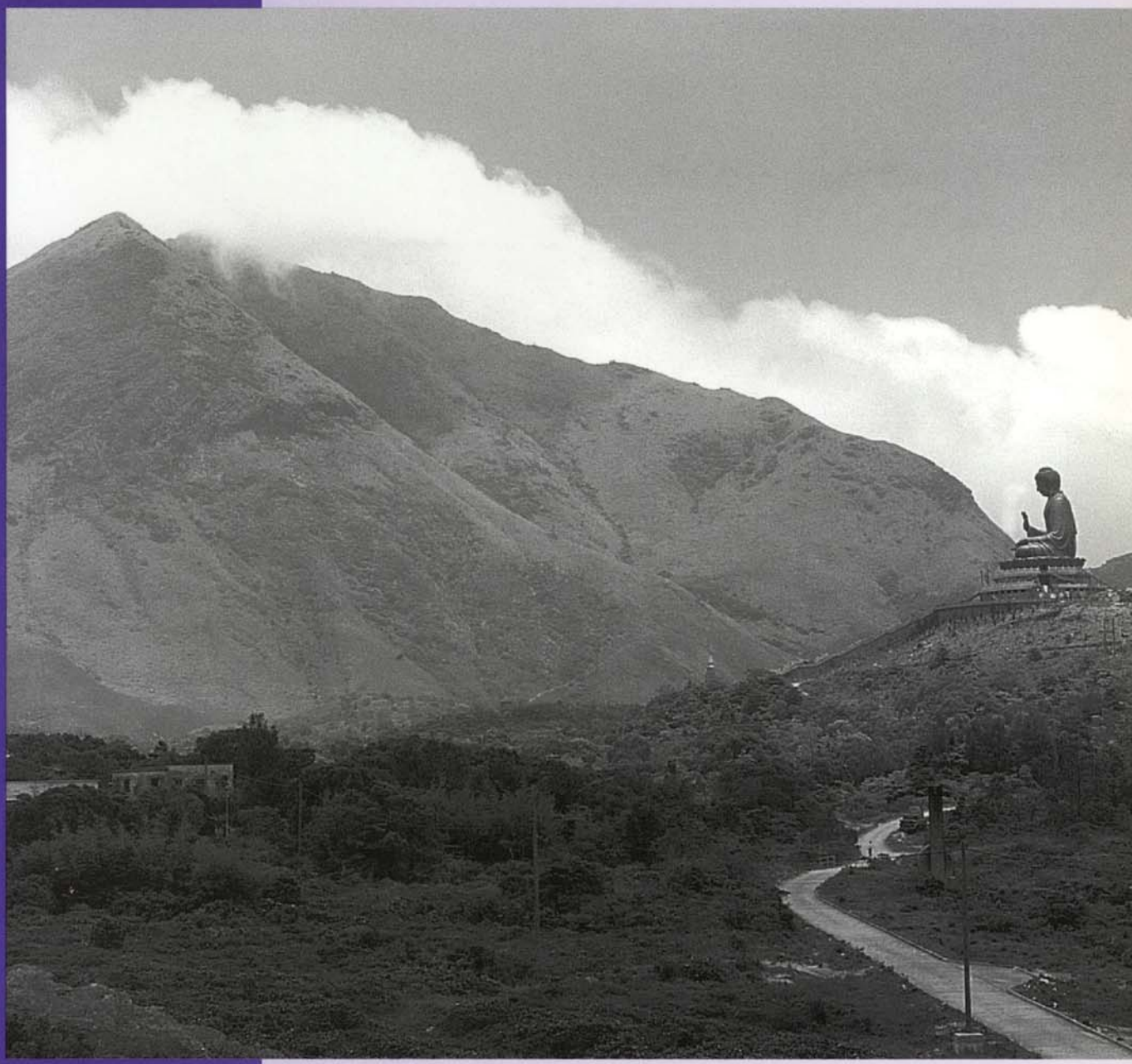
HONG KONG GEOLOGICAL SURVEY *MEMOIR NO. 6*

Geology of Lantau District



Geotechnical Engineering Office
Civil Engineering Department
HONG KONG December 1995

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Geology of Lantau District

1:20 000 Sheets 9,10,13 & 14

R.L. Langford, J.W.C. James, R. Shaw,
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Geotechnical Engineering Office
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Foreword

This memoir describes the geology of Lantau and adjacent islands, including Chek Lap Kok, The Brothers, Ma Wan, Tsing Yi, Peng Chau, Hei Ling Chau, Cheung Chau and The Sokos. The area of North Lantau and Chek Lap Kok were during preparation of the memoir, sites of major civil engineering works related to Hong Kong's new airport. Consequently, some features described here are now obliterated.

The geology described is shown on 1:20 000 scale sheets 9 (Tung Chung), 10 (Silver Mine Bay), 13 (Shek Pik) and 14 (Cheung Chau). The memoir forms part of the published results of a programme of systematic geological mapping undertaken by the Geotechnical Engineering Office (GEO), formerly Geotechnical Control Office (GCO), between 1983 and 1992. The programme has studied the onshore and offshore geology of the Territory in far greater detail than previously attempted. These geological maps and memoirs have enhanced our understanding of Hong Kong's stratigraphy and structure, and helped to establish a geological database necessary for the continuing economic development of the Territory. The mapping programme was undertaken by the Geological Survey Section of the Planning Division of the GEO. The section was led by Mr P. J. Strange, Dr R. Shaw, Dr I. R. Basham and Dr C J N Fletcher during the periods of mapping and compilation of this memoir and its accompanying maps; the Division was under the direction initially of Mr R. K. S. Chan and latterly Dr R. P. Martin.

The onshore geological survey of sheets 9, 10, 13 and 14 was largely undertaken by Dr R. L. Langford, the principal author of the memoir, from 1988-92. Tsing Yi and Ma Wan were mapped by Dr R. Addison in 1986, and part of the Tsing Chau Tsai peninsula on Lantau was mapped by Mr P. J. Strange in 1987. In 1985 Mr Strange also mapped Ching Chau (Green Island) and Lamma Island, and published his findings in Memoir 2 of this series. Parts of Sheets 9 and 10 were remapped in 1991 at 1:5 000 scale by Mr P. A. Kirk and Dr R.J.Sewell, and their early findings have been taken into account in this memoir. The principal authors of the sections on structural geology and major intrusions are Mr Kirk and Dr Sewell respectively. Dr R.Shaw and Dr S.D.G.Campbell are respectively principal authors of the sections on onshore superficial deposits and weathering, and metamorphic geology. Offshore geology for Sheets 9, 10 and 13 was compiled by Mr J. W. C. James between 1990 and 1993. Sheet 14 was compiled by Dr R.Shaw and Mr J.A.Fyfe in 1992-3. Mr James and Dr Shaw are the principal authors of the section dealing with offshore deposits. Final compilation of the memoir was undertaken by Dr Campbell. Dr Langford, Dr Addison, Mr Strange, Mr James, Mr Fyfe and Dr Campbell were seconded to the Hong Kong Government by the British Geological Survey.

Previous studies of the district were carried out within the Geotechnical Areas Studies Programme (GASP) of GEO. Reports in this series covering the district, present geotechnical information on slopes, terrain, geomorphology, vegetation, land use and erosion. These studies used solid rock geology shown on the 1:50 000 map of Allen & Stephens (1971). This memoir and the four accompanying map sheets supersede both the solid and superficial geology maps presented in the GASP reports.

The geological field survey benefitted from the co-operation of various organizations and many individuals. The Government Flying Service (formerly The Royal Hong Kong Auxiliary Air Force) provided helicopter transport to remote and rugged locations. The Marine Department and Royal Hong Kong Police supplemented commercial boats used to map the coastline and many small islands. Land transport was mostly supplied by the Islands District Office, City and New Territories Administration, and Highways Department. Latterly, the Provisional Airport Authority provided assistance with access to areas scheduled for development related to Hong Kong's new airport. The co-operation of Electronic and Geophysical Services Ltd in compiling the offshore geology is also acknowledged.

This memoir, and its accompanying map sheets, will be of interest and value to engineers and planners, to those concerned with resource investigations, to educationalists and earth scientists, and to interested members of the general public.

A. W. Malone

Principal Government Geotechnical Engineer

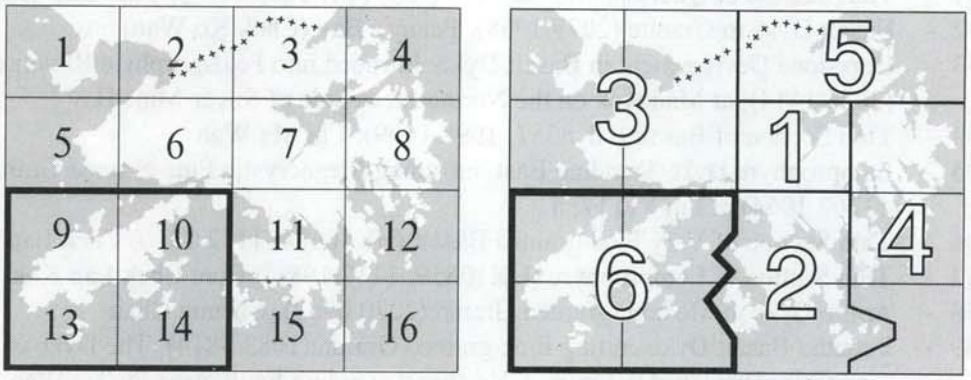
CONTENTS

(Plates)

Map and Memoir Series Notes

* This memoir describes the geology of Lantau and adjacent smaller islands. It should be read in conjunction with 1:20 000 Geological Map sheets 9 (Tung Chung), 10 (Silver Mine Bay), 13 (Shek Pik) and 14 (Cheung Chau).

* The memoir is one of a series that records the findings of the Hong Kong Geological Survey. An index of the memoirs and the 1:20 000 Geological Maps to which they relate is shown below.



* Individual superficial deposits in onshore areas are not generally considered mappable if less than 2 m thick. In the offshore areas the material on the sea-bed is shown, in most cases regardless of thickness.

* Grid references are based on the Hong Kong 1980 Metric Grid as shown on the 1:20 000 Geological Maps. Ten-figure references indicate positions to within 10 m, with Eastings followed by Northings, e.g. 80672 81239. Eight-figure references indicate positions to within 100 m. For convenience, however, the prefix figures 8, which apply to all eastings and northings in the district, are omitted.

* Hong Kong Principal Datum (PD) is 1.2 m below Mean Sea Level, and 0.15 m above Admiralty Chart Datum. The bathymetric contours shown on the 1:20 000 Geological Maps are based on Port Works Division surveys, with supplementary data from Admiralty Charts, and surveys by Electronic and Geophysical Services Ltd.

* Samples in the Territory-wide rock collection archived by the Hong Kong Geological Survey are prefixed HK followed by a serial number, e.g. HK 2263.

* Boreholes are generally referred to by the contractor's number followed by the Geotechnical Information Unit (GIU), Civil Engineering Library, accession number for the relevant ground investigation report, e.g. 1201D/03412.

* The system used in this memoir for grain size description and classification is summarized in Table 1

Table 1 — Grain Size Description and Classification of Rocks and Superficial Deposits in Hong Kong

Superficial Deposits		Grain Size mm	Solid Rocks									
			Sedimentary Rocks		Pyroclastic Rocks	Igneous Rocks					Metamorphic Rocks	
						Acid	Acid-Intermediate	Intermediate	Basic	Other	Foliated	Other
Boulders		200	Sedimentary Breccia, Conglomerate		Pyroclastic Breccia, Agglomerate	Very Coarse Pegmatite	Quartz Syenite Quartz Monzonite	Andesite	Gabbro	Lamprophyre	Schist	Quartzite, Marble, Hornfels
Cobbles		60										
Gravel	Coarse	20			Lapilli Tuff	Coarse						
	Medium	6				Medium						
	Fine	2				Granite Granodiorite						
Sand	Coarse	0.6	Sandstone		Coarse Ash Tuff	Fine						
	Medium	0.2										
	Fine	0.06				Aplite						
Mud	Silt		Siltstone	Mudstone	Fine Ash Tuff	Very Fine Rhyolite Dacite Rhyodacite	Quartz Trachyte Quartz Latite Trachydacite Quartz Trachyte				Phyllite	
	Clay	0.002	Claystone								Mylonite	

Chapter 1
Introduction

Location and Physiography

This memoir describes the geology of 1:20 000 scale sheets 9 (Tung Chung), 10 (Silver Mine Bay), 13 (Shek Pik) and 14 (Cheung Chau). This area is referred to in this account as the district (Figure 1). Lantau Island is by far the largest of the islands in the district and it is surrounded by a number of smaller islands, the largest of which are Chek Lap Kok, Tsing Yi, Hei Ling Chau and Cheung Chau. The total land area is approximately 165 sq km, while the offshore area described amounts to about 590 sq km.

Lantau Island is dominated by an eastnortheast-trending mountainous ridge, with its highest peaks, Fung Wong Shan (Lantau Peak) (934 m) and Tai Tung Shan (Sunset Peak) (869 m), near the centre. The northeastern part of the island, where the highest peak is Lo Fu Tau (465 m), is generally lower-lying, as is the southwestern part, where the highest peak is Ling Wui Shan (490 m). The only significant areas of low-lying ground, however, are around the coastline, at Tai O in the west, Shek Pik in the southwest, Pui O and Mui Wo to the southeast and Tung Chung in the north. Elsewhere, the coastline is steep and rocky, and is indented by narrow deep bays. Long, straight valleys form major northwest-, and northeast-trending features. Although many summits and ridges are grassy and easily traversed on foot, dense vegetation on the lower slopes and in valleys commonly restricts access.

During the preparation of this memoir, Lantau Island became the site of major civil engineering projects associated with Hong Kong's new airport at Chek Lap Kok. Chek Lap Kok was an island of nearly 3 sq km lying off the north coast of Lantau, near Tung Chung. Before the airport development commenced, the island rose to 121 m, with several small villages in low-lying areas. Reclamation has now greatly extended Chek Lap Kok and joined it to Lantau Island. Related construction projects have included: construction of the Lantau Expressway and extension of the Mass Transit Railway along the northern coast of Lantau; the linking of Lantau to the New Territories via the Kap Shui Mun and Tsing Ma bridges; and preparing for urban development at Tung Chung. In addition, on Lantau Island there is the developing residential complex at Discovery Bay on the east coast of Lantau. The only other urban developments of note on Lantau Island occur around the village areas of Mui Wo, Pui O - Cheung Sha, and Tai O. In addition, Shek Pik, Tong Fuk and Chi Ma Wan are the sites of prisons and refugee camps. Although there are other small settlements throughout Lantau, there has been rural depopulation in the last twenty years.

Lantau has two large country parks, Lantau South Country Park and Lantau North Country Park. They cover most of the centre and south of the island and lie within the mountainous catchment that feeds Shek Pik Reservoir which supplies water to Hong Kong Island.

The second largest island in the district is Tsing Yi, located in the northeast. It has an area of approximately 8 sq km, of which a small part lies outside the district and is described elsewhere (Langford *et al.*, 1989). The island rises to 334 m and is the site of intense residential, industrial and infrastructural expansion. The most populous part of the district after Tsing Yi is the small island of Cheung Chau, in the southeast. It has a well-developed tombolo (connecting sand spit) on which urbanisation has concentrated, but as the highest point on the island is only 95 mPD, building is widespread. The only other significant population centre is on Peng Chau in the east

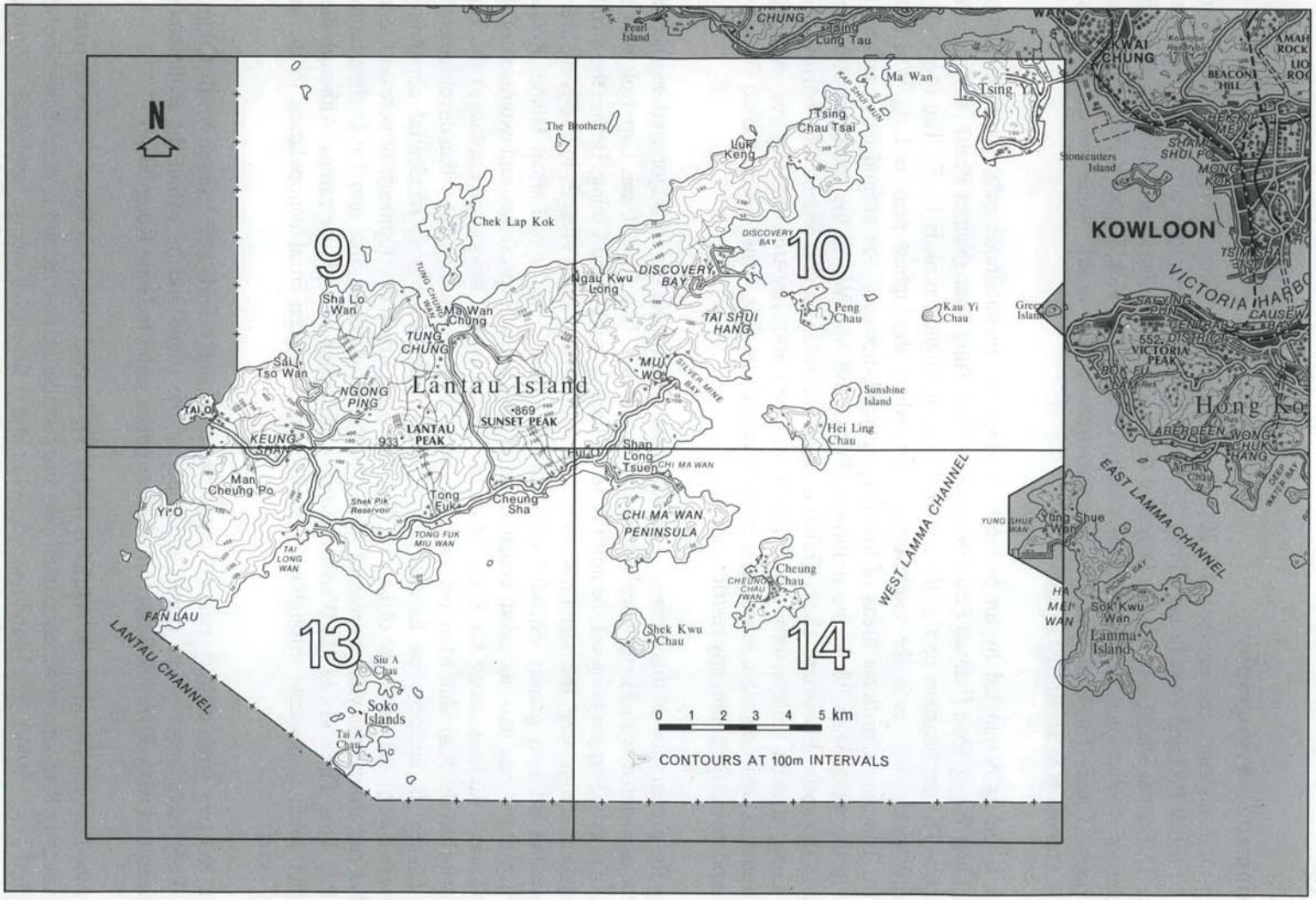


Figure 1 — Principal Topographic Features of the District

of the district. Ma Wan near Tsing Yi, has a sizeable village which is expected to expand greatly as a result of employment at the new airport.

Other sizeable islands in the district include Hei Ling Chau, Shek Kwu Chau and Tai A Chau. All are sites for government institutions and have restricted public access. Of the smaller islands surrounding Lantau, only Tai Mo To (West Brother) in the north, Chau Kung To (Sunshine Island) in the southeast, and Siu A Chau in the southwest have supported small, temporary populations. During the preparation of this memoir, The Brothers islands were largely obliterated as part of the new airport development on Chek Lap Kok. Tai O, which is separated from the body of Lantau Island by a narrow tidal channel, is considered to be part of Lantau.

Previous Work

The earliest geological survey of the Territory was undertaken between 1923 and 1927 by Brock, Uglow, Schofield and Williams, under an agreement between the Colonial Office and the University of British Columbia. A map was published at 1:84 480 scale (Brock *et al.*, 1936) which showed Lantau to be composed of the possibly Upper Jurassic, Repulse Bay Volcanics and Tai Mo Shan Porphyries, with outcrops of Cretaceous Lan Tau Porphyritic Granite in the northeast. Cretaceous Hong Kong Granite was shown as the dominant rocktype on the smaller islands, while The Brothers islands and Tai O area were ascribed to the possibly Lower Jurassic, Pan Sin Sediments of the Tolo Channel Series. Unfortunately, no descriptive memoir was produced to accompany this map, but several related publications (Uglow, 1926; Brock & Schofield, 1926; Williams, 1943; Williams *et al.*, 1945) presented many of the main conclusions related to the mapping. A book, based largely on this earlier work, was written by Davis (1952), which was followed by a detailed description of the geology of the Territory by Ruxton (1960).

A systematic survey of the Territory by geologists from the Institute of Geological Sciences, United Kingdom, resulted in the publication of two, 1:50 000 scale geological maps and an accompanying memoir (Allen & Stephens, 1971). These were the best references to the geology of the district prior to the remapping described here, which began in 1986. The Geotechnical Area Study Programme (GASP), initiated by the Geotechnical Control Office in 1979 (Brand *et al.*, 1982), produced 1:20 000 scale engineering geology and other maps for the Territory as a whole. The geology on these maps drew extensively on the work of Allen & Stephens (1971), but included new interpretations of superficial deposits and photolineaments.

Bennett (1984b) made a comprehensive review of the stratigraphy of Hong Kong and the South China region. He also reviewed the superficial deposits and weathering of the Territory (1984a), and its tectonic history, structure and metamorphism (1984c).

In the neighbouring Sha Tin district (Sheet 7), Addison (1986) established a detailed lithostratigraphy for the Repulse Bay Volcanic Group, and divided the granites using lithological criteria. His volcanic lithostratigraphy was modified in the adjoining Kowloon and Hong Kong Island district to the south (Strange & Shaw, 1986), and in the western New Territories (Langford *et al.*, 1989), and has now been extended, in its modified form, into parts of this district. The division of granite intrusions in the district is based on the classification of Strange (1984).

Palaeontological studies of plant-bearing strata (Nau & Wu, 1991; Lee *et al.*, 1990) have resulted in differing interpretations of the age of the volcanic rocks of Lantau. These ages span a range from late early Jurassic to early Cretaceous.

Before the early 1980s, publications on the geology of Hong Kong (Davis, 1952; Allen & Stephens, 1971; Bennett, 1984a) only briefly covered the offshore geology of the Territory, concentrating on sediments in the littoral and sublittoral zones. Investigations of the geotechnical

properties of the marine deposits began around this time (Lumb, 1977), as did work on the proposed site of the new airport at Chek Lap Kok (Fung *et al.*, 1984; Koutsoftas *et al.*, 1987). These investigations, which represented the first comprehensive offshore study in Hong Kong, used several techniques including: continuous, shallow reflection seismic profiling; boreholes; cone penetration tests; and field vane tests. The building of the High Island Reservoir and the Mass Transit Railway within and across limited shallow marine sections encouraged further detailed studies of the offshore geology (Fanshawe & Watkins, 1971; Kendall, 1976; Yim, 1984a and b). It was at this stage that offshore mapping was begun by the Hong Kong Geological Survey (Shaw, 1987, 1990; Shaw & Arthurton, 1988).

By the mid-1980s the increasing demand for reclamation fill created problems of supply from the traditional onshore sources. An offshore seismic and borehole study of a large area of Hong Kong waters was initiated by the Geotechnical Control Office to investigate marine fill resources (Cheung & Shaw, 1993). This activity stimulated more interpretive research and specialist meetings (Whyte, 1984; Whiteside & Arthurton, 1986; Whiteside & Wragge-Morley, 1988; Whyte *et al.*, 1988). The initiation of major port and airport projects in 1990 was accompanied by an accelerated phase of marine seismic, borehole and cone penetration test investigations (James, 1990; Binnie Consultants Ltd, 1991). Much of the information from these and earlier investigations has been used in this memoir and in compilation of the accompanying 1:20,000 scale maps. Along the north coast of Lantau Island the geology has also been mapped by the Hong Kong Geological Survey at a scale of 1:5,000.

