dominant factors (reflected by the significant change in the LQ corresponding to changes within the different attribution of the factor) in controlling the landslide distribution pattern on Lantau Island in which they were closely interrelated. An individual factor alone was insufficient to explain the landslide distribution pattern on Lantau Island of the year 1995.

"Geology" and "slope gradient" factors were interrelated: (1) Volcanics occupied most steeper gradient slopes of Lantau Island but however (2) volcanics had a lower frictional angle (30°) than granites (35°). (3) The maximum frictional angle of volcanics and granites determined the most favourable slope gradient zone of slope materials accumulation, that was, 30°-40°. "Slope gradient" was indirectly related to "rainfall" as the steeper gradients corresponded with high relief where receiving most rainfall. "Rainfall" factor influenced "geology" because weathered volcanic soil was more sensitive to rainfall (more significant drop in cohesion and more prone to positive pore water pressure) due to its finer grain size. In addition, volcanic areas received more annual rainfall caused by its higher relief. Their interrelationships explained the "clustered" landslide distribution pattern found at Central and Western Lantau.

Several important points were also noted in this study regarding to the above factors: (1)Deeper weathering layer did not necessarily cause higher number of landslides. (2)Steepest slope did not correlate with highest landslide propensity. (3)Woodlands could cause negative impacts on slope stability. (4)Rainfall distribution on landslide occurrence was greatly influenced by topography. (5)Human influence might not always be the most significant landslide controlling factor, especially on undeveloped areas.

Due to the general nature of this research and the limitations in methodology and data analysis, this study can only provide an overview about landslide phenomenon of Lantau Island. Further research is needed for more detailed information and thorough understanding of landslide occurrence on natural hillslopes, particularly a more advanced synthetically analysis on the recurring landslide distribution pattern and the landslide orientation characteristics, which have not been received adequate attention in Hong Kong.

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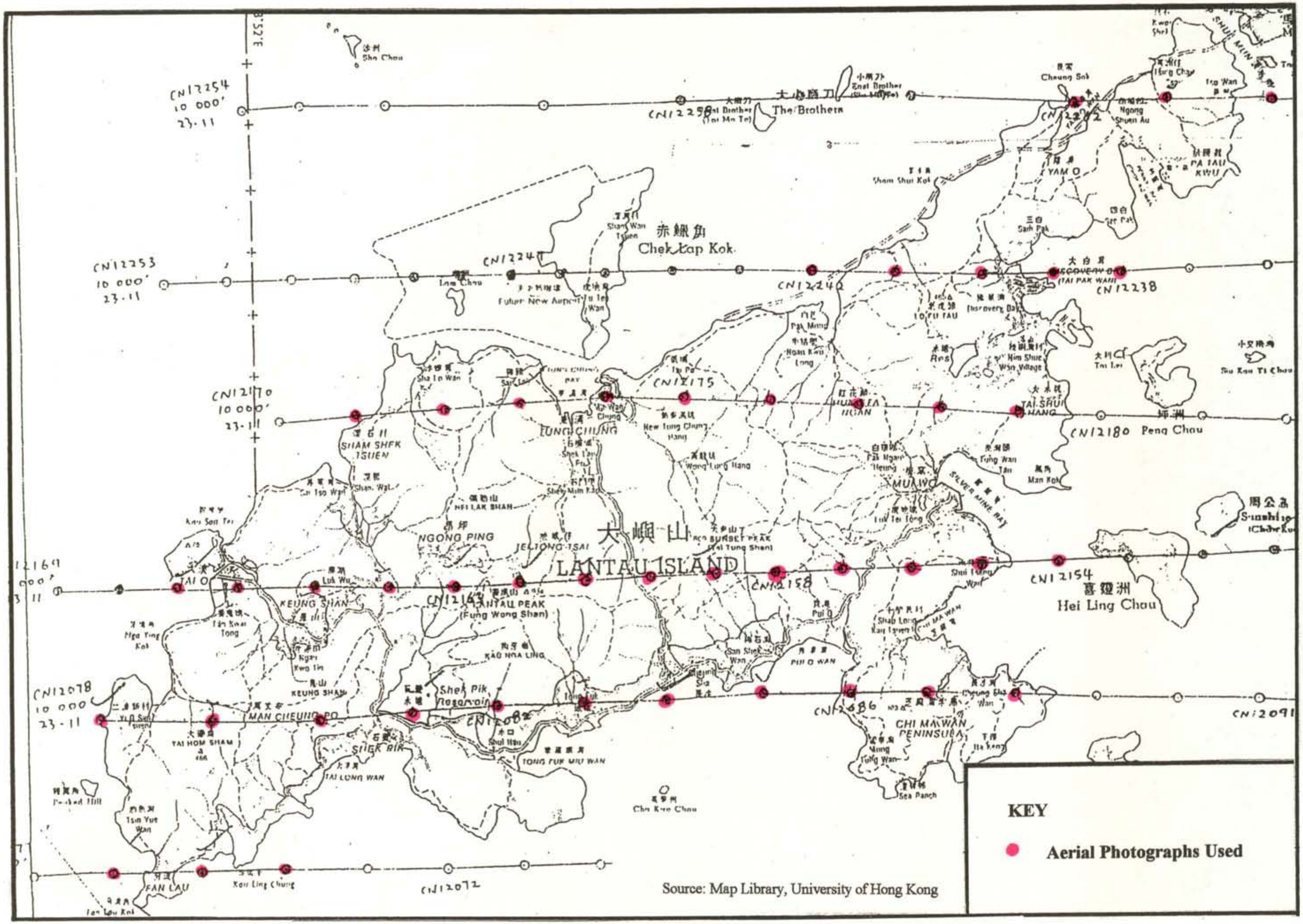
Zhang, D. Personal communication

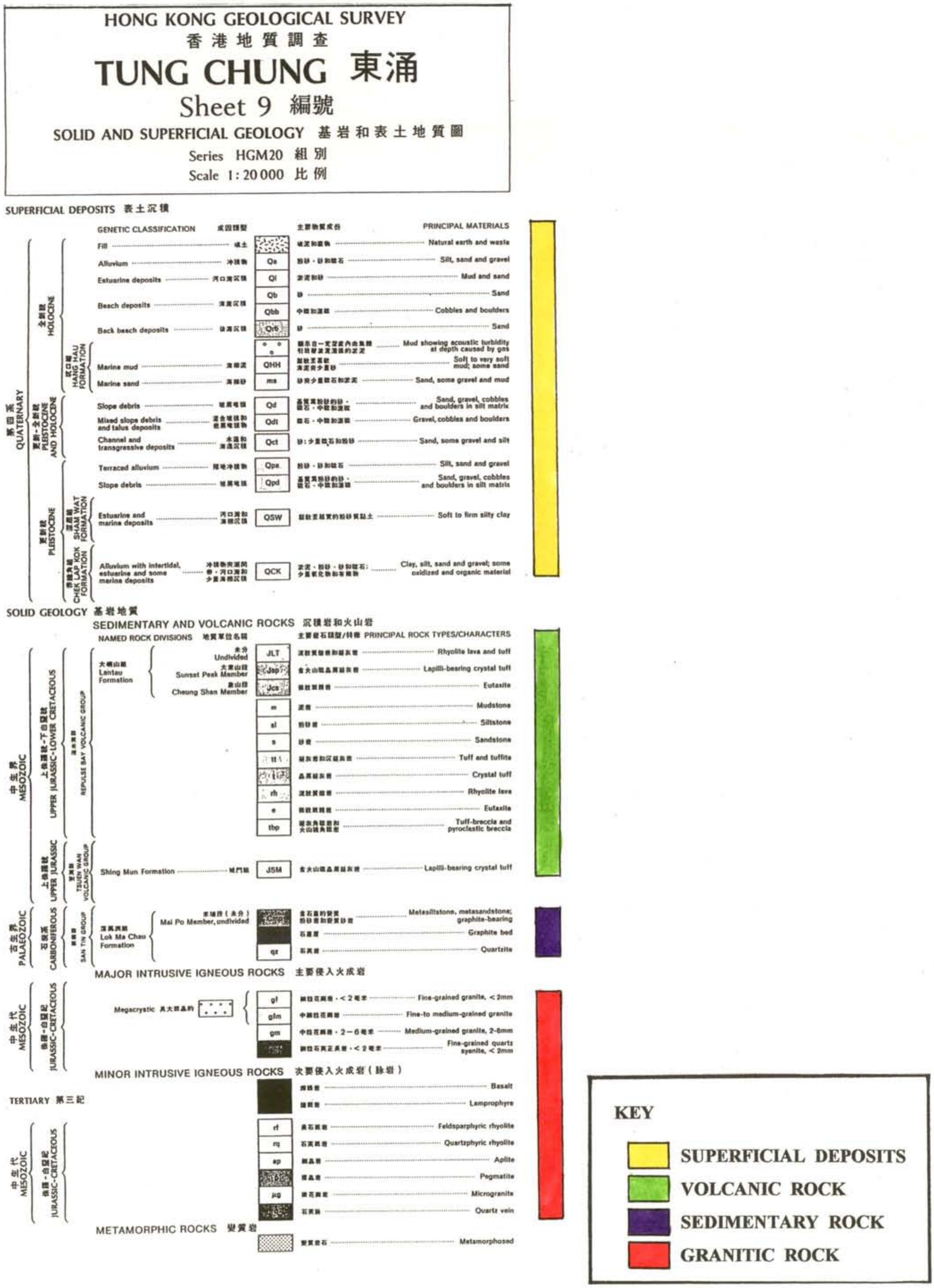
APPENDIX A



Appendix A. Aerial photo index map for vertical aerial photographs dated 23 November 1995 with flying height of 10 000 feet

