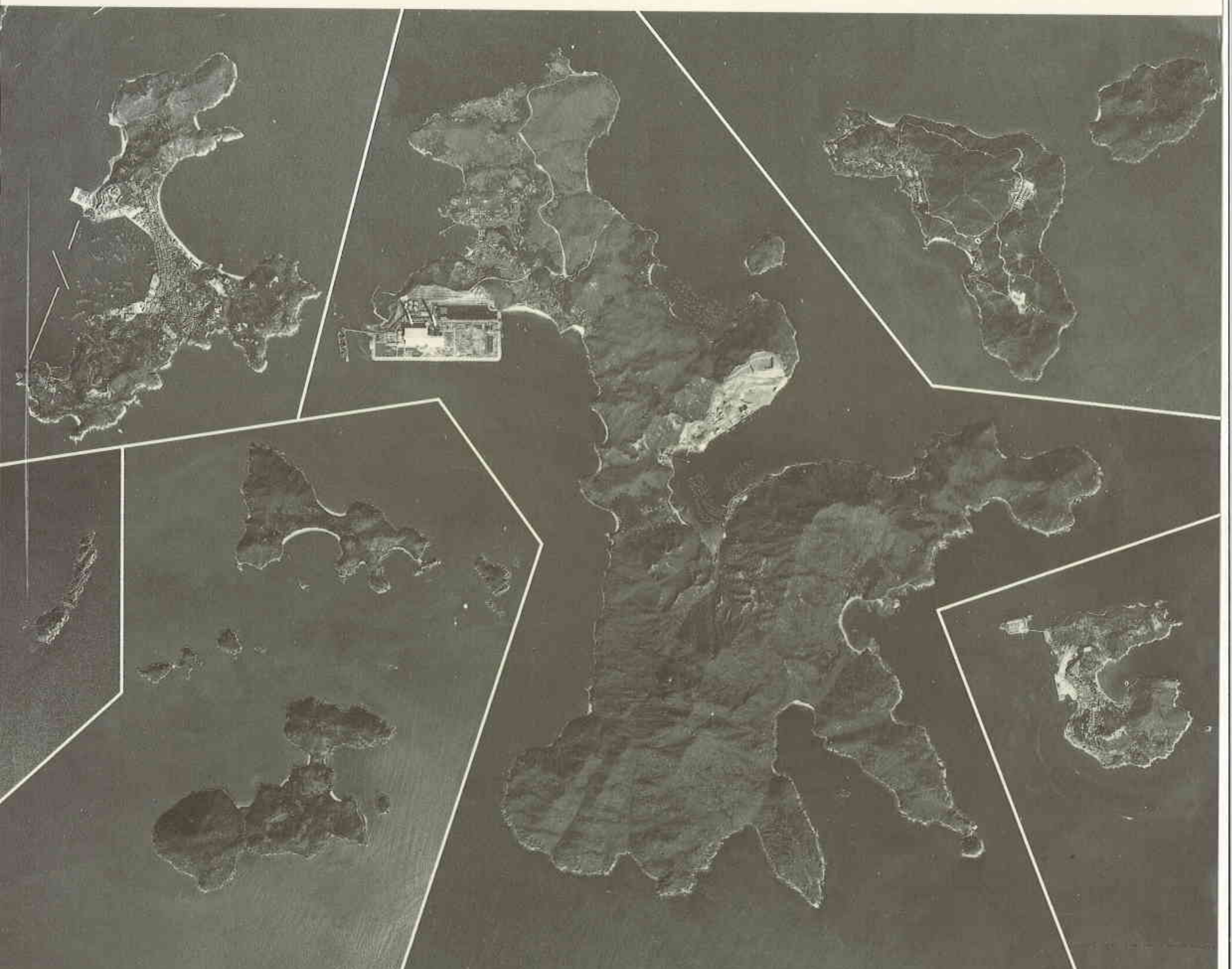
Geotechnical Area Studies Programme

GASP Report X

Islands



Geotechnical Control Office
Civil Engineering Services Department
Hong Kong

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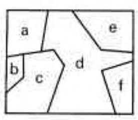
Cover photograph: vertical aerial photographs of the main islands in the southern part of the Territory



a. Cheung Chau
b. Waglan Island
c. Soko Islands
d. Lamma Island
e. Hei Ling Chau & Sunshine Island
f. Peng Chau

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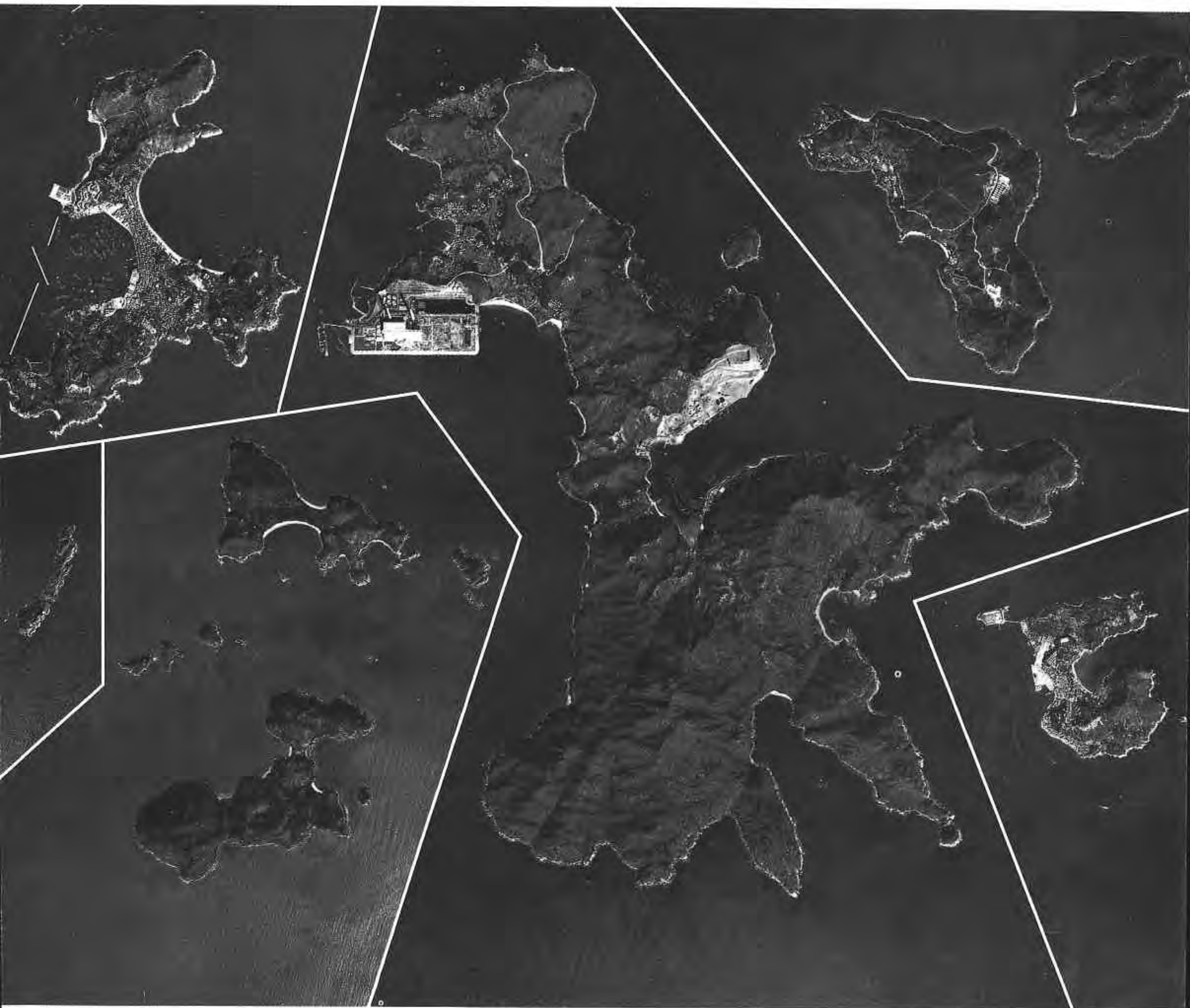

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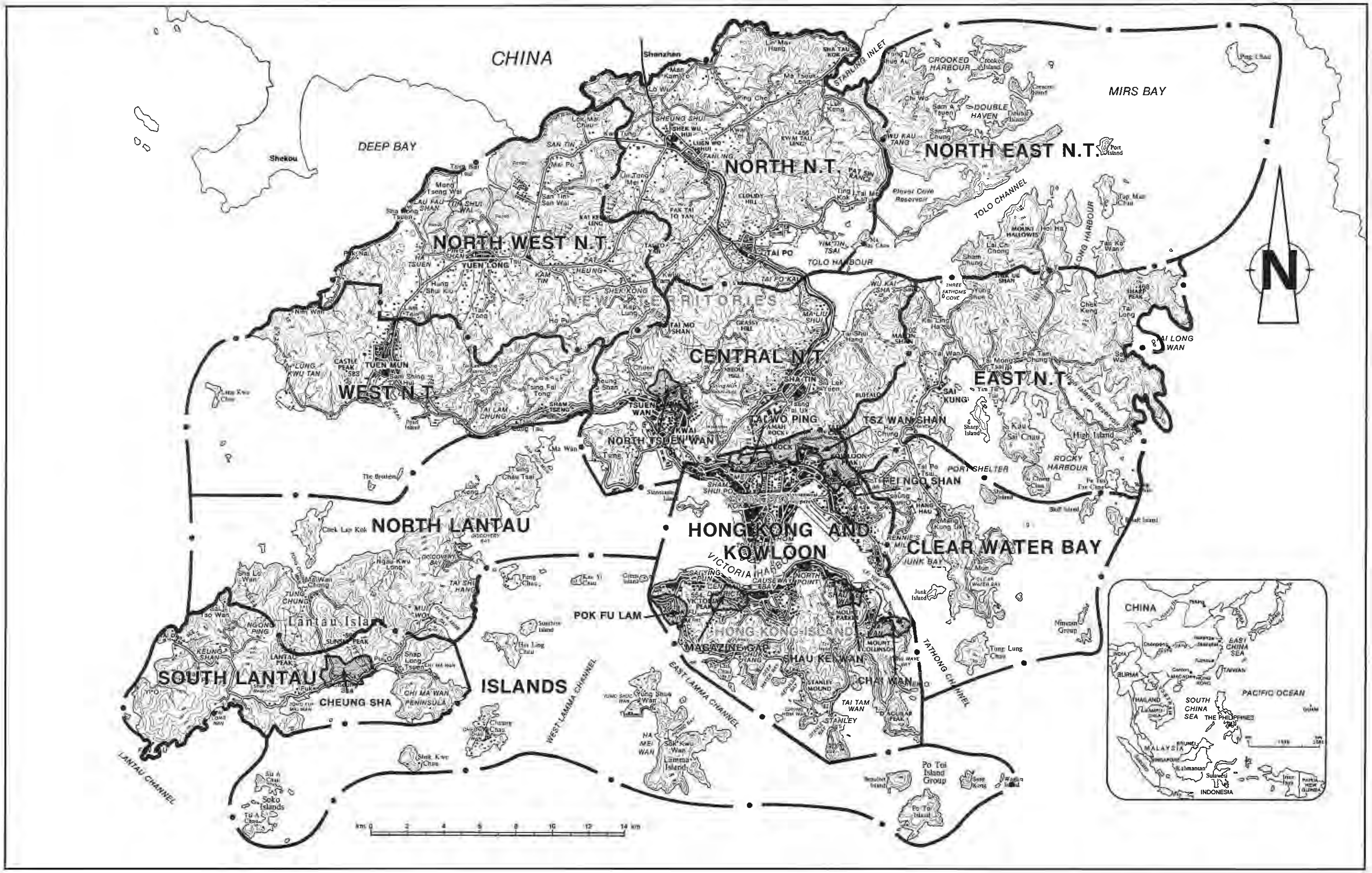

Map of the Territory of Hong Kong Showing the Locations of the Geotechnical Area Studies.
(Boundaries of the Regional Studies are shown by dashed lines and locations of District Studies are indicated by dark screens)

FOREWORD

This Report aims to provide an adequate geotechnical basis for the planning and land use management of the Islands Area, mainly by way of information presented on a series of maps at a scale of 1:20 000. It is the tenth 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 seven user-oriented maps. Four of these are supplied with this published Report—the Engineering Geology Map (EGM), Geotechnical Land Use Map (GLUM), Physical Constraints Map (PCM), and Generalised Limitations and Engineering Appraisal Map (GLEAM). The GLUM classifies the terrain into four classes according to the level of geotechnical limitations, the PCM presents the major physical constraints that are likely to influence development, and the GLEAM delineates broad areas with potential for development from the geotechnical and planning points of view. In addition to the four 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 make reference to the new 1:20 000 scale Hong Kong Geological Survey Maps and Memoirs which are being prepared by the Geotechnical Control Office. These provide more up to date geological information than is available in this Report. The Geological Map which covers Lamma Island, Lo Chau (Beaufort Is) and part of Po Toi, together with the accompanying Memoir, has recently been published (Geotechnical Control Office, 1987; Strange & Shaw, 1986). The maps and memoir for the remaining areas will be published by 1991.

This Report was originally produced in June 1986, for use within the Hong Kong Government on the basis of information assembled during the period October 1984 to July 1985. 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 Messrs J. M. Nash, A. Hansen, 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.

Acknowledgements are 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
November 1988

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1. INTRODUCTION

1.1 The Islands Geotechnical Area Study

This Report presents the results of a 1:20 000 scale Regional Geotechnical Area Study of the Islands area which was carried out in the Geotechnical Control Office between October 1984 and July 1985. The area covered by the study, which is designated as GASP X, 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. A new map which covers part of the area dealt with in this GASP Report (Geotechnical Control Office, 1987), and the accompanying Memoir (Strange & Shaw, 1986) are available. The maps and Memoir for the remaining area will be published 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 tenth of the Reports to be published; two more will follow. A number of District Studies: Stage 1 have been carried out, and whilst these District Study: Stage 1 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 Appendices A and C.

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 the Islands area. A detailed description of the Allen & Stephens (1971) geological units is provided in Appendix C.

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 the suitability for development of various parts of the study area from an engineering point of view.

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 20 are extracts from the set of maps. The full size originals of these maps are held by the Geotechnical Control Office.

A selection of photographs follow the example figures and these are presented as Plates 1 to 24. 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 geology along with information on site investigations, aerial photographs and rainfall relevant to the Islands 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), the Engineering Geology Map (EGM) and the Generalised Limitations and Engineering Appraisal Map (GLEAM) 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.

Currently, there are seven conventional line maps produced at a scale of 1:20 000 for each 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.10.

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 19a.

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 20a.

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 *Generalised Limitations and Engineering Appraisal Map (GLEAM)*

This map is prepared by an assessment of the terrain information recorded in the Terrain Classification Map, GLUM, PCM, EGM and current land management. This map evaluates the engineering-related factors which influence the potential of the terrain for future development. Areas with potential are identified at a scale of 1:20 000. The GLEAM is designed for technical and non-technical users who require information relating to the engineering suitability of the terrain for development. An example of the map is presented in Figure 18a, and a detailed discussion is provided in Section 4.2 and in Appendix A.9. A copy of the map is located in the Map Folder.

1.5.9 *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
GLEAM*	Fundamental	Fundamental	Fundamental	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 Study: Stage 1 Programme are available for areas within the Territory. No District Studies: Stage 1 have been completed within the Islands study area.

2. DESCRIPTION OF THE ISLANDS STUDY AREA

2.1 Geographical Location

The study area consists of some thirty islands of varying sizes, located to the west, south and southeast of Hong Kong Island. The total study area is 3 184 ha. The largest island is Lamma Island (Pok Liu Chau) which occupies a central position in the study area, whilst the Po Toi and Soko groups form the eastern and western flanks respectively (Figures 1 to 3). Only the three islands of Lamma, Peng Chau and Cheung Chau have major centres of population. Much of the remaining land consists of generally undisturbed terrain. The Islands study area has common boundaries with North Lantau (GASP VI), Central New Territories (GASP II), Hong Kong & Kowloon (GASP I), and South Lantau (GASP XI). Table 2.1 provides a list of the major islands in the study area.

Table 2.1 Major Islands in the Study Area

Island	% of Total Area	Hectares
Lamma Island	45.6	1 453
Po Toi Island	12.5	398
Cheung Chau	8.7	278
Hei Ling Chau	6.4	204
Tai A Chau	4.4	139
Lo Chau	4.2	135
Shek Kwu Chau	4.2	135
Peng Chau	3.7	116
Siu A Chau	2.7	86
Sunshine Island	2.0	63
Sung Kong	1.9	59
Kau Yi Chau	0.9	29
Green Island	0.5	16
Waglan Island	0.4	14
Luk Chau	0.4	12
Other small unnamed islands	1.5	47

2.2 Topography

The Islands within the study area can be divided into five groups. The topographic features of the groups are described.

(i) *Peng Chau to Cheung Chau Group*
This group contains Shek Kwu Chau, Cheung Chau, Hei Ling Chau, Peng Chau, Kau Yi Chau and a number of smaller islands. Peng Chau and Cheung Chau are relatively low-lying with gentle slopes and rounded topography. This factor, together with protected anchorages, probably accounts for their early and continued settlement. The remaining islands exhibit steep slopes rising from the sea. The highest point is 183 m on Hei Ling Chau, with a similar elevation on Shek Kwu Chu.

(ii) *Lamma Group*
This group consists of Lamma and its satellite island Luk Chau (George Island). Lamma Island is geographically divided by the inlet of Picnic Bay. Terrain to the south of the bay is generally higher and more dissected than that to the north. Mount Stenhouse reaches an elevation of 353 m, Ngai Tau, at the eastern extremity of the island, reaches a height of 148 m. The general relief of the southern portion of Lamma is rugged with several large coastal inlets and a rocky coastline, especially on the western side.

(iii) *Soko Group*
This remote group of twelve islands reaches maximum elevations of 140 m on Tai A Chau and 119 m on Siu A Chau, the two largest islands of the group. The Soko Islands have a generally rugged indented coastline with steep slopes rising from sea level.

(iv) *Sung Kong to Waglan Island Group*
These small and remote islands exhibit rugged rocky terrain rising to maximum elevations of 140 m on Sung Kong Island and 57 m on Waglan Island.

(v) *Po Toi Group*
This group includes the small islands of Castle Rock, Mat Chau and the two main islands of Beaufort Island (Lo Chau) and Po Toi. Beaufort Island exhibits steep uniform slopes rising to a maximum elevation of 270 m. The terrain on Po Toi Island is more dissected, with elevations of 152 m in the west and 244 m in the east.

2.3 Geology

2.3.1 *General*

In simple terms, the regional geology of the study area consists of mainly intrusive igneous rocks of the granitoid suite, associated dyke rocks and veins, and a limited sequence of volcanic rocks of the Repulse Bay Formation. The granitoid rocks are representatives of several phases of intensive orogenic activity which probably occurred during the Upper Jurassic Period.

The study area is structurally quite simple, although it is traversed by numerous geological photo-lineaments. Two major photo lineament orientations are apparent, with the dominant trend in a northeast to southwest direction and the second lineations orientated normal to the main trend.

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, 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 1:20 000 scale, geological maps which will result in a more precise definition of the distribution of the geological units within the Territory. A portion of the study area has already been remapped as part of the revised Geological Survey of Hong Kong (Geotechnical Control Office, 1987; Strange & Shaw, 1986), and remaining maps and Memoir No. 6 will be published by 1991.

As a precursor to the geological remapping programme, Bennett (1984 a, b, c) reviewed the superficial deposits, weathering, stratigraphy, tectonic history and metamorphism in the Territory. Further general geological information has been presented by Atherton & Burnett (1986) and Brand (1985). From an historical viewpoint, Davis (1952) is still 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, and their occurrence is 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 nature of the individual rock types is summarised below, their distribution is tabulated in Appendix B, and further geological descriptions are given in Appendix C. Their general engineering behaviour and planning significance are discussed in Section 3.1, and summarised in Table 3.1.

2.3.2 *Volcanic and Volcaniclastic Units*

Volcanic and volcaniclastic rocks of the Repulse Bay Formation occupy large portions of the northern part of Lamma, the eastern part of Kau Yi Chau, and Green Island. The rocks consist of a succession of tuffs and welded tuffs. Unassigned rocks of this Formation are probably of pyroclastic or volcaniclastic origin. The Formation is divided by Allen & Stephens (1971), on the basis of seven major lithotypes, only two of which occur in the study area.

(i) *Coarse Tuff (RBc)*
These rocks form well-developed strata of coarse-grained crystal tuff, sometimes containing volcanic ejecta. The largest outcrop is in the northern portion of Lamma Island. Outcrops also occur on Kau Yi Chau. These rocks occupy 6.3% (202 ha) of the study area.

(ii) *Undifferentiated Volcanic Rocks (RB)*
These rocks consist of unassigned members of the Repulse Bay Formation. Outcrops of pyroclastic or volcaniclastic origin occur on northern Lamma and on Green Island. These rocks occupy only 0.4% (14 ha) of the study area.

2.3.3 *Intrusive Igneous Units*

The igneous rocks, which intrude the volcanic suite, are divided by Allen & Stephens (1971) on the basis of lithology, age and intrusive relationship.

(i) *Tai Po Granodiorite (XT)*
This is the oldest intrusive unit and outcrops in the central part of Lamma Island, west of Picnic Bay. The rocks are dark-coloured and medium to coarse-grained. Weathering profiles may be deep. This unit occupies 0.5% (16 ha) of the study area.

(ii) *Sung Kong Granite (SK)*
The Sung Kong Granite is typically medium to coarse-grained and is pale grey or pink in colour. This granite is quite evenly distributed throughout the study area, occupying approximately 24.8% (790 ha) of the area.

(iii) *Cheung Chau Granite (CC)*
This unit occurs mainly in the Southern part of the study area and forms Cheung Chau and a major portion of Shek Kwu Chau and southern Lamma. Outcrops also occur in the Po Toi Group. The unit occupies 33.5% (1 065 ha) of the study area and consists of grey to pink, coarse-grained, sometimes porphyritic rock.

(iv) *Ma On Shan Granite (MS)*
The Ma On Shan Granite is essentially a fine-grained porphyritic granite and is generally pink to mauve in colour. Metasomatic mineralization is often associated with this rock unit. Ma On Shan Granite occupies 9.4% (300 ha) of the study area, predominantly in the eastern islands.

(v) *Fan Lau Porphyritic Granite (FL)*
This unit is restricted to the Soko Islands and occupies only 0.7% (22 ha) of the area.

(vi) *Feldspar Porphyry Dyke Swarm (La)*
This unit is restricted to the west and centre of the study area, and occurs in a southwest to northeast trending belt. These rocks occupy 10.6% (337 ha) of the study area.

(vii) *Quartz Monzonite and Porphyritic Adamellite (Mo)*
This unit is found predominantly in the central part of the study area, and outcrops mainly on Lamma Island. The rock is dark-coloured and medium-grained. This unit occupies 2.4% (76 ha) of the study area.

(viii) *Granophyric Microgranite (Mc)*
This fine-grained rock unit forms the eastern part of Green Island and occupies less than 0.1% (2 ha) of the study area.

(ix) *Undifferentiated Granite (G)*
These rocks consist of unassigned units of granite, and form the southern part of Peng Chau. This unit occupies 0.9% (28 ha) of the study area.

(x) *Dyke Rocks and Veins*
Several types occur in the study area as linear outcrops, but are not identified within the GEOTECS system due to their small size. Dyke rocks and veins occurring in the study area are: quartz porphyry, porphyritic microgranodiorite, dolerite, quartz monzonite, porphyritic adamellite, composite dykes and quartz veins.

In total, the intrusive igneous rocks outcrop across 2 636 ha, and cover approximately 83% of the area.

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

2.3.4 *Superficial Units*

In addition to the solid geology, both natural and man-made superficial deposits cover 10.4% of the study area. Man-made superficial deposits, such as fill and reclamation, are of limited extent because there is relatively little urban development in the study area.

(i) *Colluvium*
This material occurs on 114 ha (3.5%) of the study area. Colluvial deposits are formed by gravity transport of rock and soil debris downslope. It occurs as recent or relict deposits and is heterogeneous in its physical characteristics. In the study area, two basic types of colluvium occur, these are subdivided on the basis of parent rock type.

(*a*) Volcanic colluvium (Cv)—This material occurs predominantly as bouldery deposits in drainage channels. This unit occupies 0.4% (14 ha) of the study area. The major deposits are on the northern part of Lamma Island.

(*b*) Granitic colluvium (Cg)—Most of the study area consists of rocks of granitic origin; consequently, the major colluvial deposits are derived from granites. The material generally occurs as valley-floor deposits, and occupies 3.1% (100 ha) of the study area.

(ii) *Alluvium (A)*
The topography and surface hydrology of many of the islands preclude the development of alluvial deposits. The only sizeable development of alluvium is on Lamma Island where streams drain onto gently sloping to flat coastal terrain. Alluvium occupies 1.7% (53 ha) of the study area.

(iii) *Littoral Deposits (L)*
These deposits consist of fine to medium-grained coastal sands and gravels. Littoral deposits occupy 1.0% (33 ha) of the study area.

(iv) *Raised Beach Deposits*
Deposits of sand and gravel form slightly raised areas adjacent to existing beaches on several of the islands. The largest occurrences are on Cheung Chau and Peng Chau, where sandy deposits form a narrow isthmus. Raised beach deposits occupy 0.7% (22 ha) of the area.

(v) *Marine Deposits (M)*
These deposits occur on the sea bed and consist of a repetitive sequence of soft marine muds and shelly sands with occasional lenses of coarser-grained material. There is evidence that a complex sequence of marine deposits, related to sea level change, occurs in the Territory.

(vi) *Reclamation*
Reclamation is fairly limited within the study area, the largest area being associated with the Lamma Power Station. Materials used in reclamation may be extremely variable and include weathered and fresh representatives of any rock group. Reclamation occupies 2.9% (92 ha) of the study area.

(vii) *Fill*
The engineering behaviour of fill material depends generally on the degree of compaction during placement, the nature of the original material, and subsequent densification due to settlement. Fill may be variable in nature and consists of any of the geological materials as well as domestic and industrial waste. Fill occupies some 0.6% (18 ha) of the area.

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

2.3.5 *Structural Geology*

The study area consists mainly of rocks of intrusive igneous origin, with some representatives of the older Repulse Bay Formation.

There are two main regional structural trends present within the study area. These are:

(i) *North to Northeast Trending Fault and Structural Lineament Zone*
These structural elements are termed 'Neocathaysian' (Lai, 1977; Burnett & Lai, 1985)

(ii) *East to West Trending Fault Zone*
An east to west trending set of faults, lineations and folds, occurs with associated igneous intrusions such as the Quartz Monzonite.

These structural elements produce an interlocking system of faults, resulting in discrete fault blocks.

Numerous geological photolineaments are evident on aerial photographs. Most of the photolineaments are probably normal faults or major joint trends which result in a line of structual weakness. The distribution of photolineaments and faults is shown on the Engineering Geology Map (EGM).

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 is, of course, being updated by the revised geological mapping (Geotechnical Control Office, 1986). A detailed description of the rock units is presented in Appendix C.

2.4 Geomorphology

2.4.1 *General*

The geomorphology of the 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.

The islands generally exhibit a ria coastline typified by deep, steep-sided inlets and bays, and a generally indented sea-board. This section describes the general geomorphology of the area and classfies the terrain into six provinces. These are mountainous and sideslope, lowland, coastal, colluvial, alluvial and tombolo.

Table B5 in Appendix B provides data on the distribution of the major landform units. The distribution of slope gradients is illustrated in the GEOTECS Plot, Figure 5.

The various geological materials weather, erode or are deposited in different ways. The regional geomorphology can therefore be described in subdivisions, relating terrain type to either bedrock geology or superficial materials. These basic subdivisions refer to granitic, volcanic, colluvial and alluvial terrain.

2.4.2 *Mountainous and Sideslope Terrain*

Much of the terrain forming the smaller islands and a large proportion of Lamma and the Poi Toi Group, consists of ridgecrest, steep sideslope and deeply dissected landforms produced by stream downcutting along lines of structural weakness. Instability is apparent on many of the moderate to steep sideslopes, especially where weathering profiles are deep. Small areas of low slope gradient occur in the more elevated terrain.

2.4.3 *Lowland Terrain*

Areas of low relief exist as small hills and spurlines of rounded topography. These usually occur downslope of mountainous and steep sideslope terrain. The islands of Cheung Chau and Peng Chau are areas of essentially moderate relief with gentle slopes and rounded topography. Deep weathering is common, and soils are often susceptible to erosion. Instability may be a problem in terrain affected by gully erosion or on cut slopes.

2.4.4 *Coastal Terrain*

The coastal terrain generally consists of short steep slopes which are often subject to high rates of erosion and coastal instability. As a result there are many areas of rock outcrop. Rocky headlands are common, especially on the exposed seaboards of the islands. The numerous embayments and inlets are the result of a relative rise in sea level during the past 10 000 years, and are typical of a ria coastline.

2.4.5 *Colluvial Terrain*

Colluvium exists as minor deposits on footslopes and on many of the valley floors. It occurs below steep slopes and ridges. Bouldery colluvium is present in many of the stream lines, but is well developed only on Lamma Island which, due to its large size, exhibits a more extensive drainage pattern than the smaller islands.

2.4.6 *Alluvial Terrain*

Alluvial terrain is relatively uncommon in the study area. The short length of streams and their often uniform hydraulic gradients, reduce the incidence of alluvial deposits except in small areas near the sea (Plate 5). This terrain is flat or gently sloping, and is best developed on Lamma Island between Sham Wan and Shek Pai Wan, and east of Yung Shue Wan.

2.4.7 *Tombolo Terrain*

Many of the hills which form the cores of the islands are linked by narrow, low ridges of sands and cobbles, known as tombolos. Built up as raised or storm beach deposits in the protected area between the bedrock mounds, these landforms are of significance in the islands because they provide terrain for development. The central necks of land on Peng Chau and Cheung Chau are examples that are utilised for development.

2.5 Hydrology

2.5.1 *Surface Hydrology*

Coastal drowning and the small size of most of the islands in the study area, produce streams of short length, small catchment area and low order (Strahler, 1952). The larger size of Lamma Island results in longer streams and a more complex drainage network with some third and fourth order catchments. The smaller islands are characterised by mainly first and second order streams forming a radial network draining from high ground. Very little stream training or artificial drainage measures are present within the study area.

2.5.2 *Groundwater Hydrology*

Groundwater flow through the granite and volcanic rocks is generally by some form of conduit or fissure flow. This occurs along sheeting or tectonic joints and in zones shattered by faulting. Groundwater flow in the superficial deposits and residual soils may be within conduits such as soil pipes, or along boundaries between soil types. It can also be intergranular in nature (Nash & Dale, 1983). Flow may also occur along old buried stream courses. Low-level alluvial deposits often have high groundwater tables.

The predominantly granitoid rocks of the study area cannot generally be regarded as constituting aquifer units; however, the low-lying superficial deposits may provide a limited supply of groundwater. Extraction of groundwater on low-lying coastal terrain may lead to saline intrusion.

Within the study area there are approximately 114 ha of colluvial footslope terrain which may be affected by soil piping and tunnel erosion.

2.6 Vegetation

In this report, a nine class system is used to distinguish the broad categories of vegetation. The spatial distribution of these groups is illustrated in the GEOTECS Plot, Figure 7, whilst Figure 4 shows their relative distribution.

The natural vegetation of this area has been successively modified by man and numerous exotic species have been introduced in addition to the large number of indigenous tropical and sub-tropical species. The data is presented in Table B7 in Appendix B.

The vegetation classes are:

(i) *Grassland*
This class generally consists of indigenous and introduced grass species, which often occupy cleared shrub or woodland. Grassland occupies 16.1% (514 ha) of the study area and occurs as scattered patches, normally on terrain with fairly high relief, especially on Lamma Island.

(ii) *Cultivation*
This group occupies 4.6% (145 ha) of the study area. Intensive horticulture is practised on some of the more densely populated islands such as Peng Chau and Cheung Chau.

(iii) *Shrubland (Less than 50% Ground Cover)*
Shrubland occurs as regrowth on areas of disturbed terrain or in areas regenerating after damage by hillfires. This group occupies 17.8% (565 ha) of the study area and occurs in large tracts of the middle and upper slopes, especially in the less developed parts of the islands.

(iv) *Shrubland (Greater than 50% Ground Cover)*
Similar to (iii) but with denser cover, indicating greater maturity and a longer period of colonisation. This class occupies 24.8% (790 ha) of the study area and generally occupies middle and upper slopes.

(v) *Mixed Broadleaf Woodland*
This group occupies 5.4% (174 ha) of the study area and covers extensive tracts of valley and lower to mid slopes. This group of vegetation is probably the indigenous vegetation of this part of the South China coast.

(vi) *No Vegetation on Natural Terrain*
This is usually the result of erosion, and affects 4.4% (139 ha) of the study area.

(vii) *No Vegetation on Disturbed Terrain*
This group is normally associated with urbanisation, and occupies 11.7% (371 ha) of the study area.

(viii) *Rock Outcrop*
Areas which predominantly consist of rock outcrops occur on approximately 15.2% (484 ha) of the terrain.

(ix) *Waterbodies*
Approximately 2 ha of the study area is used for water storage.

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. The majority of the erosion observed on the natural terrain is either associated with minor disturbance by man (footpaths triggering gullying) or with minor gullying related to 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 and dense shrub ground cover, rather than the more open woodland associated with native stands. The 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 successfully used 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 displaying '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 those affected by slope instability on the Engineering Geology Map. A summary of the distribution of erosion and instability is given in the pie charts in Figure 4, tabulated in Tables 2.1 and B2 in Appendix B, and illustrated in the GEOTECS Plot, Figure 8.

Erosion and instability affect 49.8% (1 586 ha) of the study area. However, approximately 9.3% (300 ha) of the study area is currently developed, within which, erosion is restricted to unprotected platforms and slopes. Approximately 540 ha of natural terrain is subject to erosion.

Table 2.1 Erosion and Instability

Erosion		% of Total Area	Area (ha)
Instability			
—well-defined landslips		0	0
—coastal instability		9.3	296
—general instability		21.6	688
Appreciable Erosion	Sheet erosion	13.0	415
	Rill erosion	1.9	61
	Gully erosion	4.0	126
No Appreciable Erosion*		50.2	1 598
		100.0	3 184

* Approximately 2 ha of water storage are included within No Appreciable Erosion.

2.7.2 *Erosion*

(i) *Sheet Erosion*
This form of erosion produces extensive areas of bare ground devoid of vegetation. Within the study area, extensive areas of sheet erosion occur on slopes and ridgelines, especially on the coarse-grained granites. Erosion is often exacerbated by the development of footpaths which concentrate run off. Sheet erosion occupies 13.0% (415 ha) of the study area.

(ii) *Rill Erosion*
This form of erosion results from the erosion of loose soil particles by overland flow which has become concentrated into small channels. It commonly occurs on cut slopes in decomposed rock and on fill slopes with inadequate surface protection (Geotechnical Control Office, 1984 p. 118). On areas of natural ground, rill erosion forms in similar locations to sheet erosion. It is characterised by numerous subparallel drainage rivulets which produce a striated appearance and result in significant soil loss. This type of erosion often develops on slopes devegetated by hillfires. Within the study area, rill erosion affects some 61 ha of terrain.

(iii) *Gully Erosion*
This form of erosion, produced deep dissection of the land surface with consequent disruption of drainage lines, may result in tunnel erosion, soil piping and precipitate instability (Plate 1). Gully erosion affects 4.0% (126 ha) of the study area.

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 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 these features are often too small in comparison with the size of the basic mapping unit. Therefore, where a large number of small landslips or other evidence of instability occurs 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 984 ha of the terrain displays some form of instability, and this represents 30.9% of the study area.

(i) *Well-defined Landslips*
None of these features are mapped within the study area. The landslips which occur are smaller than the 1 ha, which is the minimum size required for delineation at 1:20 000 scale.

(ii) *Coastal Instability*
This form of instability is common along the extensive coastline of the islands because of the drowned nature of the topography. The more exposed coastal slopes are most susceptible, especially in their steeper sections. Coastal instability occupies 296 ha (9.3%) of the study area.

(iii) *General Instability—Recent*
This form of instability relates to colluvial and insitu terrain, where many small landslips and other evidence of instability occur, but where it is not possible to show individual landslips as discrete units on a 1:20 000 scale. This is the major class of instability, and occupies 15.8% (502 ha) of the study area. *General Instability—Recent* occurs on much of the steep terrain, especially in the area around stream sections and the headward extension of drainage lines.

(iv) *General Instability—Relict*
This form of instability occupies 5.8% (186 ha) of the study area, and occurs in areas similar to *General Instability—Recent*. The two classes are closely related. This class of instability is no less important in terms of constraints on development than *General Instability—Recent.* This type of instability may be reactivated by construction, site formation, or changes to the drainage or hydraulic regime.

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

2.8 Land Use

2.8.1 *Existing Development*

Within the Islands study area, existing urban development is restricted to the islands of Lamma, Cheung Chau and Peng Chau. The few scattered and isolated villages which occupy coastal locations on some of the other islands, are mainly fishing and agricultural communities. Some specialist land uses exist, such as the Commercial Radio transmitter on Peng Chau, the large quarry and power station on Lamma, and the lighthouse and Royal Observatory weather station on Waglan Island. The distribution is tabulated in Table B12.

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) *Residential*
Areas of residential development are identified within the GEOTECS system as being either one storey, two storey or private development. These occupy approximately 138 ha of the study area. This land use often occurs near commercial and trading areas, as on the islands of Cheung Chau, Peng Chau and Lamma. Throughout the remainder of study area, residential areas are restricted to rural villages and squatter areas. These normally consist of low rise units, and they occupy approximately 1.4% of the area which is located mainly on GLUM Classes II & III terrain.

(ii) *Commercial and Trading*
The commercial and trading areas are mainly located on the islands of Cheung Chau and Peng Chau (Plates 8 and 17). Small areas of reclamation are given over to this land use, reflecting the need for level sites. Medium density housing and light industry are associated with commercial and trading development. Although not large enough to be identified within the GEOTECS system, this class probably occupies about 0.5% of the area and is located on GLUM Classes I & II terrain.

(iii) *Quarrying*
A quarry, occupying 12 ha of GLUM Classes III & IV terrain, is located north of Picnic Bay on Lamma Island. Other small areas are also used for borrow.

(iv) *Reservoirs*
Several small service reservoirs exist in the study area, but these are generally very small features.

(v) *Country Park*
None of the islands within the study area includes Country Park.

(vi) *Undisturbed/Undeveloped Natural Terrain*
Some 90.7% (2 889 ha) of the study area is currently undeveloped, of which 2 659 ha remains essentially undisturbed. Of the undisturbed natural terrain, 94 ha is GLUM Class I, 990 ha is GLUM Class II, 780 ha is GLUM Class III and 721 ha is GLUM Class IV; the remainder is unclassified coastal terrain.

(vii) *Agricultural*
Certain tracts of land, notably those in the alluvial coastal valleys, are used for intensive agriculture (Plate 5). In other areas, agricultural land is no longer used (Plate 21). Agricultural land forms 4.6% (146 ha) of the study area and consists mainly of GLUM Classes I, II & III terrain.

(viii) *Recreational*
Most sporting facilities and recreational areas are located near the urban areas of Peng Chau, Cheung Chau and Lamma Island; but these are of limited extent. Beaches exist on most of the islands, but access is often difficult.

(ix) *Institutional and Community*
This group includes schools, hospitals and specialist facilites, including a cemetery, power station and prison. They occupy approximately 3.5% of the area.

(x) *Roads and Services*
These are generally small linear features and are rarely mapped as discrete units at 1:20 000 scale. Most of the islands are free of traffic, apart from small agricultural vehicles.

2.8.3 *Future Development*

Development principles 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 availability of 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 of the material for borrow and other possible uses 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 it may be developed beneath the marine and/or offshore terrestrial deposits laid down during a period of lower 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 are tabulated in Appendix B, Table B11. The Area Instability Index presented in the table indicates the percentage of each rock type affected by instability.

Before interpreting these results, it must be remembered that factors other than geology influence erosion and instability. In the study area, the activities of man have greatly 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 is too small for generalisation.

(iii) *Material Resources*

The geological materials, found in such great variety 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.

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. A method of identifying potential quarry sites is given in Section 4.2.4 of this Report, and 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*) Man-made deposits—fill and reclamation.

(*b*) Recent deposits—alluvium, littoral and marine deposits.

(*c*) Colluvium.

(*d*) Intrusive igneous rocks.

(*e*) Volcanic and volcaniclastic rocks.

3.1.2 *Characteristics of Fill, Reclamation, Alluvium, Raised Beach and Marine Deposits*

This group includes all superficial materials that generally occur as flat or slightly inclined deposits, namely alluvium, littoral, raised beach and marine deposits. It also includes man-made fill and reclamation. The latter two materials are of relatively limited extent in the study area. Minor fill and reclamation are also associated with the power station and quarry on Lamma Island, and to a limited extent in some of the rural settlements on the outlying islands.

The history of sea level changes has resulted in a complex subsoil stratigraphy of these materials. In geological terms, all these materials are immature and consequently weathering profiles tend to be poorly developed. Older alluvial materials may display weathered cobbles which may be derived from previously weathered material.

Erosion of these deposits is generally not a major problem in their undisturbed state because of their predominantly flat gradient. Littoral deposits are subject to continuous erosion and redeposition by the sea. The GEOTECS data presented in Table B11 and summarised in the GEOTECS Plot, Figure 8, indicates that these materials are not subject to any marked degree of erosion; however, should hydraulic conditions be altered, for example by construction, then erosion may be initiated.

The GEOTECS data also show that there does not appear to be any incidence of instability in these materials, primarily because of the low slope angles associated with these deposits. If disturbed however, these deposits may exhibit instability. Excavations may require strutting, and slopes probably need to be cut at low angles or provided with retaining structures.

There is a wide range of particle size between members of this group. Alluvial deposits contain a high proportion of gravel and cobble-sized materials. Littoral and raised beach deposits generally consist of a fairly uniform medium to fine sand. Marine deposits range from silt to coarse sand and gravel, depending on the nature and environment of deposition.

Steep-sided excavations require strutting because these superficial materials have little cohesion. There is little natural instability in these materials due mainly to their natural, low slope angle. These various deposits exhibit a wide range of shear strength; the lowest values correspond to the marine muds and the highest values to alluvial horizons. Consolidation is rapid in the alluvium and littoral deposits, but may be very slow and quite considerable in the marine deposits. The absolute magnitude of settlement is dependent on the imposed load, local groundwater conditions and the local stratigraphy. Undisturbed samples are required for laboratory tests to determine the material strength characteristics applicable to individual sites. Site investigations in alluvium may benefit from the application of geophysical techniques such as resistivity or shallow seismic refraction. Offshore, marine seismic techniques are useful in obtaining profiles of the sediments.

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 accommodated by raft foundations, but problems of differential settlement may be experienced. The pile type most appropriate for high loads will be dependent on the overall stratigraphy, but nearly all members of this group are suited to driven piles. The materials in this group are easily excavated by machine methods. Marine deposits of sand have been extracted or covered by reclamation, and the marine silts and clays are generally unsuitable as hydraulic fill.

The members of this group of materials generally have a fairly high permeability, except where the clay fraction is particularly high. Groundwater levels tend to be high, and rates of settlement are often rapid or unpredictable if the materials are dewatered. Finely-graded marine sediments are an exception and may require considerable time for settlement, this depends to a large degree on the magnitude of the load. Settlement in marine and alluvial deposits is discussed by Holt (1962).

Excavation of these materials is relatively easy using machine methods, and they have potential as a soft fill. Development tends to occur on areas of alluvium thereby reducing their use as a fill resource. Littoral deposits tend to occur adjacent to areas of alluvium.

From a planning point of view, this group of materials, although not free of problems, is generally suitable for development. The littoral deposits however, are subject to marine erosion.

3.1.3 *Characteristics of Colluvium*

Colluvium is a complex heterogeneous material which is highly variable in its engineering character. The distribution is described in Sections 2.3 and 2.4 and in Appendix C.1.3.

As well as being derived from a range of rock types, colluvium is generally 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.

The Islands study area exhibits a range of colluvium because it contains a variable suite of intrusive igneous rocks and volcanic rocks. Examination of Tables B10 and B11 in Appendix B, indicates that colluvial materials are less subject to sheet and rill erosion than are the insitu rocks in the study area. This may reflect the mode of origin of the material, because colluvium often occurs adjacent to drainage lines where the greater availability of water probably maintains a better protective cover of vegetation.