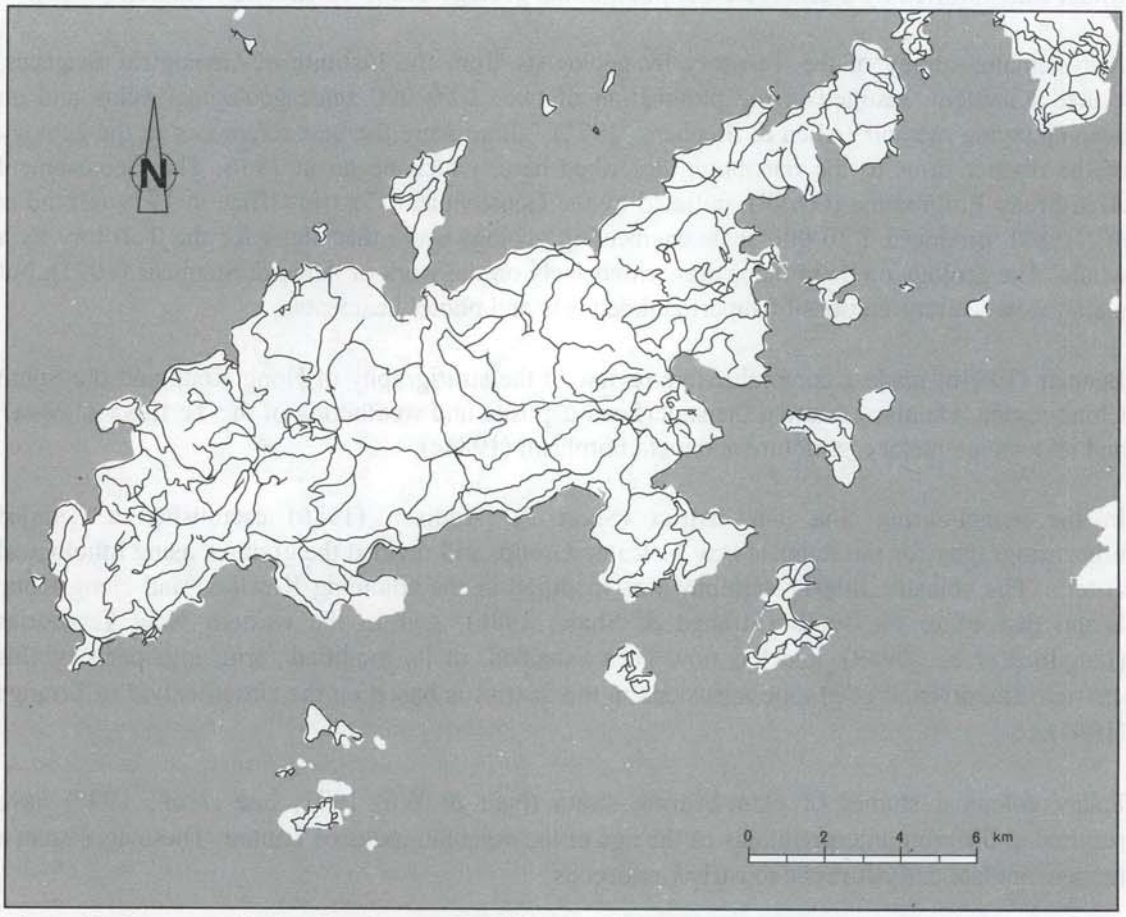


Figure 2 - Traverses Undertaken During Field Survey of the District

Present Survey

Geological field mapping in the district started on Tsing Yi in May 1986, but most was carried out between May 1988 and February 1991. Additional geological information used in this memoir includes data acquired during construction of the new Chek Lap Kok airport and other infrastructural developments up to, and including, the middle of 1992. Geological information for onshore areas was plotted directly onto 1:5 000 scale topographic base maps. It was then transferred onto 1:10 000 scale maps, and provisional geological maps were prepared at this scale. These formed the bases for the published 1:20 000 scale geological map sheets.

Traverses were made along most roads and footpaths, and accessible stream courses and coastal sections (Figure 2). Northeast Lantau Island is generally sparsely vegetated and access was relatively easy. However, the much more rugged areas of central Lantau are heavily vegetated, and traverses were restricted to ridge lines and recognized footpaths. Helicopters, provided by the Government Flying Service (formerly Royal Hong Kong Auxiliary Air Force), enabled access to the more remote and mountainous areas. Most of the coastline of north Lantau Island was easily traversed at low tide. Islands and remote coastal sections were reached using commercially-hired boats, with some additional assistance from the Royal Hong Kong Police Marine Region. However, the coastlines of the Chi Ma Wan peninsula, Cheung Chau, Shek Kwu Chau and the Soko Islands are steep and inaccessible.

Temporary sections were common in the urban areas, but relatively uncommon elsewhere. They were examined during the field mapping as sites developed. They provided much additional geological information for Tsing Yi, Discovery Bay and, latterly, Chek Lap Kok. Numerous ground investigation boreholes have been sunk in north and northeast Lantau Island, many of which were sampled. A desk study, undertaken between 1985 and the middle of 1988, involved the examination of available borehole logs, many of which contained colour photographs of sufficiently high quality to allow rock types to be determined. The logs were partly complimentary to the numerous cores examined, and were particularly useful for areas which are either poorly exposed, or are covered with fill, or marine deposits.

Photogeological interpretation of the distribution of superficial deposits and lineaments in the district was undertaken, mainly using 1963, 1964 and 1983-86 photographs. The 1949 and 1955 photographs were also useful for examining the pre-development topography of areas such as Shek Pik Reservoir, and these were used, together with old topographic maps, to establish the extent of fill. The extent of reclamation shown on the maps is based on data supplied by the Survey and Mapping Office, Lands Department.

High resolution seismic reflection profiling was the principal technique employed for offshore surveying. Sequences were interpreted from continuous seismic records calibrated by the logging of sediment and rock from boreholes and, in some localities, by cone penetration tests and vane shear testing. Figure 3 illustrates the geophysical track lines for the records interpreted for this memoir and the accompanying published maps, and Figure 4 shows the positions of boreholes and cone penetration tests. The boomer gave a depth of penetration beneath the sea surface of about 100 metres. A sparker source, with a lower frequency than the boomer, was run on two surveys over some parts of the area, and was capable of penetrating and recording reflectors from greater depths. A marine magnetometer was also deployed along some of the sparker lines, and a Territory-wide gravity survey was also carried out (Busby *et al.*, 1992; Electronic and Geophysical Surveys, 1991; Evans, 1990; Busby & Langford, 1994) in which marine gravity measurements were taken at stations spaced on a 2 km grid.

Archival Data

All records from the survey are held in the archives of the Hong Kong Geological Survey (Planning Division, Geotechnical Engineering Office), and are available for inspection. These include: 1576 rock samples of which 1208 have thin sections; field notes and photographs; manuscript maps; aerial photographs and related interpretations; analytical data (major and trace elements) for 170 samples (analysed at the University of Nottingham); 2 heavy mineral analyses (undertaken by the British Geological Survey as part of a larger sampling programme); and palaeontological determinations of pollen and plant fossils (undertaken at the Nanjing Institute of Geology and Palaeontology, Academia Sinica). In addition, the Hong Kong Geological Survey holds a computer database containing information on over 8 000 boreholes, cone penetration tests and trial pits in the district to date. Ground investigation reports, which were used to study the nature and disposition of onshore and offshore superficial deposits, weathered rocks and rock types, are held in the Geotechnical Information Unit in the Civil Engineering Library.

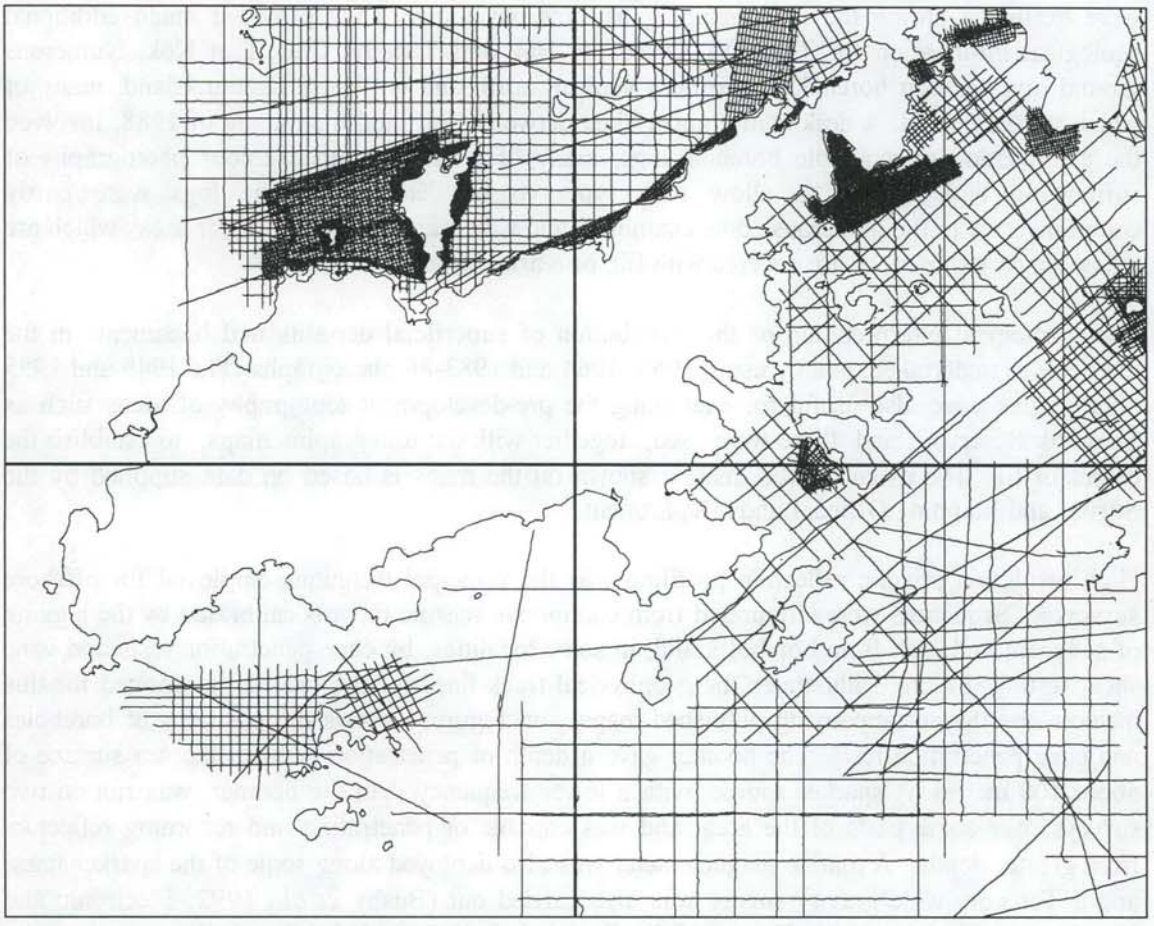


Figure 3 - Location of Seismic Reflection Survey Tracks within the District

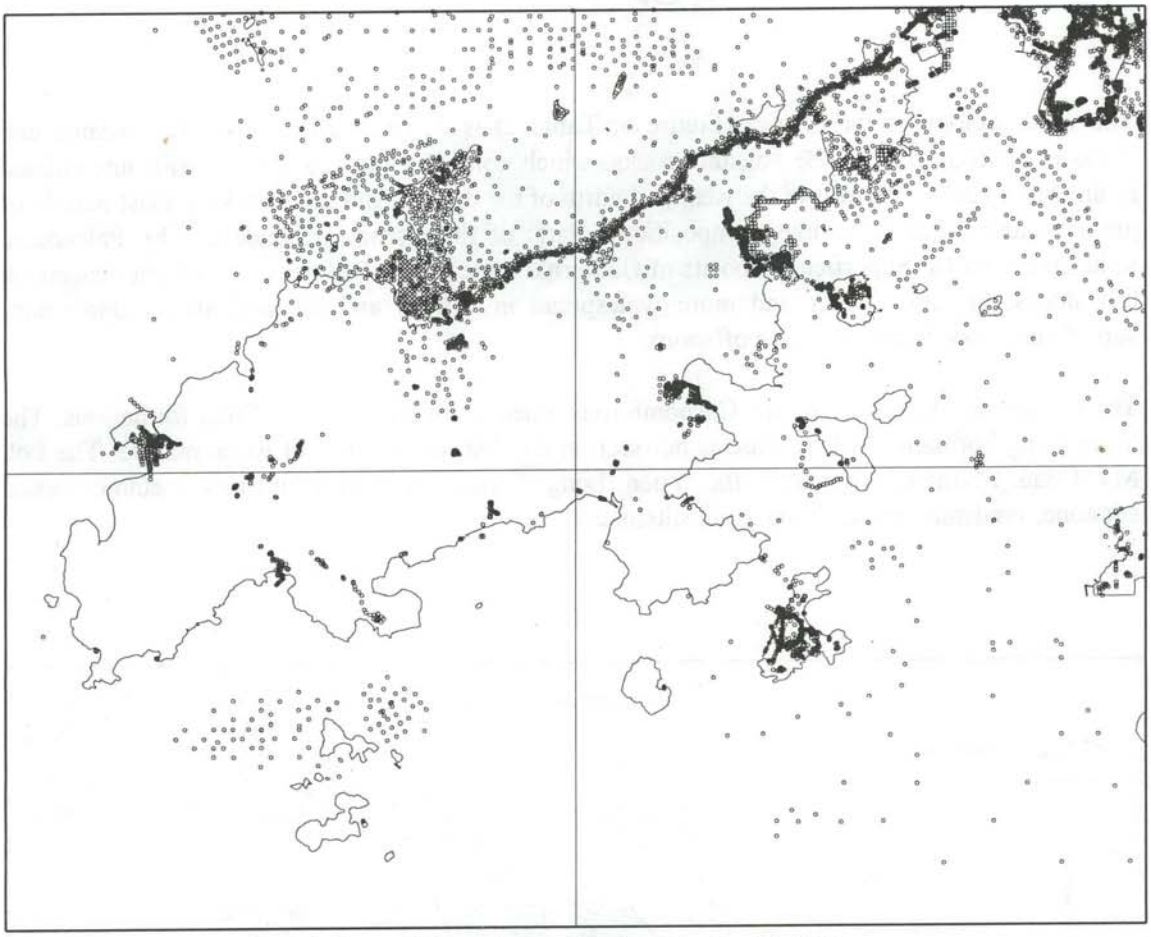


Figure 4 - Location of Boreholes and Cone Penetration Tests in the District

Chapter 2
Outline of Geology

The solid geology of the district (Figure 5; Table 2) is dominated by Mesozoic volcanic and intrusive igneous rocks. The volcanic rocks, which comprise tuffs and lavas with intercalated sedimentary rocks, crop out in the west and north of the district. Intrusive rocks consist mainly of granites, and dykes of various compositions. Parts of the district are underlain by Palaeozoic sedimentary rocks. Superficial deposits of Quaternary age (Table 2) form impersistent veneers on hill slopes, but are thicker and more widespread in valleys and lowland areas. Quaternary superficial deposits are extensive offshore.

The Palaeozoic strata include the Carboniferous Yuen Long and Lok Ma Chau formations. The Yuen Long Formation, whose base is not seen in the district, consists of white marble. The Lok Ma Chau Formation succeeds the Yuen Long Formation, and comprises metamorphosed siltstone, sandstone and carbonaceous siltstone.

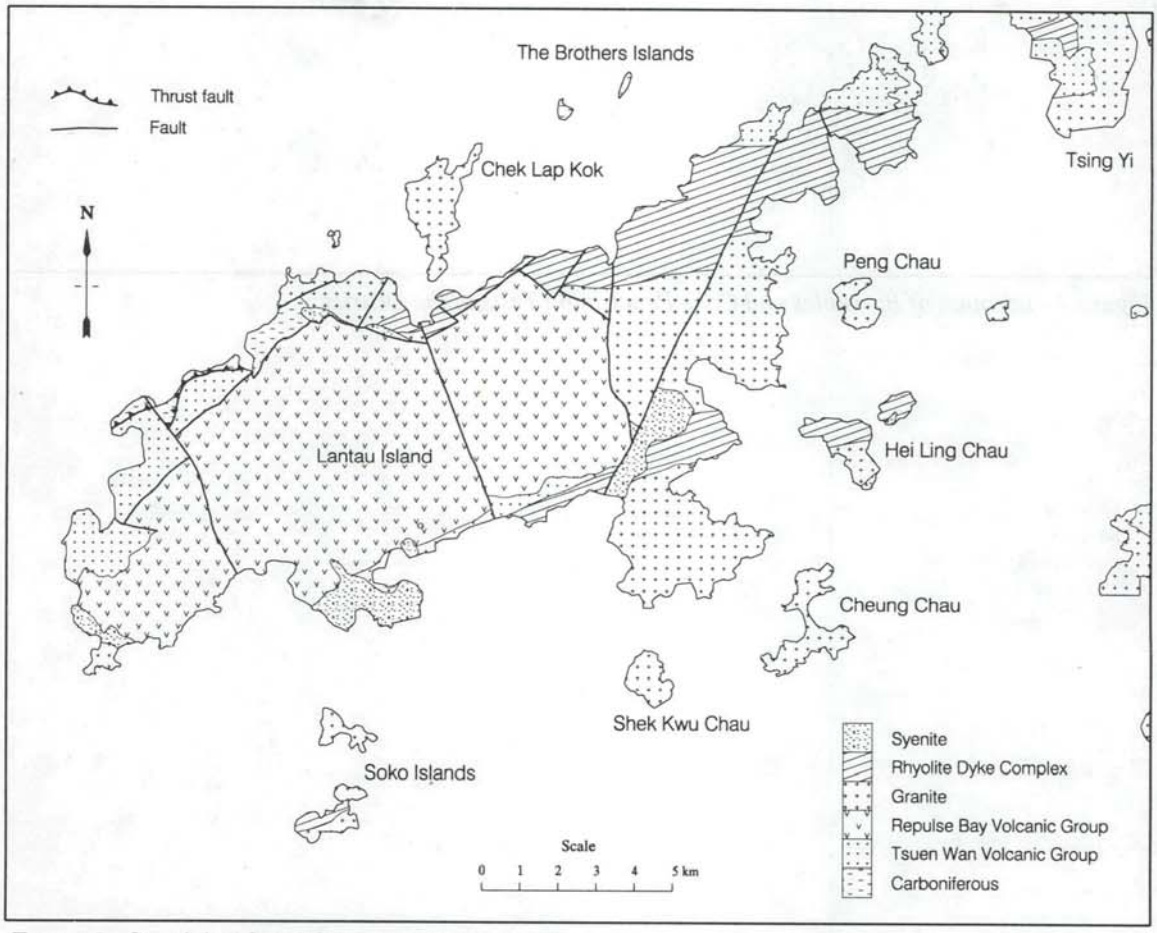


Figure 5 - Simplified Solid Geology of the District

Table 2-Solid Rocks and Superficial Deposits of the District

Superficial Deposits (Onshore)			
Age		**Genetic Classification**	
Quat-ernary	Holocene	Fill Alluvium Estuarine deposits Beach deposits Back Beach deposits	
	Pleistocene and Holocene	Colluvium, including debris flow and other slope debris deposits	
	Pleistocene	Terraced Alluvium Colluvium, including debris flow and other slope debris deposits	
Superficial Deposits (Offshore)			
Age		**Named Divisions**	**Prinicipal Materials**
Quat-ernary	Holocene	Hang Hau Formation	Mainly mud
	Pleistocene and and Holocene	Channel and Transgressive deposits	Mainly sand
		Sham Wat Formation	Clayey silt
	Pleistocene	Chek Lap Kok Formation	Clay, silt, sand and gravel
		Pre-Chek Lap Kok Formation	?Sand and gravel
Solid Rocks			
Age		**Named Division**	**Principal Materials**
Meso-zoic	Upper Jurassic to Lower Cretaceous	Repulse Bay Volcanic Group — Mount Davis Formation	Coarse ash crystal tuff
		Repulse Bay Volcanic Group — Lantau Formation	Fine ash vitric tuff and lava
		Repulse Bay Volcanic Group — (Sunset Peak Member)	Lapilli-bearing crystal tuff
		Repulse Bay Volcanic Group — (Pak Kok Member)	Tuffs, tuffites, siltstones and mudstones
		Repulse Bay Volcanic Group — (Cheung Shan Member)	Eutaxite
		Tsuen Wan Volcanic Group — Shing Mun Formation	Lithic and crystal tuffs
		Tsuen Wan Volcanic Group — (Shek Lung Kung Member)	Tuff breccia
		Tsuen Wan Volcanic Group — Yim Tin Tsai Formation	Coarse ash crystal tuff
Palae ozoic	Carboniferous	San Tin Group — Lok Ma Chau Formation	Siltstone, sandstone
		San Tin Group — (Mai Po Member)	Siltstone, sandstone; graphite-bearing siltstone
Major Intrusive Rocks			
Meso-zoic	Jurassic to Cretaceous	Fine-grained granite Fine- to medium-grained granite Medium-grained granite Coarse-grained granite Quartz syenite Granodiorite	
Minor Intrusive Rocks			
Meso-zoic	Tertiary ---------- Jurassic to Cretaceous	Basalt Lamprophyre Andesite and Dacite Feldsparphyric rhyolite Quartzphyric rhyolite	
		Aplite and Pegmatite	

The Mesozoic volcanic rocks are divided into two groups: the Tsuen Wan Volcanic Group of mid- to late Jurassic age, and the Repulse Bay Volcanic Group of late Jurassic-early Cretaceous age. The Tsuen Wan Volcanic Group comprises the Yim Tin Tsai and Shing Mun formations and crops out mainly in the east of the district, although isolated exposures of both formations also occur on the south and west coasts of Lantau Island. The Yim Tin Tsai Formation is a lithologically uniform, lapilli-bearing coarse ash tuff. The overlying Shing Mun Formation is lithologically variable, and consists of tuff, tuff-breccia and tuffite, with subordinate sandstone, siltstone and mudstone. It includes the Shek Lung Kung Member, which is a localized lapilli-tuff at the base of the Shing Mun Formation on the north coast of Lantau Island.

The Repulse Bay Volcanic Group comprises the Lantau Formation, which is widespread on Lantau Island, and the younger Mount Davis Formation, which is present only in the east of the district. The Lantau Formation consists mainly of banded rhyolitic lava, rhyolitic tuff, tuffite and subordinate sedimentary rocks. It includes three members: the Cheung Shan Member, a eutaxite at the faulted base of the formation; the Pak Kok Member, comprising tuffs, tuffites, siltstones and mudstones; and the Sunset Peak Member, a distinctive lapilli-bearing crystal tuff in the highest preserved part of the formation. The geometry of the Lantau Formation suggests it was laterally restricted within a volcanotectonic collapse structure, referred to here as the Lantau Caldera. The Mount Davis Formation comprises rhyolitic tuffs which crop out only on Kau Yi Chau and Tsing Chau. Its stratigraphic position relative to the Lantau Formation is uncertain, but isotopic age dating suggests it is younger.

The Palaeozoic and Mesozoic sedimentary and volcanic rocks are intruded by granites, granodiorites, and quartz syenites of Upper Jurassic to Lower Cretaceous age. The fine-grained granites are younger than the more voluminous coarse-, and medium-grained granites, which are often highly modified by the later intrusions. Granodiorite is the oldest of the major intrusions and forms an irregular body underlying parts of Tsing Yi. Quartz syenites are typically late-stage intrusions, and commonly form dykes around, and near the margins of the Lantau Caldera.

Numerous dykes of microgranite and megacrystic, feldsparphyric rhyolite occur especially in northeast Lantau Island, where they mainly trend eastnortheast, or east. Together with basaltic dykes, they occur mostly within the granites. Large dykes of dacite also occur, whereas fine-grained granite, aplite and pegmatite only form small dykes or veins. Dykes of andesite and lamprophyre are rare. Porphyritic, fine-grained, quartz syenite intrudes the granite and other dykes near Mui Wo and on Chau Kung To.

In general, acidic dykes in the district are only slightly younger than the granites, whereas the more basic dykes probably range from Jurassic to Tertiary in age.

The structure of the district is dominated by eastnortheast-trending faults (and associated dykes). North- and northwest-trending faults are common in the granitic rocks, and major northeast-trending faults also traverse the district. Folding is gentle and is most common in the Mesozoic volcanic rocks in the east. Close folds occur in the Palaeozoic strata. The major structural features of the district are probably related to the evolution of the Lantau Caldera, and the associated emplacement of granites and dykes. The contact between Palaeozoic sedimentary rocks and Mesozoic volcanic rocks between Tai Ho Wan to Nam Shan is an eastnortheast-trending fault, which substantially downthrows the volcanic rocks to the southsoutheast. This fault is part of the caldera margin, but it may also have had an earlier history of thrusting.

