Geotechnical Area Studies Programme

GASP Report VI

North Lantau

Geotechnical Control Office
Civil Engineering Services Department
Hong Kong

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Cover Photograph: View from Western Hong Kong Island and Kowloon Peninsula towards North Lantau.

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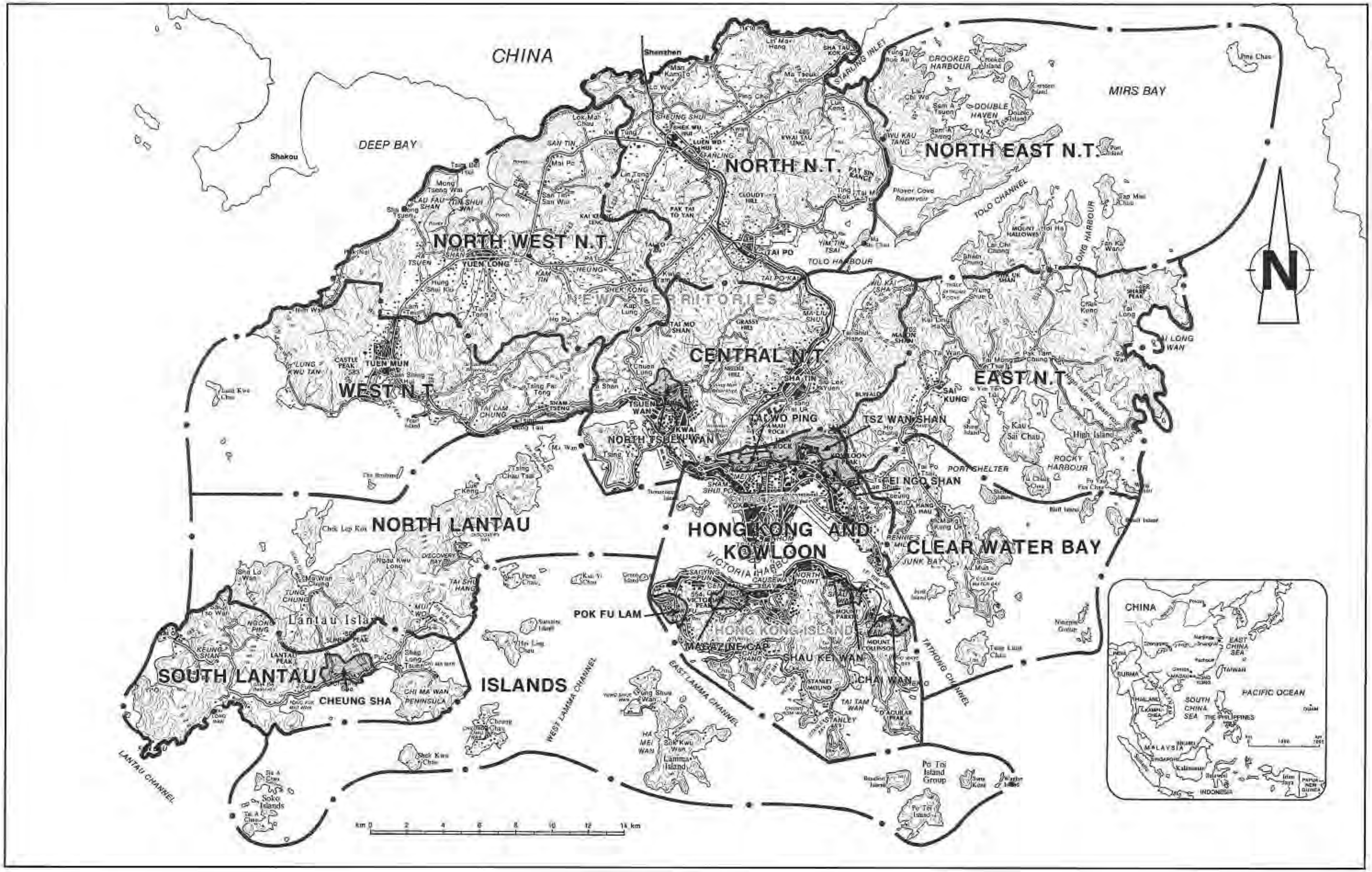

Map of the Territory of Hong Kong Showing the Locations of the Geotechnical Area Studies.
(Boundaries of the Regional Studies are shown by dashed lines and locations of District Studies are indicated by dark screens)

FOREWORD

This Report aims to provide an adequate geotechnical basis for the planning and land use management of North Lantau, mainly by way of information presented on a series of maps at a scale of 1:20 000. It is the sixth of twelve reports to be published as a result of the Territory-wide Geotechnical Area Studies Programme (GASP) carried out by the Geotechnical Control Office between 1979 and 1985.

GASP is based largely on terrain classification techniques using aerial photographs, together with field reconnaissance and the evaluation of a large number of existing site investigation records. It employs a unique system of terrain evaluation developed especially for Hong Kong conditions for the analysis and interpretation of the available data.

The GASP Reports were originally conceived as providing information almost solely for territorial land use planning, for which purpose the mapping scale of 1:20 000 is considered to be suitable. However, the information they contain also provides a good basis for engineering feasibility studies of large sites. The overall geotechnical assessment of a study area is presented on a series of six user-oriented maps. Three of these are supplied with this published Report—the Engineering Geology Map (EGM), Geotechnical Land Use Map (GLUM) and Physical Constraints Map (PCM). The GLUM classifies the terrain into four classes according to the level of geotechnical limitations, and the PCM presents the major physical constraints that are likely to influence development. In addition to the three maps accompanying this Report, the Terrain Classification Map, Landform Map and Erosion Map can be consulted in the Geotechnical Information Unit of the Geotechnical Control Office.

Users of GASP Reports should note that new 1:20 000 scale Hong Kong Geological Survey Maps and Memoirs will be prepared by the Geotechnical Control Office. These will provide more up to date geological information than is available in this Report. The Geological Maps which cover the North Lantau area, together with the accompanying Memoir, will be published by 1991.

This Report was originally produced in December 1981, for use within the Hong Kong Government on the basis of information assembled during the period October 1980 to April 1981. This fact should be borne in mind by users, who should also note that the contents of the Report have for the most part not been updated. Further, although every effort has been made to ensure the accuracy of the information contained in the Report, this cannot be guaranteed. The Geotechnical Control Office cannot therefore accept any liability for errors in the data or for misinterpretations made during the study.

It must be emphasised that this document was prepared for general planning and resource evaluation purposes. As a general rule, 1:20 000 scale maps, particularly the GLUM, should not be used to evaluate parcels of land smaller than 3 hectares in size, and should never be interpreted, reproduced or enlarged to a scale greater than 1:20 000. Failure to heed this warning could result in serious misinterpretation of the information they contain.

The GASP study was undertaken by a team of specialist Geotechnical Engineers in the Planning & Terrain Evaluation Section of the Planning Division of the GCO, which included Dr Burnett and Messrs A. Hansen, R. J. Morse and K. A. Styles. The Planning & Terrain Evaluation Section is led by Mr K. A. Styles, and the Planning Division is under the direction of Dr A. D. Burnett.

The Geotechnical Control Office acknowledges the co-operation and assistance given by the Commissioner of the Soil Conservation Service of New South Wales, Australia, who made available Mr R. J. Morse, a specialist Aerial Photograph Interpreter, to participate in the study. Acknowledgements are also due to the Survey & Mapping Office, Buildings & Lands Department of the Hong Kong Government, who provided most of the aerial photographs used in the study, a few of which are reproduced in this Report.

E. W. Brand
Principal Government Geotechnical Engineer
May 1988

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1. INTRODUCTION

1.1 The North Lantau Geotechnical Area Study

This Report presents the results of a 1:20 000 scale Regional Geotechnical Area Study of the North Lantau area which was carried out in the Geotechnical Control Office between October 1980 and April 1981. The area covered by the study, which is designated as GASP VI, is shown in Figures 1 to 3.

The study is based primarily on:

(*a*) Terrain classification using aerial photograph interpretation (API).

(*b*) Examination of geotechnical data collected from existing site investigation records and available literature.

(*c*) Field reconnaissance.

Subsurface investigations were not carried out specifically for this study.

This Geotechnical Area Study was based on the bedrock geology given on the 1:50 000 scale geological map produced by Allen & Stephens (1971). The mapping of the superficial deposits was carried out independently during the study.

It should be noted that the Geotechnical Control Office is at present remapping the whole Territory geologically to produce a new series of maps at a scale of 1:20 000, together with accompanying Memoirs. These will supersede both the bedrock geology and the mapping of superficial deposits presented in this Report. The new maps which cover the area dealt with in this GASP Report and the accompanying Memoir should be available by 1991.

1.2 The Geotechnical Area Studies Programme

The Geotechnical Area Studies Programme (GASP) was initiated by the Geotechnical Control Office in September 1979 with the aim of providing systematic geotechnical input for land management and development planning of the Territory of Hong Kong. The Programme encompasses the entire land area of the Territory at a scale of 1:20 000 and a number of selected areas at 1:2 500.

The GASP areas were selected so that the results of each Study can be used for the planning and engineering feasibility of future development. For this purpose, the study results are summarised on a series of maps.

The Geotechnical Area Studies were planned to be carried out in the following three phases:

(*a*) *Regional Study*—Initial geotechnical assessment (at a scale of 1:20 000) based entirely upon aerial photograph interpretation, site reconnaissance and existing geotechnical information.

(*b*) *District Study: Stage 1*—Initial geotechnical assessment (at a scale of 1:2 500), based entirely upon aerial photograph interpretation, site reconnaissance and existing geotechnical information, to provide a more detailed assessment of specific areas identified in the Regional Studies.

(*c*) *District Study: Stage 2*—Expanded geotechnical assessment, based upon the results of a Stage 1 Study together with data obtained from a planned programme of site investigation.

Twelve Regional Studies have been completed, which cover the Territory of Hong Kong. This is the sixth of the Reports to be published; six others will follow in due course. A number of District Studies: Stage 1 have been carried out, whilst these Reports are only for use within Government, some information in map form is available on request (see Section 1.7).

1.3 Aims of the Geotechnical Area Studies Programme

The Geotechnical Area Studies Programme (GASP) Reports produced for regional appraisal are designed for development planning and engineering feasibility at a scale of 1:20 000. They provide relatively specific physical resource information for the assessment of geotechnical limitations and the engineering geological characteristics of the terrain for outline and strategic planning purposes.

Nine terrain-related land resource factors are assessed in this study: slope angle, geological materials, terrain component, erosion and instability, slope aspect, relief, vegetation, existing land use and rainfall. All these factors are important for assessing the nature, degree and intensity of geotechnical constraint associated with the terrain. They are discussed in detail in Appendix A.

In this Report, the maps are presented in both a technical and a non-technical format to make the geotechnical information they contain usable by a wide readership. The non-technical aspects are designed for planners, landscape architects, estate surveyors and land agents, while the more technical discussion is designed for civil and geotechnical engineers and engineering geologists.

It should be noted that the need for appropriate site investigation is not obviated by the results of a Geotechnical Area Study.

1.4 Organisation of the Report

The main text, contained in Sections 1 to 4, provides a summary of the study and its findings. The figures are located after the references.

Section 2 describes the topography, geology, geomorphology, hydrology, vegetation, erosion, instability and land use of North Lantau area.

Section 3 provides an assessment of the material characteristics and summarises the technical findings of the study. Section 4 provides a geotechnical assessment for development planning and discusses suitability for development.

The conclusions are presented in Section 5, and Section 6 contains the cited references.

The figures are designed to explain and demonstrate the system used for compiling the maps from the data. Figure 13 illustrates the system, and Figures 14 to 19 are extracts from the set of maps. The full size originals of these maps are held by the Geotechnical Control Office.

A selection of stereotriplets and photographs follow the example figures and these are presented as Plates 1 to 16. These plates, together with Figure 2, provide a visual impression of the study area.

Appendix A provides details of the techniques used in the terrain evaluation system. Appendix B tabulates the terrain-related data from the study. Appendix C contains supplementary information on site investigations, aerial photographs and rainfall relevant to the study area. Appendix D discusses landform evolution and its relationship to engineering. A glossary of terms used in the Programme is presented in Appendix E.

A copy of the Geotechnical Land Use Map (GLUM), the Physical Constraints Map (PCM) and the Engineering Geology Map (EGM) of the study area are contained in the accompanying Map Folder. Information relating to the preparation and limitations of these maps is presented in Section 1.5 and in Appendix A.

1.5 Maps Produced within the Regional Study

1.5.1 *General*

Maps are available in two forms for a Regional GASP Report. They are prepared in conventional line form, and the information they contain is also summarised within a computer data bank for the production of computer-generated plots.

The conventional line maps are produced by standard cartographic processes, whereas the computer plots are totally machine generated. The conventional line maps are either completely or partially derived from the information stored on the Terrain Classification Map. Figure A1 in Appendix A shows the relationship between map type and the method of production.

The computer-generated plots are referenced to the Hong Kong Metric Grid, and information is stored within a grid cell framework. Computer-generated plots can be produced at various scales from 1:20 000 to 1:100 000.

There are six conventional line maps produced at a scale of 1:20 000 for this regional study area. The broad characteristics and purpose of each map is listed below. There are a number of general rules for the use of these maps, and these are discussed at Appendix A.9.

1.5.2 *Terrain Classification Map (TCM)*

This map records the general nature of the geological material (insitu, colluvial, alluvial, etc), slope angle, terrain component, erosion and instability. It forms the basis of the mapping system and is not designed for general distribution. The map is produced by aerial photograph interpretation and field work. An example is provided in Figure 14b.

1.5.3 *Landform Map (LM)*

This map is totally derived from the Terrain Classification Map, and it summarises the broad terrain pattern; slope angle and terrain component are delineated at a scale of 1:20 000. It is designed for the use of technical and non-technical users who require general landform data for planning purposes. An example is presented in Figure 18a.

1.5.4 *Erosion Map (EM)*

This map is totally derived from the Terrain Classification Map, and it delineates the broad pattern of erosion and instability at a scale of 1:20 000. It is designed for technical or non-technical users who require information regarding the general nature, degree and intensity of erosion and instability for planning and/or engineering purposes. An example is presented in Figure 19a.

1.5.5 *Geotechnical Land Use Map (GLUM)*

This map is totally derived from the Terrain Classification Map, and it delineates the general level of geotechnical limitation associated with the terrain at a scale of 1:20 000. It is designed for non-technical users who require general information relating to geotechnical difficulty of the terrain for development planning. A copy of the GLUM Classification System is presented at Table 1.1, and a detailed discussion is provided in Appendix A.7. An example of the map is provided in Figure 15a, and a copy of the map sheet is located in the Map Folder.

Table 1.1 GLUM Classification System

Characteristics of GLUM Classes	Class I	Class II	Subclass IIS	Class III	Class IV
Geotechnical Limitations	Low	Moderate		High	Extreme
Suitability for Development	High	Moderate	Moderate – Low	Low	Probably Unsuitable
Engineering Costs for Development	Low	Normal	Normal – High	High	Very High
Intensity of Site Investigation Required	Normal	Normal		Intensive	Very Intensive
Typical Terrain Characteristics (Some, but not necessarily all of the stated characteristics will occur in the respective Class)	Gentle slopes and insitu soils. Minor erosion on flatter slopes. Undisturbed terrain (minor cut and fill only).	Flat to moderate slopes. Colluvial soils showing evidence of minor erosion. Insitu soils which may be eroded. Reclamation. Rock outcrops. Poor drainage. Cut and fill slopes of low height.	Floodplain subject to periodic flooding and inundation.	Steep slopes. Colluvial and insitu soils showing evidence of severe erosion. Poor drainage. Cut and fill slopes of moderate height.	Combination of characteristics such as steep to very steep slopes, general instability on colluvium, severe erosion, poor drainage, high cut and fill slopes.

Note: This classification system is intended as a guide to planners and is not to be used for a detailed geotechnical appraisal of individual sites.

1.5.6 *Physical Constraints Map (PCM)*

This map is totally derived from the Terrain Classification Map, and it presents the major physical land resource constraints at a scale of 1:20 000. It is designed for technical or non-technical users who require information relating to the types of physical constraints which affect the terrain. It should be used in conjunction with the GLUM but is designed to stand alone as an assessment of the physical resources for general planning and engineering purposes. An example of this map is presented in Figure 16a and is discussed in detail in Appendix A.6. A copy of the map sheet is located in the Map Folder.

1.5.7 *Engineering Geology Map (EGM)*

Some of the information in this map is derived from the Terrain Classification Map, and some is compiled from other geological sources (Allen & Stephens, 1971). This map displays the broad pattern of geological materials at a scale of 1:20 000. It is designed for technical users who require engineering geological information for strategic planning and engineering purposes. An example is presented in Figure 17a and is discussed in detail in Appendix A.8. A copy of the map is located in the Map Folder.

1.5.8 *Computer-generated Maps*

Information from the Terrain Classification Map and other sources is summarised within the Geotechnical Terrain Classification System (GEOTECS). Land resource information is stored in a data bank management system which is referenced to the Hong Kong Metric Grid.

GEOTECS enables the rapid production of computer-generated plots which assist in the correlation of terrain attributes and other data on a Territory-wide basis. GEOTECS enables the interaction between land resources to be investigated, and permits the development of planning and engineering strategies. Computer-generated plots or tables can be based on any attribute or combination of attributes stored within the system. GEOTECS records data on a two-hectare grid cell basis and is recommended for use at a scale of approximately 1:50 000 for strategic planning and resource inventory purposes.

A number of computer-generated plots are presented which demonstrate the flexibility and multifunctional application of GEOTECS as a tool for resource evaluation.

1.6 Suitability of the Maps for Technical and Non-technical Use

The maps accompanying this Report are designed for a range of users with quite different professional backgrounds. In Table 1.2, each map is assessed in relation to its expected value to a variety of potential users. A number of professional groups which require geotechnical information (technical or non-technical) are highlighted. The list of five disciplines given in the table is by no means exhaustive, but it illustrates the potential of the maps for different requirements. A three-class user recommendation (Fundamental, Useful and Background) indicates the relative value of each map to users.

Table 1.2 Value of the Maps Produced in a Regional GASP Report

Type of Map	Value of the Maps Produced at 1:20 000 Scale for Regional Assessment (of sites generally greater than 10 ha in size)				
	—Strategic Planner —Town Planner	—Landscape Architect	—Estate Surveyor —Land Agent	—Civil Engineer	—Geotechnical Engineer —Engineering Geologist
GLUM*	Fundamental	Fundamental	Fundamental	Fundamental	Useful
PCM*	Fundamental	Fundamental	Background	Fundamental	Fundamental
EGM*	Background	Background	Background	Fundamental	Fundamental
LM	Useful	Useful	Background	Background	Background
EM	Useful	Useful	Background	Useful	Useful
TCM	Background	Background	Background	Background	Background
GEOTECS	Fundamental	Useful	Fundamental	Useful	Fundamental

* Located in the Map Folder accompanying this Report.

1.7 Access to GASP Data

Much of the data used in preparation of this Report and the maps not included in the accompanying Folder are available through the Geotechnical Information Unit (GIU) of the Geotechnical Control Office.

A number of large scale (1:2 500) maps produced within the GASP District Stage 1 Programme are also available for areas within the Territory. No District Studies Stage 1 Study has been completed within North Lantau.

2. DESCRIPTION OF THE NORTH LANTAU STUDY AREA

2.1 Geographical Location

The study area occupies approximately 7 400 ha in the northern part of Lantau Island, as shown in Figures 1 to 3. It includes the main development areas of Mui Wo and Tung Chung. The coastline of Lantau forms the eastern, northern and western boundary, but also included in the study area are the islands of Ma Wan and Chek Lap Kok. The southern boundary runs approximately east to west from the southern shores of Silver Mine Bay through Luk Tei Tong, along the major ridge line including Sunset Peak, Lantau Peak and Ngong Ping to the west coast at Sham Shek Tsuen. Selected information on the nearshore marine deposits, particularly in the vicinity of Chek Lap Kok, The Brothers and Ma Wan is included in this Report.

2.2 Topography

The topography of the area is characterised by a narrow coastal plain, which rises rapidly over undulating footslope terrain, to an almost continuous northeast trending range of hills with an elevation of about 700 m PD. This range forms the central spine of Lantau Island.

The narrow coastal plain lies parallel to the irregular and embayed coastline, and generally extends some 500 m to 1 000 m inland before giving way to the footslope terrain which occurs between the 50 m and 200 m contour.

The central range of hills forms the dominant feature of the topography in the study area. In addition to the main northeast trending range, there are three subsidiary northwest oriented spurs. Two of these lie north and south of the Ma Wan Chung to Wong Lung Hang Valley, and the third, and most prominent, extends from Lantau Peak via Ngong Ping to Sham Shek Tsuen.

The topography of the study area ranges in character from flat to precipitious. Table 2.1 gives the distribution of slope gradient within the area, and tables in Appendix B present information on the distribution of the terrain classification attributes and other land resources.

Table 2.1 Distribution of Slope Gradient

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

2.3 Geology

2.3.1 *General*

The bedrock geology of the study area consists of nearly equal proportions of volcanic rocks of the Repulse Bay Formation and the younger granitic suite of rocks. The volcanics are primarily situated in the southern half of the area, except for a narrow outcrop along the northern coast, including Ma Wan Island. The northern half of the study area, including the island of Chek Lap Kok and the adjacent San Tau/Sha Lo Wan headland, are composed of intrusive igneous rocks.

The bedrock materials, which are often heavily weathered insitu to form deep residual deposits, are sometimes overlain by deposits of younger superficial materials which are generally colluvial, alluvial or littoral in character.

The oldest rocks are the sandstones and siltstones of the Tai O Formation. These are sedimentary rocks which occur as a relatively small outcrop on the coast between Tai O and Tung Chung. They are apparently conformably overlain by the Repulse Bay Formation. These are rocks consisting mainly of pyroclastics with some sedimentary and water-laid volcaniclastic rocks. This sequence was possibly intruded, in a phased manner, by a massive batholith of various granitic rocks during the Upper Jurassic period. The batholith was of such regional extent across south China, that in the Territory, the older strata exist as roof pendants suspended on the granites. At a late stage of intrusion, numerous dykes were injected into both the early sediments and the newly emplaced granitic rocks, the latter containing the majority of the dyke rocks. A long period of quiescence possibly followed this sequence of tectonic activity. During this hiatus, prolonged weathering and erosion created an unconformity with the overlying sediments.

Extensive deposits of colluvium probably blanketed the landscape as a result of numerous individual episodes of mass wasting and erosion during the Quaternary. These episodes probably coincided with fluctuations in the palaeoclimatic regime.

In recent times, the alluvium and raised beach sediments were deposited under the combined influence of higher sea levels and fluctuating climatic conditions. The final phase in the geological evolution of the area has been the modification of the littoral sediments and the continued, but relatively reduced, formation of colluvium on mountain slopes and footslope terrain.

The locations of the various geological materials are presented in the Engineering Geology Map located in the Map Folder of this Report. The general distribution of the major geological units is summarised in the GEOTECS Plot in Figure 6.

The geological boundaries for the bedrock geology are based on those mapped by Allen & Stephens (1971). The boundaries for the superficial deposits are drawn from aerial photograph interpretation, fieldwork and a review of borehole information carried out for this study (Styles, 1983).

The Geotechnical Control Office is currently preparing a new series of geological maps of the Territory at a scale of 1:20 000. The new geological maps and memoir for the area should be published in 1991.

As a precursor to the geological remapping of the Territory, Bennett (1984 a, b, c) reviewed the superficial deposits, weathering, stratigraphy, tectonic history and metamorphism in the Territory. Further general geological information is presented by Atherton & Burnett (1986) and Brand (1988). From an historical perspective Davis (1952) is of considerable interest.

On the basis of this GASP study, the relative proportions of the geological materials are graphically illustrated in the Pie Chart in Figure 4, the GEOTECS Plot, Figure 6, and the percentages are presented in tabulated form in Table B6 in Appendix B.

The bedrock materials have generally been subjected to severe weathering. The depth of decomposition is determined by the relative resistance of the individual lithological units and groundwater regimes in association with the local geological structure. The granitic rocks tend to be the most deeply weathered.

The nature of the individual rock types and their general engineering behaviour and planning significance are discussed in Section 3 and summarised in Table 3.1.

2.3.2 *Tai O Formation*

The Tai O Formation occupies 0.6% of the area and outcrops across a 600 m wide coastal strip of foothills near San Shek Wan, at the northwestern extremity of the study area. Thinly bedded siltstones, black silty shales and sandstones form the lower member, whilst massive sandstones form the upper unit. The rocks, which are Middle to Lower Jurassic in age, are folded, faulted and metamorphosed. They strike parallel to the coast and dip to the southeast.

The contact between the Tai O Formation and the conformably overlying volcanics is evident on aerial photographs. The sandstones and siltstones form more rounded ridges with less severe gullying and more subdued topography than the volcanics of the Repulse Bay Formation.

2.3.3 *Volcanic Units—Repulse Bay Formation*

The Repulse Bay Formation consists of a succession of coarse tuffs, ignimbrites and generally acid lavas, which were deposited subaerially with several intercalated sedimentary units. All are of Middle Jurassic age. The Formation is severely folded and metamorphosed in places, probably as a result of the granite intrusion.

Within the study area, the Repulse Bay Formation consists of five discrete lithological units and a category of "Undifferentiated Volcanic Rocks".

(i) *Sedimentary Rocks and Water-laid Volcaniclastic Rocks (RBs)*
These rocks occupy a small proportion (0.4%) of the area, outcropping in central Lantau to the east of Tung Chung. They occur within the zone of undifferentiated volcanic sandstones and are continental lacustrine or fluviatile in origin. They are relatively thin and are commonly interbedded with thicker volcaniclastic sequences.

(ii) *Agglomerate (RBag)*
This is uncommon within the study area (occupying only 10 ha). It forms a prominent escarpment on the north side of Lantau Peak, where angular bombs of tuff in a lapillistone matrix may be found in impersistent beds.

(iii) *Coarse Tuff (RBc)*

This rock occurs as a continuous outcrop some 1 000 m wide stretching southwards from Ma Wan, along the north Lantau coast past Yam O Wan to Sham Shui Kok, covering an area of some 357 ha (4.8% of the area). It generally forms thick massive beds of coarse-grained crystal tuff without internal stratification; however, lithic lapilli, and more infrequently well formed volcanic bombs, are quite common. The coarse tuff horizons probably formed as a result of subaerial explosive eruptions. In composition, the rock is usually rhyodacitic or dacitic in nature, but in North Lantau the proportion of potassium feldspar is low, and the composition approaches that of a quartz andesite.

(iv) *Pyroclastic Rocks with Some Lavas (RBp)*

These rocks form a major unit of the Repulse Bay Formation on Lantau Island . A wide variety of rock types exist, including ignimbrites, fine tuff, lapilli and banded tuff. In outcrop, the rocks are generally pale green, creamy grey or white in colour, very fine-grained and weathered. Locally, the rock is interbedded with thin beds of water-laid epiclastic volcanic sandstone and pebbly sandstone. The unit occupies 6.7% of the area and occurs on the slopes west of Tung Chung. The main rock type is formed of explosively erupted fine grained tuff, and a thickness of about 1 000 m is estimated to be present in this locality.

(v) *Acid Lavas (RBv)*

Many of the lava flows within the Repulse Bay Formation are either too thin or are too irregularly exposed to be mapped. These are included with category (iv) above. However, in south Lantau it is possible to recognise two distinct, thick and continuous rhyolitic lava horizons. These extend into the study area northwest of Ngong Ping. The rhyolite is well banded and commonly contorted. The bands vary in thickness from a few millimetres to tens of millimetres. They are characterised by very thin layers which are free of phenocrysts, by a greater abundance of feldspar phenocrysts or by differences in colour or texture.

(vi) *Undifferentiated Volcanic Rocks (RB)*

In the central part of Lantau, dense vegetation and thick deposits of colluvium mask the bedrock. Within this area all the volcanic strata, except for small, locally well-defined units, are delineated as undifferentiated volcanic rocks.

2.3.4 *Intrusive Igneous Rocks*

A number of different intrusive igneous rocks occur within the regional batholith underlying the Territory. These rock types represent five phases of intrusive activity (Allen & Stephens, 1971). The first four are possibly part of a single episode of late tectonic intrusive activity, while the fifth is post tectonic. In the North Lantau area, representatives of all but the first and fourth phases occur, as shown in Table 2.2.

Table 2.2 Intrusive Igneous Rock Types in Hong Kong (Allen & Stephens, 1971)

Phase	Igneous Rock Type	Present in Study Area
1	Tai Po Granodiorite	No
2	Ma On Shan Granite Cheung Chau Granite Sung Kong Granite	Yes Yes Yes
3	Quartz Monzonite Feldspar Porphyry Dyke Swarm	Yes Yes
4	Granophyric Microgranite Needle Hill Granite Hong Kong Granite	No No No
5	Dolerite	Yes

(i) *Ma On Shan Granite (MS)*

This is essentially a grey or pinkish, massive fine-grained porphyritic granite with quartz phenocrysts up to 8 mm in length. These normally exceed the proportion of euhedral feldspar. Biotite is not normally visible to the unaided eye.

Within the area, the Ma On Shan Granite forms small, distinct intrusions southwest of Mui Wo and also at Lau Fau Sha northeast of Tung Chung. A fine-grained porphyritic granite which is mapped as quartz monzonite is probably Ma On Shan Granite. This is also exposed as a large intrusion in the eastern parts of the Sha Lo Wan area, and as numerous dykes in the western parts.

This fine-grained rock weathers easily to produce a fine sandy clay soil which may be subject to sheet and gully erosion.

(ii) *Cheung Chau Granite (CC)*
This is the most extensively outcropping granite on Lantau. It exists in two discrete areas; firstly, forming much of the coastal zone west of Tung Chung, and secondly, on Chek Lap Kok occurring over some 461 ha, or 6.2% of this study area. The rock is pale grey or pink when fresh and is generally medium to coarse-grained (3–5 mm) with very few feldspar phenocrysts. Mineralogically, this granite contains potassium feldspar, quartz (35–40% of rock), plagioclase (often andesine) and biotite. The potassium feldspar proportion is always more than 50% and frequently exceeds 65% of the total feldspar content. This granite weathers rapidly to form white or pale brown lateritic soils. Large pieces of quartz are derived from residual quartz veins. The hills underlain by this rock type are typically denuded of vegetation and incised by numerous erosion gullys.

(iii) *Sung Kong Granite (SK)*
Small mappable outcrops of Sung Kong Granite, totalling 67 ha, exist south and west of Mui Wo. In addition, this granite forms one of the three undifferentiated granites referred to in para (iv). The rock is usually pale grey or pink when fresh, coarse-grained, leucocratic and porphyritic. The main minerals are potassium feldspar, plagioclase, quartz and biotite. Phenocrysts of potassium feldspar, may reach 40 mm in length. This granite weathers readily to a pale brown or white sandy clay soil which typically contains large quartz grains. Differentiation between the Sung Kong and the Cheung Chau Granite and other acid intrusives is often difficult within the area.

(iv) *Undifferentiated Granite (G)*
The large granite intrusions of northeastern Lantau are dissected by a major northeast trending porphyry dyke swarm. The dyke rocks are more resistant to erosion than the granites and tend to dominate the topography. Detrital boulders of these dyke rocks tend to spread across the countryside far from the sites of the original intrusions. The superficial deposits conceal the more deeply weathered granites, making identification of the boundaries between types of granite both difficult and unreliable. However, rocks with similar characteristics to the Sung Kong, Cheung Chau and Ma On Shan Granites occur within the eastern Lantau area.

(v) *Feldspar Porphyry Dyke Swarm (La)*
Three types of feldspar porphyry occur in the study area:

(*a*) A granodiorite porphyry which contains large (up to 40 mm) euhedral phenocrysts of white plagioclase set in a grey or black aphanitic groundmass.

(*b*) A granite porphyry which contains pink feldspar phenocrysts in a pinkish-brown, grey or purple, fine-grained phaneritic groundmass.

(*c*) A granite porphyry with small phenocrysts has been recognised by Allen and Stephens (1971). The difference between this rock and the common granite prophyry is based solely on the small size of the phenocrysts (less than 10 mm).

Most of the dykes are less than 30 m wide but can be very long. Many exist in closely spaced groups, and these in particular, are difficult to trace for any great distance. Outcrops of country rock are always present but may occur only as thin lenses. The country rocks are normally intrusive igneous rocks, although in parts of northeastern Lantau, the dykes intrude coarse tuff.

Quartz porphyry dykes exist on Chek Lap Kok, northwest of Tung Chung and on Ma Wan. These follow a similar trend to the main feldspar porphyry dyke swarm.

A small number of quartz veins cut across the main dyke swarm in northeast Lantau, trending generally west northwest.

(vi) *Dolerites (D)*
Basic dyke rocks of relatively minor thickness and extent are found throughout the study area. These intrusions are assessed by Allen & Stephens (1971) as being of two main ages. They form part of the main, northeast trending Phase 3 dyke swarm, where they are generally younger than the porphyry dykes.

They also occur in various cross-cutting configurations where they are likely to be of Phase 5 age.

Excluding the areas covered by superficial deposits, the intrusive igneous rocks outcrop across 3 107 ha, which is approximately 42% of the area.

Many members of the intrusive igneous rock suite have similar physical properties and, from a general engineering point of view, appear to behave in a similar manner.

2.3.5 *Superficial Units*

In addition to the solid geology, both natural and man-made superficial deposits occur and they constitute some 27.3% (2 032 ha) of the land surface. These superficial deposits are classified as follows:

(i) *Colluvium*

The colluvial materials occur over 1 467 ha or 19.8% of the study area. These deposits are formed by gravity transport of rock and soil debris downslope, and occur as recent or relict deposits. They are very heterogeneous in their physical properties and, in this Report, are subdivided only on the basis of the parent rock type.

These deposits occur primarily on footslopes associated with steep mountainous terrain. Most of the colluvium in the area is derived from granitic detritus (Table 2.3). The colluvium derived from volcanic detritus forms deposits which tend to be relatively thicker and more continuous than deposits formed from the granites or from the feldspar porphyry dyke swarm.

Table 2.3 Distribution of Colluvium

Type of Colluvial Detritus	% Total Colluvium	% Total Area	Area (ha)
Volcanic	45.6	9.0	669
Granitic (including Feldspar porphyry dyke swarm)	54.0	10.7	792
Metasedimentary	0.4	0.1	6
Total	100.0	19.8	1 467

The colluvial deposits consist of a wide range of materials from silty and sandy fine slope wash typical of the granites, through sandy cobble and sandy boulder beds, to boulder fields. In some cases, voids and tunnels occur along drainage paths and beneath stream courses. There is usually no surface expression of these subsurface features.

The colluvium derived from the volcanics is characterised by a diverse variety of cobble size and boulder size fragments within a matrix of fine material. There is generally no apparent uniformity in weathering of the detrital fragments, although in some of the older deposits complete weathering may be evident.

Within the study area the main concentrations of colluvium occur as extensive continuous deposits of detrital material radiating from Sunset Peak onto the downslope terrain. Similar deposits occur on the terrain on the north facing flanks of the ridge linking Lantau Peak and Ngong Ping peak. Both these concentrations occur on volcanic bedrock. The extent of a typical deposit is of the order of 500 by 300 m, with the long axes coinciding with the drainage lines.

In the northern portion of the study area, the colluvial deposits formed from the granitic and porphyritic rocks are not so extensive or well defined. A typical deposit is of the order of 400 by 100 m in size.

(ii) *Alluvium*

The main deposits of alluvium within the area occur at Mui Wo and Tung Chung, adjacent to major stream courses. The alluvial flat behind Mui Wo is probably an infilled lagoon which formed behind a sand bar beach at the head of Silver Mine Bay. The deposits at Tung Chung may represent the infilling of a former lagoon. A total of 455 ha (6.1%) of the area is covered by these materials.

(iii) *Littoral Deposits*

These deposits are of limited extent and are essentially confined to local storm beaches and raised beaches. They form only 1.0% (75 ha) of the area.

(iv) *Marine Deposits*

On the sea bed and beneath reclamation, deposits of soft marine muds and shelly sands may be found.

(v) *Reclamation*

Approximately 0.5% (33 ha) of surface of the study area is covered by reclamation. The material used for reclamation is highly variable in nature and may contain weathered and fresh rocks, old sea walls or refuse.

(vi) *Fill*

Fill is associated with site formation and other engineering construction practices. The engineering behaviour of the material depends to a great extent on the degree of compaction at the time of emplacement.

The North Lantau study area contains a wide variety of geological materials, and the engineering behaviour of foundations and slopes can be expected to vary accordingly.

A description of the geology of the entire Territory is available in the Report of the Geological Survey of Hong Kong (Allen & Stephens, 1971). This work will be updated by the revised geological mapping of the Territory; the new maps and Memoir for Lantau will be available by 1991.

2.4 Geomorphology

2.4.1 *General*

The geomorphology of the North Lantau area reflects a complex Quaternary history of erosional and depositional response to climatic change and eustatic sea level fluctuations. Individual landforms are continually evolving, as determined by the local balance between rapid weathering rates and denudation from intense seasonal rainfall. A description of the mechanics of the weathering process and its engineering significance are contained in Appendix D.

Table B5 in Appendix B provides data on the distribution of the major landform units. A comparatively large area of sideslopes exists with moderate to steep slope gradients, but there is only a relatively limited area of alluvial deposits. The distribution of slope gradients is illustrated in the GEOTECS Plot, Figure 5.

2.4.2 *Volcanic Terrain*

Two major types of volcanic terrain exist in the study area. The dominant feature of the relief in Lantau is the 'U-shaped' ridge which surrounds the Tung Chung Valley and includes Lantau Peak (934 m high) and Sunset Peak (869 m). This feature is evident on the satellite image reproduced as Figure 2. The side-slopes of this ridge are highly dissected and possess long straight profiles. Local variability in the joint spacing gives rise to many rock outcrops and boulders on the slopes. Ma Wan and the northeast corner of Lantau are also formed of volcanic terrain; however, with a maximum elevation of 273 m, this area of low relief is only slightly dissected.

2.4.3 *Granitic Terrain*

Granitic terrain exhibits typically rounded topography. The maximum relief in the area is some 360 m. The majority of ridge crests are eroded, and are weathered to greater depth than on the volcanic terrain. Many of the upland depressions contain intermixed colluvial and alluvial deposits.

Numerous east northeast trending dykes of the feldspar porphyry dyke swarm create a subparallel pattern of ridges and depressions on the upland topography. Consequently, slope profiles are irregular. Maximum elevation of this terrain is 428 m.

2.4.4 *Colluvial Terrain*

Colluvial deposits exist over approximately 19.8% of the study area. Deposits are delineated, if they are of significance to engineering, at a scale of 1:20 000 (Styles, 1983). The mapped distribution is shown on the Physical Constraints Map and the Engineering Geology Map, and is summarised on the GEOTECS Plot, Figure 6. A breakdown of the 1 467 ha of colluvial terrain according to slope angle is also summarised in Tables 2.4 and B5 in Appendix B. Approximately 696 ha is less than 15° in slope angle. There is 771 ha within the 15 to 30° slope range. Almost 68% of the deposits which occur within the latter slope range are located on terrain which is subject to possible groundwater flow.

Colluvial deposits exist over much of the footslope terrain in the study area and occur as extensive blankets, such as in the Tung Chung Valley. Some of the colluvial deposits may exceed 30 m in thickness, but they are often deeply dissected by valleys which contain many boulders. These boulders may have been exhumed by erosion of the colluvial mass or may have been deposited by recent landslip activity. The amount of incision into the colluvial fans is dependent on the gradient and catchment area of the drainage system. Boulders are common on the surface of the majority of colluvial deposits. Much of the colluvium on steeply sloping terrain occurs within drainage lines and stream courses. These drainage lines discharge across flatter footslopes where relatively thick deposits of colluvium are common. The footslope terrain, which is subject to periodic inundation, is important because the likelihood of slope failure is higher than on adjacent relatively well drained areas of colluvium.

Table 2.4 Slope Gradient on Natural Colluvial Terrain

Slope Gradient	% of Colluvium Occupied by Drainage Plain	% of Total Colluvium	% of Total Area	Area of Colluvium (ha)
0– 5°	32.8	8.5	1.7	125
5–15°	52.2	38.9	7.7	571
15–30°	68.0	52.6	10.4	771
Total	58.8	100.0	19.8	1 467

Streams which exist in bedrock areas may disappear underground upon reaching colluvial deposits. Large natural 'tunnels' or 'pipes' occur as voids in the colluvium (Nash & Dale, 1983). The build-up of pore water pressures within colluvium during periods of rainfall is an important factor in the stability of the material.

Within the Territory, there is considerable evidence of instability associated with low angle (less than 15°) colluvial slopes in this type of hydrogeological setting. Approximately 49% of the colluvial terrain with slope gradients up to 15° is subject to concentration of surface runoff. These areas, known as drainage plains, require careful planning and land use management to minimise the likelihood of slope failure.

Some areas of colluvium display a hummocky, irregular surface which may reflect potential or previous instability. These areas are identified on the Physical Constraints Map and Engineering Geology Map.

2.4.5 *Alluvial Terrain*

The alluvial terrain is usually flat or gently sloping. There is a complex interrelationship between colluvium and alluvium, and lobes of colluvium frequently interdigitate with alluvial sediments.

Some alluvium is obscured by disturbed terrain, but the areas involved are generally too small to be recorded in the GEOTECS data bank. The terrain in these areas is usually flat or gently sloping but may also have a veneer of fill. Colluvial lenses or more extensive detrital bodies, may also exist within the alluvial sequence, and both deposits may extend below the marine deposits.

The alluvial and colluvial deposits started to infill the major valleys following the cessation of downward incision produced by the lowering of sea level during the Pleistocene. As sea level was lowered by up to 80 m, it is probable that the alluvium or colluvium could extend below present sea level to a depth up to this figure. The actual depth is dependent on how far sea level fell, and on how much incision occurred before the onset of rising sea level.

Sea level has also been slightly higher than at present, leaving small raised beach and raised alluvial terrace features in various parts of the lowland terrain. There is evidence for a higher sea level on Lantau and in the northwest New Territories. This possibility should be considered during the interpretation phase of any site investigation.

2.5 Surface Hydrology

The surface hydrology of North Lantau is based on four major catchment areas, each containing a number of subsidiary catchments, and a large number of smaller basins on the coastal slopes. The boundaries of the major natural catchments are indicated on the Engineering Geology Map and are classified in accordance with the method devised by Strahler (1952), which is described in Appendix A. 8.

The major catchments are South Tung Chung, East Tung Chung, Mui Wo and Tai Ho.

(i) *South Tung Chung Catchment*
This is the largest catchment area, occupying approximately 1 120 ha, and is located south and west of Tung Chung, on volcanic terrain. It drains the slopes of Lantau Peak and the western slopes of Sunset Peak, in two subcatchments which coalesce within the area of the Tung Chung floodplain. The western subcatchment exhibits a dendritic drainage pattern, whilst the eastern subcatchment is very elongated because the main drainage line has developed along a major line of structural weakness. This line appears as a photolineament.

(ii) *East Tung Chung Catchment*
This catchment drains the northern slopes of Sunset Peak and the western slopes of the main ridge between Tung Chung and Mui Wo. It occupies approximately 7 ha of volcanic terrain and exhibits a dendritic drainage pattern, modified along two photolineaments. A nullah system carries the discharge across the low-lying floodplain which joins the floodplain of the South Tung Chung catchment.

(iii) *Mui Wo Catchment*
This catchment occupies approximately 650 ha and contains two distinct subcatchments which converge at the Mui Wo estuary. The southern subcatchment drains the volcanic terrain of the upper sideslopes and the granitic terrain of the lower sideslopes and footslopes on the eastern side of the Sunset Peak ridgeline. The drainage pattern within the northern subcatchment is controlled by the east northeast structural trend of the feldspar porphyry dyke swarm on the granitic terrain; particularly within the dissected plateau area around Wong Kung Tin. An extensive floodplain area is common to both subcatchments.

(iv) *Tai Ho Catchment*
This catchment occupies 450 ha and drains the northern slopes of the central part of the study area. Many of the tributaries are controlled by the east northeasterly structural trend.

The drainage patterns within the major catchments are influenced by two types of structural control. North Lantau is cut by many photogeological lineaments. These features, which are shown on the Engineering Geology Map, are evident on aerial photographs. Under stereoscopic examination, they form depressions containing drainage lines. Subparallel east northeast trending structural control is produced by the feldspar porphyry dyke swarm.

2.6 Vegetation

In this Report, a nine class classification system is used to distinguish broad categories of vegetation type. The spatial distribution of these groups is illustrated in the GEOTECS Plot, Figure 7, whilst Figure 4 shows their relative proportions. About 4.3% (316 ha) of the study area is devoid of vegetation, due to man's disturbance. Denudation within the study area is generally the result of site formation and, to a lesser extent, soil erosion on the granitic terrain. The data is presented in Table B7 in Appendix B.

The vegetation classes are as follows:

(i) *Grassland*
This class generally consists of indigenous or introduced grass species which occur naturally, or after the clearing of shrubland or woodland. Grassland occupies 3 446 ha (46.6%) of the study area, if occurs on the ridges and upper sideslopes of Sunset Peak and Lantau Peak, and covers most of the terrain north and northeast of Discovery Bay.

(ii) *Cultivation*
This class occupies 353 ha (4.8%) of the study area. Most of the agricultural activity has now ceased but some horticulture remains around Mui Wo, Tung Chung and Sha Lo Wan.

(iii) *Mixed Broadleaf Woodland*
This class may contain a wide variety of native and exotic species. Small areas of woodland occur in valleys at Sha Lo Wan, Tei Tong Tsai, southwest of Pak Mong, Mui Wo and Yam O. A total of 216 ha (2.9%) is covered by this class.

(iv) *Shrubland (Less than 50% Ground Cover)*
Shrubland occurs as regrowth on areas which have been affected by disturbance of one form or other. Shrubland generally develops after grassland, particularly in areas protected from hill fires. This class occupies 939 ha (12.7%) and is common on sideslope terrain throughout the area.

(v) *Shrubland (Greater than 50% Ground Cover)*
This class is similar to the above but is characterised by denser growth. It covers 1 954 ha (26.4%) and is scattered throughout the undeveloped land, mostly on sideslope terrain.

(vi) *No Vegetation on Natural Terrain*
Predominantly bare soil which is presently, or has in the recent past, been affected by moderate or severe soil erosion, is usually marked by an absence of vegetation. This terrain occupies 165 ha (2.2%) of the study area. It occurs mainly on ridge and spur crests and upper sideslopes mostly underlain by intrusive igneous rocks, and on the littoral zones along the coast.

(vii) *No Vegetation due to Man's Disturbance*
Approximately 318 ha (4.3%) of the study area is affected by development and associated activities. Existing development is discussed in Section 2.8.1.

(viii) *Rock Outcrop*
Rock outcrops may contain sparse intermittent grass and shrubland vegetation, but the terrain is predominantly rock with little soil. Areas of rock outcrop are generally too small to be identified for the GEOTECS data bank, in which only 2 ha of rock outcrop are recorded.

(ix) *Waterbodies*
Natural streams, man-made channels and reservoirs, occupy some 8 ha of the study area, and a further 2 ha is occupied by ponds.

Vegetation cover influences the intensity of denudational processes, both by its effect on hillslope hydrology, and by exerting a degree of control on the shear strength of the soil mantle. A well developed vegetation cover acts to trap precipitation on both the plants and in the soil litter, thus reducing both volume and velocity of surface runoff. This protects the soil from erosion but promotes infiltration, which may have a detrimental effect on stability. Evapotranspiration rates are also improved by a healthy vegetation cover. Root systems act to bind the soil together, thus increasing the shear strength of the soil mantle and reducing the hazard of shallow slope failures (Carson & Kirkby, 1972). One significant effect of a substantial vegetation cover is that it reduces the degree of erosion on undisturbed natural terrain. Some of the erosion observed on the natural terrain is associated either with minor disturbance by man (footpaths triggering gullying), or with minor gullying associated with the headward extension of drainage lines.

The variation in the vegetation pattern across the area is a product of the relationship between the soils, the microclimate (aspect, exposure and elevation) and human influence. Hill fires have reduced woodland vegetation to shrubland or grassland over much of the terrain. Even the low broadleaf woodland which does exist often has a high density of thin young trees, with a dense shrub ground cover rather than the more open woodland associated with native stands. This dense ground cover is associated with regrowth.

Vegetation in Hong Kong is characterised by a wide range of species; approximately 2 350 species occur in the Territory, according to Thrower (1970). In fact, there are representatives of some 50% of the world's 441 plant families. This may have implications for the use of vegetation as a means of controlling erosion and surface instability because it indicates that growing conditions, at least for part of the year, are suitable for an extremely large number of species. Many of the strains used successfully to control erosion in other countries may be suitable for use within the Territory.

2.7 Erosion and Instability

2.7.1 *General*

The surface condition of the terrain is classified on the basis of the major forms of erosion. The presence of slope failures or instability is also recorded within this attribute.

Areas subject to erosion are classified as 'sheet', 'rill' or 'gully' erosion. Each of these classes is subdivided into three subclasses: minor, moderate or severe. Instability is subdivided into the basic classes of 'well-defined landslips', 'coastal instability' and 'general instability'. A final category of 'no appreciable erosion' is used for those areas that show no evidence of either instability or erosion.