No appreciable differences are evident in the susceptibility to erosion of the different types of colluvium in the study area, although the colluvium in some of the drainage lines may consist of large boulders which are unweathered or only slightly weathered.

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 (Nash & Dale, 1983).

One of the engineering problems associated with colluvium in Hong Kong is instability. Because this material consists mainly of the debris of past landslips, it accumulates at its angle of repose. Although these deposits may settle and become more dense with time, they are liable to subsequent movement if disturbed, whether by stream undercutting or by man.

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 Figures 4, grantic colluvium appears to have a higher proportion of instability compared with other colluvial materials in the study area. This is possibly a result of the steeper slope angles associated with the parent rock type, and of the restricted occurrence of volcanic colluvial terrain.

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.

The presence of tunnels or 'pipes' may severely disrupt the groundwater, and site investigations that involve the installation of piezometers in colluvium need to be carefully interpreted to avoid generating an inappropriate groundwater model.

An aid to anticipating the presence of these pipes is to observe the behaviour of streams that intercept the colluvial mass. If these streams disappear underground, then there is a reasonable chance that subterranean pipes are present.

Boreholes and trial pits are used to obtain samples and to provide exposures for the classification of colluvial deposits. Care should be taken however, 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 however, it may be necessary to rely on more empirical relationships for stability assessment.

Colluvium in the study area may be up to 10 m thick and is essentially unconsolidated; therefore, it has some potential for use as a soft borrow material. These deposits usually occur at the base of steep slopes and are the result of the accumulation of landslip debris; any excavation for borrow may destabilise the adjacent terrain. Older colluvial deposits may have suitable grading characteristics for use as fill, but the younger streambed deposits, generally lacking in matrix, are probably unsuitable. Excavation by machine methods could be difficult if large boulders are encountered.

A major constraint to the use of colluvial areas is that they occur on footslope terrain with complex groundwater conditions which may give rise to slope instability.

Within the study area, the effects of coastal drowning have meant that colluvial deposits are often absent because of the short length of drainage lines and lack of footslope terrain. Colluvium also tends to accumulate above nick points in the drainage systems on higher ground. No obvious areas of colluvium are evident as sources of soft borrow. Access difficulties and remoteness generally preclude the few areas which may have potential for borrow. Site formation works should not however, preclude the excavation and use of colluvial materials, provided adequate care is taken with the design of slopes. Excavation problems may occur in deposits with large boulders if machine methods are employed.

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.

3.1.4 *Characteristics of the Volcanic and Volcaniclastic Rocks*

The location and type of volcanic and volcaniclastic rocks found in the study area are discussed in Section 2.3.2 and in Appendix C.1.1. The rocks of the Repulse Bay Formation all tend to have similar material characteristics except for the minor sedimentary member.

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. 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. Site investigations for projects involving rock cut slopes should be designed to identify and define the dominant joint sets prior to engineering design.

In these rocks, weathering tends to be relatively shallow, with average depths in the order of 8 to 10 m. The volcaniclastic 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. This effect increases the erodibility of the material by streams. These streams tend preferentially to follow such lines of weakness, and can be seen on aerial photographs as lineaments.

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 Figures 4 indicate that the Repulse Bay Formation rocks show a general trend of relatively low incidence of erosion. 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 trails. That is, they are characterised by large length to width ratios (4 or 5:1).

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	QUATERNARY – RECENT?	R	RECLAMATION/FILL	Generally local or imported borrow of colluvium, decomposed volcanics or plutonics and crushed quarry rock. Often a mixture of silt, sand, gravel and cobbles. Some building waste, mine waste or sanitary fill may also be included.	Occur as extensive planar deposits adjacent to the 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 the 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. Ø' = 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 piled 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.
	QUATERNARY – RECENT?	L	LITTORAL DEPOSITS	Essentially beach and dune sand with occasional gravel horizons.	Deposits are very local in nature and generally confined to intertidal zone forming beaches and sandbars.	Nil	Generally sand-sized granular material, often uniformly graded and well rounded.	Materials are usually saturated and saline. Raised beaches may be leached by percolating 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 piled foundations.	Main development potential of existing beaches is for recreational purposes. Excavation of these materials usually prohibited.
	QUATERNARY – PLEISTOCENE?	L(RB)	RAISED BEACH DEPOSITS		Raised beaches may occur behind existing beaches and as ridges (tombolos) linking rock-cored islands.	Very little weathering as materials are predominantly quartzitic.			Raised beaches can provide local sources of partly-washed, rounded sand which are very easily excavated. Largest deposits on Cheung Chau and Peng Chau have already been mostly sterilised by development.
	QUATERNARY – PLEISTOCENE?	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' ≅ 0 – 10 kPa, Ø' ≅ 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 piled foundations.	Land deposits easily excavated. Marine deposits often form reasonable hydraulic fill. Excavation by cutter, suction or bucket dredger.
	QUATERNARY – PLEISTOCENE?	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' ≅ 0–5 kPa, Ø' ≅ 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 wave 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.
	QUATERNARY – PLEISTOCENE?	C	COLLUVIUM – VOLCANIC DERIVED; GRANITIC 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 floodplains. 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 an independent deposit 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' ≅ 0–5 kPa, Ø' ≅ 29°–42°. Standard compaction values: OMC ≅ 17–20%, MDD ≅ 1 630–1 750 kg/m³. CBR ≅ 3–8%.	This material has moved in its geologic past and is prone to reactivation if not carefully treated by use of 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 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 CRETACEOUS	D	INTRUSIVE IGNEOUS ROCKS – DYKE ROCKS – DOLERITE	Black to very dark grey, fine to medium-grained rock. Smooth joints normal to boundaries result from cooling.	Generally occur as linear structural features transecting the volcanic and granite 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.	Weathers deeply to a dark red silty clay.	No laboratory information available. Weathered mantle will contain a high proportion of clay and iron oxides leading to low Ø' values. Intact rock strength will be very high.	Restricted extent precludes detailed comment. Weathered mantle will have low relative permeability and will affect near-surface groundwater hydrology by forming barriers, divides and boundary conditions. Sub-vertical dykes may dam groundwater leading to unnaturally high groundwater levels.	Restricted extent precludes deliberate borrow or quarry activities—weathered material would make poor fill but fresh rock would make suitable high density aggregate or railway ballast.
	UPPER JURASSIC	La	INTRUSIVE IGNEOUS ROCKS – DYKE ROCKS – FELDSPAR PORPHYRY	Grey to greenish-grey. Fine-grained groundmass with up to 20% large (8–10 mm) phenocrysts of feldspar.		Generally weathers less rapidly than granitic rocks but more rapidly than volcanic rocks. Develops a thick reddish soil. Weathering depths are generally in the range 7–15 m.	Little laboratory information available. Parameters should be similar to granite but with a higher proportion of clay.	Surface hydrology can be affected by these rocks with drainage network 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.
	UPPER JURASSIC	Pq	INTRUSIVE IGNEOUS ROCKS – DYKE ROCKS – QUARTZ PORPHYRY	Grey to greenish-grey when fresh, weathers to a pale pink. Fine-grained groundmass with up to 20% large phenocrysts of quartz and minor feldspar.			No laboratory information available. Weathered mantle should contain coarse quartz sand along with silt and clay. Fresh rock parameters should be similar to granites.		
	UPPER JURASSIC	MG	INTRUSIVE IGNEOUS ROCKS – PORPHYRITIC MICROGRANODIORITE	Very fine-grained groundmass with abundant basic xenoliths.			No data available but should be similar to Tai Po Granodiorite.		
	UPPER JURASSIC	Dc	INTRUSIVE IGNEOUS ROCKS – COMPOSITE DYKE	Dyke within dyke, mixed igneous lithologies.			Material properties of dyke components noted above		
	UPPER JURASSIC	mo_q	INTRUSIVE IGNEOUS ROCKS – VEINS – QUARTZ VEIN	White or translucent microcrystalline quartz rarely over 100 mm thick. Can be associated with narrow dykes of microgranite.	Too narrow to have any significant effect on topography.	Quartz veins undergo only mechanical disintegration as they are very resistant to decomposition. Coarse angular gravel is the product.	Generally too small to be discretely sampled and tested.	Generally too small to affect structure but contained sulphides may affect groundwater chemistry and react with concrete and steel in foundations.	Restricted extent precludes deliberate borrow activity for these rocks. Weathering results in mechanical break up only of quartz and decomposition of sulphides. Fresh rock not suitable for aggregate due to potential sulphide reaction with cement. Molybdenite has been commercially mined.
	UPPER JURASSIC	—q	INTRUSIVE IGNEOUS ROCKS – VEINS – QUARTZ VEIN WITH MOLYBDENITE	As above with molybdenum sulphide in veins.					

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	Mc	INTRUSIVE IGNEOUS ROCKS (PLUTONIC)	GRANOPHYRIC MICROGRANITE	Pink to grey fine-grained non-porphyritic rock. Pink and white feldspars and quartz with granophyric texture. Jointing similar to other granitic rocks.	Outcrops on Green Island form lower sideslopes and coastal slopes.	Weathers to produce a clayey silty sand with corestones. Depth of weathering similar to other granites. Fresh rock outcrops in stream beds on occasions. Outcrops on Green Island are subject to marine erosion along shoreline, soil development very limited, shallow weathering only.	Few test results available. Grading of weathered material has given clay ≅ 10%, silt ≅ 30% and sand ≅ 60%.	As for all Hong Kong rock types weathered material may be unstable if undercut. Joints control stability in any rock cutting.	Weathered material can be machine excavated for use as fill. Limited outcrop and urban proximity restricts borrow potential to local site preparation. Fresh rock will require blasting.
		Mo		QUARTZ MONZONITE	Grey to pinkish-grey, fine to medium-grained, porphyritic, strong acid plutonic igneous rock. Phenocrysts are plagioclase. Generally displays wide rough joints.	Dissected undulating terrain. Small extent of instrusions do not produce significantly different relief from general granitic terrain, except for greater frequency of boulders.	Shallow to deep residual soil over moderately weathered rock. Corestones extensive. Quartz monzonite is more resistant to erosion than the granites and will tend to have shallower weathering profiles.	Coarse-grained fresh rock has an unconfined uniaxial compressive strength of 100–150 MPa and a DD of 2 600–2 750 kg/m^3. Point Load, Is(50) ≅ 5–8 MPa.	Relatively unknown rock type, comments as for granites but more care required with weathered materials because it is 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.
		FL		FAN LAU PORPHYRITIC GRANITE	Pale pink, fine-grained groundmass with phenocrysts of feldspar and quartz making up about half of the rock. Euhedral feldspars commonly exceed 10 mm in length; quartz usually occurs as large pools of intergrown crystals.	Small outcrop on Siu A Chau shows rounded hill with coastal cliffs.	Moderate to deep weathering on ridgecrests and slopes protected from erosion. Shallow weathering on rocks exposed to wave erosion. Soils contain large percentage of coarse quartz sand.	No laboratory information available. Parameters should be similar to granites.	Stability of the weathered material can be suspect, i.e. Zones A & B, where soil type failures may occasionally occur. Insitu material is prone 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.
		MS		MA ON SHAN GRANITE	Grey to pinkish-grey fine-grained porphyritic strong granite. Phenocrysts are quartz and feldspar. Generally displays smooth tectonic joints.	Forms extensive areas of moderate relief, broad convex hillcrests are common. Occurs as steep to precipitous terrain especially along coastlines exposed to wave action. Drainage is dendritic in nature although structural control may dislocate the general pattern. Sheet and gully erosion is 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 can exceed 10 m. 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 strength parameters are c′ ≅ 0 KPa, Ø′ ≅ 40°, roughness angles 5–10° (tectonic joints), 10–15° (sheet joints).		
		CC		CHEUNG CHAU 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.					
		SK		SUNG KONG GRANITE	Pale grey or pink, medium to coarse-grained, sparingly porphyritic, strong granite. Potassium feldspar is prevalent in this widely spaced rough jointed rock which is difficult to distinguish from Hong Kong Granite.					
		XT		TAI PO GRANODIORITE	Grey to dark grey, coarse to medium-grained, porphyritic granitoid rock. Large well formed crystals of white feldspar up to 15 mm are present in a coarse-grained matrix. Matrix minerals are potassium feldspar, plagioclase, biotite and minor quartz. Xenoliths are common. Jointing is similar to granites in that rough sheeting joints and widely spaced tectonic joints are present.	Small outcrop on central Lamma Island forms moderate ridge with narrow crest convexity. Moderately steep sideslopes are prone to instability and erosion.	Weathering depth to Zone C can exceed 10 m. Boulders and corestones are common in weathered zones. Weathering product is subangular silty sand.	Little test data available for study areas but decomposed granodiorite has the following general properties: DD ≅ 1 300–1 700 kg/m^3, clay content 2–8%, silt content 30–55%, sand 40–60%, MC ≅ 15–35%. Plasticity varies from non-plastic to PL 27–37%, LL 40–50%, c′ ≅ 0–14 kPa; Ø′ ≅ 33–42°. Standard compaction values: OMC ≅ 16–22%, MDD ≅ 1 690–1 780 kg/m^3, CBR ≅ 8–20%. Fresh granodiorite has an unconfined compressive strength of 125–175 MPa and a DD of 2 600–2 700 Kg/m^3. Point Load Is(50) ≅ 6–9 MPa.	Relatively unknown rock type in study area, comments as for granites but a little more care required with weathered materials because they are likely to be slightly more clayey. Special care must be taken in establishing adequate surface protection on newly formed slopes.	Because of the low to moderate content of quartz in the clay, weathered zone may be suitable for making bricks. Weathered zone material may be used for fill. Fresh rock is suitable for aggregate. Lower quartz content makes this material suitable for asphaltic concrete.
		G		UNDIFFERENTIATED GRANITIC ROCKS	Nature of rock uncertain but similar to granitic rocks discussed above.	Forms area of moderate to steep relief with convex hillcrest on southern part of Peng Chau.	Generally deeply weathered rock in the order of 20 m thick. Upper weathered zone porous and permeable.	As for the granitic rocks below.	Engineering characteristics as outlined for other granitic rock.	Excavation and material uses as for other granitic rocks.
	LOWER TO MIDDLE JURASSIC	RBc	VOLCANIC ROCKS — REPULSE BAY FORMATION	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.	Low to moderate relief on northern Lamma, Green Island and Kau Yi Chau. Narrow ridge convexities and moderate angle sideslopes in areas of higher relief.	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, occurs with a thin soil or weathering cover.	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′ ≅ 0–10 kPa, Ø′ ≅ 30–35°. Fresh rock properties are approximately as follows: unconfined compressive strength ≅ 150–250 MPa. Joint strength parameters are c′ ≅ 0 KPa, Ø′ ≅ 30°, roughness angles ≅ 5–10°. DD ≅ 2 500–2 700 kg/m^3. Point Load Is(50) ≅ 6–12 MPa. Tangent modulus ≅ 30 000–60 000 MPa.	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. —Opportunities for creation of platforms; sites may be small and fragmented. —Tunnelling probably easier than in granitoids. Deep weathering and close jointing should be anticipated near structural geological lineaments.	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.
		RB		UNDIFFERENTIATED VOLCANIC ROCKS	Volcanic rocks not mapped in detail but probably similar to coarse tuff below.					

* 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—kilograms per cubic metre
MDD	—maximum dry density—kg/m^3—kilograms per cubic metre
DD	—dry density—kg/m^3—kilograms per cubic 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

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 because of their fine grain-size 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 fairly shallow.

Site investigations in the volcanic 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 various intrusive igneous rocks that underlie much of the study area are of similar origin and consequently have similar engineering characteristics. A large amount of site investigation and laboratory information is already available, and these materials are generally quite well understood (Lumb 1962 a & b, 1965, 1983). The distribution and lithology of the intrusive igneous rock types is discussed in Section 2.3.3.

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, although they may cause localised variations in weathering depths and groundwater conditions. Usually they are not of great engineering significance except when they occur as a dyke swarm. In this case, rapid local variation in ground conditions may result in a complex piezometric surface.

The various granite intrusions 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 occurrence of tectonic joints increases markedly in the vicinity of photolineaments. Due to the impermeability of the fresh rock, joints are probably the major conduits of groundwater flow below the weathered mantle.

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 because of the higher porosity and rock permeability of the granitic rocks. Weathering in these rocks has been the subject of recent study in Hong Kong (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 is evident within the study area. In general, for similar locations in the terrain, these rocks are weathered to approximately 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. Weathered monzonite, dolerite, and Tai Po Granodiorite have higher concentrations of clay compared with other members of this group. This is probably due to the lower free quartz content of the original rocks.

As the residual soil is predominantly sandy, it is highly erodible in nature. The GEOTECS data presented in Figures 4 and in Tables B10 and B11 indicate relatively high levels of erosion within the intrusive igneous rocks when compared with the other rock types. There appear however, to be differences between the individual intrusive rocks.

In general, instability in these rocks is not as extensive as in colluvium or 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, resulting in settlement problems for surface footings. Artificial lowering of groundwater during construction can also adversely affect steep cuttings and can increase 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. The unweathered granitic rocks are generally favoured as a source of aggregate due to the ease of crushing and morphological characteristics (Brand et al, 1984). Quartz Monzonite has a lower quartz content than the other granitic rocks within the study area and it may thus be suitable as a source of roadstone because of favourable asphalt adhesion properties. A large quarry in the Sung Kong Granite is in operation to the north of Picnic Bay on Lamma Island.

Various dyke rocks form a minor unit within the suite of intrusive igneous rocks of the study area. These rocks are characterised by areas of slightly subdued relief with weathered rock depths between 7 and 15 m. Few diagnostic properties are available, although weathering, jointing, discontinuity and material characteristics, are similar to those of the granites.

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.

4. GEOTECHNICAL ASSESSMENT FOR PLANNING PURPOSES

4.1 Geotechnical Limitations and Suitability for Development

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 Tables B8, B9 and B13 in Appendix B. The GEOTECS Plot, Figure 10, illustrates the general extent of the various GLUM Classes.

The Generalised Limitations and Engineering Appraisal Map (GLEAM) identifies parcels of land with potential for development from a geotechnical point of view. The geotechnical limitations and other planning constraints such as, provision of access, presence of Country Parks and designated Green Belt, are highlighted.

4.1.2 *Land with Low to Moderate Geotechnical Limitations*

Within the study area, there exists a relatively small area (173 ha) with low geotechnical limitations, and approximately 1 331 ha with moderate geotechnical limitations. Terrain with low to moderate limitations (GLUM Classes I & II) forms 46.2% of the study area. Some 23.1% of the GLUM Class I and 15.1% of the GLUM Class II terrain is developed, and 1 263 ha of the GLUM Classes I & II terrain is substantially undeveloped.

Land with a low degree of geotechnical limitation 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; however in certain situations, foundation conditions could be more complex than for GLUM Class I; nevertheless 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: insitu terrain of moderate steepness or flat or gently sloping alluvial terrain. Areas of reclamation are also included in GLUM Class II.

The major areas of GLUM Classes I & II terrain which occur outside of the developed parts of the study area, are discussed in the description of potential development areas in Section 4.2.

4.1.3 *Land with High Geotechnical Limitations*

Approximately 26.7% (851 ha) of the study area has a high level of geotechnical limitation (GLUM Class III) and of this, some 4.5% is currently developed.

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 is 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, and these would need to be determined during site investigation.

Small areas of GLUM Class III terrain may be included within the Potential Development Areas (PDA) shown on the GLEAM, if they are unlikely to adversely affect the overall development opportunities of the area.

4.1.4 *Land with Extreme Geotechnical Limitations*

Approximately 23.7% (753 ha) of the area is classified as GLUM Class IV. This terrain should not be developed if alternatives exist. Only 14 ha of this class occurs within areas of existing development.

Intensive site investigation would be required at the planning stage and prior to detailed design in order 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.

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 are due to natural drainage lines crossing colluvium or to the presence of instability. These features are highlighted on the Physical Constraints Map (PCM).

4.2 Potential Development Areas

4.2.1 *General Planning Considerations*

Land utilisation 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, since not only is efficient construction 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 should ideally be unhindered by geotechnical limitations. Within the study area, there are many natural areas with potential for development, but a proportion occur within the bounds of designated Green Belt. This artificial constraint is noted, but is not used to exclude areas that have potential from a geotechnical point of view based on their natural terrain attributes.

In dealing with land which is as yet undeveloped, the Generalised Limitations and Engineering Appraisal Map (GLEAM) is valuable at two levels. At the planning stage, it identifies broad areas in which an integrated approach to large-scale development could be adopted. Subsequently, at the engineering feasibility stage, it enables possible problems to be anticipated for the design of site investigations, preliminary layout and other more detailed aspects of design. The importance of the GLEAM as a tool for integrated planning and engineering feasibility, is outlined in Section 4.2.2.

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 *Generalised Limitations and Engineering Appraisal Map (GLEAM) and Development Potential*

The GLEAM identifies 9 areas which have potential for development from a geotechnical point of view. This represents approximately 550 ha or 17% of the total area. The areas range in size from about 20 ha up to 130 ha. They occur on different types of terrain, and are not necessarily suitable for the same type of development.

The areas of potential are identified from the interpretation of the terrain and geological features, and the various levels of geotechnical engineering difficulty which they present.

Where individual features or constraints are of local significance to the planning and engineering feasibility of a 'potential' area, they are indicated on the GLEAM. These areas are referred to as Potential Development Areas (PDA). The Generalised Limitations and Engineering Appraisal Map is enclosed in the Map Folder. A description of the derivation of the map is presented in Appendix A.9.

In addition to the geotechnical constraints, the potential of a site for development is governed by other factors such as: existing land use (Green Belt or Country Park), proposed development intensity, proximity to services, access routes and intrusion on the natural landscape. Economic factors are a major consideration. Some of these factors may ultimately rule out development of a particular area, but unless the overall practicalities of development render a site unfeasible (i.e. a small site on a remote hilltop), they are shown on the GLEAM. Each area with potential for development is numbered and presented on the GLEAM.

The comments for each area reflect the general strategic considerations which influence planning and engineering feasibility. In the main, they relate to the suitability of the areas for intensive development. Reference should be made to the Geotechnical Land Use Map, Engineering Geology Map and Physical Constraints Map (PCM) for identification of factors influencing development opportunities. In particular, the PCM shows the nature of any constraint. If a constraint is identified on the PCM, and the constraint occurs within a potential development area, then the area of constraint is also shown on the GLEAM.

4.2.3 *Development Opportunities*

There are 9 areas which have potential for development from a geotechnical point of view. These areas constitute approximately 550 ha of land.

Area 1 *Po Toi Island* (65 ha approx.)
This PDA consists of moderately sloping sideslopes with some steeper and unstable slopes. The island is remote and access will be difficult. The PDA consists of mainly GLUM Classes I & II terrain.

Area 2 *North Lamma* (130 ha approx.)
This PDA occupies most of the northern part of Lamma Island. The terrain is mainly moderately sloping sideslopes and ridgecrests. Some areas of alluvial floodplain and drainage line colluvium are prone to periodic inundation. The PDA consists mainly of GLUM Class II with small areas of GLUM Classes I & III.

Area 3 *South East Lamma* (85 ha approx.)
This PDA is bisected by steep rock slopes which could provide fill. The remainder of the area consists of moderately steep sideslopes and ridgecrests. Drainage lines would require flood control measures and culverting prior to development. The area consists of GLUM Classes II & III terrain.

Area 4 *South West Lamma* (70 ha approx.)
This remote PDA has difficult access but could be developed as an extension of Area 3. The PDA consists mainly of moderately steep sideslopes dissected by drainage lines which would require culverting prior to development. This area is formed mainly of GLUM Class II, with small areas of GLUM Classes III & IV terrain.

Area 5 *Peng Chau* (25 ha approx.)
Substantial areas of Peng Chau are already developed and areas of reclamation are evident. Scope for further development exists, especially in the southern part of Peng Chau. Moderately steep sideslopes of deeply weathered rock form the main terrain elements of the PDA which consists mainly of GLUM Classes I & II terrain.

Area 6 *Cheung Chau* (40 ha approx.)
Current land formation on Cheung Chau is largely through reclamation, but further potential exists in the southern half of the island. The terrain is mainly moderately steep sideslope with few geotechnical constraints other than the depth of weathering. The PDA consists of GLUM Classes I & II terrain.

Area 7 *Hei Ling Chau & Sunshine Island* (75 ha approx.)
Combined, these two islands comprise a single PDA. Constraint areas such as steep and unstable sideslopes could be borrowed provide reclamation to join the islands. The developable terrain mainly has moderately steep sideslopes with some drainage lines. GLUM Classes I & II account for most of the terrain in the PDA.

Area 8 *Shek Kwu Chau* (20 ha approx.)
This PDA occupies the eastern half of the island, but is bisected by constraint areas of steep and unstable sideslope and drainage line colluvium. The area consists mainly of GLUM Class II terrain. Remoteness would probably preclude all but the most specialised types of development.

Area 9 *Soko Islands* (40 ha approx.)
This remote PDA would be ideally suited for specialised or recreational development. The terrain has few geotechnical hazards, except deeply weathered and eroded soil profiles. The developable terrain consists mainly of GLUM Classes I & II terrain.

4.2.4 *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 1.5.9 and described in detail in Appendix A.11.

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

(*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) *Geology, Erosion and Instability*
Figure 11 is a GEOTECS Plot showing the distribution of areas of sheet, rill and gully erosion for each of the major geological units. This map could be used for an initial assessment of the preventive measures necessary to curtail soil loss and coastal sedimentation.

(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 2 500 ha of undesignated natural terrain has potential for quarry sites. A further 140 ha with potential for quarrying occurs within existing Green Belt or areas which are under cultivation. These figures indicate that many options exist, but these options would be reduced when rock type is specified.

5. CONCLUSIONS

The findings reached during the Islands 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), the Engineering Geology Map (EGM), and the Generalised Limitations and Engineering Appraisal Map (GLEAM).

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 984 ha of the terrain (30.9%) 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 vary according to bedrock lithology, with very deep weathering occurring in some granitic areas. The competition from alternative land uses restricts the future excavation of soft borrow and rock materials. 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 114 ha of the footslope terrain is covered by colluvial deposits; 21.9% of the colluvium is affected by instability. Significant geotechnical limitations should be anticipated in zones of runoff and surface drainage across the colluvium. These occupy some 69.3% (79 ha) of the generally low angle colluvial footslope terrain.

(*d*) The granitic terrain has a slightly lower proportion of GLUM Classes I & II (44.5%) than the volcanics (75.9%). All of the colluvial terrain within the study area is subject to high to extreme geotechnical constraints (GLUM Classes III & IV).

(*e*) Approximately 18% of the study area is characterised by slopes which have gradients between 0 and 15°. A further 74.7% of the terrain has slope gradients between 15 and 40°, and 7.3% is steeper than 40°.

(*f*) Intrusive igneous rock terrain is often suitable as a source of borrow, and is also generally suitable for aggregates. Volcanic rock terrain could also be considered for extractive industries.

(*g*) Reclamation (92 ha) and other developments are of a minor nature in this study area, due in part to the comparative remoteness of many of the outlying islands. Only 9.3% of the study area is currently developed, and little in the way of large scale development exists except on Peng Chau, Cheung Chau and Lamma Island. No areas of Country Park exist within the study area.

(*h*) Squatters occupy only a very small area and are mainly located in non-designated villages. The intense squatter settlements characteristic of the large urban centres do not occur in the study area.

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 on 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 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. The Generalised Limitations and Engineering Appraisal Map (GLEAM) recognises this fact and delineates 9 areas which have overall potential for development from a geotechnical point of view. These represent a total of 550 ha or 173% of the terrain. Some areas of GLUM Class III, and possibly Class IV, terrain occur within these areas, 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 2 889 ha of currently undisturbed natural terrain. Of this figure, GLUM Classes I & II occur on some 43.7% of the terrain, and of the remaining area, 1552 ha is associated with high to extreme geotechnical limitations (GLUM Classes III & IV).

(*e*) Squatter areas occur as villages of the non-designated type. The majority of the terrain is affected by low to moderate geotechnical limitations.

(*f*) 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.

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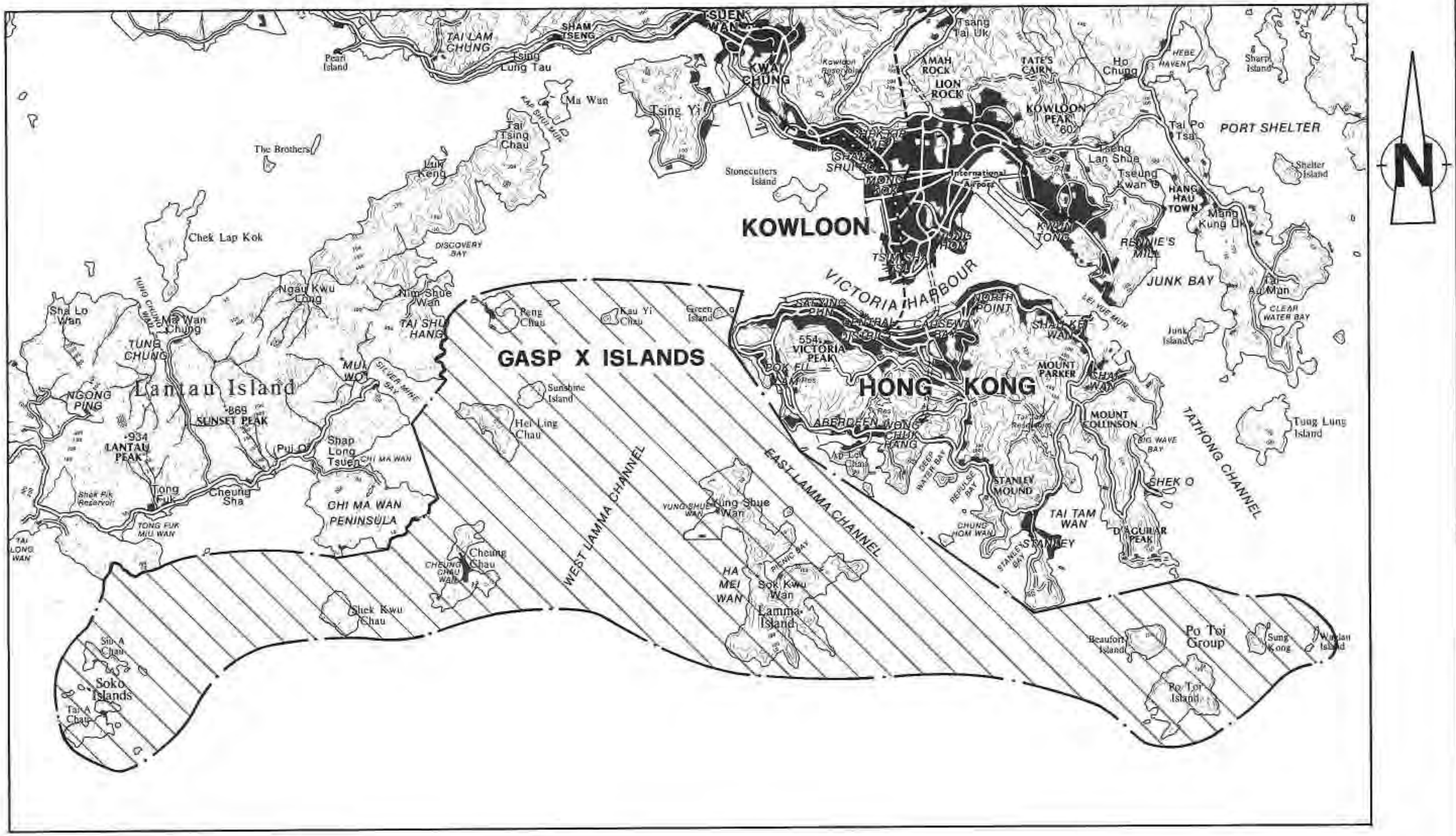


Scale 1:200 000

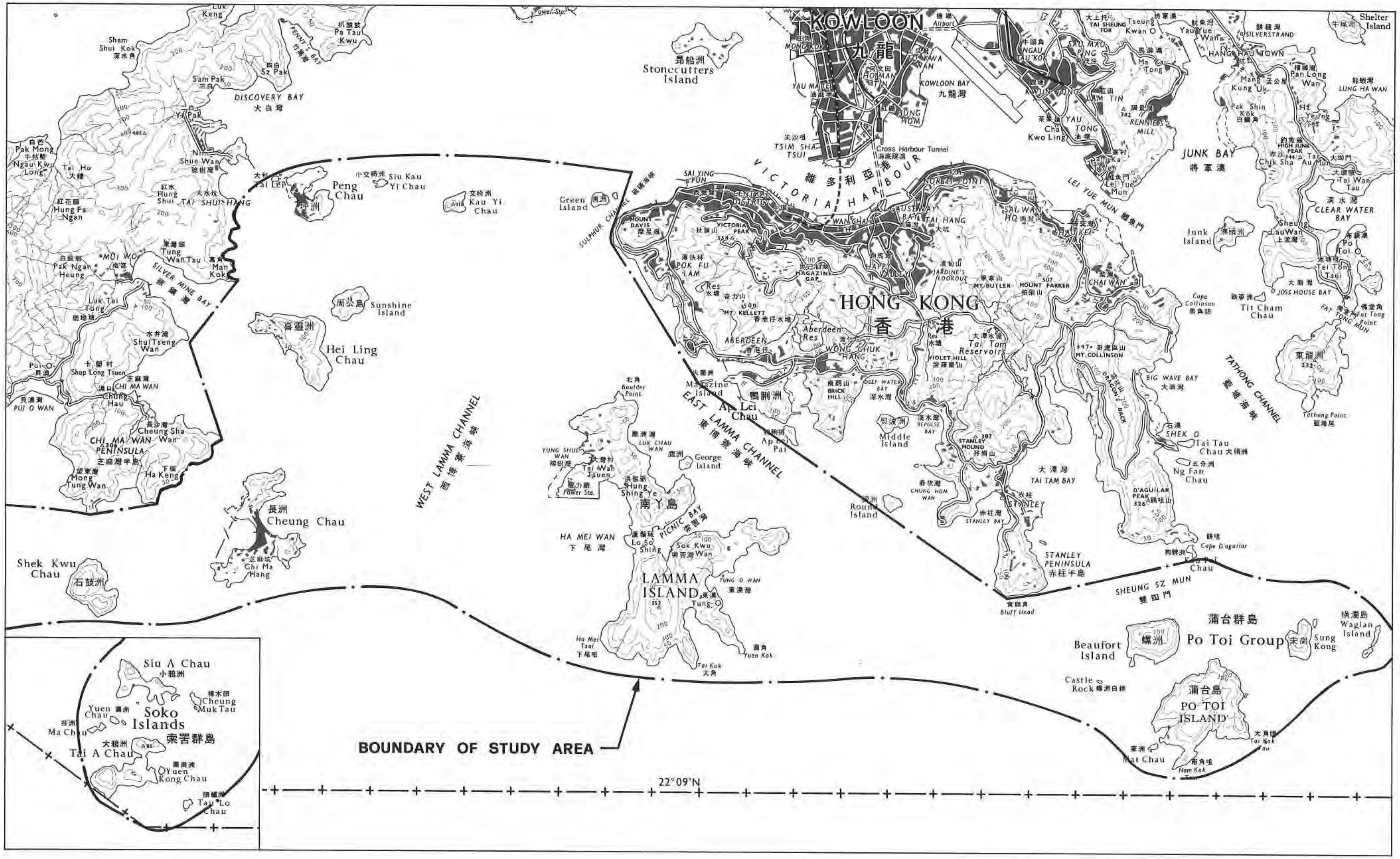
Location Map of the Islands Study Area

Fig. 1

Scale 1:100 000	Aerial Photomosaic of the Islands Study Area	Fig. 2

Compiled from photography dated Dec. '83

Scale
1:100 000



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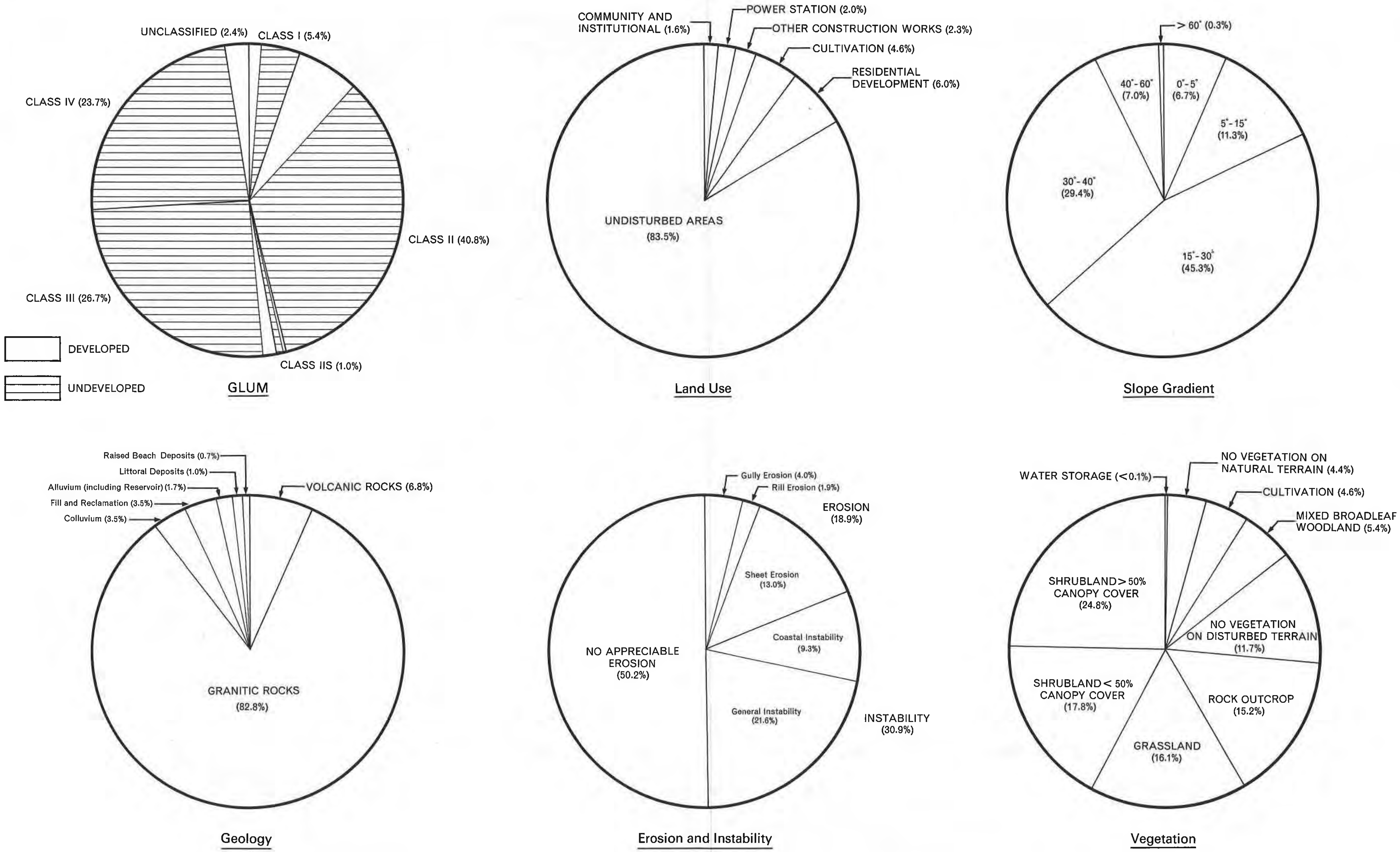
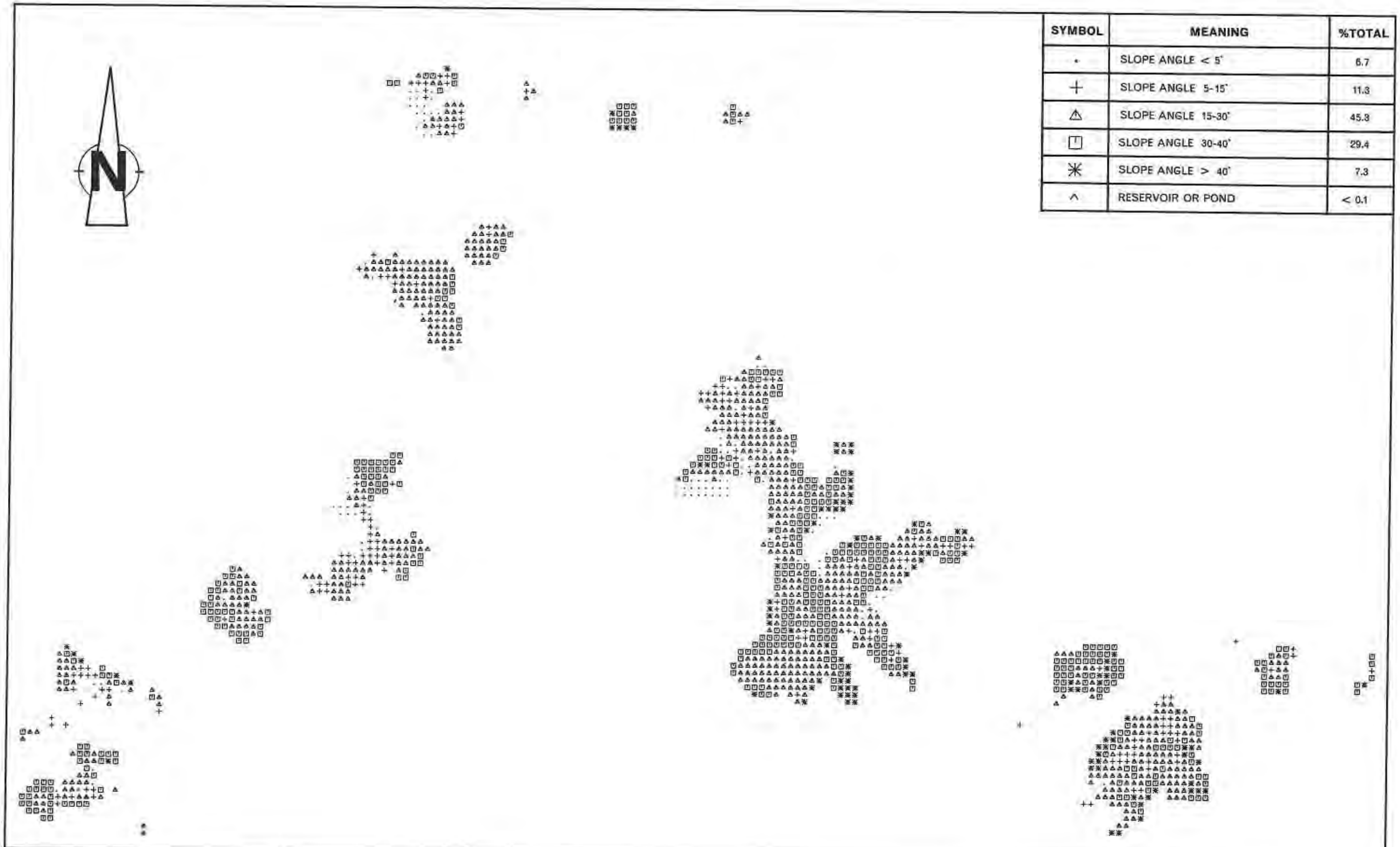
Islands Study Area