Contact (thermal) metamorphism of tuffs and epiclastic rocks around the granitoid intrusions is limited. However, in the east of Lantau Island, and within, and around the Lantau Caldera, the circulation of hydrothermal fluids caused kaolinization and greisenization of the granite, and

alteration of volcanic and adjacent intrusive rocks. The fluids were derived from the granitoids at a late stage during, or after, their emplacement. The effects of a more general (regional) metamorphism, dominantly of post-Jurassic age, can be recognized in a broad zone, trending northeast-southwest across the district. Within this zone, the intensities of dynamic and hydrothermal metamorphism vary considerably. Quartz veins, trending mostly northwest-southeast, crystallized from fluids derived at a late stage from intrusions. They are commonly associated with hydrothermal alteration.

Superficial deposits of Quaternary age form large, flat-lying areas onshore, and constitute the sea-bed in most of the offshore area. In hilly terrain, colluvium, including debris flow and other slope debris deposits, mostly of Pleistocene age, commonly mantles side slopes and lines valleys. Small alluvial deposits occur in hilly areas, but alluvium is generally restricted to fans developed downslope of the colluvial deposits. Pleistocene alluvium covers small areas around Mui Wo and Tung Chung. Beach deposits of sand usually form in front of alluvial deposits, especially in sheltered coastal bays. Pleistocene alluvial deposits also occur offshore, together with slope debris deposits, within the Pleistocene Chek Lap Kok Formation, which generally comprises complex, interbedded sand, silt, clay and gravel, with some organic material. It is probably of fluvial, estuarine and intertidal origin. It is generally overlain by the Sham Wat Formation. It comprises mainly silty clay with some thin sands, and is thickest, and most readily recognisable seismically, in the west of the district. The base of the formation is channelised and its top is locally reworked. It is overlain by the extensive Holocene marine deposits of the Hang Hau Formation which comprises dark grey mud with shells, and some sand. In several places, land reclamation has disturbed, or obscured, the alluvial and marine deposits in the coastal fringe, especially around Chek Lap Kok, the northern coast and northern Tsing Yi.

As a result of strong currents, rock is exposed in the channels around Ma Wan and northeast of Lantau Island. Elsewhere there are a few rocky shoals such as at Pun Shan Shek and Douglas Rock. The stronger currents which flow along the channel from The Brothers islands past Ma Wan to beyond Green Island, have also influenced the lithology and form of the Quaternary sediments. Coarse sandy sediments of the Hang Hau Formation are relatively extensive in these channels, and current velocities are high enough to form sand banks south of Tsing Yi and off northeast Lantau Island. Parts of these sand banks have recently been dredged for fill material. Away from the channels, current strengths decrease and the sea floor generally comprises soft to very soft mud of the Hang Hau Formation. East of Peng Chau and Hei Ling Chau, acoustic turbidity on seismic records is extensive, which reflects the presence of biogenic gas within the thick mud of the Hang Hau Formation.

A regolith, or mantle of weathered rock, occurs over most of the district. The effects of weathering vary with underlying rock types and this is reflected in topographic relief. For example, andesite, granodiorite and Palaeozoic sedimentary rocks are the most deeply weathered and eroded rocks and form the lower ground. Granite terrain is characteristically hilly and littered with exhumed corestones, and finer grained granites generally form sharper relief than coarser varieties. The acidic volcanic rocks are resistant to deep weathering and erosion, and form rocky hills with boulder fields of large, cuboidal corestones.

Although there are no active mineral workings in the district, lead and silver have been mined near Mui Wo. Tungsten and graphite have also been mined, and occurrences of lead, zinc, tin, fluorite and beryl have been recorded. There are many former small-scale workings for quartz and clay, which occur within intrusive and interleaved volcanic rocks. Although there are no aggregate quarries in the district, there are large borrow areas on Tsing Yi and smaller borrows in northeast Lantau, as well as large offshore sand dredging for reclamation fill around the Soko Islands, Ma Wan, Tsing Yi and northeastern Lantau Island.

Chapter 3
Palaeozoic Sedimentary Rocks

Classification and Distribution

Palaeozoic sedimentary rocks occur in two areas of outcrop in the district. The largest of these extends from the north coast of Tai O, northeast beyond Sham Wat towards San Shek Wan. The other extends between the three islands of West Brother island (Tai Mo To), East Brother island (Siu Mo To) and Reef Island (Tsz Kan Chau) to the north of Lantau Island. In addition, an extensive subcrop of sedimentary rocks has been proved by boreholes to the east of The Brothers islands (Mo To Chau). The strata are lithologically comparable with the main outcrop of Carboniferous rocks in the northwest New Territories. These form part of the San Tin Group (Langford *et al.*, 1989) which is divided into the Yuen Long and Lok Ma Chau formations.

The Yuen Long Formation (Lee, 1985) comprises white marble, and is only known in the district from a few boreholes, located to the east of East Brother island. The marble is similar to that seen in numerous boreholes and caissons in the type area of the formation around Yuen Long, in the northwest New Territories (Langford *et al.*, 1989; Frost, 1992). It has not been possible to date the marble sequence in Hong Kong palaeontologically. Localized carbonates are characteristic of the Caledonian marginal basin of southern China, within which the Yuen Long Formation was deposited (Huang, 1978; Nanjing University, 1980; both in Bennett, 1984b).

The Palaeozoic strata near Tai O are juxtaposed with Jurassic volcanic rocks by a fault with a steep, reverse offset, with a southeasterly-downthrow. At the northern end of the outcrop they are truncated by a younger granite intrusion. Around The Brothers islands the sedimentary rocks form either a roof-capping to the underlying granite intrusions, or a wedge adjacent to the plutons.

The Lok Ma Chau Formation (Williams, 1943) was formerly considered to be Permian (Heim, 1929), or even Lower Jurassic (Allen and Stephens, 1971). Lai (1977), however, interpreted it as Carboniferous on the basis of correlation with sequences in Shenzhen. This age has been substantiated and further refined to Lower Carboniferous by Ha *et al.* (1981) and Lai & Mui (1984). Peng (1983), Bennett (1984b) and Lee (1985) all reached a similar conclusion. Microfossils identified from the district (Appendix 1) also suggest a Carboniferous, and possibly early Carboniferous age. This broadly agrees with microfossil evidence from the northwest New Territories, which indicates that the Lok Ma Chau Formation could be either Tournaisian (Lower Carboniferous) or Namurian-Westphalian (Upper Carboniferous) (Langford *et al.*, 1989).

San Tin Group

Yuen Long Formation

The Yuen Long Formation consists of white marble. However, as it has only been seen in a few boreholes in the district, and has not been recognised in outcrop onshore, other lithologies could occur within the formation. Its presence was only confirmed after boreholes were sunk to the east of The Brothers islands in 1990 and 1991. Subsequently, it has been proved in a limited offshore area east of Tung Chung, where it probably occurs in fault slices that are separate from the main subcrop.

The thickness of the marble is poorly constrained. On the basis of steep dips in the overlying, tightly folded Mai Po Member on The Brothers islands, it could be more than 1000 m thick. A high gravity anomaly centred on the marble (Figure 6; Busby & Langford, 1994) also indicates that it is very thick. Frost (1992) estimated the marble as more than 500 m thick in the western New Territories, while regionally, across Guangdong Province, it is c.300 m thick..

In the Yuen Long area, Frost (1992) divided the formation into two members. The lower Long Ping Member is a dark grey marble, commonly with complex internal structure. The upper Ma Tin Member is a massively bedded, white marble, and probably forms most of the subcrop north of Lantau Island.

No fossils have been found in the marble, either north of Lantau Island or in the northwest New Territories. Comparison with strata exposed in Shenzhen (Lai & Mui, 1985) suggests an early Carboniferous age, and the formation may be the equivalent of the Shidengzi Formation in Guangdong.

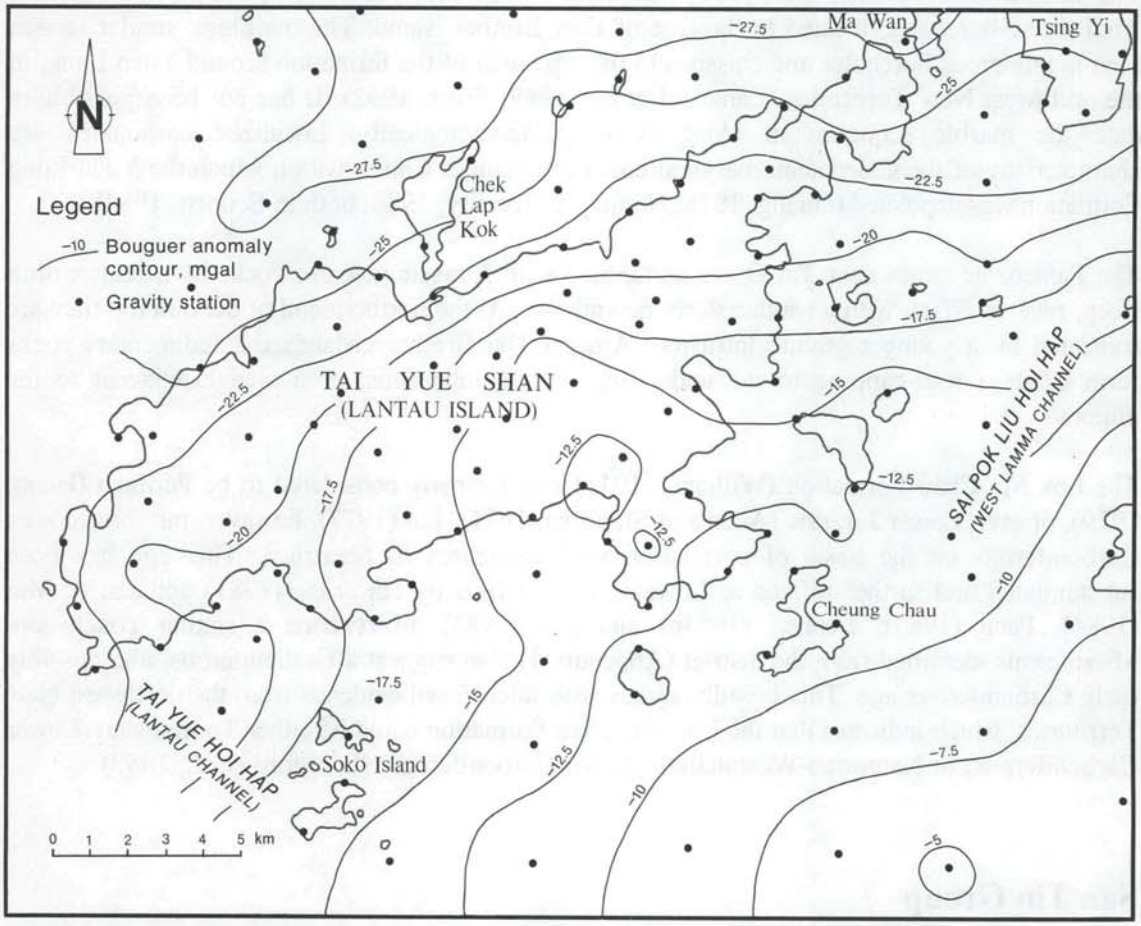


Figure 6 - Bouguer Gravity Anomaly Contour Map of the District

Details

East Brother island (prior to development). Between 1 and 2 km east of East Brother island, three boreholes intersected marble below thick superficial deposits. Borehole NS3/14460 (17050 22530) encountered white and grey marble at -53.5 mPD. The top 1.5 m of the core contained small-scale solution features, but it was mainly white, with some light grey streaks and areas of brown oxide staining or discolouration. As granite and

Carboniferous metasedimentary rocks have been proved in boreholes less than 500 m from this borehole, it must lie close to the northern edge of the marble subcrop.

To the south, in Borehole NS1/14460 (17111 21750), a predominantly white marble, with some light grey silica patches, was intersected at -49 mPD. A solution cavity, 0.17m across, and infilled with brown soil, was encountered at -54 mPD . To the east, marble also occurred in Borehole T8/3/13951 (17842 22332) at -45 mPD, which must have been located close to the eastern limit of the marble subcrop, as undifferentiated volcanic rocks occur less than 1 km away.

Tung Chung. Marble has been encountered in a few boreholes sunk on the reclamation east of Tung Chung Wan, near Lau Fau Sha, and locally abundant skarn mineralization has been observed. In Boreholes TC65 (12196 16639) and H12/17357 (12112 16599) for example, white marble with no cavities, passes downhole into greenish grey skarn comprising epidote, chlorite and magnetite. The skarn occurs where the marbles are intruded by feldsparphyric dykes and granites. Cavities, brecciation and veining also occur in the marble and may reflect intense faulting. Accordingly, the marble is interpreted as an isolated fault slice emplaced within an eastnortheasterly-trending thrust which separates Carboniferous strata to the north, from structurally-underlying Jurassic volcanic rocks to the south. Later faulting and intrusion of granites and dykes further split the marble into discontinuous, partially digested slices.

Petrography

The white marble from Borehole NS3/14460 (HK8516, 17050 22530) is formed of interlocking equigranular calcite crystals ranging in size from 0.2-0.4 mm. The rock is composed of pure carbonate, and accessory minerals are not visible.

Skarn mineralization in marble in Borehole NS1/14460 (17111 21750), east of East Brother island, is similar to that near Tung Chung. In thin section (HK8515) it comprises equigranular, pleochroic, pale brownish-white augite, and interstitial granular calcite. Most crystals are 0.2 - 0.3 mm across, although there are scarce larger crystals of plagioclase, with marked reaction rims. In hand specimen, this marble varies from pure white, near the top of the borehole, to impure marble near the base. The skarn mineralization suggests the proximity of igneous rocks at depth.

Sedimentary Environment

The Yuen Long Formation was originally a pure to slightly impure limestone, but it has been strongly metamorphosed. Hence, original sedimentary structures are no longer recognizable in the relatively few drillcores available. Therefore, it is difficult to determine the original sedimentary environment, but the limestone may have been deposited in a marginal basin or shallow sea, subject to minor influxes of sediment from its hinterland.

Lok Ma Chau Formation (Mai Po Member)

The Lok Ma Chau Formation has a large area of outcrop in the northwest New Territories, where it has been divided into the upper Tai Shek Mo Member and lower Mai Po Member (Langford *et al.*, 1989). Within the district, rocks of the Lok Ma Chau Formation lack the coarser-grained facies typical of the Tai Shek Mo Member, but closely resemble the lithology of the Mai Po Member, to which they are assigned. Widespread graphitic siltstones are characteristic of the member in its type area in the northwest New Territories (Langford *et al.*, 1989).

The Mai Po Member is present in a narrow outcrop between Tai O and San Shek Wan, in the west of the district. The outcrop is faulted against younger volcanic rocks of the Lantau Formation which are downthrown to its southeast. The member is also found on Mo To Chau, north of Lantau Island, where the contact with the adjacent granite and volcanic rocks is obscured by superficial deposits. The strata are well bedded, and often display reliable 'way-up' structures. The rocks are probably folded into close to isoclinal structures, as seen on a small scale at Sham Wat Wan. The dominant lithology is dark to light grey and red, laminated,

fine-grained sandstone and siltstone. These rocks are thought to have been regionally metamorphosed, and hence are described as metasandstones and metasiltstones on the published maps. However, the pre-fix meta- is omitted, for convenience, from the following descriptions. There are also occasional beds of massive to poorly-laminated, graphitic siltstone, up to several metres thick on West Brother island, which are pure enough to have justified commercial extraction of the graphite in the past.

The member is probably more than 400m thick around Sham Wat. However, close to isoclinal folding and additional faulting have probably repeated the sequence throughout the outcrop. On West Brother island, a graphite mine extended to - 90 mPD (Woods & Langford, 1991), yet did not reach the bottom of the succession, which may therefore be over 300 m thick. The relationship between the Mai Po Member and the adjacent marble of the Yuen Long Formation has not been established from the boreholes sunk offshore to the east of East Brother island. The contact is, however, presumed to be largely conformable, although it may be locally unconformable (Langford *et al.*, 1989; Frost, 1992).

Allen & Stephens (1971) assigned the strata of west Lantau Island and The Brothers islands to the Tai O Formation, and believed that the top of the formation was marked by a tuff lying conformably on sandstone. Ruxton (1960) had previously suggested there was an unconformity above the sedimentary sequence, but he thought that this had previously been confirmed by Uglow in the 1920s at a locality near Fan Lau (Jones, 1927, in Ruxton, 1960), but this locality lies outside the Carboniferous outcrop.

The strongest evidence of discordance at the top of the formation is at Sham Wat Wan, where the Mai Po Member is faulted against Jurassic eutaxite. Angular discordance is also evident from the dips of strata in Tai O cemetery, and on the headland west of San Chau. In all instances the dips in the siltstones and sandstones differ from those of the faulted contact, as, also, does the dip of banding, or eutaxitic fabric, in the volcanic sequence.

Details

Tai O. The Lok Ma Chau Formation on the western end of Tai O island strikes mainly eastnortheast. Steep dips to both north and south indicate that tight, to isoclinal folding may exist (e.g. at the northeastern tip of Tai O, near the sewage treatment works). Younging directions, determined from upwardly-fining units, consistently indicate that the strata are not inverted. Along the northern coast of Tai O the member comprises finely laminated siltstones, and fine-grained sandstones with abundant sedimentary structures. Lenticular bedding occurs in interbedded red to grey siltstone and fine sandstone near the western tip of the island (Plate 1, 1241 1319). Adjacent exposures show finely bedded sandstone and siltstone in upward-fining, graded units. These units dip and young to the southeast, whereas to the west (1226 1304), similar units of light grey to light red, fine-grained sandstone and siltstone, about 20 mm thick, young and dip to the northwest.

The eastnortheast-trending ridge through the summit at Fu Shan (0318 1331) is dominantly composed of massive, fine-grained quartzitic sandstone and siltstone. Similar rocks, together with finely laminated sandstone, are found to the east, on the island of Po Chue Tam (039 134).

Near the Sewage Treatment Works (0348 1361), siltstone and fine-grained sandstone dominate the sequence, and include some pebbly horizons. Rarely, the pebbles are up to 50 mm across, but more typically they range from 1 to 4 mm, and are angular to sub-rounded.

Tai O Cemetery. On the hillside above the cemetery, quartzitic sandstone and siltstone crop out close to eutaxite and tuff of the Cheung Shan Member of the Lantau Formation. The contact is inferred to be a high-angle fault, trending north-south and downthrowing the younger volcanics to the south, against the Carboniferous strata. A stream (0440 1365) to the north exposes reddish-white, fine-grained quartzitic sandstone, reddish siltstone and mudstone. However, the hillside is dominated by slope debris comprising eutaxite and tuff boulders from the hillside to the east.

Plate 1 - Fining-Upward Sequence of Well-bedded, Graded Sandstones and Siltstones (1241 1319), in the Mai Po Member (Carboniferous), near Tai O

San Chau. The footpath running east-west along the hillside at San Chau is underlain by reddish-white, fine-grained sandstone and siltstone, some of which has wavy, or lenticular bedding. Near the faulted contact between the Carboniferous and Jurassic, there are exposures of finely foliated, cherty, pale grey sandstone and siltstone (0503 1434). The foliation is parallel to the fault and dips northnorthwest at 60°. Dark grey graphitic siltstone and grey, fine-grained sandstone and siltstone are exposed on the headland west of San Chau. The graphitic siltstone is up to 2 m thick, and probably occurs as several beds in the succession, rather than as a single bed repeated by tight folding. On the west side of the headland (0459 1420), porphyritic rhyolite lava directly overlies sandstone (Plate 2), which in turn overlies a sequence including well-bedded, variably massive to well-laminated sandstones and grey to dark grey and carbonaceous siltstones (Plate 3, 0475 1444). The lava may represent the base of the Jurassic succession, unconformably overlying an eroded Carboniferous basement. However, the lava appears to be intercalated with the sandstone, and a more likely explanation is that the base of the succession is obscured, and that the sandstone is Jurassic, rather than Carboniferous in age.

Sham Wat Wan. There are two main groups of rocks in the Sham Wat area. The older, forming the low ridge of hills along the coast, comprises sedimentary rocks of the Lok Ma Chau Formation. High hills to the south are composed of largely metamorphosed (altered) volcanic rocks of the Jurassic Lantau Formation. The contact between the Carboniferous and the Lantau Formation is a high-angle fault, with the older rocks emplaced onto the younger volcanics to the south. The contact, exposed on the west side of the bay (Plate 4, 0626 1454) between easterly-dipping Carboniferous siltstones and Jurassic eutaxite, is a northeasterly-trending fault which also displaces the sedimentary rocks.

The headland at Hung Fan Shek is composed of fine-grained sandstone and silty sandstone, with occasional beds of dark grey graphitic siltstone. One of these beds (0591 1485) is tightly folded into a northerly-plunging syncline. A tight fold in a 3 m-thick graphitic bed also occurs north of Sham Wat Wan (0626 1526). The outcrop is dominated by grey siltstone and sandy siltstone, and structural features are only evident where scarce beds of dark grey graphitic siltstone are present.

San Shek Wan. Coastal exposures (Plate 5, 0678 1570) west of San Shek Wan comprise upward-fining, cross-bedded, fine-grained, quartzitic sandstone. The sandstone youngs and dips to the east, although elsewhere in the area both the younging- and dip-directions vary markedly. The sequence is dominantly composed of interbedded sandstone and siltstone, with some coarser gritty beds.

The contact between foliated sandstone and megacrystic, fine-grained granite is exposed at the northeastern end of the bay (0714 1612). The sandstone is also cut by a thin, eastnortheast-trending quartz syenite dyke. A skarn deposit has been recorded at this locality (Peng, 1991). It comprises a zone, about 5 m wide, which contains garnet, vesuvianite, diopside and epidote, with scattered magnetite.

West Brother island (prior to development). The island is dominantly composed of silty sandstone, but also contains prominent beds of graphitic siltstone. Graphite-rich horizons are also present, and were mined in the 1950s and 60s. These horizons are highly eroded and are not well exposed on the shoreline, but have been mapped underground (Ruxton, 1957; Woods & Langford, 1991). Neither the base nor top of the succession were seen, but the siltstone and sandstone sequence is at least 200 m thick.

The west coast of the island is dominated by graphitic siltstone and graphite-rich horizons. Near the abandoned mines and associated buildings, the beach is dominantly composed of pebbles and cobbles of graphitic siltstone. Near the northern tip of the island, graphitic siltstone, is well bedded, dips northeast at 52° , and underlies brown-weathering, silty sandstone. The east coast is dominated by this massive, silty sandstone, in which bedding is absent, or poorly defined. The finely interlaminated graphitic siltstone and siltstone include load structures which confirm that the sequence is the right way-up. Cross-lamination also occurs, but was not observed *in situ*. Pure graphite was only seen on spoil heaps beside the old mine workings (1456 2117). The graphite probably came from the axial zone of the northeast-plunging syncline which forms the island. The rock has lustrous foliation surfaces, and has probably been thermally metamorphosed.

The northern and eastern parts of the island are dominated by banded and massive, silty sandstone, with locally extensive mineral boxworks. Bedding is obscure in the east, but nearly vertical erosional hollows, striking eastnortheast, probably lie along softer strata.

East Brother island (prior to development) The island is dominated by red-weathering, finely laminated siltstone and sandstone (Plate 6), massive siltstone and fine-grained sandstone. Thin quartzitic sandstone beds at the southern end of the island are less than 2 m thick. Quartzitic sandstone also occurs at the northern end, and may be partly responsible for the hog-back appearance of the island. Well-defined bedding dips steeply on the west coast of the island, and can also be seen occasionally on the east coast in the more massive siltstone and silty sandstone. The succession is at least 100 m thick, but no top or base has been observed.