The areas affected by the severe forms of erosion and slope instability are shown on the Physical Constraints Map, and the latter on the Engineering Geology Map. A summary of the distribution of erosion and instability is given in the pie chart in Figure 4, is tabulated in Tables 2.5, and B2 in Appendix B, and is illustrated in the GEOTECS Plot, Figure 8.

Erosion and instability affect 25.9% (1 914 ha) of the study area. Only some 4.2% (310 ha) of the study area is currently developed, within which erosion is restricted to unprotected platforms and slopes. In the study area, approximately 2 605 ha of terrain is subject to severe erosion or instability.

Table 2.5 Erosion and Instability

	Erosion		% of Total Area	Area (ha)
Instability				
	—well-defined landslips		<0.1	2
	—coastal instability		<0.1	4
	—general instability		25.8	1 908
Appreciable Erosion	Sheet erosion	—minor	16.5	1 222
		—moderate to severe	29.1	2 156
	Rill erosion	—minor	0.1	8
		—moderate to severe	0.3	18
	Gully erosion	—minor	4.5	333
		—moderate to severe	5.0	373
No Appreciable Erosion			18.6	1 379
			100.0	7 403

2.7.2 *Erosion*

(i) *Sheet Erosion*
This form of erosion produces extensive areas of bare ground devoid of vegetation and is common within north Lantau, due to the predominance of grasslands. A total of 3 378 ha (45.6%) of the study area is affected.

(ii) *Rill Erosion*
This form of erosion is usually associated with cut and fill batters but may also occur on natural terrain. It is characterised by numerous subparallel drainage rivulets, which produce a striated appearance and result in significant soil loss. Within the study area, it is a minor class affecting less than 0.4% (26 ha) of the terrain. No geographic pattern is discernible.

(iii) *Gully Erosion*
This form of erosion produces deep dissection of the surface with consequent disruption of drainage, and it may precipitate slope instability. It affects 9.5% (706 ha) of the study area, mainly on the granitic terrain and on colluvial terrain subject to incision by steep, fast-flowing streams.

When all the forms of erosion are considered together, they account for a significant level of soil loss. These erosional forms do not in themselves constitute slope instability, but they do indicate areas that may become unstable if adequate consideration is not given to drainage and other geotechnical factors during development and redevelopment.

2.7.3 *Instability*

The term 'instability' is used in this Report to refer to 'well-defined landslips' and terrain over which there is 'general instability'. It provides an indication of the inherent weakness of the terrain and/or the occurrence of unfavourable groundwater conditions. Expensive slope stabilisation works may be required to permit development of natural unstable areas.

The term 'well-defined landslip' refers to the scar and debris associated with a slope failure. Only landslips larger than 1 ha are delineated at the mapping scale of 1:20 000. It is difficult to define very small features and individual landslip scars within a terrain classification system designed for use at 1:20 000 scale, because often, these features are too small in comparison to the size of the basic mapping unit. Therefore, where large numbers of small landslips or other evidence of instability occur on insitu or colluvial terrain, the landform is classified as being subject to 'general instability'.

Slope instability of some form or other is relatively common within the study area. Approximately 1 914 ha of the terrain displays some form of instability, and this represents 25.9% of the study area.

(i) *Well-defined Landslips*
Within the study area, mappable 'well-defined landslips' occupy only 2 ha of the land surface.

(ii) *Coastal Instability*
This form of instability is usually associated with marine erosion and undercutting of coastal slopes, only 4 ha are affected. Evidence of this form of instability occurs on many of the coastal cliffs under cut by wave action, but this zone is generally too narrow to be recorded in the GEOTECS data bank.

(iii) *General Instability—Recent*
This form of instability relates to colluvial and insitu terrain in which many failures and other evidence of instability occur, but where it is not possible to show them as discrete units on a 1:20 000 scale map because of their small size. This class occupies 1 738 ha (23.5%) of the study area and is common on steeply sloping terrain throughout the area.

(iv) *General Instability—Relict*
This form of instability occupies 2.3% (170 ha) of the area, mostly on the sideslopes of the northeastern part of the study area. This class is no less important in terms of constraints upon development than *general instability-recent,* because it may be reactivated by construction or earthworks.

The general relationships between geology, erosion and instability are discussed in Section 3.1.

2.8 Land Use

2.8.1 *Existing Development*

Existing land use has been mapped using aerial photographs in combination with other sources within this Report, and the data is stored in the GEOTECS inventory. Linear features such as roads, railways and streams tend to be under-estimated in the inventory because they rarely occupy the largest proportion of the 2 ha grid cell which forms the basic unit of the data bank. The GEOTECS Plot, Figure 9, shows the approximate distribution of existing land use groups within the study area. The distribution of existing land use with respect to geotechnical limitations (GLUM class) is discussed in Section 2.8.2. The distribution of broad land-use groupings is shown in the pie chart in Figure 4, and is summarised in Table B12 in Appendix B.

The area is generally rugged with a considerable area of mountainous terrain. Currently the population is sparse, and existing development tends to be concentrated on the valley floors and on the narrow coastal plain. The major villages are located on the Tsing Chau and Luk Keng peninsula, in the valley around Ngau Kwu Long, and on the coastal flats around Tsing Chung. Extensive development occurs at Discovery Bay.

The major economic activities of the more remote villages are pig and poultry farming, fishing and some horticulture. The larger villages particularly in the southern portion of the study area practice intensive forms of agriculture. A certain amount of forestry occurs in North Lantau, and this is concentrated on the Luk Keng peninsula.

The major industrial land uses are associated with timber in Yam O Wan and the shipyard on the eastern side of Penny's Bay. The ponds at Yam O Wan are the major log storage area within the Territory and act as a depot from which individual sawmills withdraw lumber. The ponds occupy some 85 ha of water and are only accessible from the sea.

The shipyard on the eastern side of Penny's Bay is located mainly on reclamation, and the site has an area of about 10 ha. The main activity is producing fibre-glass yachts and boats. Only a part of the leased area is currently used for this activity, with the remainder undeveloped.

The terrain in the study area is particularly spectacular and as such attracts many campers, hikers and other visitors. There are several features of general interest and these include impressive scenery, monasteries, temples, an old fort at Tung Chung and various archaeological sites.

There is some leisure development at the monastery at Shek Pik Au and at the camps of Kwo Lo Wan on Chek Lap Kok and Fau Sha. There are no gazetted beaches in the area, but beaches exist on Chek Lap Kok, Tung Chung, Hau Hok Wan and Sha Lo Wan.

Outside the developed areas, there are 1 620 ha (21.9%) of Country Park and 5 045 ha (68.1%) of undesignated undeveloped land. These two classes constitute the largest proportion of the study area and their development potential is discussed in Section 4.2.2. Their distribution is shown in the GEOTECS Plot, Figure 9.

2.8.2 *GLUM Class and Existing Land Use*

The distribution of GLUM classes is shown in the Geotechnical Land Use Map contained in the Map Folder. The general distribution of the four classes is shown in the pie chart in Figure 4. The relationship between existing land use and GLUM class is tabulated in Table B13 in Appendix B. The following is a summary of the geotechnical characteristics of the terrain associated with the current principal land uses.

(i) *Natural and Undeveloped Areas*
Some 7 093 ha (95.8%) of the area is undeveloped, and of this some 35.6% is subject to high geotechnical limitations (GLUM Class III), 21.7% is affected by extreme geotechnical limitations (GLUM Class IV), 37.8% is influenced by moderate geotechnical limitations (GLUM Class II) and 3.8% has low geotechnical limitations (GLUM Class I).

(ii) *Squatters*
Squatters appear to be located on 35 ha and this represents only 0.5% of the study area. Approximately 22.9% of the terrain occupied by squatters is classified as subject to high to extreme geotechnical limitations. In the study area, it is difficult to distinguish between squatters and single storey village developments using aerial photograph interpretative techniques. There is an additional 4 ha occupied by single storey residences which, in fact, may be squatters. When both land uses are combined, the distribution of GLUM classes is as follows; 10.3% GLUM Class I, 69.2% GLUM Class II and 20.5% GLUM Class III.

(iii) *Residential*
Approximately 1.4% of the area is occupied by residential development. This figure excludes squatters and single storey development. This development is concentrated on undulating terrain and reclamation at Discovery Bay and Mui Wo. Consequently, a high proportion of land occupied by residential development occurs on GLUM Class II. The GLUM class distribution is 2.0% in GLUM Class I, 82.6% in GLUM Class II and 15.4% in GLUM Class III.

(iv) *Commercial and Industrial*
There is very little industrial development in the area, and only a small amount of commercial activity centred on Mui Wo.

(v) *Recreational*
Sporting facilities including a golf course, and urban recreational areas occupy some 80 ha. The GLUM class distribution is 5.0% GLUM Class I, 48.7% GLUM Class II, 43.8% GLUM Class III, and 2.5% GLUM Class IV.

(vi) *Community and Institutional*
Community institutions, such as schools and hospitals, are generally too small to be recorded within the GEOTECS Data bank. Within the study area, these facilities are concentrated at Mui Wo and Discovery Bay.

(vii) *Cemeteries*
There are no designated cemeteries in the study area, although there are a large number of individual grave sites scattered throughout the area.

(viii) *Transportation*
Roads and railways occupy a significant proportion of the urbanised area but are rarely mapped as discrete units, because they usually occupy only a small proportion of the basic 2 ha grid cell. A total of 6 ha is mapped as roads occupying GLUM Classes II and III terrain. A further 20 ha of wharves occur in Penny's Bay, Mui Wo and Discovery Bay.

(ix) *Service Facilities*
This group includes service reservoirs and sewage treatment works. Water supply reservoirs, such as the one to the southwest of Discovery Bay, are unclassified within the GLUM system. One large sewage treatment plant occupies approximately 8 ha of terrain near Mui Wo, and is located on a cut platform of low GLUM Class.

(x) *Quarries and Borrow Areas*
This land use group occupies approximately 16 ha, although some former borrow areas are now used for construction purposes or are classified as incomplete development, or artificial slopes.

(xi) *Incomplete Development*
Construction zones, areas of vacant reclamation and other temporary uses occupy approximately 61 ha (0.8%) of the area. The GLUM Class distribution is 13.1% in GLUM Class I, 54.1% in GLUM Class II, 29.5% in GLUM Class III, and 3.3% in GLUM Class IV.

2.8.3 *Future Development*

Development principles for North Lantau are presented within the 'Hong Kong Planning Standards and Guidelines' (HKPSG). The future development of natural terrain and the upgrading of existing development are expected to achieve these standards, in as much as available land, suitability of terrain and local requirements allow.

The statutory requirements for the type of development, current and proposed, are set out in Outline Zoning Plans (OZP), where they exist, and more detailed intentions are defined in Outline Development Plans (ODP).

Statutory restrictions on development, as in Country Parks and designated 'green belt' areas, together with the natural constraints of the terrain, result in limiting the availability of land for development.

3. ASSESSMENT OF MATERIAL CHARACTERISTICS

3.1 Description and Evaluation of Natural Materials

3.1.1 *General*

Planning and engineering are influenced by the distribution and nature of geological materials. A wide variety of geological materials are present in the study area, and the nature and extent of their influence varies accordingly. The general properties of the rocks occurring in the study area are summarised in Table 3.1. They are described in engineering geological terms and are broadly assessed from an engineering view point. The various geological materials (columns 1 to 4) are described by their lithology (column 5) and their typical topography and weathering pattern (columns 6 and 7). Each material is also evaluated in terms of its engineering properties (column 8) and engineering performance (column 9). The suitability for borrow and possible uses of the material are given in column 10.

Particular attention should be paid to the following points. Firstly, the lithology of the material (column 5) is given for an unweathered sample. Secondly, the topographic form (column 6) with which the material is often associated, may provide a clue for its recognition and may provide an initial indication of the type of material underlying a particular site. Thirdly, the weathering potential of the material (column 7) may assist in estimation of cut and fill volumes, erodibility and vegetation regrowth potential. It should be noted that the depth of weathering may be related to the form of the local terrain. Finally, the quantitative information on engineering properties included in column 8 should be used for preliminary guidance and information only and should not be used for design purposes.

Each rock type has its own range of material characteristics, but many of these overlap. Similar engineering behaviour may occur in dissimilar rock types. The material characteristics which effect the way in which they can be used are:

(i) *Weathering*

Within the regional context, it is important to appreciate the influence of local features on determining the actual depth of weathering at a particular location. The descriptions given in column 7 of Table 3.1 are for general guidance only.

For any given rock type, the depth of weathering is largely controlled by the joint spacing, lithology and rate of erosion. The volume of fresh rock remaining after a weathering front has penetrated a given distance into a joint bounded block will depend on the original spacing of the joints. A larger volume of fresh rock usually remains in a widely jointed rock mass than in one which is narrowly jointed after being weathered for the same length of time.

Another factor that may be important in the weathering process is the presence of hydrothermally altered material. Chemical changes in the rock caused by the infiltration of hot fluids at depth increase the susceptibility to weathering. In some cases, the products of the alteration closely resemble those of weathering.

Erosion removes the soft products of weathering and reduces the actual thickness of the weathered profile. Major stream courses, if not filled with colluvium or alluvium, generally have fresh rock exposed in their beds due to incision of the weathered profile. In areas of active coastal erosion, the weathering profile is usually absent but may be developed beneath the marine and/or offshore terrestrial deposits remnant from a previous sea level.

In the Territory, weathering is largely a chemical process that transforms hard rock to soft soil, and thus the engineering character of a particular site is affected by its local weathering. On a larger, planning scale, the average depth of weathering influences the availability of soft borrow materials, the ease of site formation, the general cost of foundations and the stability of slopes.

An idealised weathering profile is presented in Table A3 in Appendix A.

(ii) *Erosion, Instability and Geology*

The different geological materials are subject to various degrees of erosion and instability (Randall & Taylor, 1982; Rodin et al, 1982; Richards & Cowland, 1986). This is reflected in the relative proportions of the various geological materials present in eroded or unstable areas and, conversely, the proportions of erosion and instability occurring within each geological class. These factors are illustrated in Figure 4 and tabulated in Appendix B, Table B11. The Area Instability Index presented in the table indicates the percentage of each rock type affected by instability.

Table 3.2 presents the relationship between slope gradient, aspect and erosion within the study area. The Area Instability Index appears to increase with increase in slope gradient. The mean for slopes in the 0–15° range is 0.23, in the 15–30° range it is 0.29, in the 30–40° range it is 0.46, and in the greater than 40° range it is 0.45. As expected, the greater the slope angle, the higher the incidence of slope failure. However, another important relationship exists between slope failure and slope aspect, within the greater than 15° ranges. The Area Instability Index within these slope ranges increases markedly in the azimuth quadrant from 315° to 045° (northwest to northeast). This may be attributable to the rainfall pattern or the effect of structural control within the insitu materials.

The relationships between the broad erosional forms and geology have been assessed from the information collected in the study. The results are summarised in Table B11 in Appendix B. This Table compares the distribution of the major geological materials and shows their erosional classification. The rock units of the Repulse Bay Formation have the highest incidences of slope failure. The largest unit is the undifferentiated volcanics which covers some 1 265 ha. Approximately 46% of this rock type is affected by instability. The agglomerate has a very high incidence of instability, but this could be influenced by the fact that it occupies relatively steep tracts of land.

Some 10% of the colluvium (1 467 ha) is affected by instability. The colluvium derived from the volcanic rocks has the higher incidence (Area Instability Index = 0.18), whereas the granitic colluvium has a much lower figure (0.03), probably due to the lower relief of the granitic terrain.

Of the other major rock types, 32% of the feldspar porphyry is affected by instability as compared with 19% of the undifferentiated granite. In general, instability is less extensive on the granitic terrain.

The basic relationships between geology and sheet, rill and gully erosion is slightly different from those for instability. Extensive sheet erosion is characteristic of all forms of granitic terrain on Lantau. It occurs on some 67% of the granites.

Approximately 35% of the colluvium is affected by gully erosion and, although this form of erosion is not always active in nature, to some extent this reflects the relationship between drainage and the colluvial deposits.

Table 3.2 Slope Gradient, Aspect, Erosion and Instability within North Lantau

Slope Gradient	Aspect	No Appreciable Erosion (ha)	Appreciable Erosion (ha)			Instability (ha)		Total Area (ha)	Area Instability Index	
			Sheet Erosion	Rill Erosion	Gully Erosion	Well-defined Landslips	General Instability			
0–5°	Flat	529	51	10	98	0	0	687	0	
5–15°	N	63	112	4	24	0	0	203	0	
	NE	41	120	2	41	0	0	204	0	
	E	51	167	0	31	0	0	249	0	
	SE	35	130	0	31	0	0	196	0	mean =0
	S	14	77	0	8	0	0	98	0	
	SW	16	117	0	10	0	0	143	0	
	W	41	67	0	27	0	0	135	0	
	NW	71	131	0	31	0	0	233	0	
15–30°	N	65	120	0	28	0	331	544	0.61	
	NE	110	194	0	96	0	216	616	0.35	
	E	61	281	2	69	0	92	505	0.18	
	SE	36	280	0	41	0	24	381	0.06	mean = 0.31
	S	16	128	0	18	0	8	171	0.05	
	SW	16	243	0	35	0	36	330	0.11	
	W	59	160	0	20	0	93	332	0.28	
	NW	102	171	2	55	2	262	594	0.44	
30–40°	N	10	24	0	4	0	177	215	0.82	
	NE	20	100	0	6	0	119	245	0.49	
	E	2	144	0	6	0	80	232	0.33	
	SE	0	111	0	0	4	40	155	0.26	mean = 0.47
	S	0	59	0	0	0	16	75	0.21	
	SW	2	134	2	6	0	34	178	0.19	
	W	0	70	0	2	0	51	123	0.41	
	NW	8	63	0	4	0	171	246	0.70	
>40°	N	2	4	0	6	0	53	65	0.82	
	NE	4	10	0	0	0	25	39	0.64	
	E	2	59	0	0	0	14	75	0.19	
	SE	0	2	0	0	0	6	8	0.75	mean = 0.51
	S	0	2	0	0	0	6	8	0.75	
	SW	0	6	0	2	0	2	10	0.20	
	W	0	26	0	2	0	16	44	0.36	
	NW	0	12	0	6	0	35	53	0.66	

These results should be interpreted with caution, because it must be remembered that factors other than geology influence erosion and instability. In the North Lantau study area, the activities of man have modified the susceptibility of the terrain to erosion and instability. In addition, the proximity to the sea, slope angle, aspect, geology, vegetation and microclimatic variations all contribute to the degree of erosion. There is a wide difference in the extent of the rock units, and consequently the sample size of some material types may be too small for generalisation.

(iii) *Material Resources*

The wide variety of geological materials found in the study area all have some potential for use in engineering activities. The geological suitability of these materials is summarised in column 10 of Table 3.1, but other factors also have to be considered when making any recommendation regarding suitability for use. These factors are: suitability of terrain and how it affects adjacent areas (e.g. instability), volume of material available, ratio of hard and soft materials, environmental considerations, accessibility potential for development or reinstatement, and finally, possible effect on water catchments.

Table 3.1 Description and Evaluation of Geological Materials

MATERIAL DESCRIPTION							EVALUATION OF MATERIAL		
Type	Age	Symbol	Map Unit	General Lithological Description	Topographic Form	Weathering and Soil Development	Material Properties*	Engineering Comment (Stability, Foundation, Hydrogeology)	Material Uses and Excavation Characteristics
SUPERFICIAL DEPOSITS	RECENT	R	RECLAMATION/FILL	Generally local or imported borrow of colluvium, decomposed volcanics or plutonics. Often a mixture of silt, sand, gravel and cobbles. Some building waste or sanitary fill also included.	Extensive planar deposits adjacent to coast (reclamation) or as platforms and adjacent slopes (fill) in otherwise undulating terrain.	These materials placed by man have no soil (pedogenic) or weathering profile but may contain weathered rocks or be underlain by natural superficial deposits and/or a pre-existing weathered profile.	These materials are highly variable depending on source of fill. Generally they can be described as low fines, low plasticity granular cobbly soils. Relative density is dependent on method and degree of compactive effort. $\phi \cong$ 25–35°. Properties for sanitary landfill cannot be quantified.	Few problems if properly compacted. Old fill slopes may be poorly compacted and subject to failure. Steep excavations require support. High groundwater requires special drainage. Low bearing pressures can be accepted directly, high loads need raft, spread or pile foundations. Settlement problems minor except in sanitary fill, which may have associated leachate and gas problems.	These areas, when properly formed, provide platforms with high development potential. Care should be taken in excavation of sanitary landfill when biodegradation is incomplete.
		L	LITTORAL DEPOSITS	Essentially beach and dune sand with occasional gravel horizons.	Deposits are very local in nature and generally confined to the intertidal zone, forming beaches and sandbars. Occasionally raised beaches may occur.	Nil	Generally sand sized granular material, often uniformly graded and well rounded.	Materials are usually saturated and saline. Raised beaches may be leached by rainwater but may remain saline at depth. Groundwater extraction may induce incursion of saline water. Poor grading characteristics—low fines. Low bearing pressures can be accepted directly, moderate and high loads need raft, spread or pile foundations.	Main development potential is as beaches for recreational purposes. Excavation of these materials usually prohibited.
		A	ALLUVIAL DEPOSITS	Generally brownish-grey silty sand with subangular gravel. Occasionally contains cobble and boulder horizons.	Material forms broad floodplains with local fan deposits upslope. May be present more continuously as horizons interdigitated with marine muds or forming channel infill deposits.	In subaerial locations very minor development of soil horizon. Relict deposits may be more weathered. Very old deposits may contain completely weathered boulders.	Very variable soil type which is often sandy and gravelly at its base and clayey towards its top. Clay fraction varies from 5–40% and silt 15–55%. SPTs range from 5 to 15 as depth and granular content increase. Material varies from medium to non-plastic. $c' \cong$ 0–10 kPa, $\phi \cong$ 20–25°.	Locally low-lying terrain may be subject to flooding. Materials are usually saturated and of a low density—clay layers are normally consolidated. Buried channels may pose local problems of high water flows into tunnels or excavations. Steep excavations require support. Groundwater may be saline if adjacent to coast. Incursion of saline groundwater following abstraction of fresh groundwater may occur. Low bearing pressures can be accepted directly, moderate and high loads need raft, spread or pile foundations.	Land deposits easily excavated. Marine deposits often form reasonable hydraulic fill. Excavation by cutter, suction or bucket dredger.
		M	MARINE SEDIMENTS	Usually dark grey silty sand or clay with traces of shell fragments, and some sand horizons, especially near shore. A mixed succession with alluvium and/or colluvium may be present.	Seabed sediments of variable thickness (0–10's of metres) below low tide mark.	Nil	Usually a soft to very soft normally consolidated soil with a high moisture content and high plasticity (LL >50%), clay content ranges from 20–35%, silt content from 50–70%. Cu <10 kPa, $c' \cong$ 0–5 kPa, $\phi' \cong$ 25°. SPT < 10 but increases with depth.	Material is poor to unsatisfactory for hydraulic fill. It is also poor as a foundation because of settlement and bearing capacity problems. Will probably be susceptible to formation of mud waves if fill is end-tipped onto it. Consolidation may be aided by wick drains and/or surcharge loading.	Easily excavated using bucket or possibly suction dredger where necessary. Sandy deposits may be used in construction but silt and clay may pose problems of disposal.
	PLEISTOCENE	C	COLLUVIUM: VOLCANIC DERIVED GRANITIC DERIVED SEDIMENTARY DERIVED MIXED	Composed of a range of materials which vary from boulder colluvium, to gravelly colluvium with clay and sand, to finer textured, gravelly sands and clay slopewash. The boulder colluvium with sand and gravel occurs on the higher sideslopes, while the gravelly sands and sandy silts and clays are to be found on the middle to lower sideslopes and footslopes. Coarse boulder colluvium exists in many stream channels.	Mainly occupies the lower sideslope and footslope terrain and may underlie much of the alluvial floodplain. Generally gentle to moderately steep, broad, low, rounded, dissected outwash-fans and interfluves with undulating and hummocky surfaces; elsewhere irregular planar to shallow concave colluvial footslopes, leading upslope to gentle to moderately steep outwash slopes.	Colluvium can occur as independent deposits of a unique age such that one deposit overlies another. The older deposits may be subject to severe weathering and may be completely decomposed to a mottled, coloured sandy silt or clayey silt similar to the insitu residual deposits of their parent materials. The depth of such weathering may be in the order of 10 m or more.	Only very general guidelines can be given for the matrix or finer components of this variable material. MC's average 20–30%, DD varies from 1 300 to 1 700 kg/m³. Grading ranges from 2–40% clay, 10–60% silt, 40–80% sand and medium gravel. Plasticity varies from PL 22–28%, LL 28–40%. Typical shear strength values are $c' \cong$ 0–5 kPa, $\phi' \cong$ 29–42°. Standard compaction values: OMC $\cong$ 17–20%, MDD $\cong$ 1 630–1 750 kg/m³. CBR $\cong$ 3–8%.	This material has moved in its geologic past and is prone to reactivation if no carefully treated by such measures as low batter angles, drainage, and surface protection, especially when saturated. Has low to moderate bearing capacity characteristics but should always be carefully drained because it may be susceptible to failure when wet. Voids may cause settlement of roads, services and buildings. Tunnelling probably difficult. Site investigation may be difficult and expensive.	May be used for borrow due to its ease of excavation by machine, broad grading characteristics and relative ease of access on hillsides. Some bouldery stream deposits will be of limited use. Large boulders may require blasting or splitting.
BEDROCK	UPPER JURASSIC	Mo	INSTRUSIVE IGNEOUS ROCKS (PLUTONIC): QUARTZ MONZONITE	Grey to pinkish-grey, fine to medium-grained, porphyritic, strong acid plutonic igneous rocks. Phenocrysts are plagioclase. Generally displays wide rough joints.	Dissected essentially planar-concave terrain with moderately broad ridge crests.	Shallow to deep residual soil over moderately weathered rock. Corestones are common	Coarser grained fresh rock has an unconfined uniexial compressive strength of 100–150 MPa and a DD of 2 600–2 750 kg/m³. Point Load, Is (50) $\cong$ 5–8 MPa	Relatively unknown rock type, comments as for granites but more care required with weathered materials because likely to be slightly more clayey. Several troublesome case histories noted.	Material can be scraped for borrow when weathered. Fresh rock must be blasted. Not often used for aggregate, but after testing to establish characteristics should be satisfactory. Should have good asphalt adhesion characteristics.
		La	INSTRUSIVE IGNEOUS ROCKS (PLUTONIC): FELDSPAR PORPHYRY DYKE SWARM	Most commonly a dark grey, fine-grained dyke rock showing light coloured large feldspar phenocrysts. Generally displays wide to moderately narrow smooth joints.	Generally occur as linear structural features transecting the volcanic and granitic units. May be of slightly depressed or elevated topographic form due to variable resistance to erosion compared to country rocks. This geological structure often controls local surface runoff and may act as loci for subsurface water concentration.	Generally weathers faster than volcanic rocks but slower than granitic rocks. Develops a thick reddish soil. Weathering depths are generally in the range 7–15 m.	Decomposed material has a moisture content from 17–25%, DD $\cong$ 1 400–1 600 kg/m³. Mg/m³. Grading ranges from 5–10% clay, 30–50% silt, 5–10% gravel. Plasticity varies from PL 22–28%, LL 30–45%.	Surface hydrology can be affected by these rocks with drainage networks aligning with the strike of the dykes. Subsurface hydrology and foundation levels will be affected by the variable rockhead.	Restricted extent precludes deliberate borrow or quarry activities. May be suitable as aggregate when fresh. Excavation conditions may be difficult and expensive.

Table 3.1 Description and Evaluation of Geological Materials *(Continued)*

MATERIAL DESCRIPTION								EVALUATION OF MATERIAL		
Type	Age	Symbol		Map Unit	General Lithological Description	Topographic Form	Weathering and Soil Development	Material Properties*	Engineering Comment (Stability, Foundation, Hydrogeology)	Material Uses and Excavation Characteristics
BEDROCK	UPPER JURASSIC	MS	INTRUSIVE IGNEOUS ROCKS (PLUTONIC)	MA ON SHAN GRANITE	Grey to pinkish-grey fine-grained porphyritic strong granite. Phenocrysts are quartz and feldspar. Generally displays smooth joints.	Forms extensive areas of moderate relief, broad convex hill-crests are common with high level infilled valleys. Occasionally occurs as steep to precipitous terrain. Drainage is dendritic in nature although structural control may dislocate the general pattern. Sheet and gully erosion are common on hillcrest and sideslope terrain.	Rock sometimes produces a poor, thin (<1 m) soil (pedogenic) horizon. At depth the decomposed rock is a silty sand with variable fine gravel content. Depth of weathering i.e. soft material, is often great and an average of 18 m has been quoted. Weathering to produce corestones is common.	The near surface completely decomposed material has a DD ≅ 1 200–1 400 kg/m^3 and is usually only 35–50% saturated. The material is a silty sand containing up to 20% silt with some fine gravel. Typical shear strength values are c' ≅ 0–10 kPa, Ø' ≅ 32–40°. Strength characteristics of fresh rock are dependent on joint strength as unconfined compressive strength in order of 100–150 Mpa. DD ≅ 2 500–2 600 kg/m^3, tangent modulus ≅ 30 000–60 000 MPa. Point Load Is (50) ≅ 5–8 MPa. Joint c' ≅ 0 kPa, Ø' ≅ 40°, roughness angles 5–10° (tectonic joints), 10–15° (sheet joints).	Stability of the weathered material can be suspect, i.e. Zones A & B, where soil type failures may occasionally occur. Insitu material is subject to severe erosion. Special care must be taken in establishing adequate surface protection on newly formed slopes. Bearing capacity characteristics are good for moderate to high loads. Generally free draining. Rock is prone to discontinuity controlled failure in the fresh to moderately weathered state.	When weathered, the material can be machine excavated to considerable depth and is thus strongly favoured as a source of granular borrow. When fresh or slightly weathered, blasting is required. These rocks are highly favoured for aggregate production.
		CC		CHEUNG CHAU GRANITE	Pale grey or pink, medium to coarse-grained, sparingly porphyritic, strong granite. Potassium feldspar is very prevalent in this widely spaced, rough-jointed rock.					
		SK		SUNG KONG GRANITE	Pale grey or pink, coarse-grained, porphyritic, strong granite. Medium-grained and non-porphyritic phases exist. Generally displays widely spaced joints. Quartz is often very abundant.					
		G		UNDIFFERENTIATED GRANITIC ROCKS	Nature of rock uncertain but similar to granitic rocks discussed above.					
	LOWER TO MIDDLE JURASSIC	RBs	REPULSE BAY FORMATION	SEDIMENTARY AND WATER-LAID VOLCANICLASTIC ROCKS	Generally hard, thinly banded black and grey siltstones and black shales, interbedded with volcanic sandstones and tuffs, sometimes cherty. Very closely spaced joints in some units.	Occasionally forms hillcrests, more usually ridges, spurs and dissected footslopes with broad, low, irregular, rounded interfluves formed at lower elevations. At higher elevations, ridges and spurs are mainly narrow and sharply rounded.	Shallow to moderately deep, reddish to brown, fine, sandy to silty clay, i.e. residual soil sometimes with ferruginous gravel and weathered rock fragments, overlying completely to highly weathered rock which grades into less weathered strongly jointed volcanic rock at depths from 5–20 m.	No test data available but likely to be variable, dependent on individual stratigraphic unit.	The sediments are bedded and fissile and weather relatively rapidly, when exposed, to a grey silt. Some stability problems may arise. Groundwater regime may be controlled by the bedded character of the rock.	Can be scraped and ripped when weathered. Fresh rock will need pneumatic machines or blasting. Due to highly variable properties and presence of chert bands, this material would not make a good source of aggregate but is well suited for filling. Scarn mineralisation with magnetite has been mined.
		RBv		ACID LAVAS	Dark green or bluish grey fine-grained with light phenocrysts, banded, strong rhyolite. The rock often displays closely spaced smooth joints.		Rock usually develops a thin (<1 m) soil horizon and a thin (<10 m) weathered zone before passing rapidly into moderately to slightly weathered bedrock.	No laboratory results available but should be similar to other volcanics as below.	Stability of weathered material and also of highly jointed rock masses may be suspect, especially during or immediately after prolonged heavy rainfall. Failures are quite common, especially in over-steepened slopes. Rapid surface runoff is common. Stability of rock slopes controlled by relatively closely spaced discontinuities in moderately weathered to fresh rock mass. —Few opportunities for creation of platforms; usable sites may be small and fragmented, —Access route selection hampered by terrain, —Tunnelling probably easier than in granitoids. Deep weathering and close jointing should be anticipated near structural geological lineaments.	Very hard and abrasive when fresh, will require blasting which may result in brittle fracture. Inadvisable for aggregate unless tested for silica/cement reaction.
		RBc		COARSE TUFF	Grey to dark grey, fine matrix with coarse well formed crystals of feldspar and quartz. Forms massive beds of crystal tuff with no internal stratification. Jointing tends to be moderately closely spaced and smooth.	Massive volcanic peaks with deeply dissected slopes forming a system of sub-parallel ridges and spurs. Crests are narrow and sharply convex with steep to very steep valley slopes. Rock outcrops are common on the upper slopes.	Rock usually produces a thin (<1 m) soil horizon, followed downwards, especially on lower slopes, by yellowish brown sandy completely weathered material overlying less weathered, locally strongly jointed rock below an average depth of 11 m. On steep, high slopes considerable rock exposure with thin soil or thin weathering cover occurs.	Fresh rock properties are approximately as follows: Unconfined compressive strength ≅ 150–250 MPa. Joint strength parameters are c' ≅ 0 kPa, Ø' ≅ 30°, roughness angle 5-10°. DD ≅ 2 500–2 700 kg/m^3. Point Load Is (50) ≅ 6–12 MPa. Tangent modulus ≅ 30 000–60 000 MPa. The near surface completely decomposed material has a DD ≅ 1:500 kg/m^3 and a saturation greater than 70%. Gradings are variable but 20–40% silt, 10–20% clay and 40–60% fine sand is common. Plasticity varies from PL 22–32%, LL 35–60%. Typical shear strength values are: c' ≅ 0–10kPa, Ø' ≅ 30–35%.		Material can be used for fill if it is weathered locally. It is possible to quarry, although very hard and not generally favoured. Coarse crystal tuff horizons may provide good aggregate.
		RBp		DOMINANTLY PYROCLASTIC ROCKS WITH SOME LAVAS	The principal rock type is grey to dark grey fine-grained rhyodacitic tuff but welded tuffs, coarse tuffs, lavas and sedimentary rocks may also be found in this unit. Jointing is usually smooth and closely spaced.					
		RB		UNDIFFERENTIATED VOLCANIC ROCKS	Rock types not mapped in detail by Allen & Stephens (1971), but probably similar to the above volcanic units.					
		T	SEDIMENTARY ROCKS	TAI O FORMATION	Lower beds comprise black silty shale, white orthoquartzite, black and white siltstone, purple sandy siltstones and some graphitic sandstone. Upper beds comprise massive white fine-grained orthoquartzite and very fine-grained micaceous sandstone interbedded with siltstone.	Occurs on lower to upper footslope terrain forming relatively dissected relief. Incision is evident along drainage lines. Terrain is essentially planar-convex in morphology, broad convex spurs are common.	Generally moderately deep (5–10 m), uniform or gradational, red to red-brown, residual clayey soil overlying completely to highly weathered sediments.	No test data available.	Fresh material is generally stable and has good bearing capacity characteristics. Weathered material subject to creep and some instability, especially when saturated. May break down to silt if weathered material is over-compacted.	Restricted outcrop precludes extensive usage. Weathered horizon can be excavated by machine, fresh rock needs pneumatic tools or blasting. Possible use as borrow but fresh rock not suitable for aggregate.

* The property values presented are only approximate and are given without prejudice for general information. These properties should not be taken as design values. The latter should be determined where necessary by separate careful site investigation and laboratory analysis.

Abbreviations

c' —effective cohesion—kPa—kilopascal
Ø' —effective angle of internal friction—°—degree
Cu —undrained shear strength—kPa—kilopascal
OMC —optimum moisture content—kg/m^3—kilogram per cubic metre
MDD —maximum dry density—kg/m^3—kilogram per cubic metre
DD —dry density—kg/m^3—kilogram per cublic metre
CBR —California Bearing Ratio—%—percent
Is (50)—point load strength index—MPa—megapascal
LL —liquid limit—%—percent
PL —plastic limit—%—percent
MC —moisture content—%—percent
SPT —standard penetration test value
≅ —about equal to

A broad division can be based on whether the material is 'soft' or 'hard', and this relates to the mode of extraction. Soft material can be economically extracted in volume by machine methods. Hard material requires blasting prior to extraction. In Section 4.2.4 of this Report, a method of identifying potential quarry sites is given and it is illustrated in the GEOTECS Plot, Figure 12.

Table 3.1 presents, in summarised form, the general characteristics of the various geological materials and how they influence engineering and planning activities. The characteristics of each material are affected by local conditions, and the comments presented in the table are intended for general guidance only.

In terms of general engineering behaviour, the geological materials of the study area are broadly classified into five groups:

(*a*) Colluvium.

(*b*) Other superficial deposits—fill, reclamation, alluvium, littoral and marine deposits.

(*c*) Volcanic and volcaniclastic rocks.

(*d*) Intrusive igneous rocks.

(*e*) Sedimentary rocks.

3.1.2 *Characteristics of Colluvium*

Colluvium is a complex heterogeneous material which is highly variable in its engineering character. Its distribution is described in Sections 2.3, 2.4.

As well as being derived from a range of rock types, generally colluvium is deposited intermittently over a period of time. This intermittent deposition results in considerable variation in the degree of weathering of its constituent boulders and detrital fragments.

Erosion in colluvium may sometimes result in the undercutting of contained boulders which subsequently move down slope. Internal erosion may also take place within the deposits, and voids may pose a hazard to earthworks and engineering design. These voids may occur as tunnels which act as major subsurface conduits for water movement.

One of the engineering problems associated with or related to colluvium is instability. The most dramatic example is the landslip disaster at Po Shan Road on Hong Kong Island in 1972 (Government of Hong Kong, 1972 *a* & *b*). Colluvium consists of material transported by gravity, and the deposits accumulate at approximately the angle of repose of the detrital material. Although the deposits may settle and become more dense with time, they are liable to slope failure if disturbed either by stream undercutting, ground movements or by man's activities.

Slope failures in colluvium are often characterised by narrow landslip scars (less than 15 m in width) with extensive debris trails. Length to width ratios are generally 4 to 6:1 for colluvium. From the GEOTECS data presented in Table B11 and in Figure 4, volcanic colluvium appears to have a much higher proportion of instability compared with other colluvial materials. This is possibly a result of the steeper slope angles associated with both the parent rock type and the volcanic colluvial terrain.

Granitic colluvium shows a moderately low incidence of instability, which is considerably less than the colluvium derived from volcanic rocks.

In general, colluvium is unsuitable as a founding material for large structures, and it is normal for caissons to be excavated through to the underlying rock. The presence of large boulders in the colluvium can make this a difficult process. Some boulders within colluvial deposits may be in excess of 5 m in diameter, and need to be identified as detrital and not as bedrock.

Colluvium is often highly permeable, especially in 'bouldery' colluvial streambeds. Older, weathered deposits may be less permeable, but the presence of internal erosion tunnels may give rise to complex groundwater patterns. Streams which exist over bedrock frequently disappear beneath areas of colluvium.

Boreholes and trial pits are used to obtain samples and exposures for the classification of colluvial deposits. Care should be taken to use drilling methods that will not result in a loss of matrix material. Trial pits often provide more reliable information when dealing with colluvium, but these are practical only in shallow deposits. Where the matrix percentage is high, appropriate laboratory tests may be carried out on undisturbed samples to provide strength and compressibility data for design. Where the boulder percentage is high, it may be necessary to rely on more empirical relationships for stability assessment.

Colluvium may exceed 30 m in thickness and is essentially unconsolidated; therefore, it has some potential for use as a soft borrow material. The grading of the material in relict weathered fans is generally suitable for use as fill as it has good compaction characteristics.

The more recent bouldery colluvium in stream channels is of limited use, because major natural constraints such as instability and concentrated groundwater flow, restrict their suitability. Within the study area, there are no obvious sites that can be recommended for soft borrow in colluvium. Site formation work may involve the excavation and use of colluvial materials, which should prove satisfactory provided adequate care is taken in the design of cut slopes. Excavation by machine methods could be difficult if large boulders are encountered.

On a planning scale, the presence of large areas of colluvium acts as a major constraint on the overall layout of a project. Problems can be minimised by avoiding designs that require large cut slopes in this material.

3.1.3 *Characteristics of Fill, Reclamation, Alluvium, Littoral and Marine Deposits*

This group includes all superficial materials that generally occur as flat or slightly inclined deposits. These are fill and reclamation, alluvium, littoral and marine deposits. The first two materials are placed by man and are more fully discussed in Appendix D.3.3.

Due to the complex history of sea level change within the study area, these materials can occur together forming a complex subsoil stratigraphy. In this area, reclamation overlies a complex sequence of marine, alluvial and colluvial materials over weathered bedrock. Many low-lying areas of alluvium in the Mui Wo area have been raised by the placement of fill. In coastal regions, marine deposits merge with littoral deposits which may be interlayered with alluvium.

In geological terms, all of these materials are immature and consequently weathering profiles are not well developed. Some older alluvial materials contain weathered cobbles, but it is not known whether these have been weathered insitu or are detritus from an already weathered source.

Due to their predominantly flat profile, erosion is not a major problem in these materials in their undisturbed state. Stream flows are normally low or confined to man-made channels or conduits. Littoral deposits are subject to continuous erosion and redeposition by the sea. It should be noted that all these materials are erodible if hydrological conditions are adversely altered by construction activity.

The GEOTECS data presented in Tables B10 and B11 of Appendix B indicate that there is a low incidence of slope instability in these materials. This is primarily due to the low slope angles associated with most of these deposits. When disturbed, however, these materials are liable to become unstable unless adequate precautions are taken. All steep-sided excavations require strutting or shoring to minimise the likelihood of slope failure, and cut slopes require cutting to low angles or construction of retaining structures.

There is a wide range in particle size between materials in this group. Alluvial deposits may contain a high proportion of gravel and cobble sized material, whereas littoral deposits consist of a fairly uniform medium to fine sand. Marine materials range from silty well-graded sand, to clayey well-graded silt and silty clay.

The shear strength of these materials is extremely variable. The highest strength is developed in well-compacted fill, and the least in marine muds. All these materials are characterised by low values of cohesion. The strength values quoted in column 8 of Table 3.1 are approximate guides only and should not be used for design purposes. It has been demonstrated that these materials are extremely variable in physical properties and they frequently occur within a complex subsoil stratigraphy. Consequently, appropriate laboratory testing of representative undisturbed samples is required in order to obtain relevant strength parameters for design.

None of the materials in this group have high bearing capacities, and all large loads need to be transferred to underlying bedrock. Low to moderate loads can be accepted on raft foundations, but problems of differential settlement may be experienced. The pile type most appropriate for high loads is dependent on the overall stratigraphy, but nearly all members of this group are amenable to driven piles. The exception is that some areas of reclamation may contain old masonry walls, large boulders or construction refuse which may require caisson-type construction to overcome penetration problems.

Due to high permeabilities, rates of settlement are often rapid, although fine-grained marine muds and silts may require considerable time. The magnitude of settlement varies depending on the imposed load, local groundwater conditions and the nature of the materials. Settlements in marine and alluvial deposits are discussed by Holt (1962). Settlement may be induced by the alteration of groundwater conditions.

In general, the materials in this class are easily excavated by machine methods and have potential for use as soft fill. Marine deposits of sand may exist offshore, but marine silts and clays are generally unsuitable for hydraulic fill. Future urban development on areas of alluvium generally restricts the use of this material for borrow.

From a planning point of view, this group of materials, although not free of problems, is generally suitable for development.

3.1.4 *Characteristics of the Volcanic Rocks of the Repulse Bay Formation*

The location and type of volcanic and volcaniclastic rocks found in the study area are discussed in Section 2.3.3. Excluding the minor sedimentary member, these rocks tend to have similar material characteristics.

The engineering behaviour of the rock mass is controlled by a combination of factors. The major factors are the frequency, orientation and roughness of joints and other discontinuities, the degree and extent of weathering, cleft water pressures and permeability characteristics.

The volcanic rocks of the Repulse Bay Formation are generally well jointed. Joint spacing (Geological Society of London, 1977) commonly ranges from 'moderately narrow' (20 to 60 mm) to 'wide' (200 to 600 mm) or, more rarely, 'very wide' (600 to 2 000 mm). Small outcrops that have a joint spacing of greater than 2 m tend to stand out on hillsides and ridges as tors. Locally, the joint spacing is very variable, often ranging from wide to narrow over distances of less than 10 m. Most exposures contain several sets of joints, each set exhibiting a range of orientations. This range is generally related to the persistence of the joints, with less persistent joints being the most variable in orientation. Joints can sometimes be seen to curve in larger exposures. Persistent joints which exist in well-defined sets tend to be fairly smooth, although they are occasionally striated. Smaller, discontinuous joints are often irregular and stepped, and are of less engineering significance. Many of the joints are steeply inclined and may result in 'unfavourable' orientations in relation to construction.

In these rocks, weathering tends to be relatively shallow, with average depths in the order of 10 m. The sedimentary rocks are generally more deeply weathered, and up to 20 m of weathered material is common. As discussed in Section 3.1.1, the depth of weathering is largely dependent on the joint spacing. Along photolineaments (shown on the Engineering Geology Map), very close jointing may be encountered which locally depresses the weathering profile. The subsurface characteristics of the photolineaments in the study area are not well known at present, but it is apparent that large depths of decomposition, unusual water flows, intense fracturing, and the possibility of differential settlement are common problems.

On weathering, the volcanic rocks tend to produce a clayey silt with minor sand and a fairly uniform profile. The coarse tuffs, if widely jointed, may produce corestones and boulders in a similar manner to granitic rocks.

The higher clay contents of the weathered materials tend to reduce the incidence of erosion in these rocks even though they occur on steep slopes. The GEOTECS data in Tables B10 and B11 and Figure 4 indicate that the Repulse Bay Formation rocks show a general trend of relatively low incidence of erosion. Due to the large statistical sample and the relative lack of urban development on these rocks, this is probably a true reflection of the erodibility of these materials. The incidence of instability, on the volcanic rocks is high, due in part to the steep, high slopes formed of these materials. The morphological forms associated with slope failure in volcanics are similar to those in colluvium, in that they are characterised by small landslip scars with extensive debris deposits. That is, they are characterised by large length to width ratios (4 or 5:1).

When fresh, these rocks generally have a high strength, but the presence of joints substantially reduces the effective mass strength. These rocks are difficult to crush and are not currently used for aggregate production, due to their fine grain and relatively high strength. The narrow joint spacing in many of the volcanic rocks may produce fragments unsuitable for aggregate when crushed. The weathered mantle may be suitable for soft borrow, but the shallow weathering depths will limit the potential yield from most sites.

The steep terrain and thin weathered mantle may make many areas of volcanic rock unsuitable for intensive development. Large volumes of excavation, much of it requiring blasting, would be necessary for site formation, and the resulting slopes may be subject to joint-controlled instability. However, where these rocks occur on flat to gently sloping terrain, foundation depths are likely to be fairly shallow.

Site investigations in the pyroclastic rocks should be designed to determine the depth and degree of weathering, the frequency and orientation of jointing and the position and seasonal fluctuations of the water table. The Standard Penetration Test can be a useful indicator of the depth of successive zones of decomposition of the rock mass. Direct shear tests on the discontinuities of Zone C/D rocks, and direct shear and triaxial tests on Zone A/B rocks, can be used to determine the shear strengths of joints and soil matrix. It should be noted that, because most failures of insitu material are shallow, the overburden pressure on a failure plane is probably quite low. Representative shear strength parameters should therefore be obtained from laboratory triaxial tests carried out at appropriately low confining pressures.

3.1.5 *Characteristics of the Intrusive Igneous Rocks*

The intrusive igneous rocks that underlie much of the northern portion of the study area are of similar origin and consequently have similar engineering characteristics. Some site investigation and laboratory information is already available, and these materials are generally quite well understood (Lumb 1962 a & b, 1965, 1983).

Amongst these rocks, a division can be made between dyke rocks and those occurring in large intrusive bodies. The dyke rocks generally are of limited width, and they may cause localised variations in weathering depths and groundwater conditions.

The various granite intrusions, along with granodiorite, all tend to have similar jointing patterns. Joints in these rocks generally range from medium to very widely spaced but tend to be widely spaced overall. Two distinct joint groups are present: sheeting joints and tectonic joints. The sheeting joints tend to be rough and wavy, orientated subparallel to the topography and spaced at about 1 to 3 m intervals. They are best developed near the surface. Tectonic joints are generally orientated normal to the sheeting joints, smooth to moderately rough, and spaced in the order of 1 m apart. On weathering, both joint groups are often preserved as relict features with coatings of limonite, manganese dioxide or thin layers of clay.