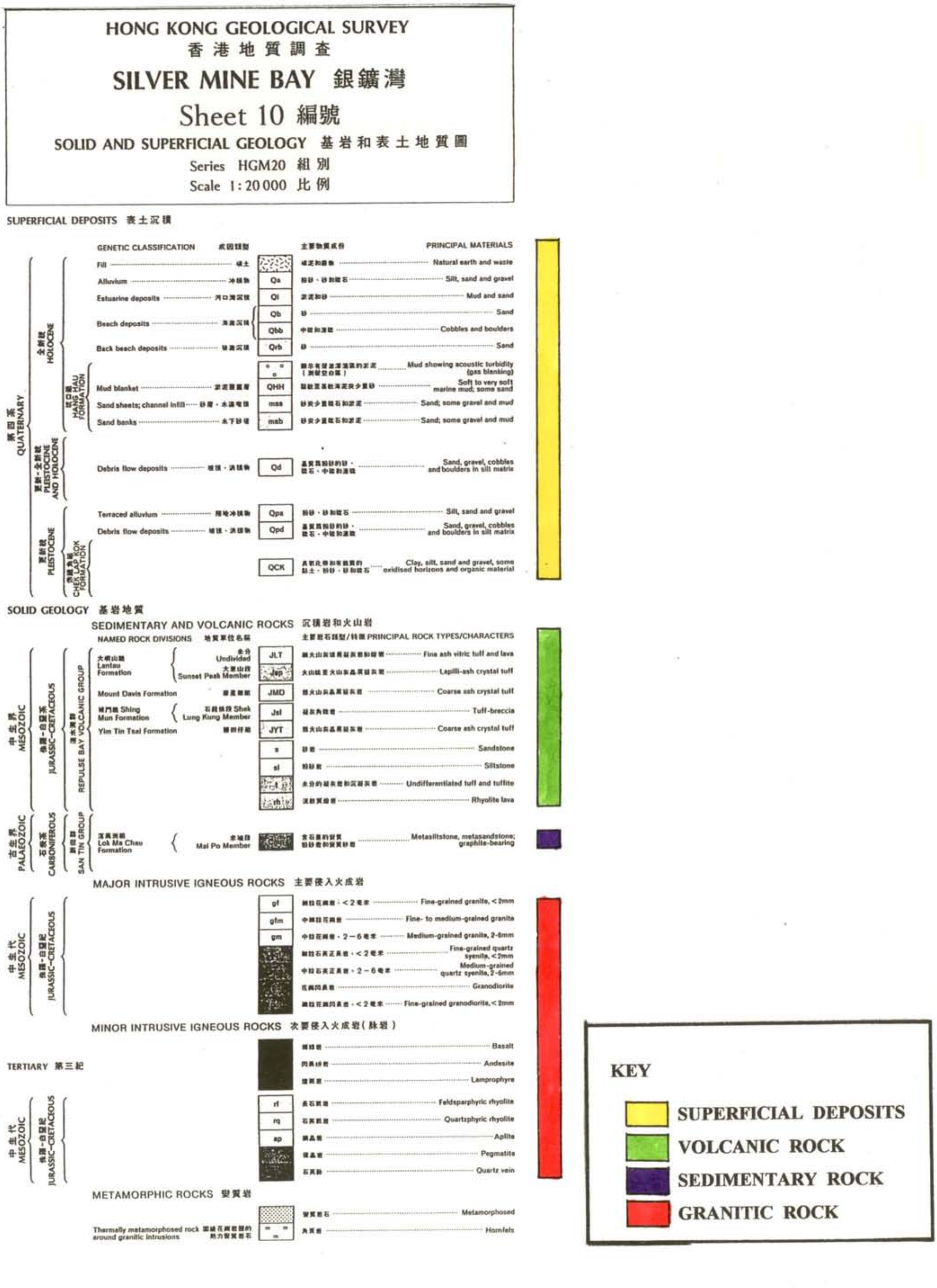
APPENDIX B

Appendix B. Simplification of Lantau geology into 4 groups



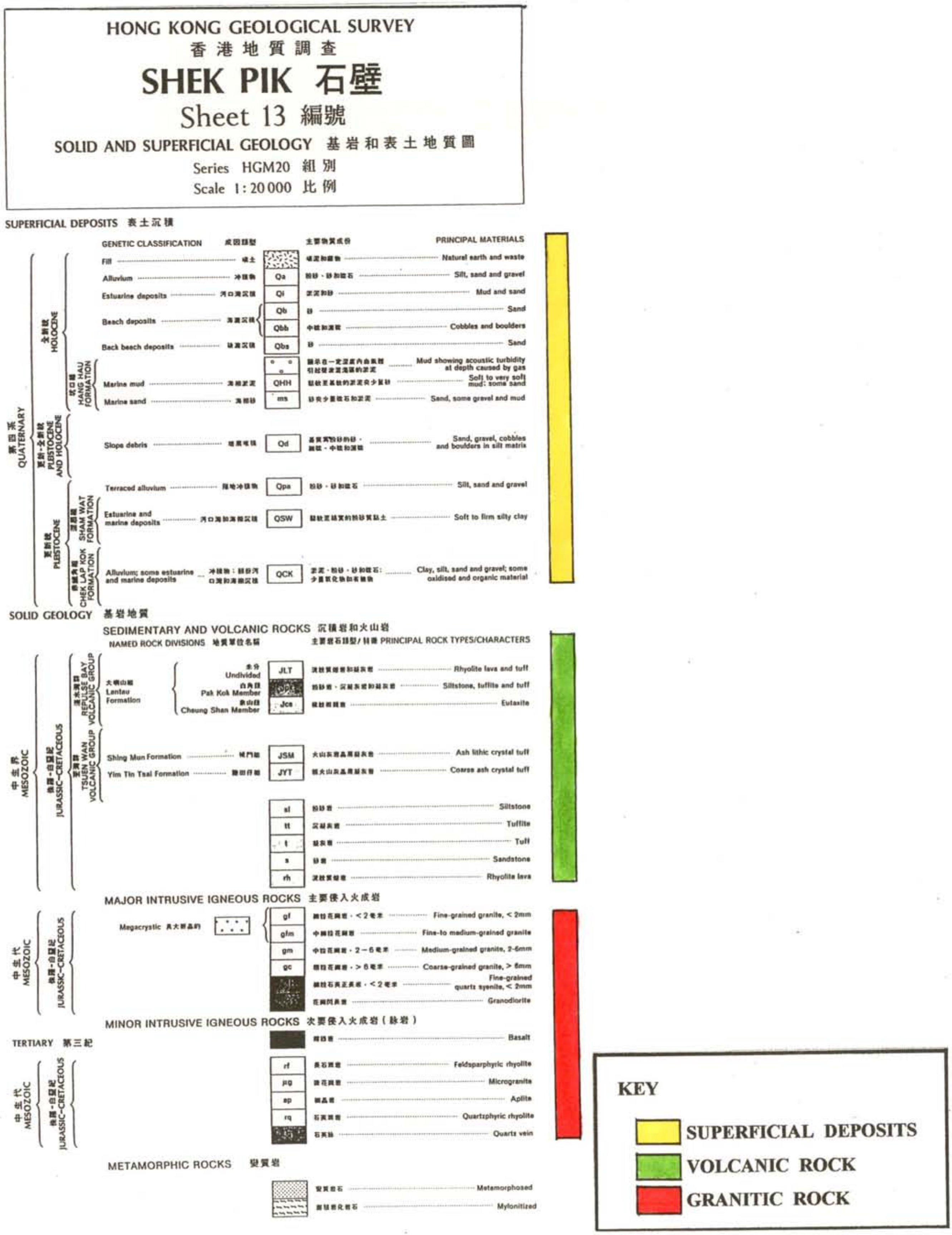
Data source: Geotechnical Engineering Office (1994)

Appendix B. Simplification of Lantau geology into 4 groups



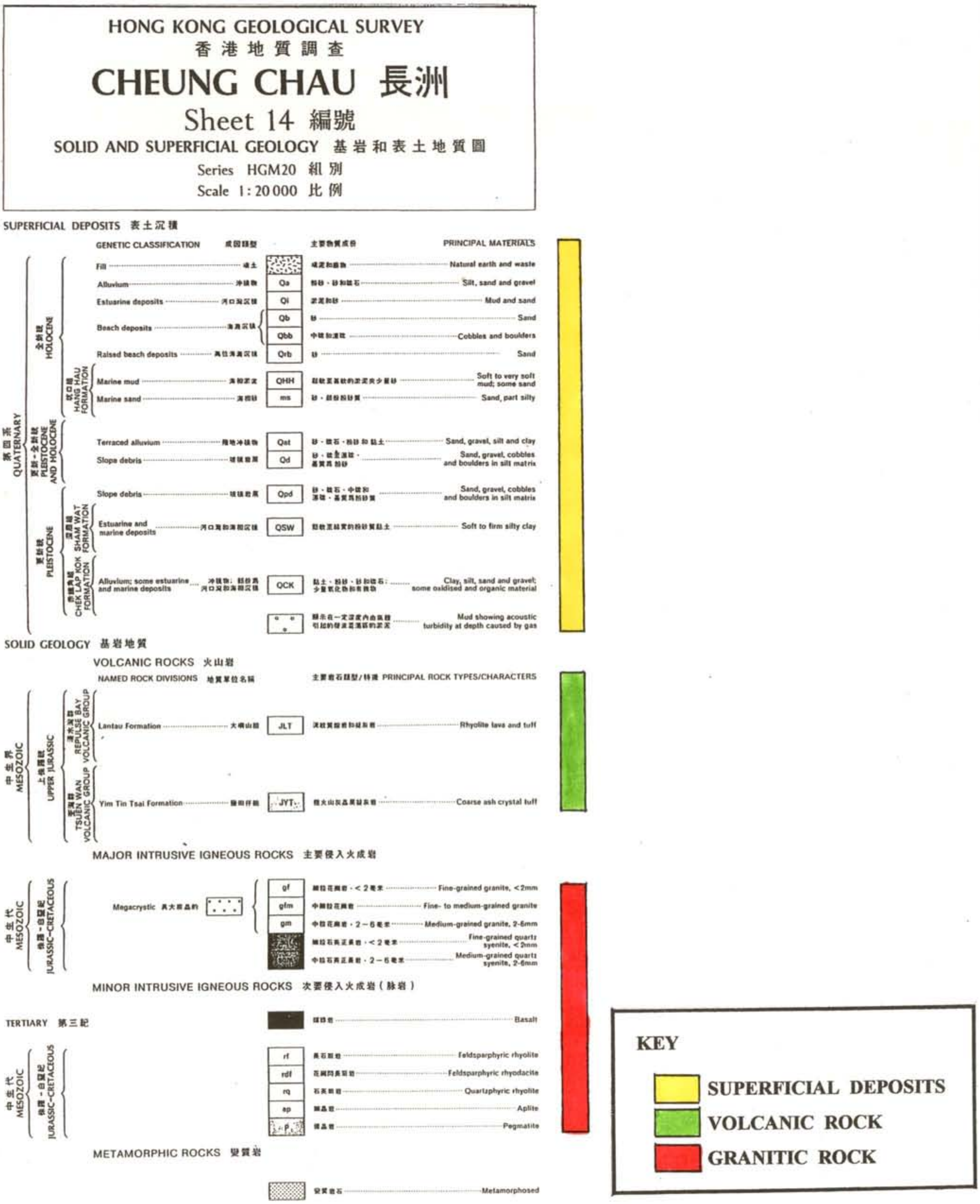
Data source: Geotechnical Engineering Office (1991)

Appendix B. Simplification of Lantau geology into 4 groups



Data source: Geotechnical Engineering Office (1995b)

Appendix B. Simplification of Lantau geology into 4 groups



Data source: Geotechnical Engineering Office (1995a)