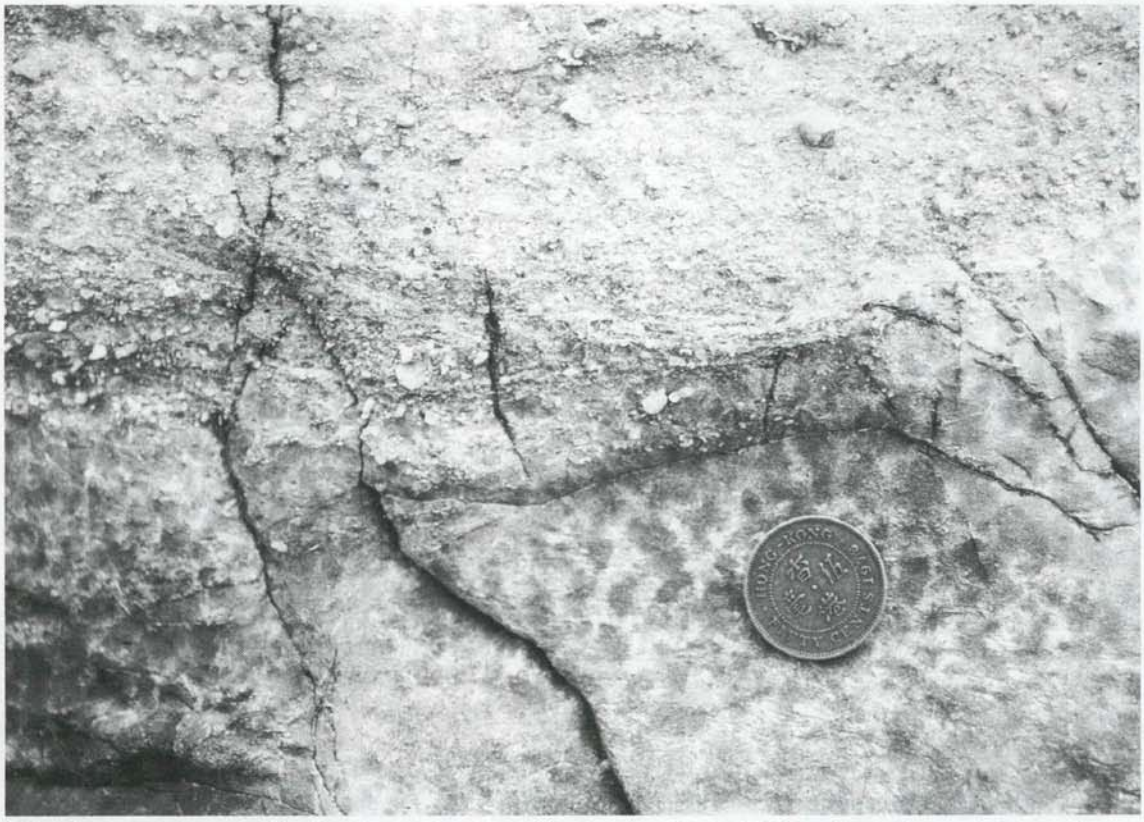


Plate 2 - Porphyritic Rhyolite Lava Overlying Sandstone (0459 1420) at San Chau. (The sandstone may be part of the Mai Po Member (Carboniferous), but it is more likely that both the lava and sandstone are Jurassic).

Plate 3 - Well-bedded Sandstones and Siltstones of the Mai Po Member (Carboniferous), Exposed on the Foreshore (0475 1444) East of San Chau

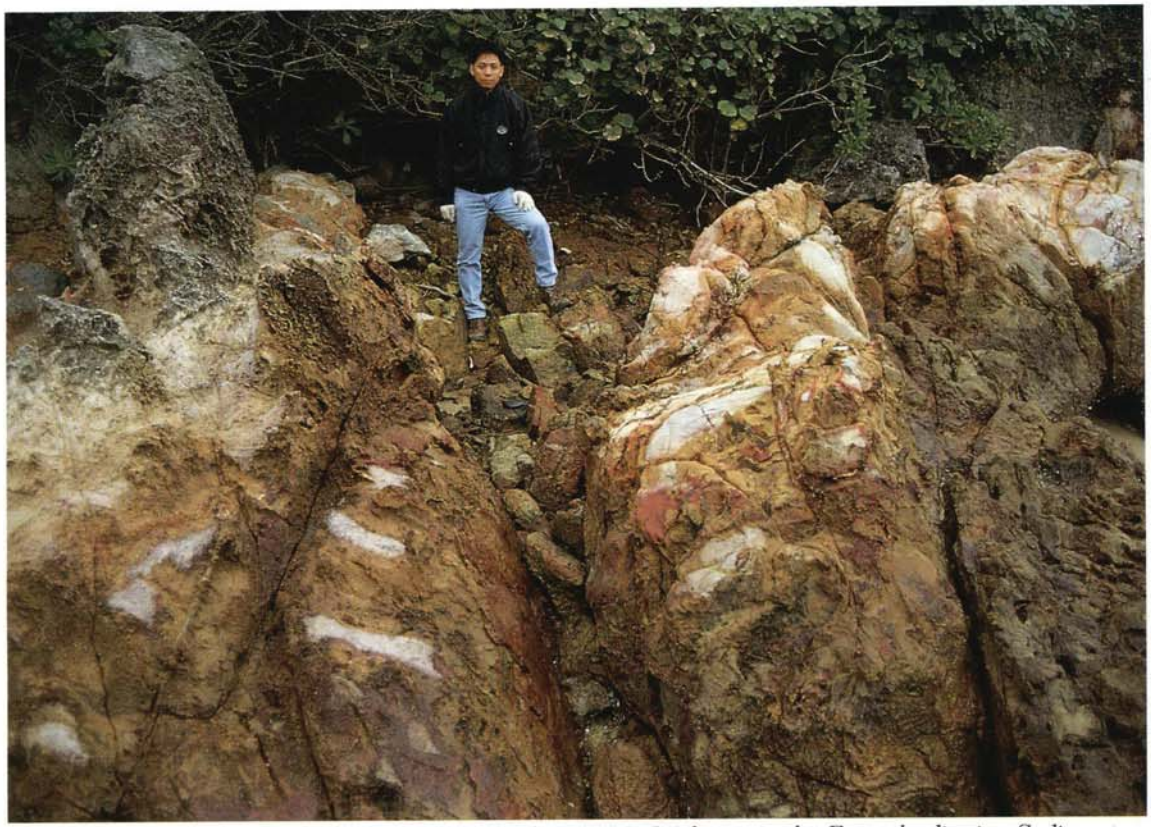


Plate 4 - Northeast-trending, High-angle Fault (0626 1454) between the Easterly-dipping Sedimentary Rocks of the Mai Po Member (Carboniferous) and Eutaxite of the Cheung Shan Member of the Lantau Formation (Jurassic), near Sham Wat

Plate 5 - Near Vertical Quartzitic Sandstone, of the Carboniferous Mai Po Member Younging and Dipping to the East, at San Shek Wan (0678 1570)

Plate 6 - Finely Laminated Siltstone and Fine-grained Sandstone, of the Carboniferous Mai Po Member on the Western Foreshore (1606 2194) of East Brother Island (Siu Mo To)

Reef Island. The northern end of the island is mainly composed of quartzite, which forms the island's highest point. The strata are massive, or poorly bedded, but a steeply inclined, northerly-dipping, graphitic parting occurs. The silty sandstone to the south contains nodules, possibly iron-cemented, and pebbly patches. Bedding, which dips 71° northnorthwest, is well defined in these red-weathering sandstones. The centre of the island is also comprised of red-weathering silty sandstone, whereas the southern end is composed of finely bedded, or massive quartzitic sandstone and graphitic siltstone. The graphitic rock is locally spotted, and may be hornfelsed. Generally, the strata dip very shallowly, varying locally up to 29°, towards the northwest or northnorthwest. There are two distinct graphite siltstone beds, each several metres thick.

Petrography

The fine-grained sandstones and siltstones are predominantly quartzitic. In sample HK 2802 (0636 1492) from Sham Wat, the quartz is largely recrystallized, and forms part of a quartz-sericite matrix with grains around 0.2 mm. Some relict quartz grains are still visible, but the metasandstone is veined, as well as altered, and most original textures are obscured. Phyllitic metasiltstone from Sham Wat (HK 2805, 0624 1514) is greenish white in hand specimen, and is dominantly comprised of a quartz-sericite matrix containing a few quartz crystal relicts, up to 0.1 mm.

Evidence of the thermal metamorphism on The Brothers islands can be seen in a carbonaceous sandstone from Reef Island (HK 8011, 1588 2083) which contains well developed andalusite crystals, with chiastolite crosses, about 0.8 mm across. The margins of the andalusite are sericitized. The matrix is dominated by quartz crystals, up to 3 mm across, which display undulose extinction, together with microcrystalline opaque graphite. Light brown, slightly weathered, graphitic siltstone with wavy, or flaser cross-bedding from West Brother island, contains abundant opaque microcrystalline graphite flakes, visible in thin section (HK 8017, 1447 2160). The quartz sericite matrix is dominantly less than 0.1 mm in grain size.

Palaeontology

Graphite from West Brother island (HK 7250, 1460 2115) yielded a sparse microfauna (Appendix 1) including *Calamospora breviradiata* and *Densosporites annulatus*. The fauna indicate a Carboniferous, and possibly early Carboniferous age. A few miospores, obtained from a graphitic siltstone from Tai O (HK 9284, 0276 1307), include (Appendix 1) *Knoxisporites litheratus, Lycospora pusilla* and *Gorgonispaeridium sp.*, all of which occur in Carboniferous strata in South China. Other graphitic rocks failed to yield recognisable palynomorphs. This limited palaeontological evidence tends to confirm the correlation of strata at Tai O, and on The Brothers, with similar lithologies in the northwest New Territories which contain better preserved microfauna.

Sedimentary Environment

The wavy and lenticular bedding in the fine sedimentary rocks suggests a tidal flat, or delta front environment of deposition. This type of bedding commonly forms where there are fluctuations in sediment supply, or current (or wave) activity. Other sedimentary structures, such as small-scale cross- bedding and grading in the fine-grained sandstones, together with rapidly alternating beds of siltstone and fine-grained sandstone, indicate a shallow water environment with varying tidal or fluvial influences. The carbonaceous material indicates a neritic environment, probably in a fan delta. Overall, the facies association is typical of a neritic tidal swamp or deltaic alluvial fan. Evidence from the northwest New Territories (Langford *et al.*, 1989) indicates progradation from a distal to a proximal fluvial floodplain sequence as the sediment coarsens into the overlying Tai Shek Mo Member.

Chapter 4
Mesozoic Volcanic and Sedimentary Rocks

Classification and Distribution

Addison (1986) and Strange & Shaw (1986) provided comprehensive summaries of early research (Uglow, 1926; Brock & Schofield, 1926; Williams *et al.*, 1945; Ruxton, 1960; Allen & Stephens, 1971; Table 3) on the stratigraphy of the Mesozoic volcanic and sedimentary rocks of Hong Kong. Allen & Stephens (1971) described these rocks, occurring across the Territory, as the Upper Jurassic Repulse Bay Formation. Addison (1986) later amended their lithostratigraphy in the Sha Tin district and proposed the Repulse Bay Volcanic Group. However, the volcanic rocks of Hong Kong were subsequently divided into two groups, the Tsuen Wan and Repulse Bay volcanic groups, on the basis of their petrography, geochemistry, and chronology. The older Tsuen Wan Volcanic Group (Geotechnical Engineering Office, 1992; Sewell *et al.*, 1993), which is dominantly composed of rhyodacitic tuffs, includes three formations that were formerly assigned to the Repulse Bay Volcanic Group by Addison (1986). It crops out mostly in the north of the Territory. Only two of these three formations, the Yim Tin Tsai and Shing Mun, occur in the Lantau district. The younger Repulse Bay Volcanic Group largely comprises rhyolitic tuff and lava, and is found mainly in the east and south of the Territory. It is represented in the district by the Lantau and Mount Davis formations, both defined here for the first time. The former crops out over large areas of the district, whereas the Mount Davis Formation, which may be the younger of the two formations, occurs only in the extreme east, where the Lantau Formation is unrecognised. As well as the formations themselves, the present survey has identified various named members and other lithological units, including epiclastic rocks (conglomerate, sandstone, siltstone), tuffaceous sedimentary rocks, eutaxite, tuff-breccia and crystal tuffs. The general volcanic sequence for the district is presented in Table 3. The nomenclature and classification of the pyroclastic rocks used below, and summarized in Figures 7a and b, are based on International Union of Geological Sciences recommendations (Schmid, 1981; Le Maitre, 1989), and the work of Fisher & Schmincke (1984). Representative whole-rock geochemical analyses of the major volcanic rock types are presented in Appendix 2.

Tsuen Wan Volcanic Group

Yim Tin Tsai Formation

The Yim Tin Tsai Formation is the oldest formation in the Tsuen Wan Volcanic Group (Sewell *et al.*, 1993). Its type locality is northeast of the district on Yim Tin Tsai, in Tolo Harbour, where approximately 200 m of strata overlie a basal sedimentary breccia (Addison, 1986). In the district, the formation crops out in several areas: in the east on Tsing Yi and Ma Wan; in northern Lantau Island, near Tsing Chau Tsai; in south Lantau Island between Pui O and Tong Fuk; and at Yi O in west Lantau Island.

The lithology, which weathers to a light brown, is a uniform grey to dark grey, lapilli-ash crystal, or vitric crystal tuff, characterized by elongate, or sub-rounded lapilli of coarsely porphyritic lava, typically with diffuse margins. Aphanitic lapilli, some with diffuse margins up to 30 mm thick, and dark green siltstone clasts also occur. Lithic blocks may be as large 150 mm. The tuffs

Table 3. Evolution of Nomenclature of Volcanic Successions in the Territory (precise correlations not intended)

Territorywide

Williams *et al.* (1945)	Allen & Stephens (1971)
Shelter Volcanics	Repulse Bay Formation
Tai Mo Shan Porphyry	
Repulse Bay Volcanics	

Within Individual Districts (New Territories and Hong Kong Island)

Sha Tin (Addison, 1986, and Kowloon/ Hong Kong Island Strange & Shaw, 1986)		NW New Territories (Langford, *et al.*, 1989)		Sai Kung/ Clearwater Bay (Strange, *et al.*, 1990)		NE New Territories (Lai & Shaw, 1992)	
				Repulse Bay Volcanic Group (RBVG)	Long Harbour Formation	RBVG	Long Harbour Formation
					Lai Chi Chong Formation		Lai Chi Chong Formation
					High Island Formation	Tsuen Wan Volcanic Group	Ngo Mei Chau Formation
					Clearwater Bay Formation		
					Mang Kung Uk Formation		Sai Lau Kong Formation
					Silverstrand Formation		
	Top not seen		*Top not seen*		Tai Mo Shan Formation		Tai Mo Shan Formation
Repulse Bay Volcanic Group	Tai Mo Shan Formation	Repulse Bay Volcanic Group (RBVG)	Tai Mo Shan Formation		Ap Lei Chau Formation		
	Ap Lei Chau Formation		Ap Lei Chau Formation		*Base not seen*		Shing Mun Formation
	Shing Mun Formation		Shing Mun Formation				*Base not seen*
	Yim Tin Tsai Formation		Yim Tin Tsai Formation				
	Breccia		Tuen Mun Formation				
			Tsing Shan Formation				

Lantau District

Lantau District	
Repulse Bay Volcanic Group (RBVG)	*Top not seen*
	Mount Davis Formation
	(Sunset Peak Member)
	Lantau Formation (Pak Kok Member)
	(Cheung Shan Member)
Tsuen Wan Volcanic Group	Shing Mun Formation
	(Shek Lung Kung Member)
	Yim Tin Tsai Formation
	Base not seen

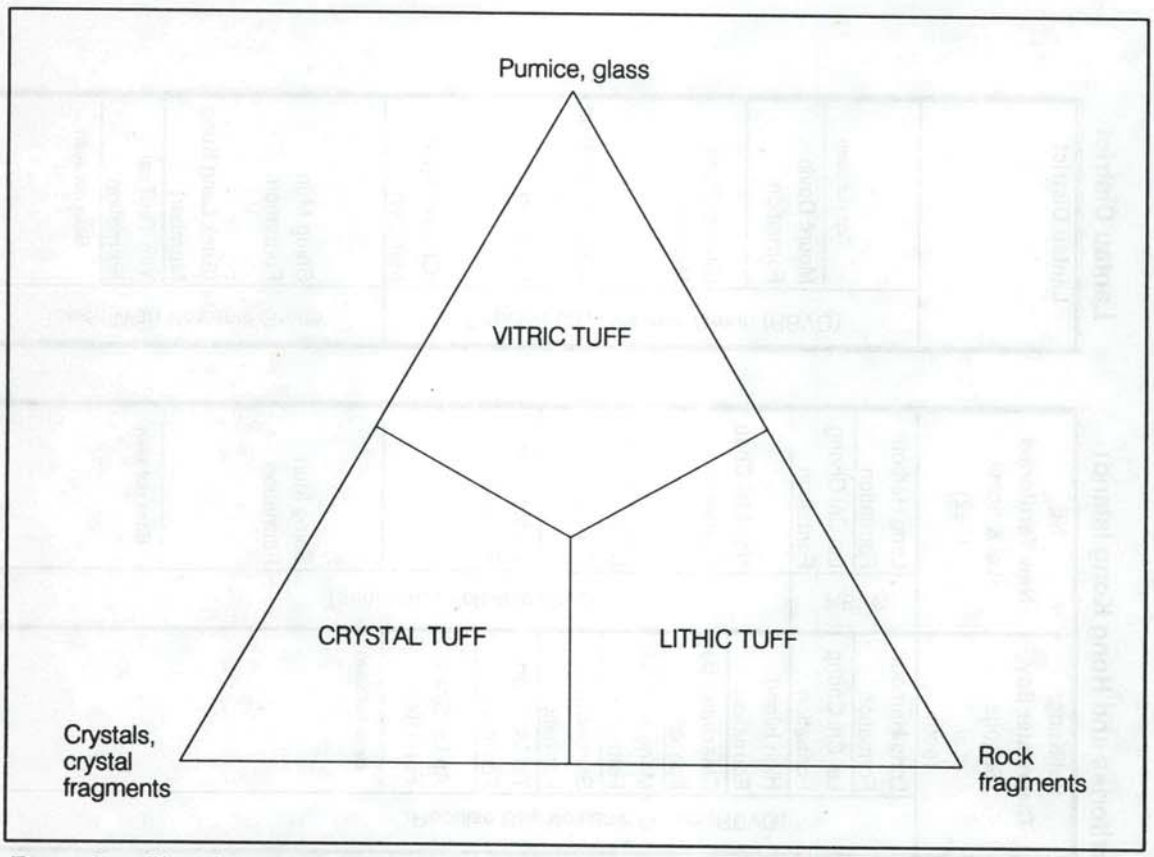


Figure 7a - Classification of Pyroclastic Rocks Based on Composition (after Le Maitre, 1989)

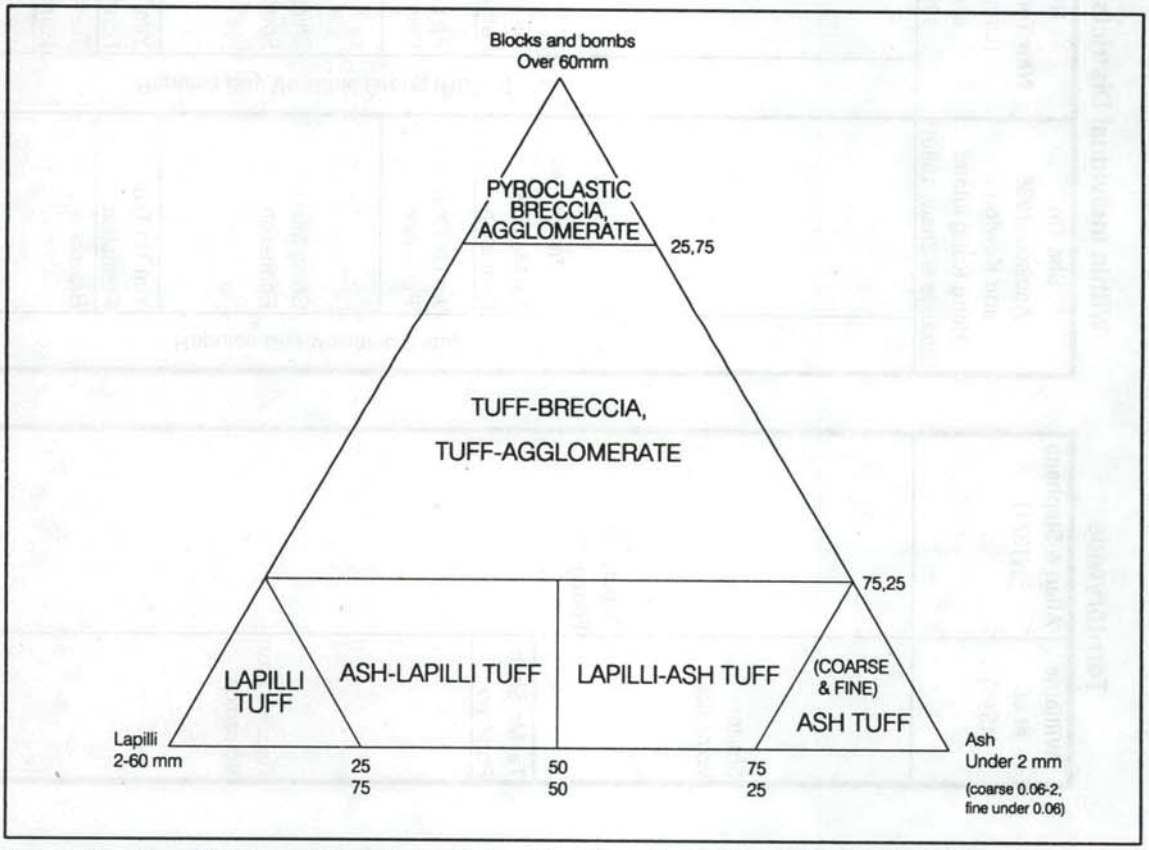


Figure 7b - Classification of Pyroclastic Rocks Based on Grain Size (Adapted from Schmid, 1981 and Fischer & Schminke, 1984)

are crudely stratified and welded in places, the latter fabrics being characterized by aligned crystal pyroclasts and compressed lithic clasts.

Crystals are commonly broken, locally flow-orientated, and mainly comprise plagioclase and microcline feldspars and quartz, with generally minor amounts of magmatic hornblende (variably pseudomorphed) and biotite. The matrix, which makes up nearly half of the rock, is a devitrified glass, and varies from microcrystalline quartz, feldspar, chlorite and sericite, to a cryptocrystalline texture. On Ma Wan, thin tuffite bands also occur. The formation is only seen in faulted contact with older rocks, but is gradationally overlain by the Shing Mun Formation.

Details

Tsing Yi and Ma Wan. The Yim Tin Tsai Formation is the principal volcanic formation on Ma Wan and Tsing Yi. It is uniform throughout, and is well exposed along the shorelines and in cut-slopes. The rock comprises lapilli-coarse ash lithic crystal tuff, and varies from light to dark grey, depending on the mafic mineral content. Feldspars are the dominant crystal type, with common hornblende, and subordinate quartz and biotite. Lithic clasts of dark green siltstone are generally prevalent. Plagioclase and biotite are the most distinctive flow-oriented phenocrysts, and the tuffs commonly have a flattening-fabric, defined by compressed lithic clasts and aligned crystal pyroclasts.

Tuffs of the Yim Tin Tsai Formation crop out over much of the northwest, and western of central Tsing Yi. They are well exposed in the cut-slopes (2785 2270) around Sai Tso Wan, where they are transected by north-, and northeast-trending faults, and intruded by numerous granitoid and basalt dykes. On the island's main ridge, the tuffs are flat-lying above granite, but locally, they dip steeply to the north. They are also intruded by easterly-trending rhyolite dykes. The tuffs are well exposed in hillside tors (2750 2310) above Kam Chuk Kok, and are intruded by granodiorite, in cut-slopes to the west. On the headland (2650 2380) west of Shek Wan, the tuffs are partly recrystallised, but lithic clasts are still recognisable.

The Yim Tin Tsai Formation is widespread on Ma Wan, forming extensive coastal outcrops in the north and southwest, and boulderfields inland. The lithology is identical to that on Tsing Yi, with a well-displayed flow-fabric in outcrops around Kau Po (2382 2388), Tung Wan (2438 2338) and Tung Wan Tsai (2476 2399). Commonly, the tuff has a well-developed welding fabric which is gently undulose. In the east, this fabric dips to the northwest, at about 30°, while in the north it dips gently southwards. At Pak Wan (2437 2398), on the north coast of the island, there is a thin, light greenish-grey, fine-grained, silty tuffite with pebbles of tuff up to 50 mm. The exposure is entirely surrounded by rhyolite dykes.