As with the volcanic rocks, the frequency of tectonic joints increases markedly in the vicinity of photolineaments. Joints are probably the major conduits of groundwater flow below the weathered mantle because of the impermeability of the fresh rock.

Despite the wider joint spacing, compared with the volcanics, the intrusive igneous rocks of this study area tend to weather to a greater extent and depth. This is primarily due to the higher porosity and rock permeability of the granitic rocks. Weathering in these rocks has been the subject of recent study in the Territory (Hencher & Martin, 1982); consequently, only a summary is presented here.

As stated in Section 3.1.1, an extremely wide range of depths of weathering of intrusive igneous rocks occurs within the study area. In general, for similar locations in the terrain, these rocks are weathered to in excess of twice the depth of volcanic rocks.

The intrusive igneous rocks normally weather inwards away from discontinuities, and quite thick weathering zones may occur along joints even in Zone C rock. Within the profile, large boulders are developed as a result of the wide joint spacing, and these may be concentrated on the surface by the erosion and removal of the soft, completely decomposed material.

As a result of weathering, joints lose their effective roughness. This, combined with the concentration of clay minerals, leads to a reduction in shear strength. The intact rock becomes weaker and more porous. The completely decomposed rock disintegrates into a silty clayey sand, with the grading depending on the original rock type.

As the residual soil is predominantly sandy, it is highly erodible in nature. The GEOTECS data presented in Figure 4 and in Tables B10 and B11 indicate a general increase in erosion within the intrusive igneous rocks when compared with the other rock types.

In general, instability in these rocks is not as extensive as in volcanic materials. Landslips do not appear to have the same impact on the terrain and tend to form small rotational or joint-controlled failures associated with natural terrain or cut slopes. Length to width ratios are generally 1 to 2:1.

Permeability in these materials varies with weathering. Completely decomposed rock that has been eluviated (clay content washed out) may be highly permeable. A transition from porous flow to joint-controlled flow occurs from weathered to unweathered rock. These materials may be subject to tunnel erosion (piping), especially in the residual soils or newly exposed completely weathered material (Nash & Dale, 1983).

The bearing capacity of the highly weathered granite will probably be satisfactory for low to moderate loading, but on occasions, an open porous structure may result in low insitu densities and settlement problems for surface footings. Artificial lowering of groundwater during construction can also adversely affect steep cuttings and predicted settlements. A further problem for the construction of deep foundations or trench excavations below the groundwater table, is the potential for piping within the coarse-grained, loose or medium dense decomposed granite. This may lead to problems with bored piles and other foundation problems.

Site investigations in the granite should identify weathering grades as well as the nature and orientation of joints. Standard Penetration Tests (SPT) can give useful information in those materials which can be difficult to sample and test, and which collapse on loading or wetting. Block sampling and air-foam drilling may be of particular value in these circumstances. (Brand & Phillipson, 1984; Phillipson & Chipp, 1981, 1982). Where deep foundations are envisaged, boreholes should be drilled to well below the proposed bearing level because weathering can be irregular, with zones of completely weathered soil underlying less weathered material.

For the construction of slopes in Zone D or Zone C granite, which has high intact rock strength and relatively lower discontinuity strength, direct shear tests should be carried out to determine shear strengths of discontinuities. In Zone A or B, the strength and compressibility of the intact decomposed materials are more important, and these should be investigated by appropriate laboratory tests.

This group of rocks is extensively used for construction materials. The deeply weathered material is easily extracted by machine methods for use as soft borrow, and the underlying rock is highly favoured for the production of crushed aggregate.

Granitic rocks are generally favoured for aggregate production because of the relative ease of crushing and shape characteristics (Brand et al, 1984). Problems, however, have been experienced with poor asphalt adhesion when these materials are used for road pavement. This is primarily due to the high free quartz content.

From a planning point of view, granitic rocks are generally favoured. They require more site formation compared with the flat superficial deposits, but the moderate slope angles, ease of excavation, high yield of fill and general stability of slopes is reflected in the extensive development which already exists on these rocks.

3.1.6 *Characteristics of the Metasedimentary Rocks*

Within the study area, metasedimentary rocks are only represented by the Tai O Formation.

The isolated location and small outcrop of this Formation within the area reduces its usefulness as a material source. These rocks are restricted to the Tai O area. They are thin cross-bedded sandstones with interbedded shales, which are folded and metamorphosed. Closely spaced jointing with some rock cleavage is characteristic of the rock mass. The rocks are normally well weathered and are not resistant to erosion. Any materials dervied from this Formation will be weak and unstable when weathered, although fresh rock may be suitable for localised construction purposes.

4. GEOTECHNICAL ASSESSMENT FOR PLANNING PURPOSES

4.1 Geotechnical Limitations

4.1.1 *Introduction*

The Geotechnical Land Use Map (GLUM) indicates the general levels of geotechnical limitation associated with the terrain. These in turn reflect the basic suitability of the land for development from a geotechnical point of view. A copy of the Geotechnical Land Use Map is described in detail in Appendix A7 and is enclosed in the Map Folder which accompanies this Report.

The distribution of the four GLUM Classes is summarised in the pie diagram presented in Figure 4 and in Table 4.1 and B9 in Appendix B. The distribution of GLUM Classes is shown in the GEOTECS Plot, Figure 10.

Table 4.1 presents the distribution of each GLUM Class and its percentage within the study area, and relates it to the area presently occupied by intensive development. The small villages and rural settlements are considered as 'undeveloped' within the context of this study and 'developed' refers to areas such as Mui Wo and the large reclamation sites.

Table 4.1 Distribution of GLUM Classes

GLUM Class	Geotechnical Limitations	Area					
		Developed		Undeveloped		Total	
		ha	%	ha	%	ha	%
I	Low	30	0.4	270	3.7	300	4.1
II & IIS	Moderate	170	2.3	2 680	36.2	2 850	38.5
III	High	98	1.3	2 526	34.1	2 624	35.4
IV	Extreme	4	<0.1	1 540	20.8	1 544	20.9
Unclassified (Waterbodies, etc.)		8	0.1	77	1.0	85	1.1
Total		310	4.2	7 093	95.8	7 403	100.0

4.1.2 *Land with Low to Moderate Geotechnical Limitations*

Within the study area, there exists a small area (300 ha) with low geotechnical limitations and approximately 2 850 ha with moderate geotechnical limitations. Terrain with low to moderate limitations (GLUM Classes I & II) forms 42.6% of the study area. Some 200 ha of the GLUM Classes I & II terrain is developed and 2 950 ha of the GLUM Classes I & II terrain is substantially undeveloped.

Some 300 ha out of a total 7 403 ha occur within GLUM Class I, and have low geotechnical limitations. These areas generally lie on gently sloping well-drained sideslope and ridge crest terrain. They often occur on terrain associated with small spur lines and within valley floors as small outcrops of insitu material. These areas are rather scattered in distribution and are relatively small, averaging only 2 to 4 ha in size.

GLUM Class II, which includes subclass IIS, is composed of land which will require careful management because it may be subject to periodic inundation or flooding. Table 4.1 also shows that the combined GLUM Class II terrain accounts for 2 850 ha (38.5%) of the study area, of which only 170 ha (6.0%) is currently developed. Considerable potential exists for future development on land in this class.

Although GLUM Class IIS terrain is marginally less suitable than the remainder of Class II, it can be utilized for development provided that the hydrogeological conditions are considered at the planning stage and in engineering design. Class IIS terrain usually occurs as flat, extensive and continuous areas of alluvial floodplain. In North Lantau, the question of alienation of agricultural land is a consideration. Since GLUM Classes I & II areas of alluvium and floodplain are prime locations for horticultural and agricultural production, an alternative to development of this land is to utilize the floodplain for agricultural purposes. This would enable the general continuity of the drainage system to be maintained, as well as ensuring the availability of water supply for agricultural production.

Land with a low degree of geotechnical limitations is expected to require only normal geotechnical investigation, with the costs of site formation, foundation and drainage work being relatively low. This terrain consists typically of gently sloping untransported (insitu) rock or residual soil. Development of land with moderate geotechnical limitations probably requires a normal site investigation but, in certain situations, foundation conditions could be more complex than for GLUM Class I. Nevertheless the costs of site formation, foundation and drainage works should not be high. GLUM Class II terrain includes those areas where instability or erosion are not problems. These are insitu terrain of moderate steepness or flat or gently sloping alluvial terrain. Areas of reclamation are also included in GLUM Class II.

4.1.3 *Land with High Geotechnical Limitations*

Approximately 35.4% (2 624 ha) of the study area has a high level of geotechnical limitation (GLUM Class III) and of this, some 98 ha is currently developed. The general pattern is shown in the GEOTECS Plot, Figure 10.

GLUM Class III terrain is expected to require intensive geotechnical investigation, and the costs associated with site investigation, site formation, foundation and drainage work will probably be high. Typical GLUM Class III land is steeper than 30° on insitu terrain without evidence of instability, and at gentler gradients where instability or colluvium are present. GLUM Class III terrain is likely to exhibit subsurface variations in material profile and drainage regime, which need to be determined during site investigation.

4.1.4 *Land with Extreme Geotechnical Limitations*

Approximately 20.9% (1 544 ha) of the area is classified as GLUM Class IV. This terrain should not be developed if alternatives exist. The general pattern is shown in the GEOTECS Plot, Figure 10. Only 4 ha of this class occurs within areas of current development.

Intensive site investigation would be required at the planning stage and prior to detailed design, to minimise the hazard of slope failure. Although investigation costs are expected to be very high, they would probably be relatively minor in comparison to the costs of site formation, foundation and drainage works and the costs associated with maintenance and remedial treatment.

Terrain attributes which contribute to the designation of GLUM Class IV include steep, insitu and colluvial terrain and areas with evidence of instability.

In most cases, it will be obvious from the topography alone that GLUM Class IV terrain would present extreme geotechnical difficulties. The steep to precipitous northern and western facing slopes of Lantau Peak, Sunset Peak and the Tung Chung Valley are examples.

Isolated GLUM Class IV terrain within the developed area is usually associated with locally steep slopes produced during site formation or road construction.

Other areas of GLUM Class IV result from natural drainage lines crossing colluvium or the presence of instability. These features are highlighted on the Physical Constraints Map (PCM).

4.2 Suitability of Land for Development

4.2.1 *General Planning Considerations*

Land utilization is governed by development requirements, which are based on demand, potential and constraint. Many of the fundamentals which influence planning decisions are not directly influenced by geotechnical considerations. However, geotechnical considerations are implicit in efficient and secure engineering. Section 4.1 has briefly discussed some of the terrain-associated constraints which cause geotechnical problems for engineering works. Some of these problems are initiated during development. For this reason, the interaction between engineering and the terrain should be an important consideration during the planning process. Efficient construction is important but long term serviceability and safety should also be fundamental aims.

From a geotechnical viewpoint, land with potential for development should generally be free of constraints. Engineering design, if possible, should be unhindered by geotechnical limitations. Within the North Lantau study area, there are many areas still unused, but a significant proportion of them occur within designated Country Parks, Green Belt and Water Supply Catchments. Thus, an integrated approach should be adopted in order to optimise the use of the remaining areas. This Report attempts to delineate the major geotechnical and terrain-related problems and to define their magnitude for planning and engineering purposes.

The Geotechnical Land Use Map, Physical Constraints Map and Engineering Geology Map enable the extent and nature of local engineering problems to be incorporated in the planning process for the whole of the study area. These maps are introduced in Section 1.5, and their background, derivation and use are described in detail in Appendix A.

4.2.2 *Land of High Suitability for Development*

There are several relatively extensive areas which occur within GLUM Classes I and II (not IIS) in the study area, and this land is highly suitable for development. These areas have low geotechnical limitations and should require only a 'normal' intensity of site investigation.

The most favourable areas for development from a geotechnical point of view occur in relatively continuous belts.

(i) The coastal headland, extending southwest from Hau Hok Wan (south of Lam Chau Island) through Sha Lo Wan and San Shek Wan to Sham Shek Tsuen, is approximately 3 km in length, and extends inland about 1 km.

(ii) The footslope and valley floor terrain, centred on Tung Chung but excluding the floodplain and colluvial drainage plain (refer to the Physical Constraints Map), extends from Ngan Au in the west through Nim Yuen, Shek Mun Kap, Ling Pei and onto the footslopes of the Wong Lung Hang valley. The area involved amounts to approximately 150 ha.

(iii) Most of Chek Lap Kok occurs within this category of terrain.

(iv) A broad north-trending band of terrain, some 2 km wide, which extends from the study boundary immediately south of Silver Mine Bay, through Luk Tei Tong, Tai Tei Tang, and Pak Ngan Heung. The area becomes quite diffuse near the region of Tai Ho Wan on the north coast.

(v) A central inland area on Tsing Chau peninsula extends northeast from the northern shoreline of Penny's Bay through Mong Tung Hang to the main ridgeline.

4.2.3 *Land of Moderate to Low Suitability for Development*

This land occurs mainly in the GLUM Class IIS on North Lantau and, as such, lies essentially on those parts of the flat, low-lying alluvial plains subject to periodic flooding and inundation. There are several concentrations of this type of land.

(i) A small floodplain extends northwards from San Shek Wan to the coast south of Lam Chau Island.

(ii) A small floodplain exists at Lau Tau.

(iii) The extensive floodplain, near the coast at Tung Chung and Ma Wan Chung, lies at the junction of three major streams and occupies and area of approximately 150 ha.

(iv) The floodplain which occurs slightly inland of the Mui Wo area includes localities of Tai Tei Tan and Luk Tei Tong.

(v) Several small floodplains adjacent to the northern coastline at Tai Po, Pak Mong and Tai Ho amount to only 25 ha.

4.2.4 *Land of Low Suitability for Development*

A major portion (about 35.4%) of the North Lantau area occurs within GLUM Class III. This land is intermediate between land of high suitability, and that which is regarded as being generally unsuitable for development. The most problematic areas, from a development viewpoint, are the colluvial drainage plains which occur on gently sloping footslope terrain. In general, development on Class III terrain will require intensive investigation at the planning and design stages to minimise the likelihood of slope instability.

Much of the GLUM Class III land is steep natural terrain. Development of these slopes will certainly be difficult from a geotechnical point of view. The remaining areas of GLUM Class III are often covered by extensive deposits of colluvium. This colluvium varies with respect to depth, origin and matrix composition. Stability problems encountered during and after construction of borrow areas on footslope terrain elsewhere in the Territory, highlight the fact that development of GLUM Class III must be approached with caution.

4.2.5 *Land which is Probably Unsuitable for Development*

Undeveloped parcels of GLUM Class IV land are considered unsuitable for development if alternatives exist. These areas contain one or more of the following geotechnical limitations:

(i) *Very Steep Slopes*
All areas which have slopes with gradients greater than 60°, regardless of their terrain component or erosion characteristics, are allocated to GLUM Class IV. Those areas which have average slope gradients in the range of 40–60° and which are colluvial footslope, drainage plain, cliff, fill and/or disturbed terrain are GLUM Class IV.

(ii) *General Erosion*
The classes within the appreciable erosion category do not necessarily constitute a geotechnical limitation. However, steep slopes associated with the more severe forms of apprecible erosion are classified as GLUM Class IV terrain.

(iii) *Instability*
Areas of instability are considered to have severe geotechnical constraints. They are either Glum Class III or IV depending on the terrain component and slope angle. All sideslope, footslope, cut and fill terrain with slopes in excess of 15° which display landslip features, as well as the colluvial drainage plains, are allocated to GLUM Class IV.

The GEOTECS Plot, Figure 10 shows that GLUM Class IV terrain is extensive and relatively continuous. In parts, it is dissected mainly by disjointed parcels of GLUM Class III terrain and broad diffuse zones of GLUM Class II terrain. The greatest concentration of GLUM Class IV occurs towards the south of the study area and is associated with the mountainous spine of Lantau. It extends from Ngong Ping through Lantau Peak to Sunset Peak and then northwards into a more irregular band occupying most of the high crest and ridge areas.

4.2.6 *Assessment of Planning Strategies Using GEOTECS*

Any search for areas suitable for a proposed land use requires an initial shortlisting of potential sites. Where the initial assessment of suitability can be defined in terms of the existing terrain and the existing land use, GEOTECS may be used to prepare computer-generated plots which indicate areas fulfilling any given strategy (Styles et al, 1986). Computer-generated plots are used to illustrate various aspects of this Report. GEOTECS is discussed in Section 1.5.8 and described in detail in Appendix A10.

The following considerations are important for the satisfactory use of the sytem:

(*a*) The highlighting of areas using GEOTECS provides only an initial assessment of potential or suitability. The results do not necessarily reveal all the options available.

(*b*) Factors other than those included in GEOTECS will influence any planning decision.

(*c*) The applicability of any such assessment depends on the selection of relevant GEOTECS attributes for the strategy.

(*d*) Each two-hectare grid-cell in the GEOTECS system is independent of adjacent cells.

(*e*) The land information stored within GEOTECS is designed for geotechnical, geological and engineering applications. It should be used to gauge the general distribution of specific attributes and/or combinations of attributes.

One of the advantages of the GEOTECS approach is that it enables a set of primary options to be derived regardless of individual local knowledge or preference. It assesses the terrain in a systematic manner according to the criteria selected from the various terrain-related attributes. Two examples are provided to illustrate the application of GEOTECS for planning and engineering purposes.

(i) *Undeveloped Terrain with Low to Moderate Geotechnical Limitations*
The areas of undeveloped terrain with low to moderate geotechnical limitations are summarised on the GEOTECS Plot, Figure 11. Some 2 930 ha (39.6%) of the undeveloped terrain has low to moderate geotechnical limitations and consequently, is generally suitable for development. If the areas which occur within Country Park are excluded, then some 2 495 ha (33.7%) of the study area has moderate to high suitability for development from a geotechnical point of view.

(ii) *Potential Quarry Sites*
The GEOTECS Plot in Figure 12 indicates areas which exhibit quarry potential on the basis of several terrain attributes. The selection criterion for areas without intensive existing land use is primarily that of a convex, straight or cliff slope less than 40° in gradient. As a secondary criterion, areas are also selected on the basis of slope angle alone. These selection criteria enable quarry potential to be maximised between the existing ground surface and the final quarry face. Thus, groups of several units with optimum potential or with occasional secondary potential may make suitable sites. Bedrock geology is not used in the initial assessment presented in the GEOTECS Plot in Figure 12, although it must be incorporated for advanced planning. Once potential rock types are selected, they can be added to the GEOTECS strategy for the production of a further plot. Hence, the refinement of alternative quarry sites is possible.

Approximately 3 700 ha of undesignated natural terrain has potential for quarry sites. A further 1 030 ha with potential for quarrying occurs within existing Country Parks or is under cultivation. These figures indicate that many options exist, but the number of options would be reduced when rock type is specified.

5. CONCLUSIONS

The findings reached during the North Lantau area study are presented on a series of physical resource, planning and engineering maps produced at a scale of 1:20 000. The major maps are: the Geotechnical Land Use Map (GLUM), the Physical Constraints Map (PCM) and the Engineering Geology Map (EGM).

The major conclusions fall very broadly into two categories which relate firstly, to materials and land resource distribution, and secondly, to land management associated with planning and engineering feasibility.

5.1 Materials and Land Resource Distribution

(*a*) Slope instability of some form or other is relatively common within the study area. Approximately 1 914 ha of the terrain (25.9%) is associated with or affected by instability. Instability is associated with most of the geological materials. Slope failures in the colluvium and volcanics are generally characterised by small landslip scars with extensive debris trails. In the case of volcanic rocks, this is probably due to the relatively steep slopes on which failure occurs. Landslips on the intrusive igneous rocks are also common, but tend to be relatively small rotational or joint controlled failures, often associated with cut slopes. Slope failures in intrusive igneous rocks usually cause less impact on the terrain than failures in volcanic rock or colluvium.

(*b*) The geology of the area is complex, and several aspects require careful investigation. Weathering depths are variable, with very deep weathering occurring in some granitic areas. The feldspar porphyry rocks have not been extensively encountered in other parts of the Territory, and experience will be required in working with this material. There are numerous photolineaments present, many of which are likely to be faults, shear zones, major joint zones or dykes. Surface erosion is more pronounced on the granitic terrain than on the volcanics.

(*c*) Approximately 1 467 ha of the footslope terrain is covered by extensive colluvial deposits; 10.1% of the colluvium is affected by instability. Significant geotechnical limitations should be anticipated on zones of runoff and surface drainage across the colluvium, which occupy some 58.8% (864 ha) of the generally low angle colluvial footslope terrain.

(*d*) The granitic terrain has a slightly higher proportion of GLUM Classes I & II (56.6%) than the volcanics (36.1%). Of the 1 467 ha of colluvial terrain which occurs within the study area, some 94.0% is subject to high to extreme geotechnical constraints (GLUM Classes III & IV).

(*e*) Approximately 29.1% of the study area is characterised by slopes which have gradients between 0 and 15°. A further 66.8% of the terrain has slope gradients between 15 and 40° and 4.1% is steeper than 40°.

(*f*) Granitic terrain is generally suitable as a source of borrow and aggregate. Future expansion of existing quarries is not so much restricted by geological constraints as by urban development, water supply catchments and Country Park.

(*g*) There is approximately 33 ha of reclamation (0.4%) within the study area. The siting of development on extensive reclamation that is underlain by thick compressible marine sediments, may give rise to foundation problems and settlement of services. This aspect will require careful design and control during construction.

(*h*) Approximately 4.2% of the study area is currently developed in some form or other. Squatters occupy 0.5% of the area, and 21.9% is allocated to Country Park. Of the remaining land, 5 045 ha consists of undisturbed natural terrain.

5.2 Land Management Associated with Planning and Engineering Feasibility

(*a*) During the last 20 years a number of large landslips within the Territory, have resulted in considerable loss of life and very substantial property damage (So, 1971; Lumb, 1975; Brand, 1984). Landslips have occurred in developed areas, squatter villages and natural terrain (Government of Hong Kong, 1972 a & b, 1977). Slope instability not only poses a threat to life and property but also diminishes the viability for development of the natural terrain which remains undeveloped. In the North Lantau study area, the geotechnical constraints associated with the terrain are important factors for land management purposes and engineering feasibility.

(*b*) Opportunities do exist for urban expansion in the study area, but it is unrealistic to envisage that future development can avoid areas with geotechnical limitations. Some areas of GLUM Class III, and possibly Class IV, terrain occur within these broad areas of development potential, but an integrated approach to planning and engineering design should minimize the hazard of slope failure.

(*c*) If areas are selected for intensive development on GLUM Classes III & IV terrain, they should be subject to terrain classification at a scale of 1:2 500 (District Study, Stage 1) or a comparable level of investigation.

(*d*) This study indicates that there is 5 045 ha of currently undisturbed natural terrain, which does not include Country Park. Of this figure, GLUM Classes I & II occur on some 42.8% (2 160 ha) of the terrain, and 2 810 ha is associated with high to extreme geotechnical limitations (GLUM Classes III & IV). There is approximately 1 620 ha of land within the Country Parks, and of this figure 435 ha is classified as either having low or moderate geotechnical limitation (GLUM Classes I & II).

(*e*) Physical land resources are considered basic input for planning and land use management. The other constraints on the suitability of an area for development should be assessed in sympathy with the physical land resource information.

6. REFERENCES

Allen, P. M. & Stephens E. A. (1971). *Report on the Geological Survey of Hong Kong.* Hong Kong Government Press, 116 p. (& 2 maps).

Atherton, J. M. & Burnett, A. D. (1986). *Hong Kong Rocks.* Urban Council, Hong Kong, 151 p.

Bennett, J. D. (1984a). *Review of Superficial Deposits and Weathering in Hong Kong.* Geotechnical Control Office, Hong Kong, 51 p. (GCO Publication no. 4/84).

Bennett, J. D. (1984b). *Review of Hong Kong Stratigraphy.* Geotechnical Control Office, Hong Kong, 62 p. (GCO Publication no. 5/84).

Bennett, J. D. (1984c). *Review of Tectonic History, Structure and Metamorphism of Hong Kong.* Geotechnical Control Office, Hong Kong, 63 p. (GCO Publication no. 6/84).

Brand, E. W. (1984). Landslides in Southeast Asia: a state-of-the-art report. *Proceedings of the Fourth International Symposium on Landslides,* Toronto, vol. 1, pp. 17–59. (Addendum, vol. 3, pp 105–106).

Brand, E. W. (1988). *Bibliography on the Geology and Geotechnical Engineering of Hong Kong to December 1987.* Geotechnical Control Office, Hong Kong, 146 p. (GCO Publication no. 1/88).

Brand, E. W., Burnett, A. D. & Styles, K. A. (1982a). The Geotechnical Area Studies Programme in Hong Kong. *Proceedings of the Seventh Southeast Asian Geotechnical Conference,* Hong Kong, vol. 1, pp 107–123.

Brand, E. W., Maunder, C. A. & Massey, J. B. (1984). Aggregates in Hong Kong. *Proceedings of the International Symposium on Aggregates,* Nice, France. (Published in *Bulletin of the International Association of Engineering Geology,* no. 29, pp 11–16).

Brand, E. W. & Phillipson, H. B. (1984). Site investigation and geotechnical engineering practice in Hong Kong. *Geotechnical Engineering,* vol. 15, pp 97–153.

Brand, E. W., Styles, K. A. & Burnett, A. D. (1982b). Geotechnical land use maps for planning in Hong Kong. *Proceedings of the Fourth Congress of the International Association of Engineering Geology,* New Delhi, vol. 1, pp 145–153.

Burnett, A. D., Brand, E. W. & Styles, K. A. (1985). Terrain evaluation mapping for a landslide inventory in Hong Kong. *Proceedings of the Fourth International Conference and Field Workshop on Landslides,* Tokyo, pp 63–68.

Burnett, A. D. & Styles, K. A. (1982). An approach to urban engineering geological mapping as used in Hong Kong. *Proceedings of the Fourth Congress of the International Association of Engineering Geology,* New Delhi, vol. 1, pp 167–176.

Carson, M. A. & Kirkby, M. J. (1972). *Hillslope Form and Process.* Cambridge University Press, London, 475 p.

Davis, S. G. (1952). *The Geology of Hong Kong.* Government Printer, Hong Kong, 231 p.

Geological Society of London (1977). The description of rock masses for engineering purposes. (Geol. Soc. Working Party Report). *Quarterly Journal of Engineering Geology,* vol. 10, pp 355–388.

Geotechnical Control Office (1984). *Geotechnical Manual for Slopes.* (Second edition). Geotechnical Control Office, Hong Kong, 295 p.

Government of Hong Kong (1972a). *Interim Report of the Commission of Inquiry into the Rainstorm Disasters, 1972.* Hong Kong Government Printer, 22 p.

Government of Hong Kong (1972b). *Final Report of the Commission of Inquiry into Rainstorm Disasters, 1972.* Hong Kong Government Printer, 94 p.

Government of Hong Kong (1977). *Report on the Slope Failures at Sau Mau Ping, August 1976.* Hong Kong Government Printer, 105 p. (& 8 drgs).

Hansen, A. (1984a). Landslide hazard analysis. *Slope Instability,* edited by D. Brunsden & D. B. Prior, pp 523–602. John Wiley & Sons, Chichester, UK.

Hansen, A. (1984b). Engineering geomorphology: the application of an evolutionary model of Hong Kong's terrain. *Zeitschrift für Geomorphologie,* supplementary vol. 51, pp 39–50.

Hansen, A. & Nash, J. M. (1984). A brief review of soil erosion in Hong Kong—causes, effects and remedial measures. *Proceedings of the Conference on Geological Aspects of Site Investigation,* Hong Kong, pp 139–150. (Published as *Geological Society of Hong Kong, Bulletin* no. 2)

Hencher, S. R. & Martin, R. P. (1982). The description and classification of weathered rocks in Hong Kong for engineering purposes. *Proceedings of the Seventh Southeast Asian Geotechnical Conference,* Hong Kong, vol. 1, pp 125–142. (Discussion, vol. 2, pp 167–168).

Holt, J. K. (1962). The soils of Hong Kong's coastal waters. *Proceedings of the Symposium on Hong Kong Soils,* Hong Kong, pp 33–51.

Howard, A. D. (1967), Drainage analysis in geologic interpretation: a summation. *Bulletin of the American Association of Petroleum Geology,* vol. 51, no. 11, pp 2 246–2 259.

Leach, B. (1982). The development of a groundwater recharge model for Hong Kong. *Journal of Hydrological Sciences,* vol. 4, pp 469–491.

Leach, B. & Herbert, R. (1982). The genesis of a numerical model for the study of the hydrogeology of a steep hillside in Hong Kong. *Quarterly Journal of Engineering Geology,* vol. 15, pp 243–259.

Lumb, P. (1962a). General nature of the soils of Hong Kong. *Proceedings of the Symposium on Hong Kong Soils,* Hong Kong, pp 19–32 (& 1 drg).

Lumb, P. (1962b). The properties of decomposed granite. *Géotechnique,* vol. 12, pp 226–243.

Lumb, P. (1964). *Report on the Settlement of Buildings in the Mong Kok District of Kowloon, Hong Kong.* Hong Kong Government Printer, 22 p. (& 8 drgs).

Lumb, P. (1965). The residual soils of Hong Kong. *Géotechnique,* vol. 15, pp 180–194. (Discussion, vol. 16, 1966, pp 78–81 & 359–360).

Lumb, P. (1972). Building settlements in Hong Kong. *Proceedings of the Third Southeast Asian Conference on Soil Engineering,* Hong Kong, pp 115-121. (Discussion, pp 394–396).

Lumb, P. (1975). Slope failures in Hong Kong. *Quarterly Journal of Engineering Geology,* vol. 8, pp 31–65.

Lumb, P. (1983). Engineering properties of fresh and decomposed igneous rocks from Hong Kong. *Engineering Geology,* vol. 19, pp 81–94.

Moye, D. G. (1955). Engineering geology for the Snowy Mountain Scheme. *Journal of the Institution of Engineers Australia,* vol. 27, pp 281–299.

Nash, J. M. & Dale, M. J. (1983). Geology and hydrogeology of natural tunnel erosion in superficial deposits in Hong Kong. *Proceedings of the Meeting on the Geology of Surficial Deposits in Hong Kong,* Hong Kong, pp 61–72. (Published as *Geological Society of Hong Kong, Bulletin* no. 1)

Phillipson, H. B. & Chipp, P. N. (1981). High quality core sampling—recent developments in Hong Kong. *Hong Kong Engineer,* vol. 9, no. 4, pp 9–15.

Phillipson, H. B. & Chipp, P. N. (1982). Airfoam sampling of residual soils in Hong Kong. *Proceedings of the ASCE Speciality Conference on Engineering and Construction in Tropical and Residual Soils,* Honolulu, Hawaii, pp 339–356.

Randall, P. A. & Taylor, B. W. (1982). Engineering geology in the Mid-levels Study, Hong Kong. *Proceedings of the Seventh Southeast Asian Geotechnical Conference,* Hong Kong, vol. 1, pp 189–204.

Richards, L. R. & Cowland, J. W. (1986). Stability evaluation of some urban rock slopes in a transient groundwater regime, in *Rock Engineering and Excavation in an Urban Environment,* proceedings of a conference held in Hong Kong. Institution of Mining and Metallurgy, London, pp. 357–363.

Rodin, S., Henkel, D. J. & Brown, R. L. (1982). Geotechnical study of a large hillside area in Hong Kong. *Hong Kong Engineer,* vol. 10, no. 5, pp 37–45.

Ruxton, B. P. (1957). Graphite seams in Hong Kong. *Colonial Geology and Mineral Resources,* vol. 6, pp 429–441.

Ruxton, B. P. (1960). The geology of Hong Kong. *Quarterly Journal of the Geological Society of London,* vol. 115, pp 233–260.

Ruxton, B. P. & Berry, L. (1957). Weathering of granite and associated erosional features in Hong Kong. *Bulletin of the Geological Society of America,* vol. 68, pp 1263–1291.

So, C. L. (1971). Mass movements associated with the rainstorm of June 1966 in Hong Kong. *Transactions of the Institute of British Geographers,* no. 53, pp 55–65.

Strahler, A. N. (1952). Dynamic basis of geomorphology. *Bulletin of the Geological Society of America,* vol. 63, pp 923–938.

Styles, K. A. (1982). Aerial photograph interpretation—terrain classification. *Proceedings of the Seventh Southeast Asian Geotechnical Conference,* Hong Kong, vol. 2, pp 149–158.

Styles, K. A. (1983). Delineation of colluvial deposits in Hong Kong using the technique of terrain classification. *Proceedings of the Meeting on the Geology of Surficial Deposits in Hong Kong*, Hong Kong, pp 103–113. (Published as *Geological Society of Hong Kong, Bulletin* no. 1)

Styles, K. A. & Burnett, A. D. (1983). The assessment of hydrogeological features using the technique of terrain classification. *Proceedings of the ESCAP-RMRDC Workshop on Hydrogeological Mapping in Asia and the Pacific Region*, Bandung, Indonesia, vol. 7, pp 121–144.

Styles, K. A. & Burnett, A. D. (1985). Geotechnical Area Studies Programme and land planning in Hong Kong. *Planning and Development*, vol. 1, no. 2, pp 13–23.

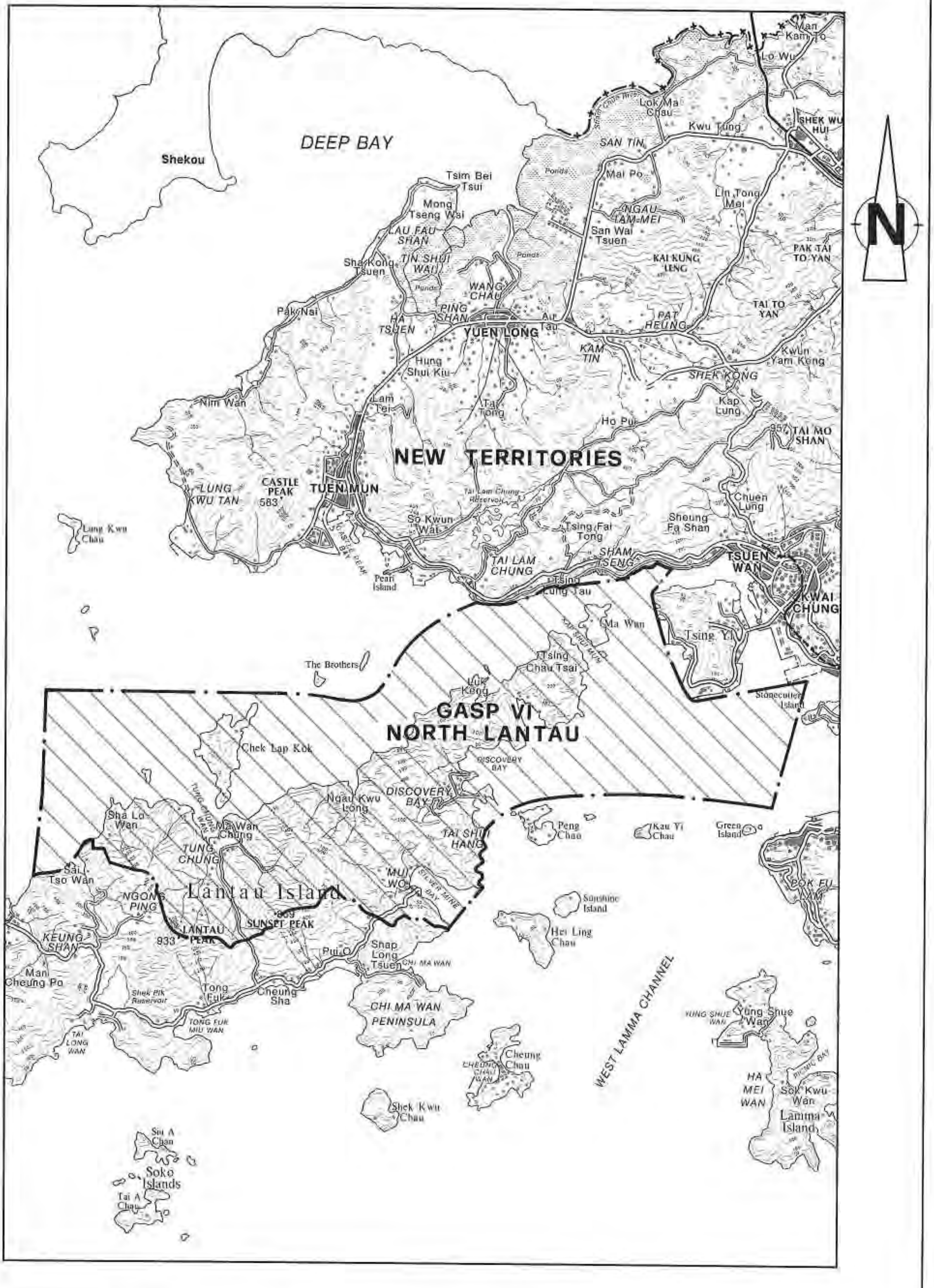
Styles, K. A., Burnett, A. D. & Cox, D. C. (1982). Geotechnical assessment of the terrain for land management and planning purposes in Hong Kong. *Proceedings of the First International Symposium on Soil, Geology and Landforms: Impact on Land Use Planning in Developing Countries (Landplan)*, Bangkok, pp F16.1–F16.9.

Styles, K. A., Hansen, A. & Burnett, A. D. (1986). Use of a computer-based land inventory for delineation of terrain which is geotechnically suitable for development. *Proceedings of the Fifth International Congress of the International Association of Engineering Geology*, Buenos Aires, Argentina, vol. 6, pp 1841–1848.

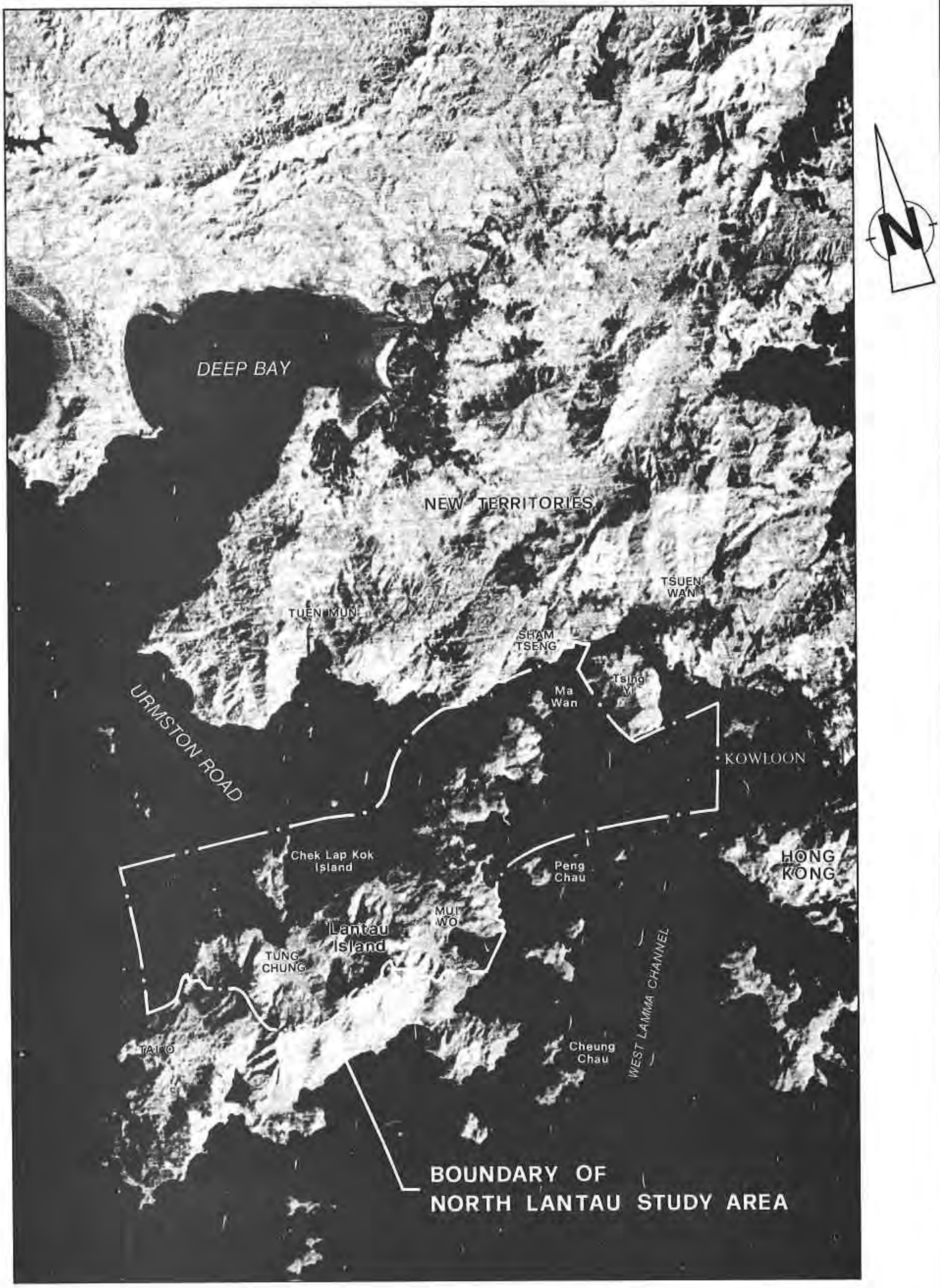
Styles, K. A., Hansen, A., Dale, M. J. & Burnett, A. D. (1984). Terrain classification methods for development planning and geotechnical appraisal: a Hong Kong case. *Proceedings of the Fourth International Symposium on Landslides*, Toronto, vol. 2, pp 561–568.

Thrower, L. B. (1970). The vegetation of Hong Kong. *Proceedings of the Royal Asiatic Society*, vol. 10, pp 21–43.

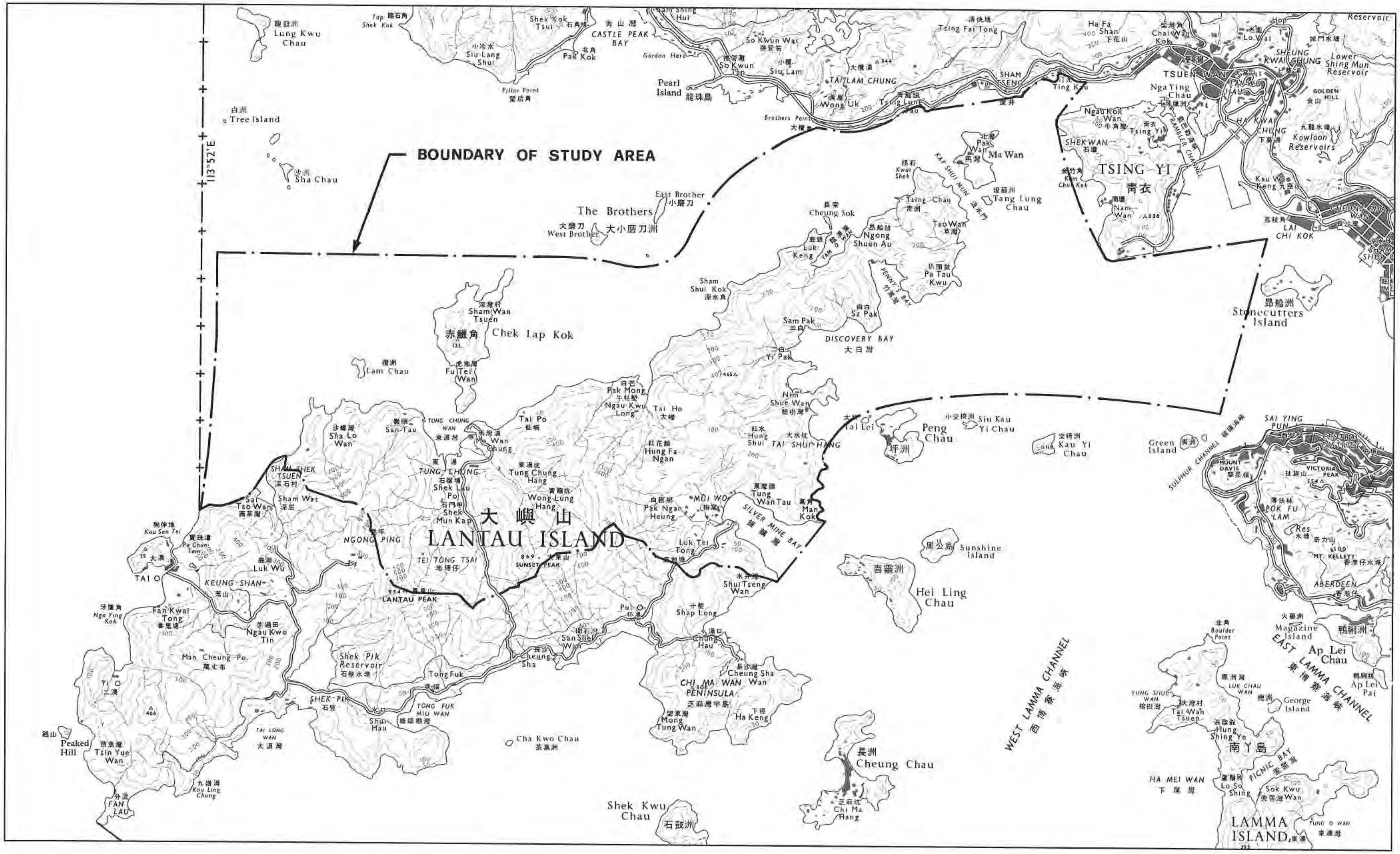
Vail, A. J. & Beattie, A. A. (1985). Earthworks in Hong Kong—their failure and stabilisation. *Proceedings of the International Symposium on Failures in Earthworks*, London, pp 15–28.