APPENDIX C

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
1	✓							✓			✓	✓								
2	✓					✓					✓	✓								
3	✓							✓			✓	✓								
4	✓						✓				✓	✓								
5	✓							✓			✓	✓								
6	✓							✓			✓	✓								
7	✓							✓			✓	✓								
8	✓							✓			✓	✓								
9	✓						✓				✓	✓								
10	✓								✓		✓	✓								
11	✓								✓		✓	✓								
12	✓							✓			✓	✓								
13	✓						✓				✓	✓								
14	✓						✓				✓	✓								
15	✓						✓				✓		✓							
16	✓							✓			✓		✓							
17	✓							✓			✓		✓							
18	✓								✓	✓			✓							
19	✓						✓				✓		✓							
20	✓					✓					✓		✓							
21	✓						✓				✓		✓							
22	✓						✓				✓		✓							
23	✓						✓			✓			✓				✓			
24	✓							✓			✓		✓							
25	✓							✓			✓		✓							
26	✓							✓			✓		✓							
27	✓							✓			✓		✓							
28	✓						✓				✓		✓							

(Record sheet 1 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
29	✓							✓		✓			✓							
30	✓							✓			✓		✓							
31	✓							✓			✓		✓							
32	✓							✓		✓			✓							
33	✓						✓				✓		✓							
34	✓					✓					✓		✓							
35	✓							✓			✓		✓							
36	✓							✓		✓			✓							
37	✓						✓				✓		✓							
38	✓								✓	✓			✓							
39	✓						✓			✓			✓							
40	✓							✓			✓		✓							
41	✓							✓			✓		✓							
42	✓							✓			✓		✓							
43	✓							✓			✓		✓							
44	✓							✓			✓		✓							
45	✓							✓			✓		✓							
46	✓							✓			✓		✓							
47	✓							✓			✓		✓							
48	✓								✓		✓		✓							
49	✓								✓		✓		✓							
50				✓				✓			✓		✓							
51				✓				✓			✓		✓							
52	✓						✓				✓		✓							
53	✓						✓				✓		✓							
54	✓						✓				✓		✓							
55	✓						✓				✓		✓							
56	✓						✓				✓		✓							

(Record sheet 2 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
57	✓							✓			✓		✓							
58	✓							✓			✓		✓							
59	✓						✓				✓		✓							
60	✓						✓				✓		✓							
61				✓		✓					✓		✓							
62	✓							✓			✓		✓							
63	✓						✓				✓			✓						
64	✓					✓					✓			✓						
65	✓					✓					✓		✓							
66	✓							✓			✓			✓						
67	✓							✓			✓			✓						
68	✓							✓			✓			✓						
69	✓							✓			✓			✓						
70	✓							✓			✓			✓						
71	✓						✓				✓		✓		✓					
72	✓						✓				✓			✓						
73	✓							✓			✓			✓						
74	✓						✓				✓			✓						
75	✓						✓				✓		✓							
76	✓						✓				✓			✓						
77	✓							✓			✓			✓						
78	✓							✓			✓			✓						
79	✓						✓				✓			✓						
80	✓							✓			✓			✓						
81	✓							✓			✓			✓						
82	✓						✓				✓			✓						
83	✓						✓				✓			✓						
84	✓						✓				✓			✓						

(Record sheet 3 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
85	✓					✓					✓			✓						
86	✓					✓					✓			✓						
87	✓							✓		✓			✓							
88	✓							✓			✓		✓							
89	✓							✓			✓		✓							
90	✓						✓				✓		✓							
91	✓							✓			✓		✓		✓					
92	✓							✓		✓			✓							
93	✓							✓		✓				✓						
94	✓							✓			✓			✓						
95	✓						✓				✓			✓	✓					
96	✓						✓				✓			✓	✓					
97	✓						✓				✓			✓	✓					
98	✓							✓			✓			✓						
99	✓							✓			✓			✓						
100	✓							✓			✓			✓						
101	✓							✓			✓			✓						
102	✓							✓			✓			✓						
103	✓							✓			✓			✓						
104	✓						✓				✓			✓						
105	✓						✓				✓			✓						
106	✓						✓				✓		✓							
107	✓						✓				✓		✓		✓					
108	✓						✓			✓			✓							
109	✓							✓		✓			✓							
110	✓					✓					✓		✓							
111	✓							✓		✓			✓							
112	✓						✓			✓			✓							

(Record sheet 4 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
113	✓							✓		✓				✓						
114				✓				✓			✓			✓						
115	✓						✓			✓			✓							
116	✓							✓			✓		✓							
117	✓							✓			✓		✓							
118	✓							✓			✓		✓							
119	✓						✓				✓	✓								
120	✓							✓		✓			✓							
121	✓						✓				✓		✓		✓					
122	✓							✓		✓			✓			✓				
123	✓						✓			✓			✓							
124	✓							✓		✓			✓							
125	✓						✓			✓			✓							
126	✓						✓				✓		✓							
127	✓							✓			✓		✓							
128	✓							✓			✓		✓							
129	✓							✓			✓		✓							
130	✓						✓				✓		✓							
131	✓						✓				✓		✓							
132	✓						✓				✓		✓							
133	✓						✓				✓		✓							
134	✓						✓				✓		✓							
135	✓						✓				✓		✓							
136	✓						✓				✓		✓							
137	✓						✓				✓		✓							
138	✓						✓				✓		✓							
139				✓			✓				✓		✓							
140	✓							✓			✓		✓							

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
141	✓							✓			✓		✓							
142	✓							✓			✓		✓							
143	✓							✓			✓		✓							
144	✓							✓			✓		✓							
145	✓							✓			✓		✓							
146	✓							✓			✓		✓							
147	✓							✓			✓		✓							
148	✓							✓			✓		✓							
149	✓						✓				✓		✓							
150	✓						✓				✓		✓							
151	✓						✓				✓		✓							
152	✓							✓			✓			✓						
153	✓								✓		✓			✓						
154	✓							✓			✓			✓						
155	✓						✓				✓			✓						
156	✓							✓			✓			✓						
157	✓							✓			✓			✓						
158	✓							✓			✓			✓						
159	✓						✓				✓			✓						
160	✓							✓			✓			✓						
161	✓								✓		✓			✓						
162	✓							✓			✓			✓						
163	✓							✓			✓			✓						
164				✓				✓			✓			✓						
165	✓							✓			✓			✓						
166	✓							✓			✓			✓						
167	✓							✓			✓			✓						
168	✓							✓			✓			✓						

(Record sheet 6 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
169	✓						✓				✓			✓						
170	✓							✓			✓			✓						
171	✓							✓			✓			✓						
172	✓						✓				✓		✓							
173	✓						✓				✓		✓							
174	✓						✓				✓		✓							
175	✓						✓				✓		✓							
176	✓							✓			✓		✓							
177	✓							✓			✓		✓							
178	✓						✓				✓		✓							
179	✓							✓			✓		✓							
180	✓							✓			✓		✓							
181	✓							✓		✓			✓							
182	✓							✓		✓			✓							
183	✓							✓			✓			✓						
184				✓			✓				✓			✓						
185	✓						✓				✓			✓						
186				✓			✓				✓			✓						
187	✓							✓		✓				✓						
188				✓				✓		✓				✓						
189	✓							✓		✓				✓						
190				✓			✓			✓				✓						
191	✓							✓			✓			✓						
192	✓						✓				✓			✓						
193	✓						✓				✓			✓						
194	✓						✓				✓			✓						
195	✓						✓				✓			✓						
196				✓		✓					✓		✓							

(Record sheet 7 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
197	✓							✓			✓		✓							
198	✓						✓				✓		✓							
199	✓						✓				✓		✓							
200	✓						✓				✓		✓							
201	✓							✓			✓		✓							
202	✓					✓					✓		✓							
203				✓				✓			✓			✓						
204				✓				✓			✓			✓						
205	✓					✓					✓			✓						
206	✓							✓			✓			✓						
207	✓							✓			✓			✓						
208	✓							✓			✓			✓						
209	✓							✓			✓			✓						
210	✓					✓					✓			✓						
211	✓					✓					✓			✓						
212	✓						✓				✓			✓						
213	✓						✓				✓			✓						
214	✓						✓				✓			✓						
215	✓						✓				✓			✓						
216				✓			✓				✓			✓						
217				✓			✓				✓			✓						
218	✓						✓				✓			✓						
219	✓						✓				✓			✓						
220	✓						✓			✓				✓						
221	✓						✓			✓				✓						
222	✓						✓				✓			✓						
223	✓						✓				✓			✓						
224	✓						✓				✓			✓						

(Record sheet 8 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
225	✓						✓				✓			✓						
226	✓						✓				✓			✓						
227	✓						✓				✓			✓						
228	✓						✓				✓			✓						
229	✓							✓			✓			✓						
230	✓							✓			✓			✓						
231	✓							✓		✓				✓						
232	✓							✓			✓			✓						
233	✓						✓				✓		✓							
234	✓						✓				✓		✓							
235	✓						✓				✓			✓						
236	✓						✓				✓			✓						
237	✓						✓				✓			✓						
238				✓		✓					✓			✓						
239	✓					✓					✓			✓						
240				✓		✓					✓			✓						
241	✓						✓				✓			✓						
242				✓			✓				✓			✓						
243	✓						✓				✓			✓						
244	✓						✓				✓			✓						
245	✓						✓				✓			✓						
246	✓						✓				✓			✓						
247	✓						✓				✓			✓						
248				✓				✓			✓			✓	✓					
249	✓							✓			✓			✓						
250	✓							✓			✓			✓						
251	✓						✓				✓			✓						
252	✓							✓			✓			✓						

(Record sheet 9 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
253	✓						✓				✓			✓						
254	✓						✓				✓			✓						
255	✓						✓				✓			✓						
256	✓							✓			✓			✓						
257				✓							✓			✓						
258	✓						✓			✓				✓						
259	✓						✓			✓				✓						
260	✓							✓		✓				✓						
261	✓							✓			✓		✓							
262				✓				✓			✓		✓							
263	✓						✓			✓			✓							
264	✓							✓			✓		✓							
265	✓							✓			✓		✓							
266				✓			✓				✓		✓							
267				✓				✓			✓		✓							
268				✓				✓			✓		✓							
269				✓				✓			✓			✓						
270	✓							✓			✓			✓						
271	✓								✓		✓			✓						
272	✓							✓			✓			✓						
273	✓								✓		✓			✓						
274	✓								✓		✓			✓						
275	✓							✓			✓			✓						
276	✓							✓			✓			✓						
277	✓						✓				✓			✓						
278	✓							✓			✓			✓						
279	✓						✓				✓			✓						
280	✓						✓				✓			✓						

(Record sheet 10 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
281	✓						✓				✓			✓						
282	✓						✓				✓			✓						
283				✓			✓				✓		✓							
284	✓						✓				✓		✓							
285	✓							✓			✓		✓							
286				✓				✓			✓		✓							
287	✓						✓				✓		✓							
288	✓							✓			✓		✓							
289	✓							✓			✓		✓							
290	✓						✓				✓		✓							
291	✓						✓				✓		✓							
292	✓						✓				✓		✓							
293	✓						✓				✓		✓							
294	✓						✓				✓			✓						
295	✓						✓				✓			✓						
296	✓						✓				✓		✓							
297	✓						✓				✓			✓						
298	✓						✓				✓			✓						
299	✓						✓				✓			✓						
300	✓						✓				✓			✓						
301	✓						✓				✓			✓						
302	✓						✓				✓			✓						
303	✓						✓				✓			✓						
304	✓							✓			✓			✓						
305	✓								✓		✓			✓						
306	✓								✓		✓		✓							
307				✓					✓		✓		✓							
308	✓								✓		✓		✓							