Tsing Chau Tsai area. The crystal tuffs in this area contain a few large, diffuse-edged porphyritic lapilli, and have a generally coarse ash to lapilli grain size, glassy matrix and well-defined mafic crystals; all features which are typical of the Yim Tin Tsai Formation. The tuffs are also characterized by aphanitic, pebble-like, lithic clasts, up to 30 mm across, which, unlike typical clasts in the overlying Shing Mun Formation, do not have altered margins. On the coast (2265 2270) at Tsing Chau Tsai, a lapilli-bearing, coarse ash tuff is exposed. Locally to the west (2210 2232), the tuffs are crudely stratified, and contain quartz and feldspar crystals (pyroclasts) up to 5 mm across.

Cheung Sha. Yim Tin Tsai Formation crystal tuffs, containing both large porphyritic lava lapilli and smaller, dark aphanitic lapilli, are exposed on the coast (140 105) near Cheung Sha Lower Village. Some of the dark lapilli have reaction (resorption or alteration) rims, although most have sharp contacts with the matrix. The porphyritic lapilli generally have diffuse margins. The tuffs are cut by granodiorite and feldsparphyric rhyolite dykes. Bluish-grey, porphyritic, lapilli-bearing ash crystal tuff is exposed along the catchwater (133 111) above the South Lantau Road. It also contains small, dark grey, aphanitic lapilli.

Exposures offshore (1196 0977) from Cheung Sha Beach include tuff and feldsparphyric rhyolite dykes. The tuff contains many prominent lapilli and has a planar fabric as is typical of the Yim Tin Tsai Formation. A very small offshore exposure (1393 0944), about 1 km south of Cheung Sha Lower Village, comprises lithic lapilli-bearing tuff and probably belongs to the formation.

Tong Fuk. Grey lapilli-ash crystal tuffs are exposed east of Tong Fuk (1126 0973). A prominent planar fabric, dipping 80° to the south, is defined by elongate porphyritic lapilli and blocks up to 150 mm. Some lapilli have diffuse margins, and appear to grade into the matrix. Smaller, dark aphanitic lapilli, up to 50 mm across, have clearly-defined margins and in some cases have reaction (resorption or alteration) rims.

Weathered surfaces expose quartz crystals (pyroclasts) from 1 to 5 mm across, and aligned mafic crystals between 1 and 3 mm in length. Boulders of grey tuff (1036 0922), exposed offshore in the middle of Tong Fuk Mui Wan,

contain porphyritic lapilli typical of the formation, as well as small, dark, aphanitic lapilli with reaction (resorption or alteration) rims.

Around the shoreline of Tong Fuk Mui Wan, there are scattered exposures of mafic-rich, lapilli-ash crystal tuff with elongate porphyritic lapilli. On the southwest side (0992 0923) of the bay these elongate lapilli define a fabric which dips northnortheast at 71°. Feldsparphyric rhyolite dykes cut the tuff on the northeast coast. On the south side (1038 0889) of the bay, the tuffs include a porphyritic lapilli-bearing tuff, with a fabric dipping approximately 80° to the southsoutheast. They are intruded by a trachytic quartz syenite. Elsewhere, this mafic-bearing, lapilli-ash crystal tuff contains dark lithic clasts, up to 20 mm across, and pale porphyritic lapilli and blocks up to 100 mm long.

Yi O. On the Tsing Lam Kok headland (0210 1080), west of Yi O, exposures of crystal lapilli-rich tuff include porphyritic lava lapilli with diffuse margins, and small aphanitic lapilli with reaction rims. Similar tuffs, with prominent mafic pyroclasts, up to 4 mm, and varying contents of porphyritic lapilli, occur around the coast to the north and west of Yi O. West of Kai Kung Shan (015 099), tuffs of the Yim Tin Tsai Formation pass transitionally up into finer grained, ash crystal tuffs of the Shing Mun Formation.

North of Yi O, around Nga Ying Kok (027 115), exposures of tuff are interpreted as lying close to the contact with the overlying Shing Mun Formation. These tuffs contain quartz crystals up to 4 mm, relict feldspars up to 5 mm, and common euhedral pseudomorphs after amphibole. The relatively coarse, mafic-rich nature of the tuff, combined with the very rare occurrence of porphyritic lava lapilli, are characteristics of the Yim Tin Tsai Formation.

Petrography

Light grey, crystal vitric tuffs from Tsing Yi (HK 5828, 2656 2370) contain disseminated mafic minerals up to 5 mm across. They comprise hornblende, biotite and chlorite, whereas the dominant crystal pyroclasts are quartz, microcline and plagioclase. The matrix comprises small quartz crystals and interlocking grains of quartz, feldspar and chlorite.

Typical vitric crystal tuff from Shui Hau Wan (HK 9986, 9845 9245) is light brownish-grey in hand specimen, with white feldspar crystal pyroclasts up to 5 mm and small porphyritic lapilli. Dark flakes of mafic minerals, up to 3 mm across, are composed of pleochroic, light brown to reddish-brown biotite, and light olive-brown hornblende. The devitrified matrix is microcrystalline and forms about half of the rock.

Lapilli-ash crystal tuff from Yi O (HK 9338, 02670 10285) contains subhedral to broken quartz crystal pyroclasts up to 4 mm across, set in a recrystallized quartz-sericite matrix. Feldspar is generally altered to fine-grained sericite, while pseudomorphs after biotite and hornblende comprise sericite and opaque minerals. Relict lithic lapilli, up to 3mm, are composed of microcrystalline quartz. Unaltered samples from the Yi O area contain strongly zoned plagioclase and perthitic alkali feldspar, as well as fresh hornblende and biotite. The devitrified matrix is cryptocrystalline or microcrystalline.

Volcanic Environment

The Yim Tin Tsai Formation is notable for its thickness and lateral extent; it stretches beyond the district to the north and east, into the Sha Tin district (Addison, 1986), as well as to the south of Hong Kong Island (Strange & Shaw, 1986). Its base is not seen in the district, but its top is gradational into the overlying Shing Mun Formation. Epiclastic units are absent, except within the uppermost transitional zone, and most of the tuffs are welded. Flow may be indicated by elongation of the lapilli, although this could equally be due to post-depositional, down-slope rheomorphism. No regional flow directions can therefore be assumed; especially considering the limited outcrop evidence. The high temperature of the flows probably caused the partial resorption of lapilli, giving them their characteristic diffuse margins. The vent from which these flows were erupted has not been located, and need not have been within the district. These characteristics suggest that the tuffs were deposited from very large pyroclastic ash flows.

Shing Mun Formation

The type locality for the formation, which was defined by Addison (1986), is northeast of Tsuen Wan, where it is characterized by its variety of lithologies. In this district, however, it is dominantly composed of units, not all of which can be differentiated on the map, of ash crystal tuffs, with subordinate epiclastics and tuffites. The formation transitionally overlies (where exposed) the Yim Tin Tsai Formation on Lantau Island in the northeast, at Cheung Sha in the south, and at Yi O in the west. In northeast Lantau Island, the formation is represented solely by the Shek Lung Kung Member, which has its type locality in the adjacent district to the north (Langford *et al.*, 1989). The member is characterized by ash crystal tuffs, with a prominent linear fabric, and small porphyritic lapilli.

Details

Cheung Sha. Lithic lapilli-bearing, ash crystal tuff of the formation is exposed on the catchwater (128 111) close to Cheung Sha, above the South Lantau Road. Boreholes drilled downslope of the catchwater intersected sedimentary or tuffaceous rocks which are also interpreted as part of the formation. The tuff is characterized by the abundance and variety of lapilli, including small limestone fragments around 10 mm across. In fresh exposures the tuff is typically greenish-grey to light grey, with aphanitic lithic fragments up to 100 mm across, set in a matrix dominated by small crystals. The contact with the underlying Yim Tin Tsai Formation is not exposed, but is presumed to be gradational. The outcrop geometry implies that the formation is unconformably overlain by lavas of the Lantau Formation, as the Shing Mun Formation is progressively cut out to the east. To the west, it is truncated by the Tung Chung Fault (Figure 10).

Greenish-grey to grey, ash crystal tuffs are exposed to the west of the Tung Chung Fault, both on the Tung Chung Road (1255 1064), and nearby on the South Lantau Road (1242 1047). The rock contains variable amounts of lithic lapilli, some up to 50 mm, and is dominantly composed of angular to subangular, dark grey aphanitic rock. The matrix is poorly sorted ash, and contains crystal pyroclasts up to 3 mm across. The stratigraphic relationship with the underlying tuffs is unknown, as the formation is cut by feldsparphyric rhyolite dykes to the south. The formation is overlain unconformably by a eutaxitic member within the Lantau Formation, and it pinches out below the eutaxite towards the west, and is not exposed in the Tong Fuk area.

Yi O. A sequence of lithic lapilli-bearing tuffs and tuffaceous sedimentary rocks is exposed on the flanks of Nga Ying Shan and Tai Hom Sham, east of Yi O. The tuffs contain relict pyroclasts, mostly of quartz, and up to 3 mm across. Some angular lithic lapilli, rarely up to 25 mm, also occur. The tuffs display a secondary foliation, and the matrix and feldspar pyroclasts have been altered. Hence, stratigraphic determination is difficult. However, the lithological diversity, which also includes tuffaceous sandstone, pebbly siltstone and sedimentary breccia, is characteristic of the Shing Mun Formation.

The sequence lies above strata typical of the Yim Tin Tsai Formation, and is in turn overlain by lavas and tuffs of the Lantau Formation, including a local basal eutaxite. However, contacts are not exposed, and the rocks of both units are strongly altered and locally foliated.

On the coast (015 098) west of Yi O there are exposures of lithic lapilli-bearing ash crystal tuff, that contain dark grey, aphanitic lapilli up to 150 mm across, and small, pale, porphyritic lapilli similar to those found in the Shek Lung Kung Member. Elsewhere along the coast to the south, the tuff contains varying, often abundant amounts of dark lithic lapilli. In this area it has not proved possible to differentiate the Shek Lung Kung Member from the main body of the Shing Mun Formation. On Kai Kung Shan (019 102), tuffs of the formation are highly altered, veined and fractured. Relict quartz pyroclasts, up to 5 mm across, pseudomorphs after biotite and lithic lapilli are the only indicators of the original pyroclastic texture.

Petrography

Uniform, grey, lithic lapilli-bearing ash crystal tuffs of the Shing Mun Formation are well exposed on the Tung Chung Road. A typical thin section (HK8544, 1249 1063), containing lapilli with reaction rims, is dominated by shards and broken crystals of quartz and feldspar, ranging in grain size from coarse to fine ash. The plagioclase is sericitized, and the alkali feldspar shows slight incipient alteration. In places, both the feldspar and the matrix are epidotized. The biotite forms flakes in the matrix, and is commonly chloritized. There are also pseudomorphs after tabular-shaped amphibole. Elsewhere in the area, the tuff contains small lithic fragments, including limestone, derived from basement strata. The tuffs are mainly fine

ashes, in contrast with the coarser Yim Tin Tsai Formation and more vitric Shek Lung Kung Member.

Around Yi O, the Shing Mun Formation tuffs are commonly altered, and in places are strongly silicified and brecciated, as on Kai Kung Shan. West of Yi O, a pyritiferous, lithic lapilli-bearing ash crystal tuff (HK 9967, 0155 0952) contains quartz pyroclasts, up to 2 mm, set in a quartz-sericite matrix. The alkali feldspar is replaced by calcite, and the biotite by muscovite and opaque minerals. There are relict lithic fragments in the matrix, and possible pseudomorphs after amphibole. Adjacent exposures (HK 9966, 0155 0981) comprise dark grey, lithic lapilli-bearing, ash crystal tuff with abundant, ragged to sharp-edged, porphyritic lapilli up to 12 mm long. These tuffs are more typical of the Shek Lung Kung Member; but the intense alteration in this area makes it impossible to identify the member with confidence.

Volcanic and Sedimentary Environment

As the Shing Mun Formation contains thin, persistent siltstone and sandstone beds it is assumed that the depositional environment was relatively stable. The sedimentary rocks probably represent lahars or mudflows that accumulated in intermontane basins close to volcanic centres. The tuffaceous content of most of the sediments indicates local erosion of the volcanic sequence. Some lithic clasts in the tuffs have reaction rims, which suggests a high emplacement temperature and water content.

Shek Lung Kung Member

The Shek Lung Kung Member is broadly equivalent to agglomerate mapped by Allen & Stephens (1971). The lithology is predominantly an ash, to lapilli-ash crystal vitric tuff (Plate 7) that characteristically displays a flow-lineation and sharp-edged porphyritic lapilli. The member outcrops only in northeast Lantau Island, but may also be present near Yi O in the west. It lies immediately above Yim Tin Tsai Formation outcrops, although the contact is not exposed.

Details

Siu Ho Wan - Ta Pang Po. Between Siu Ho Wan and Sham Shui Kok, the Shek Lung Kung Member comprises lapilli-ash crystal tuffs. The tuff is poorly exposed, but can be correlated with excellent coastal exposures of the member to the east. It forms narrow, easterly-trending bands of country rock between dykes. Between Sham Shui Kok and Ta Pang Po, the member can be identified with confidence and is characterized by sharp-edged porphyritic lapilli with a linear alignment. There is local hydrothermal alteration of the tuff east of Ta Pang Po, but for the most part it is fresh and unaltered. North of Ta Pang Po, there are uniform lapilli-ash crystal tuffs with some pebble-like lithics. However, there are also sharp-edged porphyritic lapilli, a characteristic feature of the Shek Lung Kung Member.

West of Yam O Wan. For part of the exposed coastline, between Yam Tsai Wan and Ta Pang Po, the tuffs lack the porphyritic lapilli characteristic of the Shek Lung Kung Member, and are ash crystal tuffs, with prominent mafic minerals. To the east and west, flow-fabric and abundant sharp-edged porphyritic lapilli are typical. At Luk Keng Tsuen, the characteristics of the Shek Lung Kung Member are again apparent, with a lineation defined by mafic minerals, and small, angular porphyritic lapilli. Although apparently scarce, these characteristic lapilli persist to the southwest. In Luk Keng Bay the tuff has a flow-lineation which is sub-horizontal, or plunges gently to the southsouthwest. The lithic lapilli are characteristically sharp-edged and porphyritic. On Cheung Sok Tsui, the Shek Lung Kung Member consists of a light grey, weathering to light creamish-brown, variably ash to lapilli-ash crystal tuffs. They display a prominent lineation, defined by porphyritic lapilli and laths of biotite, which plunge gently to the southsouthwest.

East of Yam O Wan. At Tai Yam, the tuffs are dominated by porphyritic, aphanitic lapilli, 10 to 30 mm in length. These lapilli define a flow-lineation, exactly as seen at the Shek Lung Kung type locality. The rock is also characterized by its pale, glassy appearance, with well-formed mafic crystals. To the east, the flow-lineation is present, but lapilli are not obvious.

Tai Che Tung. Crystal tuff, interpreted as Shek Lung Kung Member, occurs on the northern slopes of the summit of Tai Che Tung, between feldsparphyric rhyolite dykes. It is typically a lapilli-ash crystal-dominated tuff, and often has prominent mafic crystals. Dark lithic lapilli are also sometimes present. Locally, the matrix appears to comprise fine ash-grade crystals.

Petrography

Typical crystal vitric tuffs of the Shek Lung Kung Member contain smaller pyroclasts and more vitric matrix than the underlying Yim Tin Tsai Formation. The tuff is generally grey or light grey, and contains small, pinkish, sharp-edged porphyritic lapilli, often with a ragged appearance. The mafic minerals, mostly biotite, commonly define a prominent lineation. In thin section (HK 7754, 1818 2016) the quartz and feldspar crystal pyroclasts are up to 3 mm across. A strong alignment of pleochroic, dark brown to light brown biotite is evident, together with crystal pyroclasts of pleochroic, green brown to light brown magmatic hornblende. The vitric matrix is dominant, forming 60% of the rock, with the remainder consisting of roughly equal proportions of quartz and feldspar crystals.

Volcanic Environment

The Shek Lung Kung Member is a localized, welded pyroclastic flow. Its impersistence suggests that its emplacement was restricted either by a pre-existing valley, or by caldera collapse. Linear fabrics indicate (cf. Fisher & Schmincke, 1984) that the flow-direction was roughly northwest-southeast. By contrast with lapilli in the Yim Tin Tsai Formation, the lapilli in the Shek Lung Kung Member are smaller and more angular (unresorbed). This would suggest that the topographically constrained flows were smaller, and were emplaced at a lower temperature, than those in the Yim Tin Tsai Formation.

Repulse Bay Volcanic Group

Lantau Formation

The formation is defined for the first time in this memoir. It crops out only in the mountainous regions of Lantau Island, and comprises a complex sequence of rhyolite lavas, rhyolitic tuffs and tuffaceous sedimentary rocks. The lavas are typically well banded, and in their type area, around Nei Lak Shan (091 134) north of Po Lin Monastery, they occur above a sequence which includes fossiliferous mudstone. Several named members occur within the formation, as well as a number of other mappable, but unnamed members. In south and west Lantau Island, the succession is probably unconformable on tuffs of the Shing Mun and Yim Tin Tsai formations, with the former thicker in the west, and apparently cut out to the east. The top of the formation is not seen, but its overall thickness probably exceeds 1700 m.

Large areas of the outcrop have been altered by hydrothermal and dynamic processes, producing rocks with complex textures and field relations. However, the dominantly extrusive character of the formation is evident in even the most altered rocks. The unaltered lavas and less common tuffs are light grey to dark grey, and are typically characterized by large white euhedral feldspar crystals. The lavas are typically banded (Plate 8) and do not contain lithic fragments, whereas the tuffs usually contain lithic lapilli. Eutaxite, found near the base of the succession, has been mapped as the Cheung Shan Member. In the west, a mappable sequence of tuffaceous and sedimentary rocks, exposed on the coast and in adjacent hills, has been defined as the Pak Kok Member. The highest preserved part of the formation is characterized by the thin Sunset Peak Member, dominantly comprising lithic lapilli-bearing crystal tuffs. Between the extrusive flows, there are numerous thin beds of tuffaceous mudstone and siltstone, which are rarely fossiliferous.

These beds are extensive in the west of the district, but are less common in the north. Outcrops of siltstone usually form prominent ridges and positive features on the hillside, as they are more resistant to erosion than the adjacent lavas and tuffs.

Rhyolite and Banded Rhyolite Lava

Details

Nei Lak Shan. This is the type area of the Lantau Formation; from the summit of the mountain to the south (towards Po Lin Monastery) and southwest, there are exposures and corestones of banded, porphyritic, rhyolite lava. The rock is grey, with prominent white feldspar crystals and rust-coloured quartz crystals up to 5 mm. The bands, which are 5 to 20 mm thick, are uniform and planar, but with diffuse boundaries. They are best seen on weathered surfaces (Plate 9) where harder bands form upstanding ribs. In fresh exposures, compositional variation related to the ribs is unclear, but the harder bands are sometimes a slightly darker grey.

Banded lava, or uniform grey porphyritic rhyolite lava, crops out over a wide area around Nei Lak Shan, and is occasionally interbedded with thin tuffite and siltstone layers. Typical lava occurs on the hills south of Ngong Ping, northwest and northeast of Nei Lak Shan. Overall, banding is subhorizontal, albeit with local variations. For example, on the summit of Nei Lak Shan (0888 1384) and 500m southsoutheast, the lava displays roughly horizontal banding. Further south (0911 1307), it may dip up to 30° to the northwest, and between 400 and 500 m southwest of the summit, it dips 18° to the southwest.

West of Nei Lak Shan, the succession is pervasively altered and metamorphosed, but primary banding in the lavas is often preserved. Contorted, or folded banding is well displayed near the crematorium (Plate 10, 0781 1324) east of Ngong Ping. There, across a distance of 50 m, the dip of the banding varies from 67° to the south, to 61° to the north. This folding is interpreted as primary, resulting from flow irregularities during emplacement of the lava, and not due to post-consolidation tectonic processes.

About 1 km north of Nei Lak Shan, there is a zone of autobrecciation in the rhyolite lava which lies stratigraphically below an impersistent pyroclastic breccia (Plate 11). The autobrecciated lava (0898 1474) has a pitted weathering surface on corestones, and occurs with evenly-banded lava and finely-banded lava. The banded lava (0925 1494) crops out below the autobrecciated zone, and has feldspar crystals up to 8 mm in length, and bands less than 10 mm wide.

Sham Shek Tsuen. Exposures of banded lava occur in a stream (0718 1518) about 80 m from the faulted contact with Carboniferous strata. The banding dips 50-60° to the southeast, close to the subvertical reverse fault. Adjacent to a narrow tuffaceous bed, there are exposures of a contorted and autobrecciated, finely-laminated lava, containing blocks up to 0.6 m across. Planar and folded flow-laminae in the rhyolite lava are less than 1 mm thick, and fissures perpendicular to this flow-banding pervade the rock. Overall, these features indicate a much more viscous lava than the coarsely porphyritic, planar-banded lavas at the type area on Nei Lak Shan.

Tai O. Lavas exposed along the south of Tai O contain lithic fragments up to 20 mm, but lack the characteristic banding of the formation. However, the presence of glomeroporphyritic crystal aggregates and shattered, but only slightly disaggregated crystals, set in an originally vitric matrix, suggest an effusive, rather than a pyroclastic, origin. The lithic fragments in the lava near the jetty (0289 1271) on west Tai O are of black, aphanitic lava, which resembles the vitric matrix to the phenocrysts.

Southwest Lantau Island. South of the summit (0335 0900) of Tai Hom Shan, small exposures of finely banded, locally autobrecciated lava lie stratigraphically above a tuffite and tuffaceous siltstone member. Brecciated rhyolite lava, also appears overlie a fossiliferous mudstone bed on the ridge (0273 0816) southwest of Sham Hang Lek, although the contact is not exposed. The breccia is interpreted as autobreccia formed at the base of a rhyolite lava flow, which is uniform and coarsely porphyritic elsewhere in the area. North of Sham Hang Lek (0313 0890), fine banding in lava dips southwest at 18°.

Cheung Shan. At Cheung Shan (0530 1345), fine banding, 10-50 mm wide, is well developed in lava. The banding undulates gently, but generally dips 20 to 50° to the south. About 300 m to the east, on the summit of Cheung Shan, relict banding dips steeply to the southeast, and on Fan Shui Au, banded rhyolite lava dips consistently to the south at 50° to 80°. Below the Pak Kok Member, along the coast north of Pak Kok, banding in lavas is again well developed. It strikes roughly eastnortheast and dips variably 18 to 82°, but folds and angular unconformities also occur locally (0586 0886).