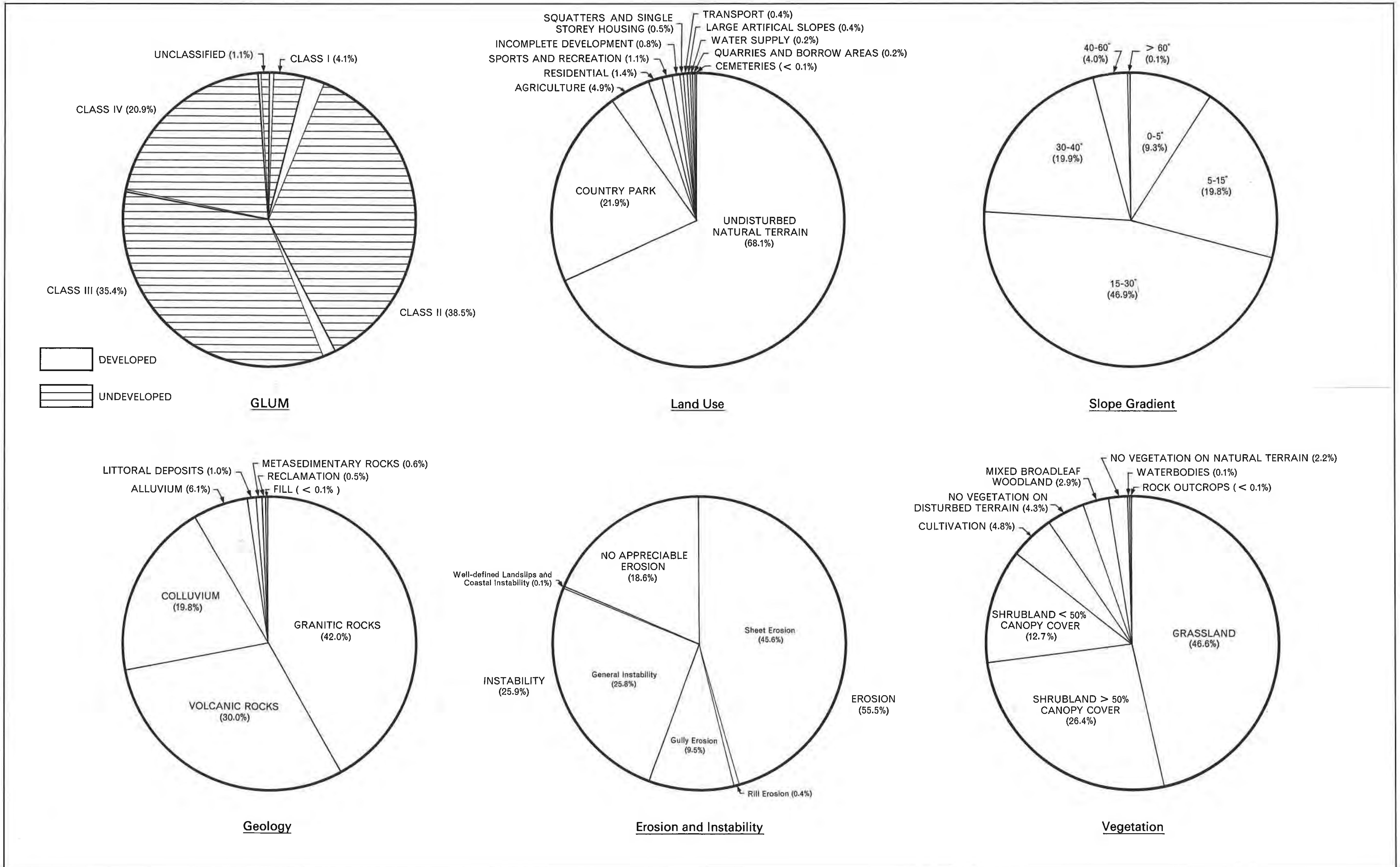
Scale 1:200 000	Location Map of the North Lantau Study Area	Fig. 1



Scale 1:250 000	Satellite Image of the North Lantau Study Area	Fig. 2

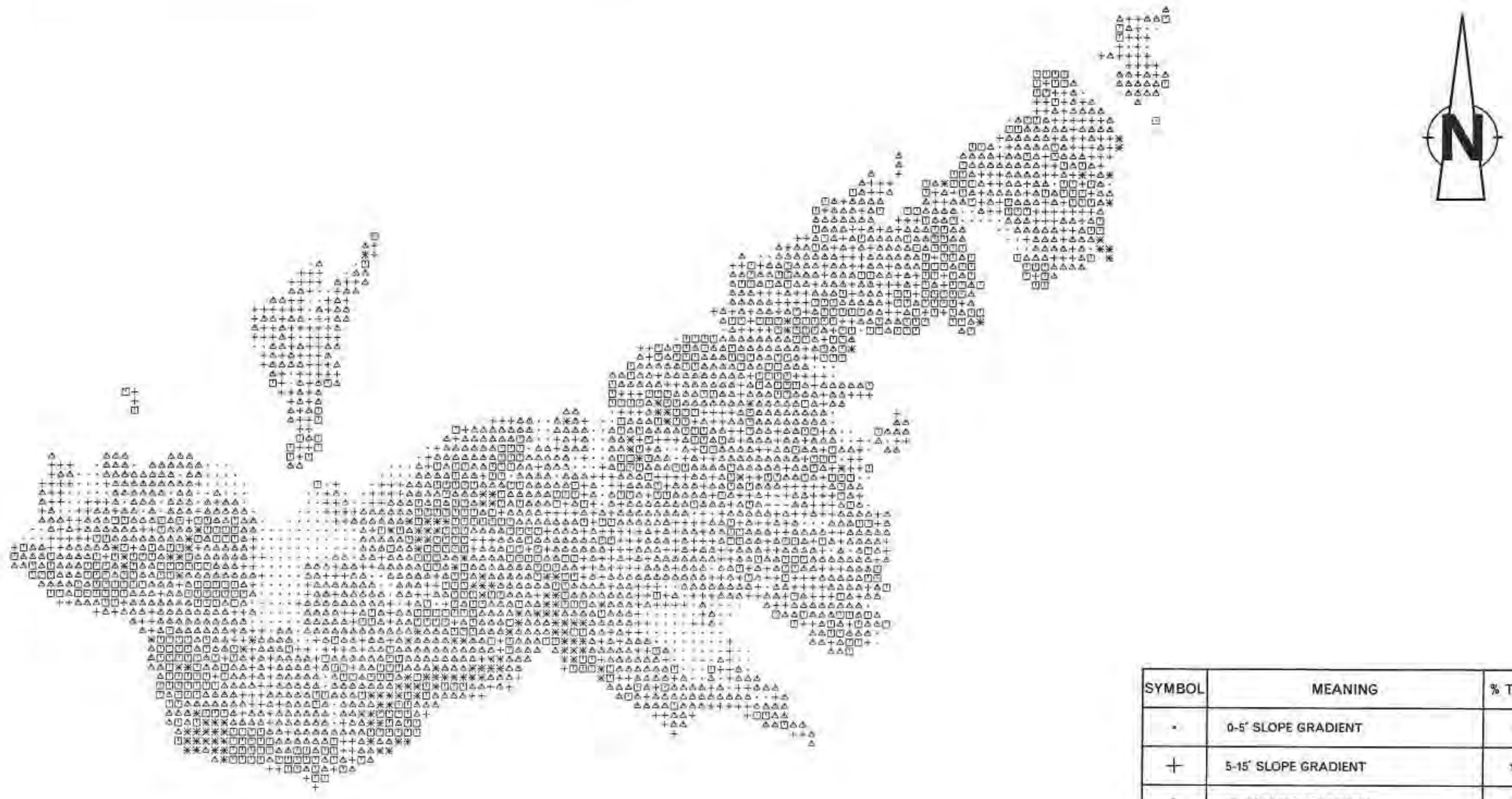


Scale 1:100 000	North Lantau Study Area	Fig. 3



Pie Charts of Selected Attributes of North Lantau

Fig. 4



SYMBOL	MEANING	% TOTAL
·	0-5° SLOPE GRADIENT	9.2
+	5-15° SLOPE GRADIENT	19.8
△	15-30° SLOPE GRADIENT	46.9
◫	30-40° SLOPE GRADIENT	19.9
✳	> 40° SLOPE GRADIENT	4.1
∽	ARTIFICIAL CHANNEL, RESERVOIR OR POND	0.1

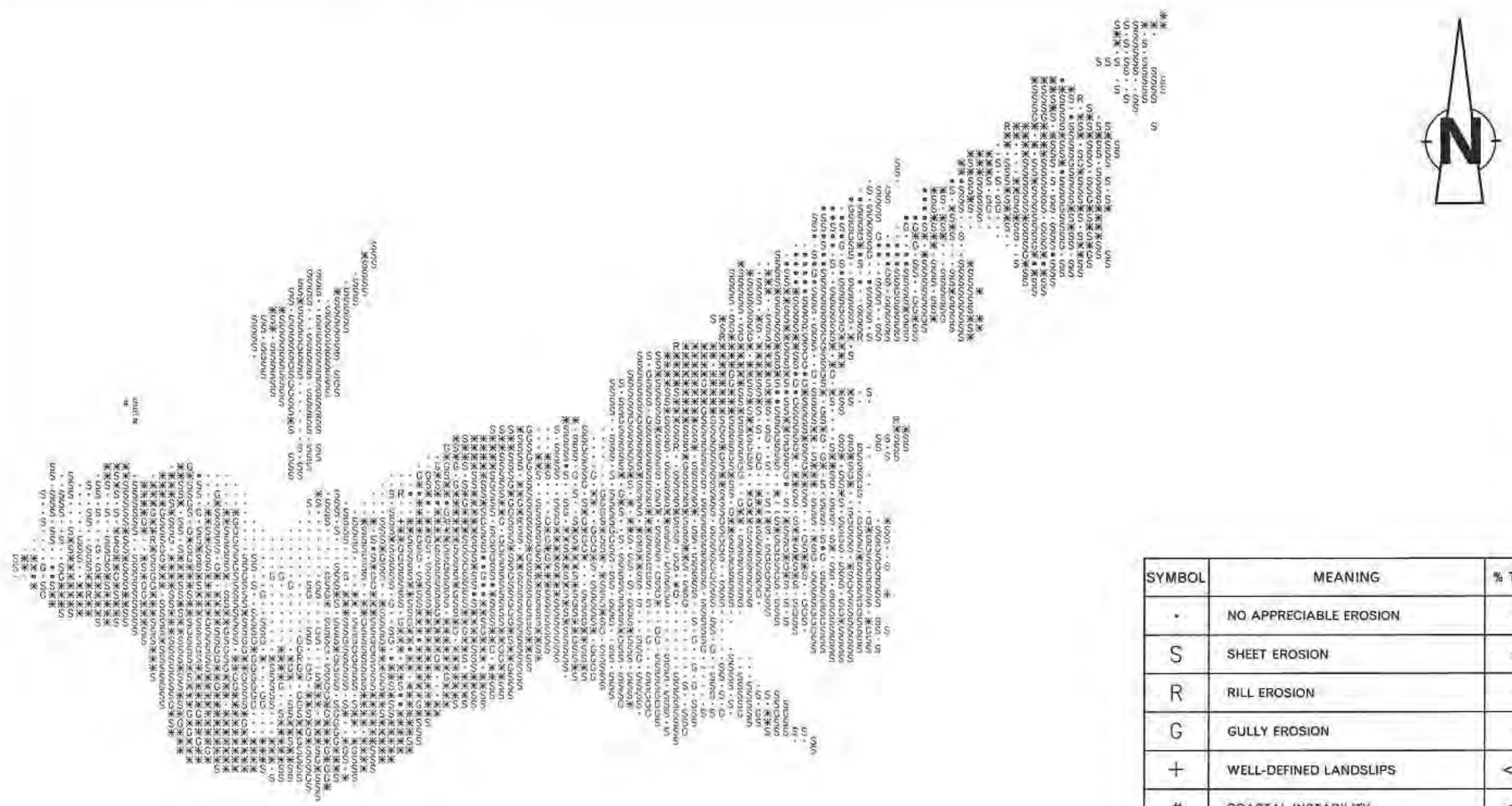
Scale 1:100 000	GEOTECS Plot - Slope Gradient	Fig. 5

SYMBOL	MEANING	% TOTAL
F	FILL	< 0.1
R	RECLAMATION	0.5
A	ALLUVIUM	6.0
Δ	COLLUVIUM	19.8
L	LITTORAL DEPOSITS	1.0
v	VOLCANIC ROCKS	30.0
≠	METASEDIMENTARY ROCKS	0.6
+	INTRUSIVE IGNEOUS ROCKS	42.0
~	RESERVOIR OR POND	0.1

Scale 1:100 000	GEOTECS Plot - Geology	Fig. 6

SYMBOL	MEANING	% TOTAL
+	GRASSLAND	46.6
C	CULTIVATION	4.8
Δ	SHRUBLAND (< 50% CANOPY COVER)	12.7
⍏	SHRUBLAND (> 50% CANOPY COVER)	26.4
⊡	MIXED BROADLEAF WOODLAND	2.9
·	NO VEGETATION ON NATURAL TERRAIN	2.2
D	NO VEGETATION ON DISTURBED TERRAIN	4.3
✳	NO VEGETATION ON ROCK OUTCROPS	< 0.1
~	WATERBODIES (STREAM, CHANNEL, RESERVOIR, PONDS)	0.1

Scale 1:100 000	GEOTECS Plot - Vegetation	Fig. 7

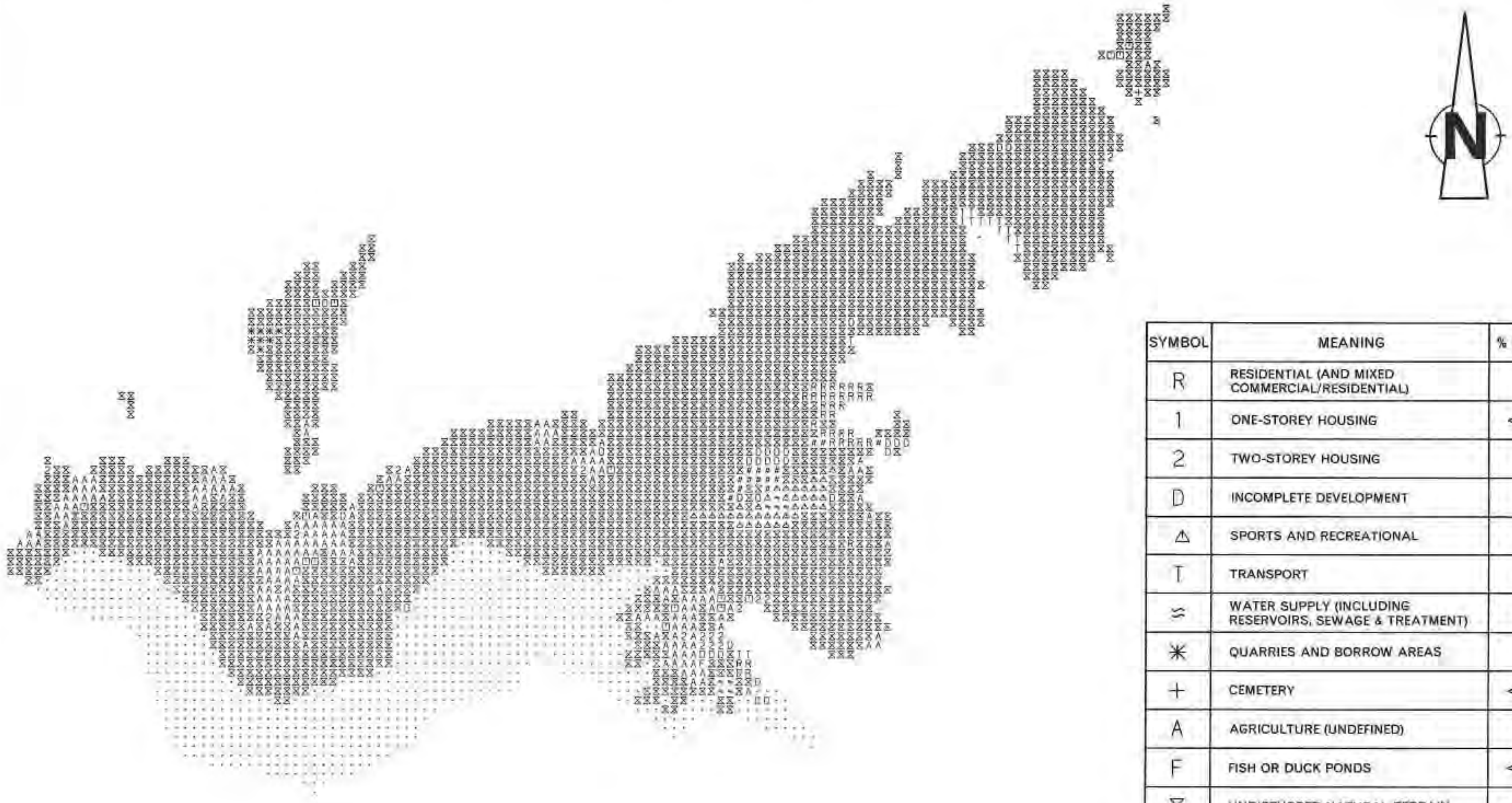


SYMBOL	MEANING	% TOTAL
·	NO APPRECIABLE EROSION	18.5
S	SHEET EROSION	45.6
R	RILL EROSION	0.4
G	GULLY EROSION	9.5
+	WELL-DEFINED LANDSLIPS	< 0.1
#	COASTAL INSTABILITY	< 0.1
✳	GENERAL INSTABILITY (RECENT)	23.5
✡	GENERAL INSTABILITY (RELICT)	2.3
~	STREAM, CHANNEL, RESERVOIR OR POND	0.1

Scale
1:100 000

GEOTECS Plot - Erosion and Instability

Fig. 8

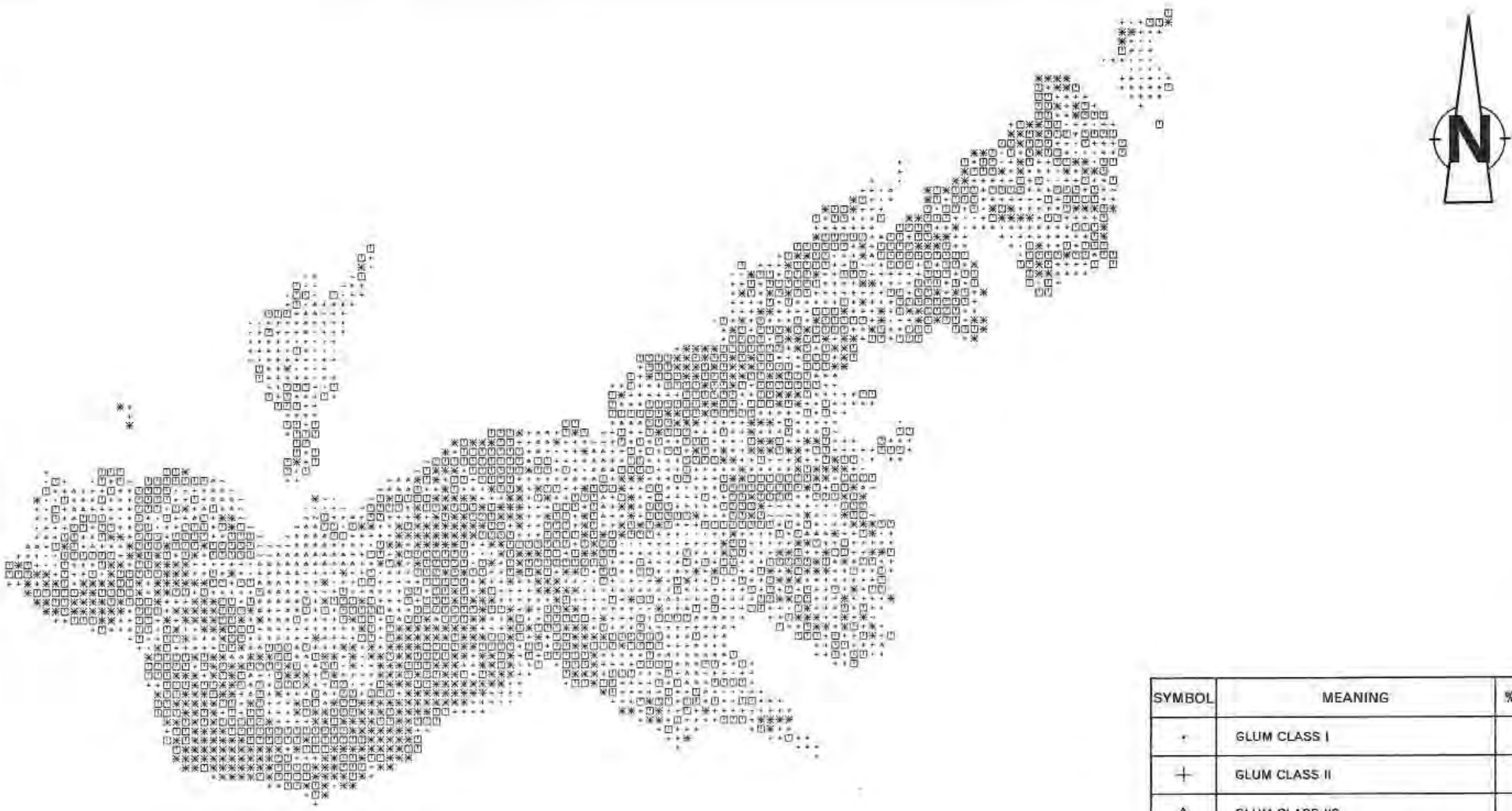


SYMBOL	MEANING	% TOTAL
R	RESIDENTIAL (AND MIXED COMMERCIAL/RESIDENTIAL)	0.9
1	ONE-STOREY HOUSING	< 0.1
2	TWO-STOREY HOUSING	0.5
D	INCOMPLETE DEVELOPMENT	0.8
△	SPORTS AND RECREATIONAL	1.1
T	TRANSPORT	0.4
≈	WATER SUPPLY (INCLUDING RESERVOIRS, SEWAGE & TREATMENT)	0.2
✳	QUARRIES AND BORROW AREAS	0.2
+	CEMETERY	< 0.1
A	AGRICULTURE (UNDEFINED)	4.9
F	FISH OR DUCK PONDS	< 0.1
⧖	UNDISTURBED NATURAL TERRAIN	68.1
·	COUNTRY PARK	21.9
⍐	SQUATTERS	0.5
#	LARGE ARTIFICIAL SLOPES	0.4

Scale
1:100 000

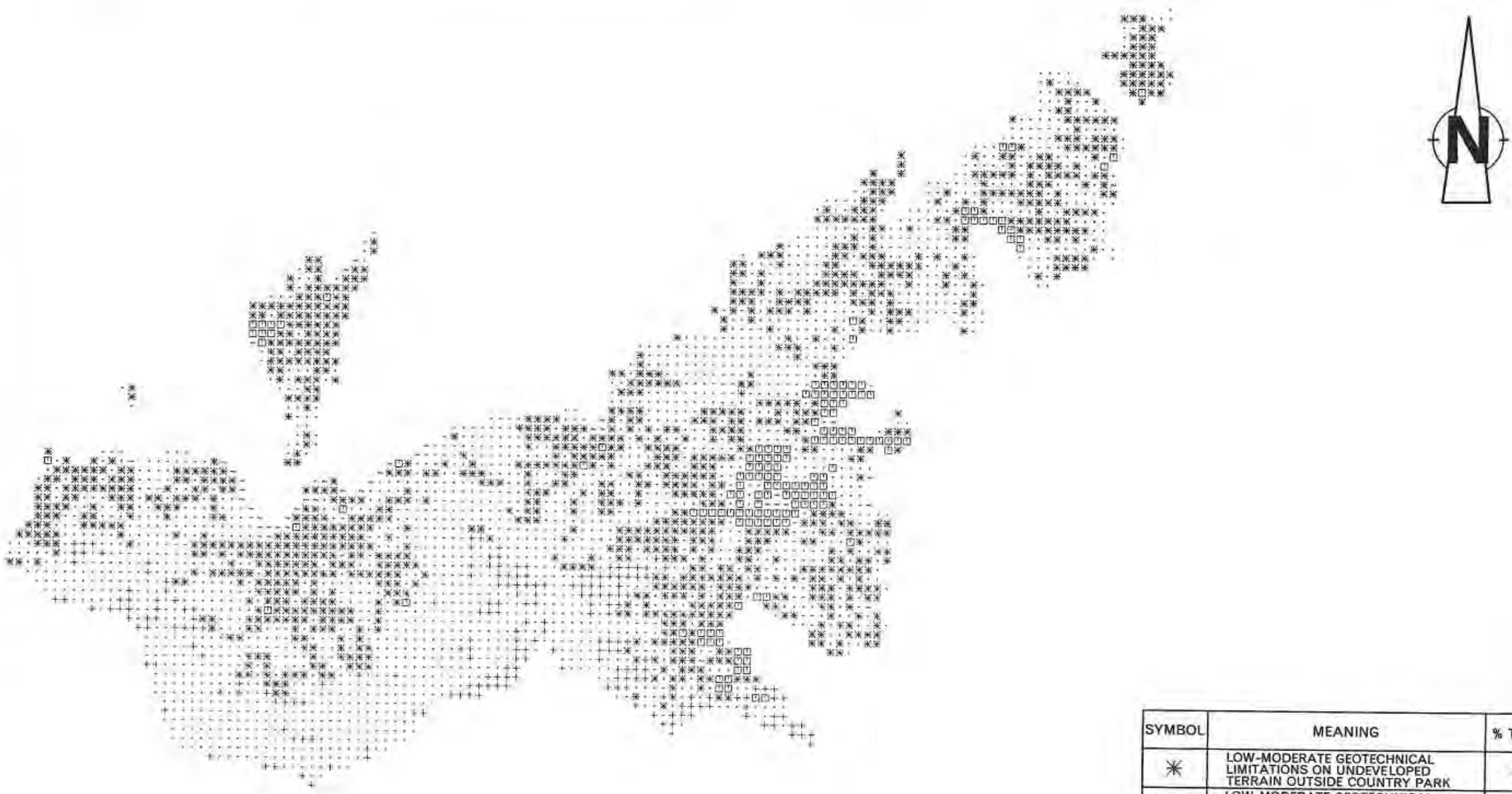
GEOTECS Plot - Land Use

Fig. 9



SYMBOL	MEANING	%TOTAL
·	GLUM CLASS I	4.1
+	GLUM CLASS II	34.2
△	GLUM CLASS IIS	4.3
⊡	GLUM CLASS III	35.4
✳	GLUM CLASS IV	20.9
~	UNCLASSIFIED	1.1

Scale 1:100 000	GEOTECS Plot - Geotechnical Land Use Map	Fig. 10

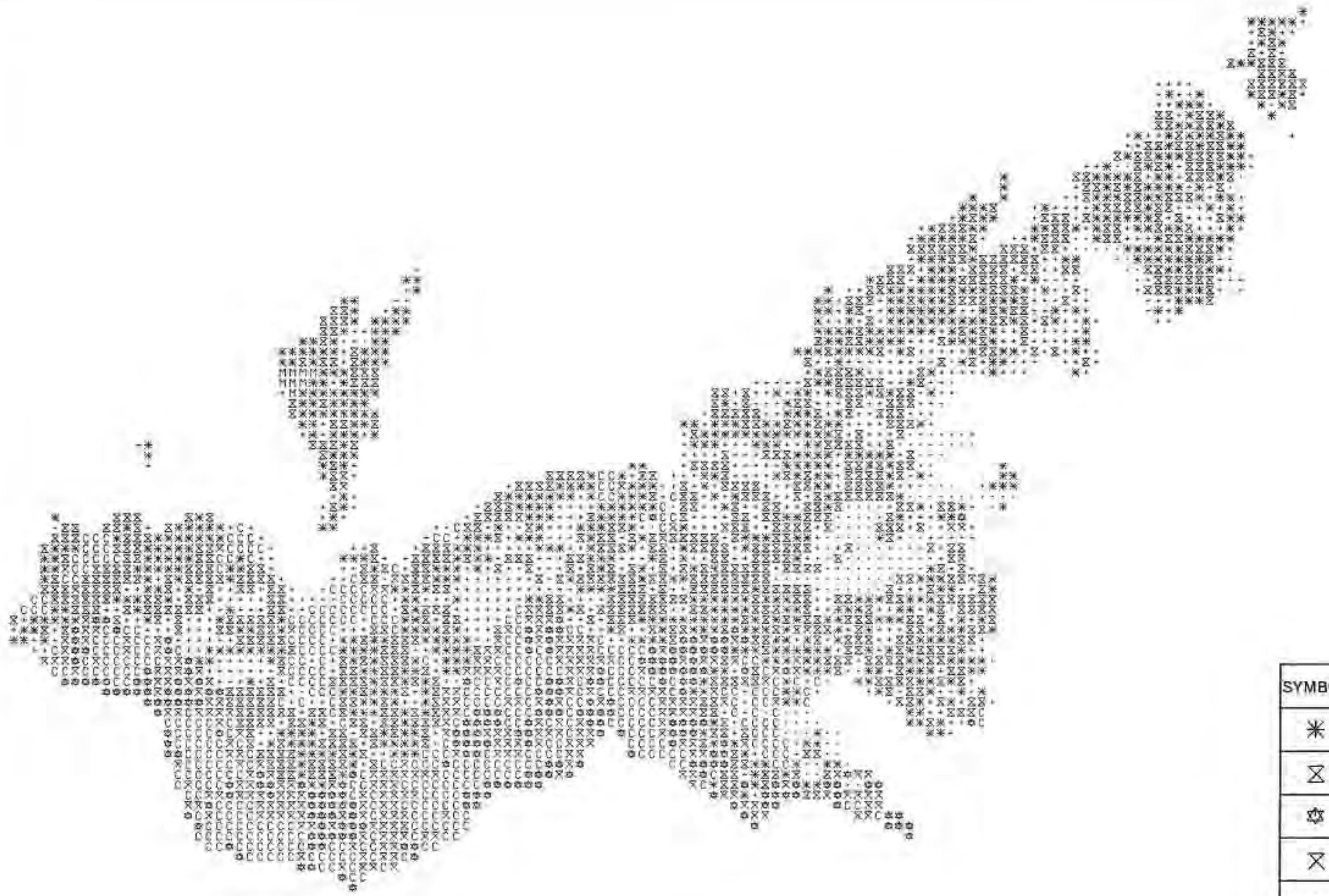


SYMBOL	MEANING	% TOTAL
✳	LOW-MODERATE GEOTECHNICAL LIMITATIONS ON UNDEVELOPED TERRAIN OUTSIDE COUNTRY PARK	33.7
+	LOW-MODERATE GEOTECHNICAL LIMITATIONS ON UNDEVELOPED TERRAIN INSIDE COUNTRY PARK	5.9
◫	EXISTING DEVELOPMENT	4.4
~	WATERBODIES AND LITTORAL ZONE	1.1
·	OTHER TERRAIN	54.9

Scale 1:100 000

GEOTECS Plot - Undeveloped Terrain with Low to Moderate Geotechnical Limitations

Fig. 11

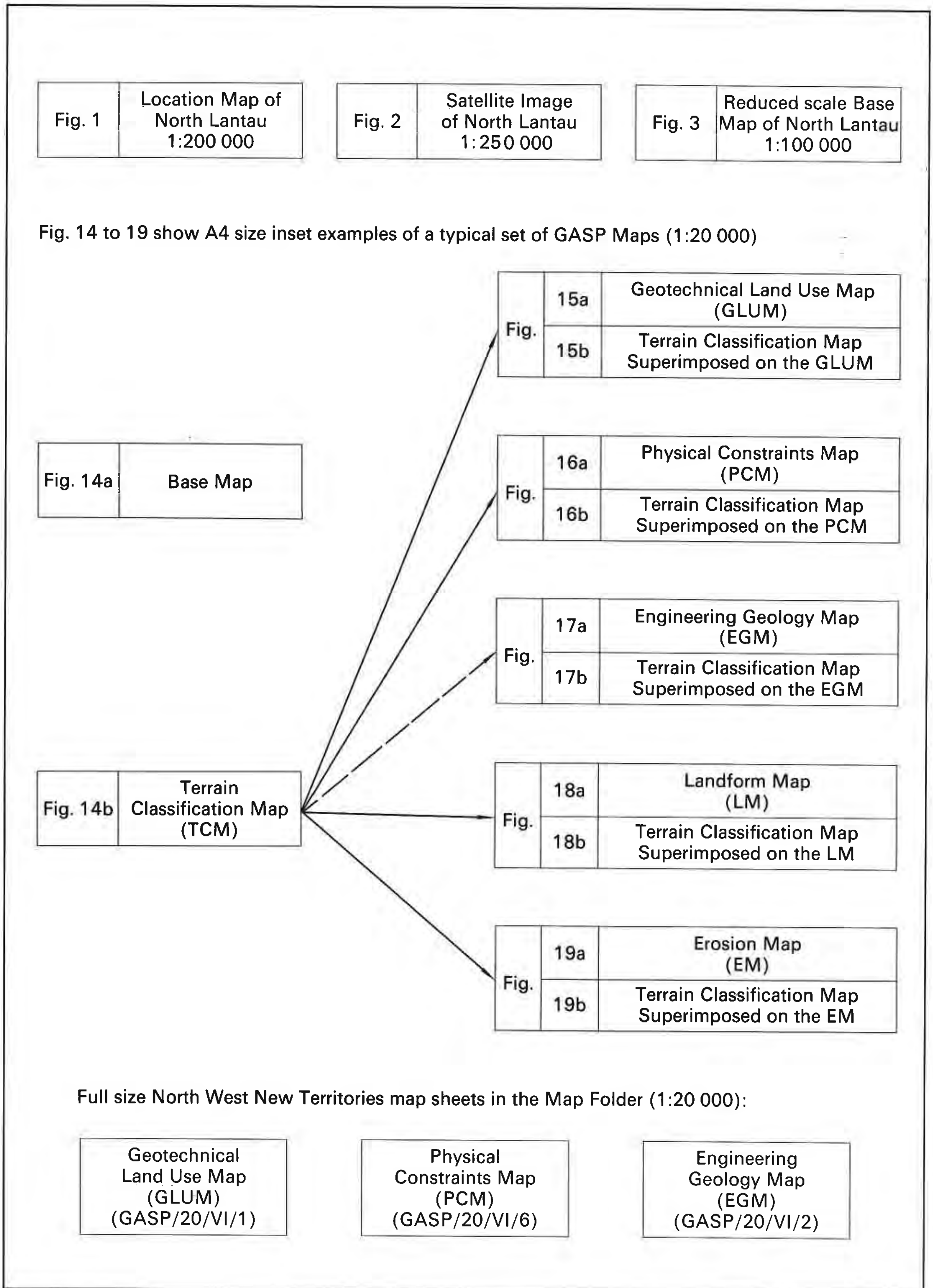


SYMBOL	MEANING	% TOTAL
✳	POTENTIAL (TERRAIN) NO CURRENT USAGE	24.6
⌛	POTENTIAL (SLOPE) NO CURRENT USAGE	25.3
✡	POTENTIAL (TERRAIN) COUNTRY PARK/CULTIVATION	6.5
⌛	POTENTIAL (SLOPE) COUNTRY PARK/CULTIVATION	7.5
·	EXISTING USAGE, RESERVOIR OR CHANNEL	4.4
M	EXISTING QUARRY OR BORROW AREA	0.2
C	OTHER TERRAIN IN COUNTRY PARK, CULTIVATION, POND	12.8
+	UNDESIGNATED - MAY HAVE MINOR POTENTIAL	18.7

Scale 1:100 000

GEOTECS Plot - Potential Quarry Sites

Fig. 12



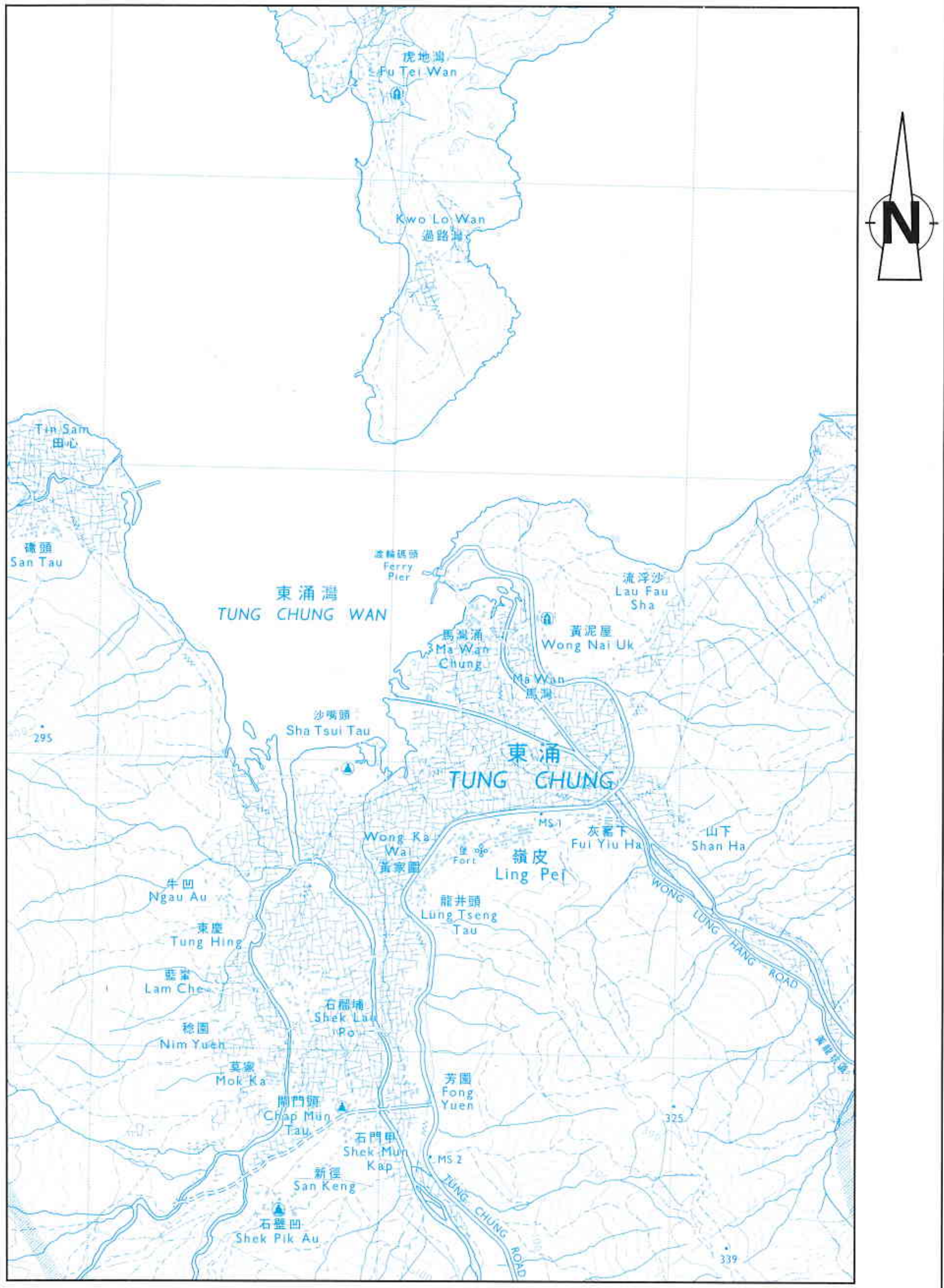
Presentation of Maps — Fig. 13

LEGEND FOR TERRAIN CLASSIFICATION MAP (Fig.14b)

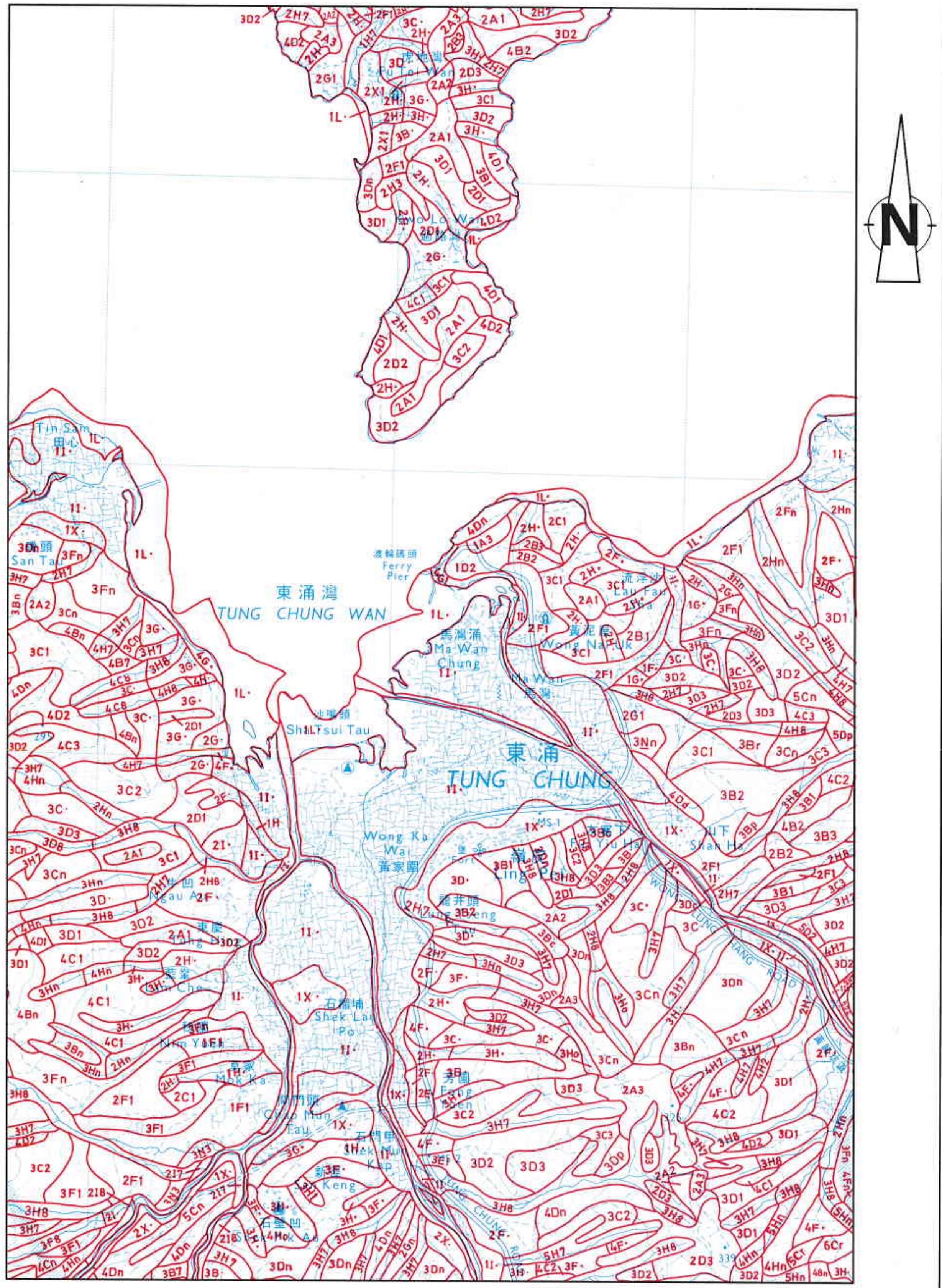
SLOPE GRADIENT	CODE
0 - 5°	1
5 - 15°	2
15 - 30°	3
30 - 40°	4
40 - 60°	5
> 60°	6

TERRAIN COMPONENT		CODE
Crest or ridge		A
Sideslope	- straight	B
	- concave	C
	- convex	D
Footslope	- straight	E
	- concave	F
	- convex	G
Drainage plain		H
Floodplain		I
Coastal plain		K
Littoral zone		L
Cliff/Rock outcrop		M
Cut	- straight	N
	- concave	O
	- convex	P
Fill	- straight	R
	- concave	S
	- convex	T
General disturbed terrain		V
Reclamation		Z
Alluvial plain		X
Waterbodies	- Natural stream	1
	- Manmade channel	2
	- Water storage dam	3
	- Fish pond	4

EROSION			CODE
No appreciable erosion			.
Sheet erosion	- minor		1
	- moderate		2
	- severe		3
Rill erosion	- minor		4
	- moderate		5
	- severe		6
Gully erosion	- minor		7
	- moderate		8
	- severe		9
Well-defined landslip > 1ha in size	- integral	- recent	a
		- relict	b
	- scar	- recent	c
		- relict	d
	- debris	- recent	g
		- relict	k
Development of general instability	- integral	- recent	n
		- relict	o
	- scar	- recent	p
		- relict	r
	- debris	- recent	s
		- relict	t
Coastal	- integral		w
	- scar		y
	- debris		z



Scale 1:20 000	Example of the Base Map	Fig. 14a



Scale 1:20 000	Example of the Terrain Classification Map	Fig. 14b

LEGEND FOR GEOTECHNICAL LAND USE MAP (Fig. 15a)

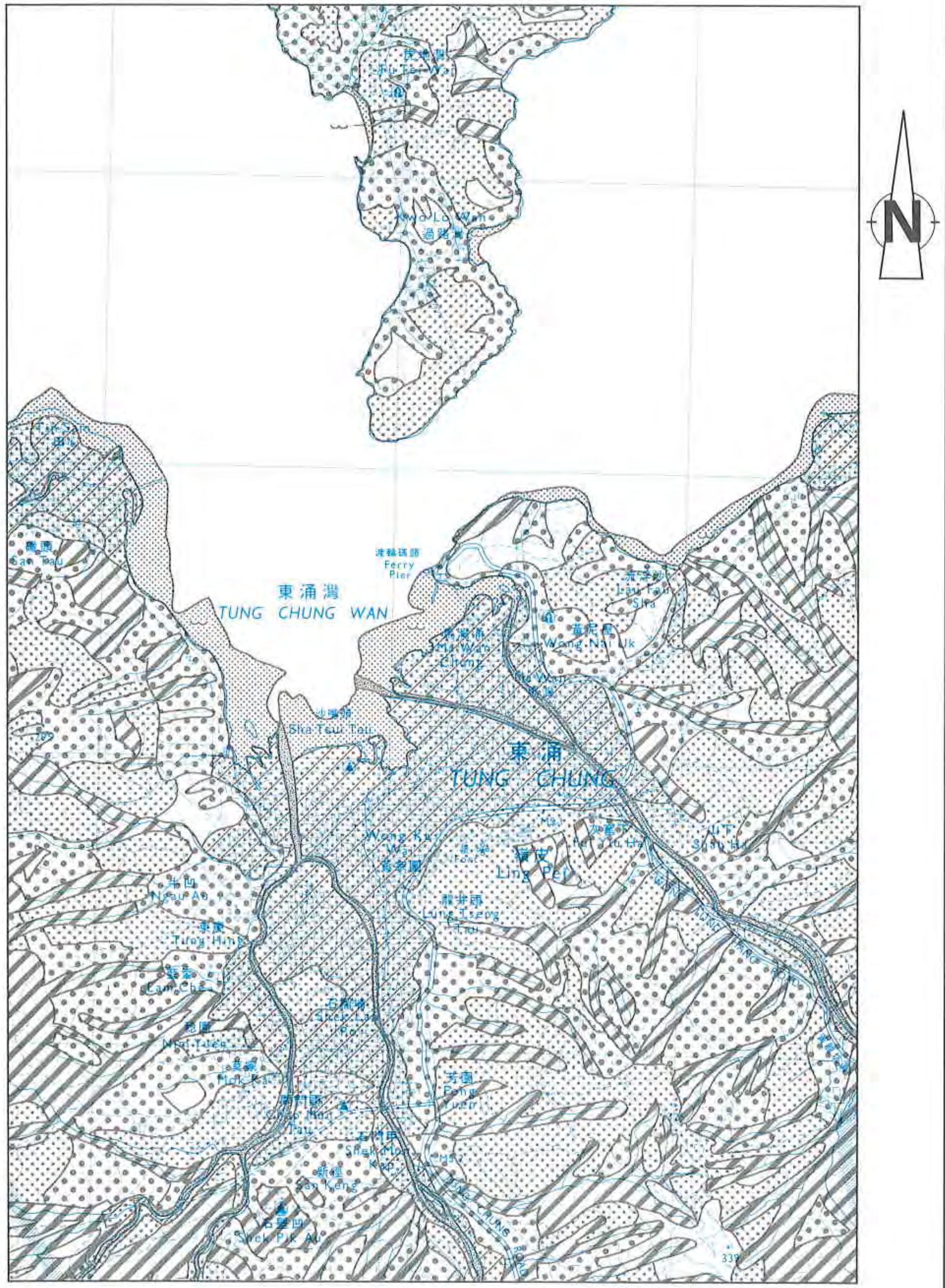
Class I - Low Geotechnical Limitations	
Class II - Moderate Geotechnical Limitations	
Class IIS - Moderate Geotechnical Limitations (including flooding)	
Class III - High Geotechnical Limitations	
Class IV - Extreme Geotechnical Limitations	
Waterbodies (streams, man-made channels, storage dams)	Unclassified
Ponds	Unclassified
Littoral zone (generally subject to tidal action)	Unclassified

LEGEND FOR TERRAIN CLASSIFICATION MAP (Fig. 15b)

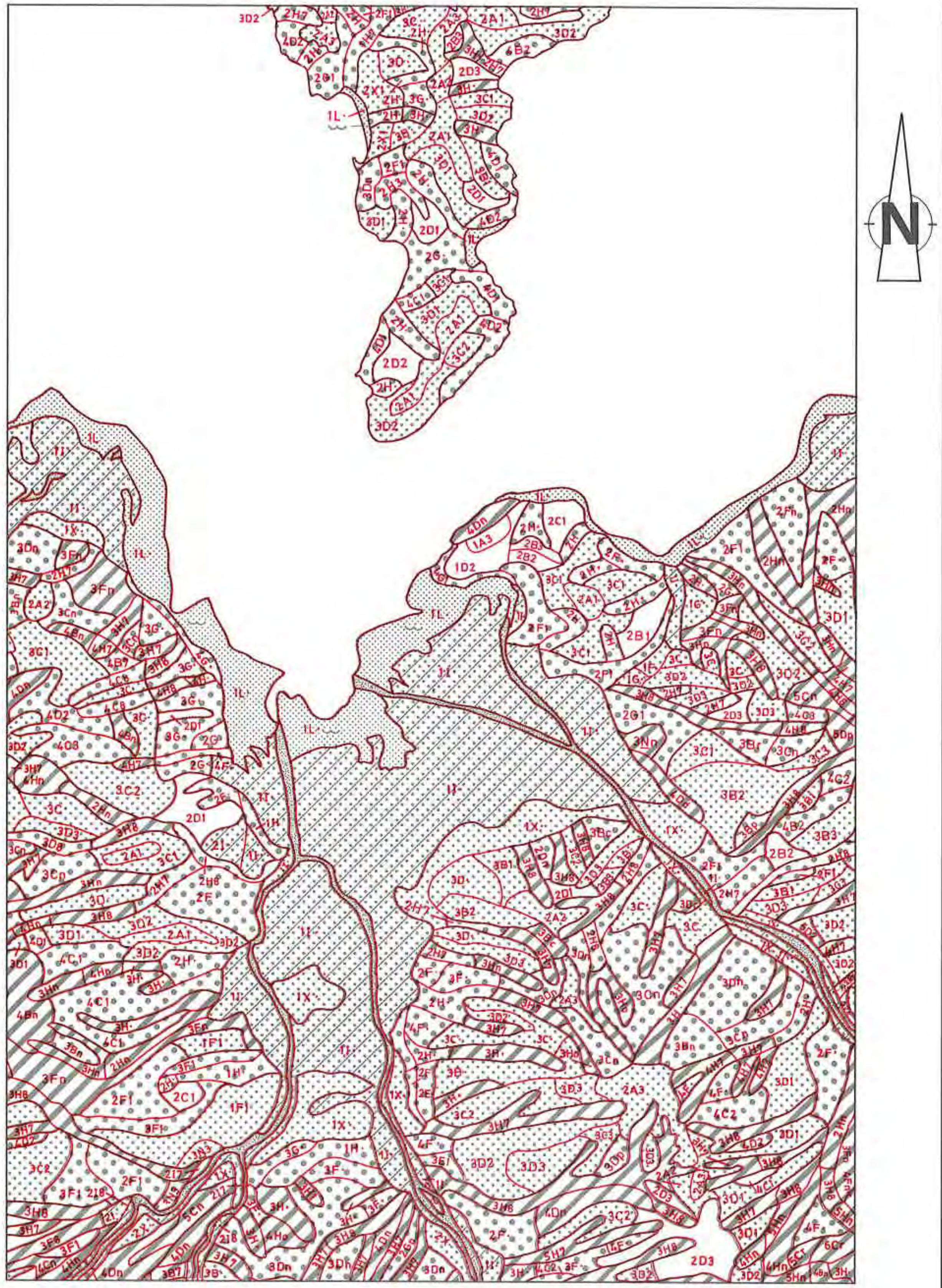
SLOPE GRADIENT	CODE
0 - 5°	1
5 - 15°	2
15 - 30°	3
30 - 40°	4
40 - 60°	5
> 60°	6