(Record sheet 11 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
309	✓								✓		✓		✓							
310				✓			✓				✓		✓							
311	✓							✓			✓		✓							
312				✓			✓				✓		✓							
313	✓						✓				✓		✓							
314	✓								✓		✓		✓							
315	✓								✓		✓		✓							
316	✓							✓			✓		✓							
317	✓								✓		✓		✓							
318	✓							✓			✓		✓							
319	✓					✓				✓				✓						
320	✓							✓			✓			✓						
321	✓						✓				✓			✓						
322	✓						✓				✓			✓						
323	✓								✓		✓			✓						
324	✓						✓				✓			✓						
325	✓						✓				✓			✓						
326	✓							✓			✓			✓						
327	✓							✓			✓			✓						
328	✓							✓			✓			✓						
329	✓							✓			✓			✓						
330	✓							✓			✓			✓						
331	✓							✓			✓			✓						
332	✓							✓			✓			✓						
333	✓						✓				✓		✓							
334	✓								✓		✓		✓							
335	✓					✓					✓		✓							
336	✓							✓			✓		✓							

(Record sheet 12 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
337	✓							✓			✓		✓							
338	✓						✓				✓		✓							
339	✓						✓				✓		✓							
340	✓						✓				✓		✓							
341	✓						✓				✓		✓							
342	✓						✓				✓		✓							
343	✓						✓				✓		✓							
344	✓						✓			✓			✓							
345				✓			✓			✓			✓							
346	✓						✓			✓			✓							
347				✓			✓			✓			✓							
348	✓						✓			✓			✓							
349				✓			✓			✓			✓							
350	✓						✓				✓		✓							
351	✓							✓		✓			✓							
352	✓							✓		✓			✓							
353	✓						✓				✓		✓							
354	✓						✓				✓		✓							
355	✓							✓			✓		✓							
356	✓							✓			✓		✓							
357	✓							✓			✓		✓							
358	✓							✓			✓		✓							
359	✓							✓			✓		✓							
360	✓							✓			✓		✓							
361	✓							✓			✓		✓							
362		✓						✓		✓			✓							
363	✓							✓			✓		✓							
364		✓					✓			✓			✓							

(Record sheet 13 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
365				✓			✓				✓		✓							
366				✓			✓				✓		✓							
367				✓			✓				✓		✓							
368				✓			✓				✓		✓							
369		✓						✓			✓		✓							
370		✓						✓		✓			✓							
371	✓						✓				✓		✓							
372	✓						✓				✓		✓							
373	✓						✓				✓		✓							
374	✓						✓			✓			✓							
375	✓						✓				✓		✓							
376	✓						✓				✓		✓							
377	✓						✓				✓		✓							
378	✓						✓				✓		✓							
379	✓						✓				✓		✓							
380	✓						✓				✓		✓							
381		✓						✓			✓		✓							
382	✓							✓		✓			✓							
383	✓						✓			✓			✓							
384	✓						✓				✓		✓							
385		✓					✓				✓		✓							
386		✓					✓				✓		✓							
387		✓					✓				✓		✓							
388		✓					✓				✓		✓							
389	✓						✓				✓		✓							
390	✓								✓		✓		✓							
391	✓								✓		✓		✓							
392	✓							✓			✓		✓							

(Record sheet 14 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
393	✓					✓				✓			✓							
394	✓								✓		✓		✓							
395	✓								✓		✓		✓							
396	✓								✓		✓		✓							
397	✓								✓		✓		✓							
398	✓							✓			✓		✓							
399	✓							✓			✓		✓							
400	✓							✓			✓		✓							
401	✓							✓			✓		✓							
402	✓						✓			✓			✓							
403	✓						✓				✓		✓							
404	✓						✓			✓			✓							
405	✓							✓		✓			✓							
406	✓							✓		✓			✓							
407	✓							✓			✓		✓							
408	✓							✓		✓			✓							
409	✓							✓			✓		✓							
410	✓						✓			✓			✓							
411	✓						✓			✓			✓							
412	✓							✓		✓			✓							
413				✓			✓				✓		✓							
414	✓						✓				✓		✓							
415	✓							✓			✓		✓							
416	✓							✓			✓		✓							
417	✓							✓			✓		✓							
418	✓						✓				✓		✓							
419	✓							✓			✓		✓							
420	✓							✓			✓		✓							

(Record sheet 15 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
421				✓			✓			✓			✓							
422	✓							✓		✓			✓							
423	✓							✓			✓		✓							
424	✓						✓				✓		✓							
425	✓							✓			✓		✓							
426	✓							✓			✓		✓							
427	✓							✓			✓		✓							
428	✓						✓				✓		✓							
429	✓						✓				✓		✓							
430	✓						✓				✓		✓							
431				✓				✓			✓		✓							
432	✓							✓			✓		✓							
433	✓							✓			✓		✓							
434	✓							✓			✓		✓							
435	✓							✓			✓		✓							
436	✓							✓			✓		✓							
437	✓						✓				✓		✓							
438	✓						✓				✓		✓							
439	✓						✓				✓		✓							
440	✓					✓				✓			✓							
441		✓				✓					✓	✓								
442		✓					✓			✓		✓								
443		✓						✓			✓	✓								
444		✓						✓			✓		✓							
445		✓					✓				✓		✓							
446		✓					✓				✓		✓							
447		✓						✓			✓		✓							
448		✓					✓			✓			✓				✓			

(Record sheet 16 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
449		✓					✓			✓			✓				✓			
450		✓					✓			✓			✓				✓			
451		✓						✓		✓			✓							
452		✓					✓			✓			✓							
453		✓					✓			✓			✓				✓			
454		✓				✓					✓		✓							
455		✓					✓				✓		✓							
456		✓						✓			✓		✓							
457		✓					✓				✓		✓							
458		✓						✓			✓		✓							
459		✓					✓				✓		✓							
460		✓							✓	✓			✓							
461		✓						✓			✓		✓							
462		✓					✓				✓		✓							
463		✓						✓		✓			✓							
464		✓					✓			✓			✓							
465		✓						✓		✓			✓							
466		✓					✓			✓			✓							
467		✓						✓		✓			✓							
468		✓						✓		✓			✓							
469		✓						✓		✓			✓							
470		✓						✓		✓			✓							
471		✓						✓		✓			✓							
472		✓					✓			✓			✓							
473		✓					✓			✓			✓							
474		✓						✓			✓		✓							
475				✓			✓				✓		✓				✓			
476		✓					✓				✓		✓							

(Record sheet 17 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

Landslide no. (1995)	GEOLOGY				SLOPE ANGLE					VEGETATION (Woodland) (1996 map)		ANNUAL RAINFALL (1995)			HUMAN FACTOR (1996 map)					
	V	G	S	D	0°-5°	5°-15°	15°-30°	30°-40°	> 40°	Yes	No	2000-2200mm	2200-2400mm	> 2400mm	Main road	Road cut	Settlement	Reclaimed land	Reservoir	Remarks
477		✓					✓				✓	✓								
478		✓					✓				✓	✓								
479		✓					✓			✓		✓								
480		✓							✓		✓	✓								
481		✓					✓				✓	✓								
482		✓					✓				✓	✓					✓			
483		✓						✓			✓		✓							
484		✓				✓					✓		✓							
485		✓					✓				✓	✓								
486		✓				✓					✓	✓								
487		✓				✓					✓	✓								
488		✓							✓		✓	✓								
489		✓					✓				✓	✓								
490		✓				✓					✓	✓								
491		✓					✓				✓	✓								
492		✓					✓				✓	✓								
493	✓					✓					✓	✓								
494		✓					✓				✓	✓								
495		✓				✓					✓	✓								
496		✓					✓				✓	✓								
497		✓					✓				✓	✓								
498		✓				✓					✓		✓							
499	✓						✓				✓	✓								
500	✓							✓			✓		✓							
501	✓					✓					✓	✓								
502	✓					✓					✓	✓								

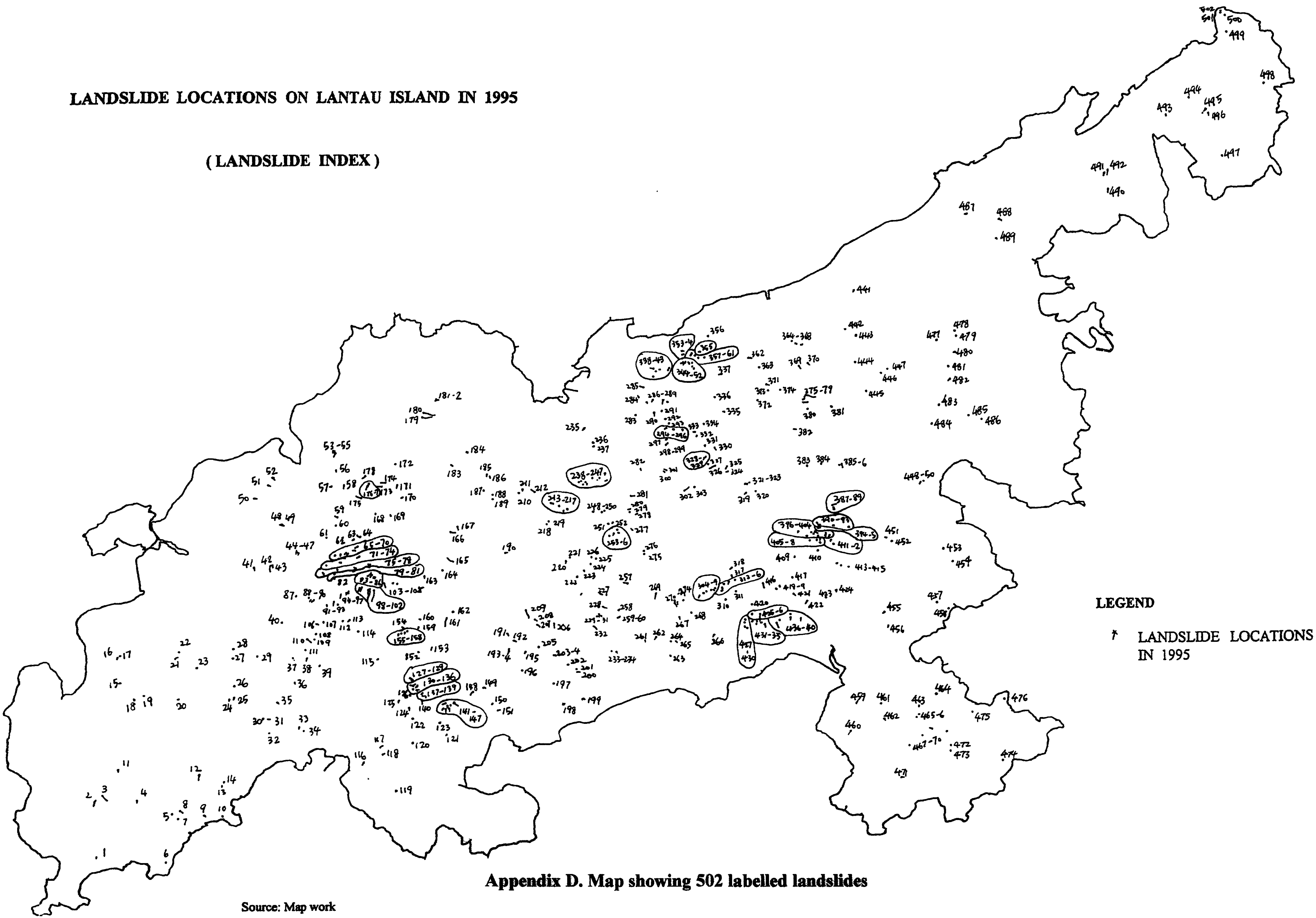
(Record sheet 18 of 18)