Shek Pik. On the east coast (0753 0868) of Tung Wan, a finely banded, flow-folded rhyolite lava, about 5 m thick, and dipping steeply south, occurs within a sequence of uniform porphyritic rhyolite lavas. To the south, the lava

Plate 7 - Lapilli-Ash Crystal Tuff with Scarce Lithic Lapilli (1952 2047), in the Shek Lung Kung Member of the Shing Mun Formation, West of Yam O

Plate 8 - Banded Rhyolite Lava (1464 1628) in the Lantau Formation, with Differential Weathering Emphasising the Banding, South of Pak Mong

Plate 9 - Banded Rhyolite Lava (0895 1364) within the Lantau Formation, Highlighting the Laterally Continuous and Parallel Banding, Nei Lak Shan

Plate 10 - Complex Ptygmatic Flow Folding in Banded Rhyolitic Lava (0896 1404), within the Lantau Formation, Nei Lak Shan

Plate 11 - Pyroclastic Breccia (0869 1399), within the Lantau Formation, North of Nei Lak Shan

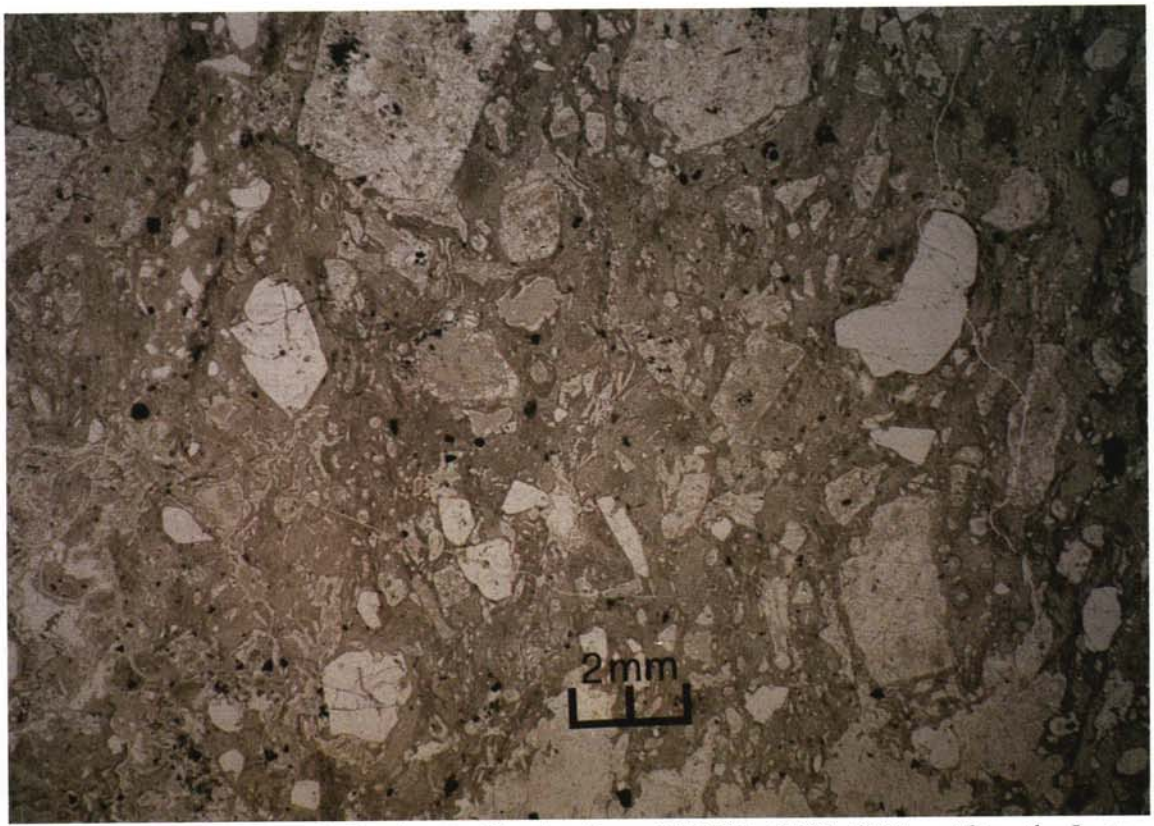


Plate 12 - Thin Section of Porphyritic Rhyolite Lava (HK9292) (0908 1339), within the Lantau Formation, Nei Lak Shan; PPL

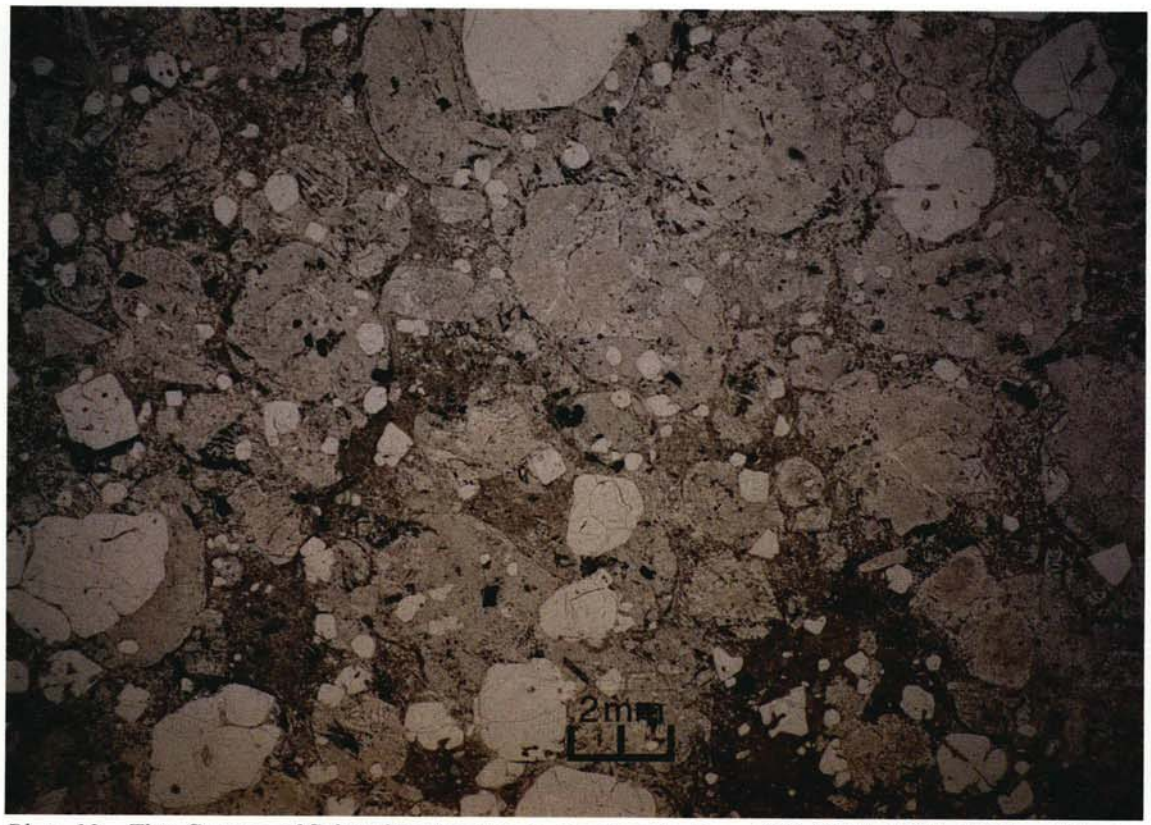


Plate 13 - Thin Section of Spherulitic Texture in Porphyritic Lava (HK 9222) (0809 1459), within the Lantau Formation, from Nei Lak Shan; XPL

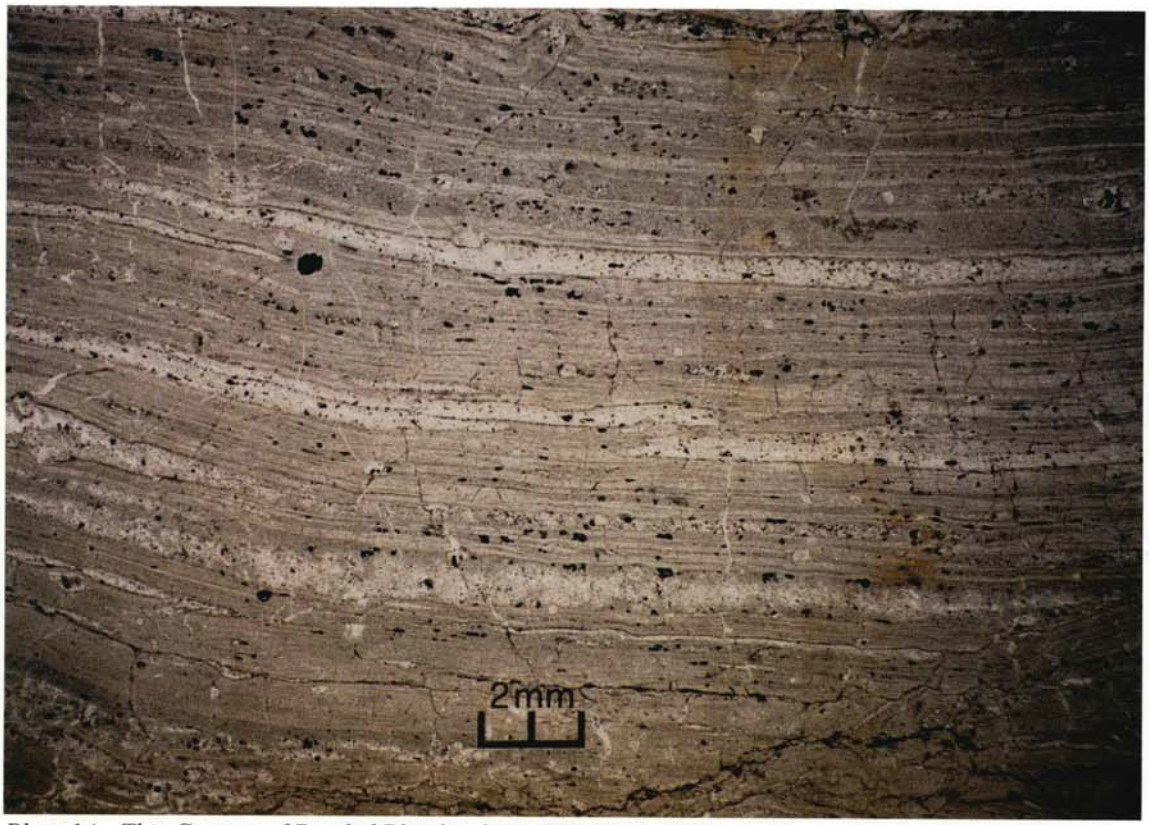


Plate 14 - Thin Section of Banded Rhyolite lava (HK 9223) (0735 1467), within the Lantau Formation, from near Sham Shek Tsuen; XPL

appears fragmental, and contains mudstone partings. This suggests autobrecciation at the base of a lava flow, and incorporation of rip-up clasts during emplacement. Banding in lava on the Tai O Road (06021163), near Kung Shan, dips 54° southeast, and on the Kung Shan Road (0692 1035) near Shek Pik dam, it dips from 17° northwest to 18° southwest.

Lantau Peak (Fung Wong Shan). Well-banded lavas dip 73 to 78° south on a knoll (0947 1150) about 850 m south of Lantau Peak . They also crop out on the ridge (1254 1148) extending to the west, with steep dips to the north and south. Corestones on a ridge north of Tong Fuk display well-developed planar banding in porphyritic rhyolite lava. The bands vary from 1 to 5 cm in thickness, and form thin, upstanding ribs on weathered surfaces. At this locality the banding dips 35° north, whereas to the north and south along the ridge-line, the dip can be as steep as 74°. Banded lavas are exposed in cut slopes along the road leading to Ma Po Ping Prison. At one locality (1046 1016) the banding dips 43° southeast in highly weathered porphyritic lava.

Sunset Peak (Tai Tung Shan). Banding in corestones of lava on the lower southeastern flanks of Sunset Peak dips 57° to the southeast. The prominent eastnortheast-trending features traversing the hillside probably reflect bedding in the underlying sequence of banded lava, lava and sedimentary rocks. To the southeast of Lin Fa Shan (158 136), steeply dipping banding in corestones and boulders strikes east. 2 km along the ridge (119 146) which trends northwest from Sunset Peak, the banding dips steeply to the eastnortheast. On a small hill top (1487 1508) about 900 m north of Lin Fa Shan, weathered surfaces of lava boulders display banding up to 0.1 m thick. Roadside exposures (1161 1386) of weathered lava on the Tung Chung Road, near the Country Park Management Centre, display well-developed planar banding which dips 37° east. Banded lava, dipping 40 to 50° northeast, is also exposed between 100 and 400 m west of the Tung Chung Road at Pak Kung Au.

Por Kai Shan. Banded lava and lava are exposed on the summit of Por Kai Shan, and on the ridges to the south and west. On the south side of the hill (1394 1626), the light grey lava is autobrecciated and grades into a tuffaceous breccia. The relationship between the banded and brecciated lavas is uncertain because of the steep, but variable dip of the strata and the rarity of exposed contacts. However, the breccias are probably autobreccias, formed at the tops, bases and fronts of successive, banded lava flows. On Por Kai Shan (1398 1633), the weathered porphyritic lava has pronounced, steeply inclined banding which dips at 60 to 90°, and generally strikes northwest. Banding, which dips approximately 50 to 60° to the north, is also well developed on a ridge (147 163) 700 m east of Por Kai Shan. About 1 km south (140 154) of Por Kai Shan, lava displays fine banding, about 5 mm thick, which dips about 60° south, and banding is also well developed at several localities between 400 and 800 m east of Pok To Yan, where it and varies from roughly horizontal, to a dip of 53° to the north.

Petrography

Typical porphyritic rhyolite lava from Nei Lak Shan (HK9292, 0908, 1339) is light grey with a pronounced banding, and contains prominent quartz phenocrysts up to 7 mm across. In thin section, the partially recrystallized vitric matrix displays a wavy flow-fabric (Plate 12). The perthitic alkali feldspar phenocrysts, which are generally up to 5 mm across, but range up to 25 mm in length, are commonly shattered. The quartz phenocrysts are mostly subhedral and embayed, but can be either broken or euhedral. The lavas can also contain a few well-developed glomeroporphyritic or bipyramidal quartz crystals around 1 to 2 mm across. Grey corestones of porphyritic rhyolite lava from Nei Lak Shan (0809 1459) show a pronounced spherulitic texture in thin section (Plate 13, HK9222). The spherulites are both compound and simple, and range up to 3 mm across. They are composed of a recrystallized quartz-sericite microcrystalline aggregate, and contrast with the more sericitized matrix of devitrified and recrystallized glass. Plagioclase is commonly glomeroporphyritic, and in hand specimen can be up to 7 mm in length. Quartz crystals, ranging from subhedral to euhedral in form, can be up to 3 mm. There is a relatively minor alkali feldspar phenocryst content, and the rock composition may tend towards rhyodacite.

Grey to light grey corestones of brecciated, flow-banded rhyolite lava crop out near Sham Shek Tsuen. In thin section (Plate 14, HK9223, 0735 1467)), banding ranges from 1 mm to less than 0.1 mm thick, and is characterized by slight grain size changes in the microcrystalline quartz-sericite matrix, and localized concentration of opaque mineral grains. The magnetic susceptibility of the rock is very high (1.2×10^{-3} cgs units), indicating that magnetite is the dominant opaque mineral. There are very few phenocrysts in the matrix, although there are a few euhedral oligoclase crystals up to 0.5 mm long.

Volcanic Environment

Euhedral crystals, and crystals that have shattered *in situ*, indicate a fluid medium (lava), whereas the larger broken crystals are consistent with a fragmental origin (pyroclastic). Branney & Kokelaar (1992) argue that there is a continuum from fountain-fed lava flows to lava-like ignimbrite. They propose that there is a transition during emplacement of ignimbrites, from particulate to non-particulate flow. This could account for the presence of both lava-like and typical ignimbrite textures in the Lantau Formation. Hence, as parts of the formation display textures indistinguishable from lavas, they can be referred to as such. Alternatively, the banded lithologies could be interpreted as high-grade ignimbrites, displaying complex lithofacies changes in individual flow units from autobrecciated through to dominantly pyroclastic textures. Flow units can be inferred by interpreting intercalated sedimentary and tuffaceous rocks as having formed during periods of relative volcanic quiescence.

The volcanic environment varied from high temperature lava fountains, possibly extruding the molten rock in pulses, to slightly lower temperature ash columns that collapsed and coalesced close to the vent, forming welded flows. Quiescent phases between the eruptions were sometimes long enough for sediments to be deposited. The abundant flora in some of these intercalations points to swampy basins on the flanks of the volcanic edifice. Mass flows, including primary lahars, and involving redeposited tuffaceous material, was probably common on the sides of the volcano and caused rapid filling of small basins and hollows.

Sedimentary and Tuffaceous Rocks

Details

Nei Lak Shan. Tuffaceous sandstone and tuffite form an erosion-resistant feature on the northern slopes of Nei Lak Shan. The member also includes porphyritic rhyolite lava, with well-developed banding, and fine ash crystal tuff, and lies above a thin pyroclastic breccia. The tuffaceous member is less than 70 m thick, and appears to be laterally impersistent. The pyroclastic breccia may be as little as 10 m thick, but has not been traced laterally.

Ngong Ping. The prominent ridges west of Ngong Ping are primarily composed of tuffite, but are locally interbedded with fossiliferous mudstone. Tuffite, tuffaceous siltstone, sandstone and rare mudstones were temporarily exposed along the Ngong Ping Road. Close to the Tai O Road (0698 1194), two 0.1 to 0.5 m thick, subhorizontal ash bands can be seen in a cut slope, separated by 5 m of tuffite.

The ridge, about 400 m southwest of the statue of the Buddha, is composed of light grey siltstone and tuffaceous siltstone. Bedding is only locally displayed. The member dips southwest at 11 to 40°, and is probably less than 50 m thick. It thins rapidly to both north and southeast. Nau & Wu (1991) recorded at least 20 m of sandstone, siltstone and mudstone, in part tuffaceous, dipping east to southeast at 17 to 23° (0802 1254), and containing some well-preserved plant fossils. These beds were also noted by Lee *et al.* (1990).

Sham Wat. Close to the weir (0655 1327) at the start of the catchwater, a sequence, dipping 10° south, comprises grey, finely laminated, cherty tuffaceous siltstone and mudstone, and contains fining-upward, graded units, 1 to 4 mm thick. About 300 m to the northwest (0654 1349), close to the Sham Wat Road, finely laminated mudstone comprising graded units, 0.5 to 3 mm thick (HK 9216), is overlain by a massive, light grey, cherty tuffaceous siltstone. Bedding dips 24° to the south, varying nearby to 28° to the north. Some of the rocks are brecciated (0629 1389), but sedimentary laminae, dipping at up to 44°, can still be discerned.

On the hillside east of Sham Wat, a tuffite unit, less than 50 m thick, lies below autobrecciated rhyolite lava. It typically comprises grey, porcellanous, tuffaceous siltstone, but varies from tuffaceous sandstone to vitric tuff.

Cheung Shan. Sedimentary rocks crop out extensively south of the summit of Cheung Shan. Near the summit (0587 1341), finely laminated siltstone dips south at 12°. Most exposures nearby are greenish-grey or light grey, bedded or finely laminated, typically cherty, and vary from mudstone to tuffaceous sandstone. Approximately 400 m south of the summit (0559 1305) fragments of mudstone, up to 50 mm long, are embedded in a tuffaceous matrix. This intraclast texture was probably formed by debris flow or slumping.

Man Cheung Po. Fossiliferous siltstone has been excavated in pits and trenches at the campsite (0428 1018). The rock is typically weathered to a brownish-white colour, and contains small fern-like leaf impressions. Nearby

exposures in the stream bed consist of tuffaceous siltstone and mudstone. Bedding is sometimes well-developed. Dips range from 8° northeast to 33° southeast.

Subhorizontal bedding of the sediments is well displayed about 1 km northwest of Man Cheung Po monastery. Laminated cherty siltstone, with laminae ranging from 2 to 20 mm in thickness, dips 16° to the east, and lies below adjacent exposures of lava (0390 1084). A small outlier of lava (039 107) crops out to the south of these siltstones, and the contact between the two forms a clear feature on the hills to the east, where finely laminated siltstones dip variously from 15° west to 12° east.

A small, disused quarry (0466 1094) on the track north of the ornamental pond at Lung Tsai Ng Yuen contains well-laminated, interbedded grey mudstone and tuffaceous siltstone, with abundant plant remains in the finer lithologies (Lee *et al.*, 1990; Nau & Wu, 1991). The strata dip up to 21° to the northeast, but are more typically horizontal in the area. For example, in a stream bed to the north (Plate 15, 0460 1128), the dark grey tuffaceous mudstone and sandstone are interlaminated in a subhorizontal to gently northwesterly-dipping sequence. The tuffaceous mudstone, siltstone and sandstone member that crops out north of Lung Tsai Ng Yuen is up to 140 m thick, but cannot be traced laterally for more than 500 m.

Keung Shan. About 500 m northeast of the summit, well-bedded tuffaceous conglomerate, sandstone and siltstone dip variably from 43° west to 55° south. It is not possible to correlate this sequence with adjacent units. However, lithological similarity to the Pak Kok Member, exposed on the hillside below and on Kwun Yam Shan, suggest that it is an outlier of the member.

Tai Hom Shan. Between 200 and 400 m south to southwest of the summit, a member of well-bedded mudstone, siltstone and poorly bedded tuffaceous siltstone and sandstone dips consistently to the southeast. Bedding surfaces exposed on the hillside dip between 23 and 45°, giving an estimated thickness of 40 to 50 m for the member.

Sham Hang Lek. The sedimentary member north of Sham Hang Lek is interpreted as the southwesterly extension of outcrops seen around Man Cheung Po. However, the member appears to thin rapidly further southwest, and on the northern ridge of Sham Hang Lek (025 087), it is probably only 20 m thick. Southwest of Sham Hang Lek, there are exposures of siltstone, mudstone and tuffaceous sandstone. In one locality (0273 0818), there are the preserved remains of mostly reed-like plant stems, up to 100 mm long. The strata are well bedded and dip to the southeast. They overlie a porphyritic rhyolite lava. Bedding planes, dipping at about 35°, are exposed on the hillside to the south.

Towards Fan Lau Teng, the sedimentary member has an extensive outcrop, being up to 500 m wide and over 2 km long. The commonest rock type is a grey, finely laminated cherty siltstone, but there are also exposures of poorly bedded siltstone and tuffaceous sandstone. The strata dip generally southeast to eastsoutheast, roughly parallel to the hillside. Dips range from 10 to 60°, but average about 25°, giving a thickness for the member of about 100 m.

Lantau Peak (Fung Wong Shan). A subhorizontal member forms a hard, erosion-resistant feature on both the east and west side of the peak. On the east side of the summit (1016 1224) there are exposures of pebbly tuffite, containing cherty lithic clasts up to 30 mm in diameter, and smaller pebbles of porphyritic lava. About 60 m downslope to the east, there are exposures of pyroclastic breccia, with abundant blocks of tuff, whereas higher up the slope, the unit includes tuffaceous sandstone. Similar exposures on the steep, westerly-facing slopes of Lantau Peak include pebbly tuffite dipping 27° southwest.

Sunset Peak (Tai Tung Shan). The outcrop consists of brownish-grey, fossiliferous siltstone interbedded with dark grey mudstone, and tuffaceous sandstone. The siltstone, exposed near the swimming pool (1394 1310), contains abundant plant remains, most of which are reed-like stems. Dip variation of 38° north to 74° southeast is related to an eastnortheast-trending fault with a southerly downthrow, exposed at the west end of the pool. Near one cottage (1432 1335) east of the summit, tuffaceous, laminated siltstone dips southwards at 20°. A small reverse fault has thrust the adjacent lavas to the east over the siltstone.

A black to grey tuffaceous mudstone member is exposed on a footpath (1368 1355) on the north side of Sunset Peak. The rocks are well laminated, with dark grey mudstone and lighter tuffitic laminae between 10 and 20 mm thick. Load structures in tuffite overlying the mudstone indicate that the strata are not inverted. Both the mudstone and tuffite contain subangular to subrounded, pebble-like clasts between 2 and 15 mm across. The member dips northwest at 65°, and is thin and impersistent.

Several thin siltstone and tuffite members, some of which persist laterally for more than 2 km, are exposed along the southern flanks of Sunset Peak. The best exposed occurs along and adjacent to the footpath that traverses the hillside at about 350 mPD. Lava is in contact with underlying black cherty mudstone at one locality (1382 1237),

and 500 m to the east (1434 1246) a well-laminated, grey to dark grey mudstone lies close to light green tuffaceous sandstone. On a small-scale, emplacement of the tuffite disturbed the underlying mudstone. Hence, the strata, which typically dip 55° to the north, are the right way up.

Kau Nga Ling. Largely tuffaceous and often finely laminated metasedimentary rocks, are extensively exposed on the southwestern flanks and ridges of Kau Nga Ling. They form erosion-resistant features, but dips measured at outcrop are variable and steep, and do not correlate well with the outcrop pattern.

Shek Lam Chau. There are good coastal exposures of a sedimentary and tuffaceous member west of the the main syenite outcrop. The rocks include pebbly conglomerate, sandstone and siltstone. A cliff (0778 0837) exposing this succession displays: a channel-form, laminated mudstone and siltstone with plant remains; beds of lava; and conglomerate with clasts up to 80 mm in diameter. The strata dip 37 to 42° to the northwest, and are overlain by rhyolite lavas. Although the contact is not seen, intercalation of conglomerate and finely porphyritic rhyolite lava (0798 0822) indicates that it is probably transitional.