Fig. 3



Pie Charts of Selected Attributes of the Islands

Fig. 4

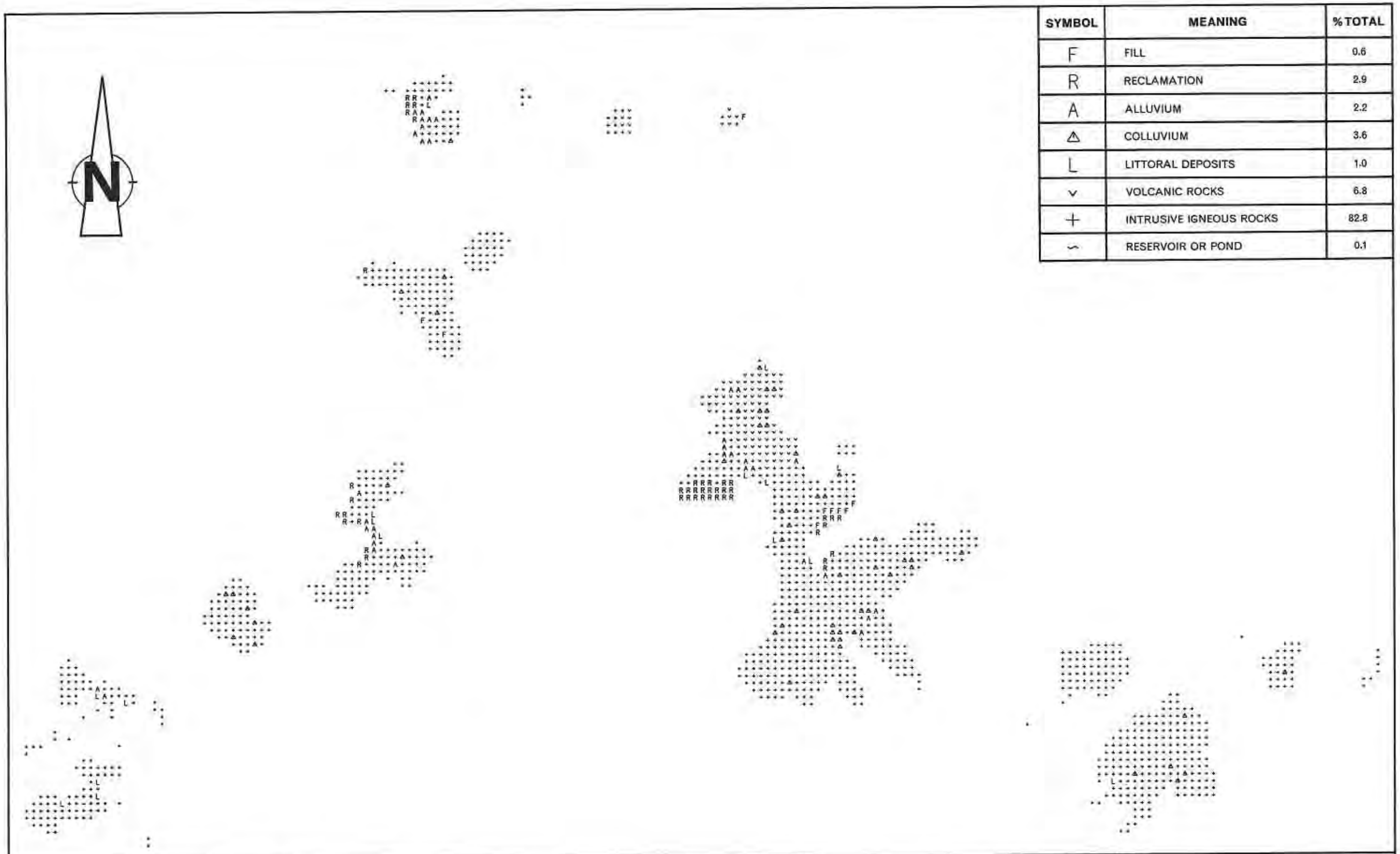


SYMBOL	MEANING	%TOTAL
·	SLOPE ANGLE < 5°	6.7
+	SLOPE ANGLE 5-15°	11.3
△	SLOPE ANGLE 15-30°	45.3
⊡	SLOPE ANGLE 30-40°	29.4
✳	SLOPE ANGLE > 40°	7.3
^	RESERVOIR OR POND	< 0.1

Scale
1:110 000

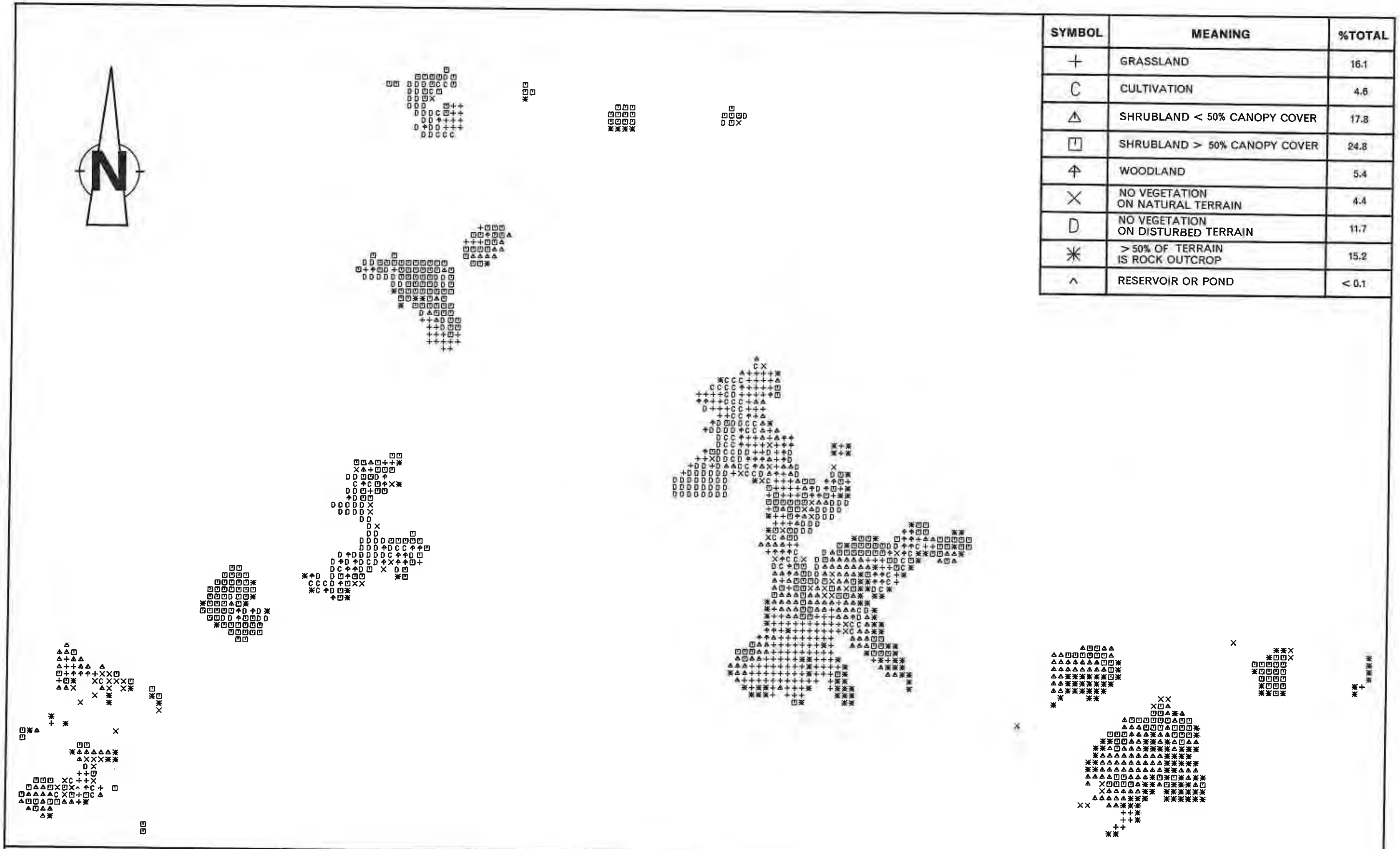
GEOTECS Plot - Slope Gradient

Fig. 5



SYMBOL	MEANING	% TOTAL
F	FILL	0.6
R	RECLAMATION	2.9
A	ALLUVIUM	2.2
△	COLLUVIUM	3.6
L	LITTORAL DEPOSITS	1.0
v	VOLCANIC ROCKS	6.8
+	INTRUSIVE IGNEOUS ROCKS	82.8
~	RESERVOIR OR POND	0.1

Scale 1:110 000	GEOTECS Plot - Geology	Fig. 6

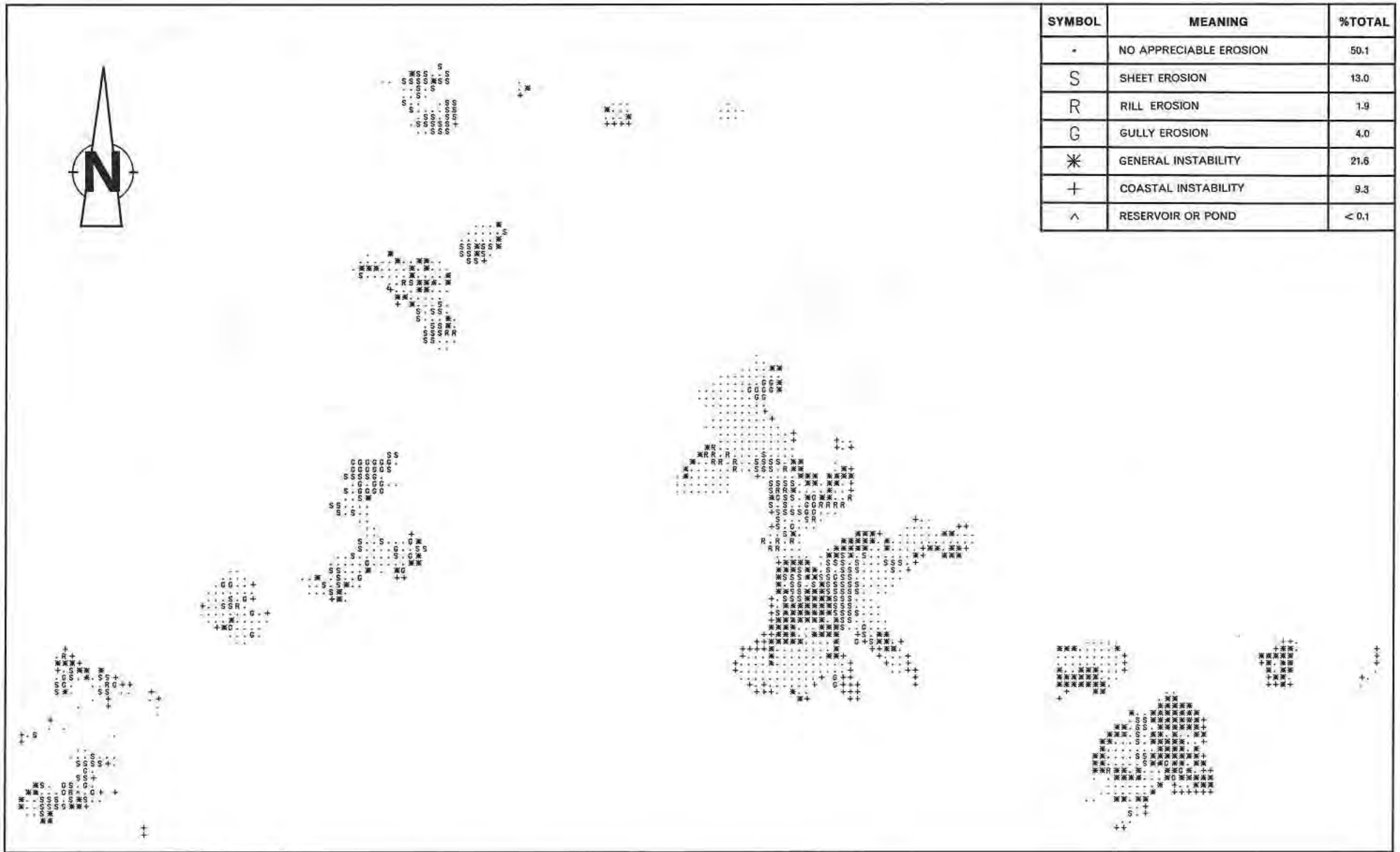


SYMBOL	MEANING	%TOTAL
+	GRASSLAND	16.1
C	CULTIVATION	4.6
△	SHRUBLAND < 50% CANOPY COVER	17.8
⊡	SHRUBLAND > 50% CANOPY COVER	24.8
↑	WOODLAND	5.4
X	NO VEGETATION ON NATURAL TERRAIN	4.4
D	NO VEGETATION ON DISTURBED TERRAIN	11.7
✳	> 50% OF TERRAIN IS ROCK OUTCROP	15.2
^	RESERVOIR OR POND	< 0.1

Scale
1:110 000

GEOTECS Plot - Vegetation

Fig. 7

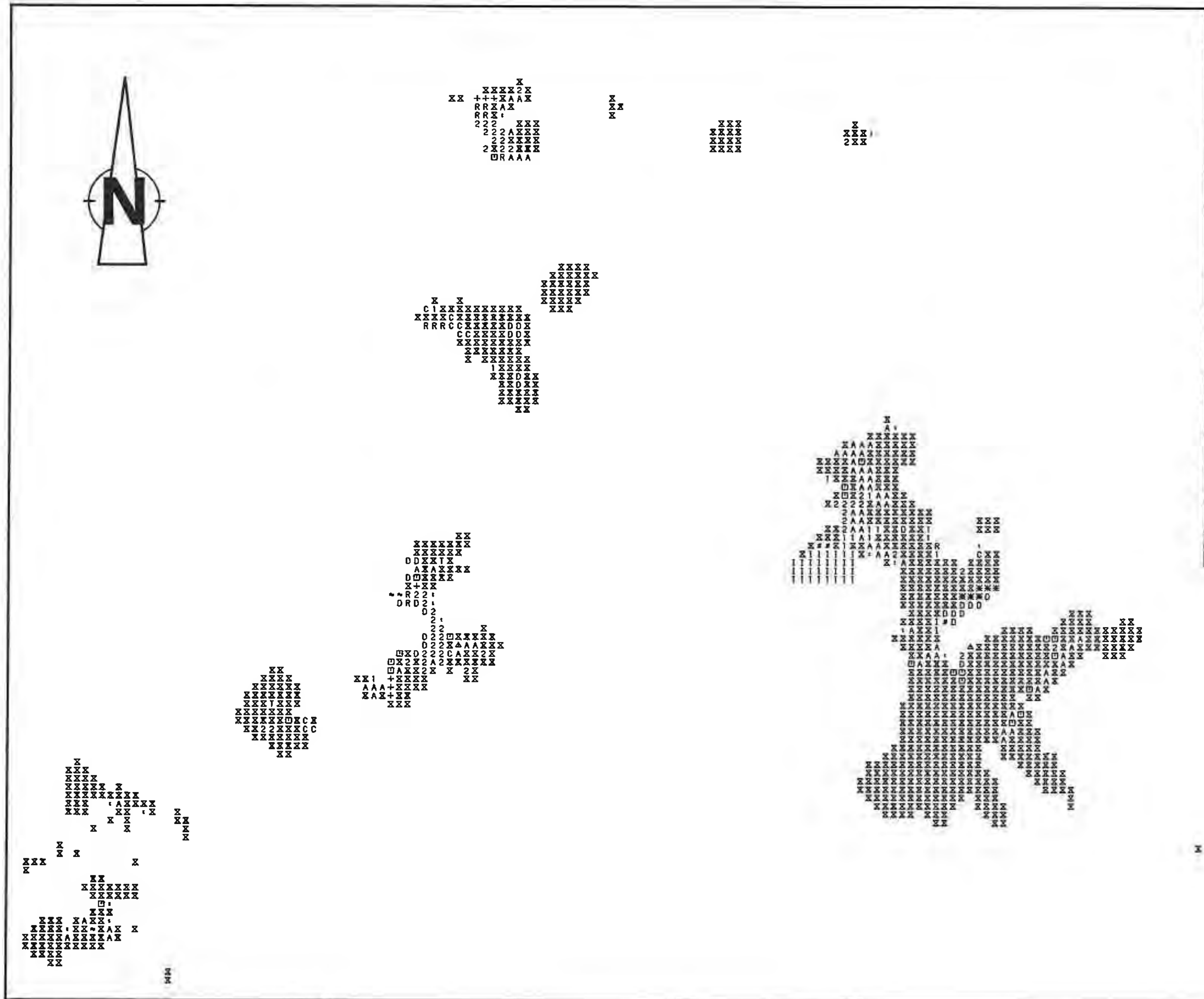


SYMBOL	MEANING	%TOTAL
·	NO APPRECIABLE EROSION	50.1
S	SHEET EROSION	13.0
R	RILL EROSION	1.9
G	GULLY EROSION	4.0
✳	GENERAL INSTABILITY	21.6
+	COASTAL INSTABILITY	9.3
^	RESERVOIR OR POND	< 0.1

Scale 1:110 000

GEOTECS Plot - Erosion and Instability

Fig. 8

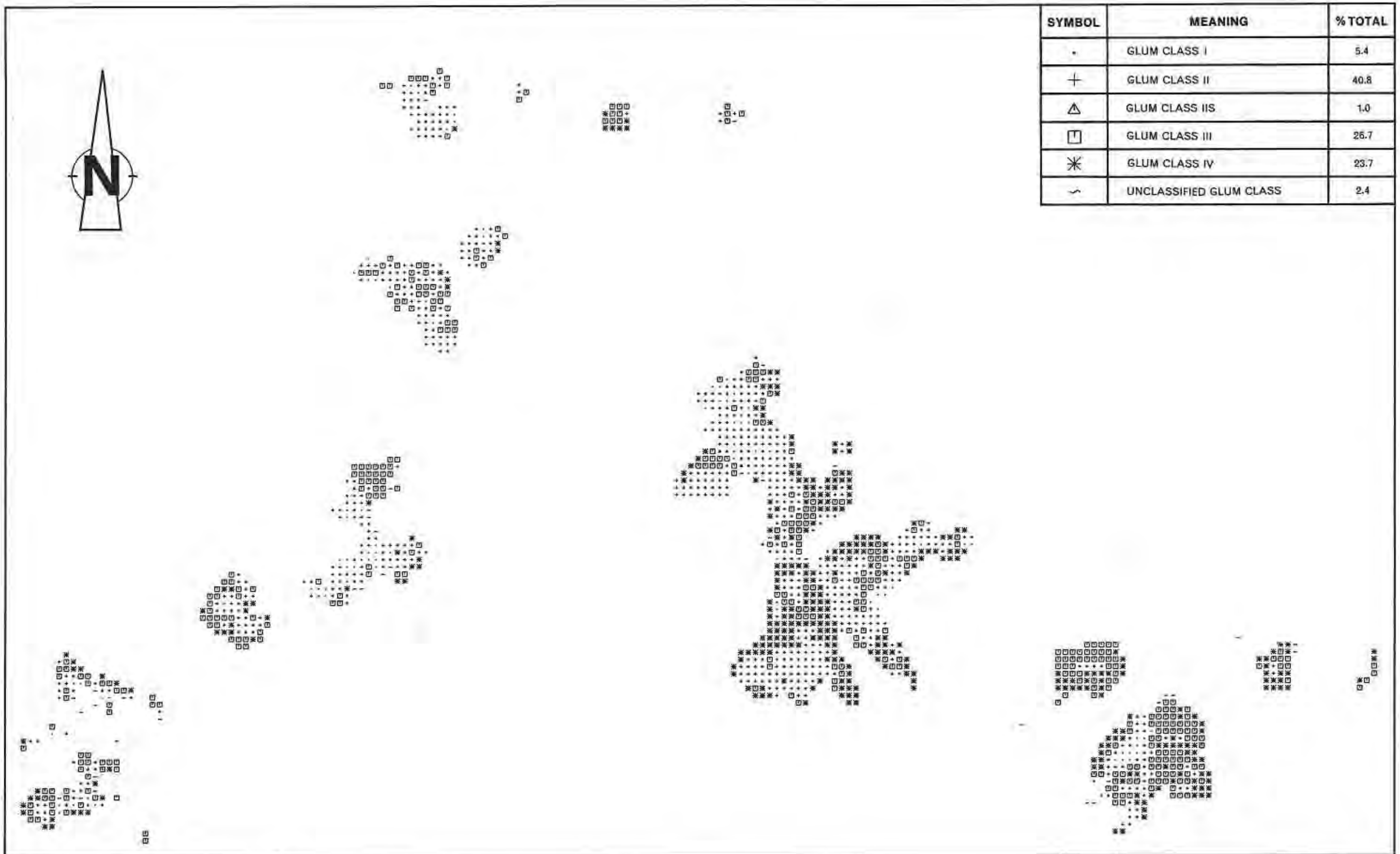


SYMBOL	MEANING	% TOTAL
R	RESIDENTIAL (MIXED COMMERCIAL/RESIDENTIAL)	0.7
1	SINGLE STOREY HOUSING	0.9
2	DOUBLE STOREY HOUSING	3.0
I	COMMERCIAL AND INDUSTRIAL	2.1
C	COMMUNITY AND INSTITUTIONAL	0.8
D	INCOMPLETE DEVELOPMENT (INCLUDING TEMPORARY RESETTLEMENT AREA)	1.6
⊡	SQUATTERS	1.4
⚠	SPORTS AND RECREATIONAL	< 0.1
T	TRANSPORT	< 0.1
#	LARGE ARTIFICIAL SLOPES	0.3
+	CEMETERY	0.4
✳	QUARRIES AND BORROW AREAS	0.4
≈	WATER SUPPLY - INCLUDING RESERVOIRS, SEWAGE & TREATMENT	0.2
A	AGRICULTURE (UNDEFINED)	4.6
⧖	UNDISTURBED NATURAL TERRAIN	82.5
:	LITTORAL ZONES	1.0

Scale
1:110 000

GEOTECS Plot - Land Use

Fig. 9

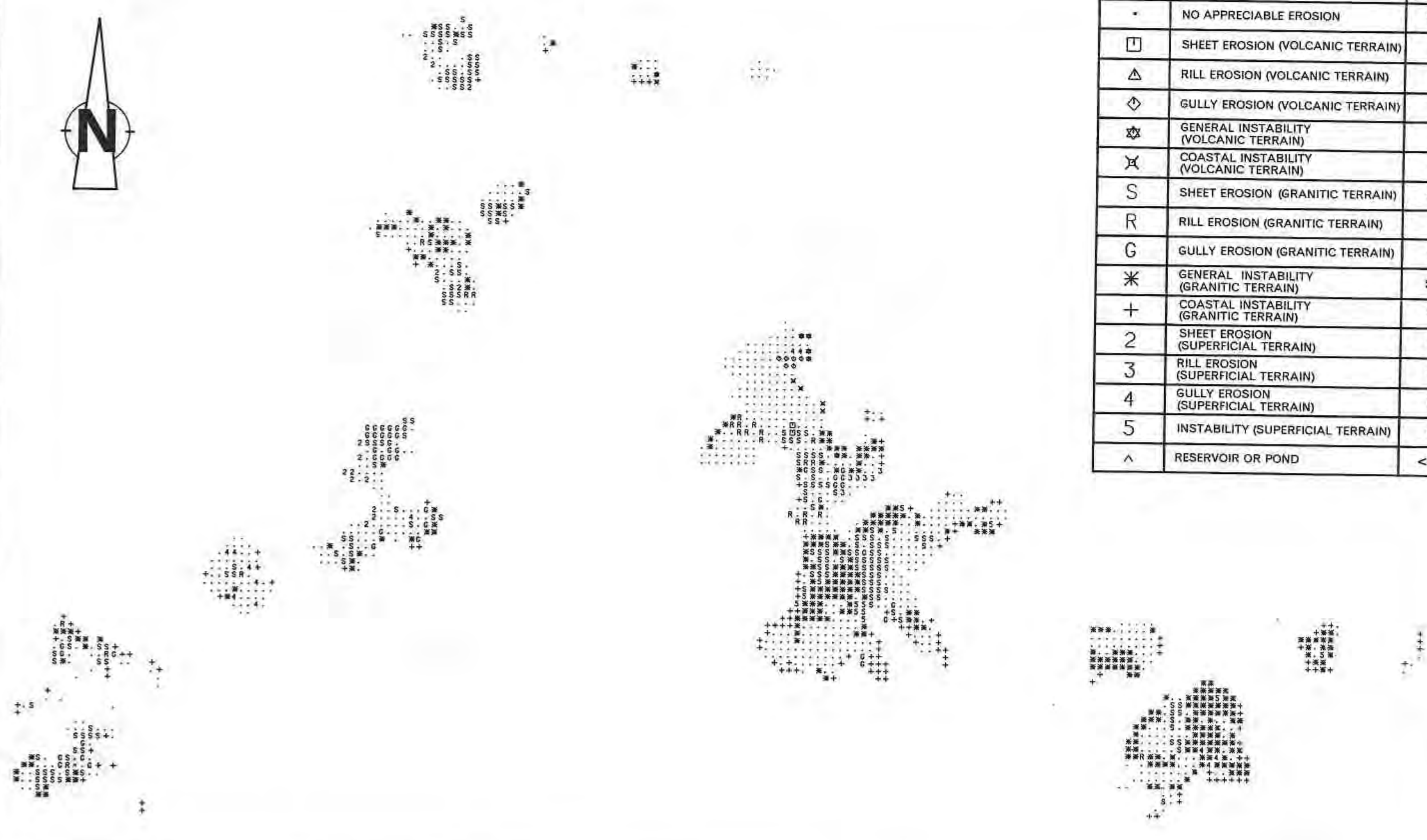


SYMBOL	MEANING	% TOTAL
·	GLUM CLASS I	5.4
+	GLUM CLASS II	40.8
⚠	GLUM CLASS IIS	1.0
⊡	GLUM CLASS III	26.7
✳	GLUM CLASS IV	23.7
~	UNCLASSIFIED GLUM CLASS	2.4

Scale
1:110 000

GEOTECS Plot - Geotechnical Land Use Map

Fig. 10

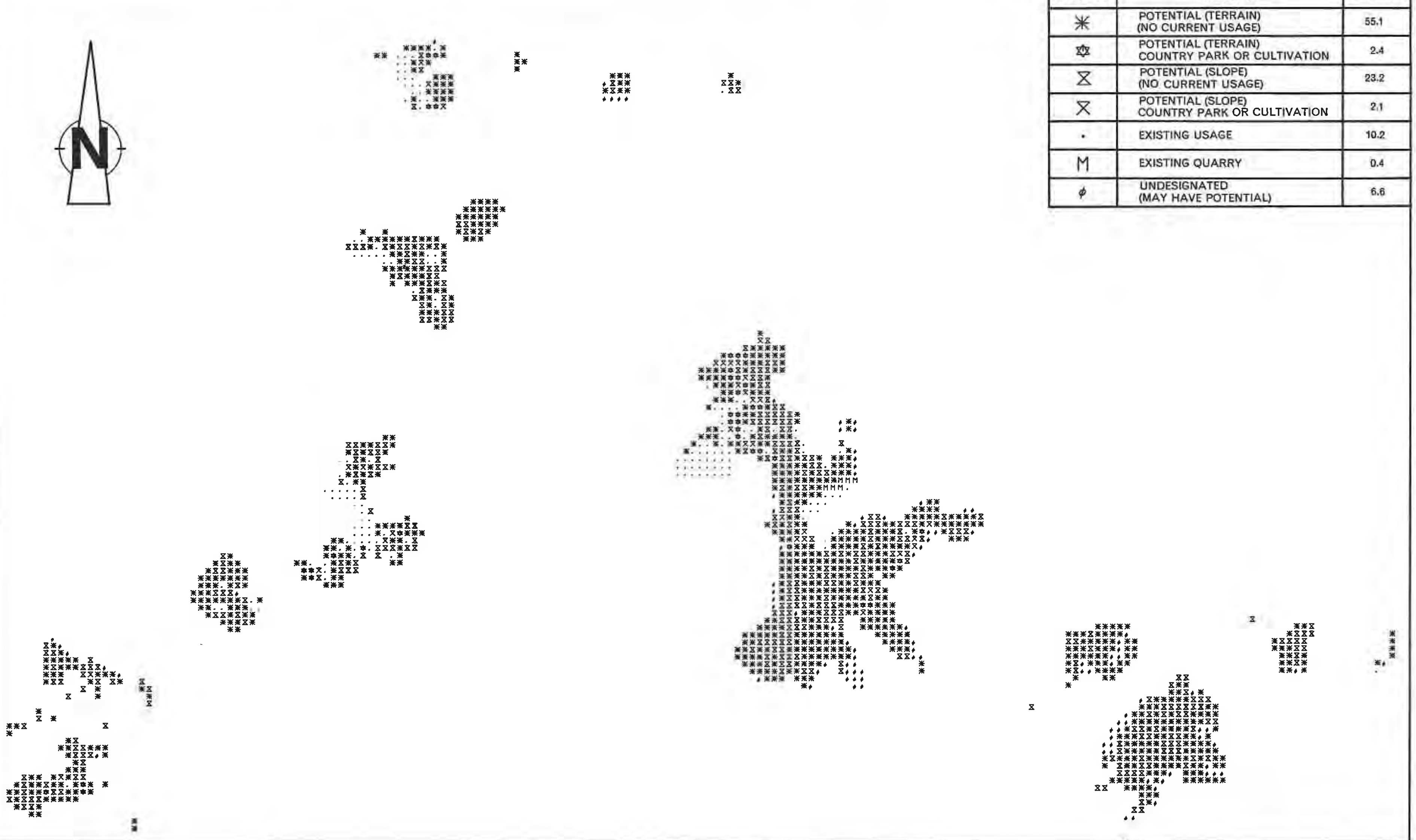


SYMBOL	MEANING	%TOTAL
•	NO APPRECIABLE EROSION	50.1
⊡	SHEET EROSION (VOLCANIC TERRAIN)	0.1
⚠	RILL EROSION (VOLCANIC TERRAIN)	0.0
◈	GULLY EROSION (VOLCANIC TERRAIN)	0.4
✡	GENERAL INSTABILITY (VOLCANIC TERRAIN)	0.4
⌘	COASTAL INSTABILITY (VOLCANIC TERRAIN)	0.3
S	SHEET EROSION (GRANITIC TERRAIN)	12.0
R	RILL EROSION (GRANITIC TERRAIN)	1.5
G	GULLY EROSION (GRANITIC TERRAIN)	2.8
✳	GENERAL INSTABILITY (GRANITIC TERRAIN)	20.4
+	COASTAL INSTABILITY (GRANITIC TERRAIN)	9.0
2	SHEET EROSION (SUPERFICIAL TERRAIN)	0.9
3	RILL EROSION (SUPERFICIAL TERRAIN)	0.4
4	GULLY EROSION (SUPERFICIAL TERRAIN)	0.8
5	INSTABILITY (SUPERFICIAL TERRAIN)	0.8
^	RESERVOIR OR POND	<0.1

Scale
1:110 000

GEOTECS Plot - Geology, Erosion and Instability

Fig. 11



SYMBOL	MEANING	%TOTAL
✳	POTENTIAL (TERRAIN) (NO CURRENT USAGE)	55.1
✡	POTENTIAL (TERRAIN) COUNTRY PARK OR CULTIVATION	2.4
⧗	POTENTIAL (SLOPE) (NO CURRENT USAGE)	23.2
⧖	POTENTIAL (SLOPE) COUNTRY PARK OR CULTIVATION	2.1
·	EXISTING USAGE	10.2
M	EXISTING QUARRY	0.4
ϕ	UNDESIGNATED (MAY HAVE POTENTIAL)	6.6

Scale
1:110 000

GEOTECS Plot - Potential Quarry Sites

Fig. 12

Fig. 1	Location Map of the Islands Study Area 1:200 000	Fig 2	Aerial Photomosaic of the Islands Study Area 1:100 000	Fig. 3	Reduced Scale Base Map of the Islands Study Area 1:100 000

Fig. 14 to 20 show A4 size inset examples of a typical set of GASP Maps (1:20 000)

Fig. 14a	Base Map
Fig. 14b	Terrain Classification Map (TCM)

Fig.	15a	Geotechnical Land Use Map (GLUM)
	15b	Terrain Classification Map Superimposed on the GLUM
Fig.	16a	Physical Constraints Map (PCM)
	16b	Terrain Classification Map Superimposed on the PCM
Fig.	17a	Engineering Geology Map (EGM)
	17b	Terrain Classification Map Superimposed on the EGM
Fig.	18a	Generalised Limitations and Engineering Appraisal Map (GLEAM)
	18b	Terrain Classification Map Superimposed on the GLEAM
Fig.	19a	Landform Map (LM)
	19b	Terrain Classification Map Superimposed on the LM
Fig.	20a	Erosion Map (EM)
	20b	Terrain Classification Map Superimposed on the EM

Full size Islands map sheets in the Map Folder (1:20 000):

Geotechnical Land Use Map (GLUM) (GASP/20/X/1)	Physical Constraints Map (PCM) (GASP/20/X/6)	Engineering Geology Map (EGM) (GASP/20/X/2)	Generalised Limitations and Engineering Appraisal Map (GASP/20/X/15)

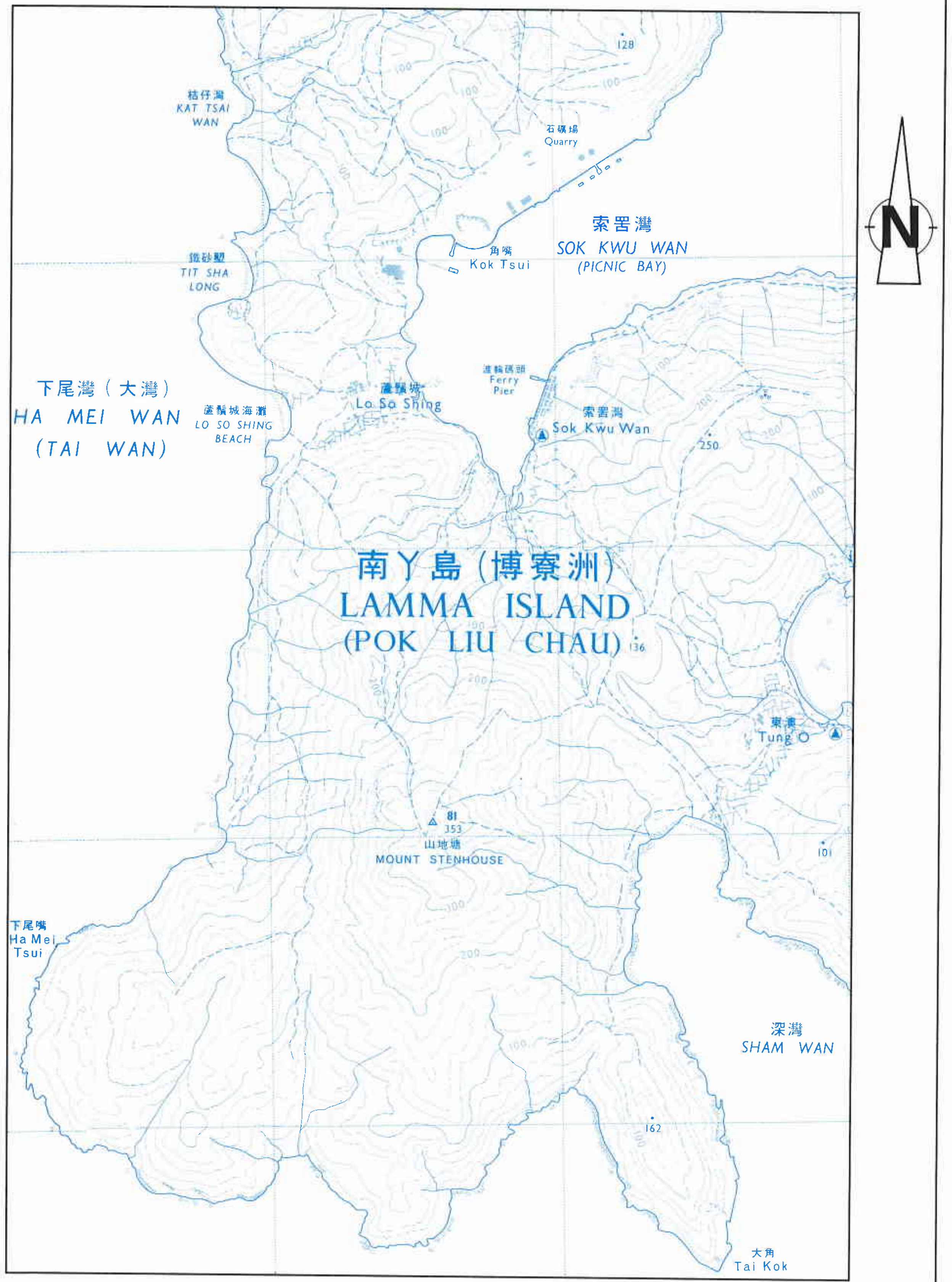
Presentation of Maps — Fig. 13

LEGEND FOR TERRAIN CLASSIFICATION MAP (Fig. 14b)

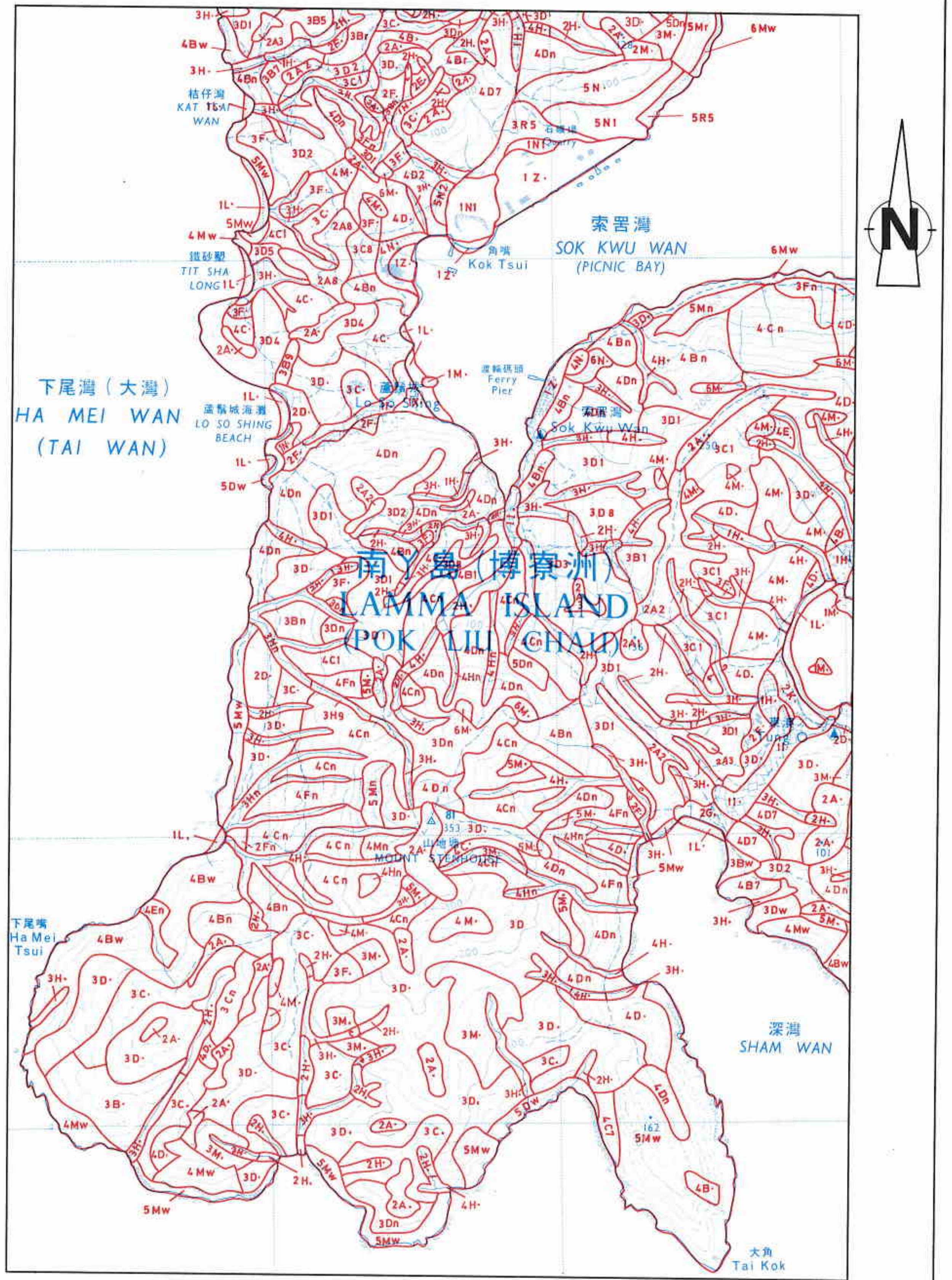
SLOPE GRADIENT	CODE
0 - 5°	1
5 - 15°	2
15 - 30°	3
30 - 40°	4
40 - 60°	5
> 60°	6

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
Rock outcrop	M
Cut - straight	N
- concave	O
- convex	P
Fill-straight	R
-concave	S
-convex	T
General disturbed terrain	V
Wave cut platform	W
Alluvial plain	X
Reclamation	Z
Waterbodies - Natural stream	1
- Man-made 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	a
General instability) recent	n
General instability) relict	r
Coastal instability	w



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



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

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

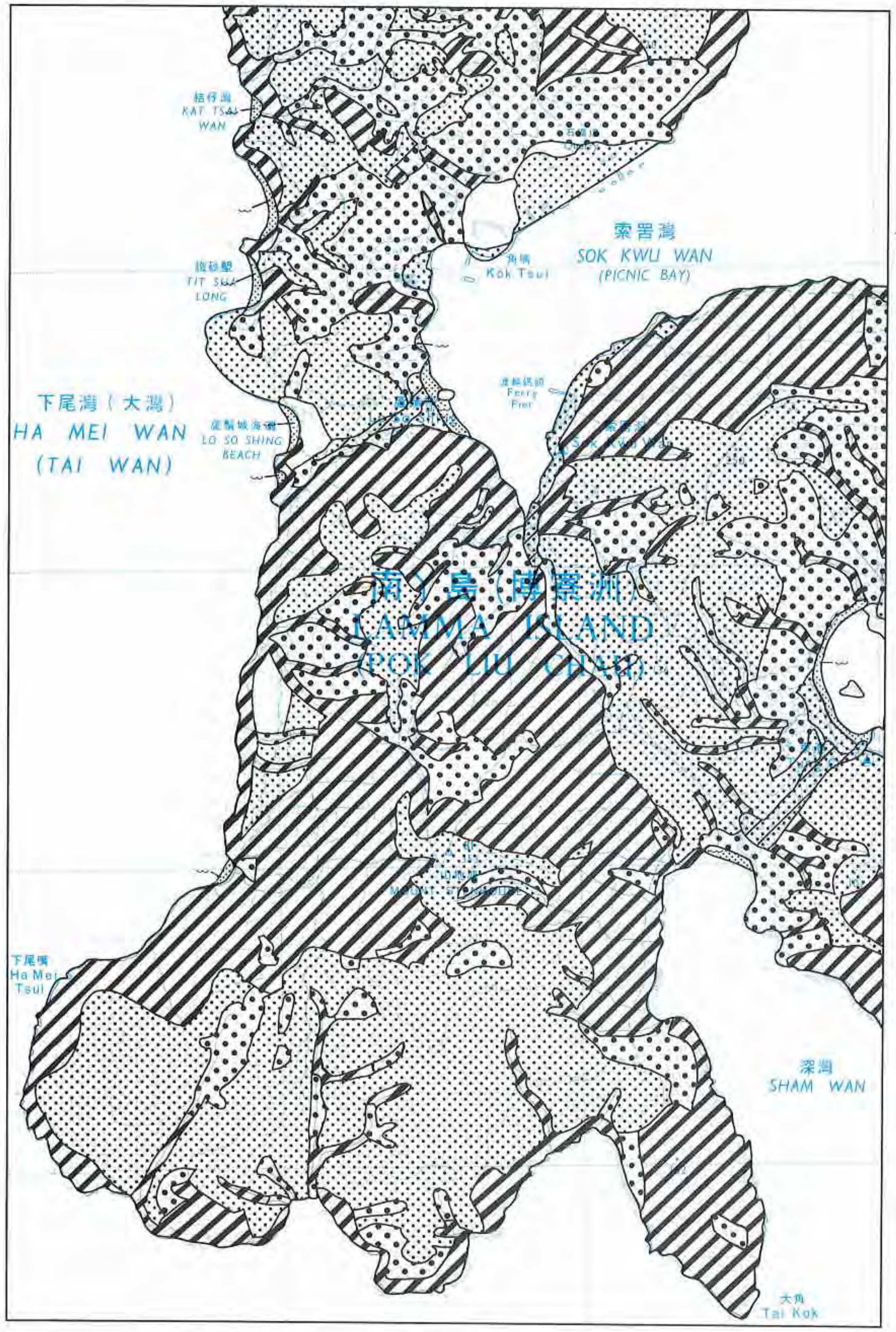
- Class I - Low Geotechnical Limitations
- Class II - Moderate Geotechnical Limitations
- Class IIS - Moderate Geotechnical Limitations (including flooding)
- Class III - High Geotechnical Limitations
- Class IV - Extreme Geotechnical Limitations
- Waterbodies (streams, man-made channels, storage dams))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

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
Rock outcrop	M
Cut - straight	N
- concave	O
- convex	P
Fill-straight	R
-concave	S
-convex	T
General disturbed terrain	V
Wave cut platform	W
Alluvial plain	X
Reclamation	Z
Waterbodies - Natural stream	1
- Man-made 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	a
General) recent	n
instability) relict	r
Coastal instability	w



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)