Appendix C. Record sheets of 502 landslides identified from the aerial photographs taken on 23 November 1995

APPENDIX D

LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1995

(LANDSLIDE INDEX)



Appendix D. Map showing 502 labelled landslides

Source: Map work

APPENDIX E

Appendix E. Data used in calculating areal extent of geology and slope angle of Lantau Island

Geological Unit	% of Total Area	Area (ha)	**Modified data :**
Reclamation	0.5	33	**Not count**
Fill	<0.1	2	
Alluvium: undifferentiated	6.1	455	
Colluvium: volcanic	9.0	669	
: granitic	10.7	792	
: sedimentary	0.1	6	**Superficial deposits TOTAL: 1997 (ha)**
Littoral deposits	1.0	75	
Repulse Bay Formation: undifferentiated volcanics rocks	17.1	1 265	
: sedimentary rocks and waterlaid volcaniclastic rocks	0.4	28	
: acid lavas	0.9	67	
: coarse tuff	4.8	357	
: agglomerate	0.1	10	**Volcanic rock TOTAL: 2221 (ha)**
: dominantly pyroclastic rocks with some lavas	6.7	494	
Tai O Formation	0.6	43	**Sedimentary rock TOTAL: 43 (ha)**
Undifferentiated granite	15.3	1 130	
Quartz Monzonite	1.1	78	
Feldspar Porphyry	18.5	1 369	
Ma On Shan Granite	<0.1	2	**Granitic rock TOTAL: 3107 (ha)**
Cheung Chau Granite	6.2	461	
Sung Kong Granite	0.9	67	
	100.0	7 403	**Overall TOTAL: 7368 (ha)**

Slope Gradient	% of Total Area	Area (ha)
0– 5°*	9.3	687
5–15°	19.8	1 465
15–30°	46.9	3 474
30–40°	19.9	1 473
40–60°	4.0	298
>60°	0.1	6
	100.0	7 403

* Approximately 8 ha of uncovered reservoirs and ponds are included in the 0–5° Class.

Data source: Geotechnical Engineering Office (1988a), North Lantau

Appendix E. Data used in calculating areal extent of geology and slope angle of Lantau Island

Geological Unit	% of Total Area	Area (ha)	**Modified data :**
Alluvium: undifferentiated	4.0	304	
: raised	0.1	8	
Colluvium: volcanic	8.5	649	
: granitic	1.1	84	
: sedimentary	0.3	24	
: mixed	0.5	39	
Littoral deposits	2.0	149	**Superficial deposits TOTAL: 1257 (ha)**
Reclamation	0.5	35	
Fill	0.9	67	**Not count**
Repulse Bay Formation: undifferentiated volcanics	17.7	1 342	
: sedimentary rocks and waterlaid volcanics	10.4	788	
: acid lavas	7.5	567	
: mainly banded acid lavas, some welded tuffs	0	0	
: coarse tuff	1.7	133	
: agglomerate	0.1	10	
: dominantly pyroclastics and some lavas	24.8	1 881	**Volcanic rock TOTAL: 4721 (ha)**
Tai O Formation	1.1	80	**Sedimentary rock TOTAL: 80 (ha)**
Quartz Monzonite	4.6	347	
Feldspar Porphyry Dyke Swarm	2.4	182	
Fan Lau Porphyritic Granite	0.2	18	
Ma On Shan Granite	0.1	8	
Cheung Chau Granite	8.8	667	
Sung Kong Granite	2.3	173	
Tai Po Granodiorite	0.3	24	
Undifferentiated Granite	0.1	10	**Granitic rock TOTAL: 1429 (ha)**
	100.0	7 589	**Overall TOTAL: 7487 (ha)**

Approximately 131 ha of reservoirs and ponds have been categorised as possessing alluvial deposits.

Slope Gradient	% of Total Area	Area (ha)
0– 5°*	7.1	539
5–15°	12.3	936
15–30°	36.1	2 738
30–40°	39.7	3 013
40–60°	4.6	349
>60°	0.2	14
	100.0	7 589

* Approximately 131 ha of uncovered reservoirs and ponds are included in the 0–5° Class.

Data source: Geotechnical Engineering Office (1988b), South Lantau

APPENDIX F

Appendix F. The transparent graph paper used for calculating unit area

Appendix F. The transparent graph paper used for calculating unit area

APPENDIX G

Appendix G. Field visit records and route map

FIELD VISIT A	
Date	6 February 1999
Objective	to have a general idea about the location and characteristics (e.g. shape, size) of landslides on Lantau Island by observation at height.
Route	Pak Kung Au (Tung Chung Au) ---> Sunset Peak (Tai Tung Shan) ---> Yi Tung Shan ---> Sheung Tung Au ---> Lin Fa Shan ---> Mui Wo
Remarks	The route taken was a hiking trail along the crest of high mountains on Lantau Island.

FIELD VISIT B	
Date	13 June 1999
Objective	to identify landslide characteristics on granitic, volcanic and vegetated (woodland) areas respectively. Landslide characteristics such as their location (height, orientation), spatial distribution (density), shape (scar or scar with a tongue) and their size were taken into account during observation.
Routes	Part I-- Pui O ---> Chi Ma Wan Road ---> Lo Yan Shan ---> Pui O Part II -- Pak Kung Au (Tung Chung Au) ---> Tung Chung Road near Shek Mun Kap
Reason for choosing these routes	Part I route: Chi Ma Wan Peninsula was chosen as a "sample" area to have a visit in order to observe landslide distribution on densely vegetated (woodland) granitic area. Part II route: Tung Chung Road was visited to observe landslides occurred on volcanic slopes on both sides of the road. This area was one of the areas has highest number of landslides.
Remarks	Part I route taken was Chi Ma Wan Country Trail along the highest hills of the peninsula. Part II route was taken along main road.

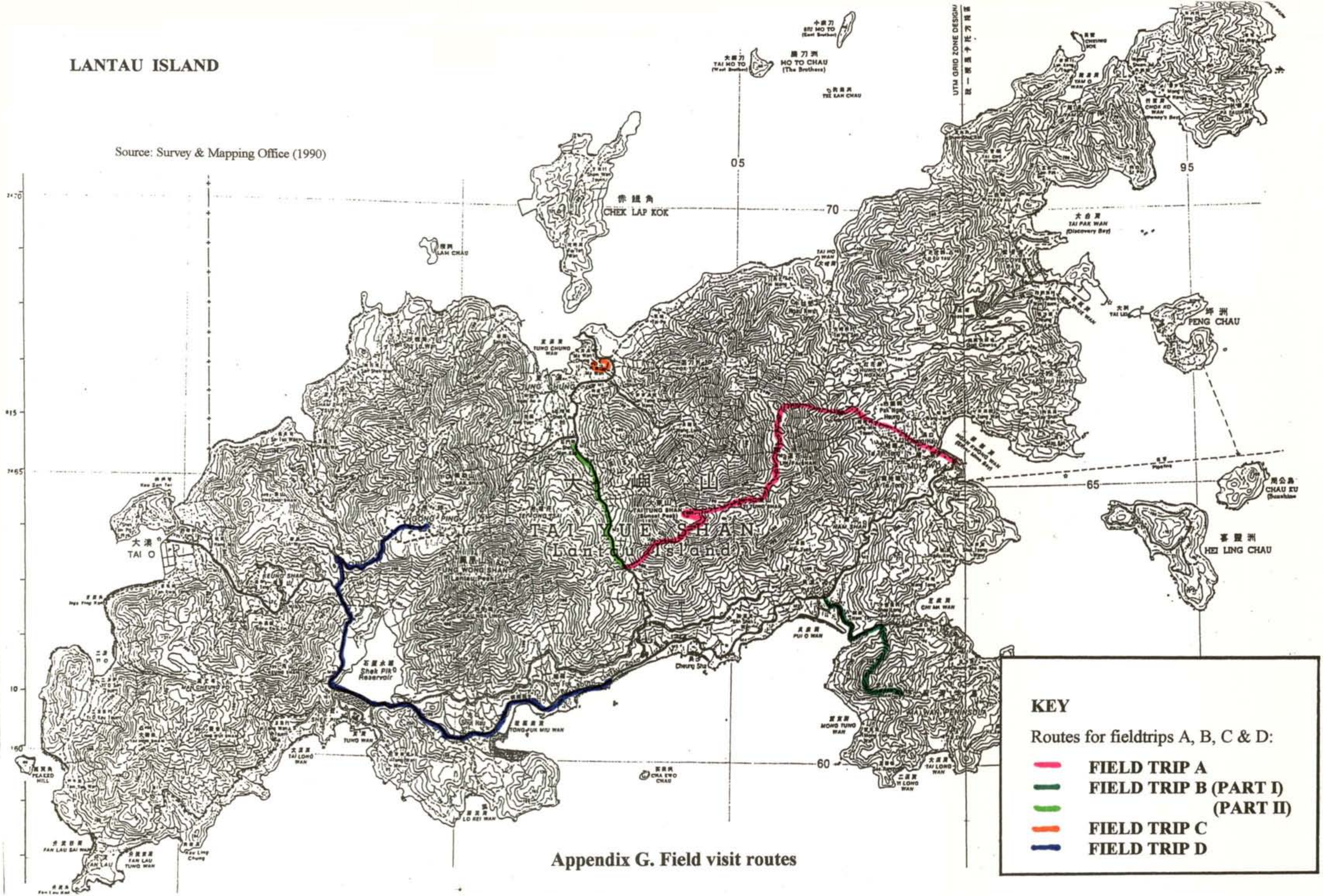
Appendix G. Field visit records and route map

FIELD VISIT C	
Date	15 June 1999
Objective	to observe landslide distribution under highly human-influenced areas
Route	Cheung Tung Road --> Yu Tung Road --> Shun Tung Road --> North Lantau Expressway
Reasons for choosing this route	The route was taken at the footslopes at the boundary of Tung Chung New Town and along the North Lantau Expressway. The slopes around these areas were mostly cut for road network and buildings.
Remarks	The route along the North Lantau Expressway was taken on the bus.