Pok To Yan. East of the summit of Pok To Yan, a feature-forming tuffaceous member extends south along the hillside for at least 750 m. The member dips to the east at up to 36°, and comprises well-bedded tuffaceous sandstone and finely laminated siltstone. Its maximum thickness is about 60 m, but it appears to thin rapidly to the north. Exposures to the east (1418 1593) comprise grey to light or reddish-grey, interlaminated mudstone and tuffaceous sandstone. These display load structures indicating that the strata, dipping 17° southeast, are the right way up. This tuffaceous member, which is possibly up to 80 m thick, can only be traced laterally for about 500 m.

Por Kai Shan. The rocks forming Por Kai Shan are generally metamorphosed, with original textures masked or obscured. However, on the northwest flanks of the hill (136 165), there are exposures of tuffaceous conglomerate, sandstone and mudstone, together with banded lava. This sequence is about 150 m thick, and dips 35° to the east and southeast. It forms part of a prominent spur as it is more erosion-resistant than the adjacent lavas. Uniform banded lavas directly underlie this tuffaceous unit, and it is overlain by what is probably the autobrecciated base of a lava.

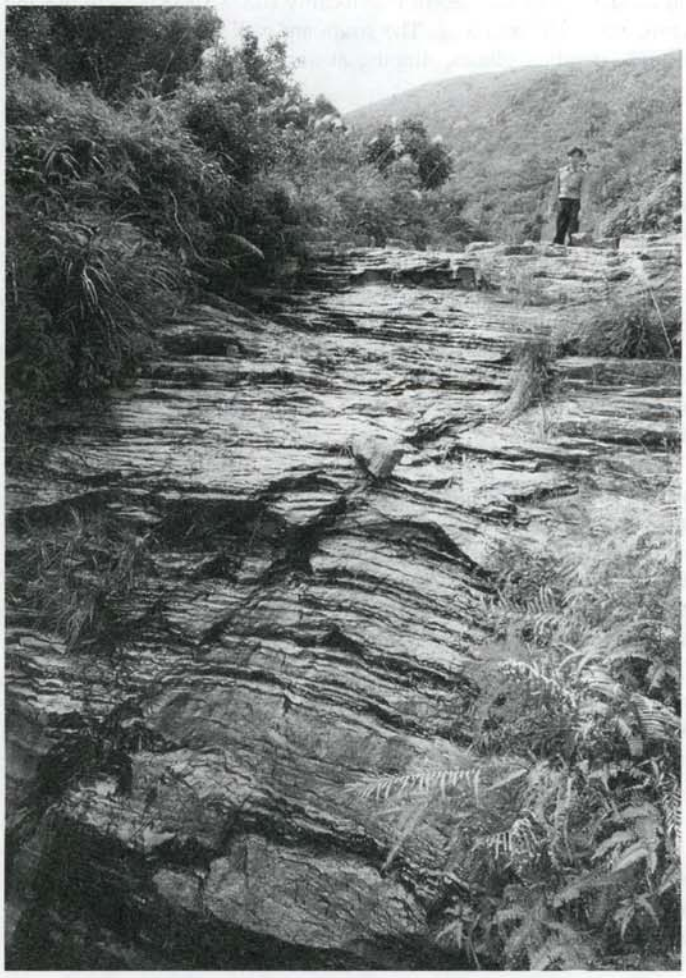


Plate 15 - Finely-Laminated, Gently Dipping Tuffaceous Mudstones and Sandstones (0460 1128), within the Lantau Formation, Northnortheast of Man Cheung Po

Lin Fa Shan. The steep eastern flanks of Lin Fa Shan are composed of alternating rhyolite lava flows and beds of tuffaceous sandstone, or siltstone. The sedimentary rocks form cliffs, most of which are inaccessible. However, on the west side of the hill, extensive exposures of the highest beds include massive, or poorly bedded, tuffaceous sandstone and scarce, finely laminated mudstone. Sandstone and siltstone beds, 200 m west of the summit (1482 1420), dip to the north at 34°, and graded units indicate they are the right way up. West of the summit, the beds generally dip steeply to the east or northeast, and may form part of a syncline whose axial plane trace trends northwards along the ridge. The ridge is capped in places by lapilli-ash tuff of the Sunset Peak Member, but their stratigraphic relationship to underlying strata is uncertain.

Sedimentary Environment

The restricted geometry of the sedimentary rocks, and the rapid gradational changes, suggests that they accumulated in small basins filled during flash floods, and by debris flow mechanisms. During more quiescent periods, silts were deposited. The pronounced grading in many of the siltstones, best seen on a microscopic scale, may have resulted from seasonal changes, or localized rainstorms on the flanks of a poorly consolidated volcanic pile. The large tuffaceous units have some mass flow characteristics, and the volcano on which these basins developed probably degraded rapidly between pyroclastic and extrusive phases. The flora, containing bennettitaleans and ferns suggest a warm, wet palaeoclimate (Zhou Z.Y., Nanjing Institute of Geology and Palaeontology, written communication, 28 May 1992).

Palaeontological and Other Age Constraints

During the present survey, fossil plants have been found at five localities within the Lantau Formation; Man Cheung Po, Lung Tsai Ng Yuen, Sham Hang Lek, Shek Lam Chau and Sunset Peak. Fossils have also been found by Lee *et al.* (1990), and Nau & Wu (1991) near Ngong Ping. Macrofossil preservation at Sham Hang Lek and Shek Lam Chau is relatively poor, as is the preservation of all miospores.

Davis (1952) recorded dark bluish-grey mudstone with fossil leaf specimens in outcrops east of Sunset Peak. These fossils were tentatively identified as *Equisetites*, *Pterophyllum*, and *Podozanites lanceolatus*, and the outcrop was thought to be part of the Jurassic Hsiaoping Series found northwest of Guangzhou. Edwards (in Lee *et al.* 1990) stated that these fossils ranged from Middle Jurassic to Early Cretaceous. Lee *et al.* (1990) examined fossil plants collected from Ngong Ping and Lung Tsai Ng Yuen, and concluded that the strata probably correlate with the Gaojiping Formation of Guangdong, although they preferred an Early Cretaceous age for the flora, as opposed to the conventionally accepted Middle to Late Jurassic age of the Gaojiping Formation. They did not, however, distinguish their flora with respect to the different geographical areas of Hong Kong, and it should be noted that only one of the plants (*Scleropteris tibetica*) used for age determination is present on Lantau Island.

Nau & Wu (1991) looked at flora from Ngong Ping and Lung Tsai Ng Yuen on Lantau Island, as well as from Cheung Sheung in the east of the New Territories. They concluded that the Lantau specimens are older than the Upper Jurassic Cheung Sheung rocks, and could be late Early to early Middle Jurassic, emphasising in particular the presence of *Coniopteris burejensis*, *Ptilophyllum pecten* and *Otozamites graphicus* as indicators of this age.

Nanjing Institute of Geology and Palaeontology have reappraised (Appendix 3) the plant fossils collected on Lantau Island by P. S. Nau (Hong Kong University), and specimens collected during the present survey, and conclude that only two fossils, *Otozamites yizhangensis* Zhang and ?*Thinnfeldia sinensis* Zhang, are of stratigraphic significance. Zhou Z.Y. (Nanjing Institute, written communication, 28 May 1992) stated that *Otozamites yizhangensis* was originally described from the basal Liassic (Hettangian to Sinemurian) strata of southern Hunan (Kindianmen Formation), and that *Thinnfeldia sinensis* has also been found in southern Hunan. Zhou concluded that this plant assemblage is of early Early Jurassic age.

Two samples from Lantau Peak, analysed for miospores by Qin G.R. (Institute of Geological Sciences of Guangdong Province, written communication, 28 August 1990) (Appendix 3), produced varied miospore populations. Sample HK9329 (1032 1224) is a grey, poorly laminated, slightly tuffaceous mudstone from an exposure on the footpath about 1 km east of Lantau Peak. Qin has reported that several species obtained from this sample also occur in Mesozoic flora in South China, and that the dominance of *Classopollis annulatus* and *Psophosphaera minor* indicates a Late Jurassic age. A sample (HK 9314, 0927 1086) of grey, finely laminated mudstone from Kau Nga Ling, about 1.5 km south of Lantau Peak, had insufficient diagnostic miospore species to constrain it to anything other than the Jurassic.

The age of these sedimentary rocks has also been constrained by isotopic dating of quartz syenite intrusions, at Tong Fuk and Fan Lau, which clearly cross-cut the Lantau Formation. Hence, the minimum age of the sedimentary rocks is c.145 my (early Late Jurassic; see Darbyshire, 1993). The Early Cretaceous age proposed by Lee *et al.* (1990) appears, therefore, to be too young, and even the Late Jurassic age suggested by Qin (written communication, 28 August 1990) may be too young. Other palaeontological ages discussed above are equivocal, but a late Middle to early Late Jurassic age is not inconsistent with available field evidence.

Cheung Shan Member

The Cheung Shan Member is defined for the first time in this memoir. It is the basal, eutaxitic member of the Lantau Formation, and its type locality is on Cheung Shan in west Lantau Island, where it is about 500 m thick. The member is locally unconformably overlain by rhyolite lavas of the upper part of the Lantau Formation. Its contact with Carboniferous strata to the northwest is a high-angle reverse fault .

In the hills south of Tai O, the member is about 150 m thick. It is succeeded by siltstone and lava, and overlies tuff of the Shing Mun Formation. Eutaxite, interpreted as part of the same basal member, is also exposed at Cheung Sha between tuffs below, and rhyolite lava above; there the member is about 200 m thick. Farther west, the wispy fiamme, which are generally less than 20 mm long, are distinctive. The eutaxite is greyish-white to light red and yellow, with relict quartz crystals up to 2 mm across. Fresh exposures of eutaxite are only seen in south Lantau Island, where the rock is a grey, or light grey, crystal-bearing vitric tuff. Thin, wispy fiamme, ranging from 1 to 20 mm in length, are visible on weathered surfaces.

Details

Cheung Shan. West of the summit of Cheung Shan, there are exposures of lithic lapilli-bearing tuff and eutaxite. The eutaxite is the main component of this pyroclastic member. The eutaxitic fabric is well preserved even though some exposures display a well-developed platy foliation in addition to alteration of feldspars and matrix. Exposures (0535 1390) on a knoll northwest of Cheung Shan consist of greyish-white eutaxite, weathering red and yellow, with abundant relict, wispy fiamme up to 10 mm wide and 40 mm long, and relict quartz crystals up to 2 mm across. Nearby exposures (0555 1370) of tuff contain small, pebble-like lithic lapilli set in a vitric matrix.

Sham Wat. On the southeast side of Sham Wat Wan, the contact between Carboniferous siltstone to the north and tuff to the south is well exposed. The tuff is light grey, but reddish in parts, with quartz crystals, mostly less than 2 mm across, but ranging up to 8 mm. As well as abundant relict fiamme, there are scarce, siliceous, pebble-like lapilli. These can be up to 200 mm long and are composed of porphyritic rhyolite with strongly aligned pseudomorphs after feldspar and mafic crystals. Unlike the typical eutaxite of this member, these rocks are characterized by large fiamme. The flattened fiamme dip to the southwest at 18°, contrasting with the steep, easterly dip of the Carboniferous strata. The contact with the Carboniferous is a near-vertical fault, trending northeast-southwest.

San Chau. On the ridge and headland west of San Chau, the structural association of the eutaxite and Carboniferous strata is complex. A knoll (0489 1417) south of the contact, consists of light grey, finely foliated eutaxite which weathers to red and yellow. The rock only occurs as boulders from which it is not possible to measure the dip of the primary pyroclastic fabric. To the north, there is an isolated outcrop (048 144) of eutaxite which is interpreted as being in faulted contact with Carboniferous strata on both sides. A streaky eutaxitic fabric,

dipping northwest at 46°, is present in a deeply weathered tuff in exposures (0480 1380) near the footpath to Tai O.

Tai O. Eutaxite boulders are common in debris deposits on the hills east of Tai O, together with less common boulders of vitric tuff and quartzitic sandstone. Exposures (0448 1340) of highly weathered vitric tuff can be seen above Tai O cemetery. The weathered rock is white and contains small, broken to euhedral quartz crystals. Nearby, there are boulders of eutaxite which are more typical of the member.

At San Tsuen, south of Tai O, a north-trending ridge is composed of quartz ash-bearing tuff with a fine fabric of relict fiamme. Near the Service Reservoir (0447 0396), the relict fiamme dip westsouthwest at 38°. Further west, altered and mylonitized tuffs of the Shing Mun Formation are exposed across a northwest-trending fault.

Tsim Fung Shan - Tai Hom Shan. The member forms a narrow, laterally discontinuous outcrop which extends from Tsim Fung Shan (041 114), south through Nga Ying Sham, Shui Lo Cho and Man Cheung Po, to Tai Hom Shan (033 093). Most of the exposures on the northwest flanks of Tsim Fung Shan consist of crystal ash-bearing vitric tuff. At several localities, well-developed eutaxitic fiamme, 10 to 30 mm long, are preserved in the tuff. No clear base to the member has been defined, although tuff and tuffaceous sandstone to the west are probably part of the Shing Mun Formation. The member is overlain by lavas, tuffaceous sandstones and tuffites of the Lantau Formation (undivided). West of Man Cheung Po, the member crops out below a fossiliferous siltstone sequence. The eutaxitic fabric is occasionally visible in the quartz and feldspar vitric tuffs. The pyroclasts are generally less than 2 mm across.

Southwest of Man Cheung Po, towards Tai Hom Shan, a faint streaky fabric is often visible, although its orientation is rarely clear. The relict fiamme are, atypically for the member, generally less than 20 mm long, and the euhedral to subhedral quartz crystals rarely exceed 2 mm. The member lies below siltstone of the Lantau Formation, and above lapilli-ash tuff of the Shing Mun Formation. However, neither contact is exposed, and the stratigraphic relationships can only be inferred.

Cheung Sha. The only unaltered exposures of the member occur in a narrow outcrop in south Lantau Island which dominantly comprises eutaxite, with minor, coarse ash-bearing vitric tuff. The eutaxitic fabric is well displayed in an old quarry (1214 1065) adjacent to the catchwater. White fiamme, which are coarsely porphyritic, and have sharp, ragged edges, dominate the grey tuff. They define a fabric which dips northwards at 70°, and similarly steep, northerly dips also occur at several localities along the Tung Chung Road. Stratigraphically above the eutaxite, the tuffite and lava belong to the Lantau Formation, whereas below, the tuffs are typical of the Shing Mun Formation, but contact relationships have not been seen. East of the Tung Chung Road, the member has not been seen, but to the west, boulders confirm its presence on the hillside above Tong Fuk.

Volcanic Environment.

The dominant eutaxitic welding fabric indicates that the tuff was deposited from a hot, massive ash-flow eruption. Its eruption marked the onset of eruptions from a large magma chamber situated beneath Lantau. Older pyroclastic flow deposits contain a noticeable lithic component, but the eutaxite is essentially monomict, and its fiamme are compositionally related to the ensuing, lava-dominated succession. These early eruptions of the Lantau Formation were followed by a period of quiescence, during which sediments accumulated in local depressions.

Pak Kok Member

The Pak Kok Member is defined for the first time in this memoir. It includes tuffs, tuffites, siltstones and mudstones which crop out in southwest Lantau Island. Whereas most epiclastic, or tuffaceous, horizons in the Lantau Formation are lithologically homogeneous and, or, generally thin, this member is heterogeneous and thick. At its type locality, Pak Kok (065 081) on the southwest coast of Lantau Island, the member is at least 300 m thick, and includes hydrothermally altered, pyroclastic and epiclastic deposits including ash-bearing vitric tuff, pebbly tuffite, and siltstone. The member also crops out at Shek Pik; and between Kwun Yam Shan and Kung Shan, and may also include relatively thin and discontinuous tuffites and siltstones that crop out further northeast, towards Ngong Ping.

Details

Pak Kok. On the east side of the headland (056 082), finely bedded tuffite and tuffaceous siltstone are dominant. They weather to a light greenish-grey and can contain abundant quartz crystals up to 1 mm across. Bedding, which is defined by abrupt variations in the abundance of quartz grains, dips 57° to the southeast. Further south, the tuffite is stratigraphically overlain by quartz crystal ash-bearing tuffs, and underlain to the north, by tuffites, sandstones and siltstones. On the coast west of Pak Kok, the member comprises grey to dark grey, laminated mudstones and siltstones. It is underlain by banded porphyritic lavas, but the overlying sequence has not been preserved.

Kau Ling Chung. Poorly bedded, pebbly tuffaceous sandstone, which is exposed along the footpath (0358 0750) to Fan Lau, dips gently to the southeast. Overlying strata include lithic lapilli-bearing tuff and porphyritic lava, but the upper contact of the member can not be distinguished.

At Kau Ling Chung (041 071), laminated siltstone and tuffaceous sandstone are overlain by rhyolite lava. The sequence is well bedded, dipping 21° to the southeast, and the common laminae are less than 1 mm thick. The siltstone displays small-scale sedimentary structures, including syn-depositional microfaults, flattened sand balls and graded beds. A narrow (<100 mm wide) cross-cutting, sandy tuffaceous body, is interpreted as a tuffisite dyke, intruded before compaction of the sediments. It probably fed a thin ash unit exposed at the base of conformably overlying lava.

The sequence is faulted along a northnorthwest-trending contact with lava to both southwest and northeast. A series of small faults, which downthrow to the southwest, suggest that these exposures may be a faulted continuation of both the type locality of the Pak Kok Member to the northeast, and hillside exposures to the northwest.

Shek Pik. West of Shek Pik dam, siltstone, pebbly tuffite and tuff overlie porphyritic lava. Finely bedded, cherty siltstone which dips to the south at 36° on the road (0659 0965) to the catchwater, is the only indication of the general dip in the area. A distinctive pebbly lithology is exposed along the road south towards the headland, whereas the headland itself is dominated by greenish-white-weathering, crystal lapilli-ash bearing tuff. The quartz crystals are up to 4 mm across, and the rock also contains cherty lithic lapilli up to 80 mm across. Intense alteration obscures original textures, but lithic lapilli indicate that the rock is pyroclastic. The thickness of the known succession, from the basal siltstone through to the tuffs, is probably less than 400 m in this area.

Kung Shan - Kwun Yam Shan. The sequences exposed along the southeastern flanks of Kung Shan, and on Kwun Yan Sham, are readily correlated with that at Shek Pik. These sequences form prominent topographic features. They dip mainly at 20 to 30° to the southeast, but locally, there are pronounced variations. On the southern and eastern flanks of Kung Shan, the member comprises laminated, or poorly bedded, tuffaceous siltstone and pebbly tuffite. It is both stratigraphically overlain and underlain by porphyritic lava.

Around Kwun Yam Shan, the member includes siltstone, tuffite and tuff, and south of the summit (0665 1107), light grey pebbly tuffites, with subrounded lithics up to 10 mm across. A greenish-white, crystal ash-bearing tuff was probably a welded, vitric tuff. On Kwun Yam Shan, the succession from siltstones and tuffites at the base, to tuff at the top, is about 100 m thick. The member has not been recognised to the northeast, but tuffite, siltstone and mudstone east of the Tai O Road may be correlated with it, although the succession is thin, and probably of limited lateral extent. The only area where the upper contact of the member can be mapped, is around Kung Shan, where the member occurs within a lava-dominated succession.

Petrography

Although pebbly tuffite is common, the member is lithologically diverse and is invariably altered. On Kwun Yam Shan (HK9298, 0665 1107), rounded, aphanitic, lithic clasts, up to 5 mm across occur in a matrix of broken quartz crystals which are less than 1 mm across. The devitrified matrix contains microcrystalline quartz and sericite, and all feldspars are altered.

Volcanic Environment

The poor sorting of both the pyroclasts and lithic fragments is typical of a partially reworked pyroclastic deposit. The diverse lithologies, dominated by admixtures of epiclastic and pyroclastic components, were deposited from debris flows and by fluvial aggradation remobilising and reworking partially consolidated pyroclastic and extrusive deposits. The limited lateral extent and thickness of the member suggests that it was deposited in a restricted basin, possibly on the flanks of a volcanic edifice, or in a structurally controlled depression or caldera.

Sunset Peak Member

The Sunset Peak Member is defined for the first time in this memoir. It coincides in part with agglomerate outcrops mapped by Allen & Stephens (1971) on both Sunset Peak (Tai Tung Shan) and Lantau Peak (Fung Wong Shan). The member is almost entirely pyroclastic and dominantly comprises tuff-breccia and lithic lapilli-bearing tuff, but also includes eutaxitic tuff. A notable characteristic is the flattening of clasts, which imparts a planar fabric.

The member only crops out in restricted areas on the highest peaks in east Lantau Island. Its type locality is the summit (1336 1305) of Sunset Peak, where it is about 50 m thick. There is a smaller outcrop on a lower peak to the east, and substantial exposures occur on, and around, Lin Fa Shan, where the member is less than 70 m thick. An isolated outcrop around the summit of Lantau Peak is less than 100 metres thick.

Details

Sunset Peak (Tai Tung Shan). Lapilli-bearing tuff and tuff-breccia form much of the summit of Sunset Peak, the type locality of the member. On the summit (1318 1317), the tuff is poorly banded and includes quartz crystals up to 8 mm, and a few pebble-like lithic lapilli set in a fine ash matrix. Although exposures are mostly exhumed corestones, the banding is generally sub-horizontal. Tuff-breccias near the summit (Plate 16, 1336 1305) are light grey when fresh, and contain clasts of vitric tuff or lava, up to 1 m across, although most clasts are less than 60 mm across. There are also rare volcanic lava bombs, and the matrix consists of crystal-bearing vitric tuff. A eutaxitic vitric tuff occurs locally (1345 1306), and is dark grey, with flat, streaky pumice lapilli which are visible on weathered surfaces. Its dominantly vitric matrix contains a few quartz and feldspar crystals up to 2 mm across. At the base of the member, there are tuffaceous siltstones and mudstones, but their contact with the underlying succession of mainly lava and tuff is not exposed.

East of Sunset Peak, there are exposures (1446 1389) of lithic lapilli-bearing crystal tuff or tuff-breccia., similar to those on both Sunset Peak and Lin Fa Shan. The pock-marked surface of the light, brownish-grey boulders indicates the presence of abundant, rounded lithic clasts. In tuffs (1432 1332) to the west, rounded lapilli of vitric tuff, or lava are up to 30 mm across. The matrix is comprised mainly of coarse ash crystals, and there is an indeterminate layering defined by clast orientation.

Lin Fa Shan. On the summit (1502 1514), light grey, lapilli-ash crystal tuff with a fine ash matrix includes lithic lapilli which weather preferentially, leaving elongate hollows (Plate 17) up to 50 mm long. Fabric in the corestones appears to dip to the east at 40°. Elsewhere on the summit, fabric is poorly developed, but the rock contains angular tuff blocks, up to 300 mm across, which weather preferentially. The slopes to the south are dominated by displaced boulders of elongate lapilli- and block-bearing tuff. The member is underlain by tuffaceous sandstone. Although the contact is not exposed, it may be locally unconformable. The succession is preserved in a synclinal core, whose northerly-trending axial plane passes through the summit.

Lantau Peak (Fung Wong Shan). South of the summit of Lantau Peak (0975 1217), the member comprises a block- and lapilli-bearing vitric tuff. The blocks, which are up to 250 mm across, are set in a dominantly vitric matrix which contains ash crystals. On the eastern ridge of the peak, the block-bearing tuff, or tuff-breccia, contains sub-rounded blocks up to 200 mm across, and on the northwestern ridge (0960 1244), the blocks define a sub-planar surface. In the crystal-bearing vitric matrix, there is also a streaky eutaxitic fabric which dips 45° to the northwest. The member overlies porphyritic rhyolite lava and pebbly tuffite, and is capped on the summit by poorly banded, porphyritic rhyolite lava.

Petrography

The typical block-, and lapilli-bearing tuff has a welded matrix (HK 7886, 1500 1418) that incorporates subhedral to broken crystals. Small quartz crystal aggregates suggest either rheomorphism of the vitric matrix, or a pyroclastic origin from a lava-dominated vent. The matrix of vitric tuff from Sunset Peak (HK 8432, 1337 1328) is vitroclastic and contains abundant, small, strained shards, and some well-defined, broken bubble-shaped shards. There are small, subhedral to euhedral quartz and feldspar crystals, which are generally less than 2 mm across. The feldspar is partially replaced by chlorite and calcite. Typical tuff-breccia from the type locality on Sunset Peak (HK 8435, 1336 1305) is light grey, with clasts up to 1 m across, set in a crystal-rich vitric matrix. Most of the pyroclasts are broken, and in thin section there are

abundant very fine-grained lithic fragments. The rock also displays some secondary alteration to calcite and sericite.