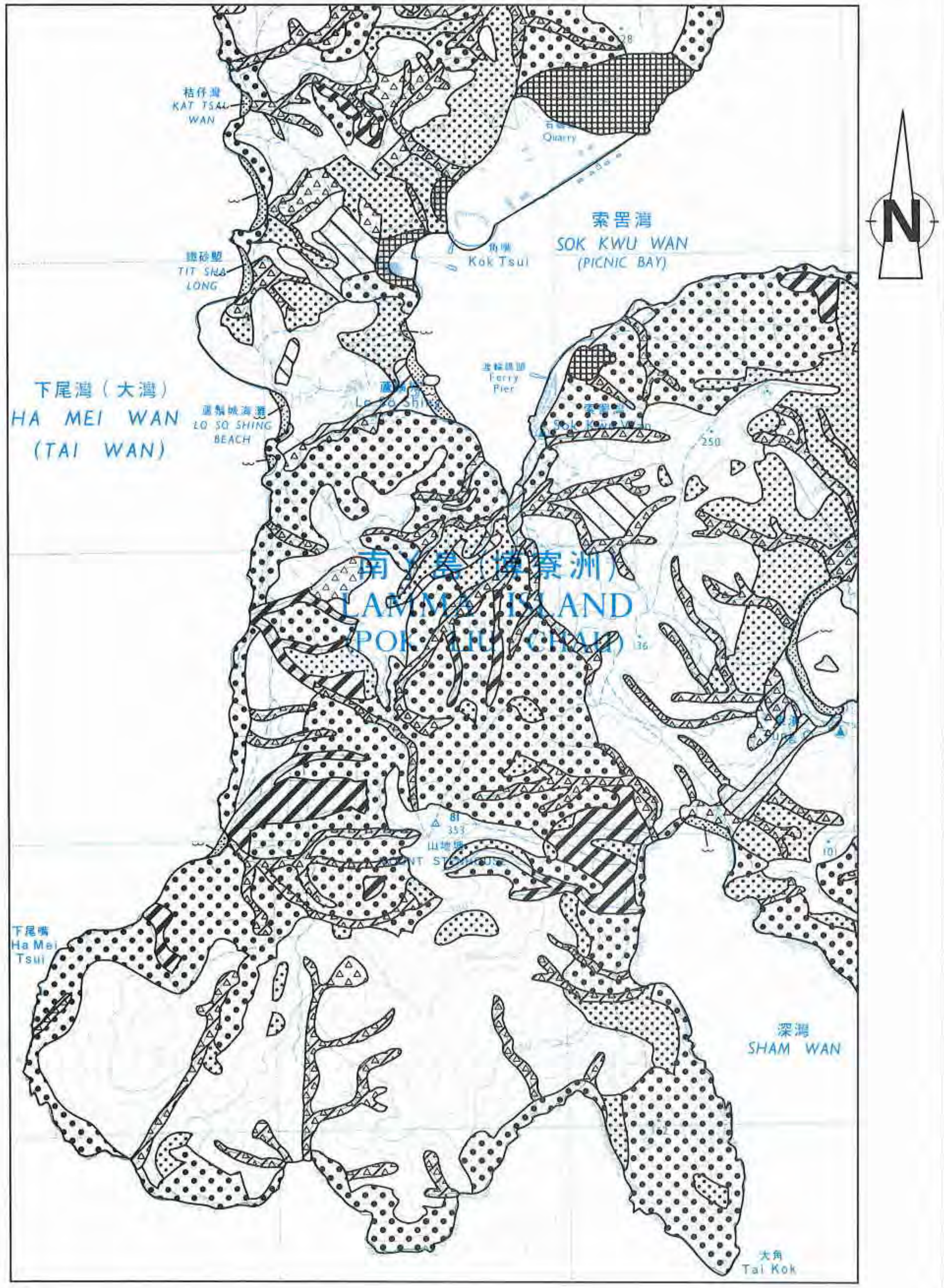
- Colluvium
- Zones of colluvium which are subject to overland flow and periodic inundation. Evidence of unusual groundwater regime (delineated as drainage plain on Landform Map)
- Floodplain - subject to overland flow and regular inundation. Evidence of unusual groundwater regime (delineated as floodplain 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)
- Wave cut platform

LEGEND FOR TERRAIN CLASSIFICATION MAP (Fig 16b)

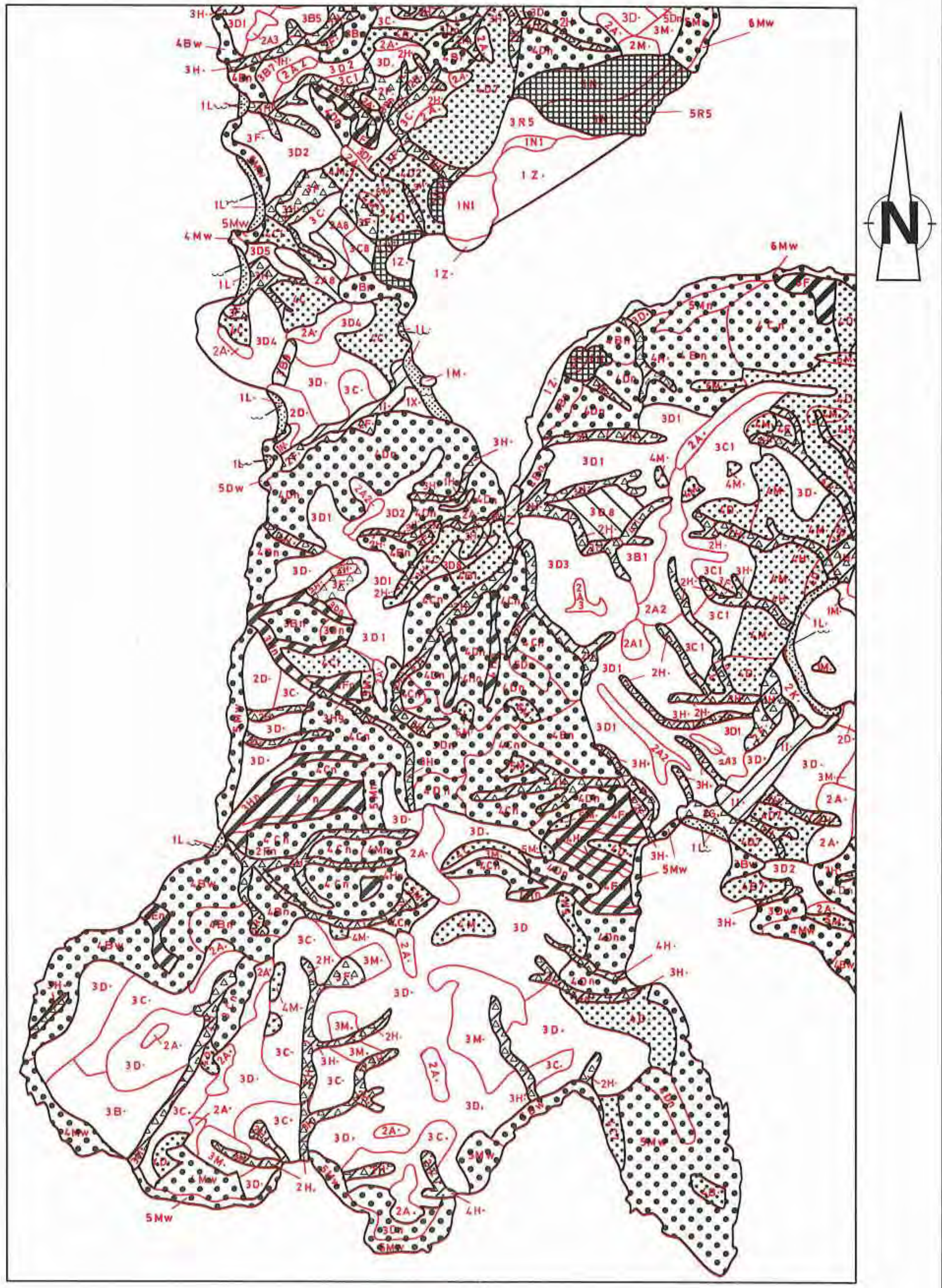
SLOPE GRADIENT	CODE
0 - 5°	1
5 - 15°	2
15 - 30°	3
30 - 40°	4
40 - 60°	5
> 60°	6

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
Rock outcrop	M
Cut - straight	N
- concave	O
- convex	P
Fill-straight	R
-concave	S
-convex	T
General disturbed terrain	V
Wave cut platform	W
Alluvial plain	X
Reclamation	Z
Waterbodies - Natural stream	1
- Man-made 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	a
General instability) recent	n
General instability) relict	r
Coastal instability	w



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	Undifferentiated volcanic rocks
Reclamation	Coarse tuffs
Littoral deposits	Geological cross-section line (A – A')
Alluvium (undifferentiated)	Catchment boundary with order shown
Colluvium (undifferentiated)	Geological boundary, position approximate.
Cheung Chau Granite	Geology boundary (superficial)
Ma On Shan Granite	Trace of dyke & vein (certain)
Sung Kong Granite (SK)	Trace of dyke & vein (uncertain)
Fan Lau Porphyritic Granite	Geological photolineament (approximate)
Undifferentiated granitic rock	Isopachs of submarine superficial deposit (metres)
Granophyric microgranite (MC)	Depth in fathoms
Feldspar porphyry dyke swarm	General instability
Quartz monzonite and porphyritic adamellite	
Tai Po Granodiorite	

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
Rock outcrop	M
Cut - straight	N
- concave	O
- convex	P
Fill-straight	R
-concave	S
-convex	T
General disturbed terrain	V
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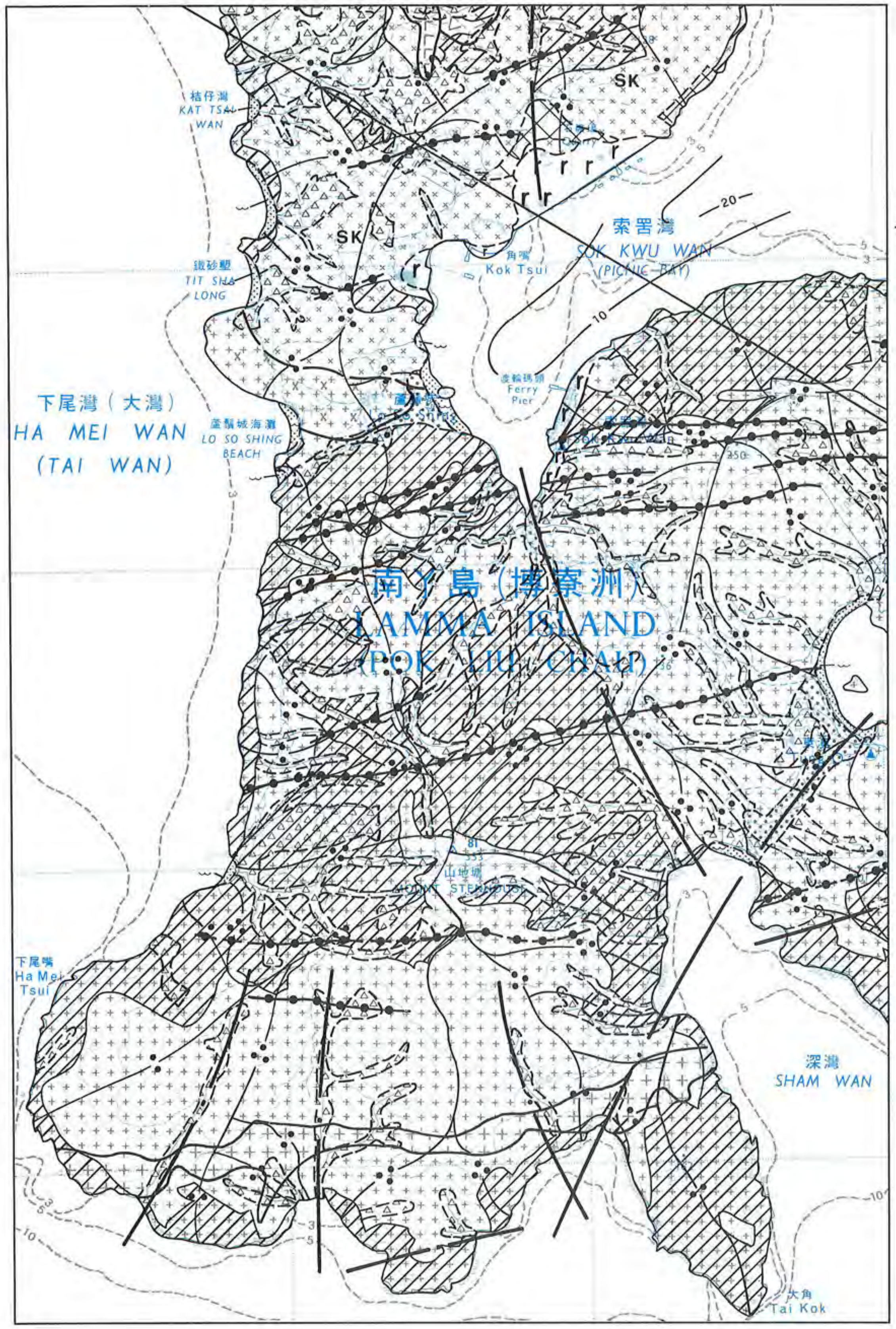
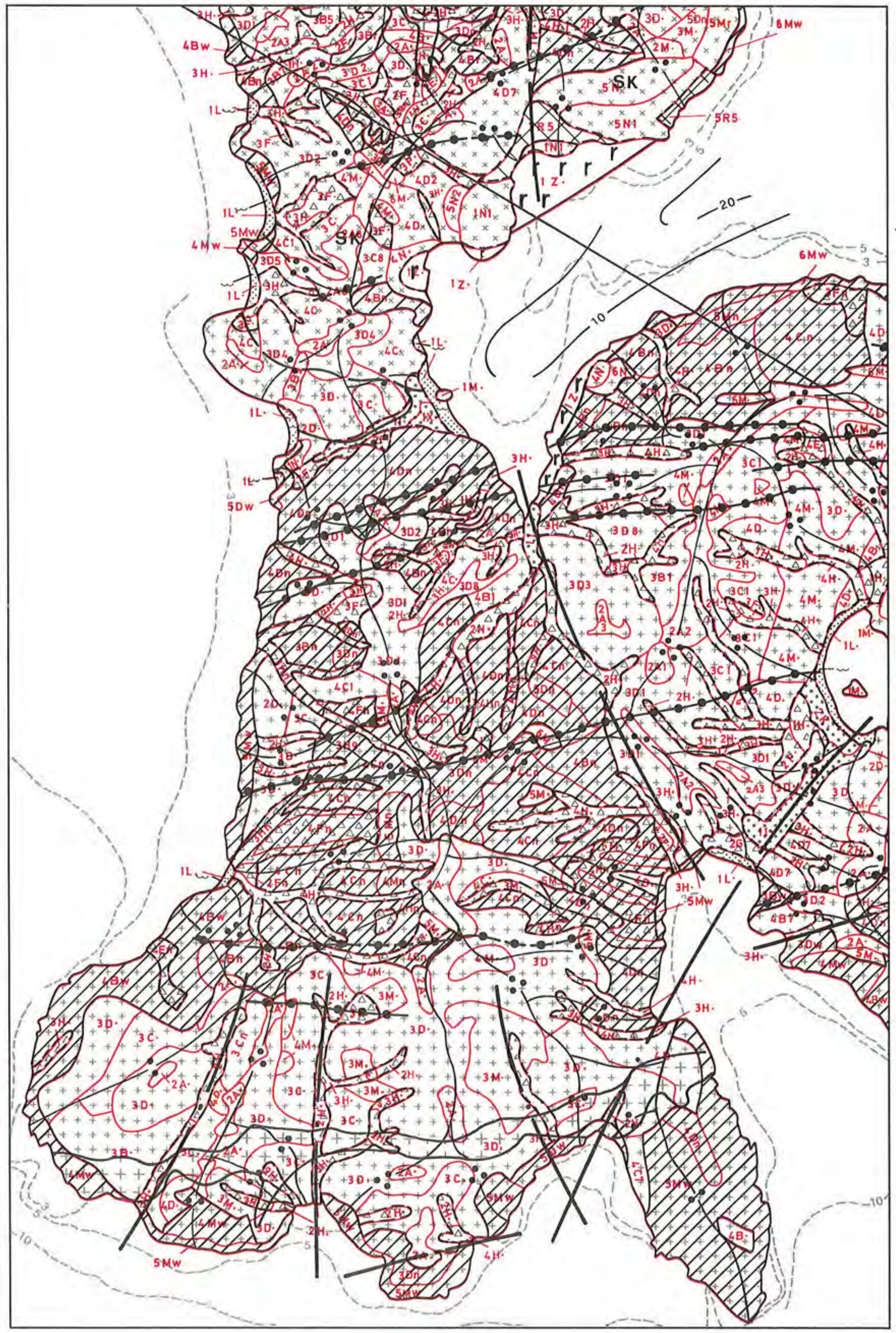
Alluvial plain	X
Reclamation	Z
Waterbodies - Natural stream	1
- Man-made channel	2
- Water storage dam	3
- Fish pond	4

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	a
General instability) recent	n
) relict	r
Coastal instability	w



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 GENERALISED LIMITATIONS AND ENGINEERING APPRAISAL MAP (Fig. 18a)

DEVELOPMENT PLANNING ZONES

- Zone of potential for development (assessed in geotechnical terms)
- Zone of local geotechnical constraints (identified on PCM) within general PDA
- Zone of constraints for development (assessed principally in geotechnical terms)
- Zone of existing development, (based on principal use of 2ha GEOTECS grid unit)
- —c— Catchwater

NOTE: Numerals on map refer to relevant general planning/engineering notes

Abbreviations

Dp.	Deep
Mod.	Moderate
Sh.	Shallow
Sl.	Slopes
St.	Steep
W.	Weathering
PDA	Potential development areas

FEATURES OF ENGINEERING SIGNIFICANCE

- Geological photolineament
- —R— Ridgeline
- =D=DI= Drainage, incised drainage
- Coll. Colluvium in PDA
- B> Boulders
- Steeper slopes influencing area (orientation of symbols indicates downslope direction)
- Instability influencing area
- Potential for borrow or extensive cut and fill : opportunity to create site formation in 'constrained' area, or larger site formation in 'potential' area.

NOTE

i) Features are generally indicated only where significance to identified potential development areas.

ii) For explanation of significance of identified features, see Report Appendix A, Table A5, and Section 4.2.

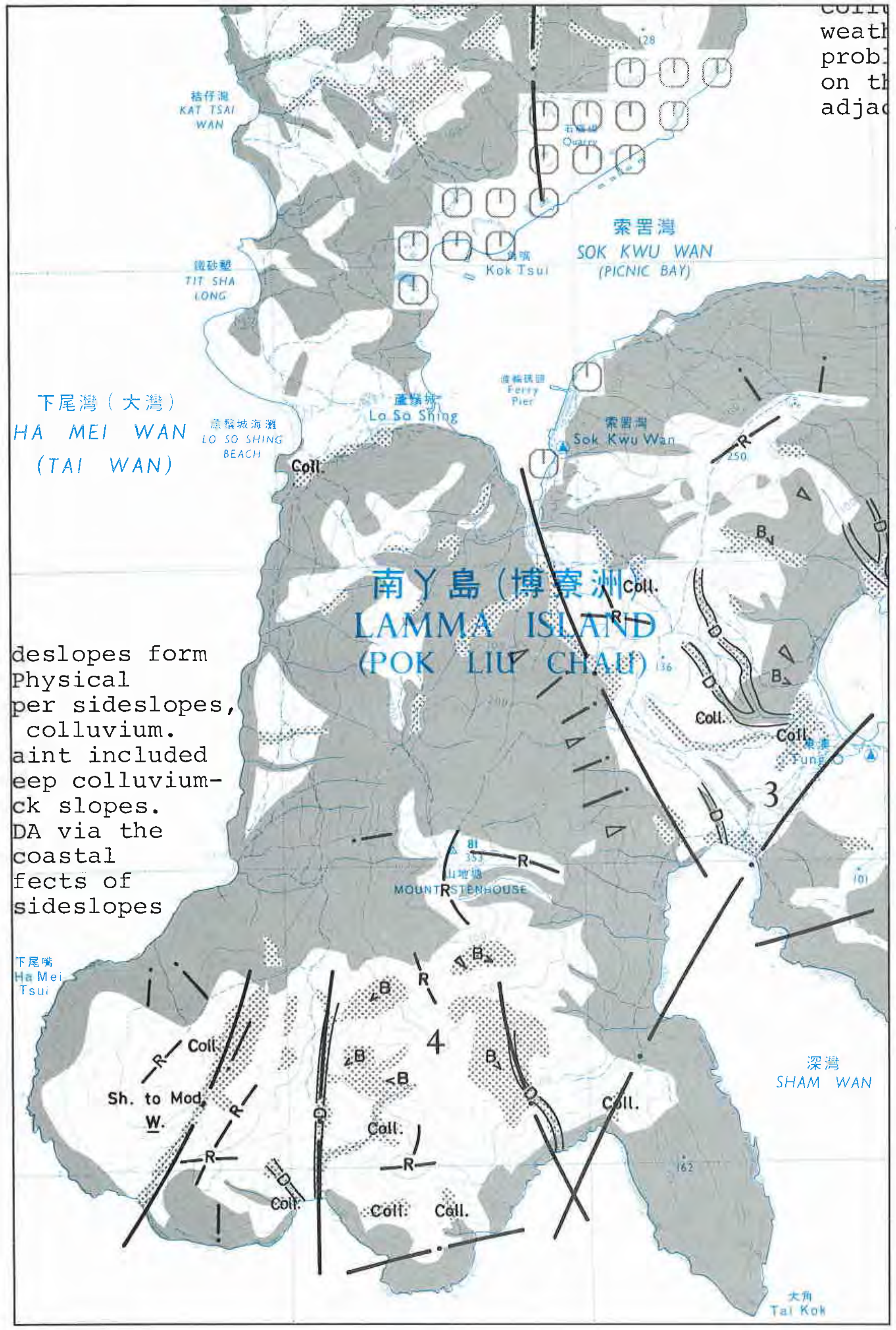
iii) Geological boundaries and photolineaments are shown in full on the EGM. Those lineaments indicated represent the surface expression of obvious structural discontinuities which affect the PDAs.

LEGEND FOR TERRAIN CLASSIFICATION MAP (Fig. 18b)

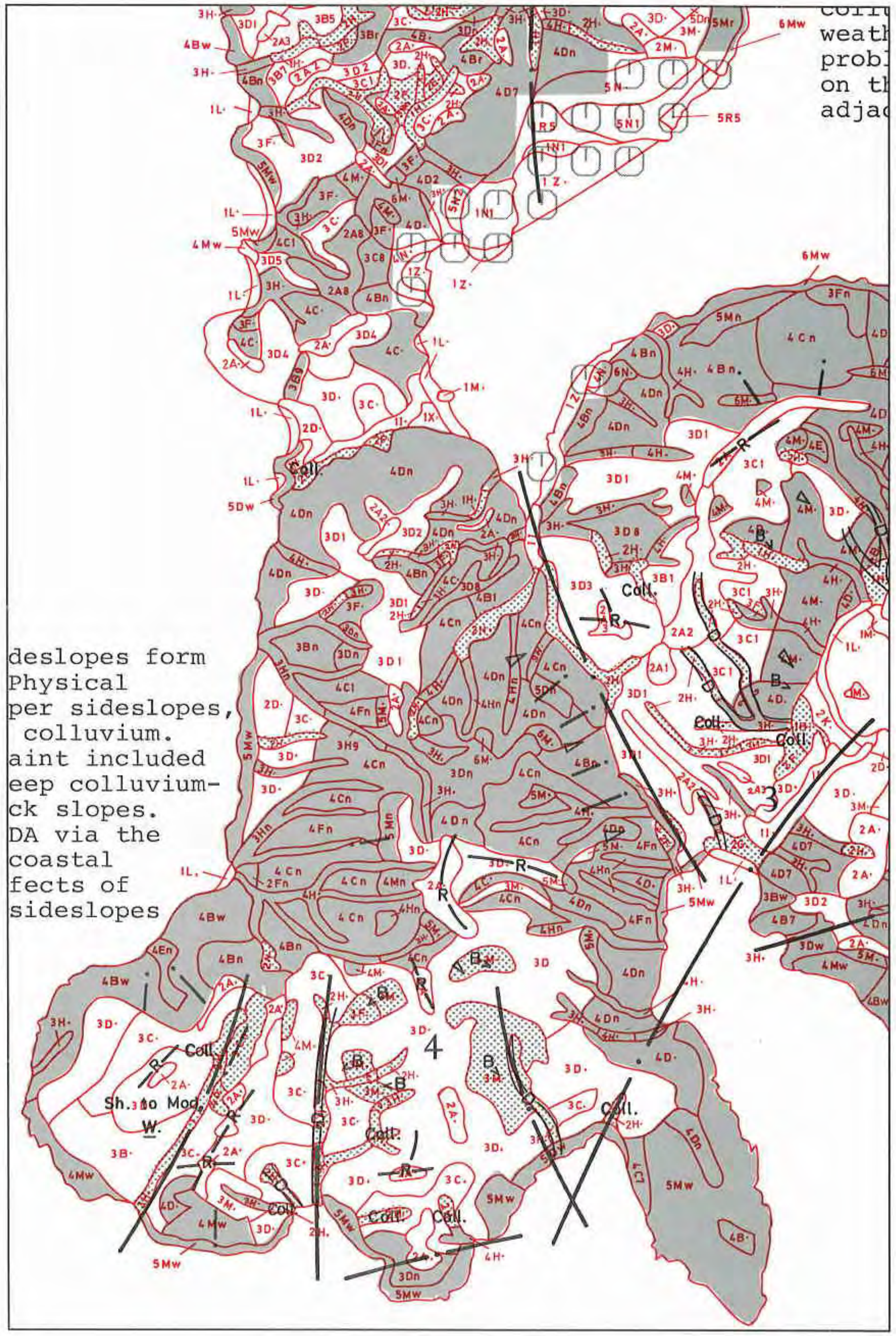
SLOPE GRADIENT	CODE
0 - 5°	1
5 - 15°	2
15 - 30°	3
30 - 40°	4
40 - 60°	5
> 60°	6

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
Rock outcrop	M
Cut - straight	N
- concave	O
- convex	P
Fill-straight	R
-concave	S
-convex	T
General disturbed terrain	V
Wave cut platform	W
Alluvial plain	X
Reclamation	Z
Waterbodies - Natural stream	1
- Man-made 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	a
General instability) recent	n
) relict	r
Coastal instability	w



Scale 1:20 000	Example of the Generalised Limitations and Engineering Appraisal Map (GLEAM)	Fig. 18a



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

LEGEND FOR LANDFORM MAP (Fig. 19a)

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

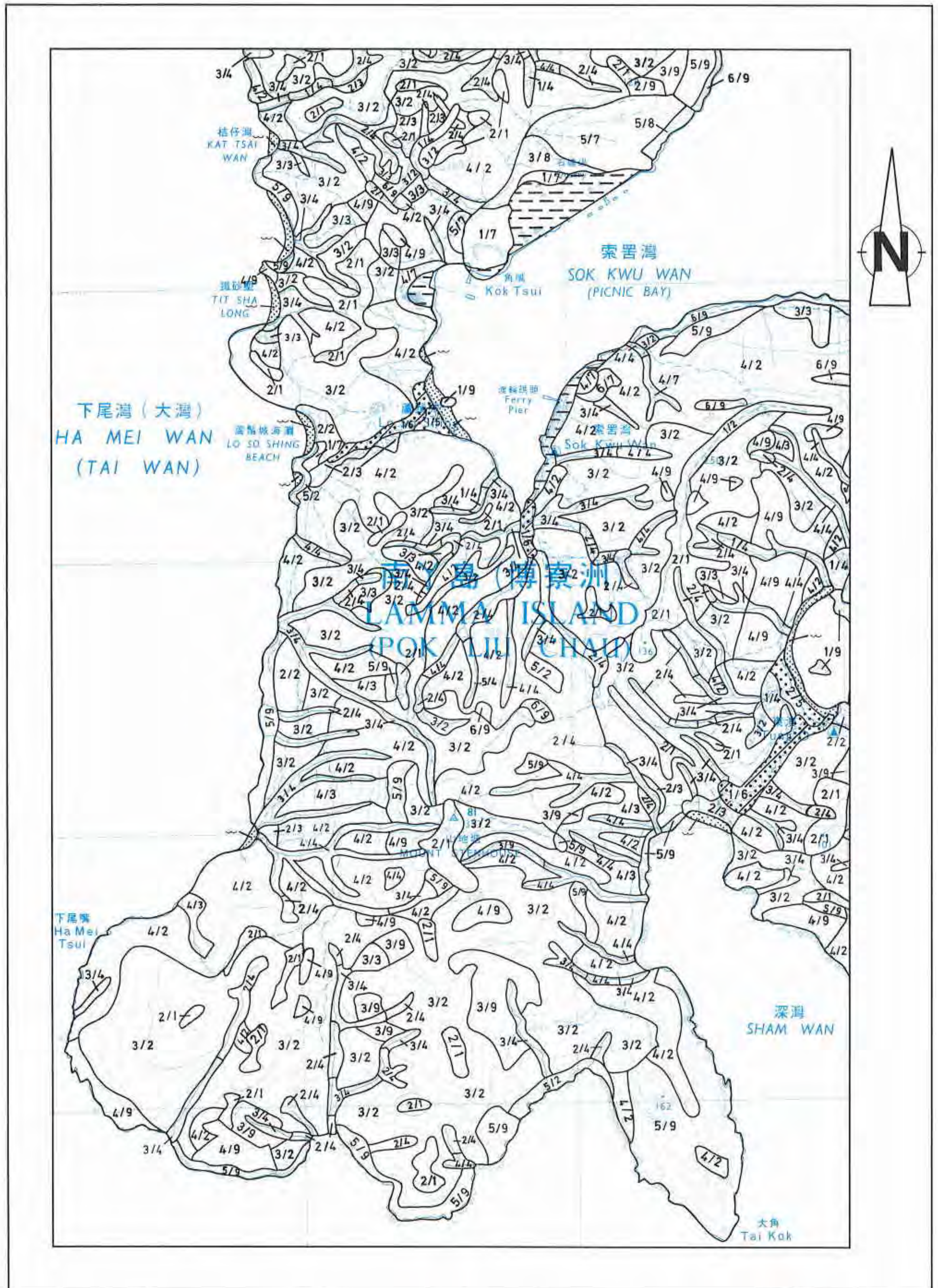
DESCRIPTION	CODE
Crest or ridge	1
Sideslope - insitu	2
Footslope - colluvium	3
Drainage plain - colluvium subject to overland flow and regular inundation. Unusual groundwater regime.	4
Alluvial plain - includes raised terraces.	5
Flood plain - portion of alluvial plain subject to overland flow and regular 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)	
Wave cut platform	

LEGEND FOR TERRAIN CLASSIFICATION MAP (Fig. 19b)

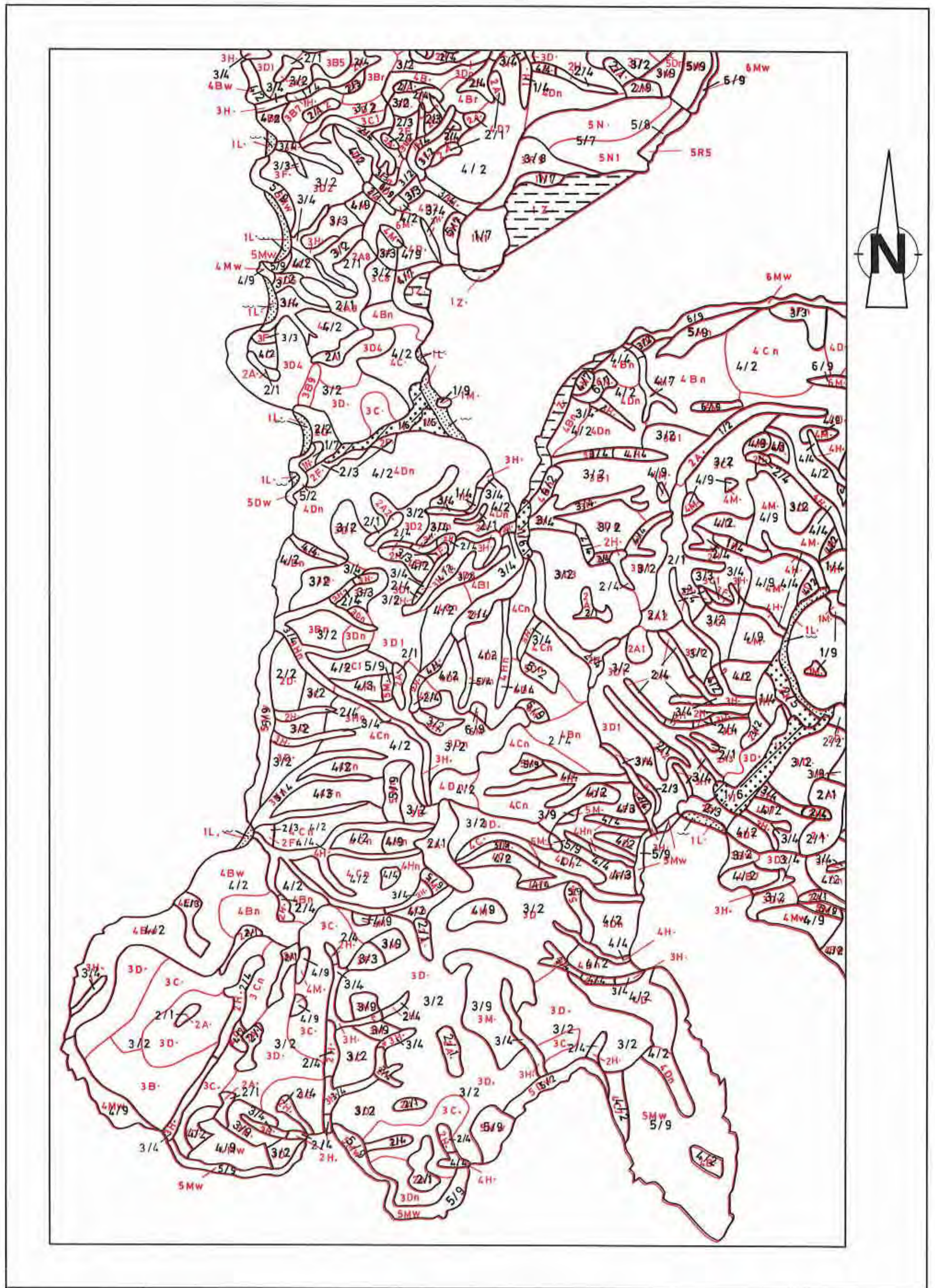
SLOPE GRADIENT	CODE
0 - 5°	1
5 - 15°	2
15 - 30°	3
30 - 40°	4
40 - 60°	5
> 60°	6

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
Rock outcrop	M
Cut - straight	N
- concave	O
- convex	P
Fill-straight	R
-concave	S
-convex	T
General disturbed terrain	V
Wave cut platform	W
Alluvial plain	X
Reclamation	Z
Waterbodies - Natural stream	1
- Man-made 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	a
General instability) recent	n
) relict	r
Coastal instability	w



Scale	Example of the Landform Map (LM)	Fig. 19a
1:20 000		



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

LEGEND FOR EROSION MAP (Fig. 20a)

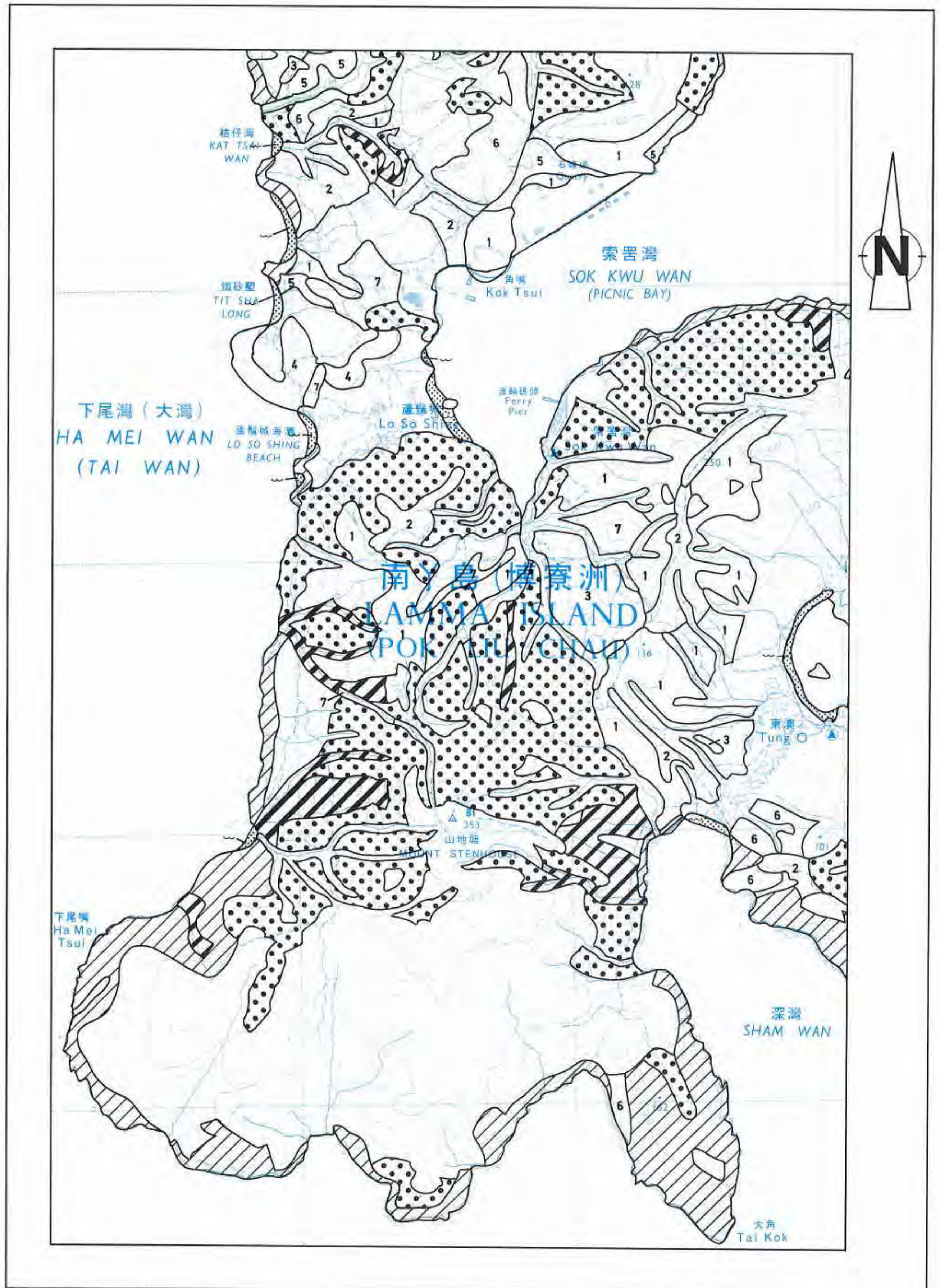
(blank box)	No appreciable erosion
1	Minor sheet erosion
2	Moderate sheet erosion
3	Severe sheet erosion
4	Minor rill erosion
5	Moderate to severe rill erosion
6	Minor gully erosion
7	Moderate to severe gully erosion
	Zones of general instability associated with predominantly insitu terrain
	Zones of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

LEGEND FOR TERRAIN CLASSIFICATION MAP (Fig. 20b)

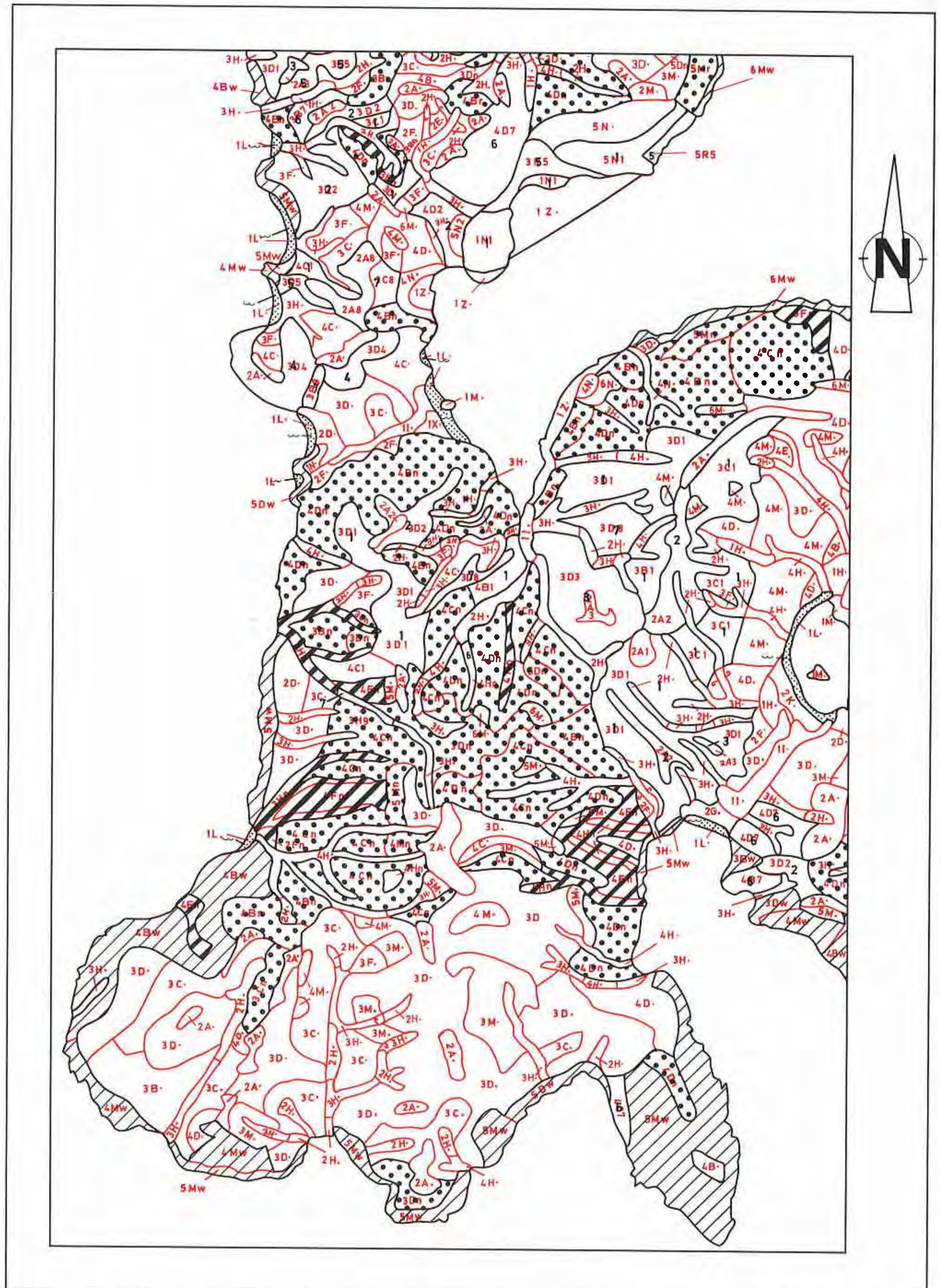
SLOPE GRADIENT	CODE
0 - 5°	1
5 - 15°	2
15 - 30°	3
30 - 40°	4
40 - 60°	5
> 60°	6

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
Rock outcrop	M
Cut - straight	N
- concave	O
- convex	P
Fill-straight	R
-concave	S
-convex	T
General disturbed terrain	V
Wave cut platform	W
Alluvial plain	X
Reclamation	Z
Waterbodies - Natural stream	1
- Man-made 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	a
General instability) recent	n
General instability) relict	r
Coastal instability	w



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



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

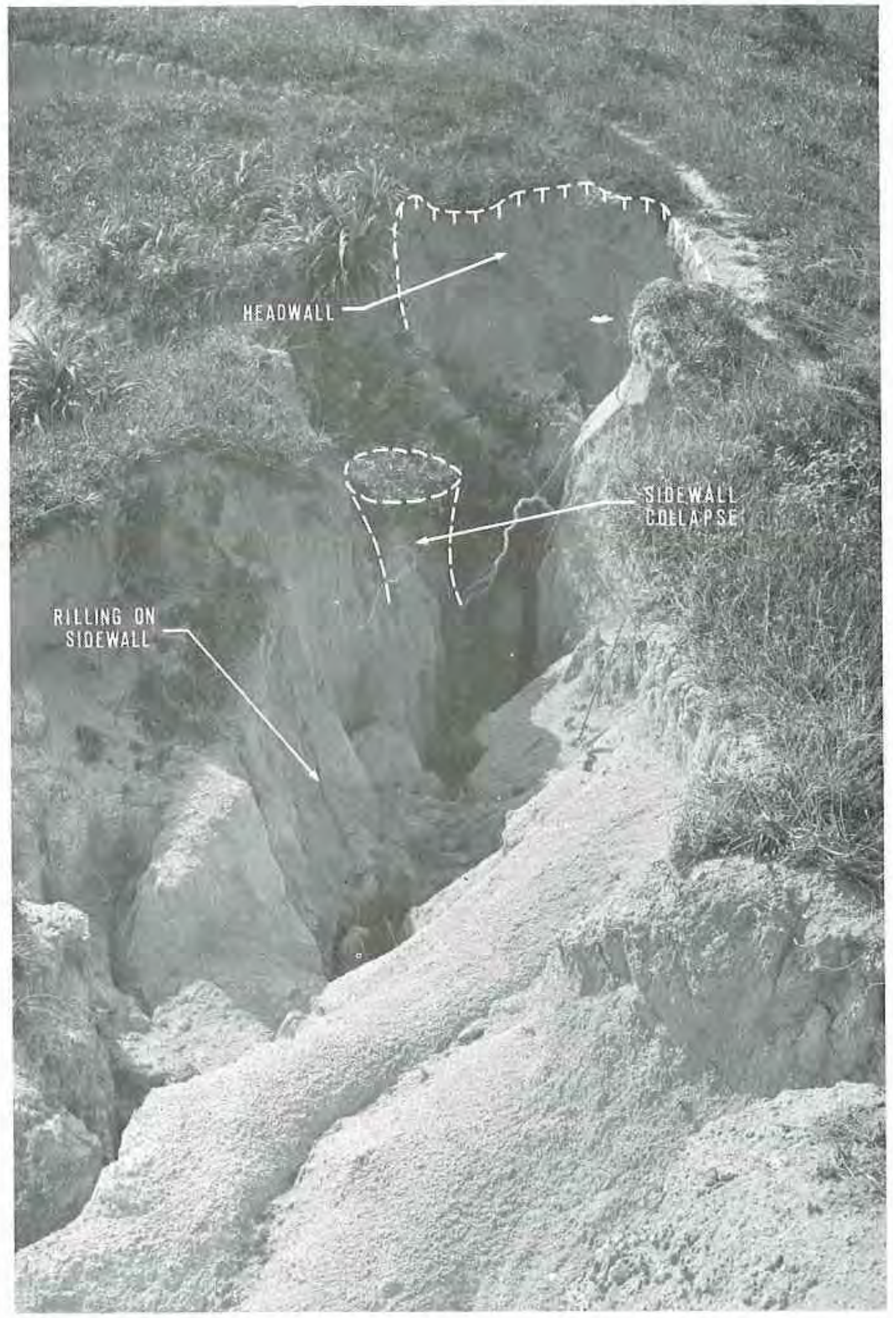


Plate 1. Gully Erosion in Cheung Chau Granite. The Plate shows a deeply incised gully with an actively eroding headwall, in completely weathered granite. The weathered rock consists of weathering Grades IV, V and VI. (GCO/TP 1984/52–18).