FIELD VISIT D	
Date	20 June 1999
Objectives	a) to visit and observe the environmental characteristics of one of the highest landslide density areas. b) to recognise landslides at road cuts
Route	Po Lin Monastery (Ngong Ping) --> Ngong Ping Road --> Tai O Road --> Keung Shan Road --> Shek Pik --> South Lantau Road --> Cheung Sha
Reasons for choosing this route	a) Ngong Ping and the hillslopes surrounding Shek Pik Reservoir were the areas that experienced highest density of landslides. b) Main roads were chosen to observe landslides at roadcuts.
Remarks	The whole route was taken along main roads.

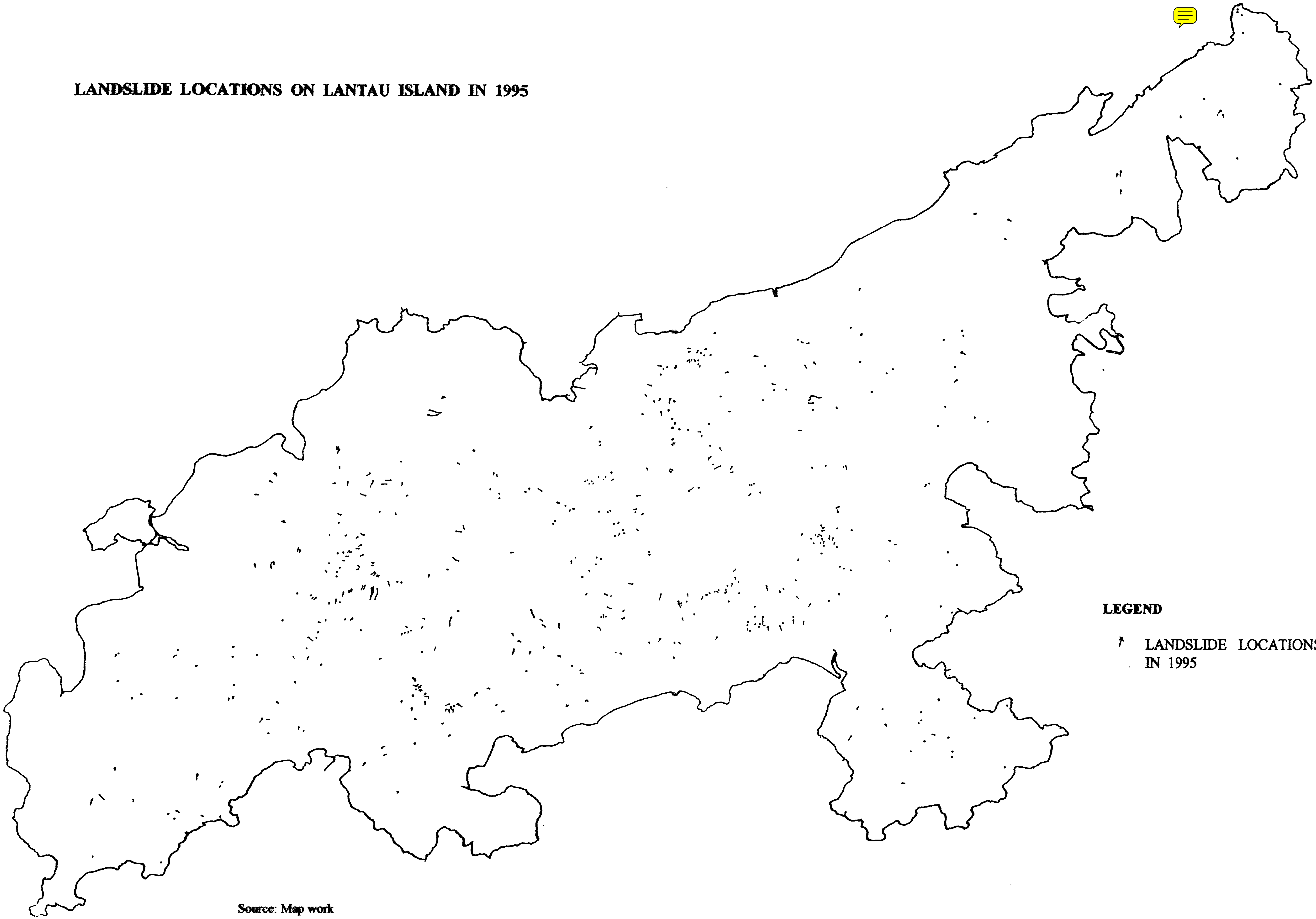
LANTAU ISLAND

Source: Survey & Mapping Office (1990)



Appendix G. Field visit routes

LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1995



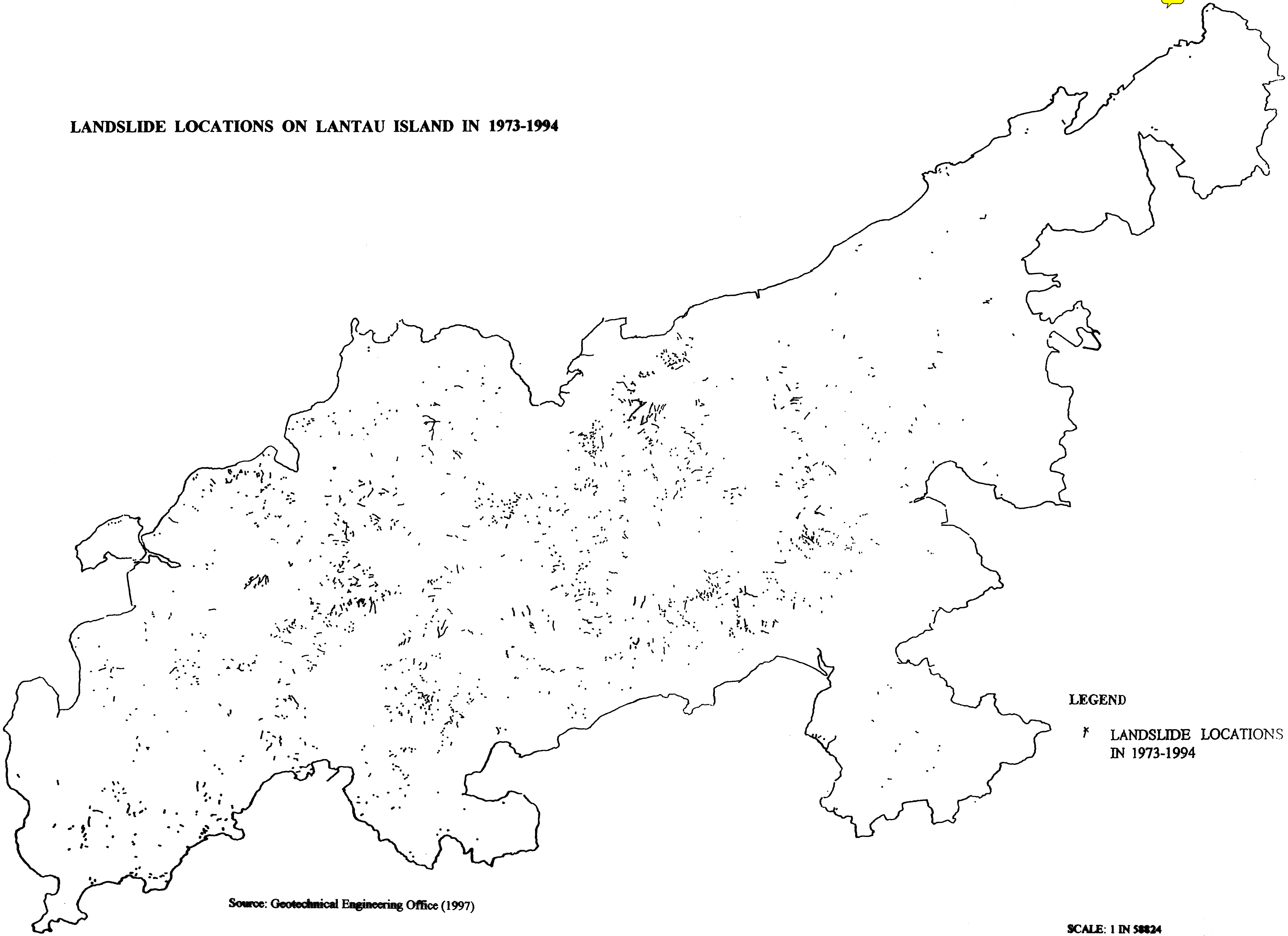
LEGEND

LANDSLIDE LOCATIONS IN 1995

Source: Map work

SCALE: 1 IN 58824

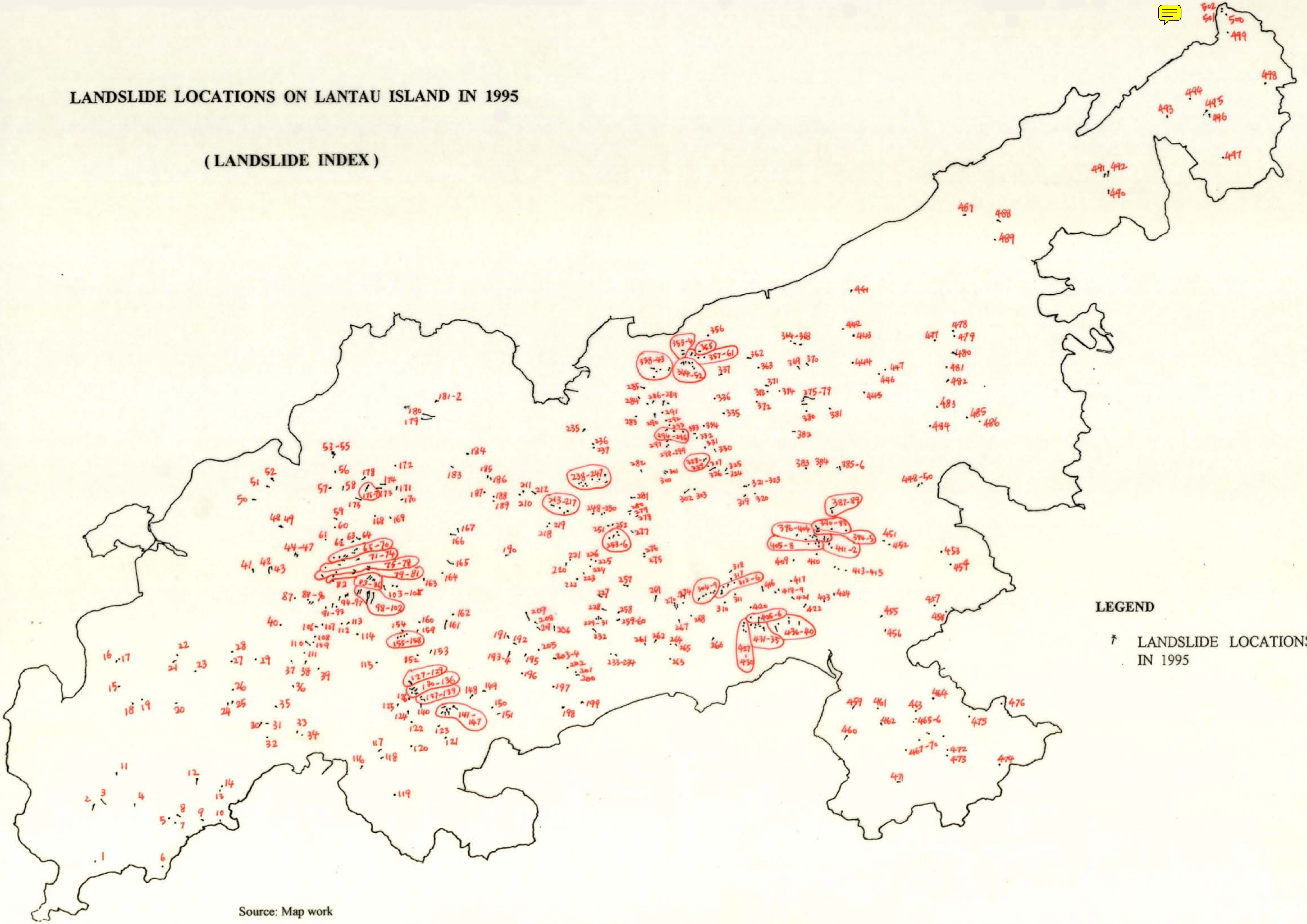
LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1973-1994