TERRAIN COMPONENT		CODE
Crest or ridge		A
Sideslope	- straight	B
	- concave	C
	- convex	D
Footslope	- straight	E
	- concave	F
	- convex	G
Drainage plain		H
Floodplain		I
Coastal plain		K
Littoral zone		L
Cliff/Rock outcrop		M
Cut	- straight	N
	- concave	O
	- convex	P
Fill	- straight	R
	- concave	S
	- convex	T
General disturbed terrain		V
Reclamation		Z
Alluvial plain		X
Waterbodies	- Natural stream	1
	- Manmade channel	2
	- Water storage dam	3
	- Fish pond	4

EROSION			CODE
No appreciable erosion			·
Sheet erosion	- minor		1
	- moderate		2
	- severe		3
Rill erosion	- minor		4
	- moderate		5
	- severe		6
Gully erosion	- minor		7
	- moderate		8
	- severe		9
Well-defined landslip > 1ha in size	- integral	- recent	a
		- relict	b
	- scar	- recent	c
		- relict	d
	- debris	- recent	g
		- relict	k
Development of general instability	- integral	- recent	n
		- relict	o
	- scar	- recent	p
		- relict	r
	- debris	- recent	s
		- relict	t
Coastal	- integral		w
	- scar		y
	- debris		z

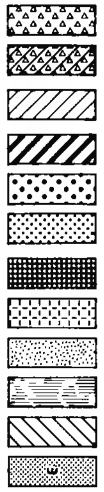


Scale 1:20 000	Example of the Geotechnical Land Use Map (GLUM)	Fig. 15a



Scale 1:20 000	Example of the Terrain Classification Map Superimposed on the GLUM	Fig. 15b

LEGEND FOR PHYSICAL CONSTRAINTS MAP (Fig. 16a)



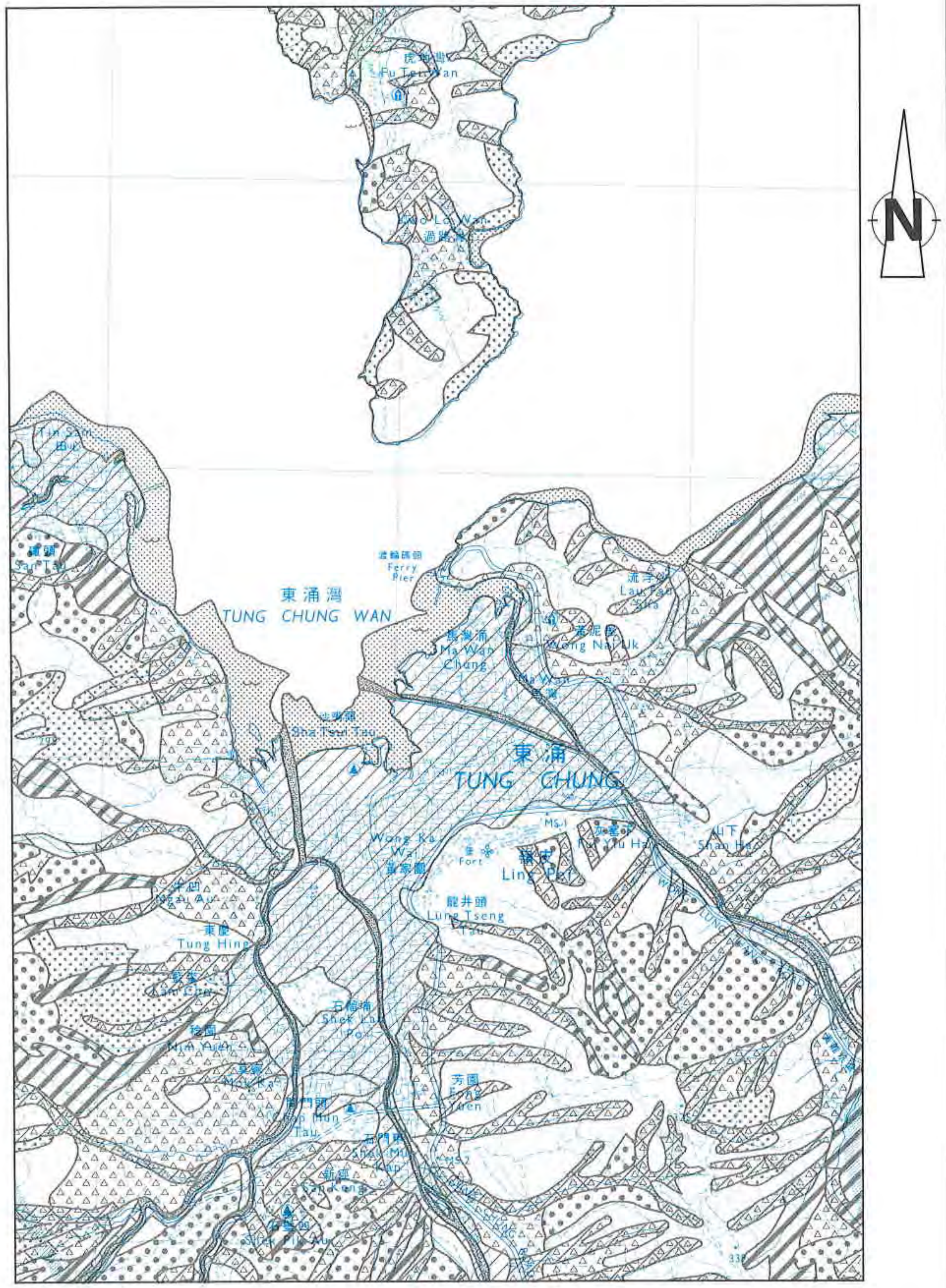
- Colluvium
- Zones of colluvium which are subject to overland flow and periodic inundation. Evidence of unusual groundwater regime (delineated as drainage plain on Landform Map)
- Floodplain - subject to overland flow and regular inundation. Evidence of unusual groundwater regime (delineated as floodplain on Landform Map)
- Zones of general instability associated with predominantly colluvial terrain
- Zones of general instability associated with predominantly insitu terrain
- Slopes on insitu terrain which are generally steeper than 30° (other than those delineated as colluvial or unstable)
- Disturbed terrain - extensive cut and fill batters which generally exceed 30°
- Instability on disturbed terrain
- Waterbodies (streams, man-made channels, storage dams)
- Ponds
- Moderate or severe gully erosion (may be superimposed upon other constraints)
- Littoral zone (generally subject to tidal action)

LEGEND FOR TERRAIN CLASSIFICATION MAP (Fig. 16b)

SLOPE GRADIENT	CODE
0 - 5°	1
5 - 15°	2
15 - 30°	3
30 - 40°	4
40 - 60°	5
> 60°	6

TERRAIN COMPONENT		CODE
Crest or ridge		A
Sideslope	- straight	B
	- concave	C
	- convex	D
Footslope	- straight	E
	- concave	F
	- convex	G
Drainage plain		H
Floodplain		I
Coastal plain		K
Littoral zone		L
Cliff/Rock outcrop		M
Cut	- straight	N
	- concave	O
	- convex	P
Fill	- straight	R
	- concave	S
	- convex	T
General disturbed terrain		V
Reclamation		Z
Alluvial plain		X
Waterbodies	- Natural stream	1
	- Manmade channel	2
	- Water storage dam	3
	- Fish pond	4

EROSION			CODE
No appreciable erosion			.
Sheet erosion	- minor		1
	- moderate		2
	- severe		3
Rill erosion	- minor		4
	- moderate		5
	- severe		6
Gully erosion	- minor		7
	- moderate		8
	- severe		9
Well-	- integral	- recent	a
defined		- relict	b
landslip	- scar	- recent	c
> 1ha		- relict	d
in size	- debris	- recent	g
		- relict	k
Develop-	- integral	- recent	n
ment of		- relict	o
general	- scar	- recent	p
instability		- relict	r
	- debris	- recent	s
		- relict	t
Coastal	- integral		w
	- scar		y
	- debris		z



Scale 1:20 000	Example of the Physical Constraints Map (PCM)	Fig. 16a

Scale 1:20 000	Example of the Terrain Classification Map Superimposed on the PCM	Fig. 16b

LEGEND FOR ENGINEERING GEOLOGY MAP (Fig. 17a)

- Fill
- Reclamation
- Littoral deposits
- Alluvium - exposed at surface
- Raised alluvial terrace
- Colluvium (undifferentiated)
- Undifferentiated volcanic rocks)
- Sedimentary rocks and water-laid volcaniclastic rocks)
- Acid lavas)
- Coarse tuff)
- Agglomerate)
- Dominantly pyroclastic rocks with some lavas)

Repulse Bay Formation

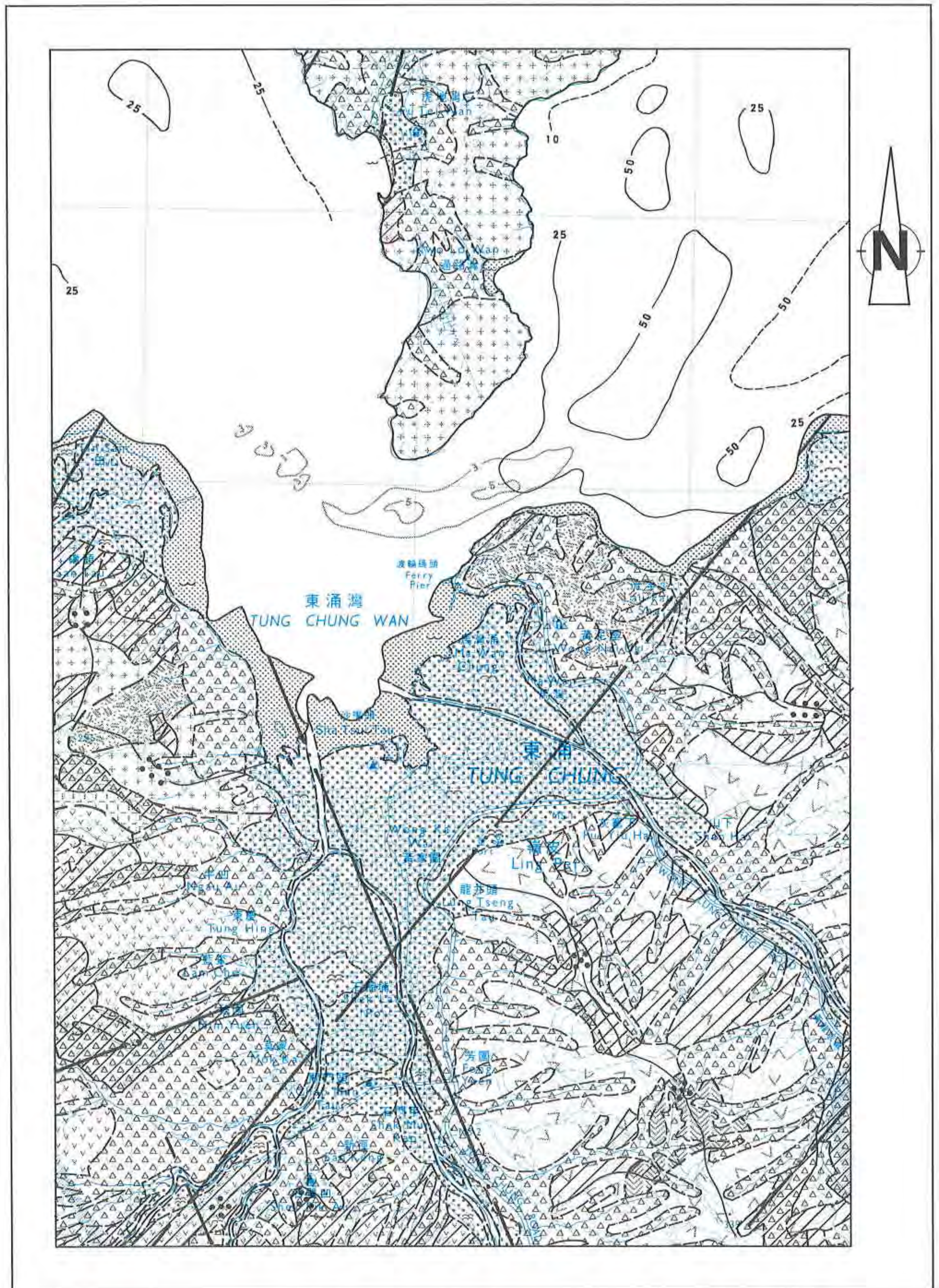
- Undifferentiated granitic rock
- Tai O Formation
- Quartz monzonite
- Ma On Shan Granite
- Cheung Chau Granite
- Sung Kong Granite
- Feldspar porphyry dyke swarm
- Geological photolineament
- Geological boundary (solid)
- Geological boundary (superficial)
- General Instability
- Catchment boundary (order indicated by number of dots)
- Seabed level (metres)
- 'Rock head' (Top of moderately weathered / fresh rock)

LEGEND FOR TERRAIN CLASSIFICATION MAP (Fig. 17b)

SLOPE GRADIENT	CODE
0 - 5°	1
5 - 15°	2
15 - 30°	3
30 - 40°	4
40 - 60°	5
> 60°	6

TERRAIN COMPONENT	CODE
Crest or ridge	A
Sideslope - straight	B
- concave	C
- convex	D
Footslope - straight	E
- concave	F
- convex	G
Drainage plain	H
Floodplain	I
Coastal plain	K
Littoral zone	L
Cliff/Rock outcrop	M
Cut - straight	N
- concave	O
- convex	P
Fill - straight	R
- concave	S
- convex	T
General disturbed terrain	V
Reclamation	Z
Alluvial plain	X
Waterbodies - Natural stream	1
- Manmade channel	2
- Water storage dam	3
- Fish pond	4

EROSION			CODE
No appreciable erosion			.
Sheet erosion	- minor		1
	- moderate		2
	- severe		3
Rill erosion	- minor		4
	- moderate		5
	- severe		6
Gully erosion	- minor		7
	- moderate		8
	- severe		9
Well-defined landslip > 1ha in size	- integral	- recent	a
		- relict	b
	- scar	- recent	c
		- relict	d
	- debris	- recent	g
		- relict	k
Development of general instability	- integral	- recent	n
		- relict	o
	- scar	- recent	p
		- relict	r
	- debris	- recent	s
		- relict	t
Coastal	- integral		w
	- scar		y
	- debris		z



Scale 1:20 000 | Example of the Engineering Geology Map (EGM) | Fig. 17a

Scale 1:20 000 | Example of the Terrain Classification Map Superimposed on the EGM | Fig. 17b

LEGEND FOR LANDFORM MAP (Fig. 18a)

SLOPE GRADIENT	CODE
0 - 5° (gently sloping)	1
5 - 15° (gently-moderately sloping)	2
15 - 30° (moderately sloping)	3
30 - 40° (steep)	4
40 - 60° (mountainous)	5
> 60° (precipitous)	6

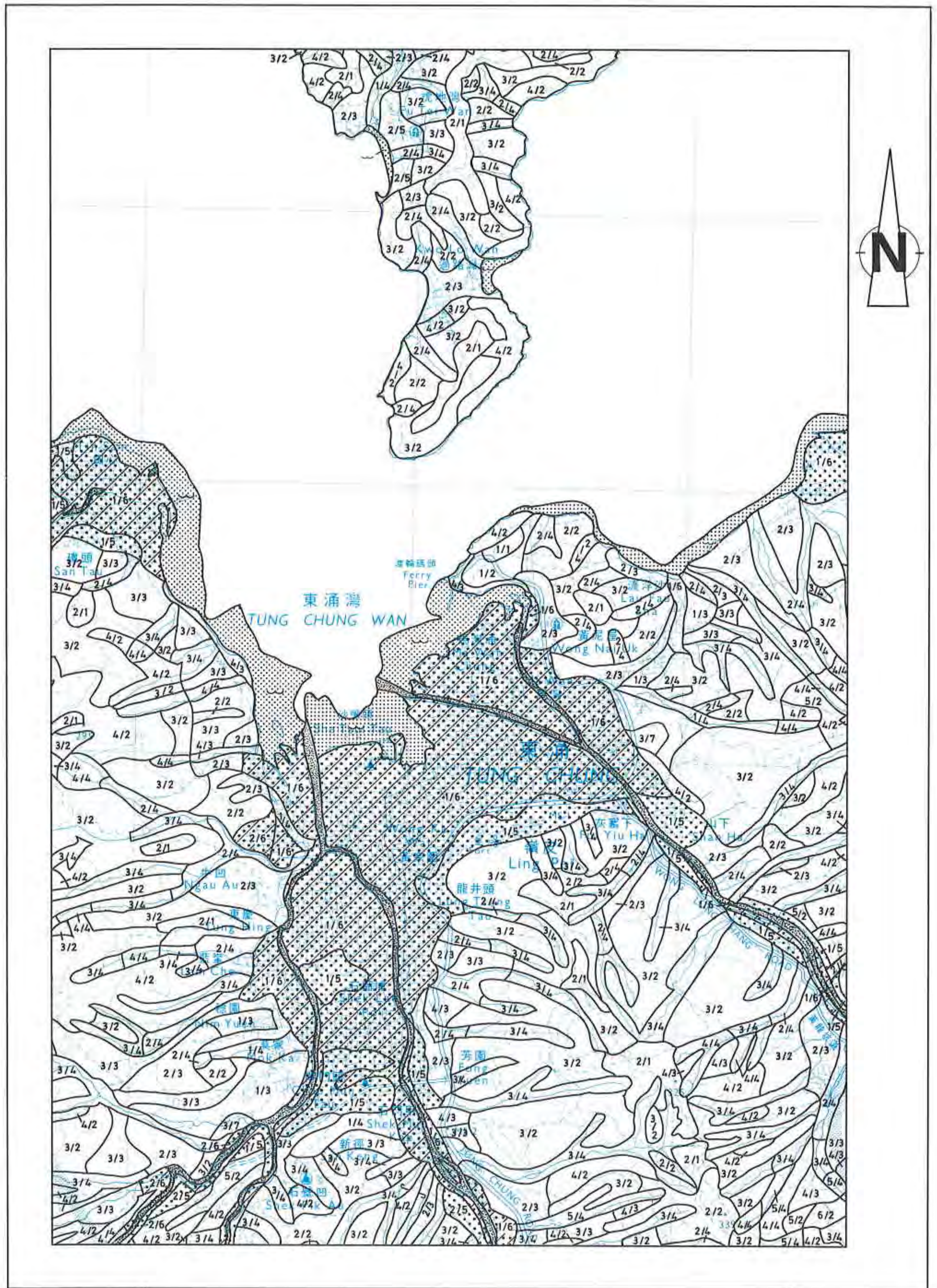
DESCRIPTION	CODE
Crest or ridge	1
Sideslope - insitu	2
Footslope - colluvium	3
Drainage plain - colluvium subject to overland flow and regular inundation. Unusual groundwater regime.	4
Alluvial plain - includes raised terraces.	5
Flood plain - portion of alluvial plain subject to overland flow and regular inundation. Unusual groundwater regime.	6
Disturbed terrain - cut	7
Disturbed terrain - fill	8
Cliff and rock outcrop	9
Reclamation	
Waterbodies (Streams, man-made channels, storage dams)	
Ponds	
Littoral zone (generally subject to tidal action)	

LEGEND FOR TERRAIN CLASSIFICATION MAP (Fig. 18b)

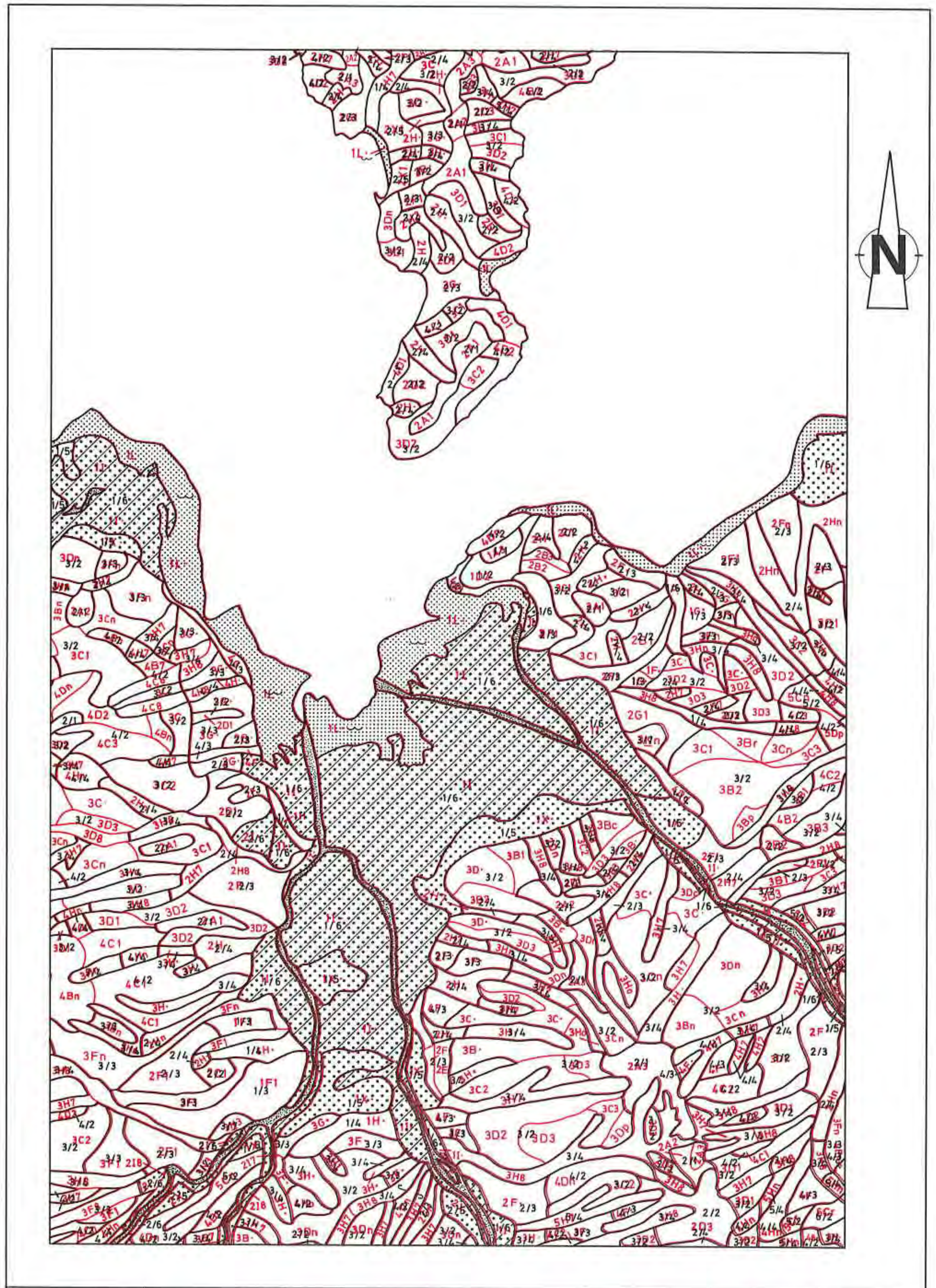
SLOPE GRADIENT	CODE
0 - 5°	1
5 - 15°	2
15 - 30°	3
30 - 40°	4
40 - 60°	5
> 60°	6

TERRAIN COMPONENT		CODE
Crest or ridge		A
Sideslope	- straight	B
	- concave	C
	- convex	D
Footslope'	- straight	E
	- concave	F
	- convex	G
Drainage plain		H
Floodplain		I
Coastal plain		K
Littoral zone		L
Cliff/Rock outcrop		M
Cut	- straight	N
	- concave	O
	- convex	P
Fill	- straight	R
	- concave	S
	- convex	T
General disturbed terrain		V
Reclamation		Z
Alluvial plain		X
Waterbodies	- Natural stream	1
	- Manmade channel	2
	- Water storage dam	3
	- Fish pond	4

EROSION			CODE
No appreciable erosion			.
Sheet erosion	- minor		1
	- moderate		2
	- severe		3
Rill erosion	- minor		4
	- moderate		5
	- severe		6
Gully erosion	- minor		7
	- moderate		8
	- severe		9
Well-defined landslip > 1ha in size	- integral	- recent	a
		- relict	b
	- scar	- recent	c
		- relict	d
	- debris	- recent	g
		- relict	k
Development of general instability	- integral	- recent	n
		- relict	o
	- scar	- recent	p
		- relict	r
	- debris	- recent	s
		- relict	t
Coastal	- integral		w
	- scar		y
	- debris		z



Scale 1:20 000 | Example of the Landform Map (LM) | Fig. 18a



Scale 1:20 000 | Example of the Terrain Classification Map Superimposed on the LM | Fig. 18b

LEGEND FOR EROSION MAP (Fig. 19a)

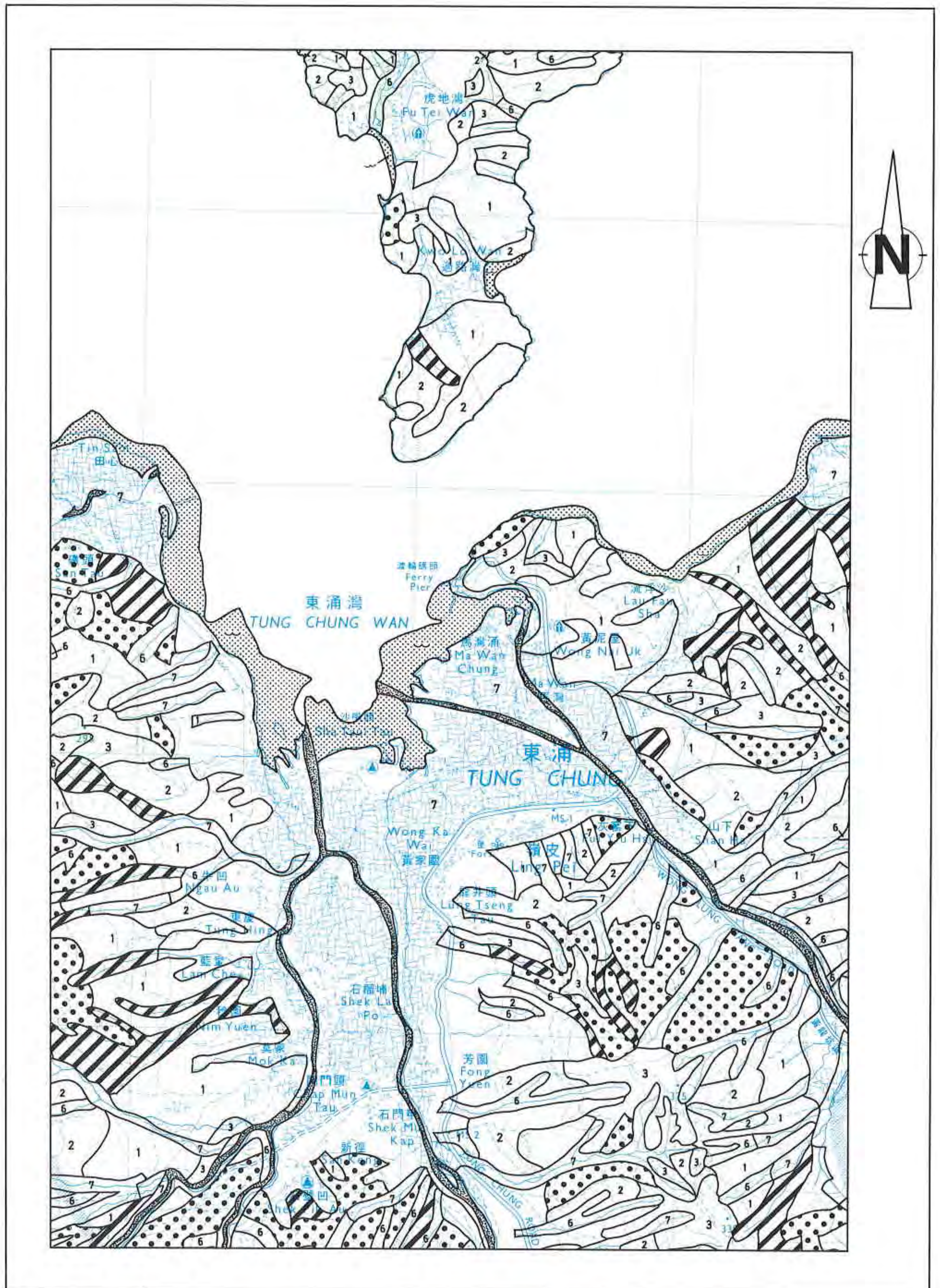
(blank box)	No appreciable erosion
1	Minor sheet erosion
2	Moderate sheet erosion
3	Severe sheet erosion
4	Minor rill erosion
5	Moderate to severe rill erosion
6	Minor gully erosion
7	Moderate to severe gully erosion
(dotted pattern)	Zones of general instability associated with predominantly insitu terrain
(hatched pattern)	Zones of general instability associated with predominantly colluvial terrain
(stippled pattern)	Waterbodies (streams, man-made channels, storage dams)
(dashed pattern)	Ponds
(shaded pattern)	Littoral zone (generally subject to tidal action)

LEGEND FOR TERRAIN CLASSIFICATION MAP (Fig. 19b)

SLOPE GRADIENT	CODE
0 - 5°	1
5 - 15°	2
15 - 30°	3
30 - 40°	4
40 - 60°	5
> 60°	6

TERRAIN COMPONENT		CODE
Crest or ridge		A
Sideslope	- straight	B
	- concave	C
	- convex	D
Footslope	- straight	E
	- concave	F
	- convex	G
Drainage plain		H
Floodplain		I
Coastal plain		K
Littoral zone		L
Cliff/Rock outcrop		M
Cut	- straight	N
	- concave	O
	- convex	P
Fill	- straight	R
	- concave	S
	- convex	T
General disturbed terrain		V
Reclamation		Z
Alluvial plain		X
Waterbodies	- Natural stream	1
	- Manmade channel	2
	- Water storage dam	3
	- Fish pond	4

EROSION			CODE
No appreciable erosion			.
Sheet erosion	- minor		1
	- moderate		2
	- severe		3
Rill erosion	- minor		4
	- moderate		5
	- severe		6
Gully erosion	- minor		7
	- moderate		8
	- severe		9
Well-defined landslip > 1ha in size	- integral	- recent	a
		- relict	b
	- scar	- recent	c
		- relict	d
	- debris	- recent	g
		- relict	k
Development of general instability	- integral	- recent	n
		- relict	o
	- scar	- recent	p
		- relict	r
	- debris	- recent	s
		- relict	t
Coastal	- integral		w
	- scar		y
	- debris		z



Scale 1:20 000 | Example of the Erosion Map (EM) | Fig. 19a

Scale 1:20 000 | Example of the Terrain Classification Map Superimposed on the EM | Fig. 19b

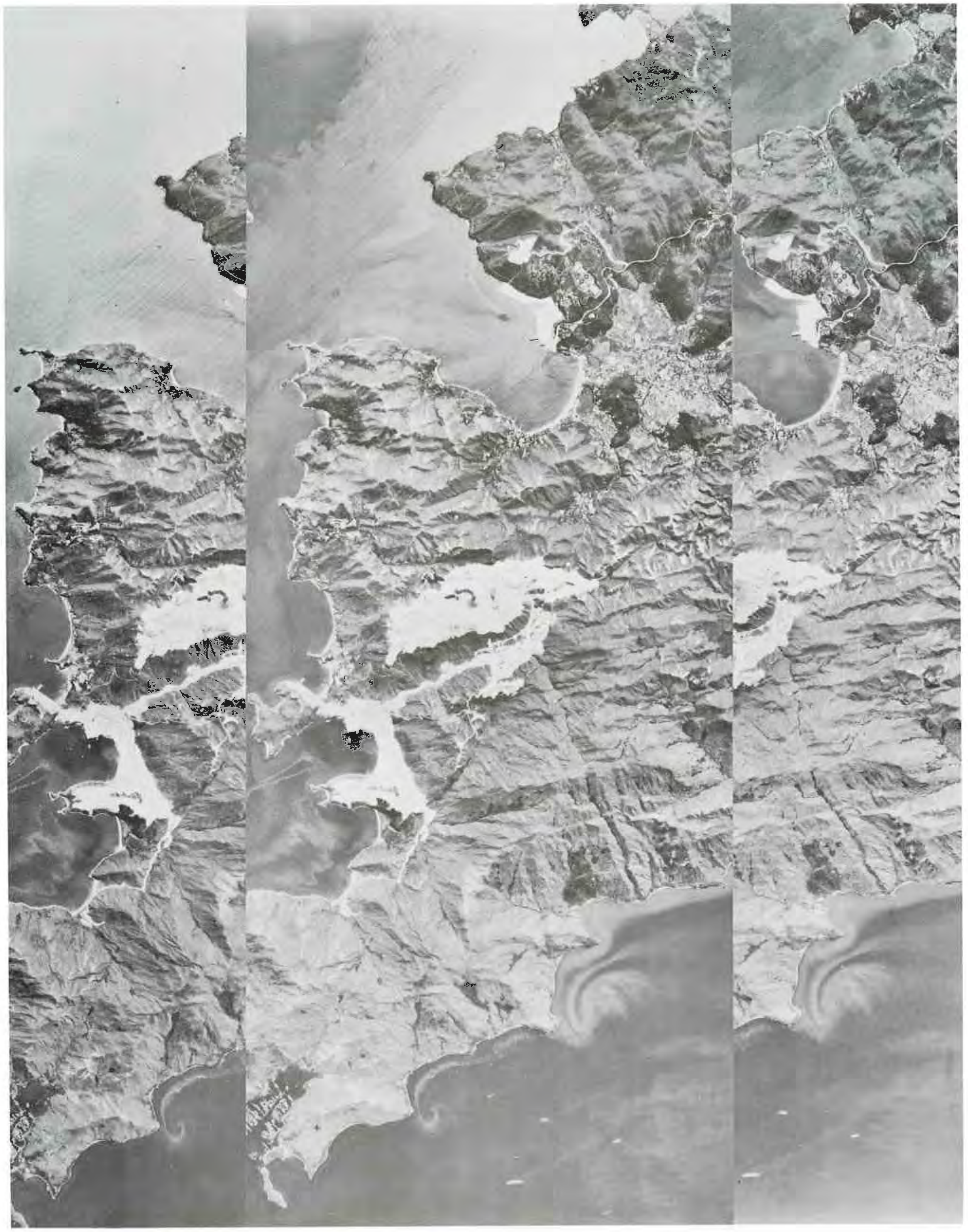


Plate 1. *Stereotriplet of Vertical Aerial Photographs of North Lantau between Mui Wo and Yam O Wan.* Scale approximately 1:50 000. This composite photograph should be viewed with a pocket stereoscope (1981, 36748–36750).

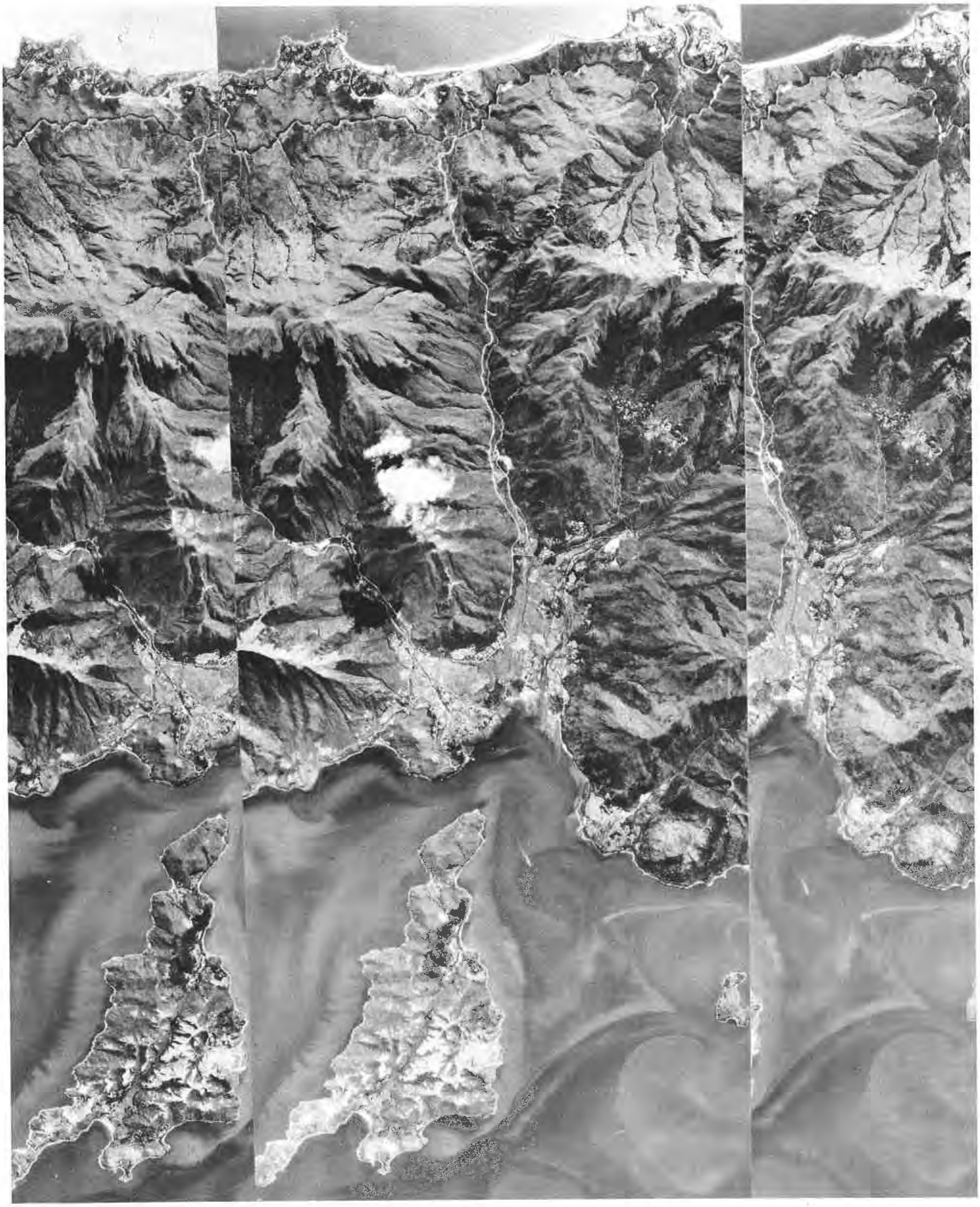


Plate 2. Stereotriplet of Vertical Aerial Photographs of North Lantau between Cheung Sha and Chek Lap Kok. Scale is approximately 1:50 000. This photograph should be viewed with a pocket stereoscope (1981/36752–36754).

Plate 3. High Oblique Aerial Photograph Looking Southwest across Northern Lantau from above Yi Pak (GCO/OAP 1981/5249).

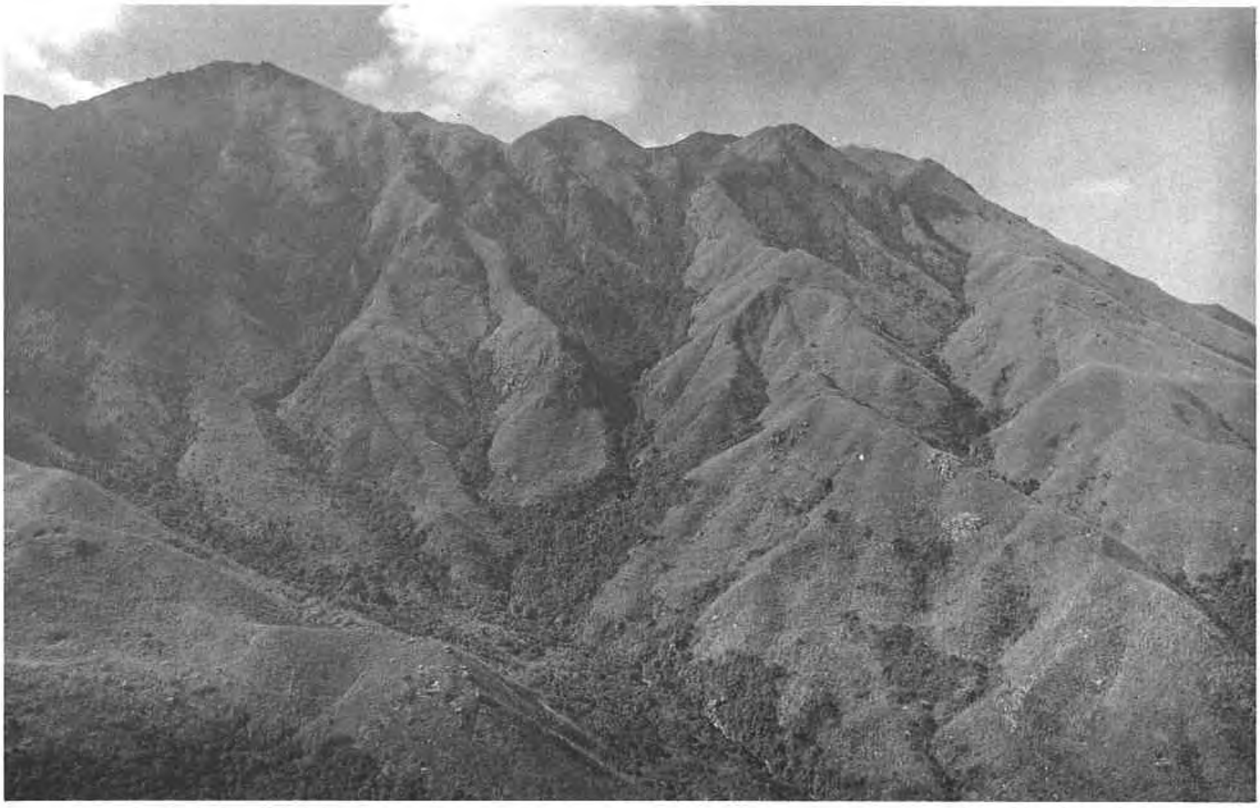


Plate 4. Low Oblique Aerial Photograph Looking West from A Po Long, towards the Steep Dissected Volcanic Terrain Northwest of Pak Ngan Heung (GCO/OAP 1981/4589).

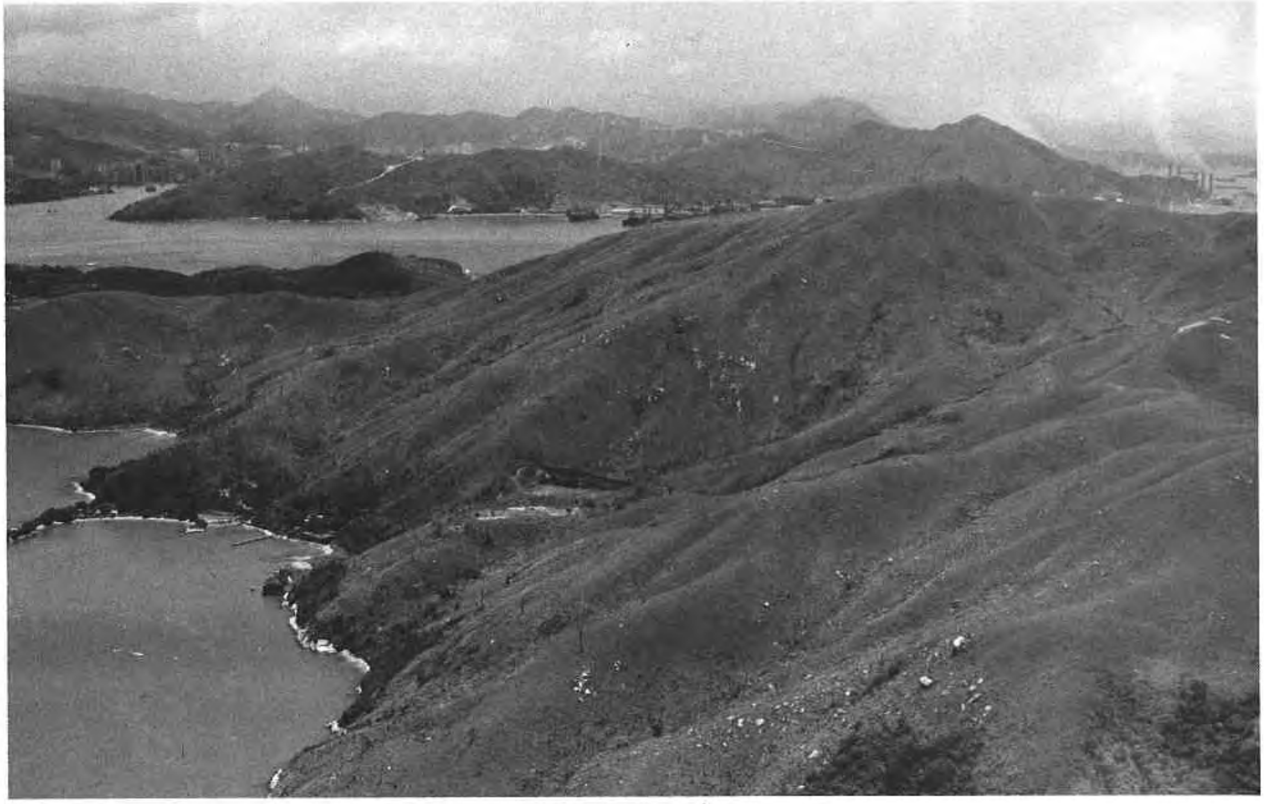


Plate 5. Low Oblique Aerial Photograph Looking Northeast along the Coast of Tsing Chau Wan towards Tsing Yi (GCO/OAP 1981/5279).

Plate 6. Low Oblique Aerial Photograph Looking Northeast across Northern Discovery Bay towards Tsing Yi. Note the trace of a possible fault towards the left margin of the photograph (GCO/OAP 1981/6313).

Plate 7. Oblique Aerial Photograph Looking West across Mui Wo Towards Pui O. In the foreground the low, undulating relief is typical of the decomposed granite whilst in the background the steep terrain is composed of volcanics. Colluvial deposits occur on the footslopes and within the drainage lines associated with volcanic terrain. (GCO/OAP 1981/5316).

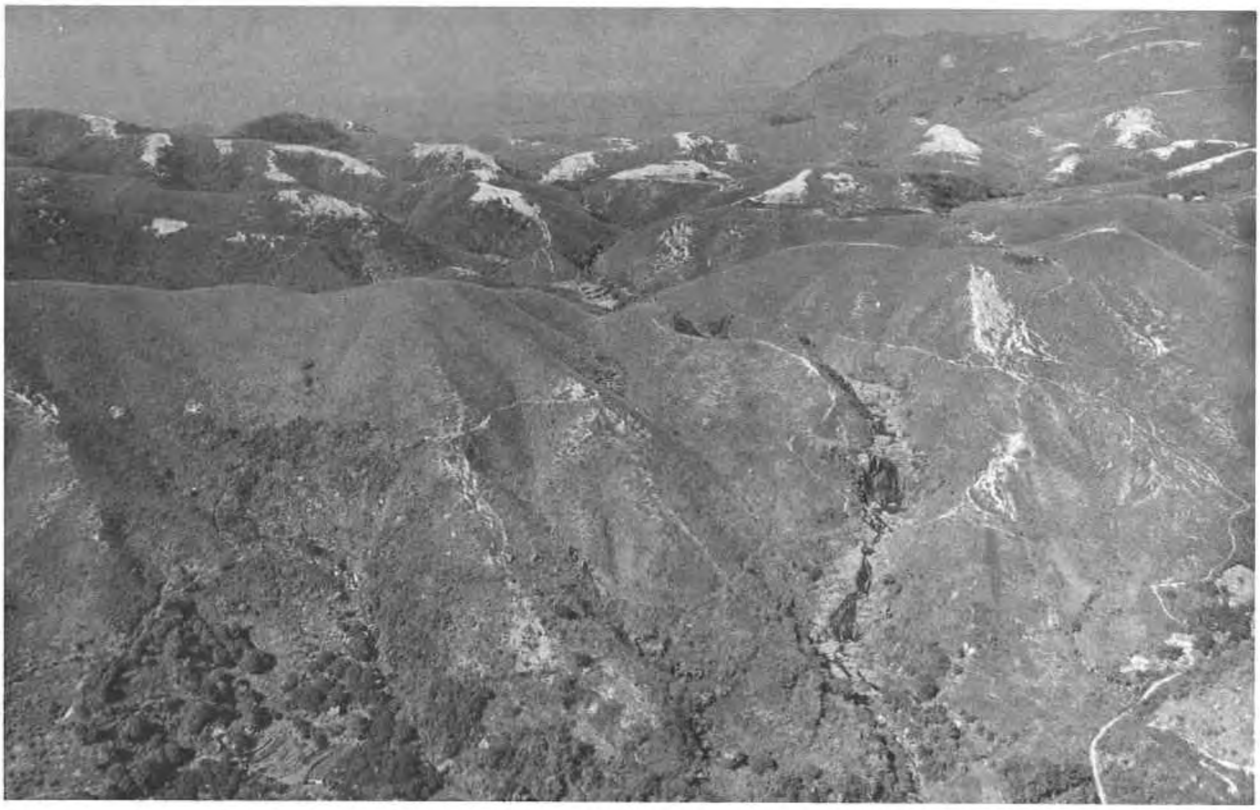


Plate 8. Low Oblique Aerial Photograph Looking North towards the Weathered Granitic Plateau (GCO/OAP 1981/4591).