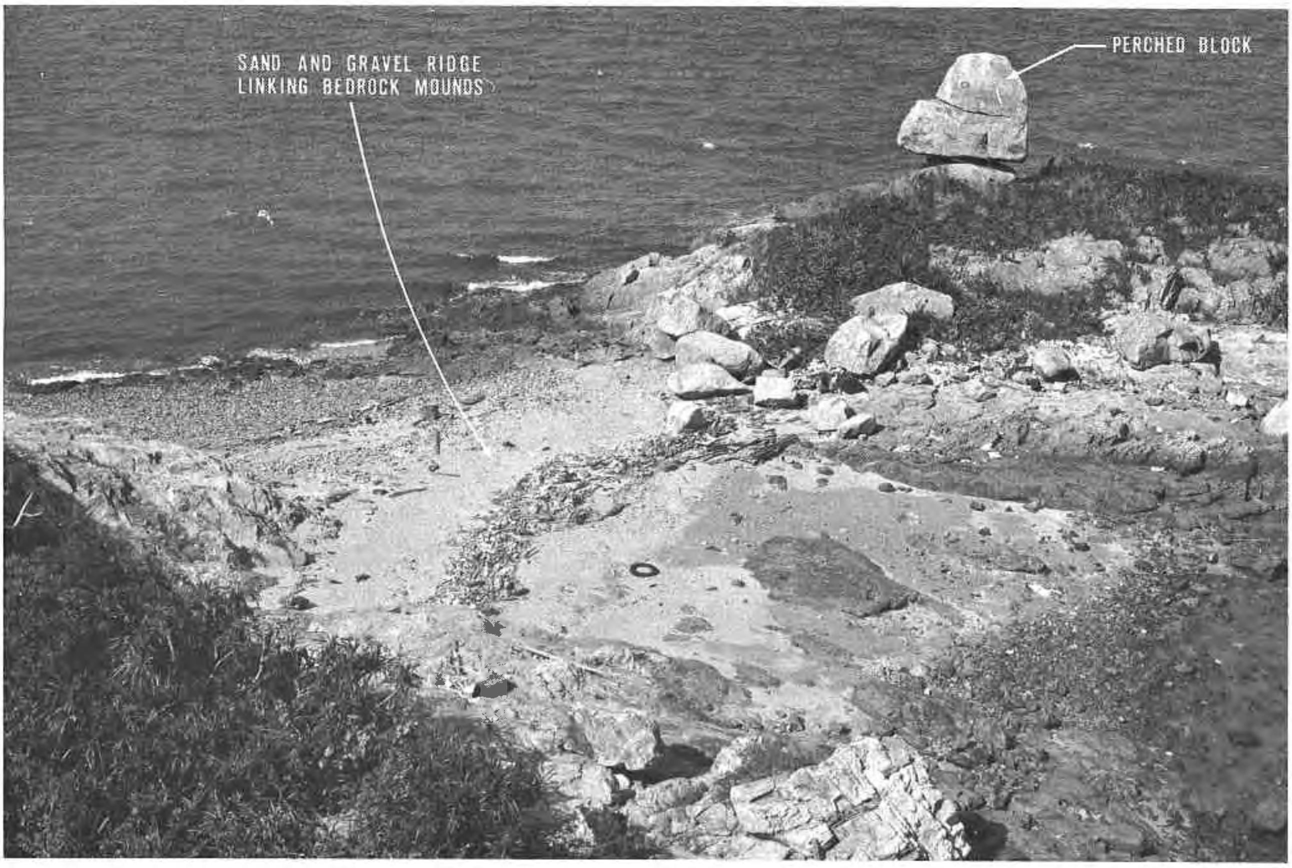


Plate 2. Small Tombolo on Peng Chau. The main island of Peng Chau is linked to a small islet by a sandbar formed by longshore drift. (GCO/TP 1984/49–30).

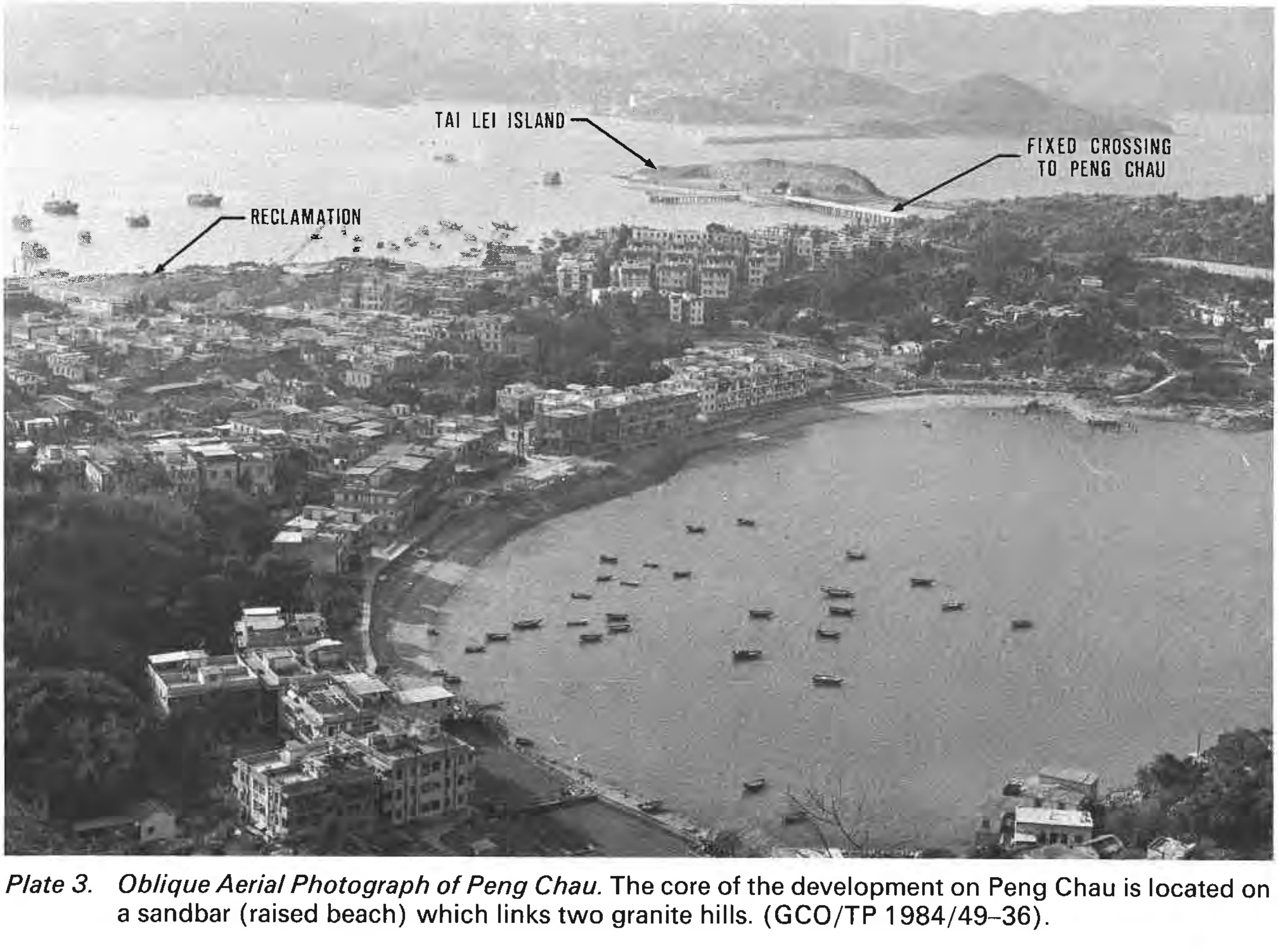


Plate 3. Oblique Aerial Photograph of Peng Chau. The core of the development on Peng Chau is located on a sandbar (raised beach) which links two granite hills. (GCO/TP 1984/49–36).

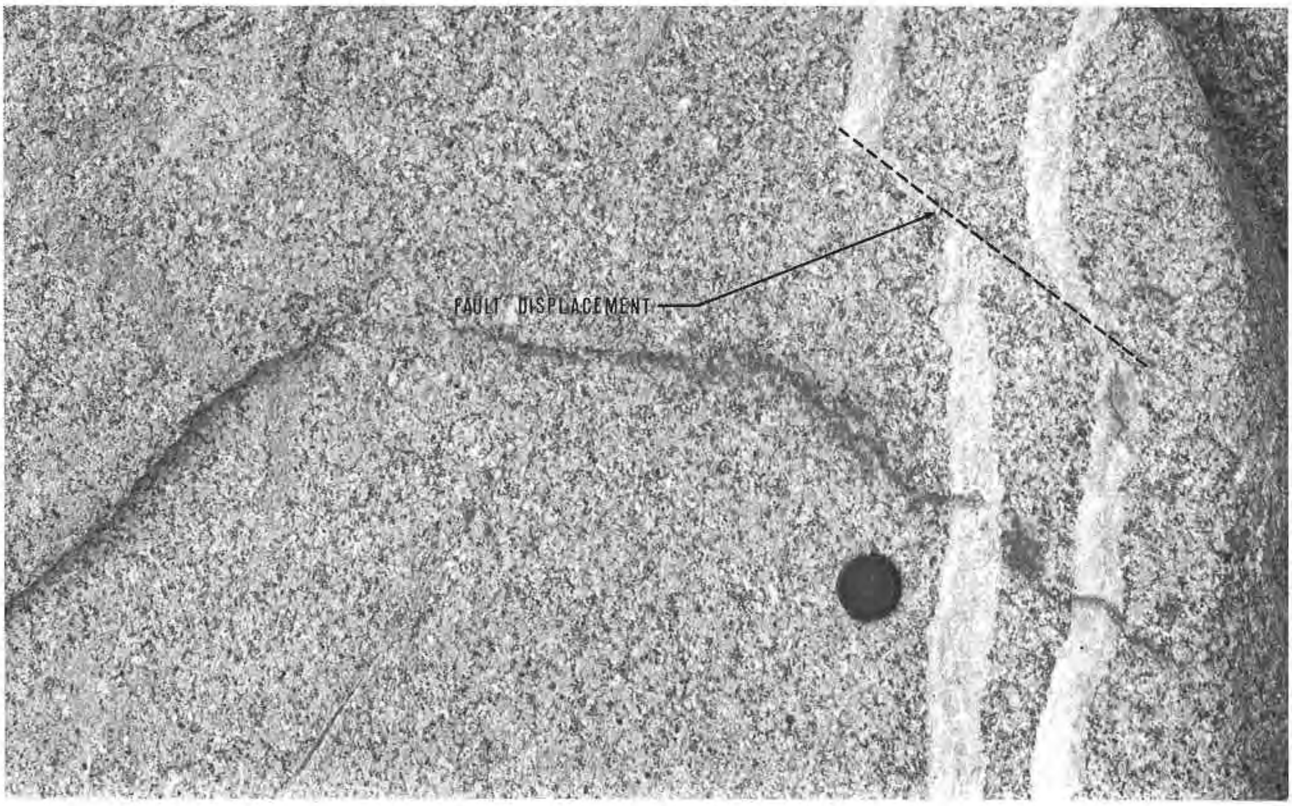


Plate 4. Sung Kong Granite with Faulted Quartz Veins. (GCO/TP 1984/48–27).

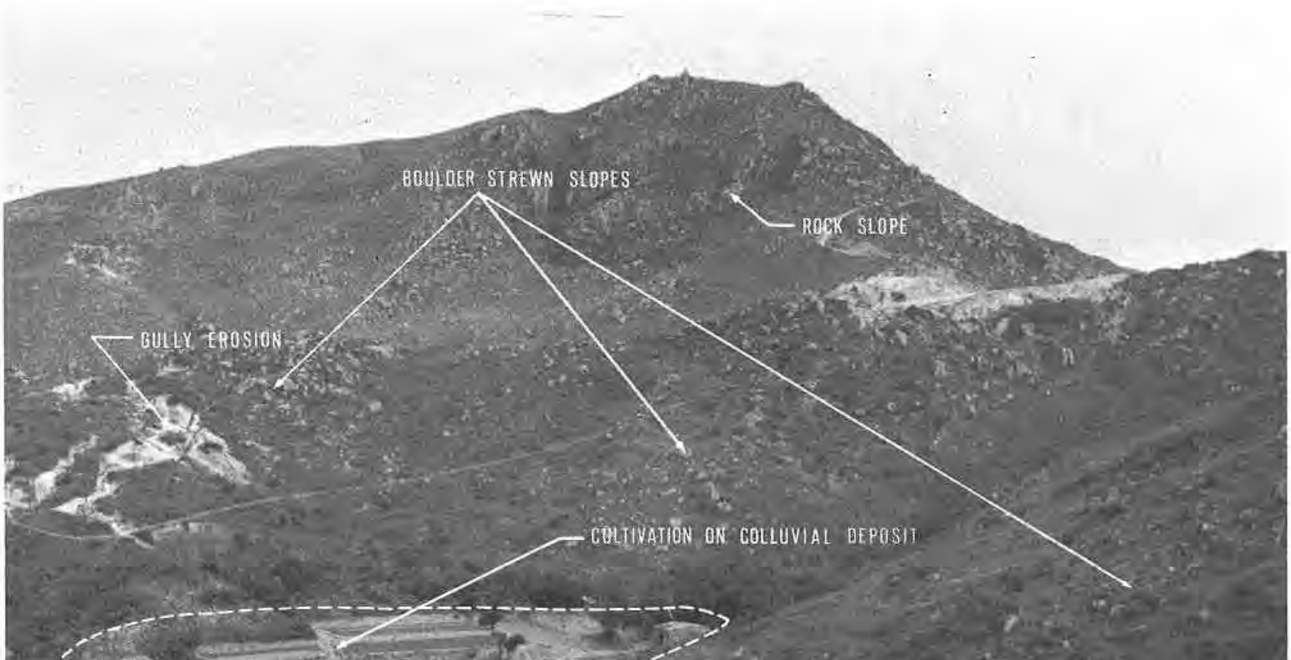


Plate 5. Sideslope and Footslope Terrain on Lamma Island. Boulder-strewn sideslopes formed from Sung Kong Granite are adjacent to eroded spurcrests. Material transported downslope from the eroding sideslopes is deposited in the valley floor, where it is often formed into agricultural terraces. (GCO/TP 1984/48–20).

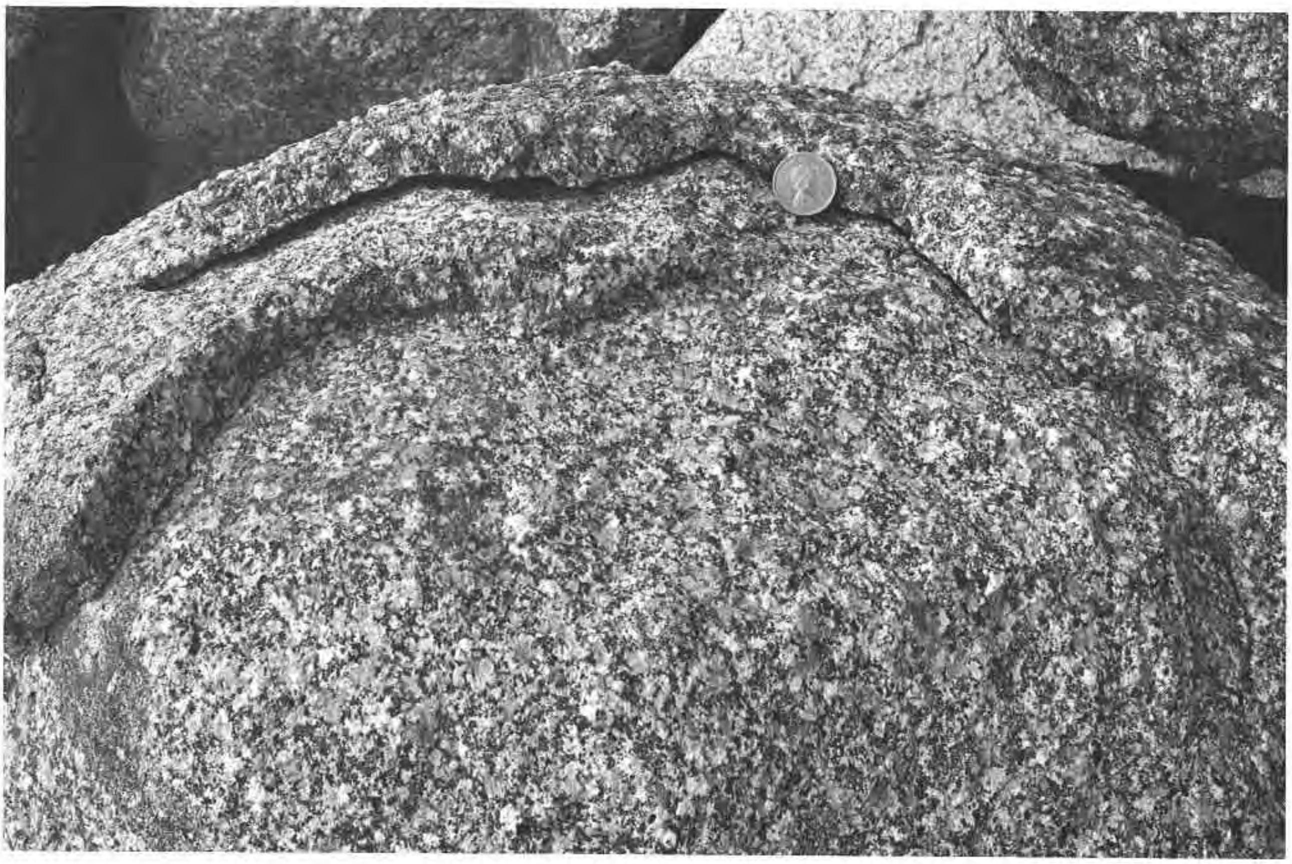


Plate 6. Exfoliation in Tai Po Granodiorite This boulder displays well-developed spheroidal (onion skin) weathering. (GCO/TP 1984/48–28).

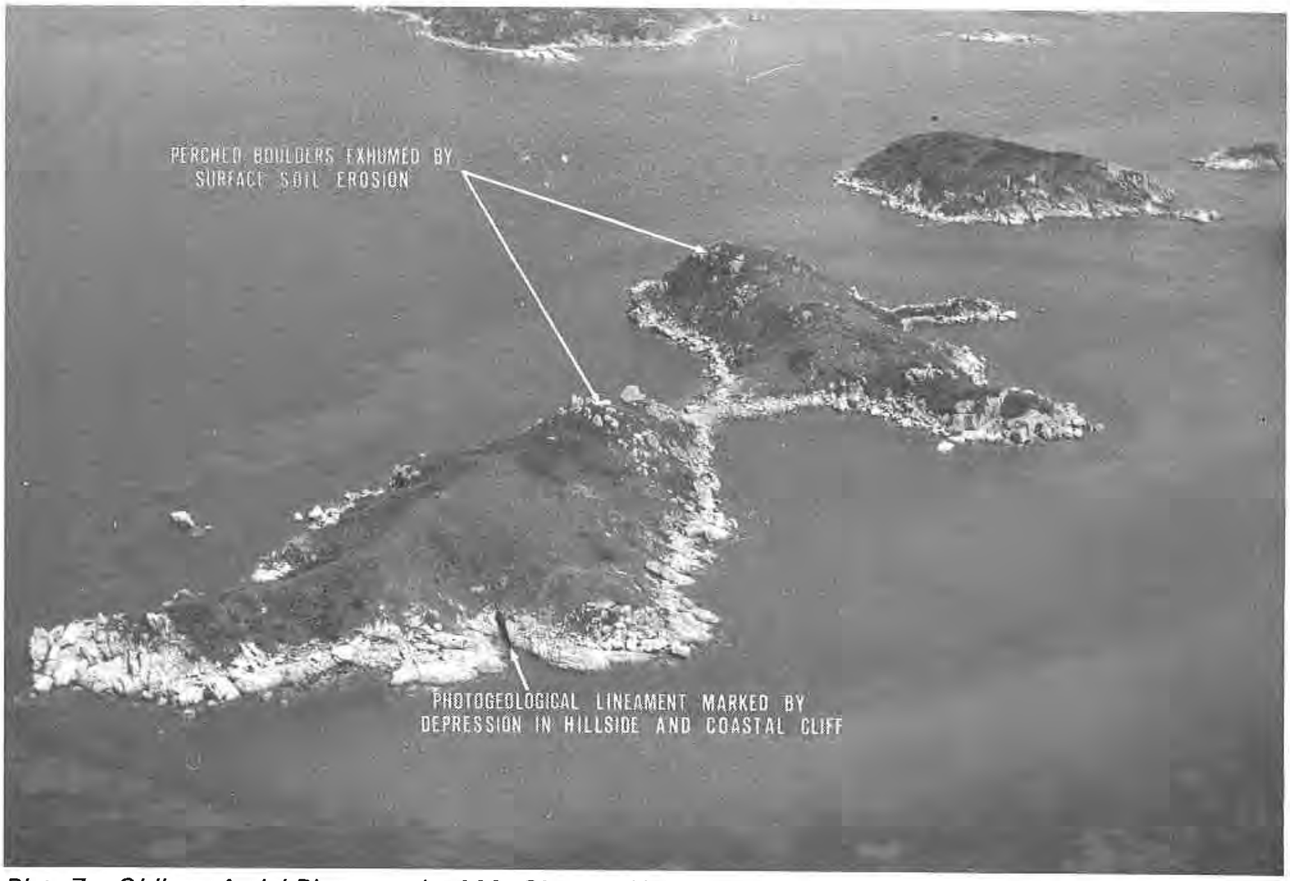


Plate 7. Oblique Aerial Photograph of Ma Chau and Yuen Chau (Soko Islands). These uninhabited islands are composed of the well-jointed Fan Lau Porphyritic Granite. (GCO/OAP 1984/10802).

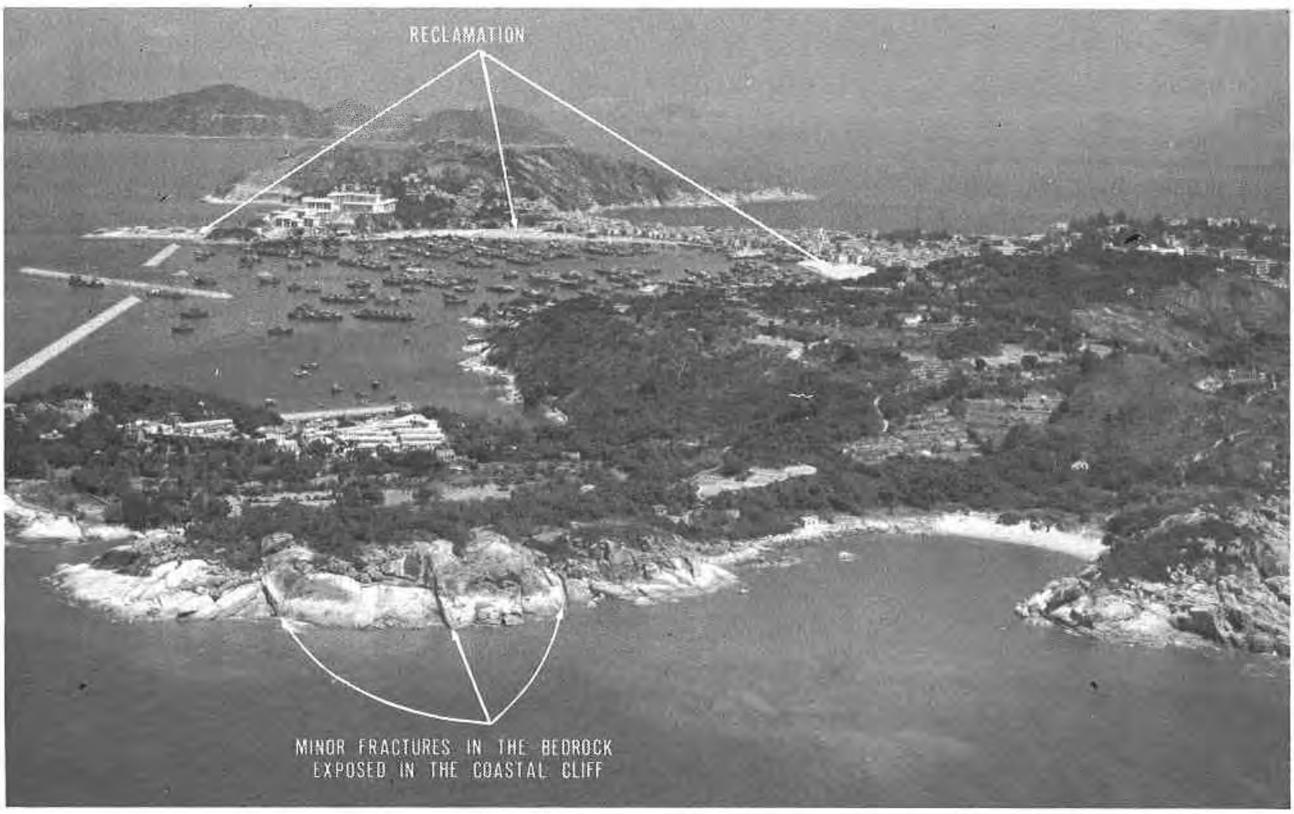


Plate 8. Oblique Aerial Photograph of Cheung Chau. The narrow raised beach linking the granite hills has been utilised for urban development. (GCO/OAP 1984/10713).

Plate 9. Oblique Aerial Photograph of Siu A Chau (Soko Islands). The extremely bouldery and barren terrain consists mainly of Sung Kong Granite, Fan Lau Porphyritic Granite and the Feldspar Porphyry Dyke Swarm. A minor sandbar links the rock outcrop in the foreground to the rest of the island. (GCO/OAP 1984/10811).

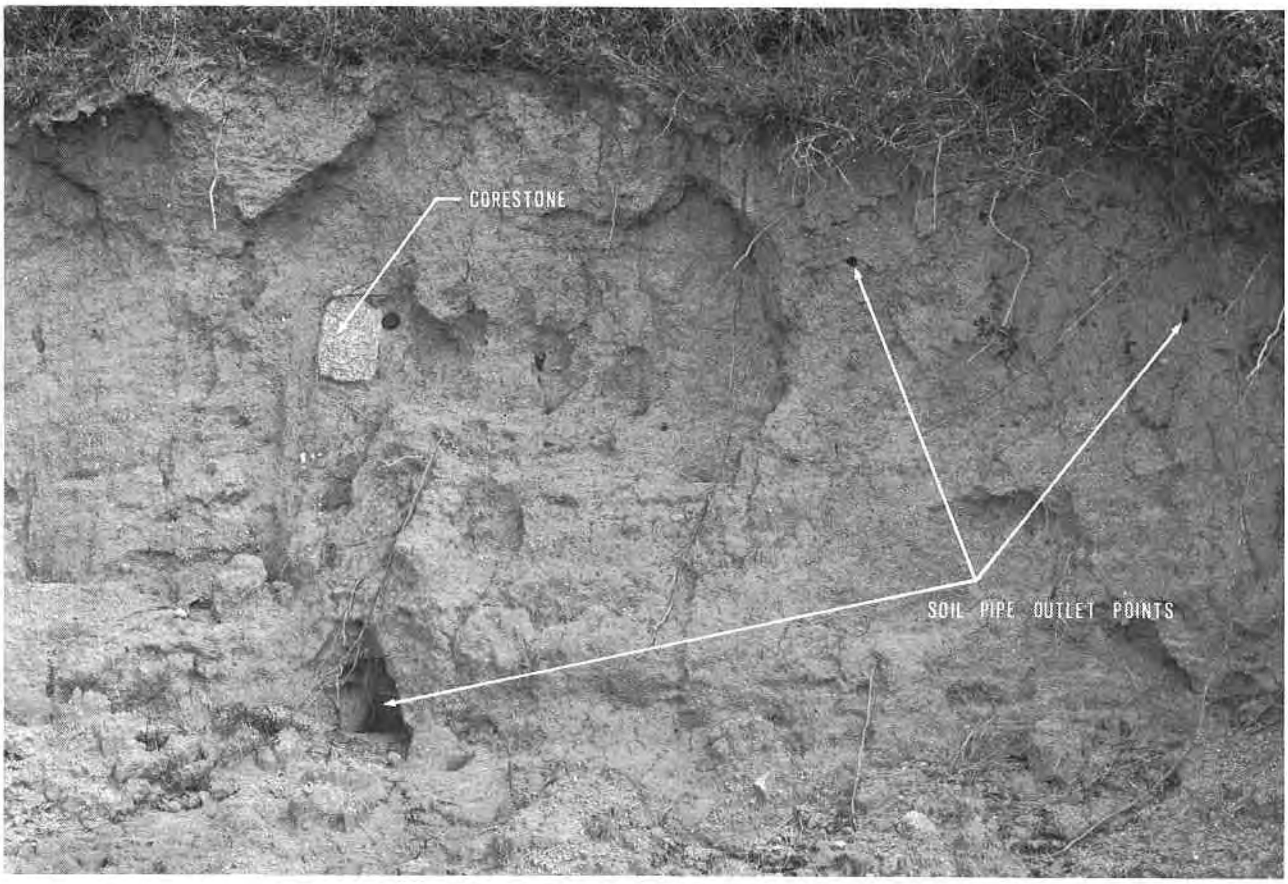


Plate 10. Weathered Tai Po Granodiorite with Corestone. (GCO/TP 1984/48–24).

Plate 11. Oblique Aerial Photograph of Shek Kwu Chau. This island is composed almost entirely of Cheung Chau Granite. (GCO/OAP 1984/10711).

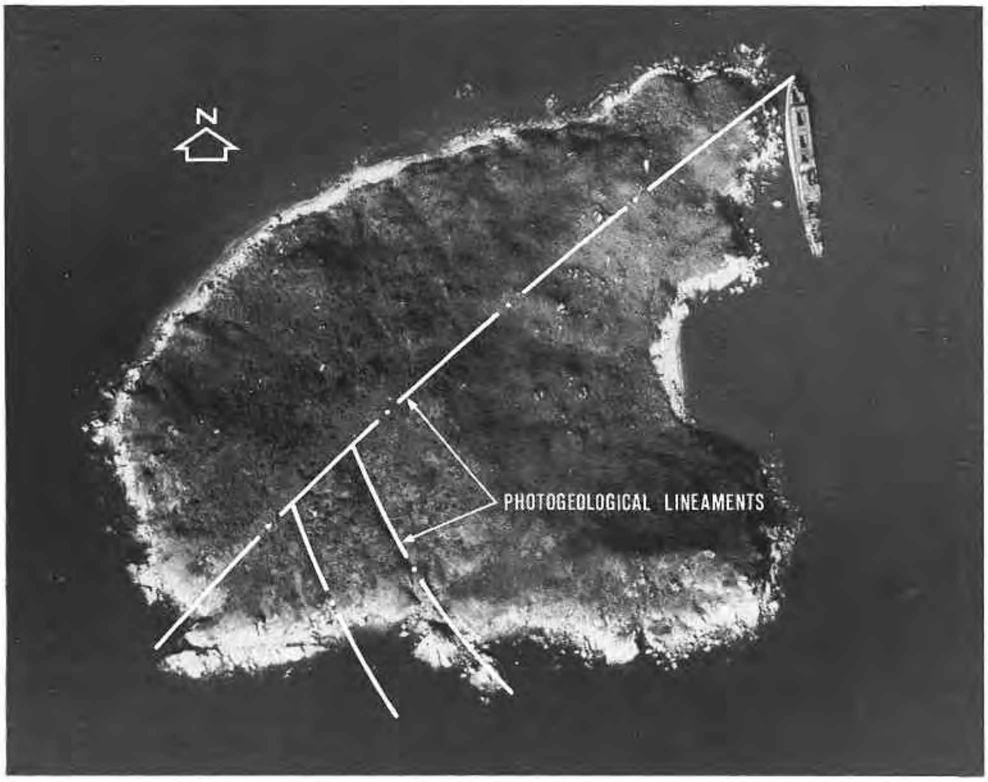


Plate 12. Vertical Aerial Photograph of Kau Yi Chau. The ship was grounded on the northeastern coast of the island during Typhoon Ellen in 1983. The island is formed of Sung Kong Granite, Coarse Tuffs of the Repulse Bay Formation, Feldspar Porphyry Dyke Swarm rocks, and is traversed by several geological photolineaments. (1983/51346).

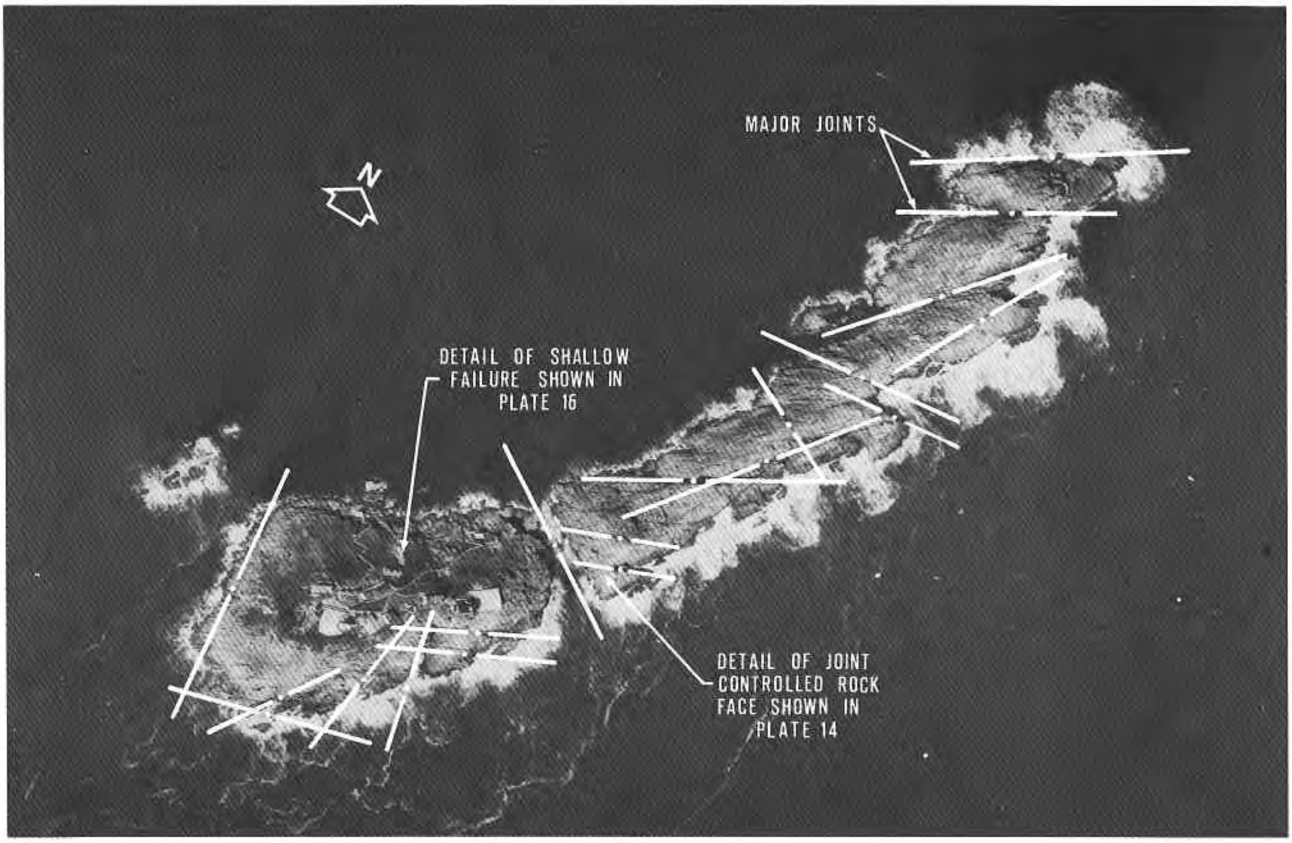


Plate 13. Vertical Aerial Photograph of Waglan Island. Several major joint sets traverse the barren and extremely exposed islands. The Royal Observatory weather station and the lighthouse installation are located on the southern island (1983/51223).

Plate 14. Northern Section of Waglan Island. The well-jointed granite is almost completely devoid of a weathered mantle and vegetation. (GCO/TP 1984/50–16A).

Plate 15. Southern Coast of Sung Kong Island. Note the dark-coloured intrusive dyke in the centre of the Plate, which probably consists of a central core of quartz feldspar rock with dolerite at its flanks.

Plate 16. Landslip on the West Coast of Waglan Island.

1963: Village settlement is concentrated on the low ground in the central part of the island. Some minor reclamation is present on the northwestern side of the island. (1963/341)

1983: Reclamation is evident on the western side of the island to the north of the ferry pier. A fixed crossing to Tai Lei is under construction. (1983/51348).

Plate 17. Development of Peng Chau between 1963 and 1983.

Plate 18. Coastal Instability in Granite on Northwest Cheung Chau. (GCO/TP 1984/52–34).

Plate 19. Boulder-strewn Slope on Cheung Chau Granite. Corestones, exposed by erosion of deeply weathered granite, litter this slope on northern Cheung Chau. The top of the slope, which has been cut to form a platform, formerly housed a radar station. Instability resulting from gully erosion in the weathered profile is evident in the left foreground. (GCO/TP 1984/52–84).

Plate 20. Alveoli Weathering in Cheung Chau Granite. Also known as honeycomb weathering, the pitted surface which forms the alveoli is the result of differential weathering. (GCO/TP 1984/52–25).

Plate 21. Abandoned Agricultural Terraces on Northern Cheung Chau. Colluvial valley floor terrain is modified by a terraced spurline. (GCO/TP 1984/61–8).

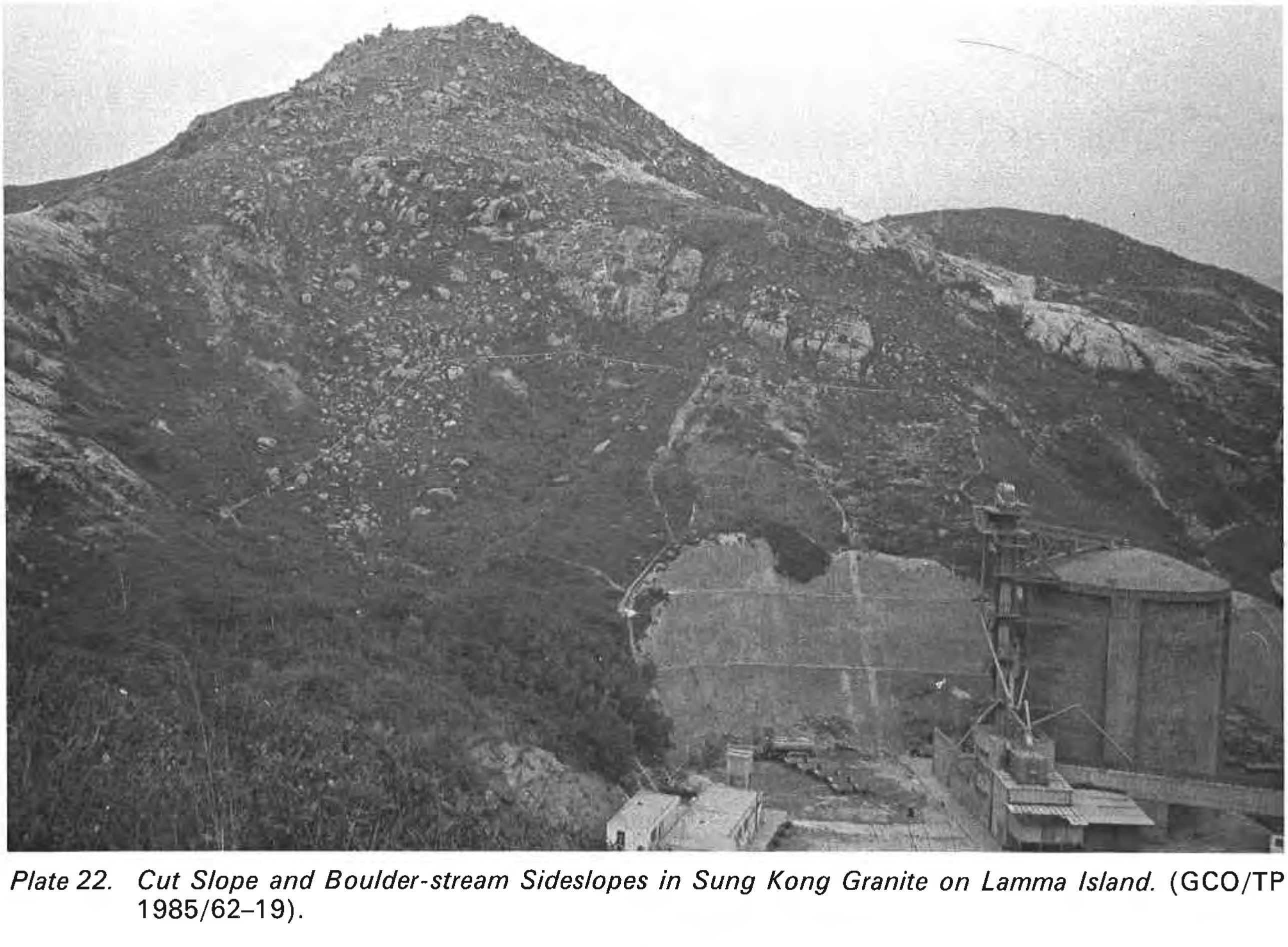


Plate 22. Cut Slope and Boulder-stream Sideslopes in Sung Kong Granite on Lamma Island. (GCO/TP 1985/62–19).