Source: Geotechnical Engineering Office (1997)

LANDSLIDE LOCATIONS ON LANTAU ISLAND IN 1995

(LANDSLIDE INDEX)

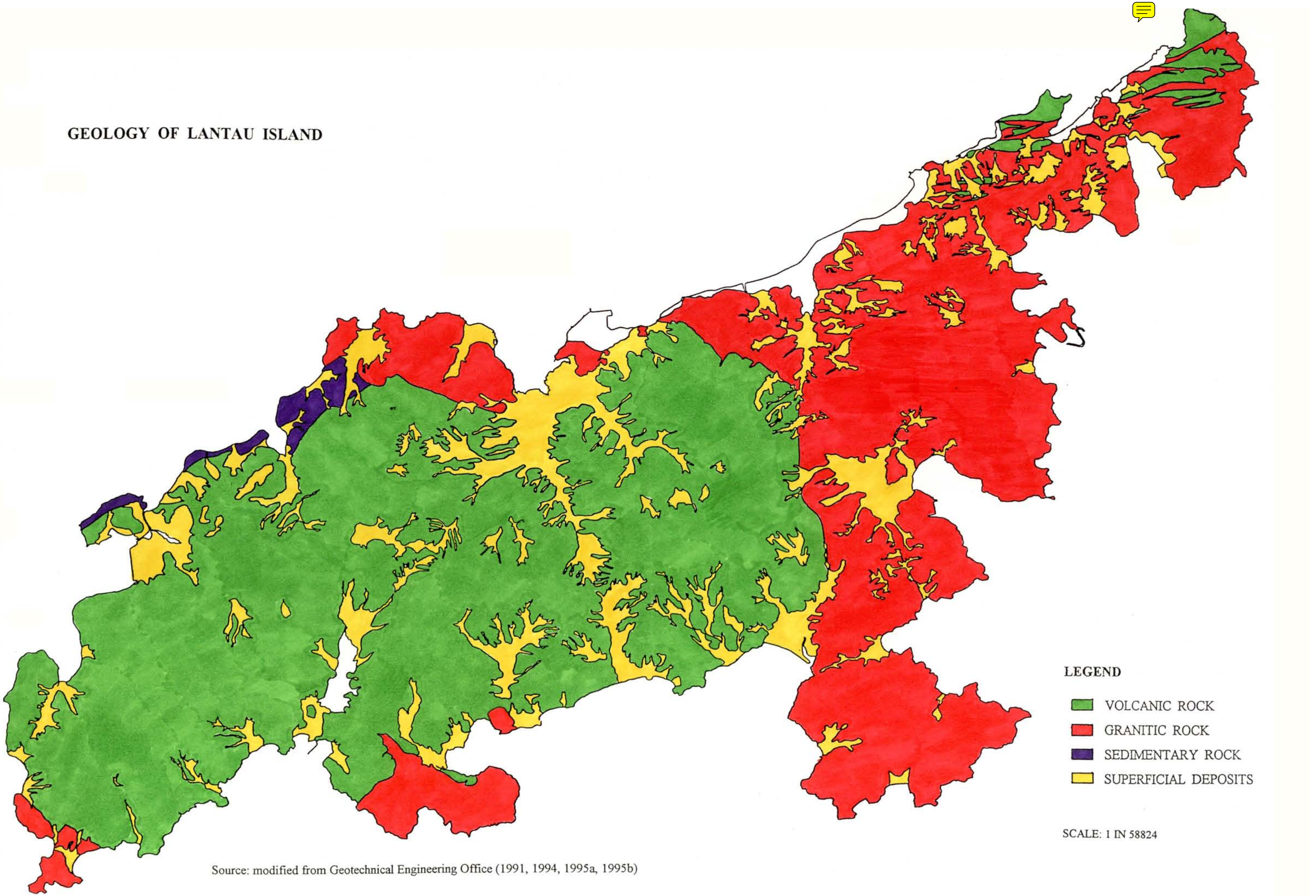


LEGEND

LANDSLIDE LOCATIONS IN 1995

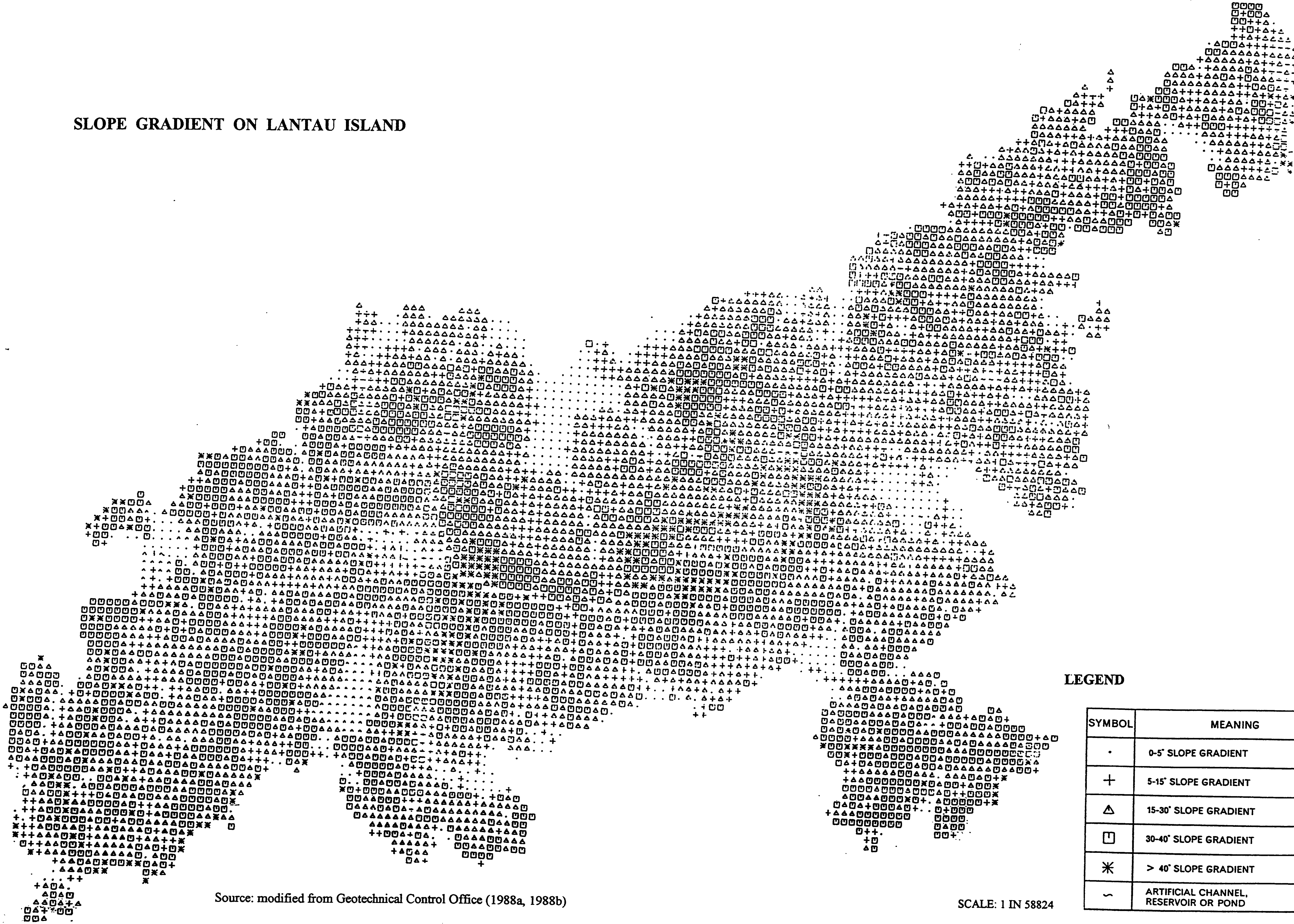
Source: Map work

SCALE: 1 IN 58824



Source: modified from Geotechnical Engineering Office (1991, 1994, 1995a, 1995b)