Plate 9. Oblique Aerial Photograph of Volcanic and Granitic Terrain on the Northern Coast of Lantau Island. This plate shows the degree of local variability of terrain within the area of the feldspar prophyry dyke swarm. Approximately 2 km northeast of Tai Ho Wan a drainage line has eroded along a probable faulted boundary between the gently undulating, deeply weathered granitic terrain and rocky, shallow-soiled essentially volcanic terrain (GCO/OAP 1981/4477).

Plate 10. Oblique Aerial Photograph Looking Southwest across the Tung Chung Valley. Cloud obscures Lantau Peak in the upper left of the photograph. The village of Ling Pei occupies the central foreground. Much of the footslope terrain is covered by colluvium and is affected by geotechnical constraints. A considerable portion of this terrain will require careful land management to minimise the hazard of slope failure during any development. The valley floor is a floodplain which is periodically inundated and has poor drainage. (GCO/OAP 1981/5322).

Plate 11. Landslip Scars at the Head of a Drainage Line on Volcanic Terrain (GCO/OAP 1979/1763).

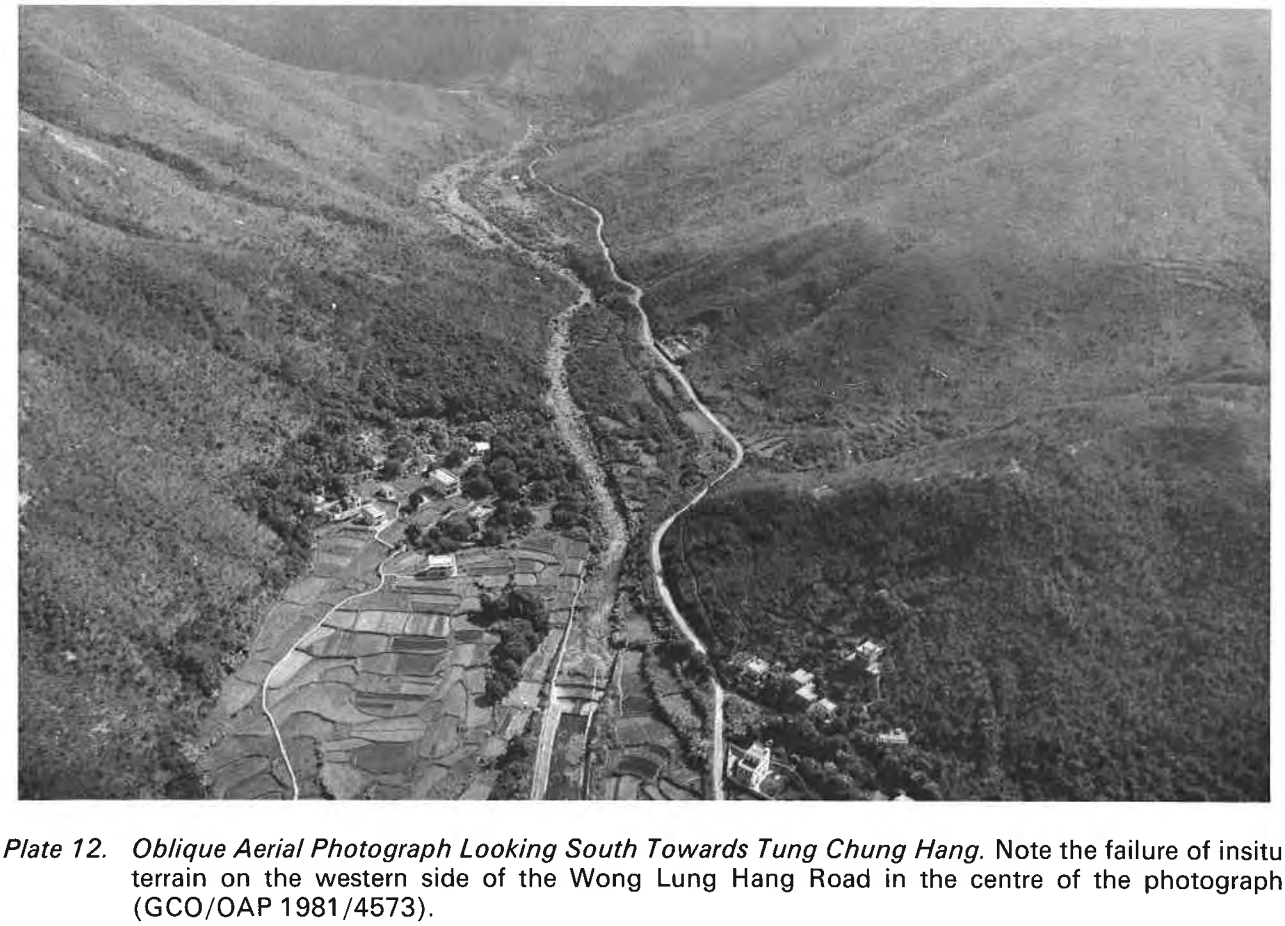


Plate 12. Oblique Aerial Photograph Looking South Towards Tung Chung Hang. Note the failure of insitu terrain on the western side of the Wong Lung Hang Road in the centre of the photograph (GCO/OAP 1981/4573).

Plate 13. Oblique Aerial Photograph Looking Northwest from Tung Chung Wan towards the Colluvial Fan at Tin Sam (GCO/OAP 1981/4577).

Plate 14. Oblique Aerial Photograph Looking Northwards towards Chek Lap Kok. The subdued relief of the deeply weathered granitic terrain has been highly eroded. The village of Kwo Lo Wan is in the foreground (GCO/OAP 1981/5260).

Plate 15. Oblique Aerial Photograph Looking Southwest from Discovery Bay. Much of the earthworks on the plateau is associated with the Discovery Bay Country Club (GCO/OAP 1981/5236).

Plate 16. Oblique Aerial Photograph Looking Eastwards across Penny's Bay towards the Steep Granitic Terrain of Northeast Lantau. Note the gully erosion and instability associated with the ridgelines and steeper sideslopes (GCO/OAP 1981/5204).

APPENDIX A

SYSTEM OF TERRAIN EVALUATION AND ASSOCIATED TECHNIQUES

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APPENDIX A

SYSTEM OF TERRAIN EVALUATION AND ASSOCIATED TECHNIQUES

A.1 Background

Terrain evaluation involves the identification of landform and terrain related features. This technique is used both to identify land use limitations and to assess in broad terms overall land use suitability. It is used as a planning tool and has a major application in the field of geotechnical engineering. In this Geotechnical Area Study, a systematic approach is used to collect, characterise and rationalise the natural variations which occur across the terrain. The structure and presentation of the terrain evaluation system used in this Report is illustrated in Figure 14.

The mechanism of producing a summary or inventory of physical land resources is known as *terrain classification*. This involves the systematic classification of the terrain to form a two-dimensional landform model. The Terrain Classification Map forms:

(*a*) The framework for the evaluation of the basic physical resource data designed specifically for geotechnical engineering purposes.

(*b*) The basis for the user-oriented derivative maps, particularly the Geotechnical Land Use Map (GLUM) and the Physical Constraints Map (PCM). These maps are designed specifically for planning and land use management purposes and do not require specialist geotechnical interpretation.

A flow-chart depicting the basic technique of data acquisition and map production is shown in Figure A1. The GAS Programme is discussed by Styles & Burnett (1983, 1985), Styles et al (1982, 1984, 1986), Brand et al (1982 a & b), Burnett & Styles (1982) and Burnett et al (1985).

A.2 Technique of Terrain Classification

Terrain classification involves the systematic mapping and delineation of terrain characteristics. The major tool for the collection of these data is *aerial photograph interpretation* (API). This technique enables the stereoscopic examination of the terrain in a uniform and systematic manner. Aerial photograph interpretation greatly aids the collection of physical resource information, the types of data which can be derived from aerial photographs being many and varied. Any object or feature which can be recorded as a photographic image can be identified using API. The techniques are well established in the earth sciences for the delineation of resource data.

The main benefit of API lies in the significant reduction in the amount of field work, with consequent increased speed and uniformity of data acquisition (Styles, 1982). Access into, and evaluation of, difficult terrain can also be simplified using API.

In systematic mapping studies, the fundamental requirements for efficient API and terrain classification are thorough ground control and field reconnaissance.

In this study, three characteristics (attributes) are delineated on the 1:20 000 scale Terrain Classification Map, of which an example is given in Figure 14b. The three terrain attributes adopted for the analysis are:

(*a*) Slope gradient.

(*b*) Terrain component and morphology.

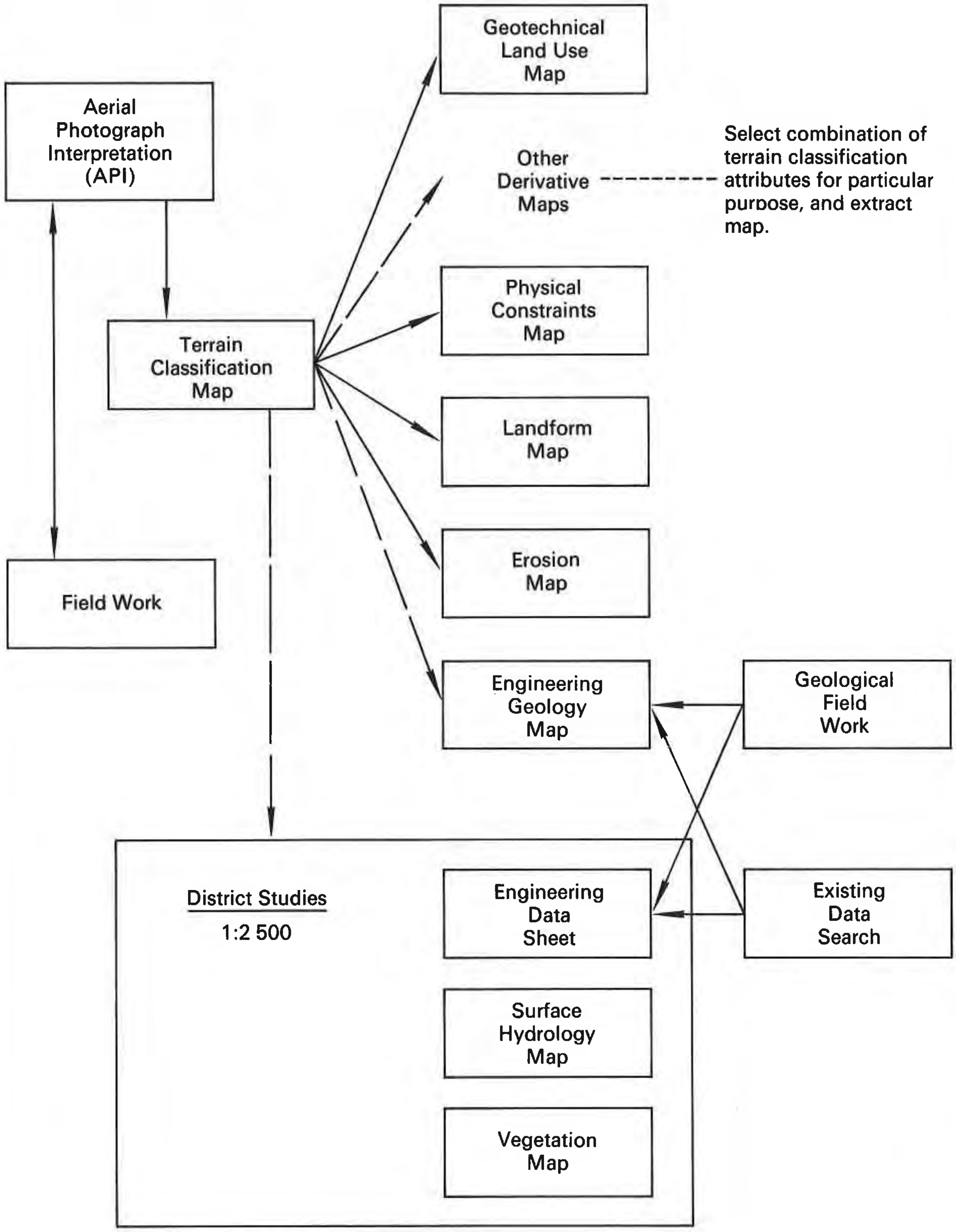
(*c*) Erosion and instability.

The complete terrain classification schedule is presented in Table A1. The information is presented in alphanumeric form, which enables the efficient delineation of multi-attribute map units. This method minimises the possibility of misinterpretation of map units by reducing the number of work sheets and by simplifying the production of derivative maps. As an example, a map unit designated as '2Ga' represents a convex slope, at an angle of 5–15°, composed of colluvium, in a footslope location, which contains a well-defined recent landslip.

The data collected in this study forms part of the Territory-wide programme of systematic terrain classification at a scale of 1:20 000. The physical resource information is integrated into a data bank management system known as the Geotechnical Terrain Classification System (GEOTECS). GEOTECS is discussed briefly in Sections 1.5.8 and A.10.

A.3 Terrain Classification Map

A brief description is given below of the three terrain attributes which are included in the terrain classification (refer to Table A1). The Terrain Classification Map is a work sheet and data base for the collection of land resource data and is not intended for use outside the GCO.



Technique of Data Acquisition and Derivation of Maps | Fig. A1

Table A1 Terrain Classification Attributes

Slope Gradient	*Code*	*Terrain Component*	*Code*	*Erosion and Instability*	*Code*
0– 5°	1	Hillcrest or ridge	A	No appreciable erosion	.
5–15°	2	Sideslope —straight	B	Sheet erosion —minor	1
15–30°	3	—concave	C	—moderate	2
30–40°	4	—convex	D	—severe	3
40–60°	5	Footslope —straight	E	Rill erosion —minor	4
>60°	6	—concave	F	—moderate	5
		—convex	G	—severe	6
		Drainage plain	H	Gully erosion —minor	7
		Floodplain	I	—moderate	8
		Coastal plain	K	—severe	9
		Littoral zone	L	Well-defined recent landslip >1 ha in size —integral—recent	a
		Rock outcrop	M	—relict	b
		Cut —straight	N	—scar —recent	c
		—concave	O	—relict	d
		—convex	P	—debris —recent	g
		Fill —straight	R	—relict	k
		—concave	S	Development of general instability —integral—recent	n
		—convex	T	—relict	o
		General disturbed terrain	V	—scar —recent	p
		Alluvial plain	X	—relict	r
		Reclamation	Z	—debris —recent	s
		Waterbodies:		—relict	t
		Natural stream	1	Coastal instability —integral	w
		Man-made channel	2	—scar	y
		Water storage	3	—debris	z
		Fish pond	4		

Notes:
1. In this classification, all footslope and drainage plain terrain corresponds to colluvium (terrain components E, F, G, H).
2. Disturbed colluvial terrain is indicated by underlining the landform code (terrain components N, O, P, R, S, T, V).
3. Disturbed alluvial terrain is indicated by double underlining the landform code (terrain components N, O, P, R, S, T, V).

A.3.1 *Slope Gradient*

Slope gradient is classified in degrees and is divided into six groups according to the schedule defined in Table A1. The slope angle of each terrain unit is measured along the direction of greatest declivity. This direction, which is normal to the contour, enables the identification of the most limiting slope angle.

A.3.2 *Terrain Component and Morphology*

The terrain component attribute describes the physical appearance of the slope. The terms used are essentially morphological descriptions and do not necessarily infer the geomorphological processes which are occurring on a slope. The terrain definitions adopted in this study are presented in the Glossary of Terms in Appendix E.

There are 13 major terrain component classes:

(*a*) Hillcrest (Code A).

(*b*) Sideslope (Codes B, C, D).

(*c*) Footslope (Codes E, F, G).

(*d*) Drainage plain (Code H).

(*e*) Alluvial plain (Code X).

(*f*) Floodplain (Code I).

(*g*) Coastal plain (Code K).

(*h*) Littoral zone (Code L).

(*i*) Cliff or rock outcrop (Code M).

(*j*) Cut slope (Codes N, O, P).

(*k*) Fill slope (Codes R, S, T).

(*l*) General disturbed terrain (Code V).

(*m*) Reclamation (Code Z).

In this study, all the footslope and drainage plain terrain consists of colluvium, and all the flood and alluvial plains consist of alluvium, whereas all the sideslope terrain consists of insitu geological materials. Other colluvial and alluvial subclasses occur in the cut slope, fill slope and general disturbed terrain components (Table A1).

The terrain component classes also indicate the general shape of the slope profile. The basic morphological classes are straight, concave and convex.

A.3.3 *Erosion and Instability*

These attributes describe the surface condition of the terrain on the basis of the major forms of terrain denudation. Slope failure and slope instability are indicated under this attribute. The five major erosion classes are:

(*a*) No appreciable erosion (Code .).

(*b*) Sheet erosion (Codes 1, 2, 3) is divided into three subclasses. Where vegetation is absent, the soil surface is subject to sheet erosion. Minor to severe sheet erosion appears as varying tones in aerial photographs. Severe sheeting appears as a highly reflectant white tone, which indicates the absence of almost all ground cover. Sheet erosion is classified in terms of the approximate proportion of bare ground. This type of erosion usually precedes rill and gully erosion.

(*c*) Rill erosion (Codes 4, 5, 6) is a form of denudation which occurs typically on exposed cut and fill slope batters. It is characterised by subparallel drainage rivulets which produce a typically striated appearance and result in significant soil loss.

(*d*) Gully erosion (Codes 7, 8, 9) often results in severe disruption of the terrain surface. Gully erosion produces significant hydrological problems due to infiltration and concentration of water flow, and may lead to slope failure. This class is divided into the three subclasses: minor, moderate and severe.

(*e*) Instability (Codes a to z) is divided into subclasses which relate to well-defined landslips and zones of general instability. The latter term relates to colluvial and insitu terrain where many failures and other evidence of instability occur, but due to their small size, it is not possible to delineate small landslips as discrete map units on a 1:20 000 scale map.

A.4 Landform Map

The Landform Map provides a simple model of the broad geomorphological classes and delineates the extent and distribution of the major terrain units within the study area. The Landform Map (example in Figure 18a) extracts from the Terrain Classification Map the significant terrain component and slope gradient classes. This information is presented as a separate map. In this form, it is easier to appreciate, understand and interpret the pattern of landform distribution.

The Landform Map uses a numeric code to classify the study area into parcels or zones of particular landform character. The broad terrain features are:

(*a*) Hillcrest or ridge.

(*b*) Sideslope (by definition consisting of insitu materials).

(*c*) Footslope (by definition consisting of colluvial materials).

(*d*) Drainage plains (colluvial areas subject to overland flow and regular inundation often associated with unusual groundwater regimes).

(*e*) Alluvial plain (including raised terraces).

(*f*) Floodplain (those portions of the alluvial plains which are subject to overland flow and regular inundation and possibly unusual groundwater regimes).

(*g*) Disturbed cut terrain (by definition man-made cuts, e.g. construction sites, quarries, borrow areas, utility corridors).

(*h*) Disturbed fill terrain (by definition man-made fills, e.g. construction sites, fill platforms).

(*i*) Cliff and rock outcrop.

It should be noted that areas of alluvium are indicated with a light stipple on the map. Floodplain within the alluvium is shown with a diagonal hatch.

In addition to these broad landform units, the map also shows slope gradient information. This is incorporated into the landform classes so that it is possible to establish the average slope angle of the terrain.

Finally, the Landform Map shows by means of various symbols: reclamation, waterbodies (i.e. streams, channels and reservoirs), ponds and the littoral zone.

A.5 Erosion Map

The Erosion Map is derived from the Terrain Classification Map and delineates the major forms of erosion within North Lantau. The pattern of erosion can be related to the weathering characteristics of the geological units and to land use (Hansen & Nash, 1984). An example of this type of map is given in Figure 19a.

The map is important because it presents the general pattern of instability associated with the colluvial and insitu terrain. The following features are also shown:

(*a*) No appreciable erosion (Code .).

(*b*) Minor sheet erosion (Code 1).

(*c*) Moderate sheet erosion (Code 2).

(*d*) Severe sheet erosion (Code 3).

(*e*) Minor rill erosion (Code 4).

(*f*) Moderate to severe rill erosion (Code 5).

(*g*) Minor gully erosion (Code 6).

(*h*) Moderate to severe gully erosion (Code 7).

(*i*) General instability associated with insitu terrain (Codes a to z).

(*j*) General instability associated with colluvial terrain (Codes a to z).

In common with all the other maps in the series, the areas of waterbody, pond and littoral zone are also shown.

The Erosion Map provides a simple reference, not only to those areas showing general instability in the form of landslips, but also to the other forms of denudation.

A.6 Physical Constraints Map

The Physical Constraints Map (PCM) presents the major physical constraints which will influence development in the area. It is extracted from the Terrain Classification Map and is designed specifically to supplement the GLUM. An example is presented in Figure 16a.

This is an interpretative map which synthesizes the natural physical constraints for land use management, planning and engineering purposes. The GLUM is a basic assessment of the geotechnical limitations associated with the terrain, whereas the Physical Constraints Map delineates the type of constraint. Obviously, areas that remain unclassified (blank) on the PCM are most suitable for development from a geotechnical point of view. These areas correspond to Class I and Class II in the GLUM system.

The major constraints which are shown on the map are:

(*a*) Zones of general instability associated with predominantly colluvial terrain.

(*b*) Zones of general instability associated with predominantly insitu terrain.

(*c*) Colluvium.

(*d*) Zones of colluvium which are subject to overland flow and periodic inundation (delineated as drainage plain on the Landform Map).

(*e*) Slopes on insitu terrain which are generally steeper than 30° (other than those delineated as colluvium or unstable).

(*f*) Floodplain (subject to overland flow and regular inundation and delineated as floodplain on the Landform Map).

(*g*) Disturbed terrain (extensive cut and fill batters which generally exceed 30°).

(*h*) Major waterbodies.

A.7 Geotechnical Land Use Map

The Geotechnical Land Use Map (GLUM) represents a systematic method of interpreting and synthesizing terrain classification and geotechnical data into a format suitable for land management purposes (Table A2). The GLUM is therefore suitable *only for planning purposes.* Further limitations on the use of the GLUM are presented later in this section and must not be overlooked.

Table A2 GLUM Classification System

Characteristics of GLUM Classes	Class I	Class II	Subclass IIS	Class III	Class IV
Geotechnical Limitations	Low	Moderate		High	Extreme
Suitability for Development	High	Moderate	Moderate – Low	Low	Probably Unsuitable
Engineering Costs for Development	Low	Normal	Normal – High	High	Very High
Intensity of Site Investigation Required	Normal	Normal		Intensive	Very Intensive
Typical terrain characteristics (Some, but not necessarily all of the stated characteristics will occur in the respective Class)	Gentle slopes and insitu soils. Minor erosion on flatter slopes. Undisturbed terrain (minor cut & fill only).	Flat to moderate slopes. Colluvial soils showing evidence of minor erosion. Insitu soils which may be eroded. Reclamation. Rock outcrops. Poor drainage. Cut & fill slopes of low height.	Floodplain subject to periodic flooding and inundation.	Steep slopes. Colluvial & insitu soils showing evidence of severe erosion. Poor drainage. Cut & fill slopes of moderate height.	Combination of characteristics such as steep to very steep slopes, general instability on colluvium, severe erosion, poor drainage, high cut & fill slopes.
Note: This classification system is intended as a guide to planners and is not to be used for a detailed geotechnical appraisal of individual sites.					

The GLUM is derived from the Terrain Classification Map. The slope, terrain component and erosion attributes described in Table A1 are considered in evaluating the general level of geotechnical limitation. A GLUM class is assigned to each combination of attributes to represent the limitation which is likely to be imposed on development. An appropriate GLUM class can therefore be allocated to each landform unit identified during the terrain classification of the study area. These are represented on the GLUM, an example of which is presented in Figure 15a. There are four GLUM Classes.

(i) *Class I—Low Geotechnical Limitations*
These areas are characterised by a low level of geotechnical limitation, and consequently have the highest suitability for development. Costs of site formation, foundation works and drainage works are expected to be low. Only normal geotechnical investigations will probably be required and investigation costs are expected to be low.

(ii) *Class II—Moderate Geotechnical Limitations*
These areas are characterised by moderate geotechnical limitations, and consequently are of moderate suitability for development, although the terrain conditions are more complex than in Class I. Costs of site formation, foundation works and drainage works will not be high. It is probable that normal geotechnical investigations only will be required, and investigation costs are not expected to be high.

Class IIS is a subclass defined specifically for the 1:20 000 scale studies. These areas are likely to be affected by periodic inundation and flooding. Although this factor alone will not significantly affect the geotechnical constraints associated with this flat, low-lying terrain, the general suitability for development can be considered moderate to low.

(iii) *Class III—High Geotechnical Limitations*
These areas are characterised by high geotechnical limitations, and consequently are of low suitability for development. Costs of site formation, foundation works and drainage works can be expected to be high. Intensive geotechnical investigations will be necessary, and investigation costs will be high.

(iv) *Class IV—Extreme Geotechnical Limitations*
These areas are characterised by extreme geotechnical limitations, and consequently development should be avoided if possible. In normal circumstances these areas would not be considered for development. If development of these areas is unavoidable, the costs of site formation, foundation works and drainage works will be very high. It is unlikely that the threat to development from natural hazards can be completely eliminated. Very intensive geotechnical investigations will be necessary both at the planning stage and prior to detailed design, and investigation costs will be extremely high.

The above descriptions are summarized in Table A2. Typical terrain characteristics which may be expected in each class are also given in the table, but it should be noted that not all of these characteristics need necessarily be present in any one map unit.

The following *important aspects* of the GLUM must be noted:

(*a*) The GLUM contains geotechnical information adequate *only for planning purposes.*

(*b*) The descriptions of the four GLUM classes should be taken *only as a guide* to the general level of geotechnical limitations associated with the terrain and consequent suitability for development.

(*c*) The GLUM class system assists in the assessment of the suitability of land for development from a geotechnical point of view. 'Development' is taken to mean high density residential, industrial, institutional and community uses.

(*d*) The GLUM should not be used for engineering judgement of individual sites, nor does it obviate the need for adequate site investigation prior to the development of a particular parcel of land. When used in conjunction with the Engineering Geology Map and Physical Constraints Map, however, the GLUM will help to identify the major constraints which are present or are likely to occur on a particular parcel of land.

(*e*) The GLUM classes provide *only an indication* of the extent and relative costs of the geotechnical investigations required for the development of a parcel of land. The particular local ground conditions, the nature of the intended development and existing knowledge of the site and its surroundings will govern the final extent and cost of investigation.

(*f*) A GLUM class is assigned to a parcel of land directly from the terrain classification. In assigning the GLUM class, *no consideration is given to the nature of adjoining parcels of land.* In using the GLUM, therefore, it must be remembered that a parcel of land will be affected by the classes of land along its boundaries. Again, reference to the PCM and EGM will assist in determining more general conditions.

(*g*) The GLUM system is based essentially on the classification of the terrain by its *surface* features. Therefore, the GLUM does not provide reliable information about the deep subsurface geology or the subsurface hydrology, and detailed site investigation at a particular location might reveal subsurface conditions not predicted by the GLUM.

(*h*) Conservative GLUM classes are assigned to fill areas.

(*i*) In this Report, the GLUM is designed as a broadscale planning tool for use at a scale of 1:20 000. It should only be used to assess the *general level* of geotechnical limitations associated with a relatively large parcel of land rather than with an individual site. As a general rule, it should not be used to evaluate parcels of land smaller than 3 ha in size. An area designated a particular class at 1:20 000 scale (Regional Study) may consist, in part, of very small areas of other classes if examined at 1:2 500 scale (District Study). This is due to the size of the terrain classification map units at 1:20 000 scale as opposed to 1:2 500. At the latter scale, the average area of each map unit is approximately 0.1 ha, whereas the average area of each map unit at 1:20 000 scale is approximately 2 ha. Therefore, *the GLUM presented in a Regional Study must never be interpreted, reproduced or enlarged to scales larger than 1:20 000.* Failure to heed this warning will result in serious misinterpretation of the GLUM.

In the derivation of GLUM class, the pre-existing slope angles of the terrain are inferred where the natural slope profile is destroyed by cut and fill operations. The pre-existing slopes are determined from aerial photography of the site (if available) taken before disturbance, or by extrapolation from undisturbed slopes above, below or adjacent to the disturbed area. However, where quarry or construction operations increase the gradient of the constructed slope, the new slope gradient is recorded. Modification of the natural terrain may increase the geotechnical limitations, with a resultant increase in the costs associated with its use.

A.8 Engineering Geology Map

A.8.1 *Background*

The compilation and assessment of data for the Engineering Geology Map is undertaken during and after the terrain classification phase of a Geotechnical Area Study.

The comments made in this Report with regard to the engineering geology of North Lantau are intended for use at a planning level and are based on the following:

(*a*) Extraction of selected information from the API source data; this was supplemented by limited field reconnaissance.

(*b*) Records of a limited amount of reliable site investigation data; this assisted the establishment of a three-dimensional appreciation of the geology and hydrology of the study area.

A.8.2 *Production of the Engineering Geology Map*

The Engineering Geology Map was compiled from selected information from the Terrain Classification Map, to which was added various existing data (Allen & Stephens, 1971) and information collected during the field reconnaissance. The Engineering Geology Map presents on one map the bedrock and superficial geology of the area and indicates the general geomorphology and material properties of the lithological units.

The Engineering Geology Map for the North Lantau GASP is contained in the Map Folder accompanying this Report and an example is located at Figure 17a. Note that this map will be superseded during the remapping of the geology of the Territory (See Section 1.1).

The data selected for inclusion on the Engineering Geology Map in this Report are:

(*a*) Boundaries of major lithologies and superficial deposits.

(*b*) Major photolineaments.

(*c*) Major topographic features.

(*d*) Level and depth to rockhead for seabed off northern Lantau coast.

(*e*) Boundaries of major catchments.

(*f*) Zones of general instability.

(*g*) Zones of reclamation.

The catchment boundaries are indicated on the Engineering Geology Map according to the method suggested by Strahler (1952). By this system, all streams without tributaries are designated 'first order' streams. When two first order streams join, the resulting stream rises to second order status, and two second order streams, on joining, produce a third order stream. Thus, a unit increase in order takes place downstream of the junction of two streams with the same order. A stream of higher order has a larger number of tributaries, a higher discharge, and usually a broader valley than a stream of lower order.

A.8.3 *Colluvium Classification System*

A simple classification system is used to aid in the delineation and the description of colluvial deposits. This classification system is a simplified form of the system which was originally used in the colluvium mapping project undertaken on a Territory-wide basis by the GCO in 1979. The system is based on the origin of the major (usually the cobble and boulder) component of the colluvium and is divided into materials which are:

(*a*) Essentially volcanic derived.

(*b*) Essentially granite derived.

(*c*) Essentially metasediment derived.

(*d*) Mixed origin.

This classification is applied to the colluvial deposits on the basis of the parent geology. The classification is based on API and is not extensively field checked. These classes are not presented on the Engineering Geology Map but are included in the GEOTECS data bank.

A.8.4 *Data Collection*

The information presented on the Engineering Geology Map is a compilation of data gathered from a brief study of available Geotechnical Information Unit (GIU) site investigation reports, from field reconnaissance and from the extraction of the pertinent components of the terrain classification mapping and the Allen & Stephens (1971) geological mapping.

Details of the aerial photographs used for the terrain classification are given in Appendix C.2 and Table C.1.

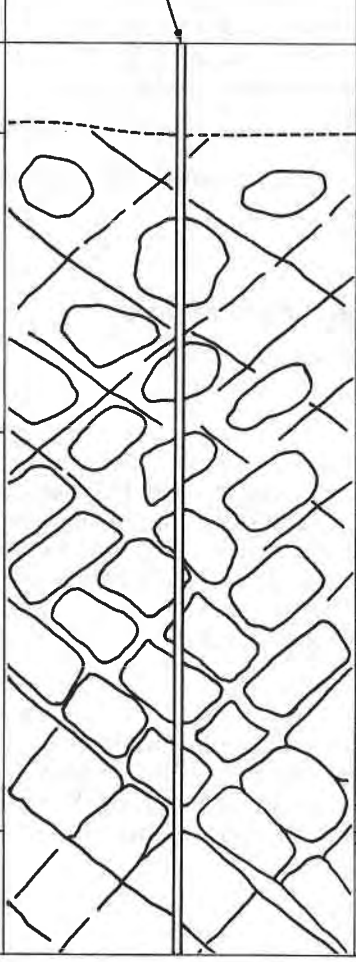
A.9 General Rules for the Use of the Maps and Associated Data

There are several basic rules regarding the use of the maps produced in the GAS Programme. Failure to heed these rules may result in the serious misinterpretation of the maps produced in this Report. The rules are:

(*a*) The maps are designed for use at a scale of 1:20 000. They should never be enlarged to scales larger than the published scale.

(*b*) The type of information shown on the map is designed for users who require data at 1:20 000 scale. The information presented on the 1:20 000 maps may not be valid at larger scales.

Table A3 Rock Weathering System

Zones of Decomposition Seen in Exposures (based on Ruxton & Berry, 1957)	Drillhole	Material Grade (see table below)	Probable Judgement of Zones Based on Drillcore Only
Zone A—Structureless sand, silt and clay. May have boulders concentrated at the surface.		VI	Zone A
Zone B—Predominantly grades IV or V material with core boulders of grades I, II or III material. The boulders constitute less than 50% of the mass and are rounded and not interlocked.		V III V III V	Zone B
Zone C—Predominantly core boulders of grades I, II and III material separated by seams of grades IV and V. The core boulders constitute more than 50% of the mass and are rectangular.		III V II III IV III IV II IV I IV	Zone C
Zone D—Material of grades I or II constitutes more than 90% of the mass.		II I	Zone D

Classification of Weathering Profile of Igneous Rock, as Seen in Exposures and Drillcores

Grade	Degree of Decomposition	Diagnostic Features in Samples and Cores
VI	Soil	No recognisable rock texture; surface layer contains humus and plant roots.
V	Completely decomposed	Rock completely decomposed by weathering in place, but texture still recognisable.
IV	Highly decomposed	Rock weakened so that fairly large pieces can be broken and crumbled in the hands.
III	Moderately decomposed	Large pieces (e.g. NX drill core) cannot be broken by hand.
II	Slightly decomposed	Strength approaching that of fresh rock – slight staining.
I	Fresh rock	

Classification of the Degree of Decomposition from Weathered Rock of Igneous Origin (after Moye, 1955).

(*c*) The conventional line maps produced for use at a scale of 1:20 000 should not be used to evaluate parcels of land smaller than about 3 ha in size.

(*d*) The GEOTECS plots must never be used to evaluate specific small sites (less than 5 ha in size). They are designed for broad planning and engineering feasibility studies. GEOTECS plots should not be used at a scale larger than 1:20 000.

A.10 Measurement, Analysis and Storage of Data (GEOTECS)

A data bank has been established for each of the GASP areas. This facilitates the examination and analysis of the distribution of the physical resource attributes occurring in the area and their planning and engineering implications. It also provides a method of investigating the interrelationships among various attributes which occur within the areas.

The terrain classification for this study is part of the small-scale (1:20 000) systematic terrain classification which has been completed for the entire Territory of Hong Kong. The GASP VI data bank consists of 3 629 grid cells, each of which covers approximately 2.04 hectares (49 cells per grid kilometre square) and is referenced to the Hong Kong Metric Grid. This programme, which is known within the Geotechnical Control Office as the Geotechnical Terrain Classification System (GEOTECS), is discussed briefly in Section 1.5.8. Nine natural resource attributes are recorded for each grid cell. The attributes are: slope gradient, terrain component, erosion and instability, aspect, relief, superficial and bedrock geology, existing land use, and vegetation.

The area measurements are calculated on the number of grid cells which occur within the study area. The area occupied by a particular attribute is measured by recording the Terrain Classification Map unit which occupies the largest proportion of each cell.

The measurement of irregular shaped map units by a regular graticule inevitably results in some inaccuracies in area calculation. However, there is an overall 'averaging' effect which minimises the errors inherent in this method. Errors are limited to a few percent in total and, in comparison with inaccuracies prevalent in the area measurement of steeply sloping terrain, are considered insignificant.

On completion of the manual coding process, the data is stored for use in the computer. The attribute measurements are sorted, correlated and tabulated. The resulting tables can be broadly classified into three groups:

(*a*) Single attribute tables which present the total area of each attribute under consideration, e.g. slope gradient (Tables B1, B2, B3, B5, B6, B7, B9 and B12).

(*b*) Single attribute correlations which present the tabulated relationships between one single attribute and another, e.g. slope gradient versus aspect (Tables B4, B8, B11 and B13).

(*c*) Multiple attribute correlations which present the relationship between a combination of two or more attributes and an additional attribute, e.g. slope gradient/aspect/geology versus erosion (Table B10). Within the framework of these tables, it is possible to define a multi-attribute unit based on any user-defined combination of attributes.

APPENDIX B

DATA TABLES FOR THE NORTH LANTAU GEOTECHNICAL AREA STUDY

Table B1 Slope Gradient

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.

Table B2 Erosion and Instability

Erosion		% of Total Area	Area (ha)
Instability			
—well-defined landslips		<0.1	2
—coastal instability		<0.1	4
—general instability		25.8	1 908
Appreciable Erosion	Sheet erosion—minor	16.5	1 222
	—moderate to severe	9.1	2 156
	Rill erosion —minor	0.1	8
	—moderate to severe	0.3	18
	Gully erosion—minor	4.5	333
	—moderate to severe	5.0	373
No Appreciable Erosion*		18.6	1 379
		100.0	7 403

* Approximately 8 ha of uncovered reservoirs are included within the No Appreciable Erosion category.

Table B3 Aspect

Aspect	% of Total Area	Area (ha)
North	13.9	1 030
Northeast	14.9	1 104
East	14.4	1 063
Southeast	10.0	741
South	4.8	355
Southwest	9.0	663
West	8.5	632
Northwest	15.2	1 128
Flat/Unclassified*	9.3	687
	100.0	7 403

* Approximately 8 ha of uncovered reservoirs are included in the Flat/Unclassified category.

Table B4 Aspect and Slope Gradient

Aspect	Slope Gradient					Total Area (ha)
	5–15°	15–30°	30–40°	40–60°	>60°	
North	204	545	216	65	0	1 030
Northeast	204	616	245	39	0	1 104
East	248	506	233	74	2	1 063
Southeast	196	382	155	8	0	741
South	100	172	75	8	0	355
Southwest	143	330	180	10	0	663
West	135	330	122	43	2	632
Northwest	235	593	247	51	2	1 128
0–5° (Flat/Unclassified)						687
						7 403

Table B5 Landform

Terrain (Landform)	Slope Gradient	% of Total Area	Area (ha)
Hillcrest		8.0	588
Sideslope	0– 5°	0.1	6
"	5–15°	3.8	281
"	15–30°	35.7	2 644
"	30–40°	19.6	1 452
"	>40°	4.1	300
Cliff/Rock outcrop	0–30°	0	0
"	>30°	<0.1	2
Footslope (colluvium)	0– 5°	1.1	84
"	5–15°	3.7	273
"	15–30°	3.3	247
"	30–40°	0	0
"	>40°	0	0
Drainage plain (colluvium)	0– 5°	0.6	41
"	5–15°	4.0	298
"	15–30°	7.1	524
"	30–40°	0	0
"	>40°	0	0
Alluvial plain	0– 5°	1.5	110
"	>5°	0.3	24
Floodplain	0– 5°	3.9	290
"	>5°	0.4	29
Littoral zone	0–15°	1.0	75
Cut platforms : insitu	0– 5°	0.4	27
: colluvium	0– 5°	0	0
: alluvium	0– 5°	0	0
Cut slopes : insitu	>5°	0.9	63
: colluvium	>5°	0	0
: alluvium	>5°	0	0
Fill platforms : insitu	0– 5°	<0.1	2
: colluvium	0– 5°	0	0
: alluvium	0– 5°	0	0
Fill slopes : insitu	>5°	0	0
: colluvium	>5°	0	0
: alluvium	>5°	0	0
Reclamation	0–30°	0.4	33
General disturbed terrain/platforms: insitu	0– 5°	0	0
General distrubed terrain/slope: insitu	>5°	0	0
: colluvium	>5°	0	0
: alluvium	>5°	0	0
Natural stream		0	0
Man-made channel		0	0
Water storage		0.1	8
Pond		<0.1	2
		100.0	7 403

Table B6 Geology

Geological Unit	% of Total Area	Area (ha)
Reclamation	0.5	33
Fill	<0.1	2
Alluvium: undifferentiated	6.1	455
Colluvium: volcanic	9.0	669
: granitic	10.7	792
: sedimentary	0.1	6
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
: dominantly pyroclastic rocks with some lavas	6.7	494
Tai O Formation	0.6	43
Undifferentiated granite	15.3	1 130
Quartz Monzonite	1.1	78
Feldspar Porphyry	18.5	1 369
Ma On Shan Granite	<0.1	2
Cheung Chau Granite	6.2	461
Sung Kong Granite	0.9	67
	100.0	7 403

Table B7 Vegetation

Vegetation	% of Total Area	Area (ha)
Grassland	46.6	3 446
Cultivation	4.8	353
Mixed broadleaf woodland	2.9	216
Shrubland (<50%)	12.7	939
Shrubland (>50%)	26.4	1 954
No vegetation on natural terrain	2.2	165
No vegetation due to disturbance of terrain by man	4.3	318
No vegetation due to rock outcrop	<0.1	2
Waterbodies (including ponds)	0.1	10
	100.0	7 403

Table B8 Geology and GLUM Class

Geological Unit	Area in GLUM Class (ha)				
	I	II	III	IV	Unclassified
Reclamation	0	23	10	0	0
Fill	0	2	0	0	0
Alluvium: undifferentiated	0	451	0	2	2
Colluvium: volcanic	0	24	288	357	0
: granitic	0	64	465	263	0
: sedimentary	0	0	4	2	0
Littoral deposits	0	0	0	0	75
Repulse Bay Formation: undifferentiated volcanic rocks	29	387	457	392	0
: sedimentary rocks and waterlaid volcaniclastic rocks	2	12	4	10	0
: acid lavas	0	28	29	10	0
: coarse tuffs	51	147	106	53	0
: agglomerate	0	0	0	10	0
: dominantly pyroclastic rocks with some lavas	8	137	198	151	0
Tai O Formation	8	19	8	8	0
Undifferentiated granite	51	661	318	92	8
Quartz Monzonite	6	60	8	4	0
Feldspar Porphyry	59	538	594	178	0
Ma On Shan Granite	0	2	0	0	0
Cheung Chau Granite	84	236	131	10	0
Sung Kong Granite	2	59	4	2	0
	300	2 850	2 624	1 544	85

Table B9 GLUM Class

GLUM Class	% of Total Area	Area (ha)
I	4.1	300
II	34.2	2 530
IIS	4.3	320
III	35.4	2 624
IV	20.9	1 544
Unclassified	1.1	85
	100.0	7 403

Table B10 Slope Gradient, Aspect, Geology, Erosion and Instability

Slope Gradient	Aspect	Surface* Geology	No Appreciable Erosion (ha)	Appreciable Erosion (ha) Sheet	Rill	Gully	Instability (ha) WDL	GI	Area (ha)	Area Instability Index
0–5°	Flat	V	2	0	0	0	0	0	2	0
		G	35	14	0	4	0	0	53	0
		S	0	0	0	0	0	0	0	—
		C	51	33	10	31	0	0	125	0
		A	335	4	0	63	0	0	402	0
		L	75	0	0	0	0	0	75	0
		F	31	0	0	0	0	0	31	0
5–15°	N	V	4	43	0	0	0	0	47	0
		G	8	53	4	4	0	0	69	0
		S	6	0	0	0	0	0	6	0
		C	39	16	0	8	0	0	63	0
		A	4	0	0	12	0	0	16	0
		F	2	0	0	0	0	0	2	0
	NE	V	8	37	0	2	0	0	47	0
		G	6	67	0	4	0	0	77	0
		S	0	0	0	0	0	0	0	—
		C	25	16	2	29	0	0	72	0
		A	2	0	0	6	0	0	8	0
		F	0	0	0	0	0	0	0	—
	E	V	0	39	0	0	0	0	39	0
		G	8	108	0	0	0	0	116	0
		S	0	0	0	0	0	0	0	—
		C	33	20	0	27	0	0	80	0
		A	10	0	0	4	0	0	14	0
		F	0	0	0	0	0	0	0	—
	SE	V	0	14	0	0	0	0	14	0
		G	0	98	0	4	0	0	102	0
		S	0	0	0	0	0	0	0	—
		C	33	18	0	27	0	0	78	0
		A	2	0	0	0	0	0	2	0
		F	0	0	0	0	0	0	0	—
	S	V	0	8	0	0	0	0	8	0
		G	0	59	0	0	0	0	59	0
		S	0	0	0	0	0	0	0	—
		C	14	10	0	8	0	0	32	0
		A	0	0	0	0	0	0	0	—
		F	0	0	0	0	0	0	0	—
	SW	V	0	14	0	0	0	0	14	0
		G	0	78	0	0	0	0	78	0
		S	0	0	0	0	0	0	0	—
		C	16	25	0	10	0	0	51	0
		A	0	0	0	0	0	0	0	—
		F	0	0	0	0	0	0	0	—
	W	V	0	12	0	0	0	0	12	0
		G	2	39	0	2	0	0	43	0
		S	0	0	0	0	0	0	0	—
		C	37	14	0	25	0	0	76	0
		A	2	2	0	0	0	0	4	0
		F	0	0	0	0	0	0	0	—
	NW	V	0	35	0	0	0	0	35	0
		G	6	63	0	0	0	0	69	0
		S	2	0	0	0	0	0	2	0
		C	59	33	0	27	0	0	119	0
		A	4	0	0	4	0	0	8	0
		F	0	0	0	0	0	0	0	—
15–30°	N	V	18	49	0	4	0	112	183	0.61
		G	14	69	0	0	0	182	265	0.69
		S	0	0	0	0	0	2	2	1.00
		C	33	2	0	24	0	35	94	0.37
		F	0	0	0	0	0	0	0	—
	NE	V	16	78	0	8	0	114	216	0.53
		G	27	108	0	6	0	80	221	0.36
		S	4	0	0	0	0	2	6	0.33
		C	61	8	0	82	0	20	171	0.12
		F	2	0	0	0	0	0	2	0
	E	V	6	96	0	6	0	41	149	0.28
		G	20	173	0	2	0	35	230	0.15
		S	0	0	0	0	0	0	0	—
		C	35	12	2	61	0	16	126	0.13
		F	0	0	0	0	0	0	0	—
	SE	V	0	39	0	0	0	4	43	0.09
		G	10	237	0	2	0	8	257	0.03
		S	2	0	0	0	0	0	2	0
		C	24	4	0	39	0	12	79	0.15
		F	0	0	0	0	0	0	0	—
	S	V	0	18	0	0	0	4	23	0.17
		G	8	108	0	2	0	4	122	0.03
		S	0	0	0	0	0	0	0	—
		C	8	2	0	16	0	0	26	0
		F	0	0	0	0	0	0	0	—
	SW	V	0	82	0	0	0	20	102	0.20
		G	2	147	0	0	0	14	163	0.09
		S	2	4	0	0	0	0	6	0
		C	12	10	0	35	0	2	59	0.03
		F	0	0	0	0	0	0	0	—
	W	V	12	76	0	2	0	35	125	0.28
		G	12	74	0	2	0	27	115	0.23
		S	2	0	0	0	0	0	2	0
		C	33	10	0	16	0	31	90	0.34
		F	0	0	0	0	0	0	0	—
	NW	V	31	69	2	6	2	82	192	0.43
		G	22	102	0	2	0	145	271	0.54
		S	4	0	0	0	0	2	6	0.33
		C	45	0	0	47	0	33	125	0.26
		F	0	0	0	0	0	0	0	—

* For legend see Table B10 (Continued) on next page.