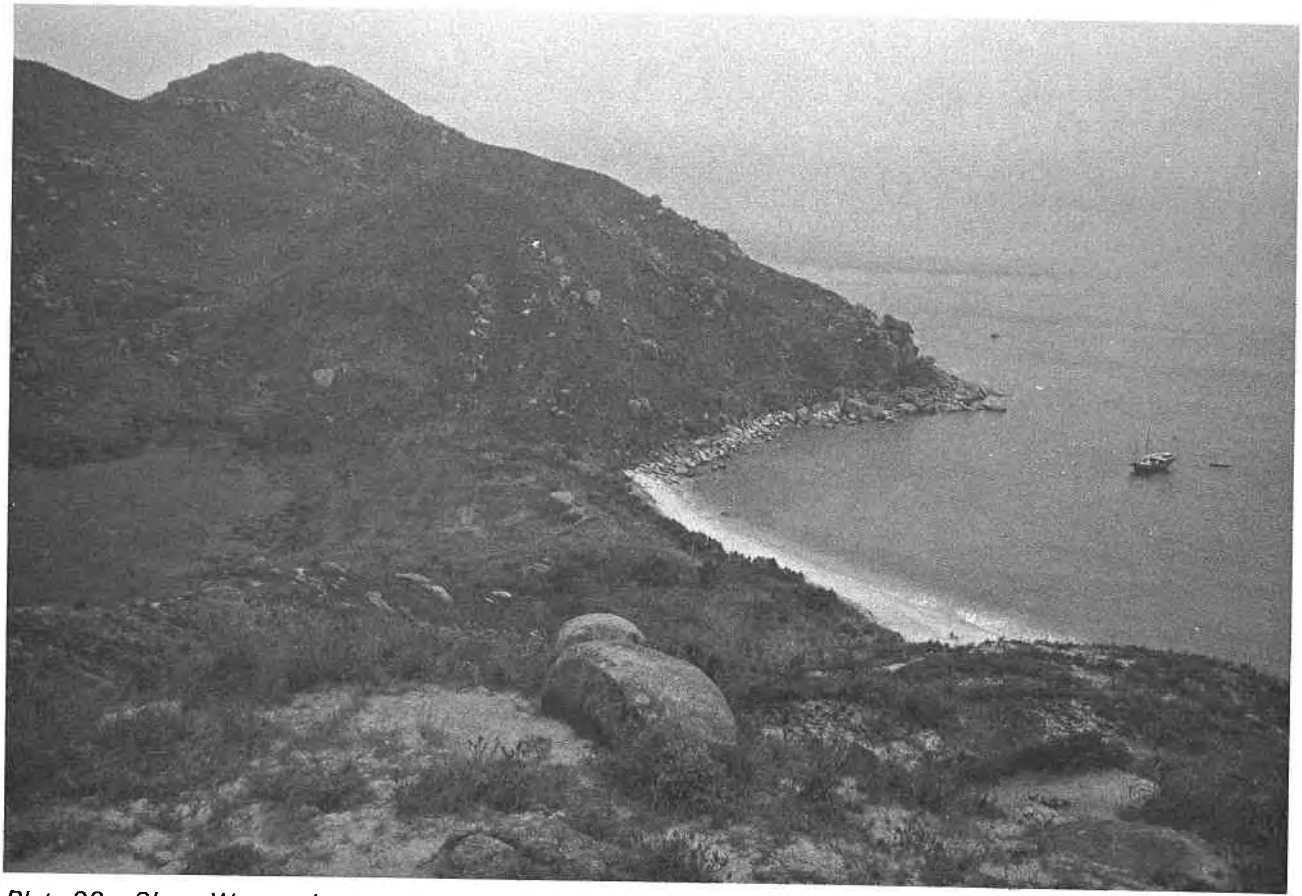


Plate 23. Sham Wan on Lamma Island. A raised beach and alluvial plain form the low ground between the bouldery sideslopes. (GCO/TP 1985/62–30).

Plate 24. Mount Stenhouse on Lamma Island. Ridgecrests and sideslopes are littered with large blocks of Cheung Chau Granite which have spalled away from the insitu rock mass due to adverse jointing. (GCO/TP 1985/62–31).

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 13.

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), the Physical Constraints Map (PCM) and the Generalised Limitations and Engineering Appraisal Map (GLEAM). 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.

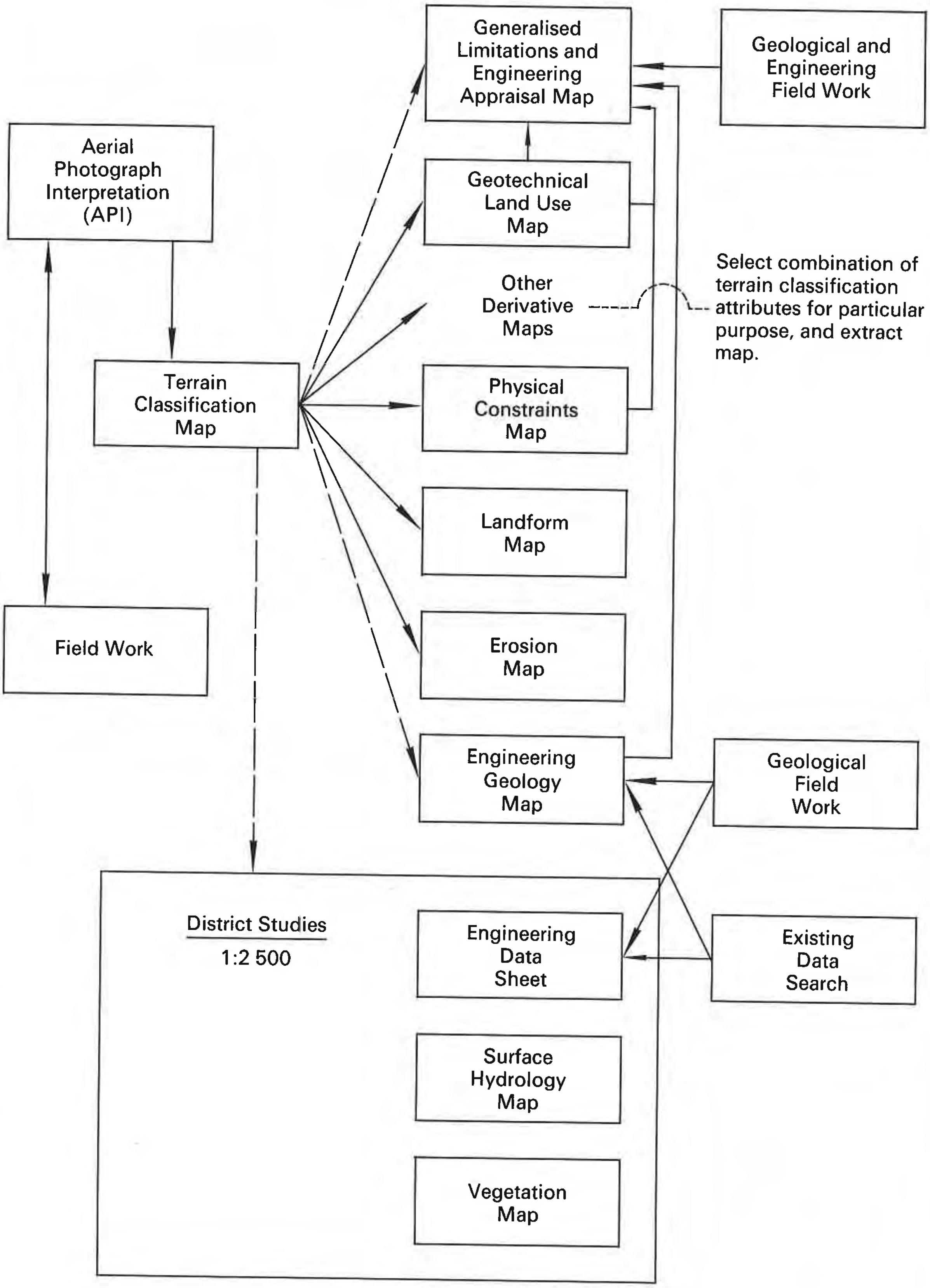
(*c*) Erosion and instability.

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 1.5.9 and A.11.

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	a
		Rock outcrop	M	Development of general instability —recent	n
		Cut —straight	N	—relict	r
		—concave	O	Coastal instability	w
		—convex	P		
		Fill —straight	R		
		—concave	S		
		—convex	T		
		General disturbed terrain	V		
		Alluvial plain	X		
		Reclamation	Z		
		Wave cut platform	W		
		Waterbodies:			
		Natural stream	1		
		Man-made channel	2		
		Water storage	3		
		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 the following 14 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*) Wave cut platform (Code W).

(*n*) 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, n, r, w) 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 19a) 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.

(*j*) Wave cut platforms.

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 the study area. 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 20a.

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, n, r, w).

(*j*) General instability associated with colluvial terrain (Codes a, n. r, w).

(*k*) Wave cut platforms.

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.

(*i*) Moderate and severe gully erosion.

(*j*) Instability on disturbed terrain.

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. Further assistance in identifying larger areas with development potential is available within the GLEAM.

(*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. The GLEAM will assist in evaluating the impact of local geotechnical constraints on those areas with development potential.

(*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 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 the Central New Territories 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 (Appendix C) 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 study area 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*) Isopachs of submarine superficial deposits.

(*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.

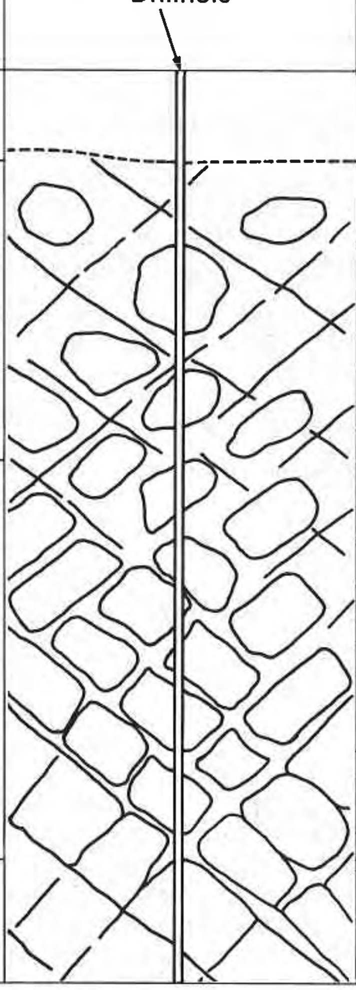
This classification is applied to the colluvial deposits on the basis of the parent geology. The classification is based on API and is not extensively field checked. These classes are not presented on the Engineering Geology Map but are included in the GEOTECS data bank.

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.3 and Table C.2.

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 II	Zone C
Zone D—Material of grades I or II constitutes more than 90% of the mass.		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).

A.9 Generalised Limitations and Engineering Appraisal Map

A.9.1 *Introduction*

Long-term strategic development planning requires an early and fundamental appreciation of areas suitable for extensive and/or intensive development. Development in the study area has been influenced by the geotechnical constraints associated with the terrain since the start of urban expansion in Hong Kong. With the obvious shortage of suitable terrain and the continuing pressure for expansion, it is essential that geotechnical influences are considered in detail at the start of any planning or engineering project. The maps produced within the GAS Programme are fundamental to this approach.

The Generalised Limitations and Engineering Appraisal Map (GLEAM) is intended to extend the guidance on geotechnical problems given in the GLUM, the PCM and the EGM. It enables the planner or engineer to take a broader view of the opportunities for development in geotechnical terms. In addition, it highlights the features of the terrain which represent geotechnical constraints but are not considered detrimental to the overall development potential of the terrain.

The derivation of the GLEAM and its implications for planning and engineering are described below.

A.9.2 *Derivation of the GLEAM*

The GLEAM is derived from the Terrain Classification Map with further detailed aerial photograph interpretation and fieldwork. During its production, use is made of the GLUM, the PCM and the EGM. The general sequence is summarised in flowchart form in Figure A2.

The GLEAM identifies areas of potential for development. Continuous areas of already developed land are excluded from comment. 'Man-made' restrictions such as Country Parks, catchwaters and catchments are delineated, and principal access routes which would ease expansion are also shown.

An initial estimate of the boundary between geotechnical potential and constraint is made from the Terrain Classification Map. Potential areas are those generally less than 30° in insitu materials and 15° in fill and colluvium, where instability is not identified and erosion is limited. Slopes steeper than 30° would require extensive cuts or high retaining structures to provide useful platforms, and platforms constructed in fill or colluvial slopes would require long back slopes to achieve a suitable level of safety. Instability indicates that the natural slope is liable to present a hazard, and lines of excessive erosion would require entrainment of stream courses to avoid the risk of blockage, flooding and destabilising infiltration. The criteria used for initial assessment of the potential or constraint boundary are shown in Table A4.

To a certain extent, the constraints outlined above are similar to those identified in the Physical Constraints Map and in GLUM Classes III & IV, but their interpretation depends on the local situation and the nature of the engineering problem which is present.

In generalising the boundary between potential and constraint, small areas which have geotechnical constraint are included where they do not contradict the overall assessment of potential. In these cases, the nature of the constraint is reflected in the engineering notes, and the area is highlighted on the map as a stipple.

Further interpretation of the engineering geology and physical constraints is made using oblique and vertical aerial photographs. In this way, the boundaries are refined, and the basic engineering notes are prepared for the GLEAM.

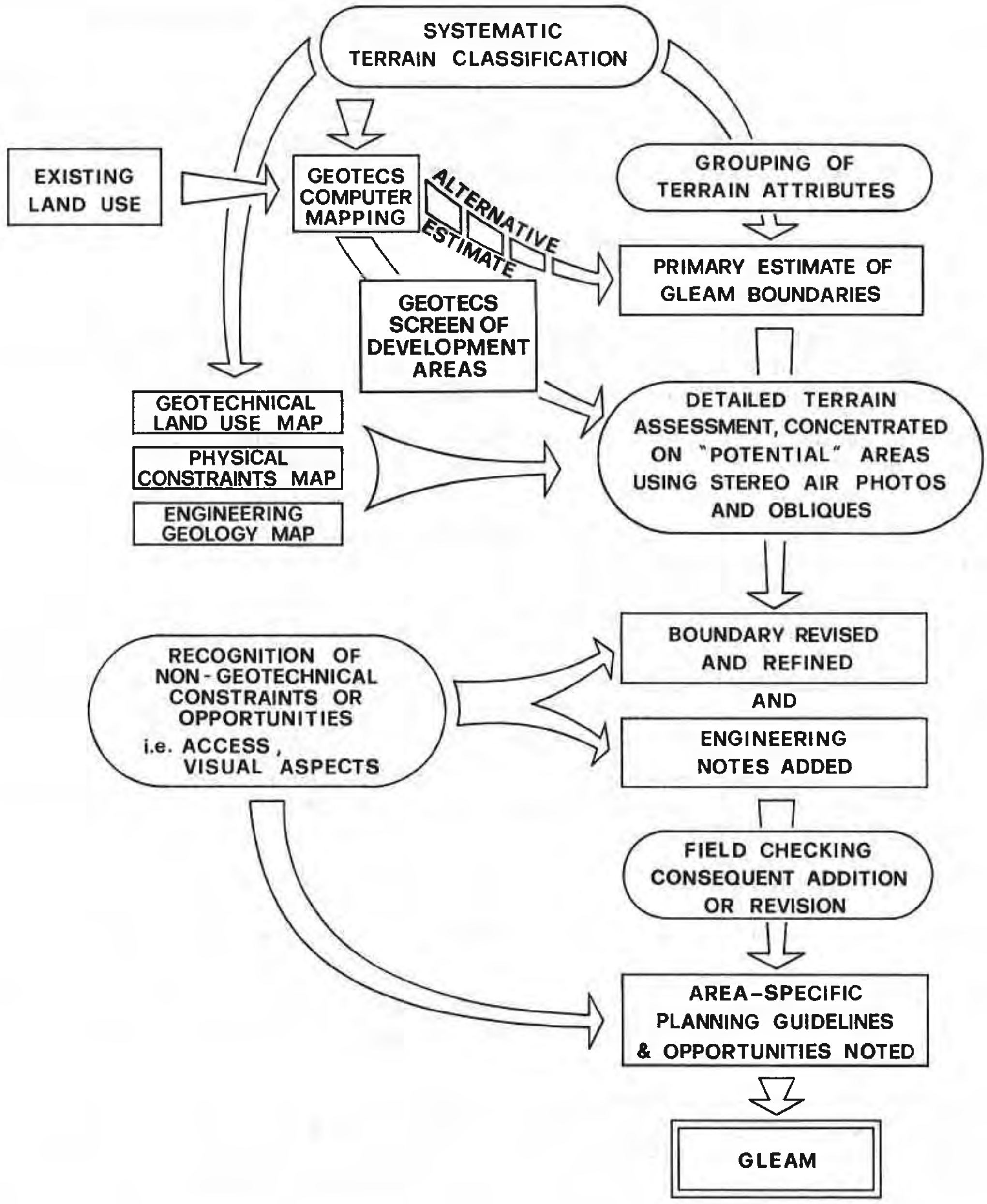
The engineering notes are presented in the form of standard symbols which are described in the legend. They highlight local geotechnical constraints which would influence layout or the design details of a project. General constraints identified on the Physical Constraints Map are shown as a background to these notes. The features indicated on the GLEAM are described and discussed in note form in Table A5. The production of the GLEAM is supplemented by field checks of pertinent areas.

An appreciation of the non-geotechnical considerations of the potential development areas and of the implications of geotechnical suitability on planning considerations enables specific planning opportunities to be highlighted. These factors include the necessity for access across difficult terrain, visual intrusion or severe influence on natural environment resulting from construction works.

Hence, the GLEAM is a map that is designed to provide a broad indication of development opportunities assessed from a geotechnical point of view and to identify geotechnical considerations with local implications for planning and engineering.

A.9.3 *Application of the GLEAM in Strategic Planning*

The general boundaries between areas of 'Potential' and 'Constraint' should be used at a strategic planning stage to enable new development to be placed where it can most effectively use the opportunities provided by the terrain, and where it will be relatively unhindered by geotechnical difficulties. Where difficulties cannot be avoided, they are clearly indicated. Where large areas are suitable for development, the nature and scale of development should be planned to utilize all available opportunities.



Derivation of Generalised Limitations and Engineering Appraisal Map	Fig. A2

Table A4 Criteria for Initial Assessment of GLEAM Potential/Constraint Boundaries

Terrain Component*	Slope Gradient*	Erosion/Instability Classification		
		Erosion*		Instability*
		(., 1, 2, 3, 4, 5, 6, 7)	(8, 9)	(a, n, r, w)
A	1	Yes	Yes	No
	2, 3	Yes	No	No
B, C, D, M N, O, P	1, 2, 3	Yes	No	No
	4, 5, 6	No	No	No
E, F, G, H, I^Δ^ K^Δ^, R, S, T, X^Δ^	1, 2	Yes	No	No
	3, 4, 5, 6	No	No	No
N, O, P** R, R, S T, V, V	1, 2	Yes	No	No
	3	Subject to interpretation	No	No
	4, 5, 6	No	No	No
Z	1, 2	Yes	Yes	No

Yes = Potential development   No = Constraint†

Note: * See Table A1 for description of terrain classification codes.

Δ Terrain components I, K and X are only mapped at slope gradients of 1 and 2.

** The potential/constraint boundary is subject to interpretation. These terrain components are generally unlikely to occur outside developed or developing areas which are not considered in the GLEAM.

† All initially derived potential/constraint boundaries are subject to revision on assessment of the overall area, in particular erosion classifications 8 and 9. Instability is generally assessed as constraint.

Piecemeal development often results in considerable wastage of potential development land. Individual developers could be encouraged to conform to an outline site layout which maximises the use of the site resources.

Notes are incorporated on the GLEAM which assess in general, but in geotechnically based terms, the development opportunities of potential areas. These are prepared without detailed consideration of other planning constraints (political, socio-economic, aesthetic) which may influence the area but, nevertheless, the geotechnical constraints are of fundamental significance to the potential of an area for development.

A.9.4 *Application of the GLEAM in Engineering Feasibility and Detailed Planning*

After the identification of areas for development, planners, architects and engineers prepare the form, layout and design details of the scheme. At this stage, the GLEAM is also of value because it indicates the particular nature of local geotechnical difficulties which influence the design aspects of the project and which require consideration in preliminary layout and design. Details such as the limitations on site formation and the requirement for retaining structures, the optimum foundation type, special provisions for subsurface drainage and entrainment of natural drainage, the threat of boulders or rock instability, inconsistency in soil properties or local rock structures, are all important for planning and design. They must be considered in the initial stages of planning if the optimum development of sites is to be achieved. Often, designs reach an advanced stage before major geotechnical constraints are identified.

Table A5 incorporates notes on the engineering implications of local features highlighted on the GLEAM. Further discussion of the engineering aspects of terrain features and of the interaction between landforming processes of relevance to construction work are included in this Report.

Table A5 Notes on Features Indicated on the GLEAM

1. Colluvium
   - indicated where expected to be deep or irregular.
   - extent of colluvium is shown on PCM & EGM.
   - notes on colluvium are given in Sections 3.1.2 and Appendix D.3.5.
2. Drainage
   - indicated where expected to be subject to large flows,
   - masked drainage or hidden drainage indicated where ephemeral flows may cause problems or where original drainage pattern may still exist beneath surface disturbance.
   - may pose the risk of piping pressures or leaching of materials.
   - ephemeral flows together with smooth surface contours may indicate deeper weathering and may be associated with a structural weakness, thus forming a geological photolineament.
3. Incised drainage
   - may be associated with structural weakness.
   - in weathered material, may present local oversteepening.
4. Structure
   - local surface indication of jointing pattern, or localised resistance to weathering or movement, and therefore not necessarily a weakness.

     NOTE: When 'terrain associated with Drainage and Structure' or similar is noted – this is the surface result of drainage forming a 'pattern', recognisable from vertical aerial photographs, associated with a jointing or local faulting pattern.
5. Weathering
   - indicated where surface features, i.e. smoothness of terrain, or extensive gullying, show that deep weathering may be expected.
   - in general, deeper weathering is associated with granitic terrain, and occurs beneath ridge and spur lines.
6. 'Control'
   - terrain influenced by features as noted. i.e. D & S cont. = Drainage & Structure Control
7. Instability
   - indicated where the natural landform exhibits instability which poses a threat to development unless accommodated.
8. Steep slopes
   - indicated where the presence of a steeper slope would result in extensive cuts or high walls being necessary to produce a platform.
   - tends to restrict site formation possibilities.
9. Lineament
   - identified from aerial photography.
   - indicates a structural weakness or strength through an anomaly in the surface features.
   - lineaments (some) also shown on EGM.
   - further notes on lineaments in 2.

The information presented in the GLEAM, because it is interpretative in nature, cannot be conclusive in its application to a particular engineering project; nor from the nature and scale of the study can the comments be exhaustive. The GLEAM does indicate areas of potential for development whilst clearly defining the major geotechnical restrictions which are likely to influence planning and engineering feasibility.

A.9.5 *Production of the GLEAM and Evaluation of Planning Strategies*

Using the Geotechnical Terrain Classification System (GEOTECS) described in Section 1.5.9, it is possible to construct various strategies based on priorities of land utilisation in combination with the systematic data collected in the terrain classification process.

Particular types of existing land use can be isolated, and the engineering suitability or potential for an intended use can be evaluated. This can be achieved by the selection of appropriate terrain attributes. The attributes include: geology, slope angle, aspect, terrain component, erosion and instability, GLUM, relief, vegetation and land use.

Typical strategies and the computer maps are described in Section 4.2.4. The potential for development of squatter areas or possible quarry sites assessed in geotechnical terms are provided as examples.

The maps produced using GEOTECS are conceptual in nature, and further study of any potential development area is essential. Nevertheless, the mechanism of land resource appraisal afforded by the GEOTECS approach provides a powerful tool for land management purposes and engineering feasibility.

A.10 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.

(*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.11 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 X data bank consists of 1 560 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 1.5.9. 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 ISLANDS GEOTECHNICAL AREA STUDY

Table B1 Slope Gradient

Slope Gradient	% of Total Area	Area (ha)
0– 5°*	6.7	214
5–15°	11.3	359
15–30°	45.3	1 441
30–40°	29.4	937
40–60°	7.0	223
>60°	0.3	10
	100.0	3 184

* Approximately 2 ha of water storage is included in the 0–5° Class.

Table B2 Erosion and Instability

	Erosion	% of Total Area	Area (ha)
Instability			
	—well-defined landslips	0	0
	—coastal instability	9.3	296
	—general instability—recent	15.8	502
	—relict	5.8	186
Appreciable Erosion	Sheet erosion—minor	7.4	235
	—moderate to severe	5.6	180
	Rill erosion —minor	0.6	20
	—moderate to severe	1.3	41
	Gully erosion—minor	2.3	71
	—moderate to severe	1.7	55
No Appreciable Erosion*		50.2	1 598
		100.0	3 184

* Approximately 2 ha of water storage is included within No Appreciable Erosion.

Table B3 Aspect

Aspect	% of Total Area	Area (ha)
North	10.6	339
Northeast	11.6	369
East	10.4	331
Southeast	14.4	459
South	9.0	286
Southwest	12.1	384
West	12.1	386
Northwest	13.1	416
Flat/Unclassified*	6.7	214
	100.0	3 184

* Approximately 2 ha of water storage is 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	53	133	133	14	6	339
Northeast	57	141	136	35	0	369
East	18	159	123	29	2	331
Southeast	51	228	139	41	0	459
South	45	129	79	31	2	286
Southwest	35	228	92	29	0	384
West	33	245	90	18	0	386
Northwest	67	178	145	26	0	416
0–5° (Flat/Unclassified)						214
						3 184

Table B5 Landform

Terrain (Landform)	Slope Gradient	% of Total Area	Area (ha)
Hillcrest		3.1	100
Sideslope	0– 5°	<0.1	2
"	5–15°	5.5	176
"	15–30°	38.5	1 225
"	30–40°	23.6	750
"	>40°	1.1	35
Cliff/Rock outcrop	0–30°	4.6	145
"	>30°	10.6	339
Footslope (colluvium)	0– 5°	0	0
"	5–15°	0.3	8
"	15–30°	0.4	12
"	>30°	0.4	15
Drainage plain (colluvium)	0– 5°	0.3	8
"	5–15°	0.4	12
"	15–30°	1.7	53
"	>30°	0.2	6
Alluvial plain	0– 5°	0.2	6
"	>5°	0.3	10
Floodplain	0– 5°	1.0	31
"	>5°	<0.1	2
Littoral zone	0–15°	1.0	33
Raised beach	0–15°	0.7	22
Cut platforms : insitu	0– 5°	0.3	8
: colluvium	0– 5°	0	0
: alluvium	0– 5°	0	0
Cut slopes : insitu	>5°	1.0	33
: 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°	2.9	92
Wave cut platform	—	1.3	41
General disturbed terrain/platforms: insitu	0– 5°	0.6	82
General distrubed terrain/slope: insitu	>5°	0.5	16
: colluvium	>5°	0	0
: alluvium	>5°	0	0
Natural stream		0	0
Man-made channel		0	0
Water storage		<0.1	2
		100.0	3 184

Table B6 Geology

Geological Unit	% of Total Area	Area (ha)
Alluvium: undifferentiated	1.1	35
: raised	0.6	18
Colluvium: volcanic	0.4	14
: granitic	3.1	100
: sedimentary	0	0
: mixed	0	0
Littoral deposits	1.0	33
Raised beach deposits	0.7	22
Reclamation	2.9	92
Fill	0.6	18
Repulse Bay Formation: undifferentiated volcanics	0.4	14
: sedimentary rocks and waterlaid volcanics	0	0
: acid lavas	0	0
: mainly banded acid lavas, some welded tuffs	0	0
: coarse tuff	6.3	202
: agglomerate	0	0
: dominantly pyroclastics and some lavas	0	0
Granophyric Microgranite	<0.1	2
Needle Hill Granite (Fine grained phase)	0	0
Hong Kong Granite	0	0
Quartz Monzonite	2.4	76
Feldspar Porphyry Dyke Swarm	10.6	337
Fan Lau Porphyritic Granite	0.7	22
Ma On Shan Granite	9.4	300
Cheung Chau Granite	33.5	1 065
Sung Kong Granite	24.8	790
Tai Po Granodiorite	0.5	16
Undifferentiated Granite	0.9	28
	100.0	3 184

Table B7 Vegetation

Vegetation	% of Total Area	Area (ha)
Grassland	16.1	514
Cultivation	4.6	145
Mixed broadleaf woodland	5.4	174
Shrubland (<50%)	17.8	565
Shrubland (>50%)	24.8	790
No vegetation on natural terrain	4.4	139
No vegetation due to disturbance of terrain by man	11.7	371
No vegetation due to rock outcrop	15.2	484
Waterbodies	<0.1	2
	100.0	3 184

Table B8 Geology and GLUM Class

Geological Unit	Area in GLUM Class (ha)				
	I	II	III	IV	Unclassified
Alluvium: undifferentiated	0	33	0	0	2
: raised	0	18	0	0	0
Colluvium: volcanic	0	0	6	8	0
: granitic	0	0	33	67	0
Littoral deposits	0	0	0	0	33
Raised beach deposits	0	22	0	0	0
Reclamation	0	92	0	0	0
Fill	0	2	4	12	0
Repulse Bay Formation: undifferentiated volcanics	0	4	8	2	0
: coarse tuffs	29	131	22	20	0
Granophyric Micrograinite	0	0	0	0	2
Quartz Monzonite	0	55	6	15	0
Feldspar Porphyry Dyke Swarm	20	173	121	23	0
Fan Lau Porphyritic Granite	2	8	6	4	2
Ma On Shan Granite	20	63	145	65	7
Cheung Chau Granite	59	437	249	308	12
Sung Kong Granite	35	265	245	227	18
Tai Po Granodiorite	2	12	2	0	0
Undifferentiated Granite	6	16	4	2	0

Table B9 GLUM Class

GLUM Class	Geotechnical Limitations	% of Total Area	Area (ha)
I	Low	5.4	173
II	Moderate	40.8	1 298
IIS	Moderate	1.0	33
III	High	26.7	851
IV	Extreme	23.7	753
Unclassified		2.4	76
		100.0	3 184

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

Slope Gradient	Aspect	Surface Geology*	No Appreciable Erosion (ha)	Appreciable Erosion (ha)			Instability (ha)		Area (ha)	Area Instability Index
				Sheet	Rill	Gully	WDL	GI		
0–5°	Flat	V	2	0	0	0	0	0	2	0
		G	24	0	0	0	0	0	24	0
		C	8	0	0	0	0	0	8	0
		A	53	0	0	0	0	0	53	0
		L	33	0	0	0	0	0	33	0
		F	69	25	0	0	0	0	94	0
5–15°	N	V	10	0	0	0	0	0	10	0
		G	33	2	0	2	2	2	41	0.10
		C	0	0	0	2	0	0	2	0
		A	0	0	0	0	0	0	0	0
		F	0	0	0	0	0	0	0	0
	NE	V	2	0	0	0	0	0	2	0
		G	29	8	0	0	0	8	45	0.17
		C	4	0	0	0	0	0	4	0
		A	6	0	0	0	0	0	6	0
		F	0	0	0	0	0	0	0	0
	E	V	2	0	0	0	0	0	2	0
		G	4	6	0	0	0	0	10	0
		C	6	0	0	0	0	0	6	0
		A	0	0	0	0	0	0	0	0
		F	0	0	0	0	0	0	0	0
	SE	V	4	0	0	0	0	0	4	0
		G	21	10	0	0	0	10	41	0.24
		C	2	2	0	0	0	0	4	0
		A	2	0	0	0	0	0	2	0
		F	0	0	0	0	0	0	0	0
	S	V	6	0	0	0	0	0	6	0
		G	25	6	0	0	0	2	33	0.06
		C	2	0	0	0	0	0	2	0
		A	4	0	0	0	0	0	4	0
		F	0	0	0	0	0	0	0	0
	SW	V	2	0	0	0	0	0	0	0
		G	25	4	0	0	2	0	31	0.06
		C	0	0	0	0	0	0	0	0
		A	2	0	0	0	0	0	2	0
		F	0	0	0	0	0	0	0	0
	W	V	0	0	0	0	0	0	0	0
		G	22	4	0	0	0	0	26	0
		C	0	0	0	0	0	0	0	0
		A	6	0	0	0	0	0	6	0
		F	0	0	0	0	0	0	0	0
	NW	V	12	0	0	0	0	0	12	0
		G	39	8	0	0	0	6	53	0.11
		C	2	0	0	0	0	0	2	0
		A	0	0	0	0	0	0	0	0
		F	0	0	0	0	0	0	0	0
15–30°	N	V	8	0	0	0	0	0	8	0
		G	71	14	0	2	2	27	116	0.25
		C	2	0	0	4	0	2	8	0.25
		F	0	0	0	0	0	0	0	0
	NE	V	25	0	0	0	0	0	25	0
		G	49	22	2	2	4	33	112	0.33
		C	2	0	0	0	0	2	4	0.50
		F	0	0	0	0	0	0	0	0
	E	V	12	0	0	2	0	0	14	0
		G	59	31	4	4	4	29	131	0.25
		C	6	0	0	2	0	2	10	0.20
		F	2	2	0	0	0	0	4	0
	SE	V	4	0	0	6	0	0	10	0
		G	108	55	4	6	8	31	212	0.18
		C	4	0	0	6	0	0	10	0
		F	0	0	0	0	0	0	0	0
	S	V	10	0	0	2	0	0	12	0
		G	57	20	6	0	8	23	114	0.27
		C	2	0	0	0	0	0	2	0
		F	0	0	0	0	0	0	0	0
	SW	V	16	4	0	0	0	0	20	0
		G	102	49	4	2	14	27	198	0.21
		C	4	0	0	6	0	0	10	0
		F	0	0	0	0	0	0	0	0
	W	V	22	0	0	2	0	0	24	0
		G	106	53	6	2	10	29	206	0.19
		C	8	0	0	2	0	4	14	0.29
		F	0	0	0	0	0	0	0	0
	NW	V	12	0	0	0	0	0	12	0
		G	78	35	4	6	2	35	160	0.23
		C	6	0	0	0	0	0	0	0
		F	0	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 G C	14 41 0	0 4 0	0 6 0	0 6 0	0 8 0	2 51 0	18 116 0	0.11 0.51 0
	NE	V G C	4 41 0	0 6 0	0 2 0	0 12 0	2 14 0	2 51 2	8 126 2	0.50 0.52 1.00
	E	V G C	4 35 2	0 8 0	0 2 0	2 2 0	4 10 0	6 39 8	16 6 10	0.62 0.51 0.80
	SE	V G C	2 57 2	0 8 0	0 2 0	2 18 0	0 12 0	2 31 2	6 128 4	0.33 0.34 0.50
	S	V G C	0 22 0	0 6 0	0 0 0	0 4 2	0 16 0	0 29 0	0 77 2	0 0.58 0
	SW	V G C	0 35 0	0 4 0	0 0 0	0 6 0	0 18 0	0 29 0	0 92 0	0 0.51 0
	W	V G C	2 27 0	0 6 0	0 0 0	0 2 0	0 12 0	0 39 2	2 86 2	0 0.59 1.00
	NW	V G C	0 35 0	0 8 0	0 6 0	0 12 0	0 20 0	0 63 0	0 144 0	0 0.58 0
>40°	N	V G	0 4	0 2	0 0	0 0	0 12	0 2	0 20	0 0.70
	NE	V G	0 6	0 0	0 0	0 0	2 23	0 4	2 33	1.00 0.82
	E	V G F	0 6 0	0 0 2	0 0 0	0 0 0	0 21 0	0 2 0	0 29 2	0 0.79 0
	SE	V G F	0 10 0	0 0 4	0 0 0	0 0 0	2 16 0	0 8 0	2 34 4	1.00 0.71 0
	S	V G F	0 8 0	0 0 4	0 0 0	0 0 0	0 12 0	0 8 0	0 28 4	0 0.71 0
	SW	V G F	0 2 0	0 0 2	0 0 0	0 0 0	0 17 0	0 8 0	0 27 2	0 0.93 0
	W	V G	0 0	0 0	0 0	0 0	0 12	0 6	0 18	0 1.00
	NW	V G	0 0	0 0	0 0	0 0	0 4	0 23	0 27	0 1.00

Legend: V= volcanic and volcaniclastic rocks
G= granitic rocks
C= colluvium
A= alluvium
F= fill

Table B11 Geology, Erosion and Instability

Geological Unit	No Appreciable Erosion (ha)	Appreciable Erosion (ha)			Instability (ha)		Total Area (ha)	Area Instability Index
		Sheet	Rill	Gully	Coastal Instability	General Instability		
Reclamation	69	23	0	0	0	0	92	0
Fill	2	4	12	0	0	0	18	0
Alluvium:								
—raised	18	0	0	0	0	0	18	0
—undifferentiated	35	0	0	0	0	0	35	0
Littoral Deposits	33	0	0	0	0	0	33	0
Colluvium:								
—volcanic	10	0	0	4	0	0	14	0
—granitic	53	2	0	20	0	25	100	0.25
Raised Beach Deposits	22	0	0	0	0	0	22	0
Repulse Bay Formation:								
—undifferentiated volcanics	12	0	0	0	2	0	14	0
—coarse tuff	165	4	0	12	10	11	202	0.11
—dominantly pyroclastics and some lavas	0	0	0	0	0	0	0	0
Granophyric Microgranite	2	0	0	0	0	0	2	0
Needle Hill Granite (Fine grained phase)	0	0	0	0	0	0	0	0
Quartz Monzonite	45	8	4	0	6	13	76	0.25
Feldspar Porphyry Dyke Swarm	173	83	2	8	8	63	337	0.21
Ma On Shan Granite	143	18	2	0	25	112	300	0.46
Cheung Chau Granite	490	153	2	60	114	246	1 065	0.33
Sung Kong Granite	304	98	33	22	117	216	790	0.42
Tai Po Granodiorite	10	0	6	0	0	0	16	0
Undifferentiated Granite	2	20	0	0	6	0	28	0.21

Table B12 Existing Land Use (From aerial photograph interpretation by the Geotechnical Control Office in 1984)

Existing Land Use	%	Area (ha)
Developed terrain:		
Private development	0.4	14
2 storey development	3.0	96
1 storey development	0.9	28
Residential/commercial	0.3	8
Industrial	0.1	4
Institutional and community:		
Schools	<0.1	2
Temple or church	0.1	4
Park	<0.1	2
Sports complex	<0.1	2
Lighthouse	<0.1	2
Radar station (disused)	<0.1	2
Roads	<0.1	2
Sewerage works	0.1	4
Power station	2.0	63
Cemetery	0.4	14
Prison	0.5	16
Construction	0.8	24
Artificial slopes	0.3	6
Water storage	<0.1	2
Undeveloped terrain:		
Squatters—low intensity	1.3	43
Squatters—high intensity	<0.1	2
Horticulture	4.3	138
Agriculture (undefined)	0.3	8
Undisturbed areas	83.5	2 659
Quarry	0.4	12
Reclamation (unused platforms)	0.8	27
	100.0	3 184

Table B13 Existing Land Use and GLUM Class

Existing Land Use	Area in GLUM Class (ha)				
	I	II	III	IV	Unclassified
Developed terrain:					
Private development	8	4	0	2	0
2 storey development	20	72	2	2	0
1 storey development	4	12	10	2	0
Residential/commercial	0	8	0	0	0
Industrial	0	0	4	0	0
Insitutional and community:					
Schools	0	2	0	0	0
Temple or church	0	2	2	0	0
Park	0	2	0	0	0
Sports complex	2	0	0	0	0
Lighthouse	0	0	2	0	0
Radar station (disused)	0	0	2	0	0
Roads	0	2	0	0	0
Sewerage works	0	4	0	0	0
Power station	0	59	2	2	0
Cemetery	2	12	0	0	0
Prison	2	10	4	0	0
Construction	2	12	6	4	0
Artificial slopes	0	0	4	2	0
Water storage	0	0	0	0	2
Undeveloped terrain:					
Squatters—low intensity	4	29	6	4	0
Squatters—high intensity	0	2	0	0	0
Horticulture	29	80	23	6	0
Agriculture (undefined)	6	2	0	0	0
Undisturbed areas	94	990	780	721	74
Quarry	0	0	4	8	0
Reclamation (unused platforms)	0	27	0	0	0
Total 3 184	173	1 331	851	753	76

APPENDIX C

SUPPLEMENTARY INFORMATION

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APPENDIX C

SUPPLEMENTARY INFORMATION

C.1 Description of Geological Units

C.1.1 *Volcanic and Volcaniclastic Rocks*

Volcanic rocks of the Repulse Bay Formation are exposed in several parts of the study area. The main rock type consists of a succession of coarse tuffs. These rocks were deposited during the regional volcanic activity of the Mid-Jurassic period. The rocks of the Repulse Bay Formation are approximately 160 million years old, and represent a period of intense volcanic activity interspersed with periods of quiescence. The Repulse Bay Formation is faulted, folded and subject to local metamorphism. The rocks of the Repulse Bay Formation in the study area are classified into two units by Allen & Stephens (1971).

(i) *Coarse Tuff (RBc)*
This rock is extensively exposed in the northern part of Lamma Island. The rock generally consists of coarse-grained crystal tuff and forms thick unstratified beds. The grain size varies from coarse tuff to lapillistone and is dark grey, greenish-grey or bluish-grey. The main minerals consist of quartz and feldspar, with subsidiary biotite and hornblende. The coarse tuff is characterised by features which indicate explosive and subaerial origins. These include the presence of volcanic bombs, lack of internal stratification and a wide range of fragment sizes. The Coarse Tuffs are generally very thick deposits and show features of explosive strain, especially in thin section where grains (normally quartz) are shattered and partly recrystallised, and often show bottle-shaped embayments. Mineral grains vary in shape from euhedral to blade-like slivers (shards). The coarseness of the grain size may be linked to the partly crystallised state of the parent magma during its eruption. The grain size of the coarse tuffs is thought to be related to the size and abundance of the phenocrysts in the enclosed volcanic bombs.

(ii) *Undifferentiated Volcanic Rocks (RB)*
These rocks outcrop on Lamma Island and some of the less accessible islands to the north. These rocks are not described by Allen & Stephens (1971), and remain unassigned within the Repulse Bay Formation.

C.1.2 *Intrusive Igneous Rocks*

Five phases of intrusive igneous activity are identified in Hong Kong by Allen & Stephens (1971). All these are represented in the study area, and Table C1 indicates the various phases of intrusion.

Table C1 Intrusive Igneous Rock Types in Hong Kong (Allen & Stephens, 1971)

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

The predominantly granitic rocks represent a complex multi-phase batholith formed by successive magma injections into the existing rocks.

(i) *Tai Po Grandiorite (XT)*
The Tai Po Granodiorite is the oldest intrusive rock type in the study area and is intruded by all the younger phases. The rock is usually coarse or medium-grained, grey to dark grey and prophyritic in nature. Large well formed crystals of white feldspar up to 15 mm in length are present in a coarse

matrix of 2 to 5 mm crystals of potassium feldspar, plagioclase, biotite and minor quartz. One of the distinctive features of this rock is the presence of remnants of volcanic boulders and cobbles (xenoliths) that are partly absorbed by the magma. These appear as patches of fine-grained dark rock rarely larger than 600 mm in size.

The jointing in the Tai Po Granodiorite is similar to other granitic rocks, and is widely spaced and irregular. In addition to tectonic joints, sheeting joints that are subparallel to the topography, occur as a result of vertical stress relief.

The weathering is generally deep and produces a sandy, clayey silt. The lower quartz content, compared to granite, reduces the quantity of sand sized fragments and slightly increases the plasticity of the soils which are usually red in colour due to the high content of iron-bearing minerals.

(ii) *Sung Kong Granite (SK)*

The outcrops of Hong Kong Granite are scattered throughout the study area, the most extensive areas are on Lamma Island. This unit is characterised by a pale grey or pink (when fresh) coarse-grained porphyritic rock. These granites are difficult to distinguish from other granites, except when weathered, because the coarse quartz grains are prominent. The rock exhibits widely spaced tectonic joints and shallow, open, irregular sheeting joints, similar to the other coarse-grained granites of the Territory. The weathering is consequently deep, and large boulders remain on the surface after erosion of the weathered material.