SLOPE GRADIENT ON LANTAU ISLAND

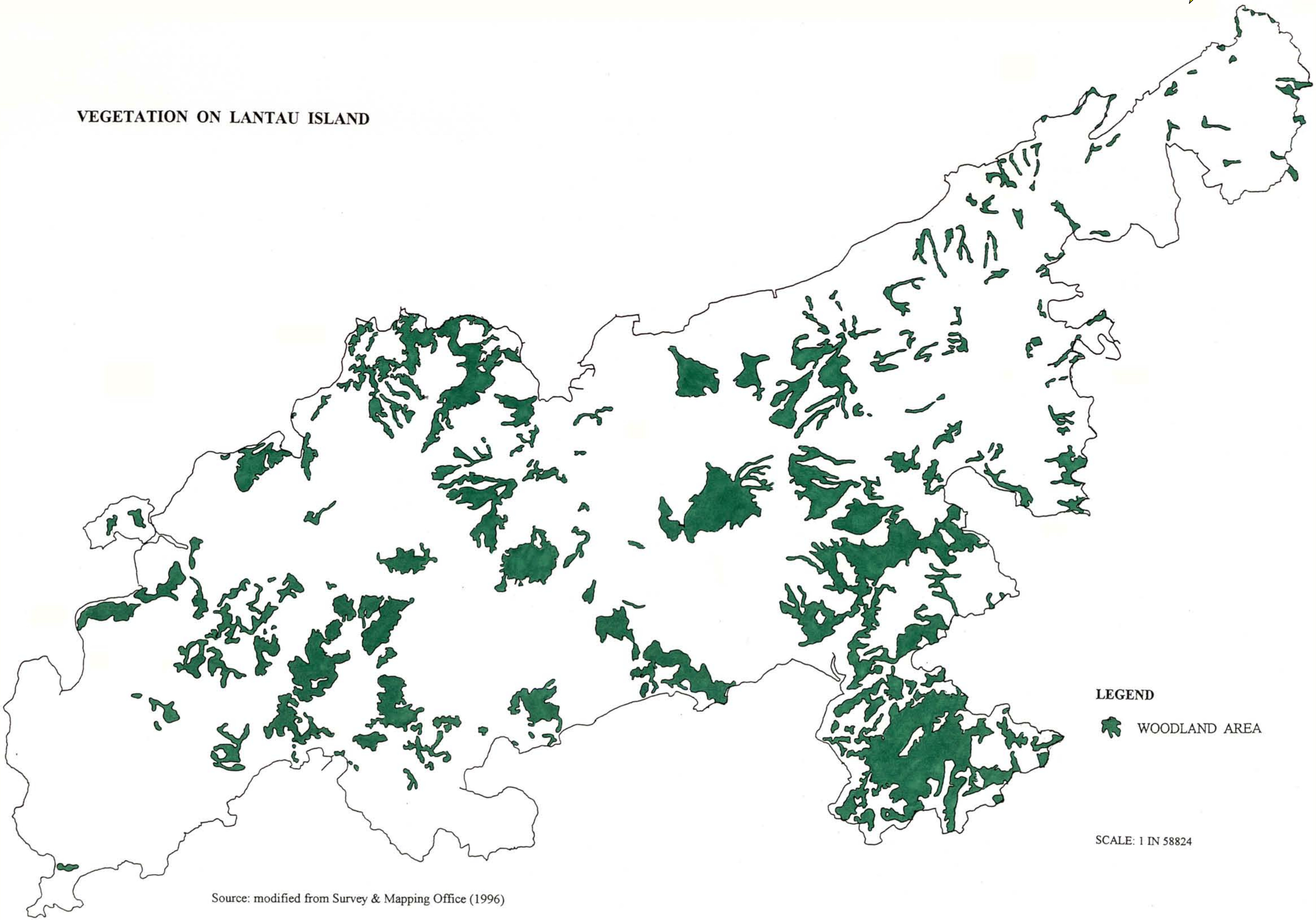


Source: modified from Geotechnical Control Office (1988a, 1988b)

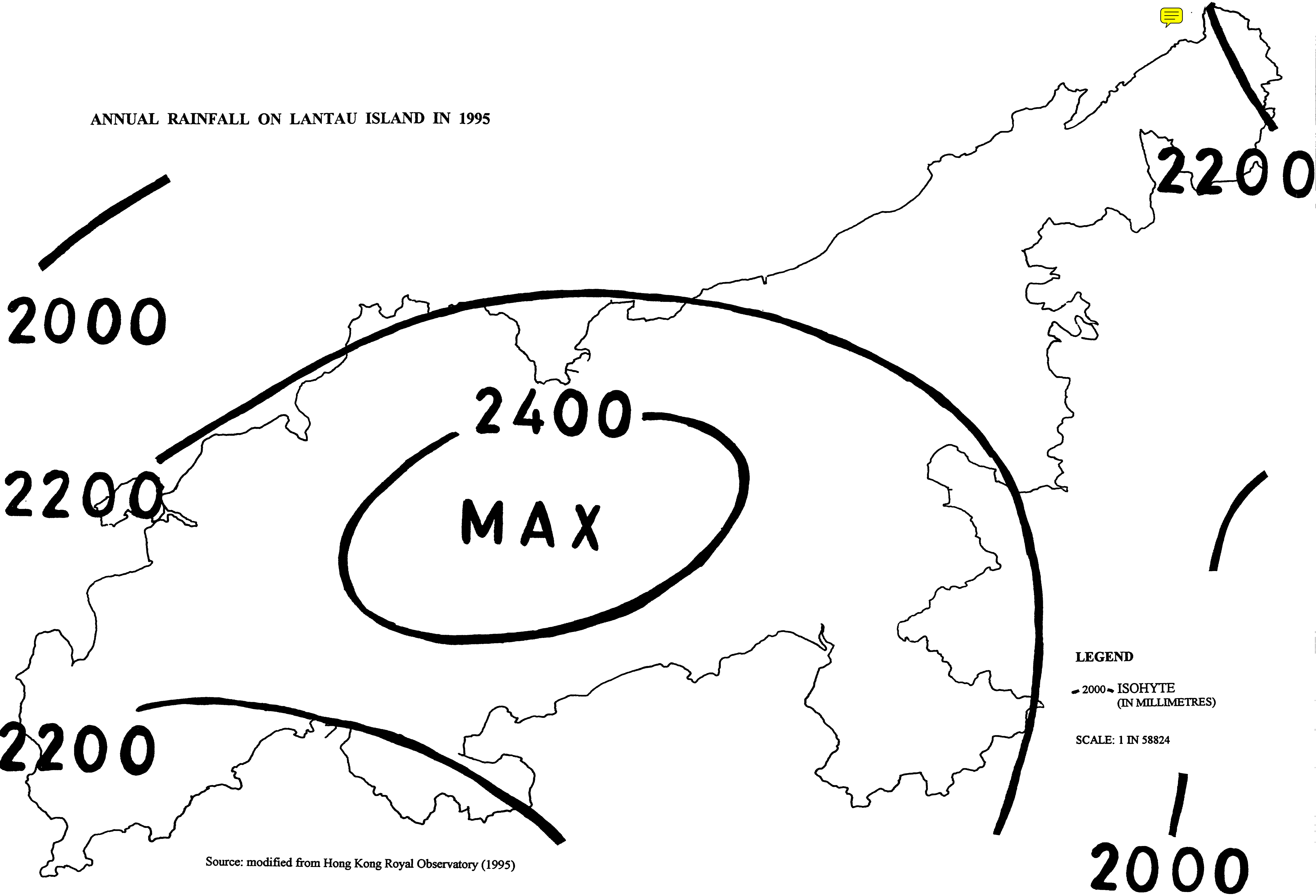
LEGEND

SYMBOL	MEANING
·	0-5° SLOPE GRADIENT
+	5-15° SLOPE GRADIENT
△	15-30° SLOPE GRADIENT
⊡	30-40° SLOPE GRADIENT
✳	> 40° SLOPE GRADIENT
~	ARTIFICIAL CHANNEL, RESERVOIR OR POND

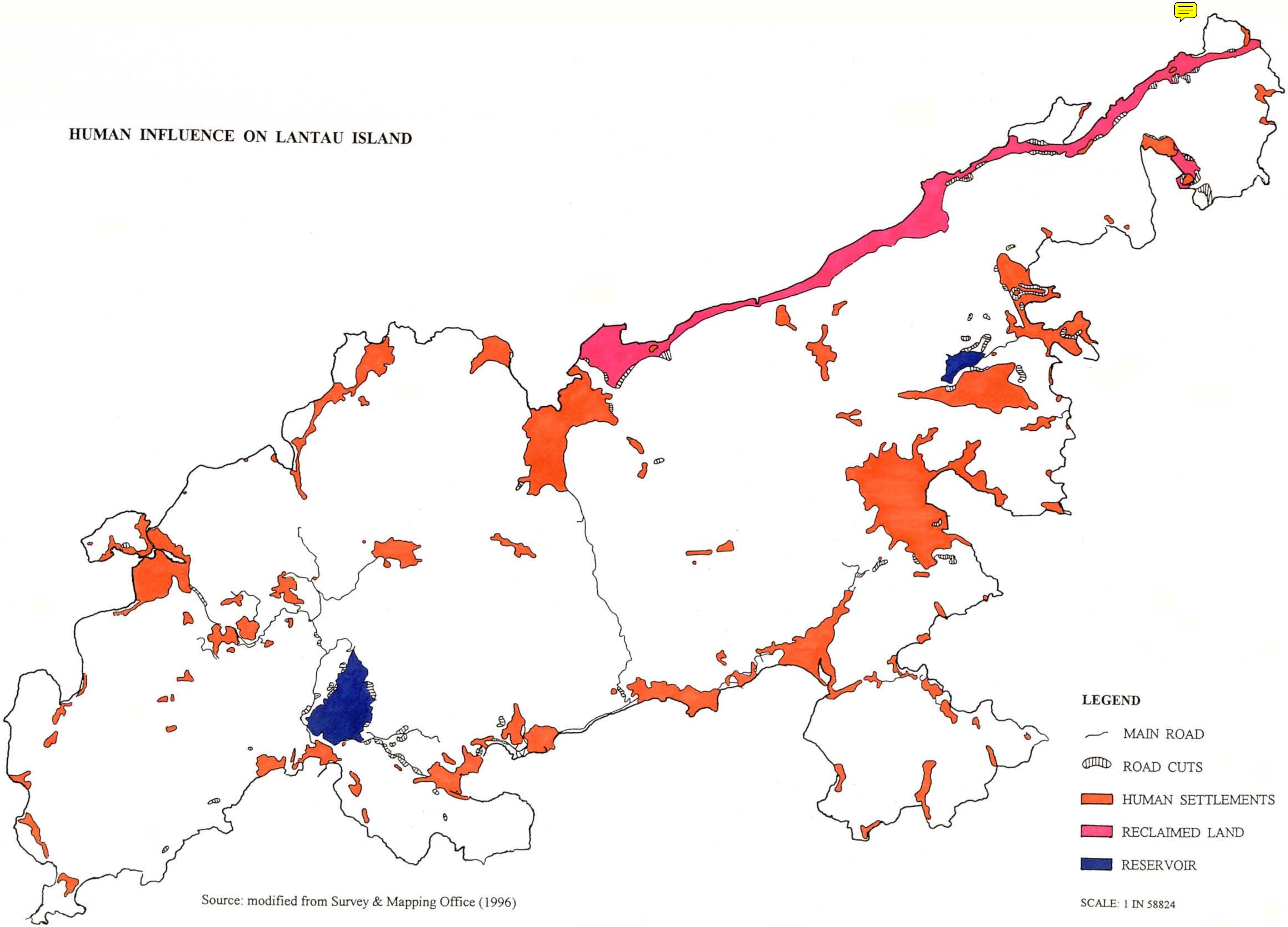
SCALE: 1 IN 58824


VEGETATION ON LANTAU ISLAND
LEGEND
WOODLAND AREA
SCALE: 1 IN 58824
Source: modified from Survey & Mapping Office (1996)

ANNUAL RAINFALL ON LANTAU ISLAND IN 1995



Source: modified from Hong Kong Royal Observatory (1995)


HUMAN INFLUENCE ON LANTAU ISLAND
LEGEND
MAIN ROAD
ROAD CUTS
HUMAN SETTLEMENTS
RECLAIMED LAND
RESERVOIR
Source: modified from Survey & Mapping Office (1996)
SCALE: 1 IN 58824