Table B10 Slope Gradient, Aspect, Geology, Erosion and Instability *(Continued)*

Slope Gradient	Aspect	Surface Geology	No Appreciable Erosion (ha)	Appreciable Erosion (ha)			Instability (ha)		Area (ha)	Area Instability Index
				Sheet	Rill	Gully	WDL	GI		
30–40°	N	V	2	12	0	2	0	124	140	0.89
		G	8	12	0	2	0	51	73	0.70
		S	0	0	0	0	0	2	2	1.00
	NE	V	6	45	0	4	0	90	145	0.62
		G	14	53	0	2	0	27	96	0.28
		S	0	2	0	0	0	2	4	0.50
	E	V	0	71	0	2	0	35	108	0.32
		G	2	73	0	4	0	45	124	0.36
		S	0	0	0	0	0	0	0	—
	SE	V	0	27	0	0	0	16	43	0.37
		G	0	84	0	0	4	24	112	0.25
		S	0	0	0	0	0	0	0	—
	S	V	0	16	0	0	0	6	22	0.27
		G	0	43	0	0	0	10	53	0.19
		S	0	0	0	0	0	0	0	—
	SW	V	2	24	0	2	0	20	48	0.42
		G	0	110	2	4	0	14	130	0.11
		S	0	0	0	0	0	0	0	—
	W	V	0	41	0	2	0	45	88	0.51
		G	0	29	0	0	0	6	35	0.17
		S	0	0	0	0	0	0	0	—
	NW	V	6	22	0	4	0	98	130	0.75
		G	2	41	0	0	0	69	112	0.62
		S	0	0	0	0	0	4	4	1.00
>40°	N	V	2	2	0	6	0	53	63	0.84
		G	0	2	0	0	0	0	2	0
		S	0	0	0	0	0	0	0	—
	NE	V	4	6	0	0	0	25	35	0.71
		G	0	4	0	0	0	0	4	0
		S	0	0	0	0	0	0	0	—
	E	V	0	43	0	0	0	10	53	0.19
		G	2	16	0	0	0	4	22	0.18
		S	0	0	0	0	0	0	0	—
	SE	V	0	0	0	0	0	0	0	—
		G	0	2	0	0	0	6	8	0.75
		S	0	0	0	0	0	0	0	—
	S	V	0	2	0	0	0	6	8	0.75
		G	0	0	0	0	0	0	0	—
		S	0	0	0	0	0	0	0	—
	SW	V	0	4	0	2	0	2	8	0.25
		G	0	2	0	0	0	0	2	0
		S	0	0	0	0	0	0	0	—
	W	V	0	16	0	2	0	16	34	0.47
		G	0	10	0	0	0	0	10	0
		S	0	0	0	0	0	0	0	—
	NW	V	0	4	0	4	0	35	43	0.81
		G	0	8	0	2	0	0	10	0
		S	0	0	0	0	0	0	0	—

Notes: V=volcanic rocks; G=granitic rocks; S=sedimentary and metasedimentary rocks
C=colluvium; A=alluvium; L=littoral deposits
F=fill and reclamation
WDL=well defined landslips and coastal instability
GI=general instability

Table B11 Geology, Erosion and Instability

Geological Unit	No Apprecia-able Erosion (ha)	Appreciable Erosion (ha)			Instability (ha)		Total Area (ha)	Area Instability Index
		Sheet	Rill	Gully	WDL & CI	GI		
Reclamation	33	0	0	0	0	0	33	0
Fill	2	0	0	0	0	0	2	0
Alluvium:								
—undifferentiated	359	6	0	90	0	0	455	0
Littoral Zone	75	0	0	0	0	0	75	0
Colluvium:								
—volcanic	198	98	10	241	0	122	669	0.18
—granitic	359	133	6	267	0	27	792	0.03
—sedimentary	0	4	0	2	0	0	6	0
Repulse Bay Formation:								
—undifferentiated volcanic rocks	67	583	0	31	2	582	1 265	0.46
—sedimentary rocks and waterlaid volcaniclastic rocks	0	16	0	2	0	10	28	0.36
—acid lavas	12	27	0	6	0	22	67	0.33
—coarse tuff	20	202	0	0	0	135	357	0.38
—agglomerate	0	0	0	2	0	8	10	0.80
—dominantly pyroclastic rocks with some lavas	21	216	2	18	0	237	494	0.48
Tai O Formation	23	6	0	0	0	14	43	0.33
Undifferentiated granite	80	810	2	22	4	212	1 130	0.19
Quartz Monzonite	14	60	0	2	0	2	78	0.03
Feldspar Porphyry Dyke Swarm	86	819	4	17	0	443	1 369	0.32
Ma On Shan Granite	0	2	0	0	0	0	2	0
Cheung Chau Granite	22	339	2	6	0	92	461	0.20
Sung Kong Granite	8	57	0	0	0	2	67	0.03

Notes: WDL = well-defined landslips
CI = coastal instability
GI = general instability

Table B12 Existing Land Use (From aerial photograph interpretation by the Geotechnical Control Office in 1982)

Existing Land Use	Area (ha)	Existing Land Use	Area (ha)
Private development	61	Undefined agriculture	18
2 Storey development	35	Fish ponds	2
1 Storey development	4	Undisturbed areas	5 045
Commercial/residential	8	Country park	1 620
Golf course	80	Water storage	8
Wharves	20	Squatters – low intensity	23
Roads	6	Squatters – medium intensity	12
Sewerage works	8	Squatters – high intensity	0
Quarries – borrow	16	Construction	51
Cemetery	2	Reclamation (unused)	10
Horticulture	343	Artificial slopes	31
		Total	7 403

Table B13 Existing Land Use and GLUM Class

Existing Land Use	Area in GLUM Class (ha)				
	I	II	III	IV	Unclassified
Private development	0	53	8	0	0
2 Storey development	2	27	6	0	0
1 Storey development	4	0	0	0	0
Commercial/residential	0	6	2	0	0
Golf course	4	39	35	2	0
Wharves	10	10	0	0	0
Roads	0	2	4	0	0
Sewerage works	6	2	0	0	0
Quarries – borrow	2	14	0	0	0
Cemetery	0	2	0	0	0
Horticulture	8	290	41	4	0
Undefined agriculture	0	6	10	2	0
Fish ponds	0	0	0	0	2
Undisturbed areas	237	1 923	1 908	902	75
Country park	19	416	553	632	0
Water storage	0	0	0	0	8
Squatters – low intensity	0	19	4	0	0
Squatters – medium intensity	0	8	4	0	0
Squatters – high intensity	0	0	0	0	0
Construction	8	29	12	2	0
Reclamation (unused)	0	4	6	0	0
Artificial slopes	0	0	31	0	0
Total	300	2 850	2 624	1 544	85

APPENDIX C

SUPPLEMENTARY INFORMATION

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APPENDIX C

SUPPLEMENTARY INFORMATION

C.1 Site Investigation Data

Numerous site investigations have been conducted both onshore and offshore by the public and private sector. Many reports are held by the Geotechnical Information Unit (GIU) and some of these are available to the public in the Civil Engineering Library operated by the Geotechnical Control Office.

The Geotechnical Control Office GIU Report entry and retrieval system is based on a master grid marked on reference sheets. Each grid block is provided with an index card listing all the reports held within that individual grid block.

C.2 Aerial Photographs

The North Lantau study area has been extensively photographed from the air, and a very large number of vertical and oblique photographs are available from the Photographic Library of the Survey & Mapping Office, Buildings & Lands Department. An abbreviated list of photographs is presented in Table C1.

C.3 Rainfall Data Relevant to the North Lantau Study Area

A general appreciation of the annual and monthly rainfall distributions for the study area can be obtained from Figures C1 and C2. Figure C1 is a reproduction of the mean annual rainfall isohyets for the years 1952 to 1976, published by the Royal Observatory. Figure C2 is a histogram of monthly rainfall for three selected Royal Observatory rainfall stations. There are a total of 6 rainfall stations within the study area, the locations of which are indicated on Figure C3. Detailed monthly and annual rainfall information for these stations is available from the Royal Observatory.

Table C1 Selection of Aerial Photographs

Year	Photograph Serial Number	Photograph Scale (Approx.)
1981	36777–36756	1:50 000
	36110–36225	1:4 000
1980	34854–34876	1:4 000
	33397–33465	1:20 000
1979	28058–28068*	1:20 000
	28110–28112*	1:20 000
	28054–28042*	1:20 000
	27986–27801*	1:20 000
	27980–27971*	1:20 000
1978	20741–20744	1:25 000
	20800–20881	1:25 000
	20776–20793	1:25 000
	20836–20830	1:25 000
	21003–21010	1:5 000
	21775–21789	1:4 000
	20685–20688	1:12 000
	21002–20997	1:12 000
	20679–20673	1:12 000
	20982–20994	1:12 000
	23955–23968	1:8 000
	24000–23996	1:8 000
	21828–21832	1:4 000
1977	19875–19880	1:25 000
	19017–19031	1:25 000
	19147–19130	1:25 000
	18924–19016	1:12 000
	19863–19854	1:12 000
	18777–18759	1:5 000
	18801–18779	1:5 000
	19196–19174	1:5 000
	19236–19229	1:5 000
	19873–19869	1:12 000
1976	15941–15957	1:25 000
	16610–16616	1:25 000
	15855–15850	1:25 000
	16592–16600	1:25 000
1975	12002–11997	1:25 000
	12036–12045	1:25 000
	11690–11692	1:25 000
	11686–11682	1:25 000
	12035–12030	1:25 000
1974	9769–9777	1:25 000
	9552–9561	1:25 000
	8361–8371	1:12 000
	9539–9545	1:25 000
	10276–10299	1:8 000
1973	8021–8015	1:25 000
	3863–3927	1:12 000
	3804–3836	1:12 000
	3951–3945	1:12 000
1964	2620–2612	1:25 000
	2560–2548	1:25 000
	2923–2917	1:25 000
	2897–2881	1:25 000

Note: 1. *indicates aerial photographs used during systematic terrain classification.

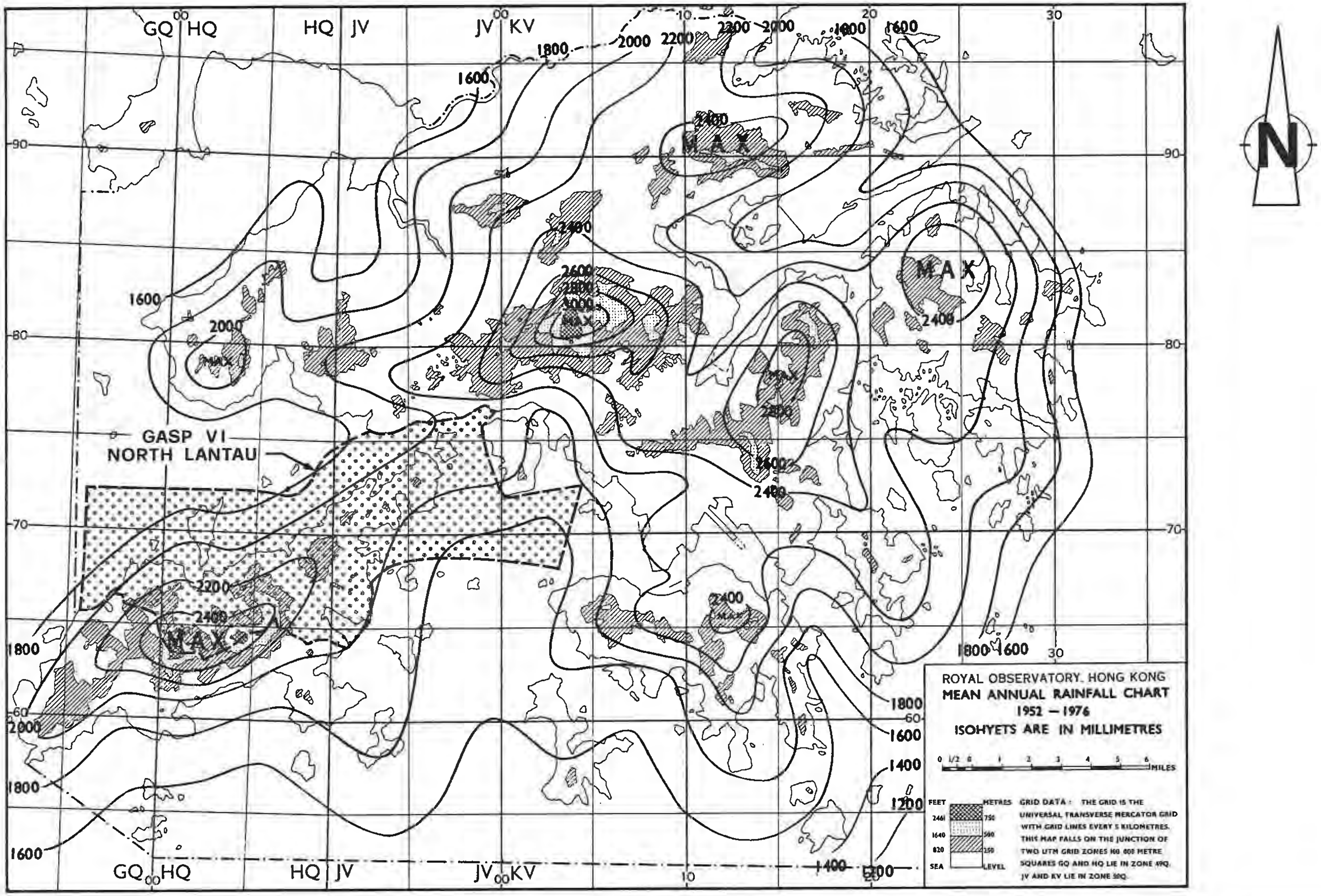
2. Vertical and oblique aerial photographs are available from the Photographic Library, Survey & Mapping Office, Buildings & Lands Department, 14th Floor, Murray Building.

Table C1 Selection of Aerial Photographs *(Continued)*

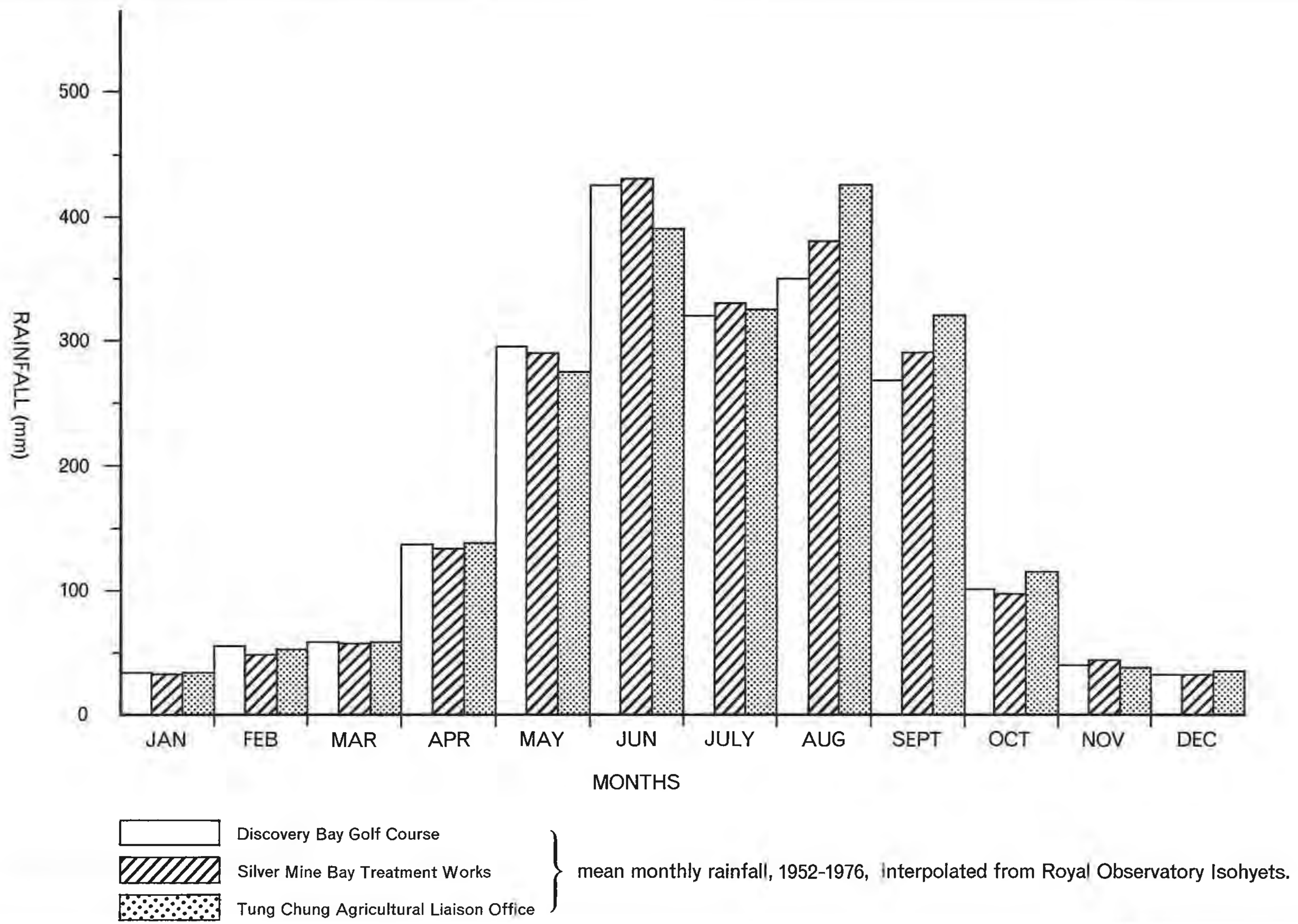
Year	Photograph Serial Number	Photograph Scale (Approx.)
1963	4693–4702	1:7 800
	4687–4673	1:7 800
	4538–4570	1:7 800
	1044–1028	1:7 800
	4624–4668	1:7 800
	4436–4516	1:7 800
	4410–4375	1:7 800
	4249–4271	1:7 800
	1078–1066	1:7 800
	4241–4233	1:7 800
	2923–2917	1:25 000
	2897–2883	1:25 000
	2620–2612	1:25 000
	2560–2548	1:25 000
1961	F41 0092–0107, 0028–0043	1:10 000
	F42 0092–0121, 0061–0080, 0028–0046	1:10 000
	F43 0095–0122, 0028–0049	1:10 000
	F44 0098–0120	1:10 000
1945	4094–4107 (681/5)	1:10 000
	4178–4162 (681/5)	1:10 000
	3001–3018 (681/6)	1:10 000
	4100–4081 (681/6)	1:10 000
	4001–4017 (681/6)	1:10 000
	3094–3074 (681/6)	1:10 000
	3095–3117 (681/6)	1:10 000
1924	8, 13, 21 (H41)	1:10 000
	18–30 (H57)	1:10 000
	8, 11 (H46)	1:10 000

Note: 1. *indicates aerial photographs used during systematic terrain classification.

2. Vertical and oblique aerial photographs are available from the Photographic Library, Survey & Mapping Office, Buildings & Lands Department, 14th Floor, Murray Building.

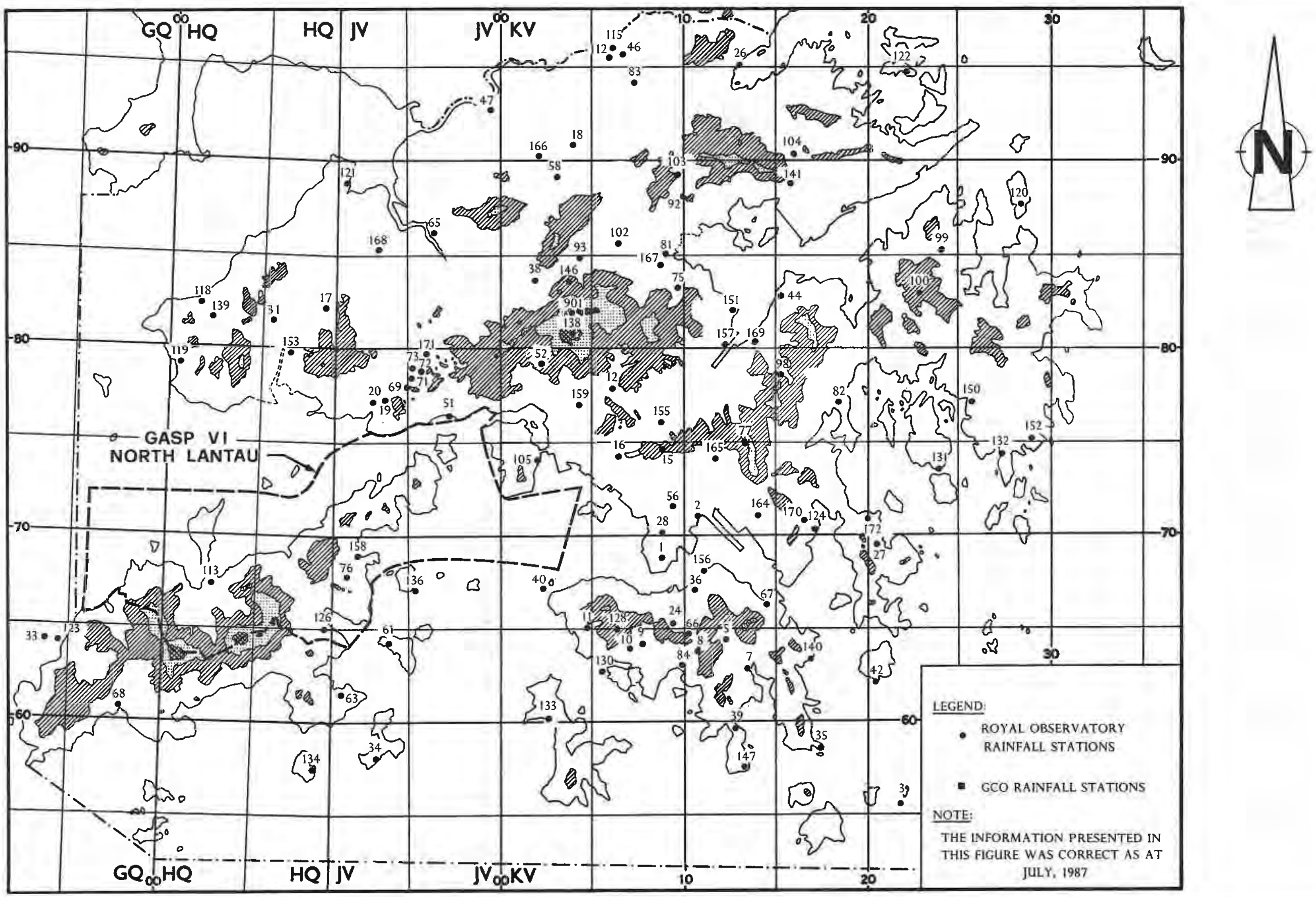


Mean Annual Rainfall Isohyets (1952–1976)	Fig. C1



Summary of Mean Monthly Rainfall Data

Fig. C2



Locations of Rainfall Stations

Fig. C3

APPENDIX D

INFLUENCE OF ROCK MASS AND TERRAIN CHARACTERISTICS ON PLANNING AND ENGINEERING IN HONG KONG

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APPENDIX D

INFLUENCE OF ROCK MASS AND TERRAIN CHARACTERISTICS ON PLANNING AND ENGINEERING IN HONG KONG

D.1 Introduction

The descriptions of the material characteristics and properties which are contained in this Appendix are intended to give planners and engineers a background understanding of the components of the Territory's terrain and materials. These components are described in the context of natural landform evolution. Consideration of the significance of natural landform evolution will allow interpretation of the terrain as it relates to engineering properties and behaviour and their influence on development. The information contained in this Appendix is presented as background to Section 3.

D.2 Rock Mass Characteristics

These sections outline the principal reasons for the differing rock mass characteristics and their influence on the development and behaviour of weathered rock and soil, both in the evolution of natural terrain and in their relevance to engineering. In this context, they are relevant at the planning stage of a project as they are capable of influencing the engineering feasibility of a particular form of project through construction cost, ancillary works and long-term maintenance. Particular problems, if anticipated at the earliest stages, can be avoided or accommodated with the minimum disruption, delay or expense. The main discussion on the planning and engineering significance of geotechnical problems is given in Sections 3 and 4.

The portion of Figure D1 devoted to Rock Mass Characteristics, and reproduced in Figure D2, shows in sequence the factors which contribute to rock properties and which, through mass strength and structure, permeability and chemical stability, contribute to the control of landforming processes and engineering performance. The succeeding sections explain in general terms how the variations in rock mass characteristics arise. They are not intended to be thorough from the geological point of view. Geological descriptions of the particular rock types are given in Section 2.3. The engineering properties such as strength or permeability are not specified in quantitative terms. Significant differences in the engineering properties of the individual rock types may occur, and these are indicated in Section 3.1 and in Table 3.1. However, the principal rock types exposed in the study area, the granites and volcanics, exhibit characteristic trends of mass behaviour. It is the qualitative differences in performance and characteristic terrain which can be interpreted at the planning stage to improve the quality of any planning decision.

D.2.1 *Mode of Generation and Texture*

It is the mode of generation of the rock which is often the major factor which controls the subsequent development of mass characteristics.

The mode of generation influences the grain or crystal size and texture and, hence, the intact strength, physical stability and intact porosity. Weathering is in part a direct function of porosity combined with chemical stability, which is related to mineralogy and mode of generation.

The tectonic history is related to the mode of generation of the rock, and on this depends the development of mass structure over a broad range of scale. Joints and faults are the result of the release of stresses built up during cooling, burial, intrusion, tectonic movement and unloading.

D.2.2 *Joints*

Joints are small fractures involving minimal movement, which generally occur at close spacings in the volcanics and wider spacings in the granites. Differences between volcanic and granite jointing occur and these enable the nature of potential stability problems to be anticipated. Jointing directly influences mass transport through mass strength and structural control, and indirectly through permeability and groundwater flow. In this latter respect, it directly influences weathering development and the form of the weathered profile.

Volcanic rock is subject to a variety and range of tectonic stresses, which generally result in intense jointing of the rock. The volcanic joints, at 0.2 to 1 m spacing, are often not laterally extensive (of the order of 5 m), and their orientations appear to be fairly random. This generally has the effect of allowing fairly uniform permeation of groundwater through the rock mass, although groundwater flow may be locally restricted.

By contrast to the volcanics, joints in granitic rock are often spaced from 2 to 10 m and are laterally extensive. Their wide spacing and open nature tend to concentrate groundwater flow in the joints. Extensive 'sheeting joints', parallel to the ground surface, are characteristic. Being tension cracks, the granite sheeting joints are rough and thus usually have a high apparent angle of friction.

The more randomly oriented, smoother, volcanic joints will influence the stability of cut faces although this may only result in surface 'ravelling'. Granite joints by contrast are less likely to bring about failure in rock unless steeply inclined, due to their high roughness or vertical orientation. Note, however, that weathering on joint planes effectively reduces their roughness, thereby decreasing stability.

D.2.3 *Porosity and Permeability*

Neither the porosity nor the permeability of the rock or soil mass have a significant bearing on large-scale planning decisions. However, the groundwater regime can adversely influence stability if changes of permeability occur, for instance in the construction of piled foundation or basements. Lumb (1964, 1972) discussed building settlements within the Territory.

Porosity relates to the capacity of rock or soil to hold liquid, and is thus an important factor in determining the rate of weathering. Permeability controls the rate of throughflow, which influences weathering and also stability through water pressure. Mass permeability is influenced by jointing in granites, since flow tends to be concentrated in the open joints, whilst in volcanics, water permeation is more uniform. Hence, both porosity and permeability are important factors in weathering decomposition and in the nature of the weathered profile.

D.2.4 *Weathering and the Weathered Profile*

The weathering process and its products exert a significant influence on the performance of the materials and on their response to transport processes. At the planning stage, therefore, consideration of the weathering process and its effects will help to produce feasible layouts for projects, so that they are less influenced by geotechnical threat and, hence, less costly to construct and maintain.

The nature of weathering and its problems may often be inferred from the shape of the terrain, its geology and evidence of existing landforming processes, factors which are all discussed or presented in this Report. The factors shown in Figure D3, some of which are discussed above, all exert varying influences on the weathering process. The rate of weathering breakdown is usually a function of rock porosity and permeability in conjunction with active and fluctuating groundwater flow. The differing chemical stability of various minerals comprising the rock results in non-uniform breakdown of the rock.

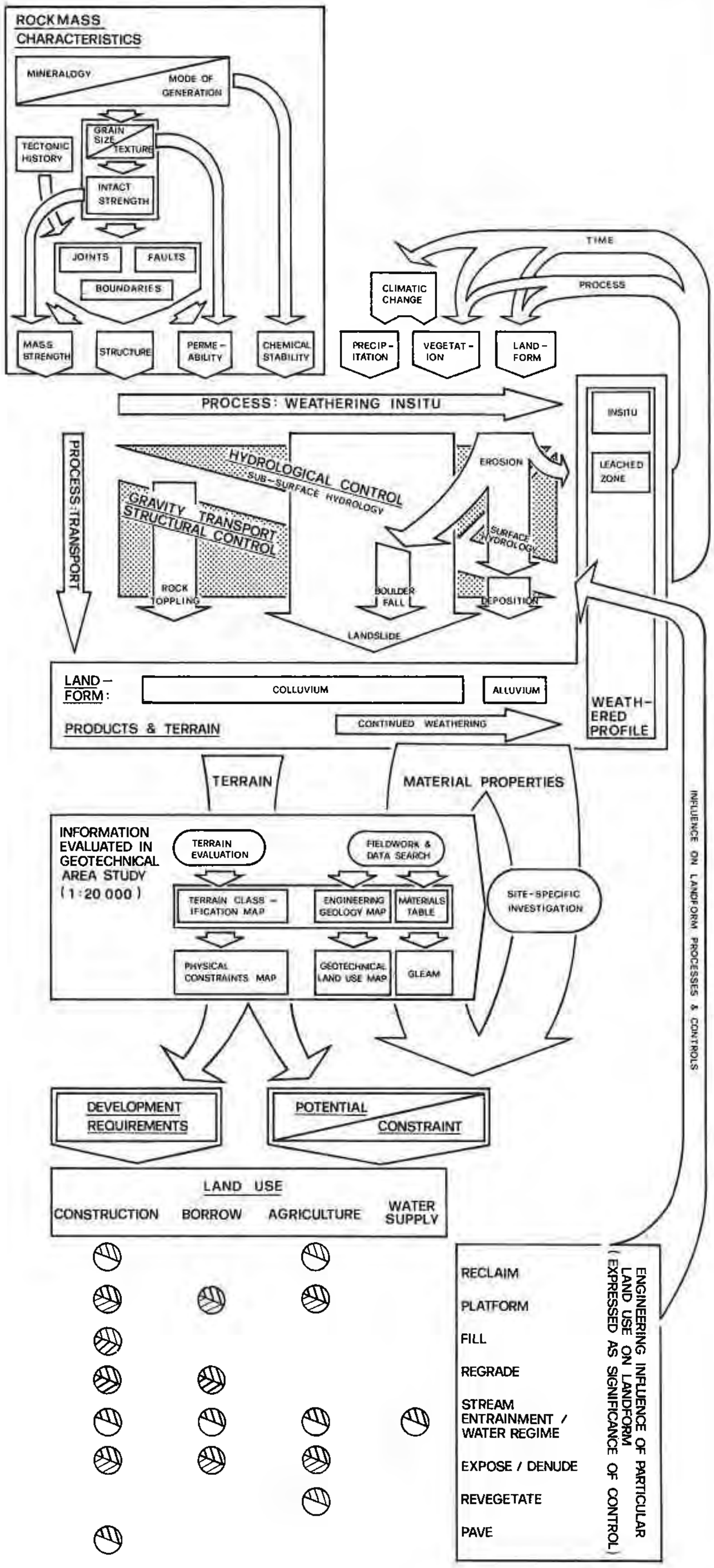
The weathered product of granitic rock is a loose, granular quartz soil because feldspars are broken down during weathering. The proportion of clay in the weathered soil depends on the balance between eluviation and deposition, which is related to the terrain. The texture of weathered granite makes it particularly susceptible to erosion on ridgecrests and other situations where natural vegetation is removed. By contrast, the weathered volcanic rocks have a higher proportion of silt size particles and, due to their clay content, to some extent are more resistant to erosion.

Weathering progresses as a function of porosity and permeability. Mass permeability is important in determining the nature of the weathered profile. Table A3 in Appendix A shows schematically the constituents of a complete weathering profile in granitic rock. Water flowing through the joints initiates breakdown of the intact rock away from the joints and leaves core boulders of relatively unweathered material in a matrix of weathered soil. This particular problem is associated with boulders in granite and granitic colluvium. As weathering progresses, the depth of completely weathered material increases (Zone A) until, in an old profile, Zones B and C may be almost completely absent. The depth of Zone D is thought to be related to the lowest depth of active groundwater flow, although weathering by other processes, may operate below this depth. The depth of the weathered profile in granite may exceed 90 m, which is considerably greater than that established in volcanic rock.

In volcanic rock, where the joint spacing is close and mass permeability is therefore more uniform than in granite, weathering appears to progress more uniformly, so that corestones are not often evident. The reasons for the generally thinner depth of the weathered mantle and for the rapid change from unweathered to completely weathered rock in volcanics are uncertain and are not widely considered in the literature. They may be due to topographic and hydrological factors prevailing during earlier climatic periods as well as to material properties.

Time, climatic change and the landform type combine with the physical characteristics outlined above to influence the processes and the present condition of the terrain. These are important variables, since they may introduce apparent anomalies into the weathered profile. Weathering profiles and landform patterns form, over considerable periods of time and are balanced between the processes of weathering and erosion. Hence, rejuvenation or abandonment of an established weathering profile, removal of portions of a weathered mantle, or deposition and subsequent weathering of a colluvial blanket may result in a change in this balance. These changes often result from altered hydrological conditions. Although certain inferences may be made from the shape of the terrain as to trends in depth of the weathered profile (Ruxton & Berry, 1957, Ruxton, 1960), the current terrain may be the result of more recent transport processes, as described in Appendix D.3.

NATURAL AND MAN-MADE INFLUENCES ON LANDFORM EVOLUTION IN HONG KONG ; THE ENGINEERING CHARACTERISTICS AND PROCESSES WHICH INFLUENCE LAND USE POTENTIAL , AND THEIR EVALUATION WITHIN THE GAS PROGRAMME.



NATURAL LANDFORMING INFLUENCES :
SUBSURFACE & SURFACE VARIABLES.

LANDFORMING PROCESSES :
RELATIVE INFLUENCE OF HYDROLOGY, STRUCTURE & WEATHERING ON TYPES OF TRANSPORT PROCESS. (BACKGROUND TRIANGLES SHOW PROPORTION OF INFLUENCE OF CONTROL).

LANDFORM :
INDICATED AS PRODUCTS OF VARIOUS LANDFORMING PROCESSES.

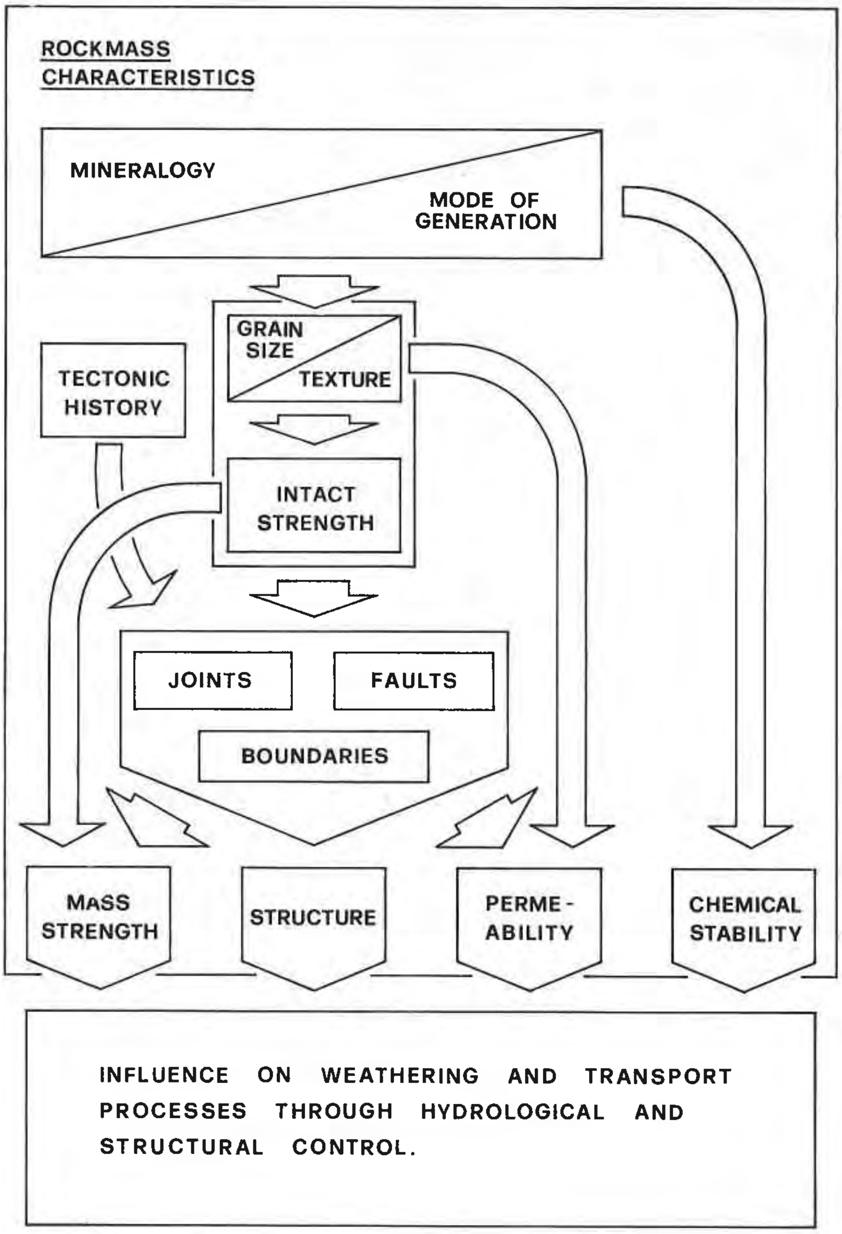
GEOTECHNICAL AREA STUDIES :
CLASSIFICATION OF TERRAIN & ENGINEERING MATERIALS, INTERPRETATION OF LANDFORM IN TERMS OF GEOTECHNICAL POTENTIAL & CONSTRAINT FOR STRATEGIC PLANNING & ENGINEERING FEASABILITY STUDIES. G A S PROVIDES PRELUDE TO SITE SPECIFIC INVESTIGATION.

INFLUENCES ON LAND USE :
POTENTIAL, CONSTRAINT, DEVELOPMENT REQUIREMENTS.

LAND USE CHART :
INTENSITY OF SHADING INDICATES ENGINEERING INFLUENCE OF PARTICULAR LAND USE ON
HYDROLOGICAL CONTROL
STRUCTURAL CONTROL
THROUGH MODIFICATION OF LANDFORM :
SLIGHT
MODERATE
SIGNIFICANT

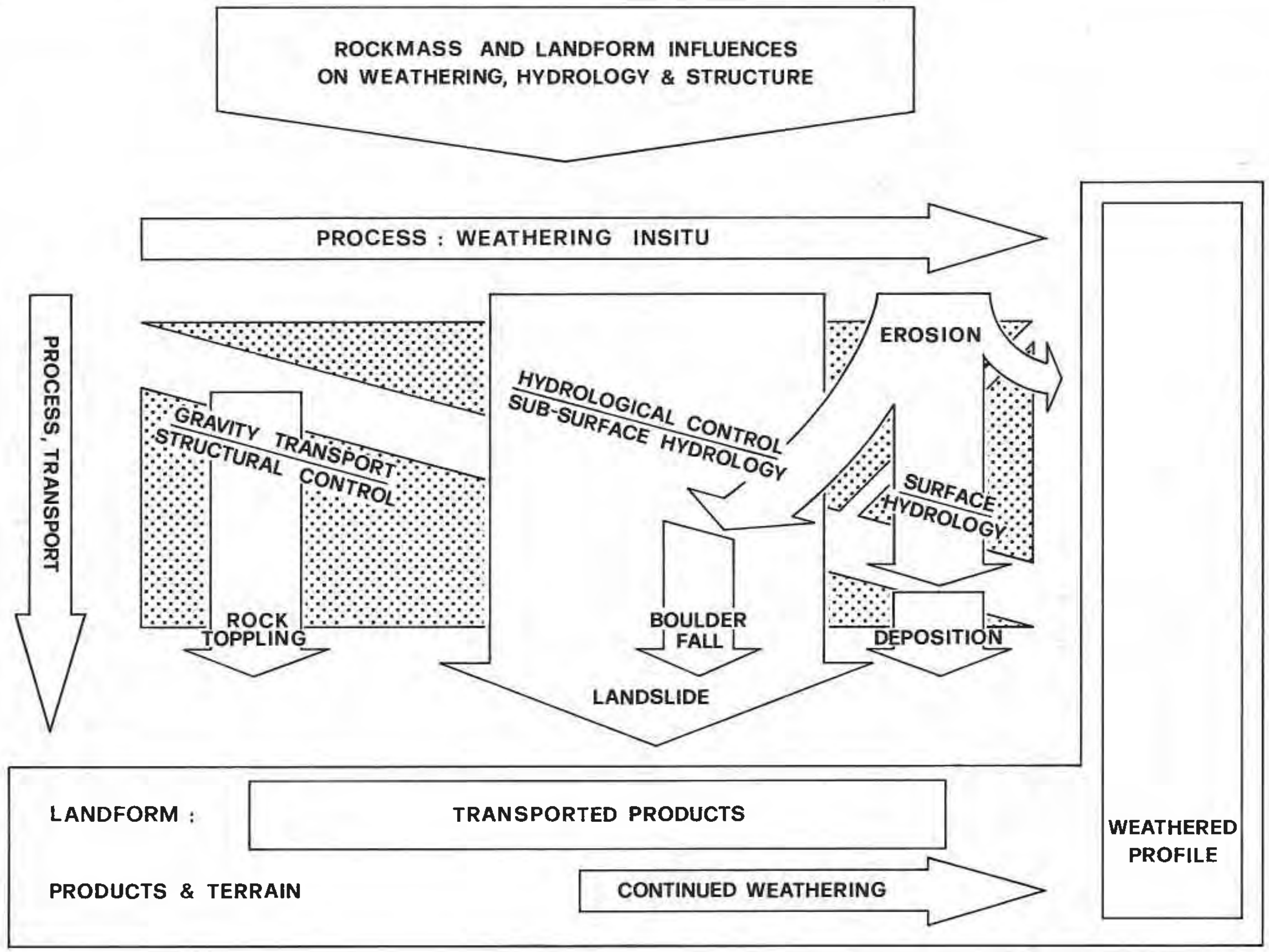
LEGEND :
BOXES INDICATE : CAUSE OR PRODUCT
ARROWS INDICATE : INFLUENCE, PROCESS, OR MECHANISM
CIRCLES INDICATE : HUMAN INVOLVEMENT

Influence of Landforming Processes — Fig. D1



SUMMARY OF ROCKMASS CHARACTERISTICS WHICH ARE SIGNIFICANT IN INFLUENCING NATURAL LANDFORM AND ENGINEERING WORKS IN HONG KONG. (EXTRACT FROM FIG.D1)

Rock Mass Characteristics	Fig. D2



SUMMARY OF LANDFORMING PROCESSES IN TERMS OF THE RELATIVE IMPORTANCE OF WEATHERING HYDROLOGY AND STRUCTURE. (EXTRACT FROM FIG. D1)

(BACKGROUND TRIANGLES SHOW PROPORTION OF INFLUENCE OF HYDROLOGY AND STRUCTURE)

Landforming Processes	Fig. D3

D.2.5 *Faults*

A fault is a fracture in rock along which there is an observable amount of displacement. Faults rarely occur in isolation, and more extensive faults or fault zones often display associated local shattering of the rock. Hence they may cause concentration of groundwater flow which permits deeper weathering to occur. If so, they often become observable in surface reconnaissance and from aerial photograph interpretation as photo-geological lineaments.

D.2.6 *Boundaries*

Geological boundaries are often reflected geomorphologically and are sometimes enhanced by changes in vegetation. They commonly control the local hydrological regime and this, together with the local variations in structure and rock properties, is of significance in engineering work. Many geological boundaries are also faulted.

D.3 Engineering Considerations for Development Planning

D.3.1 *General*

Geotechnical problems will be minimised if development takes place in a manner which reflects the basic suitability of the terrain for a particular use. The following sections discuss the engineering significance of the major terrain-related factors which influence the suitability of land for development. The discussion relates to those features which are particularly important for planning and engineering feasibility.

In the Territory, the relief of the terrain is dramatic, and the pressures for development are very high. A considerable portion of the currently developed terrain and natural terrain with potential for development is subject to high to extreme geotechnical limitations. These limitations are often associated with, or are related to, either natural or man-made features. For example, Vail & Beattie (1985) discuss the failure and stabilization of earthworks in the Territory. Further development within the study area will necessitate the utilisation of natural or man-made terrain which has geotechnical limitations. Some of these features continually recur across the landscape and have similar engineering problems. This section seeks to identify the major constraints associated with a number of engineering geological factors.

D.3.2 *Geotechnical Constraints to Development*

Within this study area, slope instability is a major geotechnical constraint to development. Instability may be associated with moderate to steeply sloping insitu or colluvial terrain or with land which has been disturbed by man. Landslips and other forms of slope instability are common occurrences on both natural and man-made terrain in the Territory. A number of serious landslip disasters have resulted in considerable loss of life and extensive property damage.

Rock toppling, rock slides and boulder falls are essentially structure controlled, although movement, which is usually sudden and without warning, may be initiated by groundwater pressure. Structural control is also affected by man's influence, because construction exposes release joints along which sliding may occur. Boulder falls usually require the erosion of weathered material or decomposition along planes of weakness through hydrological influence.

Landslips in weathered material pose a considerable hazard, but they are often preceded by signs of distress. Although largely controlled by relict jointing in moderately weathered material, natural failure is often precipitated by the subsurface water regime in conjunction with landslip-prone topography. Leach (1982) and Leach & Herbert (1982) studied the question of groundwater flows on Hong Kong Island.

Whilst erosion alone does not pose as great a hazard as slope instability, it can cause severe problems for engineering work. In addition, changes to the terrain and hydrology through construction or earthworks may cause erosion which may create conditions conducive to mass movement. The loose structure of weathered granites make these more susceptible to erosion than the volcanics when vegetation is removed. Evidence of this occurs in the denuded, eroded and bouldery upper sideslopes of the granitic terrain, where landslips are common at the heads of drainage lines. The debris from such landslips may travel at high velocity for considerable distances, blocking drains and resulting in surface water infiltration.

Deep weathering may be present, particularly where it is accelerated by shattered rock structure or active subsurface groundwater. Although weathering is not a severe constraint, it may pose considerable difficulties during construction, especially if very localised. Localised problems associated with geological photolineaments are discussed in Section D.3.4.

The following sections outline a number of specific problem areas which are important for planning and engineering feasibility.

D.3.3 *Fill and Reclamation*

Fill is soil or rock which has been used to provide site formation above the level of the natural terrain. The nature of the fill depends on the source material, the natural terrain, and the quality and control of construction. These factors, together with the history of filling, influence the engineering characteristics of the material.

The locations of fill and reclamation are shown on the Engineering Geology Map and the Physical Contraints Map. The nature and the engineering problems associated with fill can be categorised into the following:

(i) *Cut and Fill Platforms on Steep Terrain*
This technique is used in the Territory to provide level platforms on otherwise steep terrain. A typical example is associated with the earthworks for the construction of the development at Discovery Bay, where numerous cut slopes, platforms, fill slopes or retaining walls mask the natural slope profile.

Since the disastrous fill slope failures at Sau Mau Ping in 1972 and 1976 (Government of Hong Kong, 1972 *a* & *b*, 1977), fill has been recognised as a potentially hazardous engineering material. Consequently, recent fill platforms and slopes are designed and constructed to stringent requirements. Common problems in older fills on steep terrain are due to the fact that many were 'end tipped'. This results in:

(*a*) Poor compaction – a generally loose structure makes the fills susceptible to liquification resulting from infiltration of rainwater, movement of groundwater, through-flow or from fractured water mains. This leads to sudden loss of strength and failure of the slopes. Loose fill is also liable to settlement and possible lateral movement on loading.

(*b*) Stratification parallel to the natural slope – this enables the infiltration of water from the level platform into the fill and also creates inclined planes of potential weakness liable to preferential failure.

Old fill has often been tipped into unprepared natural drainage lines, and the natural groundwater regime may persist beneath the fill, leading to saturation and instability. The material behaviour is also subject to the variability of the source material. Completely weathered rock would result in a fairly uniform fill, whilst fill of less weathered rock may contain boulders and voids.

(ii) *Fill on Low-lying Terrain*
Few engineering problems are envisaged in these areas, with the exception of settlement. Large buildings are generally piled. Deep excavations may experience difficulties due to high groundwater tables in underlying alluvium.

(iii) *Land Reclaimed from the Sea*
Some of the coastal areas are modified by reclamation and considerable recent and proposed development is based on these areas.

Although most areas of reclamation are subject to current or proposed development, it is relevant to note that older reclamation materials may be very variable in quality. The following engineering problems should be anticipated during development in areas of reclamation:

(*a*) Lateral variability of materials—the extension of reclamation areas over a long time may result in material of differing sources and quality being present. Borehole samples should be examined and interpreted with this in mind.

(*b*) Variability of materials with depth—reclamation materials may vary with depth and cause local artificial aquifers and dense or loose zones. These should be anticipated in the choice of construction method and evaluated during site investigation. Boulders, timbers and other extraneous materials may be present in older areas. These may require localised measures during construction, such as hand-dug excavations. Better quality, more uniform material may allow driven piles for low structures such as warehouses, or larger diameter mechanically excavated sleeved caissons for heavier structures.

(*c*) Presence of old structures—within areas of reclamation, features such as old foundations and sea walls may occur. Consultation of archive sources may help avoid local difficulties or anticipate setbacks during the critical foundation construction period.