(iii) *Cheung Chau Granite (CC)*

The Cheung Chau Granite is younger than the Sung Kong Granite and probably extends beneath it. The rock is pale grey or pink when fresh, and is generally medium to coarse-grained (3 to 5 mm) with very few feldspar phenocrysts. It contains similar minerals to the other granites, from which it is distinguished only by its relationship with other the intrusives. It tends to be characterised by a more extensive system of quartz veins, some of which contain mineralisation. Molybdenite and wolframite are associated with these veins.

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

Minor outcrops of the Ma On Shan Granite occur on Lo Chau in the Po Toi group. The rock is pale pink or grey, and fine-grained with a porphyritic texture. The phenocrysts of feldspar are up to 8 mm in length. Dark minerals such as biotite are evident only in thin section, as they form part of the fine-grained matrix. This granite has a finer-grained groundmass than the other granites present in the study area.

Weathering of the Ma On Shan Granite appears to be a fairly rapid process, and it results in a fine sandy clay soil which is susceptible to erosion. Jointing is similar to the other granites.

(v) *Fan Lau Porphyritic Granite (FL)*

This rock is pale pink, fine-grained and porphyritic. Within the study area, its outcrop is restricted to the Soko Islands. The rock is composed of about 50% phenocrysts, normally of quartz and feldspar. The groundmass is formed of microperthite, albite, quartz and mica.

(vi) *Quartz Monzonite (Mo)*

Quartz Monzonite outcrops in isolated localities throughout the study area. Minor outcrops occur on Lamma Island.

The rock is grey or pinkish grey, fine to medium-grained and porphyritic in nature. The large phenocrysts are pink or white feldspar with occasional quartz.

Monzonitic outcrops of this unit are generally more resistant to weathering and erosion than the other granites in the study area, and areas of outcrop are often strewn with boulders. On weathering, these rocks form a clay with high plasticity.

(vii) *Granophyric Microgranite (Mc)*

Exposures of fine-grained alkali porphyritic granite are rare in the study area. The Granophyric Microgranite exhibits phenocrysts of microperthite and albite. Chloritised biotite occurs, occasionally in association with sericite and calcite. The age of the Microgranite is difficult to determine but probably represents the last phase of igneous intrusion before intrusion of the post-tectonic dolerite dykes.

(viii) *Undifferentiated Granite (G)*

The outcrop on Peng Chau is probably an extension of the main area of Undifferentiated Granite which forms the eastern part of Lantau. In the latter area the granite is traversed by a swarm of porphyry dykes. The Undifferentiated Granite is not easily allocated, in terms of age relationship or lithology, to any of the main granitic classes.

(ix) *Dyke Rocks (D, MG, MO, C. Q, Pg)*

Dyke rocks occur on most of the islands in the study area. Although the main dyke rocks are Feldspar Porphyries (La) small dykes of Quartz Porphyry (Pq) also exist. The Feldspar Porphyry Dykes trend in a predominantly northeast to southwest direction and are structurally controlled. Phenocrysts are of white or pink feldspar, whilst the quartz porphyry has large phenocrysts of quartz. The mineralogy of these two dyke rocks is essentially the same, and weathering is expressed in their relief relative to the surrounding country rock. If the surrounding rock is harder, the dykes form depressions, if the reverse occurs then the dykes form ridges. Dykes often influence the pattern of surface and subsurface hydrology.

Dolerite dykes form an independent igneous phase. Dolerite is mineralogically and chemically different from the granitic suite of rocks because it is undersaturated in silica. Free quartz or potassium feldspar are not present. The rock is fine to medium-grained, and black in colour with a chilled margin about 10 mm in thickness. Dolerite dykes are rarely more than 10 m wide, and on weathering they decay to dark red clayey soils.

C.1.3 Superficial Deposits

Overlying bedrock and its residual mantle, unconsolidated, natural and man-made superficial deposits may occur. These form the surface material over a large proportion of the study area and are of significant engineering importance.

(i) *Colluvium (C)*

Colluvium results from the concentration of material transported downslope through the influence of gravity. Deposits may also be formed by soil creep, slope failure, boulder fall and local slopewash. Colluvium may occur as broad, fan-shaped deposits on footslopes associated with steep mountainous terrain and as lenticular deposits along drainage lines.

Colluvial deposits consist of a wide range of materials and grain sizes, according to the source rock, nature of deposition and age of the deposit. In the study area, there are two main source rock types. These are intrusive igneous and volcanic rocks. Granitic colluvium is typically composed of sandy silt derived from slopewash, whilst volcanic colluvium contains many large boulders. Very coarse deposits of angular boulders with only a small amount of interstitial soil occur, and these have marginal stability. Young colluvium on the footslope terrain is normally coarser-grained and less weathered than the older deposits; the latter may be highly weathered, compacted and fine-grained with a few large fragments. In the coarser colluvium, soil pipes or tunnels may develop, creating linear voids which enable groundwater to be transmitted through the soil. Colluvium derived from volcanic sediments generally forms relatively fine-grained deposits, but is of very limited extent in the study area.

(ii) *Alluvial Deposits (A)*

Alluvial deposits within the study area occur on the low-lying coastal plains and estuarine areas. Alluvial deposits also occur upstream of the nick points which indicate the headward extension of stream downcutting resulting from changes of sea level.

Alluvium is generally composed of material with a range of grain sizes. Coastal alluvium is often finer-grained than upland alluvium due to the greater distance of sediment transport and consequent increase in abrasion, attrition and sorting of the constituent particles. The drowning of the coastline has reduced the area of alluvium above sea level, and only small pockets of very recent alluvium occur near the mouths of the drowned valleys.

(iii) *Littoral Deposits (L)*

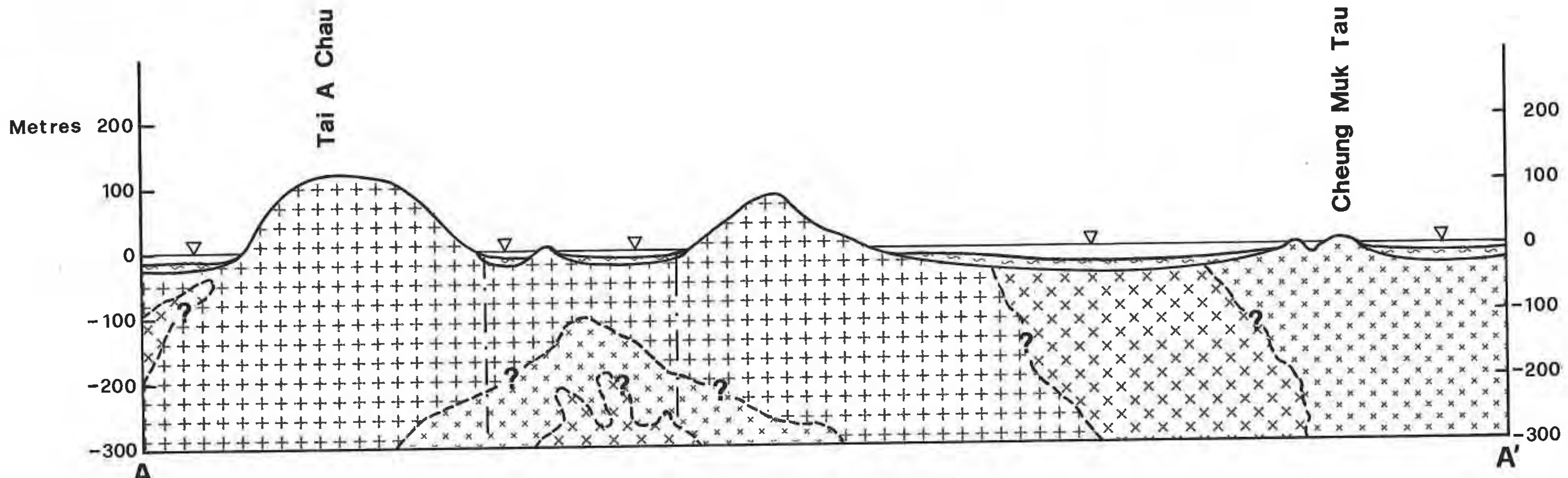
Littoral deposits are well developed in many bays, and consist of fine yellow to white sand. These sand deposits may be reach 15 m in thickness. Strand lines or shoals of coarser-grained (pebble size) material, develop in the intertidal zone in some localities.

(iv) *Raised Beach Deposits (L(RB))*

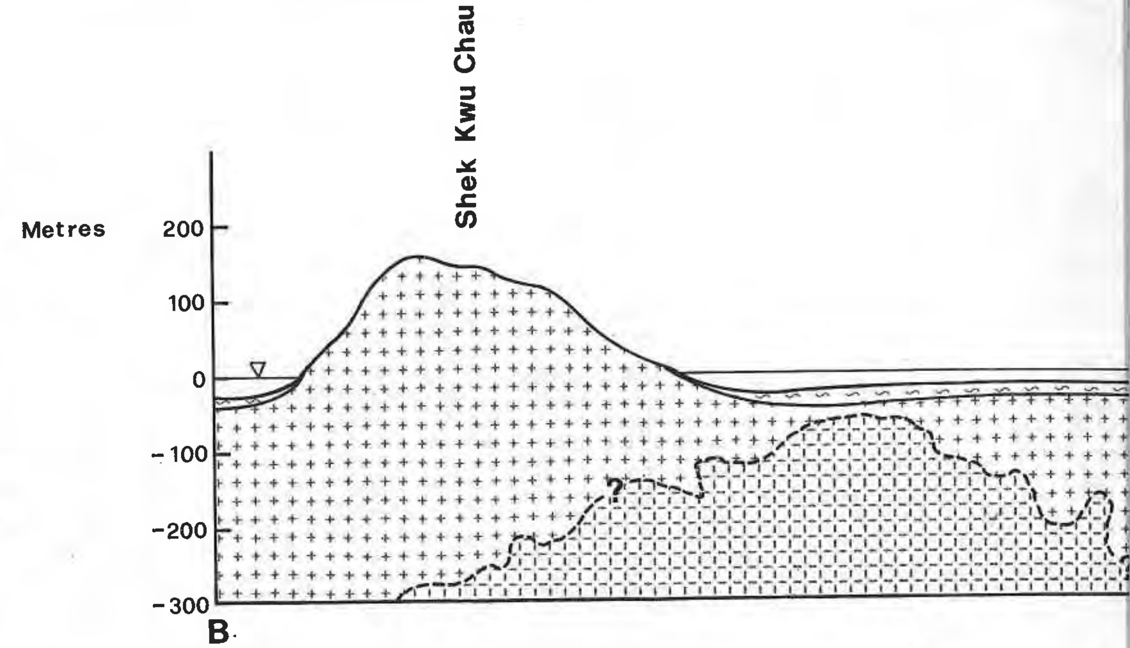
Several of the islands contain narrow sandbars linking mounds of bedrock. These form in the shelter of the bedrock, often creating bays. The elevation of these 'tombolo' landforms indicate that they were formed as storm beach deposits, possibly during a period of slightly higher level sea than exists at present. They consist of well-rounded and generally well-sorted sands, with some coarser (pebble sized) material.

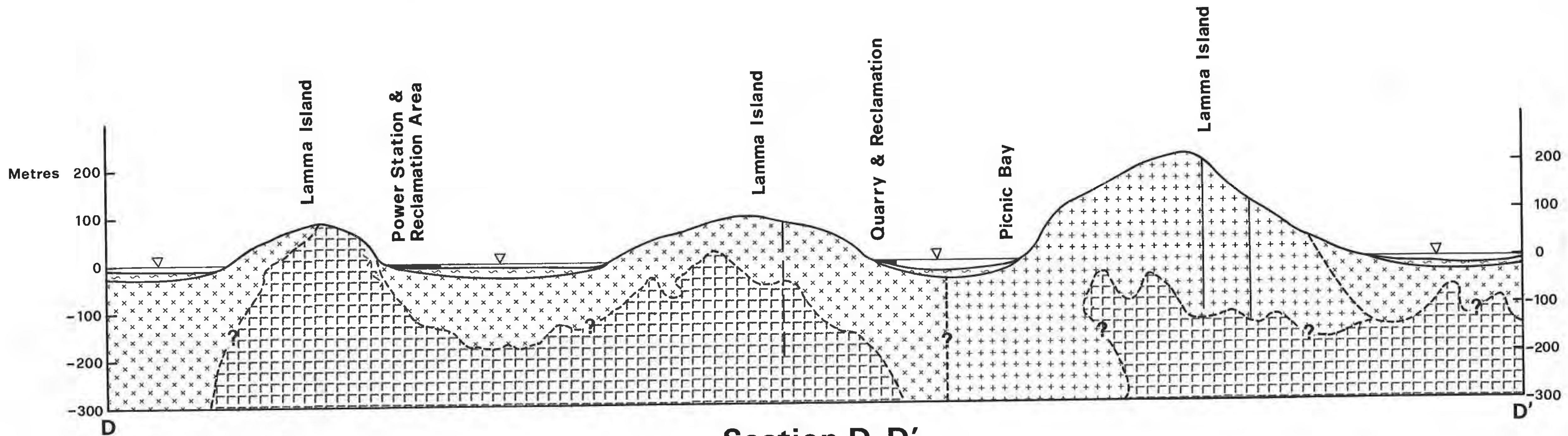
(v) *Marine Deposits (M)*

Marine deposits within the Territory are variable and related to sea level changes. The marine deposits may interdigitate with alluvium and colluvium deposited during periods of lower sea level. Dark-coloured marine muds alternate with coarser deposits of silty sand with shell fragments and occasional gravels. At depth, fine silt and clayey silt predominate. The marine deposits are generally soft and unconsolidated.

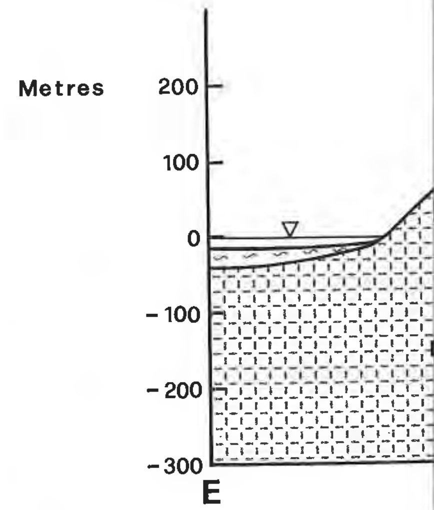


Section A-A′

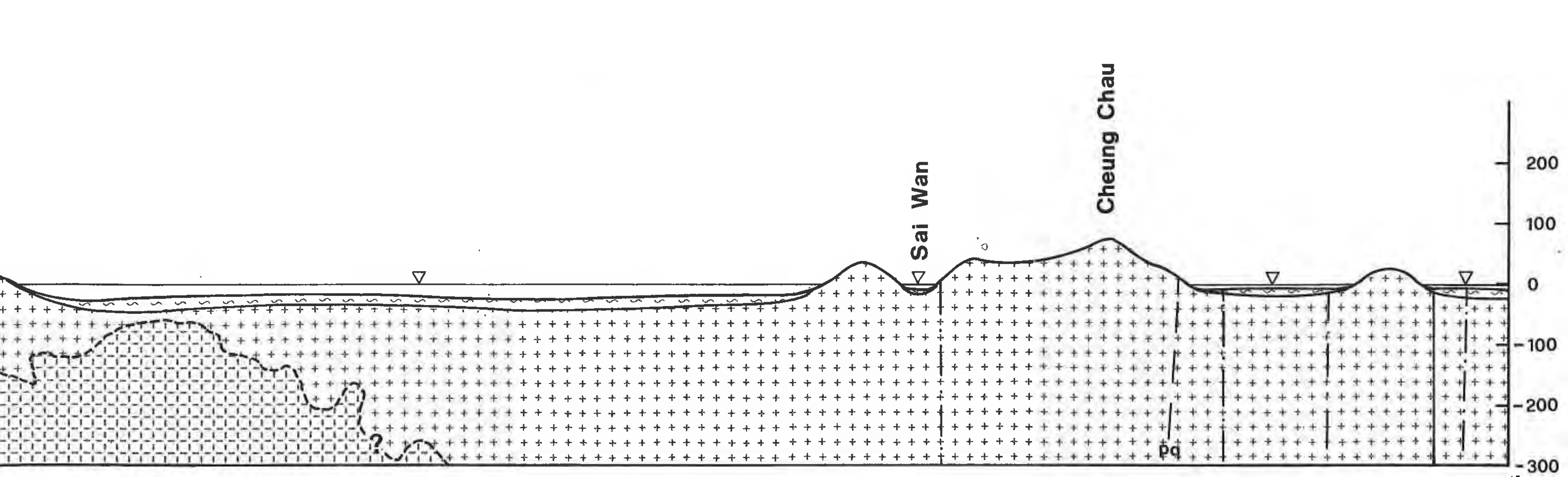




Section D-D′



Geological Cross-s



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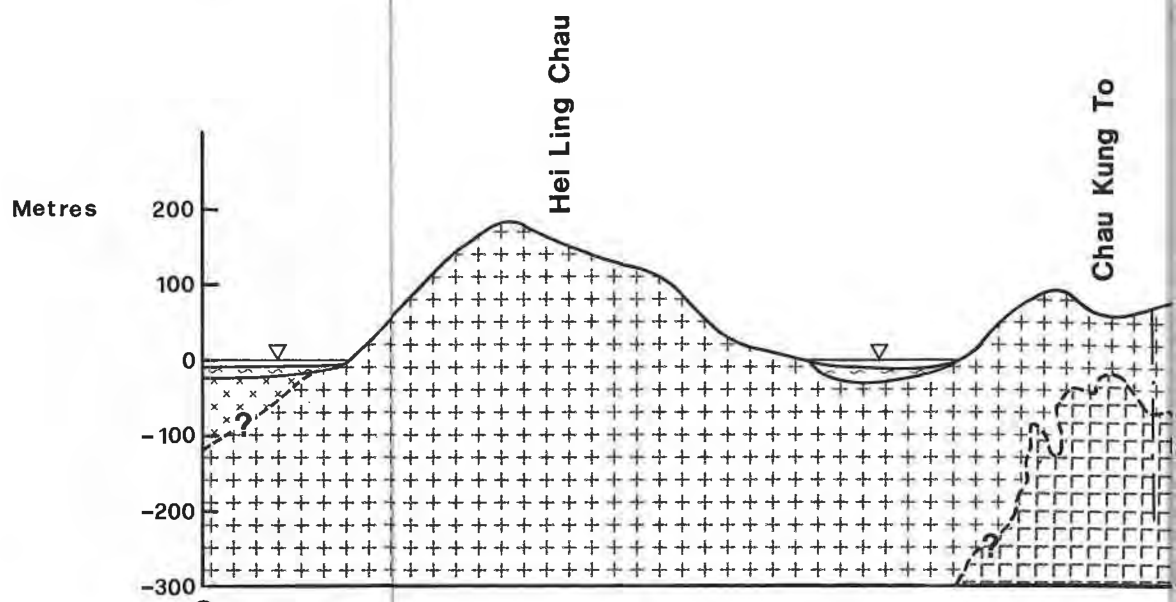
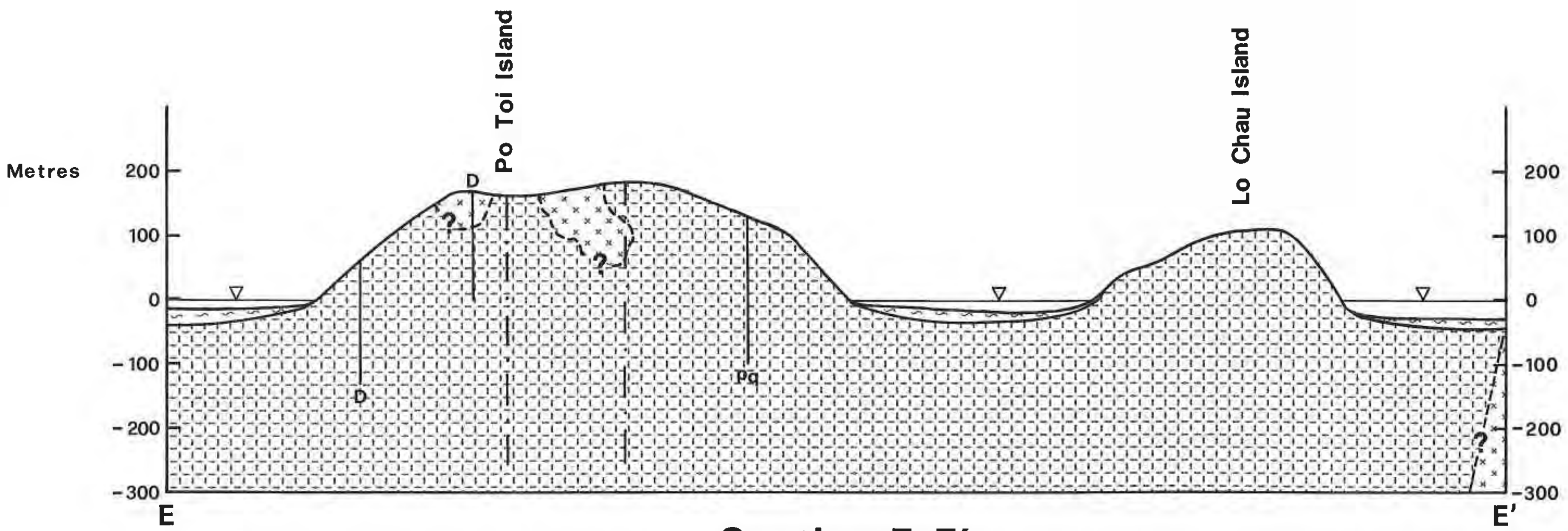
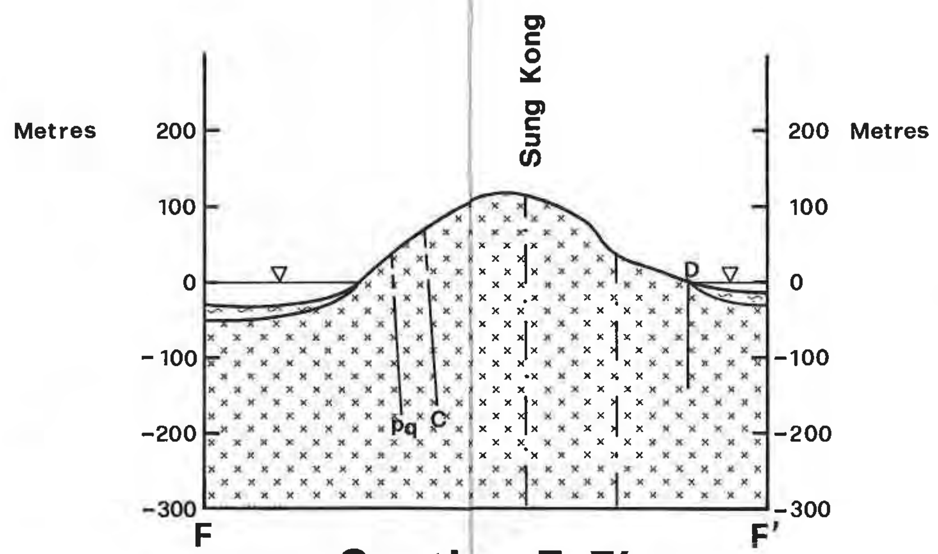


Section C-C'



Section E-E'



Section F-F'

- For location of secti
- For legend see Figur
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- All heights are in me
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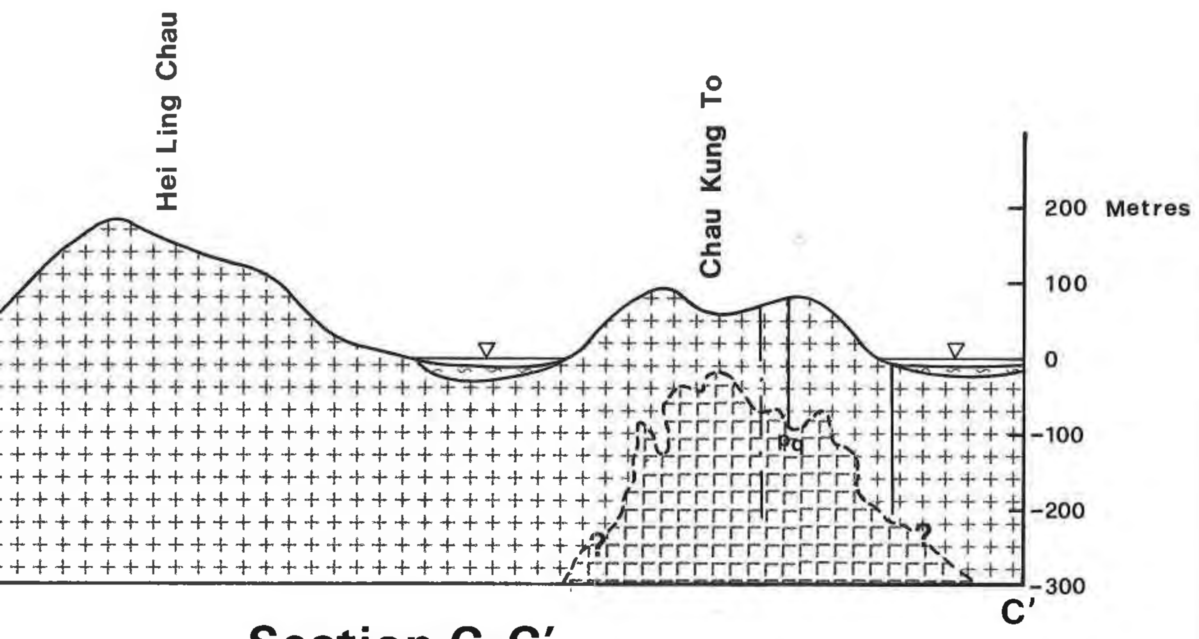
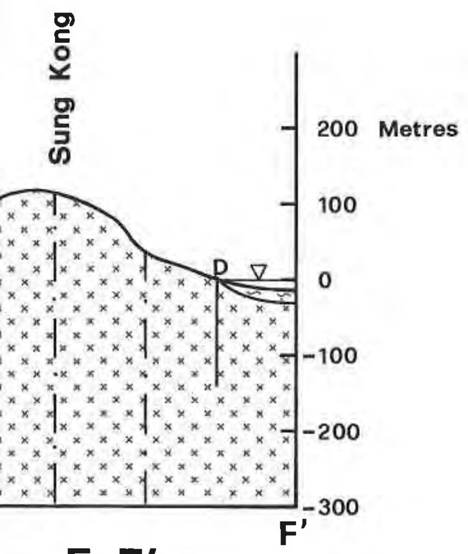
Geological Cross-sections – Islands



Section C-C'



on F-F'

$\frac{V}{H} = 1$

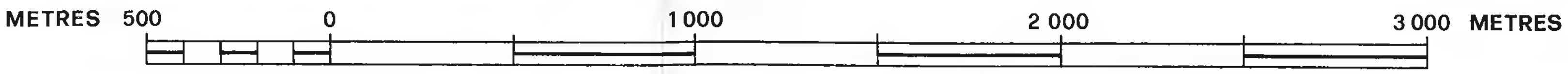
- For location of sections refer to Engineering Geology Map.
- For legend see Figure 17a.
- These Cross-sections are scaled schematic diagrams only. The illustrated relationships are consistent with those presented in Allen & Stephens (1971).
- All heights are in metres above Principal Datum which is approximately 1.20m below Mean Sea Level.

> **ATTENTION : USERS**
> 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.

LEGEND

- Reclamation
- Marine deposits & submarine colluvium & alluvium
- Cheung Chau Granite
- Ma On Shan Granite
- Fan Lau Porphyritic Granite
- Feldspar Porphyry Dyke Swarm
- Sung Kong Granite
- Quartz monzonite and porphyitic adamellite
- D — Dolerite
- Pq — Quartz porphyry
- C — Composite dyke
- Lithological boundary
- Geological photolineament
- Water surface level
- ? — Uncertain
- Mineral vein: Certain / Uncertain

Scale 1 : 20 000



Compiled: J. M. Nash	Drawn: S. Y. Lam	Fig. C1
Scale: 1:20 000	Date: October, 1985	

(vi) *Reclamation (R)*
Reclamation is generally restricted to the islands with some development, such as Peng Chau, Cheung Chau and Lamma. Natural topographic constraints result in reclamation often forming an option for the creation of flat land. These areas of reclamation tend to complement the existing development in the main centres of population within the study area. Materials for reclamation are derived from a wide variety of sources, and hence may represent any or all of the rocks and soils within the Territory, as well as demolition material, industrial and domestic refuse. The degree of compaction varies according to the age and nature of the reclaimed areas.

(vii) *Fill (F)*
Large areas of fill are relatively uncommon in the study area. Small areas of fill occur in the developed areas, and the materials have similar characteristics to those in reclamation. Cut and fill techniques generally result in the local soil and rock being used as a fill material.

C.2 Site Investigation Data

A number of site investigations have been conducted by the public and private sectors. 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.3 Aerial Photographs

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

C.4 Rainfall Data Relevant to the Islands Study Area

A general appreciation of the annual and monthly rainfall distribution for the Islands area can be obtained from Figures C2 and C3. Figure C2 is a reproduction of the mean annual rainfall isohyets for the years 1952 to 1976, published by the Royal Observatory. Figure C3 is a histogram of monthly rainfall for seven selected Royal Observatory rainfall stations. There are a total of seven rainfall stations within the study area the locations of which are indicated on Figure C4. Detailed monthly and annual rainfall information for these stations is available from the Royal Observatory.

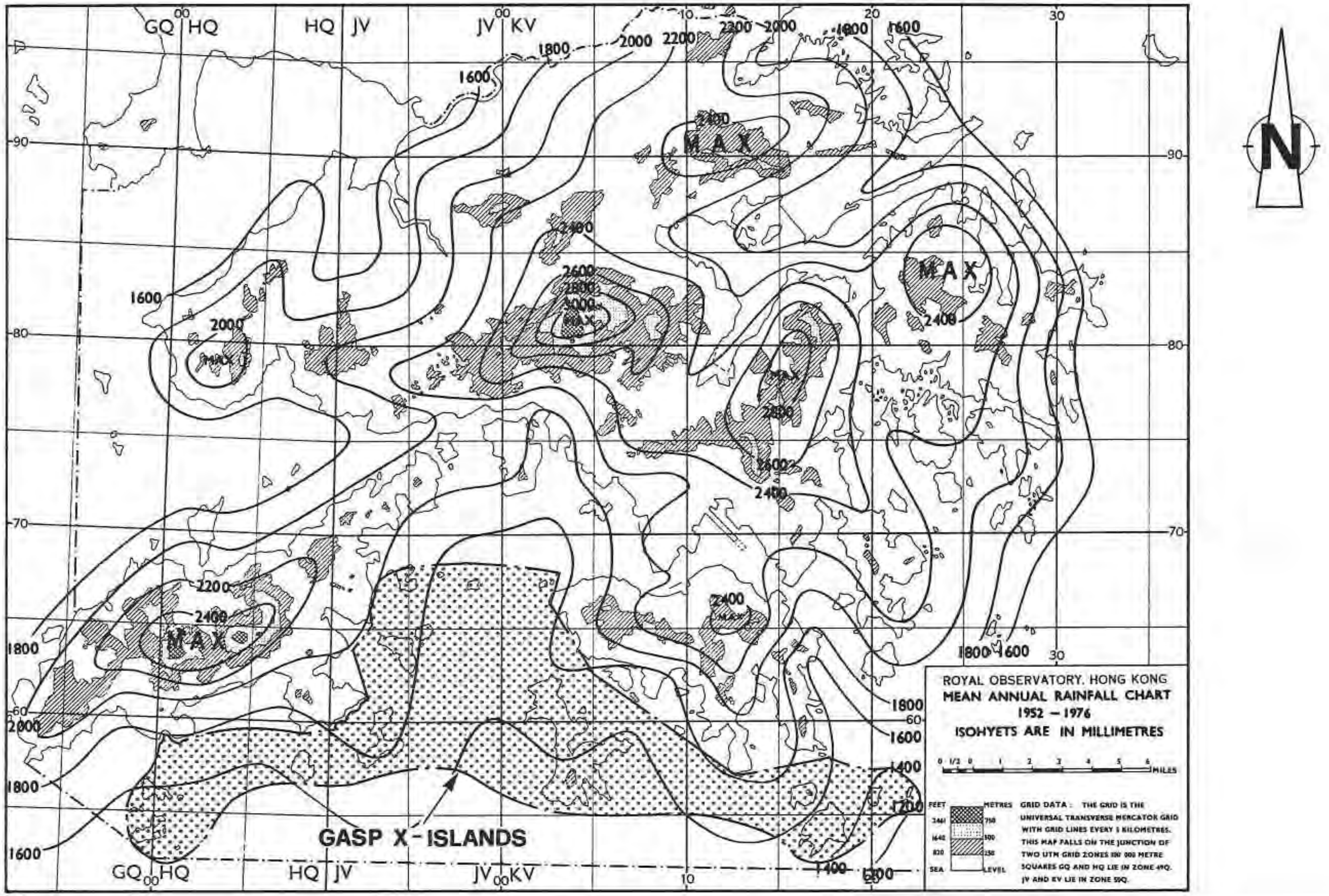
Table C2 Selection of Aerial Photographs

Year	Photograph Serial Number	Photograph Scale (Approx.)
1983	51763–51765	1:40 000
	51735–51747	1:40 000
	51695–51699	1:40 000
	51715–51727	1:40 000
	51344–51349	1:20 000
	51315–51316	1:20 000
	51278–51279	1:20 000
	51270–51274	1:20 000
	51245–51260	1:20 000
	51223–51237	1:20 000
	47194–47227	1:40 000
	47170–47180	1:40 000
	41749–41757	1:40 000
1982	44815	1:20 000
	44797–44798	1:20 000
	44477–44480	1:20 000
	44475	1:20 000
	44441–44438	1:20 000
	44419–44420	1:20 000
	44413–44416	1:20 000
	44391–44402	1:20 000
	44383–44381	1:20 000
	44351–44356	1:20 000
1981	39113–39117	1:20 000
	39008–39013	1:20 000
	38977–38980	1:20 000
	38974	1:20 000
	38938–38945	1:20 000
	38909–38916	1:20 000
	38875–38890	1:20 000
	38865–38870	1:20 000
	36772–36780	1:25 000
	36770–36771	1:31 000
	36743–36747	1:50 000
	36712–36727	1:50 000
1980	33412–33416	1:20 000
	33387–33389	1:20 000
	33384	1:20 000
	47225	1:20 000
	33231–33236	1:20 000
	33219–33222	1:20 000
	33216–33217	1:20 000
	33210–33215	1:20 000
	33202–33207	1:20 000
	33198–33200	1:20 000
	33189–33192	1:20 000
	33184–33188	1:20 000
	33181–33183	1:20 000
	27999–28005	1:20 000
	27968–27971	1:20 000
	27964–27966	1:20 000
	27776	1:20 000
	27741–27744	1:20 000
	27732–27734	1:20 000
	27715–27729	1:20 000
	27701–27711	1:20 000
	24629–24635	1:25 000
	24610–24617	1:25 000
	24598–24604	1:25 000
	24587–24595	1:25 000
1978	20914–20923	1:25 000
	20906–20911	1:25 000
	20890–20900	1:25 000
	20823–20830	1:25 000
	20793–20796	1:25 000
1976	15894–15916	1:25 000
	15879–15888	1:25 000
	15867–15873	1:25 000
	15847–15851	1:25 000

Table C1 Selection of Aerial Photographs *(Continued)*

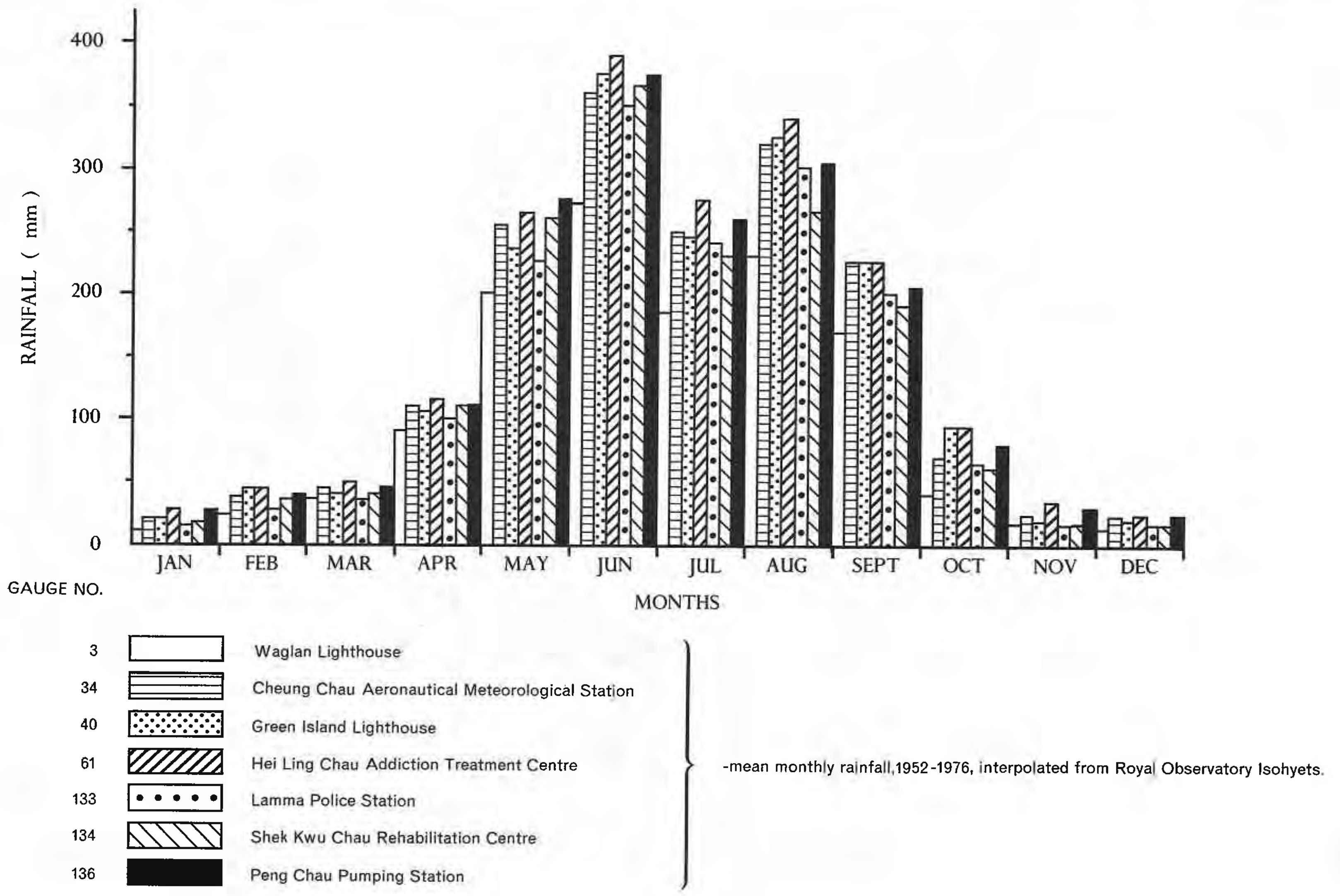
Year	Photograph Serial Number		Photograph Scale (Approx.)
1975	11697–11700		1:25 000
	11676–11682		1:25 000
	11629–11659		1:25 000
1974	9669–9690		1:25 000
	9644–9660		1:25 000
	9573–9574		1:25 000
	9567–9568		1:25 000
	9539–9541		1:25 000
	8211–8224		1:25 000
	8191–8205		1:25 000
1973	8093		1:25 000
	8062–8072		1:25 000
	8025–8027		Not calculated
	6196–6197		Not calculated
	6146		Not calculated
	6134		Not calculated
	6009–6128		Not calculated
	6121		Not calculated
	6098		Not calculated
1972	2301		1:26 000
	2051–2052		Not calculated
	1987–1991		Not calculated
1970	2476–2480		Not calculated
1969	1991–2014		Not calculated
	1769–1771		Not calculated
	1263–1266		Not calculated
1968	938–967		Not calculated
	768–777		Not calculated
	633–634		Not calculated
1964	5166–5176		1:5 400
	2928–2932		1:25 000
	2911–2913		1:25 000
	2883–2879		1:25 000
	2839–2847		1:25 000
	2505–2530		1:25 000
	2486–2492		1:25 000
	2465–2469		1:25 000
	2423–2433		1:3 000
1963	8731–8797		1:7 800
	8163–8190		1:7 800
	7489		1:5 400
1962	F 43/81A/RAF/642	0122	1:10 000
	F 42/81A/RAF/642	0103–0112	1:10 000
	F 41/81A/RAF/642	0103–0112	1:10 000
1961	F 44/81A/RAF/600	0174–0179	1:10 000
	F 43/81A/RAF/600	0170–0179	1:10 000
	F 42/81A/RAF/600	0171–0178	1:10 000
	F 41/81A/RAF/600	0173–0175	1:10 000
1956	F 22/81A/RAF/557	0219–0220	1:10 000
	F 22/81A/RAF/557	0185–0188	1:10 000
	F 21/81A/RAF/557	0185–0187	1:10 000
1954	V81A/RAF/550	121–123	1:25 000
	V81A/RAF/552	1–3	1:25 000
1949	81A/117	6207	1:4 800
	81A/127	6183	1:4 800
	81A/127	6181	1:4 800
	81A/133	6153	1:5 160
	81A/127	6099	1:4 800
	81A/127	6098	1:5 160
	81A/128	6054	1:4 800
	81A/127	6001–6007	1:5 160
1945	681/6	4141–4169	1:12 000
	681/6	4122–4129	1:12 000
	681/6	4075–4082	1:12 000
	681/6	4017–4025	1:12 000
	681/6	3138–3159	1:12 000
	681/6	3115–3122	1:12 000
	681/6	3070–3074	1:12 000
1924	H 57	18–19	1:15 000
	H 71	16	1:13 320
	H 41	13, 21	1:15 000

Note: Vertical and oblique aerial photographs are available from the Photographic Library, Survey & Mapping Office, Buildings & Lands Department, 14th Floor, Murray Building, Garden Road, Hong Kong.



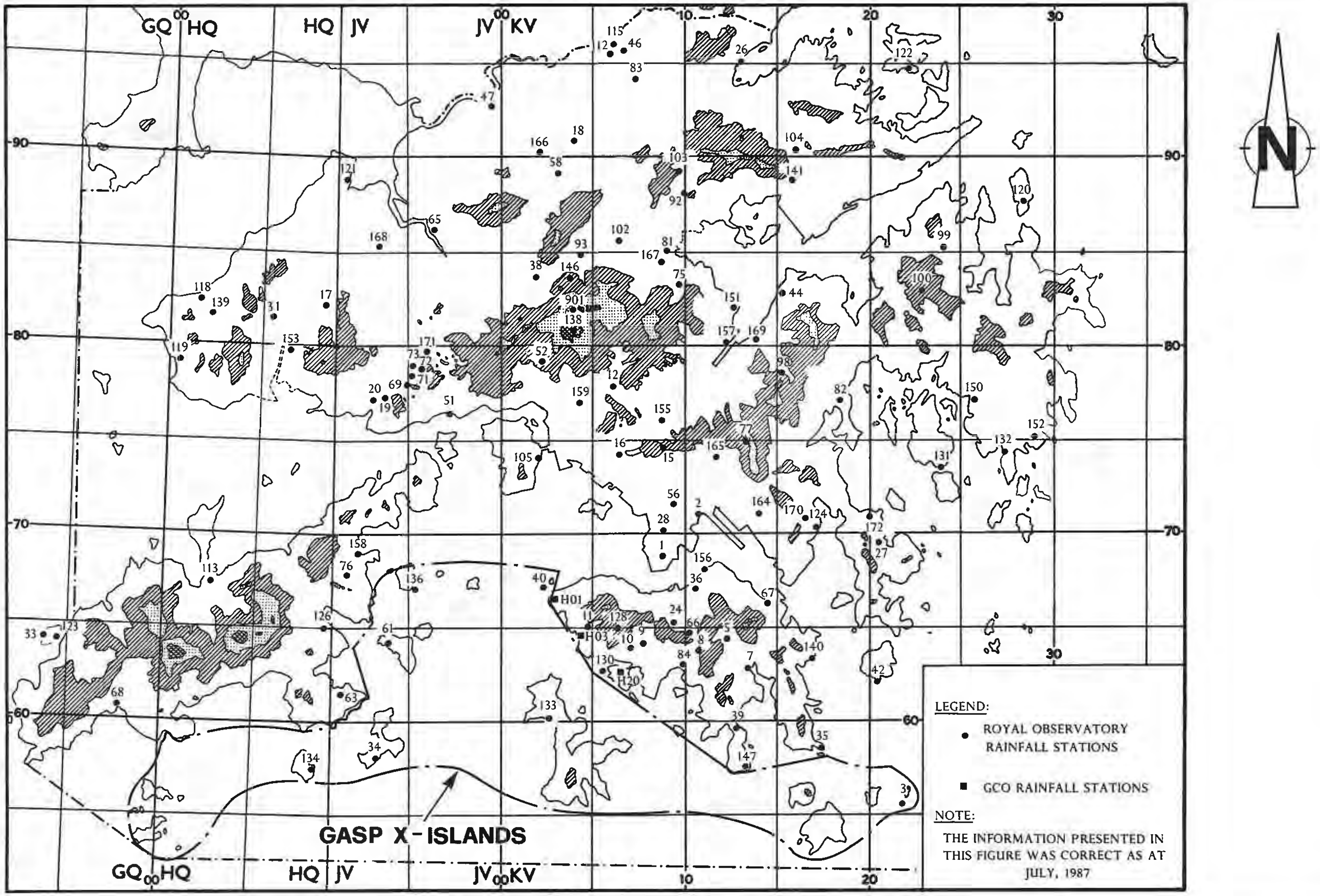
Mean Annual Rainfall Isohyets (1952–1976)

Fig. C2



Summary of Mean Monthly Rainfall Data

Fig. C3



Locations of Rainfall Stations

Fig. C4

APPENDIX D

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

List of Figures

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 Appendix C.1. 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.

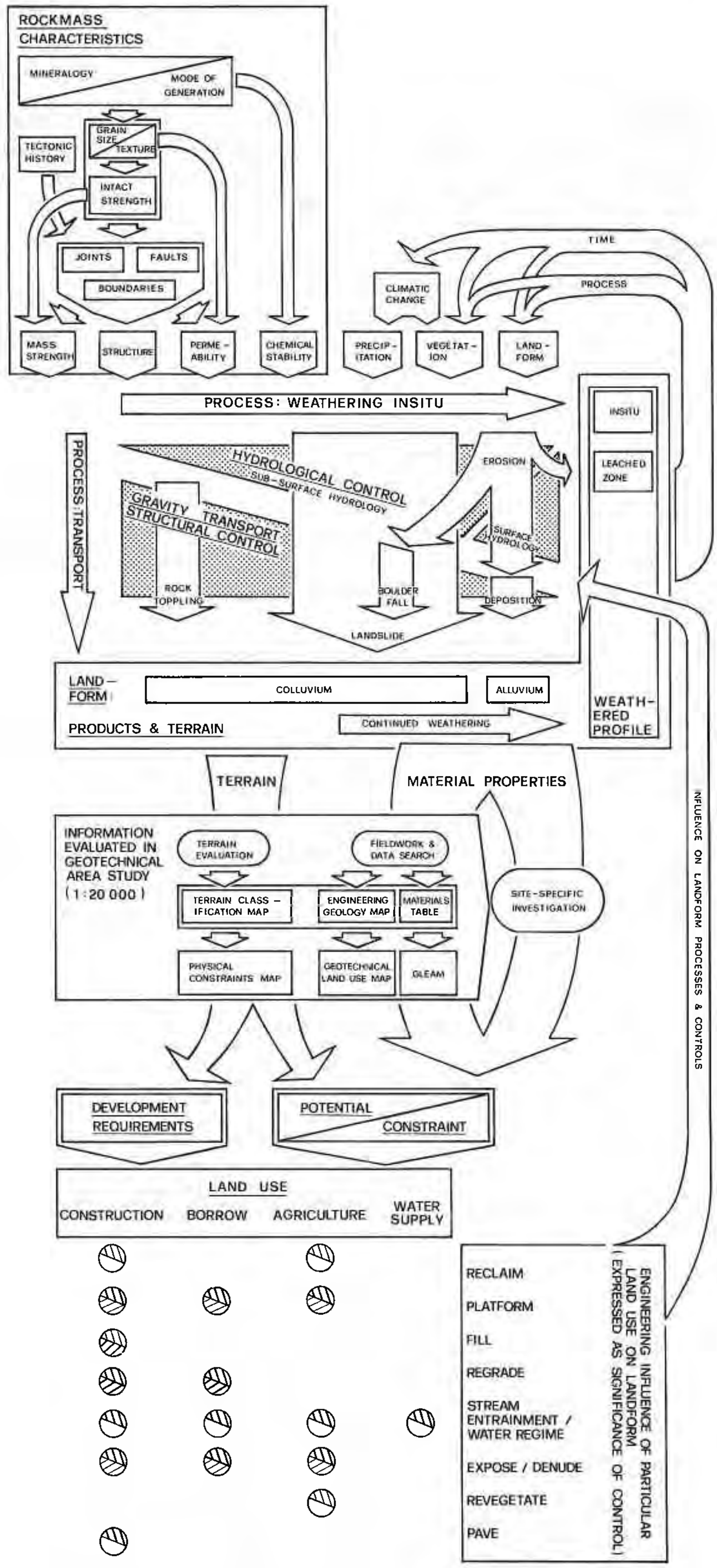
The weathered product of granitic rock is a loose, granular quartz soil because feldspars are broken down during weathering. The proportion of clay in the weathered soil depends on the balance between eluviation and deposition, which is related to the terrain. The texture of weathered granite makes it 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.

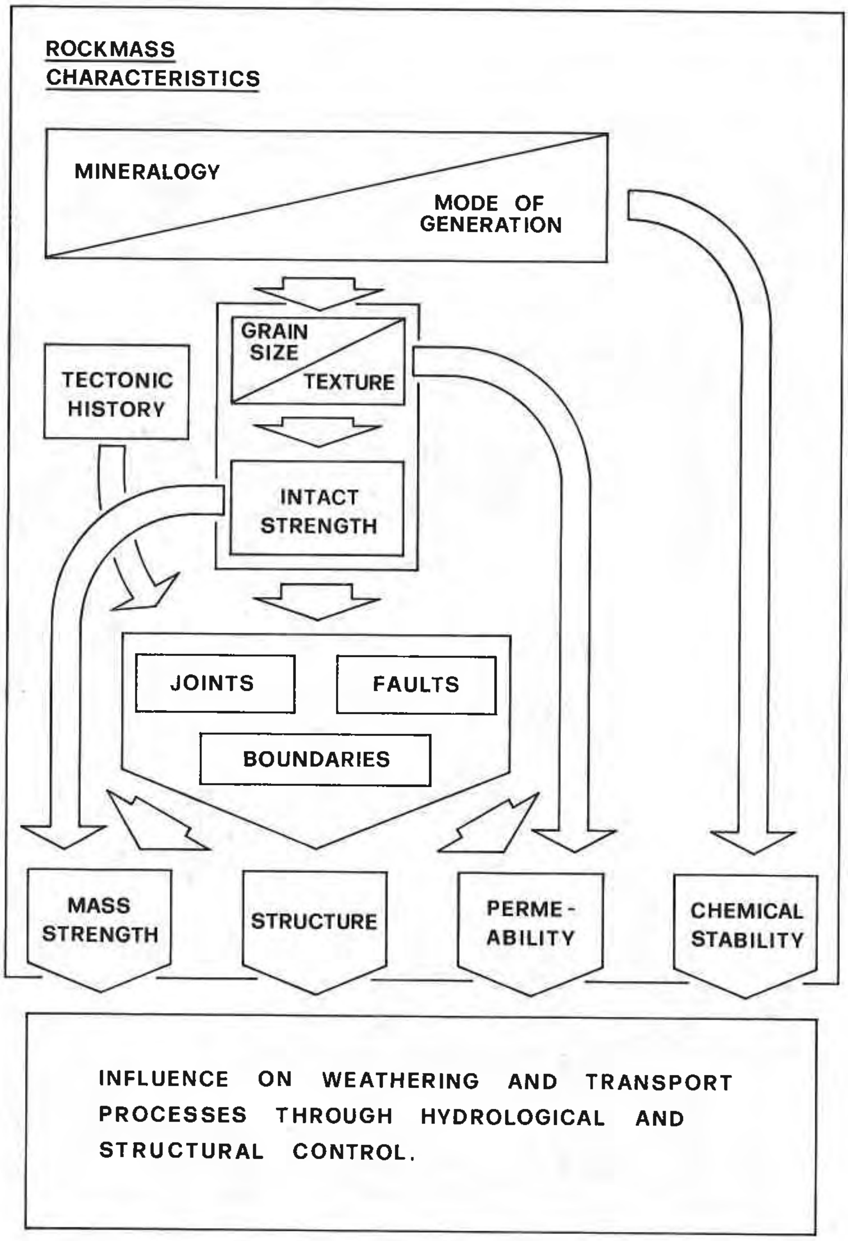
GEOTECHNICAL AREA STUDIES :
CLASSIFICATION OF TERRAIN & ENGINEERING MATERIALS, INTERPRETATION OF LANDFORM IN TERMS OF GEOTECHNICAL POTENTIAL & CONSTRAINT FOR STRATEGIC PLANNING & ENGINEERING FEASIBILITY STUDIES. G A S PROVIDES PRELUDE TO SITE SPECIFIC INVESTIGATION.

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

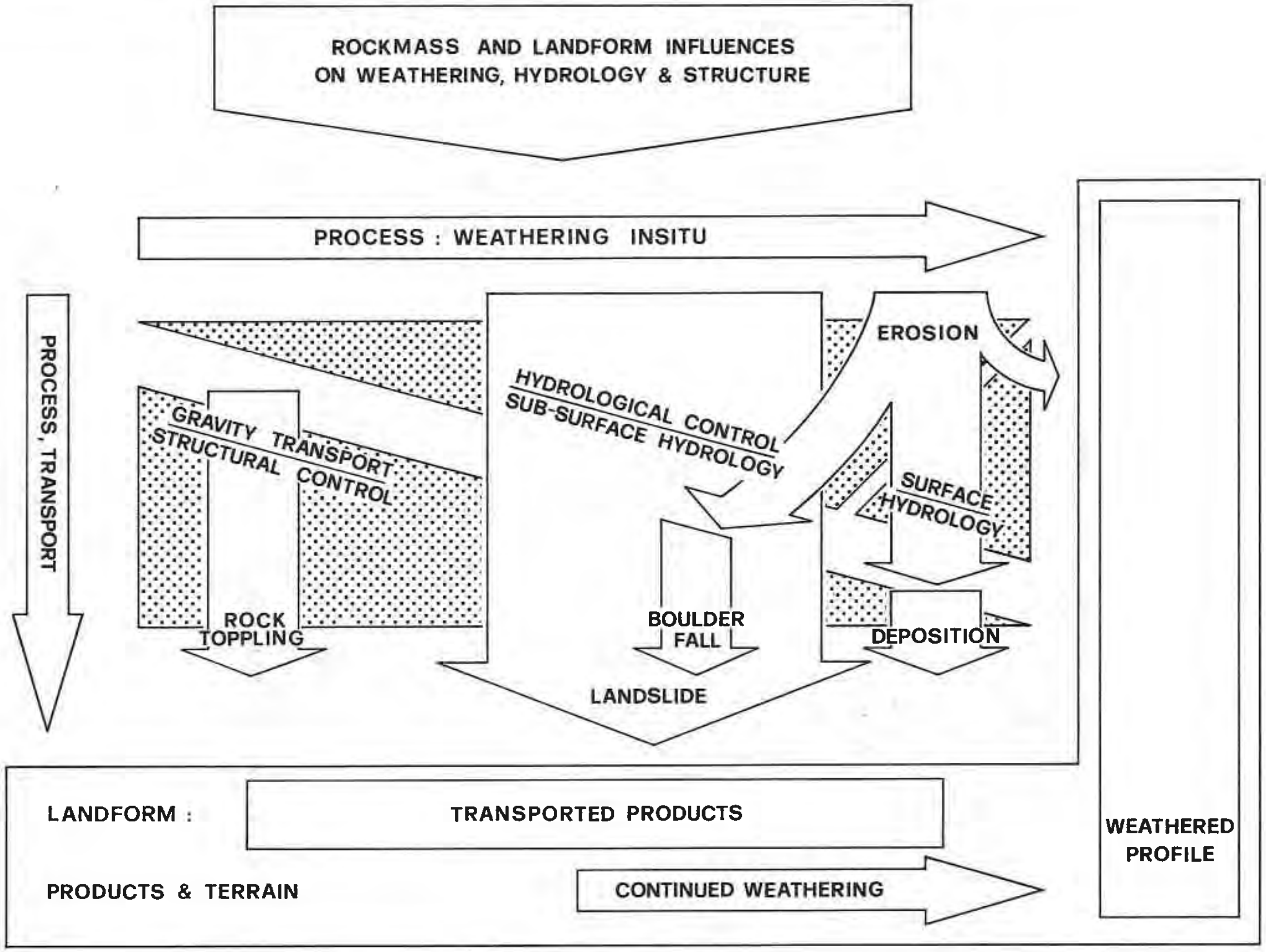
LEGEND :
BOXES INDICATE : CAUSE OR PRODUCT
ARROWS INDICATE : INFLUENCE, PROCESS, OR MECHANISM
CIRCLES INDICATE : HUMAN INVOLVEMENT

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 the 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 building platforms on otherwise steep terrain. 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. These features and some more minor lineaments are also shown on the GLEAM if they are significant in the engineering feasibility of potential development areas.

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. The GLEAM shows the influence of structure on drainage in this area; 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 strength of the adjacent 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 inspite of surface water entrainment.

(v) *Seismic Influence*
Some lineaments are identified on the Engineering Geology Map (after Allen & Stephens, 1971) as faults, and other major lineaments may also indicate faults. Faults may extend laterally for short distances or 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 3.1.3. 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 over-consolidation 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 usually 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 3.1.3, 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 footslopes 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 flows caused by torrential rain are 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 areas with potential for development, boulders and rock outcrops are indicated on the GLEAM where they are obvious in aerial photographs. 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. Their geological characteristics are discussed in Appendix C.

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 and structural control are indicated on the GLEAM. 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 3.1.3. Colluvium overlies the insitu rocks in many of the potential development areas outlined in this Report. 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, 1972a & 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 EGM, PCM and GLEAM. 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. Figure C2 gives an indication of the distribution and intensity of site investigation records held in the GIU.

(*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.

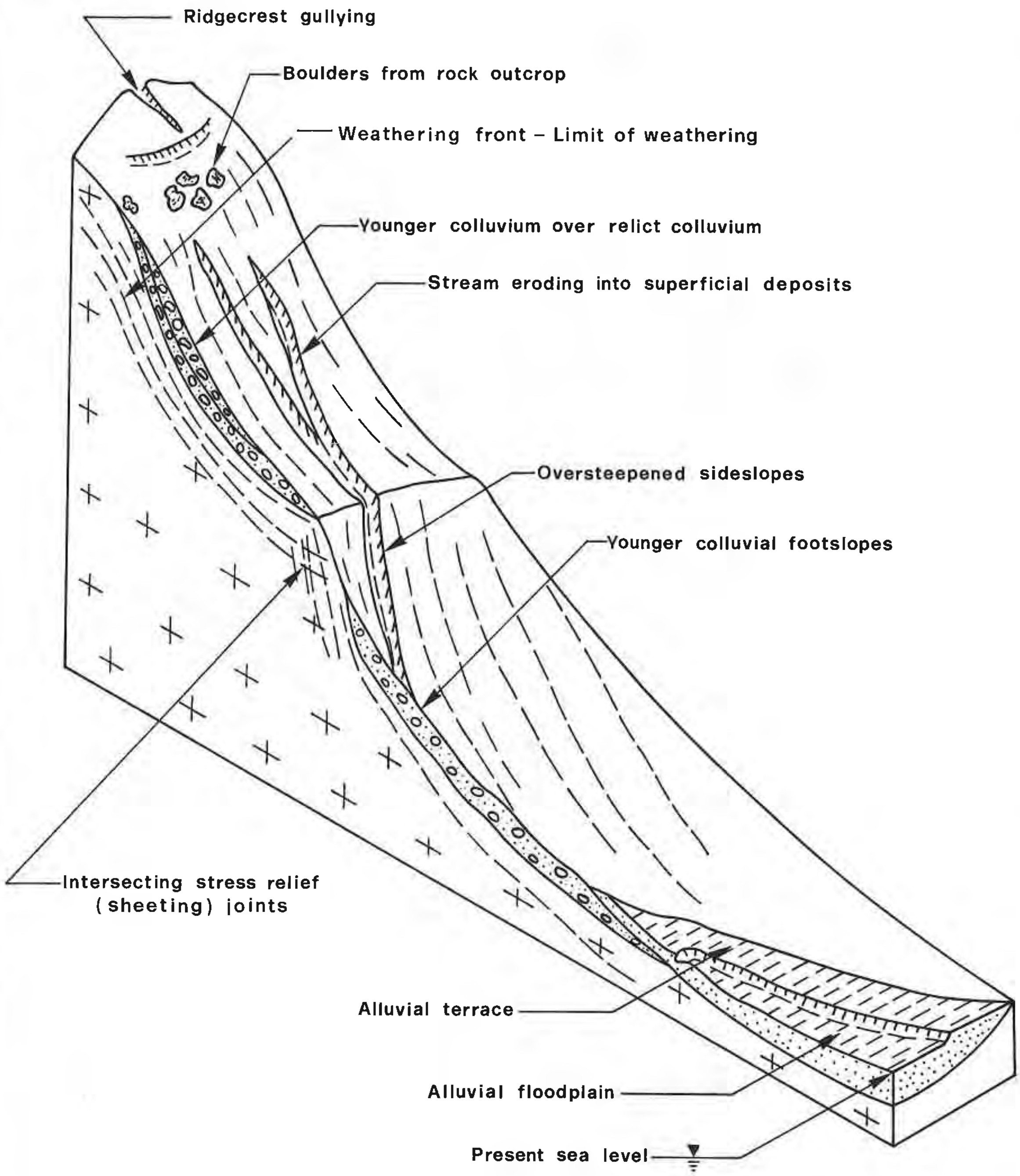
(*c*) The site investigation should be designed to highlight the scope of any available information, the anticipated material, its nature and variability, and the type and form of the engineering project.

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.

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.

ALLUVIUM

Sediment transported and deposited by a river or stream.

APHANITE

Rock with microcrystalline or cryptocrystalline texture that is too small to be seen with the naked eye.

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.

DACITE

Extrusive equivalent of quartz diorite. The principal minerals are plagioclase, quartz, pyroxene and hornblende. The rock is glassy or fine grained with occasional phenocrysts.

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'.

DOLOS

Interlocking precast concrete structures of regular geometric form, normally used for protection against marine erosion.

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.

GENERALISED LIMITATIONS AND ENGINEERING APPRAISAL MAP (GLEAM)

Map which delineates potential development areas in terms of geotechnical and other constraints.

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.

GRABEN

Downfaulted block between two or more parallel (or subparallel) faults.

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.

HORNFELS

Fine-grained non-schistose metamorphic rock, usually derived from fine-grained sediments.

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.

IMBRICATE STRUCTURE

Tabular or sheet structures that overlap each other in response to uni-directional forces.

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.

NICK POINT

Point of interruption of a stream profile at the head of a second-cycle valley, usually as a result of a change in base level.

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.

PHYLLITE

Argillaceous rock of intermediate metamorphic grade.

PHYSICAL LAND RESOURCES

Physical characteristics of land.

PIPE (=SOIL PIPE)

Tubular erosion conduit within the soil mantle, through which groundwater may flow.

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.

SPHERULITE

Small radiating, and usually concentric arrangement of one or more minerals formed by radial growth of acicular crystals.

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.

TRANSMISSIVITY

The rate at which water is transmitted through a unit width of aquifer, under a unit hydraulic gradient.

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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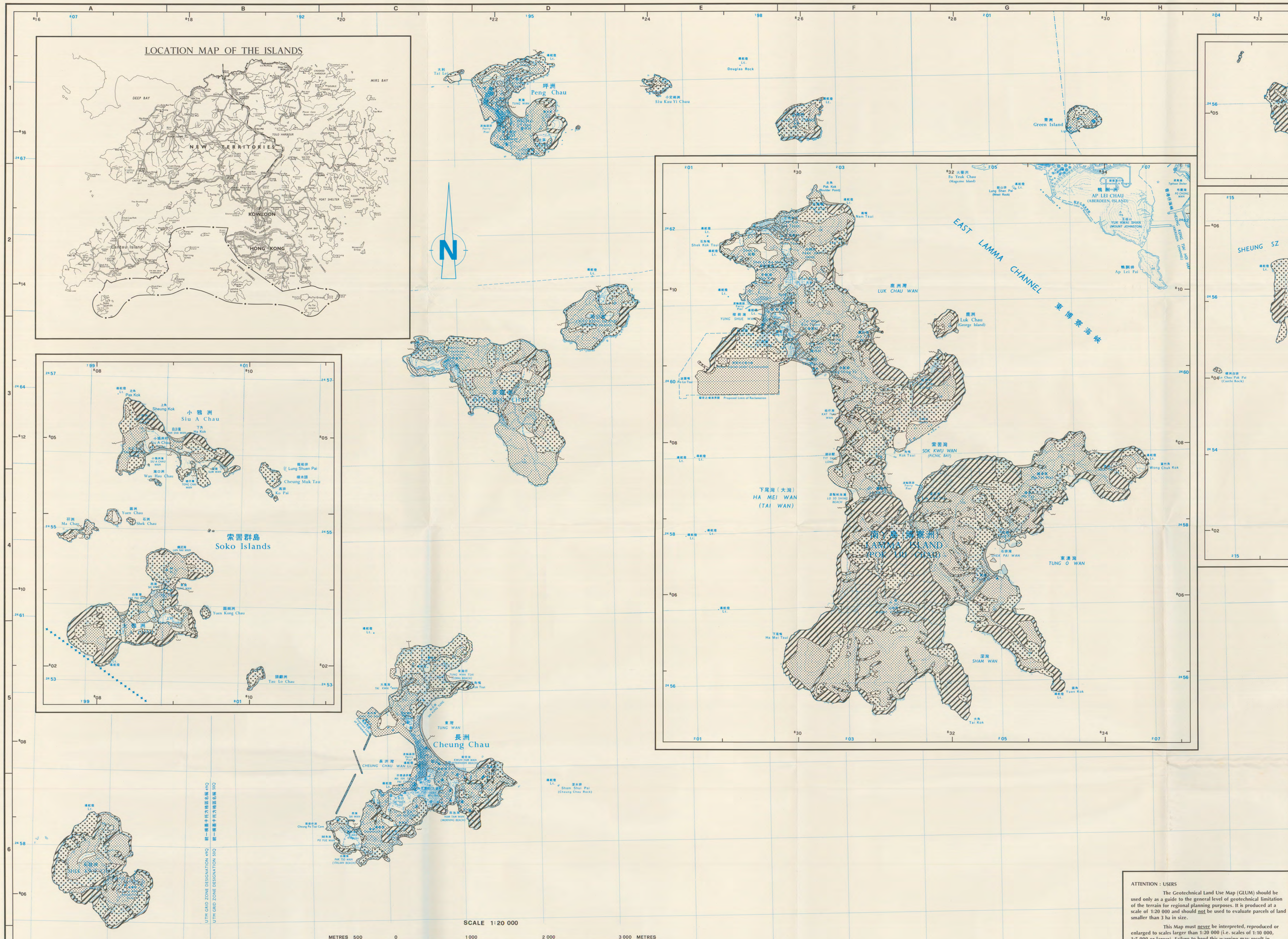
GEOTECHNICAL AREA STUDIES PROGRAMME

GEOTECHNICAL LAND USE MAP — ISLANDS



Note : The topographic base of this map is derived from Sheet 10 - Edition 3 of 1985, Sheet 13 - Edition 2 of 1983, Sheet 14 - Edition 2 of 1982, Sheet 15 - Edition 2 of 1980 and Sheet 16 - Edition 1 of 1976 of the HM20C Series produced by the Survey and Mapping Office of the Buildings and Lands Department, Hong Kong.

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 the GLUM system.

- Waterbodies (streams, man-made channels, storage dams)
- Ponds
- Littoral zone (generally subject to tidal action)
- Wave cut platform

$^{2}15$ Universal Transverse Mercator (UTM) Grid Reference

$^{8}10$ Hong Kong Metric Grid Reference

ATTENTION : USERS

The Geotechnical Land Use Map (GLUM) should be used only as a guide to the general level of geotechnical limitation of the terrain for regional planning purposes. It is produced at a scale of 1:20 000 and should not be used to evaluate parcels of land smaller than 3 ha in size.

This Map must never be interpreted, reproduced or enlarged to scales larger than 1:20 000 (i.e. scales of 1:10 000, 1:5 000 or larger). Failure to heed this warning may result in serious misinterpretation of the data.

Please consult the Islands Geotechnical Area Studies Programme Report (GASP X) which discusses in detail the purpose, application and limitations of this Map.

Geotechnical Control Office
Civil Engineering Services Department

Title: GEOTECHNICAL LAND USE MAP — ISLANDS	
Compiled: A.Hansen & J.M.Nash	Drawn: N.L.Yuen
Scale: 1: 20 000	Date: Original January, 1985; 2nd Edition August, 1988
Map Ref. No. GASP / 20 / X / 1 2nd Edition	Sheet:

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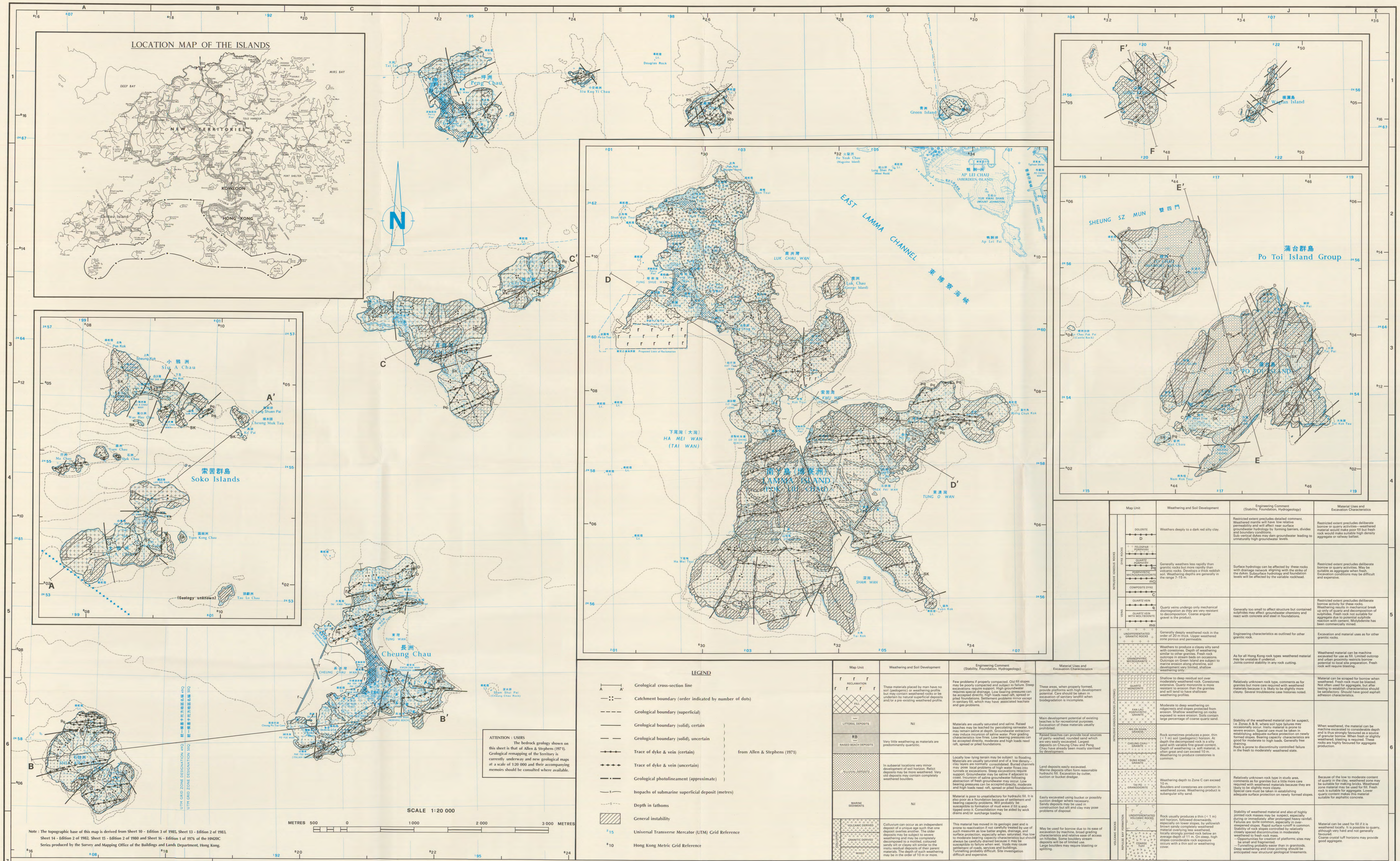

GEOTECHNICAL AREA STUDIES PROGRAMME

ENGINEERING GEOLOGY MAP — ISLANDS

Geotechnical Control Office
Civil Engineering Services Department

Title: ENGINEERING GEOLOGY MAP — ISLANDS	
Compiled: J.M.Nash & A.Hansen	Drawn: S.Y.Lam
Scale: 1:20 000	Date: Original January, 1985 2nd Edition August, 1988
Map Ref. No. GASP/20/X/2 2nd Edition	Sheet:

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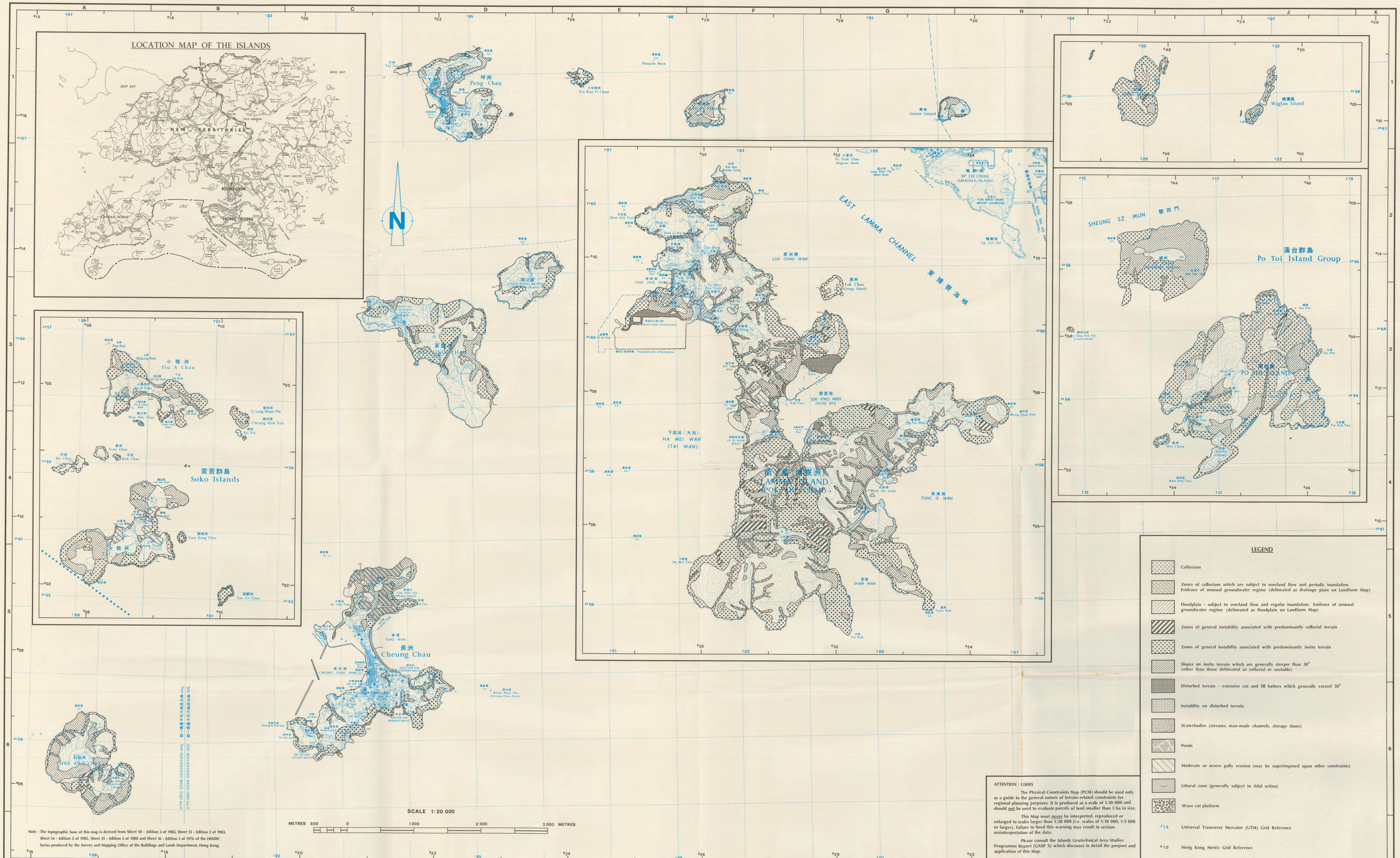
GEOTECHNICAL AREA STUDIES PROGRAMME

PHYSICAL CONSTRAINTS MAP — ISLANDS



LEGEND

- 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)
- Wave cut platform
- $^{2}15$ Universal Transverse Mercator (UTM) Grid Reference
- $^{8}10$ Hong Kong Metric Grid Reference

ATTENTION : USERS

The Physical Constraints Map (PCM) should be used only as a guide to the general nature of terrain-related constraints for regional planning purposes. It is produced at a scale of 1:20 000 and should not be used to evaluate parcels of land smaller than 3 ha in size.

This Map must never be interpreted, reproduced or enlarged to scales larger than 1:20 000 (i.e. scales of 1:10 000, 1:5 000 or larger). Failure to heed this warning may result in serious misinterpretation of the data.

Please consult the Islands Geotechnical Area Studies Programme Report (GASP X) which discusses in detail the purpose and application of this Map.

Note : The topographic base of this map is derived from Sheet 10 - Edition 3 of 1985, Sheet 13 - Edition 2 of 1983, Sheet 14 - Edition 2 of 1982, Sheet 15 - Edition 2 of 1980 and Sheet 16 - Edition 1 of 1976 of the HM20C Series produced by the Survey and Mapping Office of the Buildings and Lands Department, Hong Kong.

Geotechnical Control Office
Civil Engineering Services Department

Title: PHYSICAL CONSTRAINTS MAP — ISLANDS	
Compiled: A.Hansen & J.M.Nash	Drawn: N.L.Yuen
Scale: 1 : 20 000	Date: Original January, 1985; 2nd Edition August, 1988
Map Ref. No. GASP/20/X/6 2nd Edition	Sheet:

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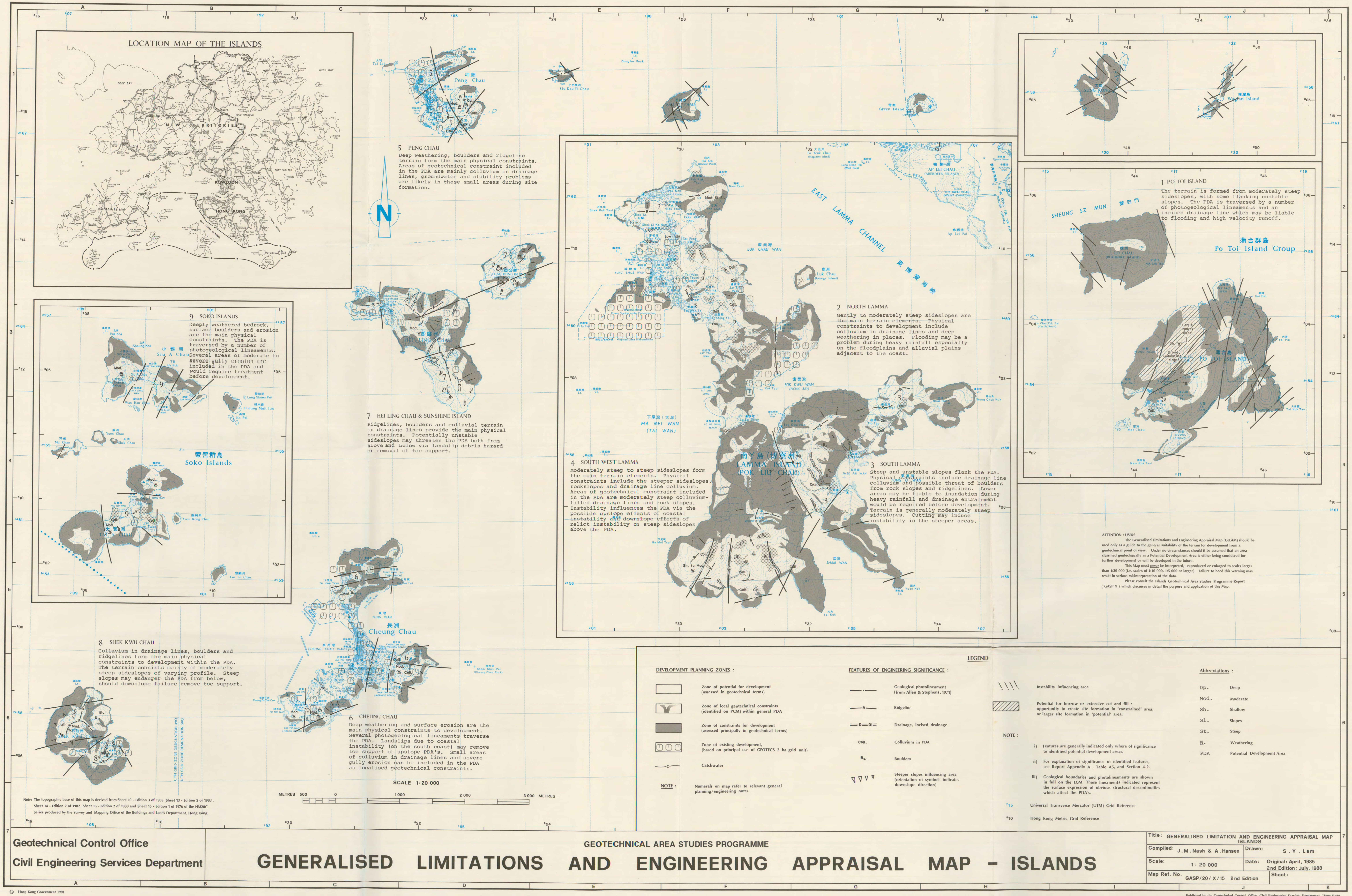
LOCATION MAP OF THE ISLANDS
NEW TERRITORIES
KOWLOON
HONG KONG
5 PENG CHAU
Deep weathering, boulders and ridgeline terrain form the main physical constraints. Areas of geotechnical constraint included in the PDA are mainly colluvium in drainage lines, groundwater and stability problems are likely in these small areas during site formation.
坪洲 Peng Chau
7 HEI LING CHAU & SUNSHINE ISLAND
Ridgelines, boulders and colluvial terrain in drainage lines provide the main physical constraints. Potentially unstable sideslopes may threaten the PDA both from above and below via landslip debris hazard or removal of toe support.
周公島 CHAU KUNG ISLAND (SUNSHINE ISLAND)
喜靈洲 HEI LING CHAU
9 SOKO ISLANDS
Deeply weathered bedrock, surface boulders and erosion are the main physical constraints. The PDA is traversed by a number of photogeological lineaments. Several areas of moderate to severe gully erosion are included in the PDA and would require treatment before development.
小鴉洲 Siu A Chau
索罟群島 Soko Islands
8 SHEK KWU CHAU
Colluvium in drainage lines, boulders and ridgelines form the main physical constraints to development within the PDA. The terrain consists mainly of moderately steep sideslopes of varying profile. Steep slopes may endanger the PDA from below, should downslope failure remove toe support.
石鼓洲 SHEK KWU CHAU
6 CHEUNG CHAU
Deep weathering and surface erosion are the main physical constraints to development. Several photogeological lineaments traverse the PDA. Landslips due to coastal instability (on the south coast) may remove toe support of upslope PDA's. Small areas of colluvium in drainage lines and severe gully erosion can be included in the PDA as localised geotechnical constraints.
長洲 Cheung Chau
SCALE 1:20 000
METRES 500 0 1 000 2 000 3 000 METRES
Note: The topographic base of this map is derived from Sheet 10 - Edition 3 of 1985, Sheet 13 - Edition 2 of 1983, Sheet 14 - Edition 2 of 1982, Sheet 15 - Edition 2 of 1980 and Sheet 16 - Edition 1 of 1976 of the HM20C Series produced by the Survey and Mapping Office of the Buildings and Lands Department, Hong Kong.
EAST LAMMA CHANNEL
東博寮海峽
2 NORTH LAMMA
Gently to moderately steep sideslopes are the main terrain elements. Physical constraints to development include colluvium in drainage lines and deep weathering in places. Flooding may be a problem during heavy rainfall especially on the floodplains and alluvial plains adjacent to the coast.
4 SOUTH WEST LAMMA
Moderately steep to steep sideslopes form the main terrain elements. Physical constraints include the steeper sideslopes, rockslopes and drainage line colluvium. Areas of geotechnical constraint included in the PDA are moderately steep colluvium-filled drainage lines and rock slopes. Instability influences the PDA via the possible upslope effects of coastal instability and downslope effects of relict instability on steep sideslopes above the PDA.
南丫島 LAMMA ISLAND (POK LIU CHAU)
3 SOUTH LAMMA
Steep and unstable slopes flank the PDA. Physical constraints include drainage line colluvium and possible threat of boulders from rock slopes and ridgelines. Lower areas may be liable to inundation during heavy rainfall and drainage entrainment would be required before development. Terrain is generally moderately steep sideslopes. Cutting may induce instability in the steeper areas.
1 PO TOI ISLAND
The terrain is formed from moderately steep sideslopes, with some flanking unstable slopes. The PDA is traversed by a number of photogeological lineaments and an incised drainage line which may be liable to flooding and high velocity runoff.
SHEUNG SZ MUN 雙四門
蒲台群島 Po Toi Island Group
螺洲 LO CHAU (BEAUFORT ISLAND)
ATTENTION : USERS
The Generalised Limitations and Engineering Appraisal Map (GLEAM) should be used only as a guide to the general suitability of the terrain for development from a geotechnical point of view. Under no circumstances should it be assumed that an area classified geotechnically as a Potential Development Area is either being considered for further development or will be developed in the future.
This Map must never be interpreted, reproduced or enlarged to scales larger than 1:20 000 (i.e. scales of 1:10 000, 1:5 000 or larger). Failure to heed this warning may result in serious misinterpretation of the data.
Please consult the Islands Geotechnical Area Studies Programme Report (GASP X) which discusses in detail the purpose and application of this Map.
LEGEND
DEVELOPMENT PLANNING ZONES :
Zone of potential for development (assessed in geotechnical terms)
Zone of local geotechnical constraints (identified on PCM) within general PDA
Zone of constraints for development (assessed principally in geotechnical terms)
Zone of existing development, (based on principal use of GEOTECS 2 ha grid unit)
Catchwater
NOTE : Numerals on map refer to relevant general planning/engineering notes
FEATURES OF ENGINEERING SIGNIFICANCE :
Geological photolineament (from Allen & Stephens, 1971)
Ridgeline
Drainage, incised drainage
Coll. Colluvium in PDA
Boulders
Steeper slopes influencing area (orientation of symbols indicates downslope direction)
Instability influencing area
Potential for borrow or extensive cut and fill : opportunity to create site formation in 'constrained' area, or larger site formation in 'potential' area.
NOTE :
i) Features are generally indicated only where of significance to identified potential development areas.
ii) For explanation of significance of identified features, see Report Appendix A, Table A5, and Section 4.2.
iii) Geological boundaries and photolineaments are shown in full on the EGM. These lineaments indicated represent the surface expression of obvious structural discontinuities which affect the PDA's.
Universal Transverse Mercator (UTM) Grid Reference
Hong Kong Metric Grid Reference
Abbreviations :
Dp. Deep
Mod. Moderate
Sh. Shallow
Sl. Slopes
St. Steep
W. Weathering
PDA Potential Development Area
Geotechnical Control Office
Civil Engineering Services Department
GEOTECHNICAL AREA STUDIES PROGRAMME
GENERALISED LIMITATIONS AND ENGINEERING APPRAISAL MAP - ISLANDS
Title: GENERALISED LIMITATION AND ENGINEERING APPRAISAL MAP ISLANDS
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Drawn: S.Y. Lam
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