(*d*) Dewatering problems—the reclamation material, in its loose, permeable, saturated stage, is likely to have water problems which may cause heaving in deep excavations. Grouting or dewatering may therefore be necessary. Dewatering may cause settlement problems in adjacent slabs and unpiled structures. Permanent or temporary impermeable barriers to water flow, such as continuous walling, may also cause problems to adjacent buildings by interrupting groundwater flow and raising water levels.

(*e*) Basements—these require tanking or water resistant design. External drainage may be necessary to prevent an increase in water levels if drainage paths are blocked.

(*f*) Settlement—unpiled structures are subject to settlement and should be designed to redistribute loads or else to be flexible. Foundation stresses are subject to variation from fluctuating water levels in response to the tide. Piled structures may require design for negative friction in recent or deep reclamation.

(*g*) Underlying materials—the problems of construction on reclamation may be aggravated by considerable depths of marine or alluvial deposits and weathered bedrock. The depth of these will vary depending on the original ground profile. The general depth of underlying materials may be determined from site investigation, whilst local variation may be identifiable in the features of the old coastline and the onshore terrain.

(iv) *Sanitary Landfill*

Sanitary landfills are used for the disposal of domestic refuse. Typical engineering problems associated with the development of sanitary landfills include:

(*a*) Heterogeneous materials which are difficult to remove.

(*b*) Unpredictability of stability of landfill slopes and embankments.

(*c*) Unpredictable, large settlements.

(*d*) Fire hazard from methane gas emission.

(*e*) Erratic water flows within landfill.

(*f*) Noxious leachates, posing pollution problems and chemical attack of concrete and steel.

For these reasons, recently completed sanitary landfills and adjacent platforms are probably unsuitable for development other than as open space or recreation areas.

D.3.4 *Geological Photolineaments*

Major geological photolineaments are shown on the Engineering Geology Map for the study area.

Lineaments are the surface expression of subsurface structural features and, hence should be carefully examined during planning and engineering feasibility. Differences in rock type, structure or strength are amplified by the landforming processes to produce contrasts in erosion or vegetation, or linear patterns in relief or drainage. Such contrasts are readily identified using API and are often apparent during site reconnaissance. It should be noted that structural features causing lineaments will probably continue beneath superficial deposits such as alluvium, colluvium or fill and their influence should be anticipated in foundation works through these materials.

In general terms, contrasts in the terrain are a reflection of the resistance or susceptibility of the underlying material to erosion. Surface features are often good indicators of local engineering characteristics.

Lineaments tend to be localised and therefore they may often be avoided during the layout and design stages of an engineering project.

Engineering factors which are often associated with lineaments may be classified into the following:

(i) *Deep Weathering*

Shatter and shear zones in the rock tend to concentrate water flow and result in deep weathering. Localised rock shattering may be due to faulting and is likely to appear as a major lineament. Foundation difficulties may occur due to rapidly changing ground conditions. Many of the photolineaments are major features which are continuous across the study area.

(ii) *Slickensiding*

Slickensiding is evidence of larger scale movements in rock and soil. Smoothing and striation on a fault plane render it more susceptible to failure if a cut slope were to intercept and release a slickensided joint. Whilst this problem may not be obvious prior to excavation, it should be anticipated where fault lineaments are indicated.

(iii) *Changes in Rock Mass Structure and Properties*

Smaller scale lineaments are often identified from preferential drainage caused by a weakness or adjacent strength of the rock mass. This may be due to variation in the rock itself or in its structure. Where the lineament is evidence of a structural weakness, problems may be encountered in the founding of caissons and in the construction of rock cut slopes.

Small scale, as well as major, photolineaments may be associated with anomalies in the general pattern of weathering depth which may cause differential settlements of raft foundations.

Regular patterns of lineaments are evidence of the regional pattern of structure present at smaller scale. Engineering works in the area may experience instability problems on cut slopes at particular orientations.

In areas of active coastal erosion, the local rock structure is often apparent from the pattern of erosion and instability.

Boundaries between rock types may or may not form photolineaments, partly depending on whether they are faulted or not. Identified rock boundaries are shown on the Engineering Geology Map. Changes in structure are likely at granite/volcanic boundaries due to cooling stresses, and in strength and weathering due to contact metamorphism.

(iv) *Preferential Groundwater Flow*
The preceding engineering features of photolineaments are usually associated with preferential groundwater flow, both at and below the surface. This should be a consideration in the construction of fills in valleys where the subsurface hydrology may be largely unaffected despite surface water entrainment.

(v) *Seismic Influence*
Some photolineaments are identified on the Engineering Geology Map (after Allen & Stephens, 1971) as faults, and other major photolineaments may also indicate faults. Faults may extend laterally for short distances or for many thousands of kilometres. The Government of the Peoples Republic of China has published a national seismic map which shows extensive fault-zones of NE or ENE trend in Guangdong Province and western Fujian Province. One of these fault-zones lies along the northern boundary of the Territory of Hong Kong, while others intersect the coast of Guangdong Province to the east of Hong Kong. Sources in China regard many of the faults of the region as active, the degree of activity being inferred from recent earthquake data and that derived from the historical geological record.

Throughout the world, even in seismically 'quiet' areas, many major faults are active to some extent. For example in the UK, which is classified as an area of low to moderate seismicity, a few hundred earthquakes occur every year, although they are rarely felt by individuals. Most of the earthquakes recorded by the Royal Observatory short-period seismograph network, originated elsewhere in the Southeast. Asian region. The few which actually have been felt by individuals in Hong Kong were mostly related to earthquakes in various parts of China. Nevertheless, minor seismic events originating within the Territory have also been recorded by the Royal Observatory, and these events may be attributed to minor movements on faults at depth giving rise to seismic waves but no apparent ground displacement. To date no clear relationship is obvious between these local seismic events and known faults within the Territory.

On the basis of observations of the historical geological record and mapping work undertaken to date, it appears that, although minor crustal readjustments have been occurring in Hong Kong, the Territory is not characterised by local major fault movements or related severe seismic events.

D.3.5 *Colluvial Deposits*

Colluvium is a transported material, whose nature and engineering characteristics depend on the origin of the material, the conditions of its deposition and its subsequent history. Various types of colluvium exist within the study area, and their location, nature and material properties are discussed in Sections 2.3, 2.4 and 3.1.4. The extent of colluvium as identified by terrain classification is shown on the Engineering Geology Map.

Colluvium need not necessarily be regarded as a constraint for engineering. Relict colluvium in a completely weathered state may be strengthened by overconsolidation and be virtually indistinguishable in material behaviour from its weathered parent. However, colluvium is inherently variable and, as demonstrated by the Po Shan Road disaster in 1972, when a portion of a large colluvial slope failed, it is often an extremely difficult material to assess in engineering terms (Government of Hong Kong, 1972 a & b).

Engineering factors which are often associated with colluvium may be classified into the following:

(i) *Physical Properties*
Colluvium is subject to local variations of structure, density, strength and water content, both horizontally and vertically. In particular, concentrations of subsurface water flow may result in voids and pipes caused by the removal of fines, and in local piezometric variation. Stratification of these deposits may cause perched water tables and variations in the strength profile. Settlements under load may be unpredictable. Hence, heavily loaded structures should be founded on caissons through to bedrock. In situations were loading of the colluvium could cause instability, measures should be taken to ensure that loads are not transferred to the colluvium. The variable nature of colluvium will often require the use of hand dug caissons. As discussed for boulder colluvium in Section 3.1.4, measures should be taken to avoid any adverse influence on the groundwater regime.

(ii) *Water Conditions*
The potential for localised flows and perched water tables should be anticipated if piezometers are to be installed. A single piezometer within the profile is seldom adequate to determine the groundwater regime, and the location of piezometers should be based on the observations of the site investigation. In particular, the water pressures should be monitored and interpreted, if significant to design, with respect to strata within the profile. Pressures in underlying weathered material are also important.

(iii) *Stability*

The stability of cut slopes is very susceptible to local variations in strength and water pressure. Since it may not be possible to define these fully from the site investigation, the progress of excavations should be closely monitored to accommodate local variation.

Particular attention should be paid to material boundaries, voids and seepage zones. These may render modelled design conditions doubtful. Many of the cuts in colluvium on footslope terrain show zones of water seepage. Local instability in natural oversteepened colluvial slopes results from emerging groundwater. In cuts in colluvium such conditions may lead to progressive collapse of a loose soil structure upslope with considerable debris flow.

(iv) *Site Investigation*

In heterogeneous deposits such as extensive recent colluvium and boulders, site investigation alone cannot reveal a comprehensive model of the ground, nor can appropriate strength values be accurately assessed. Carefully monitored trial caissons are often justified in colluvial deposits. Attention should be paid to variations in bedrock and its level in boreholes to ensure that foundations do not rest on boulders.

D.3.6 *Boulders and Rockfalls*

Boulder and rockfalls are a feature of the wet season in the Territory and have on occasion resulted in loss of life and considerable property damage.

Boulders are large blocks of rock which often result from wide joint spacing. They occur often in granitic rocks as the unweathered remnant corestones between completely weathered joints. If exposed on steep hillsides or in drainage lines, they may be liable to movement.

Adverse jointing and an exposed location may result in potential rockfalls in both granitic and volcanic terrain. In this case, weathering, except as a local weakening of the joints, is not a major contributing factor. In granitic rock, the presence of extensive sheeting joints also contributes to the rockfall potential.

Boulders, joint blocks and wedges may also be present in, or as exposed remnants of, both granitic and volcanic colluvium. Boulders may also exist in drainage lines where they are likely to be restrained and interlocked. However, high flow caused by torrential rain is liable to increase the likelihood of movement. Boulders in drainage lines may also trap detritus and torrential flows may cause mud or debris flows. In many situations, boulders are hidden from view by dense vegetation.

Engineering solutions to the boulder and rockfall problem depend largely on the local situation, but may consist of one or a combination of the following:

(*a*) Removal—isolated boulders may be removed from the slope if the situation permits. This could be achieved by blasting or excavation.

(*b*) Restraint—it may be possible to restrain or support isolated boulders and rock wedges by buttressing, anchoring, or cable support.

(*c*) Protection—in areas with long slopes and many potentially unstable boulders or blocks of small to moderate size, identification and removal of critical boulders may not be warranted or may detrimentally affect stability. In such cases, general protection measures may be more appropriate, such as sterile zones, trap ditches or bunds, catch fences, protection nets or deflection barriers.

D.3.7 *Boulders below Ground*

In the granites and colluvium of the study area, boulders are often present within the weathered matrix. Site investigation and construction of load bearing foundations should examine these features. For deep foundations, hand excavation may be required. Blasting of boulders in caissons or cuttings may cause loosening or collapse of the surrounding matrix. Variations in the bedrock level and in the bedrock material may also indicate the presence of boulders.

In bouldery colluvium, voids are likely beneath boulders as a result of the nature of deposition or due to washing out of the matrix in underground drainage lines. This poses particular problems for the construction of deep foundations through these materials.

D.3.8 *Marine Deposits*

Marine deposits are not considered in detail from an engineering point of view in this Report, except in relation to reclamation.

D.3.9 *Cut Slopes*

Cut slopes and/or slope support structures are an aspect of most large-scale developments in the Territory. Different considerations govern the use and design of slopes depending on the geological material, its state and structure. Hence, the overall form of a development should also relate to the engineering opportunities of the terrain.

The height and angle of a cut slope are a matter for design based on a model of the rock or soil strength and structure as determined by site investigation. Preliminary assessment of the size and form of slopes and retaining structures may be made on the basis of the engineering properties of the local rock type, as indicated on the Engineering Geology Map and in the Materials Table (Table 3.1). At the planning stage, flexibility of layout should be retained, especially where large cuts are involved, so that local variations in strength and structure can be accommodated in design. Lineaments indicate a degree of structural control of the landforms by the underlying geology. Structural control may indicate shallow bedrock, and the structure will influence the stability of cuts in rock. Lineaments indicate a local structural feature which may influence the final slope design, probably requiring a shallower angle cut on the weaker rock zone.

In large developments on steep terrain, a more geotechnically economical use of the site can be made by providing a stepped site formation which follows the terrain, rather than a large level formation with very large cuts. The benefits of this approach occur in different ways, for each of the major geological materials occurring on steep terrain:

(i) *Volcanic Terrain*
Weathering depths of less than 15 m are generally noted for steep volcanic terrain in the study area, with rapid transition from weathered to fresh rock. In such terrain, structures can economically be founded at shallow depths and large fresh rock cuts avoided. Where fresh rock cuts are formed, the jointing of the rock may cause some surface ravelling, and net protection or a safety zone may be required to maximize slope angles. Locally persistent or unstable joints may require shallower angled cuts or support measures.

(ii) *Granite Terrain*
Considerable depths of various grades of weathering are encountered in the granitic areas. Large structures founded in this terrain will generally require caisson foundations to bedrock. If large flat site formations are to be created in steep granitic terrain, major cuttings and retaining structures should be provided through a range of weathered rock. The only advantage of this is that shallower caissons can be used, and that extensive flat areas can be created.

The design of cut slopes in less weathered granite (greater than Grade III) may require empirical approximations to model the strengthening influence of boulders. In cuts in fresh rock, sheeting joints are likely to be encountered which require additional support or the draining of water. These local measures enable steep cuts to be made in fresh granite, but the particular form of additional support cannot be determined in advance.

(iii) *Colluvial Terrain*
The creation of extensive cuts in colluvium should be avoided. Aspects of this material affecting stability are noted in Section 3.1.2. Colluvium overlies the insitu rocks in many of the potential development areas. Colluvium has been associated with a number of serious slope failures in the Territory, and there are many instances where local failure has occurred on cuts formed for development platforms on steeper terrain.

D.3.10 *Maintenance of Natural Drainage*

In colluvial areas and in the vicinity of man-made fills, where stability of excavations and slopes is particularly sensitive to water pressure and localised erosion, the pattern of natural drainage should be maintained as far as is practicable.

Diversion of natural drainage, if poorly maintained or of inadequate capacity, may cause overtopping of channels with consequent erosion and infiltration on slopes during heavy rains when stability is most vulnerable. Many streams in the study area carry large amounts of silt from surface wash, which is often deposited on bends or flatter sections of entrainment schemes.

The pattern of subsurface flow beneath any superficial or partly weathered material is unlikely to be affected by most surface water entrainment schemes. Subsurface flows may enter fill in valleys from beneath, even though surface drainage reduces infiltration. It is possible that the fill slope failures at Sau Mau Ping (Government of Hong Kong, 1972 a & b, 1977) were the result of such subsurface flows.

Even in situations where the natural drainage pattern is not significantly altered, an impermeable surface cover such as a large paved area can considerably increase the quantity of surface runoff and reduce the time of concentration. Flooding and consequent infiltration of slopes may become a problem even though, in the natural terrain, it is not the case. Old nullahs located in developing areas are often subject to overtopping in intense rain for this reason.

The natural and post-development hydrology requires careful investigation and design due to their influence on slope stability.

D.3.11 *Site Investigation*

A 'desk study' is a necessary preliminary to any site investigation. The GASP report summarises, interprets and presents much of the information which would be reviewed in a desk study and, in addition, is reinforced by field reconnaissance.

The 1:20 000 GASP Report is designed for use at a strategic planning and engineering feasibility study stage. The GLUM indicates the general level of site investigation envisaged for each class of map unit and is summarised in Table A2. Information on the engineering geological characteristics, the local geological and terrain constraints, and the general suitability of an area is shown on the GLUM, EGM and PCM. Only in determining the engineering feasibility of a large uninvestigated area should a preliminary site investigation be based only on a 1:20 000 GASP Report.

When interpreting the GLUM with regard to site investigation, the following points should be considered:

(*a*) In the study area, extensive site investigation for a range of engineering projects is available. Some of the reports are accessible in the GCO's Geotechnical Information Unit (GIU), and many provide a great deal of the background geotechnical information necessary for a new project.

(*b*) A field reconnaissance of the site and the surrounding area is a necessary preliminary to planning a site investigation. On undisturbed sites, much can be inferred with regard to the strength of underlying materials, the pattern of superficial deposits, and local weaknesses in rock from site observations of the contrasts in landform and the pattern of drainage on and around the site.

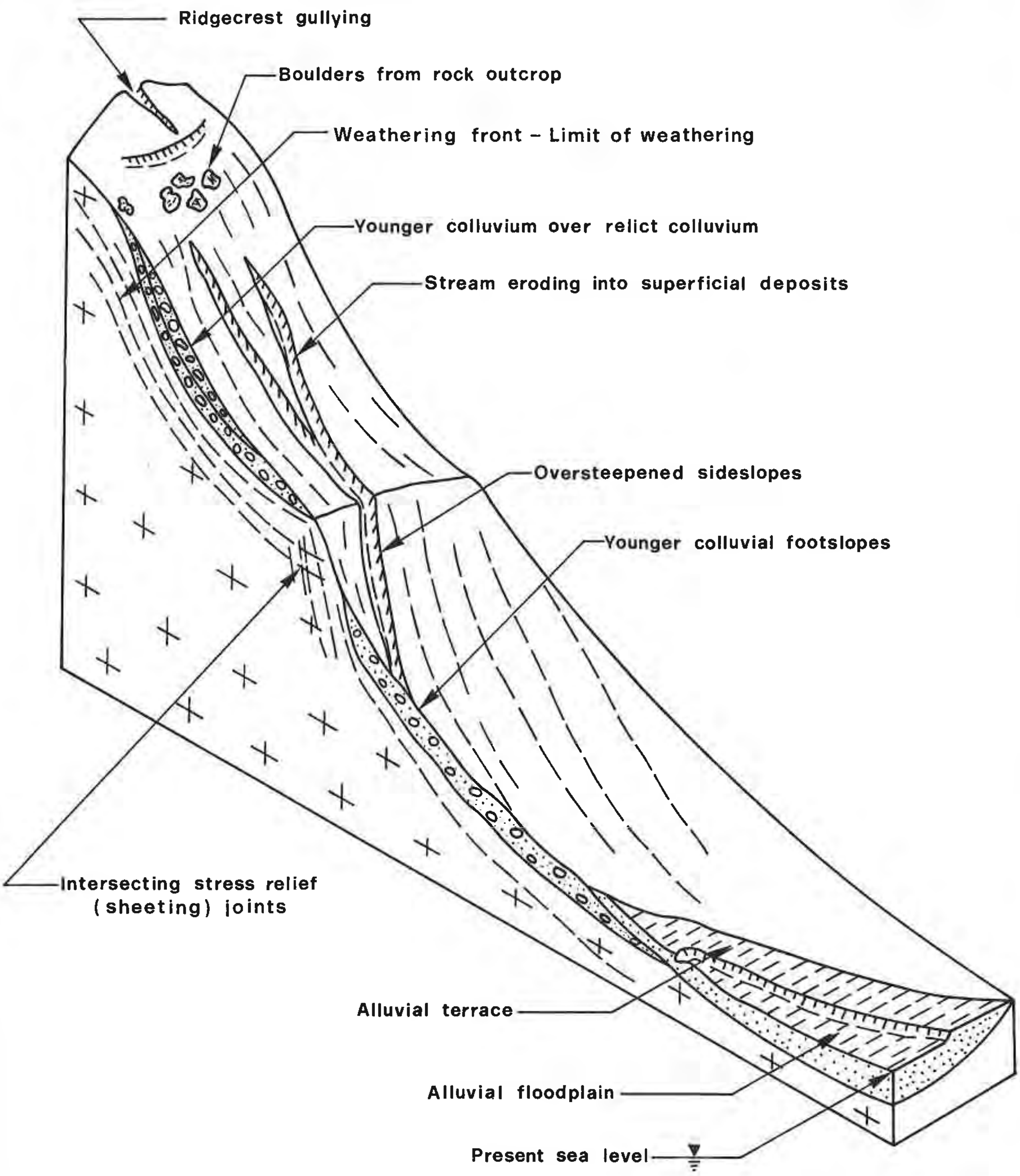
(*c*) The site investigation should be designed to highlight the scope of any available information, the anticipated material, its nature and variability, and the type and form of the engineering project.

D.4 Landform Model of the Terrain in Hong Kong

Landforms are the product of the local balance between weathering, erosion and deposition and are continually evolving. The mechanics of the system and its various components are shown in Figure D1 and described in Appendix D.3.1 (Hansen, 1984 a & b). This section discusses the significance of the sequence of landform evolution to the engineering properties of the materials within the study area. This is achieved in terms of their distribution and thickness. Many of the geomorphological processes act at rates that engineers consider insignificant. However an understanding of the evolutionary system will aid an engineering appreciation of the terrain, because the consequences of slope processes affect the materials with which an engineer constantly deals. Figure D4 provides a simplified hillslope model and relates to the following text.

Slopes that are too steep for the weathered material to remain stable are subject to periodic failure. The magnitude of failure may be isolated and small or catastrophic in nature. Therefore, the recognition of slope process is important in order to highlight the landslip hazard. The origin of many of the oversteepened inland slopes in the Territory lies in the consequences of the fall in sea level that resulted from the growth of the ice sheets during the Pleistocene. During this period, the sea level fluctuated dramatically; there is evidence in southern China that stream incision occurred and produced oversteepened slopes adjacent to the channels. Gradually, the incision progressed inland, taking advantage of structural weaknesses in the underlying geology, with the result that many valleys are narrow with steep sides. The increased rate of erosion removed much of the weathered mantle adjacent to the streams. This, in part, explains the occurrence of shallow weathering depths and slightly weathered bedrock along the floors of many incised valleys in the Territory.

Drainage courses are the main axes of erosion within a valley. The density of drainage pattern responds to and is influenced by the materials and structural control. Incision and removal of material creates over-steepened sideslopes adjacent to the drainage lines by erosion and slope failure. This process continues to induce oversteepening of the terrain, which causes lateral recession of the hillsides. Oversteepening progresses upslope through erosion by instability, as the depth of weathered mantle increases to a limiting value. The terrain on either side of the oversteepened slope section contains different associations of landforms (as shown in Figure D4) as each part of the slope is reacting to a different set of denudational conditions. Below the oversteepened sideslopes, the landforms are comparatively young. Boulders in the colluvium, deposited as a result of landslips and slopewash from the oversteepened slope, are generally unweathered. The oversteepened sideslopes contain many landslip scars, often as recent and relict features, as well as rock outcrops protruding through the thin soils. Above the level of slope oversteepening, the landforms are generally much older. Thus, the spurlines are more deeply weathered and may possess a relict colluvial cover with boulders that are decomposed insitu. In some situations in the study area, younger colluvium overlies older relict deposits. Stream incision occurs at a faster rate than the upslope migration of the oversteepened slopes. This promotes instability adjacent to the stream channels through undercutting. Erosion may result in the exhumation of corestones or boulders which are either distributed across the terrain or are concentrated within drainage lines.



Hillslope Model	Fig. D4

Irregularities in slope profile can also be the result of variations in the resistance to erosion of the underlying rock types. The existence of dykes, faults or more resistant strata are examples. However, these features usually result in a different spatial distribution of landforms and may can be distinguished through the careful use of aerial photograph interpretation and field mapping.

Provided that the debris resulting from the erosion of the oversteepened slope is continually transported away from the slope, instability will continue regardless of changes to the denudational system downslope. If the debris is not removed as fast as it is being deposited, colluvial fans form. If sediment supply decreases or base level is lowered, then incision of the fans results.

With the retreat of the ice sheets at the end of the Pleistocene, the sea level gradually rose. The deepened valleys became sediment traps for the material that was eroded from the sideslopes. Great thicknesses of alluvium (mainly sands and silts with occasional gravel lenses) accumulated, particularly in the lower reaches of the valleys in which there was an abundant sediment supply. Alluvium at the sides of these valleys is interlayered with colluvium deposited by landslips. As both alluvium and colluvium were deposited during the period of lower sea level, they may both exist beneath, as well as intercalating with marine sediments.

APPENDIX E

GLOSSARY OF TERMS

AERIAL PHOTOGRAPH INTERPRETATION

Technique of interpreting data from aerial photographs which are viewed stereoscopically. This method enables the evaluation of the terrain in three-dimensions.

AGGLOMERATE

Pyroclastic rock consisting mainly of fragments greater than 60 mm in diameter; rounded pyroclastics predominate.

ALLUVIUM

Sediment transported and deposited by a river or stream.

ALLUVIAL FAN

Mass of sediments deposited at a point along a river or drainage line where there is a decrease in gradient. The fan is thickest at its point of origin and thins rapidly in a downstream direction.

AQUIFER

Water-transmitting rock or soil. Type aquifers are those which are normally associated with high transmissivity such as sandstone, limestone and chalk and are often used for water supply purposes.

AREA INSTABILITY INDEX

Proportion of a particular area of land which is affected by instability.

ASPECT

Direction in which a slope faces.

BATHOLITH

Large intrusive igneous rockmass.

BEDROCK (=SOLID GEOLOGY)

Insitu rock exposed at the surface or underlying any superficial material such as topsoil, residual soil, alluvium or colluvium.

BLOCKS

Solid pyroclastic fragments greater than 60 mm ejected from volcanoes by volcanic action.

BOMBS

Partially or wholly molten pyroclastic fragments greater than 60 mm ejected from volcanoes by volcanic action. These fragments often acquire distinctive shapes or surface textures during ejection and subsequent transport.

BRECCIA

Rock consisting of coarse grained (>60 mm) angular fragments implying minimal transport of material. Breccias are poorly sorted and commonly contain rock fragments derived from a restricted source. Also see FAULT BRECCIA.

CATCHMENT AREA

Area from which a river or stream collects surface runoff. Often used synonymously with DRAINAGE BASIN.

CHLORITISATION

Replacement by, conversion into, or introduction of chlorite into the rock substance.

CHUNAM

Cement-lime stabilised soil used as a plaster to protect the surfaces of excavations from erosion and infiltration. The recommended mix for chunam plaster, the proportions being measured by weight, is one part Portland cement, three parts hydrated lime and 20 parts clayey decomposed granite or volcanic soil.

COASTAL PLAIN

Terrain component defined as flat terrain lying between the littoral zone and mountain footslopes.

COLLUVIUM

Heterogeneous deposit of rock fragments and soil material transported downslope through the influence of gravity, including creep and local slopewash.

COUNTRY ROCK (=HOST ROCK)

General term applied to rocks penetrated by and surrounding an igneous intrusion.

CUT SLOPE AND CUT PLATFORM

Surface which remains after volume of soil and/or rock has been excavated. Within the terrain classification system, such units with gradients in excess of 5° are cut slopes, while those with gradients less than 5° are cut platforms.

DETRITAL

Term applied to any particles of minerals or, more commonly, rocks which are derived from pre-existing rocks by processes of weathering and/or erosion.

DIP (or TRUE DIP)

Angle of a plane to the horizontal, measured in a direction perpendicular to the strike of the plane.

DIP DIRECTION

Direction or azimuth of dip.

DISCONTINUITY

Interruption, usually of a planar nature, to the homogeneity of a rockmass (i.e. joints, faults). The description and classification of discontinuities is given in the 'Geotechnical Manual for Slopes' produced by the Geotechnical Control Office. (1984).

DISTURBED TERRAIN

Terrain component, defined as land permanently altered from its original state by man. Cut and fill slopes are usually designated as 'disturbed terrain'.

DRAINAGE PLAIN

Terrain component, defined as an area subject to periodic overland flow of water, and within the GASP it is defined as colluvial in nature. It may be an area of spring activity. In some situations, drainage plains may include deeply incised drainage channels.

DURICRUST (=HARD PAN)

Near surface cemented layer occurring in soils or weathered rocks as a result of groundwater action. The cementing agent may be siliceous, calcareous, ferruginous or aluminous.

DYKE

Wall-like body of igneous rock which is discordant, i.e. cuts across bedding or structural planes of the host rock. Usually near vertical. A set of dykes in a parallel or radial pattern constitutes a DYKE SWARM.

EPHEMERAL STREAM

Stream which only flows for short periods of the year.

EROSION

Natural process which involves the wearing away and/or removal of the land surface by the action of a transporting medium or its entrained debris. The agents of transportation can be water, wind or gravity.

FABRIC

Overall appearance of a rock or soil exposure or hand specimen resulting from the combined features of texture and structure.

FAULT

Fracture in rock along which there has been an observable amount of displacement.

FAULT BRECCIA

Assembly of broken fragments formed by crushing or grinding along a fault plane.

FILL SLOPE AND FILL PLATFORM

Surface which is artificially constructed from soil or rubble transported by man. Within the terrain classification system, such units with gradients in excess of 5° are fill slopes, while those with gradients less than 5° are fill platforms.

FLOODPLAIN

Terrain component, defined as a flat area in alluvial terrain which is subject to periodic inundation.

FOOTSLOPE

Terrain component, which is essentially a zone of deposition and which usually occupies a basal position in the terrain. Within the Regional GASP, footslopes are defined as being colluvial in nature.

GENERAL INSTABILITY

Terrain attribute defined for use in 1:20 000 scale GASP mapping to describe areas where large numbers of small landslips or other instability occur.

GEOTECHNICAL AREA STUDIES PROGRAMME (GASP)

Geotechnical study of a specific area by the GCO on the basis of systematic terrain classification using aerial photograph interpretation, fieldwork and engineering assessment.

GEOTECHNICAL LAND USE MAP (GLUM)

Map which delineates the general geotechnical limitations of the terrain for planning purposes.

GULLY EROSION

Terrain attribute, characterised by incised drainage channels formed by the removal of soil or decomposed rock by the surface flow of water.

HILLCREST

Terrain component, which is convex in shape. The terrain surrounding this component falls away in all directions.

HYDROGRAPH

Graph showing the volume of stream (or channel) discharge against time. A 'flashy' hydrograph has a steep rising limb and indicates a very rapid increase of discharge following rainfall.

IGNIMBRITES (=WELDED TUFFS)

Chiefly a fine-grained rhyolitic tuff formed mainly of glass particles (shards), in which crystals of quartz, feldspar and sometimes other minerals are embedded. The glass shards are welded or bent around the crystals, having been viscous when deposited. The glass shards are often devitrified.

INCISED DRAINAGE CHANNEL

Terrain component consisting of the channel and banks of a drainage line. Identification of this feature is largely dependent upon the scale of the survey and scale of the aerial photograph.

INDURATION

Process by which a soft soil or rock material becomes hard. Generally includes hardening by baking, pressure or cementation.

INSITU MATERIAL

Material in original position of formation as opposed to loose, disconnected, transported or derived material.

INTRUSION

Body of igneous rock which has forced itself into pre-existing rocks, either along some definite structural feature or by deformation and cross-cutting of the invaded rock.

LAND CAPABILITY

Capacity or potential of a parcel of land to sustain a particular use.

LANDFORM

General shape and characteristic morphology of the land surface.

LANDSLIP (=LANDSLIDE)

General name for downhill movements of soil or rock involving shear failure. Term is generally restricted to failures in soils. Rock failures are more commonly termed ROCKSLIDES or ROCKFALLS.

LAPILLI

Pyroclastic fragments measuring between 2 and 60 mm ejected from volcanoes by volcanic action.

LENTICULAR COLLUVIUM

Colluvial deposit which is essentially confined by valley sideslopes or is marginal to a natural drainage line. These deposits are usually ribbon shaped features.

LITHOLOGY

General physical character of a rock, including mineral constituents, texture and structure.

LITHOSTRATIGRAPHY

Stratigraphy based only on the physical and petrographic features of rocks (as opposed to a biological or age basis).

LITHOTYPE

Rock defined on the basis of certain selected physical characteristics.

LITTORAL ZONE

Terrain component, defined as the area between the highest and lowest levels of spring tides, i.e. beach.

MANTLE

Weathered rock material overlying fresh rock.

MASS WASTING

General term for the dislodgement and downslope movement of soil and rock material.

MATRIX

Finer grained fraction within a soil or rock containing large particles.

MAXIMUM DRY DENSITY

Density obtained using a specific amount of compaction at the optimum moisture content (British Standard Test: BS 1377).

NATURAL SLOPE

Area of sloping ground substantially unaltered by man.

OUTCROP

Part of a geological formation or rock that appears at the ground surface. The exposure of bedrock or strata projecting through the overlying cover of detritus or soil.

PEGMATITE

Igneous rocks of very coarse texture found usually as dykes or veins associated with a large mass of plutonic rock of finer grain size (e.g. granite).

PERENNIAL STREAM

Stream that flows throughout the year.

PHYSICAL LAND RESOURCES

Physical characteristics of land.

POLYCYCLIC

Many cycles of development.

PYROCLASTIC ROCK

Volcanic rock composed of rock fragments (including molten material and fragments of country rock) explosively ejected from a volcano. TUFF is a general name for consolidated pyroclastic ash.

RECLAMATION

Area of land reclaimed from the sea or other waterbody.

RELICT

Term used to describe remnants of earlier landscapes or surface deposits. Also used to describe traces of lithological features in residual soil.

RESIDUAL SOIL

Soil resulting from the weathering of rock insitu.

RILL EROSION

Terrain attribute characterised by subparallel sets of small narrow channels formed by the concentration of surface runoff.

ROCK EXPOSURE (=ROCK OUTCROP as defined for Terrain Classification)

Discrete area of rock exposed at surface.

ROOF PENDANT

Mass of older country rock forming the roof of a major igneous intrusion (e.g. a granite batholith). On a map, a roof pendant is completely surrounded by the rock of the batholith.

SCREE (=TALUS)

Debris resulting from the mechanical weathering of rock which accumulates at the foot of a cliff or a steep slope.

SESQUIOXIDES

Oxides of iron and aluminium which are generally mobilized as ions in solution by groundwater and which, upon precipitation, often act as the cementing agent in the formation of duricrust.

SHEET EROSION

Terrain attribute, characterised by the removal of the surface layers of soil by wind or water.

SHEETING JOINT

Discontinuity produced by pressure release or exfoliation. Sheeting joints may separate large rock masses, e.g. of granite into tabular bodies or lenses, roughly parallel with the rock surface. Often persistent for large distances and generally following the shape of the landform.

SIDESLOPE

Terrain component, used to describe the terrain between footslope and hillcrest. This terrain unit is usually erosional.

STRIKE

Azimuth of a horizontal line drawn on a bedding plane. Strike is at right angles to the direction of true dip.

STRUCTURE

Relationship between different features (and their causes) in a rock mass or soil, e.g. bedding, jointing, cleavage, faulting, contacts between different lithologies and, in a regional context, the geographical distribution of these features.

TECTONIC

Relating to a period of deformation or mountain building e.g. granite emplacement. Post-tectonic refers to events occurring after a particular deformation period. Syntectonic implies an event taking place coextensively with a definite period of deformation, intrusion, etc.

TERRAIN ATTRIBUTE

Characteristic of the terrain as defined within the terrain classification system. (Refer to Table A1).

TERRAIN CLASSIFICATION

Systematic terrain evaluation based on the use of terrain attributes for the production of a landscape model for engineering or other purposes.

TERRAIN COMPONENT

Geomorphological unit, e.g. hillcrest, floodplain. One of the attributes by which terrain is classified.

TERRAIN EVALUATION

Assessment of an area of ground for engineering or other purposes. The technique of aerial photograph interpretation is used to assess the landscape features.

TEXTURE

Relationship between the grains of minerals forming a rock, mainly in terms of size, shape and arrangement.

TOR

Landform characterised by an elevated pile of rock slabs or loose boulders formed by weathering and erosion of insitu materials.

TUFF

General rock name given to consolidated pyroclastic ash. Tuffs are classified as being essentially vitric (>50% glassy fragments), lithic (>50% rock fragments) or crystal (>50% crystal fragments) in composition, and fine (<0.06 mm), coarse (0.06–2 mm), lapilli (2–60 mm) and breccia (>60 mm) in size.

VOLCANICLASTIC

Clastic rock containing volcanic material in any proportion without regard to its origin or environment.

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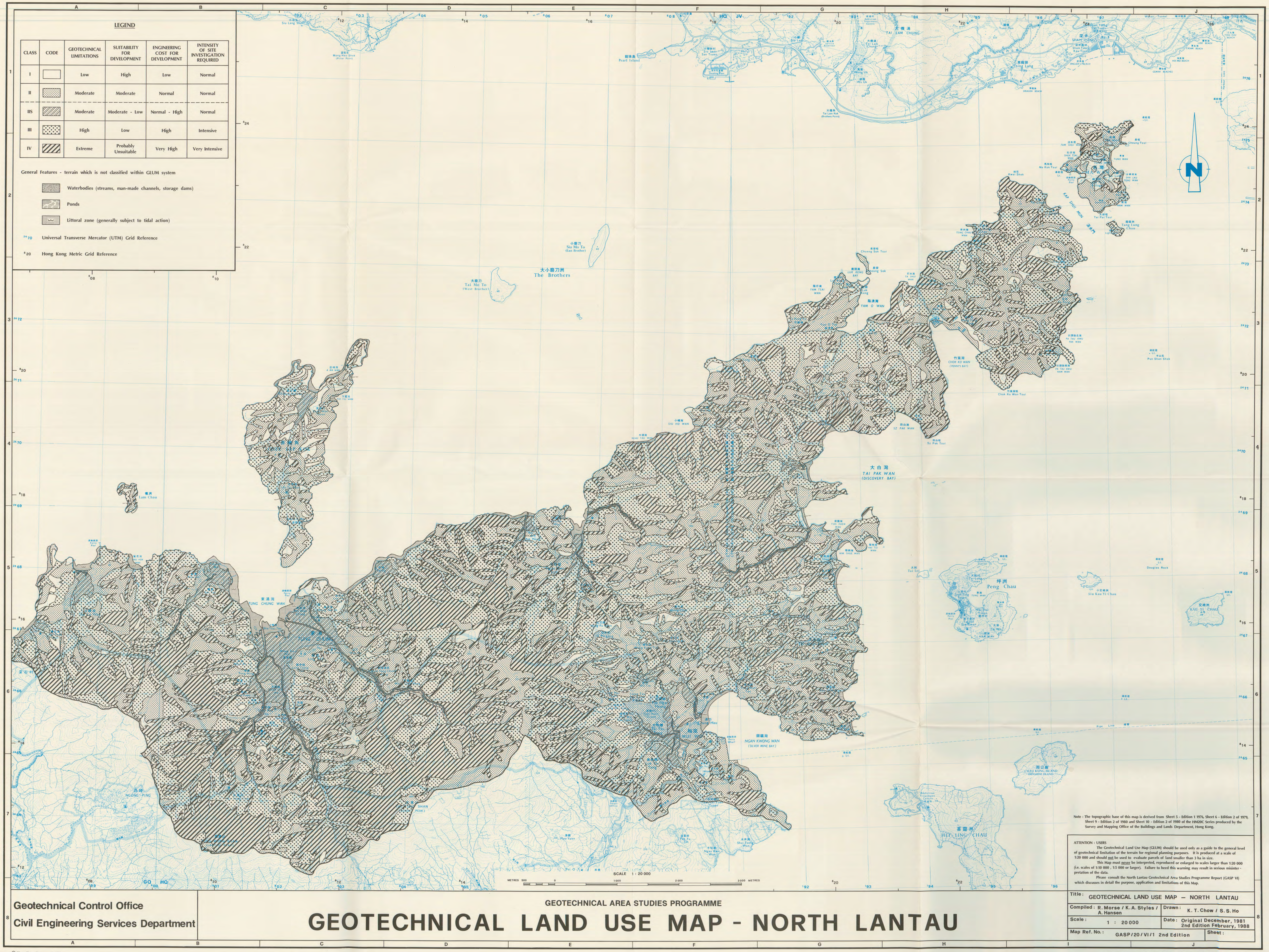

LEGEND

CLASS	CODE	GEOTECHNICAL LIMITATIONS	SUITABILITY FOR DEVELOPMENT	ENGINEERING COST FOR DEVELOPMENT	INTENSITY OF SITE INVESTIGATION REQUIRED
I		Low	High	Low	Normal
II		Moderate	Moderate	Normal	Normal
IIS		Moderate	Moderate - Low	Normal - High	Normal
III		High	Low	High	Intensive
IV		Extreme	Probably Unsuitable	Very High	Very Intensive

General Features - terrain which is not classified within GLUM system

- Waterbodies (streams, man-made channels, storage dams)
- Ponds
- Littoral zone (generally subject to tidal action)

24 70 Universal Transverse Mercator (UTM) Grid Reference

8 20 Hong Kong Metric Grid Reference

Note : The topographic base of this map is derived from Sheet 5 - Edition 1 1976, Sheet 6 - Edition 2 of 1979, Sheet 9 - Edition 2 of 1980 and Sheet 10 - Edition 2 of 1980 of the HM20C Series produced by the Survey and Mapping Office of the Buildings and Lands Department, Hong Kong.

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Please consult the North Lantau Geotechnical Area Studies Programme Report (GASP VI) which discusses in detail the purpose, application and limitations of this Map.

Title : GEOTECHNICAL LAND USE MAP — NORTH LANTAU

Compiled : R. Morse / K. A. Styles / A. Hansen

Drawn : K. T. Chow / S. S. Ho

Scale : 1 : 20 000

Date : Original December, 1981; 2nd Edition February, 1988

Map Ref. No. : GASP/20/VI/1 2nd Edition

Sheet :

Geotechnical Control Office
Civil Engineering Services Department

GEOTECHNICAL AREA STUDIES PROGRAMME

GEOTECHNICAL LAND USE MAP - NORTH LANTAU

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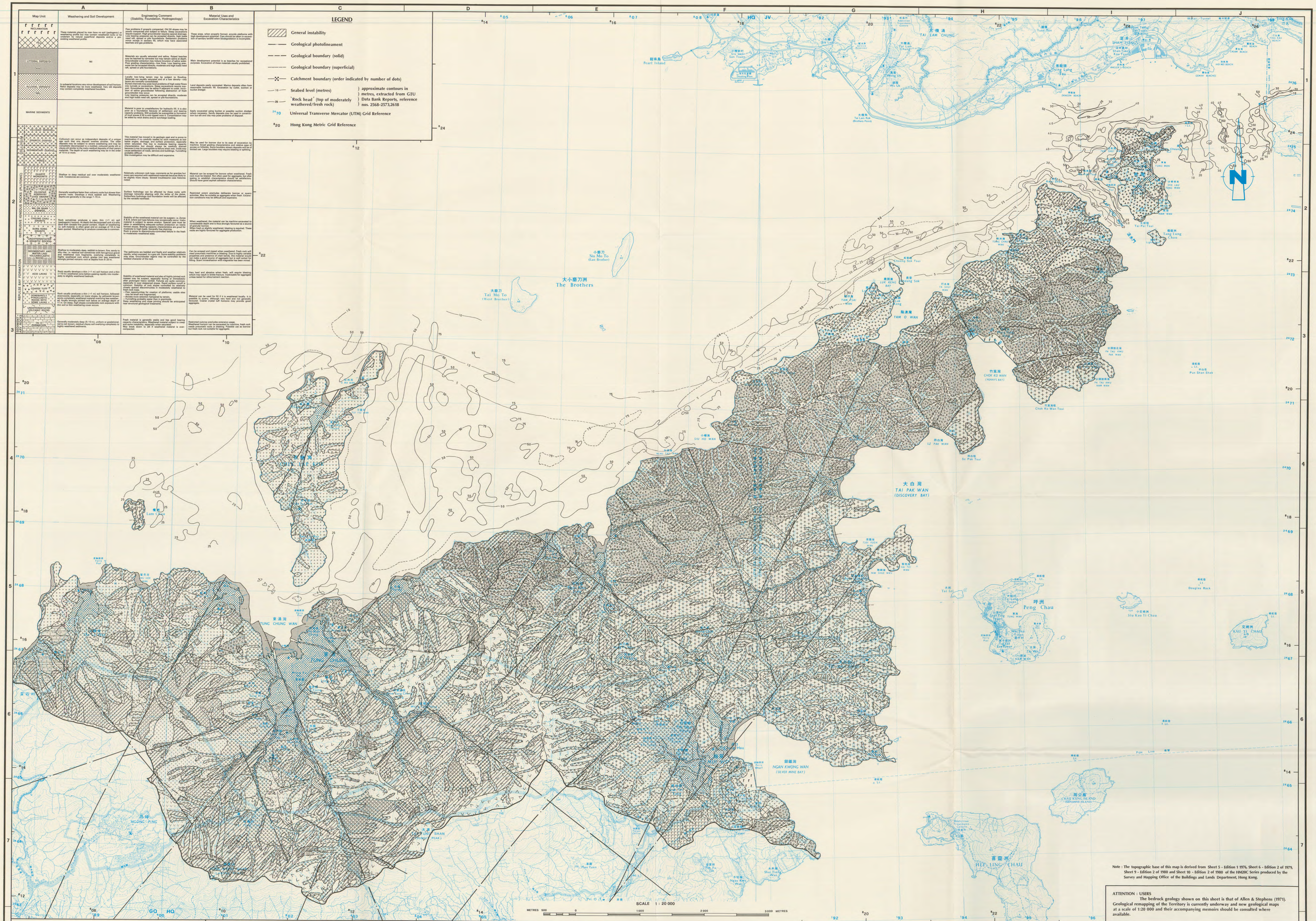

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The bedrock geology shown on this sheet is that of Allen & Stephens (1971). Geological remapping of the Territory is currently underway and new geological maps at a scale of 1:20 000 and their accompanying memoirs should be consulted where available.

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GEOTECHNICAL AREA STUDIES PROGRAMME

ENGINEERING GEOLOGY MAP - NORTH LANTAU

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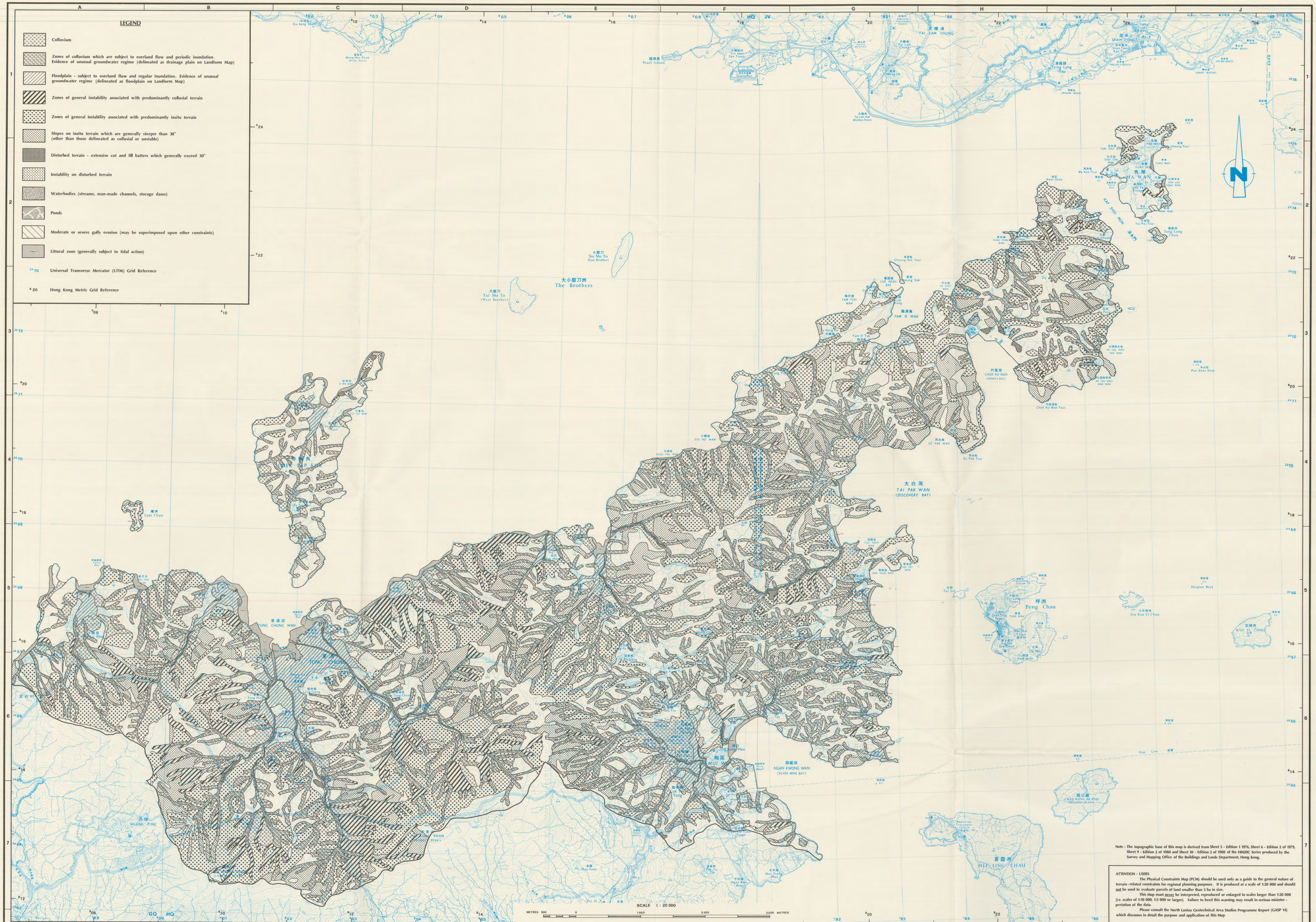

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Please consult the North Lantau Geotechnical Area Studies Programme Report (GASP VI) which discusses in detail the purpose and application of this Map.

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PHYSICAL CONSTRAINTS MAP - NORTH LANTAU

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