Volcanic Environment

The Sunset Peak Member is a localized, welded pyroclastic flow that formed during a late, relatively quiescent stage in the development of the volcanic pile. The member includes eutaxites deposited from ash flows, but is dominated by tuffs, with cognate lithic fragments, which were erupted from small vents, or fissures. The volcanic pile is complex and has a varied stratigraphy.

Mount Davis Formation

The Mount Davis Formation, which forms part of the Repulse Bay Volcanic Group (Table 3), is defined for the first time in this memoir. It comprises the coarse ash crystal tuff of western Hong Kong Island formerly ascribed to the Tai Mo Shan Formation (Strange & Shaw, 1986). The type locality is Mount Davis, on Hong Kong Island, immediately east of the Lantau district. The formation, which includes eutaxitic tuffs and epiclastic beds, overlies the Ap Lei Chau Formation. There is no stratigraphic overlap between the Mount Davis and Lantau formations. On Sheet 10 (Silver Mine Bay), it was implied that the Lantau Formation is younger than the Mount Davis Formation. Subsequently, however, Rb-Sr age-dating of the Ap Lei Chau and Lantau formations by Darbyshire (1990, 1993) has suggested that the Mount Davis Formation may be younger than the Lantau Formation. Thermally metamorphosed rocks of the Mount Davis Formation are exposed, in the district, on Green Island (Strange & Shaw, 1986) and on Kau Yi Chau to the west.

Details

Kau Yi Chau. Lapilli-ash crystal tuff, with elongate, dark, lithic lapilli, is exposed along the east coast of the island. The lapilli and mafic crystals define a prominent lineation. There may also be small, sharp-edged porphyritic lapilli. Blocks of eutaxite on the beach are probably derived from a higher, but unexposed stratigraphic level within the formation. The eutaxite is black, with abundant crystals of quartz and feldspar up to 5 mm. The fiamme are up to 300 mm by 50 mm, and the rock resembles eutaxite partings in the Tai Mo Shan Formation. The tuffs are cut by quartzphyric and feldsparphyric rhyolite dykes. At the northern end of the beach (2620 1624), there is an easterly-trending contact between lapilli-ash crystal tuff to the south, and a chilled, largely aphanitic dyke to the north.

Plate 16 - Block and Lapilli-bearing Tuff (1436 1305) in the Sunset Peak Member, within the Lantau Formation, Lin Fa Shan

Plate 17 - Careous Weathering in Lapilli-bearing Tuff (1520 1395) from the Sunset Peak Member, within the Lantau Formation, Lin Fa Shan

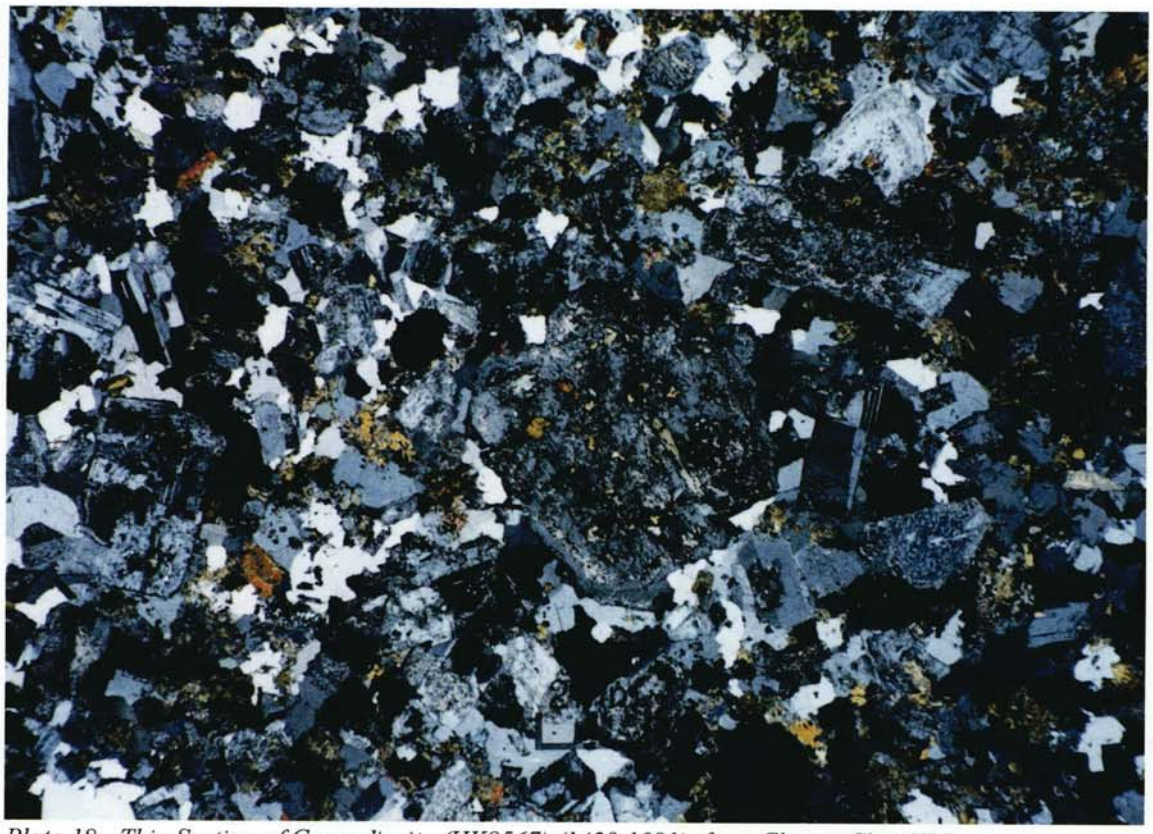


Plate 18 - Thin Section of Granodiorite (HK8567) (1429 1081), from Cheung Sha; XPL

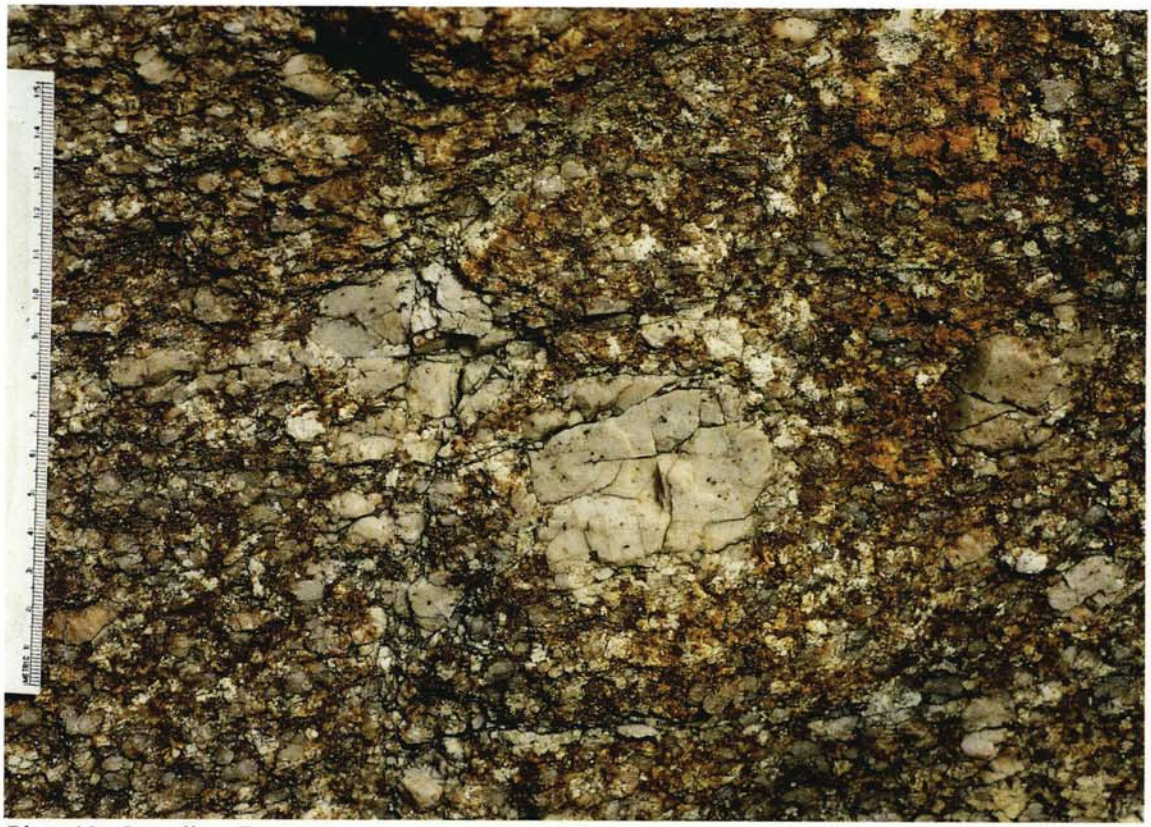


Plate 19 - Lamellar Fracturing in Coarsely Megacrystic Medium-grained Granite (2144 1899), Sz Pak Tsui

Chapter 5
Major Intrusions

Classification

The major intrusions within the district comprise granodiorite, granite and quartz syenite. They have been subdivided, on the basis of texture, into medium , fine to medium, and fine grainsize divisions (after Strange 1984). Megacrystic texture in granite is shown by an overprint on map sheets 9, 13 and 14.

Modal mineral analysis is the primary method of igneous rock classification (Figure 8). Where rocks are too fine for modal determination, they are classified according to bulk rock chemical composition using a total alkali-silica (TAS) diagram. The prefix micro- is used for plutonic rocks that are very fine grained, but not so fine that a volcanic origin is likely.

Whole rock major and trace element analyses have been determined on 95 samples from major intrusions in the district. Representative analytical data are presented in Appendix 2.

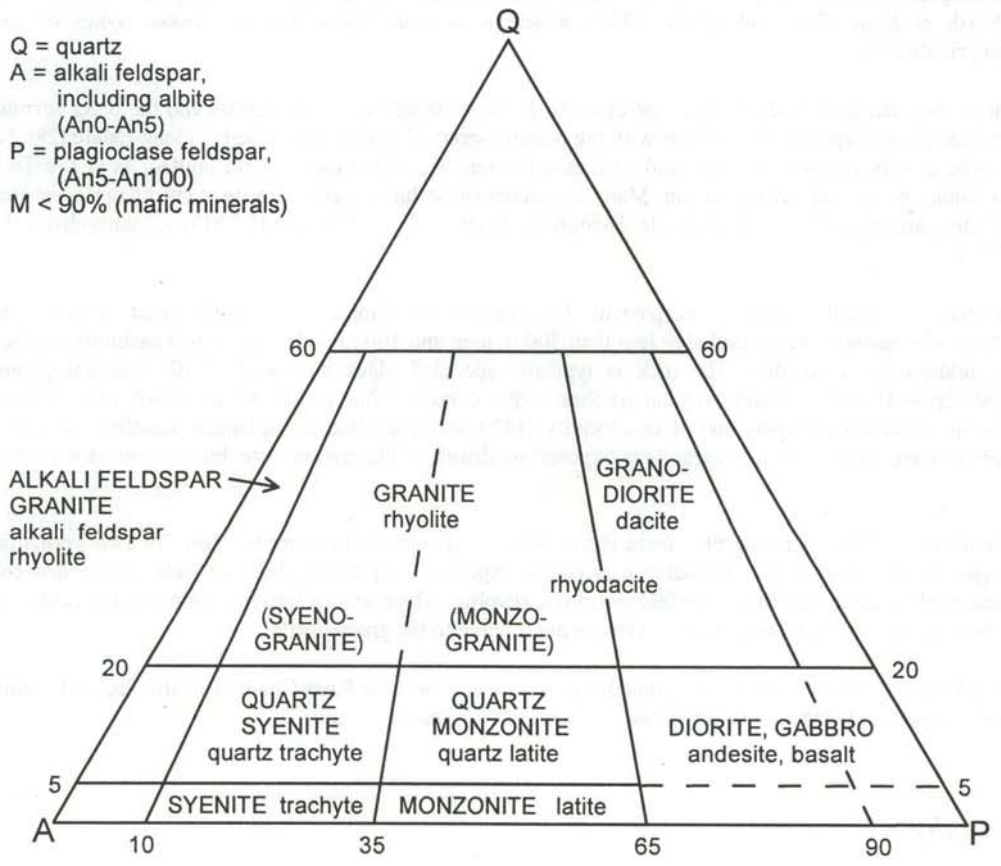


Figure 8 - General Classification and Nomenclature of Major and Minor Intrusive Rocks (after Streckeisen, 1974)

Granodiorite

Distribution and Lithology

Granodiorite crops out within the district on Tsing Yi, and at Cheung Sha in south Lantau Island, and in boreholes offshore of north Lantau Island. Of the two main areas of outcrop on Tsing Yi, the larger is around Lo Uk in the northeast of the island, and the smaller around Kam Chuk Kok in the northwest. There are also small outcrops at Cheung Sha in south Lantau Island, and on Cha Kwo Chau. Exposures are generally very poor, but landform, soil colour and changes in vegetation are often useful field indicators of granodiorite bedrock.

The granodiorite is generally dark grey, and fine to medium grained, with conspicuous pink megacrysts of alkali feldspar and white megacrysts of plagioclase. Plagioclase and quartz are in roughly equal proportions, with abundant clots of black biotite throughout the matrix. The rock is generally texturally uniform and sometimes contains fine-grained melanocratic inclusions.

The granodiorite forms intrusions with many irregularities in their upper surfaces. When weathered, the rock forms a reddish-brown saprolite, usually many metres thick. Granodiorite landforms tend to be smoother as a result of this thick soil cover, which supports a richer vegetation compared with saprolites formed from weathered granite.

Details

Tsing Yi. Granodiorite forms the lower slopes of a small headland at Kam Chuk Kok (2700 2300). It is interpreted as a dome-like body with a gently sloping or flat upper surface overlain by tuffs. The granodiorite is cut by north-trending quartzphyric rhyolite dykes (2701 2304) and easterly-dipping sheets of feldsparphyric rhyolite (2710 2296). North of Kam Chuk Kok (2692 2336), a screen of granodiorite occurs between dykes of coarsely feldsparphyric rhyolite.

The form of the outcrop around Lo Uk is not clear as the contacts between granodiorite and the older surrounding country rocks are not exposed. The contact with the medium-grained granite near Cheung Hong Estate (2802 2347) appears to be steeply inclined, sinuous, and northeasterly-trending. Other contacts are faulted, as at Liu To (2802 2347), or cannot be located with precision. Many exposures show that the granodiorite is cut by northeast-trending dykes of fine-grained granite (2872 2342), feldsparphyric rhyolite (2856 2354, 2845 2345) or quartzphyric rhyolite (2862 2348).

Cheung Sha. Two small outcrops of porphyritic, fine-grained granodiorite occur on the coast south and east of Cheung Sha. The eastern body is probably less than 300 m long and 100 m wide, and trends eastnortheast between dykes of feldsparphyric rhyolite. The rock is typically speckled black and white, with euhedral plagioclase phenocrysts up to 15 mm long and irregular patches of quartz up to 7 mm across, set in an aphanitic groundmass. Xenoliths are relatively common, and at one locality (1429 1081) a siliceous, aphanitic xenolith up to 250 mm across can be seen. Porphyritic microgranite is exposed southwest of the granodiorite, but its contact with the latter is not.

On the beach (136 104) at Cheung Sha, there is a complex exposure of granodiorite, Yim Tin Tsai Formation tuff and younger rhyolite dykes. The granodiorite is poorly exposed, at or below the high-water mark, and contains many small melanocratic xenoliths. The feldsparphyric rhyolite, which grades into microgranite, is presumed to be younger because of the lack of alteration and fracturing relative to the granodiorite.

Cha Kwo Chau. A small exposure of granodiorite is present on Cha Kwo Chau. It is lithologically similar to granodiorite exposed at Cheung Sha and is in fault contact with quartz syenite.

Petrography

Hand specimens of granodiorite commonly show signs of alteration and shearing. In many thin sections, the biotite is intensely chloritized, quartz phenocrysts are granulose, feldspars sericitized, and epidotization, fracturing and veining occur. A sample from Cheung Sha has relatively less altered texture and mineralogy in thin section (HK 8567, 1429 1081). There is abundant zoned plagioclase, both as phenocrysts and in the groundmass (Plate 18), which ranges

in grain size from 0.4 to 1.5 mm, and includes biotite, most of which has been replaced by chlorite. Accessory minerals include hornblende, zircon, apatite, titanite and allanite.

Age Relations

The granodiorite belongs to a large sheet-like intrusion known as the Tai Po Granodiorite (Allen & Stephens, 1971) which crops out over a broad area in the New Territories. It is thought to be the oldest intrusive unit in the Territory (Addison, 1986) but has not yet been isotopically dated.

Medium-grained Granite

Distribution and Lithology

Medium-grained granite forms the principal bedrock on central Lantau Island and Tsing Yi, and in many of the offshore islands including Peng Chau, Sha Chau, Kau Yi Chau, Shek Kwu Chau, Cheung Chau, and Siu A Chau. The granite is pink to pinkish-grey and varies texturally from equigranular to strongly megacrystic. The medium-grained granite is commonly intruded, except on Sha Chau, by feldsparphyric rhyolite dykes of the Lantau dyke swarm. Xenoliths have been noted at several localities.

Details

Tsing Yi. Medium-grained granite on Tsing Yi is typically pale pink and equigranular with euhedral to subhedral flakes of biotite set in a mosaic of subhedral quartz, plagioclase and alkali feldspar. The best exposures are in cut slopes around Leung Ching Estate in North Tsing Yi, and on the southeast and southwest ridges of the southern peak of Tsing Yi. The medium-grained granite intrudes tuff of the Yim Tin Tsai Formation, and is commonly chilled to a fine grain size within the contact zone. On the main ridge (2848 2274) of Tsing Yi, the width of the chilled zone is quite narrow, but it is much broader in the area south of Chung Mei owing to the subhorizontal attitude of the contact.

Medium-grained granite is well exposed in the cut slopes along the main roads to the east and west of the Cheung Ching Estate (2920 2303) and is intruded by northeast-trending dykes of fine-grained granite (2915 2295) and coarsely feldsparphyric rhyolite (2915 2295, 2905 2345).

West of Tai Shan Ha (2852 2243), medium-grained granite is separated from the tuffs which comprise the country rock by a relatively thin (20-25 m) zone of chilled fine-grained granite. The sub-horizontal attitude of the contact is apparent from the manner in which it may be traced along the ridge and around the spurs. The medium-grained granite is equigranular, except in zones close to the contact and in exposures in the Oil Depot (2924 2243).

Exposures of medium-grained granite occur to the west of Nam Wan, beside the Tsing Yi Road (2754 2174 to 2788 2123) and in the quarries (2758 2113) southwest of Nam Wan. The dominant lithology is equigranular medium-grained granite but sheets of megacrystic fine-grained granite have gradational contacts with the medium-grained granite (2755 2172), or are chilled against it (2753 2159 and 2749 2119). In the quarry (2758 2111) a screen of medium-grained granite is present between dykes of fine-grained granite that have rhyolitic margins.

On the peak (2863 2190) west of Chun Fa Lok, an outcrop of medium-grained granite includes a number of subhorizontal sheets of fine-grained granite. The sheets are chilled against the overlying medium-grained granite but grade down, through richly megacrystic fine-grained granite, into typical equigranular medium-grained granite (2871 2177). A number of feldsparphyric dykes intrude the granite northeast of Chun Fa Lok (2853 2195) and around Nam Wan (2846 2157) and Nam Wan Kok (2886 2123).

The medium-grained granite on Tsing Yi has the overall form of a dome. Contacts in the north and southeast appear to dip steeply (2886 2332, 2775 2175), but on the main ridge contacts are horizontal or gently dipping (2851 2241, 2864 2186, 2833 2181). Feldsparphyric rhyolite dykes are common in the southwest of the island.

Pa Tau Kwu. Slivers of equigranular medium-grained granite are present between feldsparphyric rhyolite dykes on the coast of Lantau Island northeast of Penny's Bay, between Chok Ho Wan Tsui and Pa Tau Kwu Wan. The granite is typically pinkish grey and hypidiomorphic-granular in texture. Small (< 2 m) pods of medium-grained granite may also occur within the feldsparphyric rhyolite dykes. The margins of the dykes are commonly chilled

against the granite country rock. Medium-grained granite, very similar to that exposed at Pa Tau Kwu, is present as a small pod on Tang Lung Chau.

Penny's Bay (Chok Ko Wan). Along the coast between Sam Pak Wan and Sz Pak Wan (2058 1900) there is a small outcrop of granite in contact with younger, easterly-trending rhyolite dykes. The granite is porphyritic and medium grained with pinkish alkali feldspar phenocrysts up to 30 mm long. Aplite dykes which cut this granite also cut the adjacent rhyolite dykes. Less than 100 m to the west, the granite contains dark xenoliths.

At Sz Pak Tsui there are well exposed contacts between granite and rhyolite dykes. The granite is medium grained, and contains aplite dykes and pegmatitic patches. At one locality (Plate 19, 2145 1898), it is coarsely porphyritic, with feldspar megacrysts up to 60 mm across, and a groundmass ranging from medium-, to coarse-grained. The granite also contains sub-horizontal, fine-grained granite dykes, and has well-defined intrusive contacts with younger feldsparphyric rhyolite dykes to the north and south.

Siu Ho Wan. Porphyritic medium-grained granite with characteristics similar to that at Sam Pak Wan is exposed along the coast north of Siu Ho Wan. It occurs as pods between dykes of feldsparphyric rhyolite and is thought to intrude crystal tuff belonging to the Shing Mun Formation (Shek Lung Kung Member) exposed on hills to the east. The contact between the tuff and granite is obscured by the rhyolite dykes.

Discovery Bay. Weathered granite, forming a fine gravel quartz sand, is occasionally exposed between rhyolite dykes at the golf course. The granite appears to be medium grained and equigranular, at least in part, with prominent, single biotite crystals. However, less weathered exposures show that the main lithology is a fine-grained, conspicuously megacrystic granite, which may grade into fine- to medium-grained granite. Single biotite flakes characterize the rock, and the groundmass crystals are typically less than 1 mm. Larger feldspar crystals are up to 10 mm across, with quartz up to 6 mm.

The granite exposed in cut slopes east of the Discovery Bay ferry pier is porphyritic and medium grained, with euhedral white alkali feldspar phenocrysts up to 40 mm long and individual biotite flakes up to 4 mm across. Pinkish porphyritic medium-grained granite is also exposed at the eastern end of the golf course (Plate 20), although the dominant bedrock type is feldsparphyric rhyolite, occurring as numerous dykes cutting the granite.

West of the Trappist Haven Monastery, there are exposures of granite and dykes which have been hydrothermally altered and silicified. At one locality (1940 1589), the altered medium-grained granite comprises quartz relicts from 1 to 8 mm across set in a light brown, slightly weathered, aphanitic matrix. This zone of alteration extends east and west for no more than 500 m, but has no obvious structural control.

Weakly megacrystic, medium-grained granite is the main bedrock lithology around Hai Kam Tsui. Minor zones of sparsely megacrystic fine-grained granite, grading into fine- to medium-grained granite have been reported in boreholes of the Discovery Bay Phase V development.

Silver Mine Bay (Mui Wo). At Tung Wan Tau, north of Silver Mine Bay, there are exposures (1854 1515) in a stream bed of slightly weathered porphyritic medium-grained granite, with large pink alkali feldspar and small individual biotite flakes. The granite is cut by thin aplite dykes, and is texturally similar to the granite at Sam Pak Wan. Exposures on the adjacent hillsides and ridges are limited to highly weathered corestones, although the presence of coarsely granular quartz-rich soil is a good indication of medium-grained granite bedrock. This contrasts with the fine, clay-rich soil that is a characteristic of the weathered rhyolite dykes. Extending for up to 400 m to the northnortheast, there are exposures and debris deposits consisting of altered granite and feldsparphyric rhyolite. These rocks are light green when fresh, and are composed of quartz and sericite. The quartz relicts give an indication of the primary texture of the rock. The extent of alteration cannot be accurately mapped, but it is probably coincident with a northeast-trending fault that forms part of the Pui O-Sha Tau Kok Fault Zone (Lai & Langford, 1991).

From Man Kok to Kau Shat Wan, east of Silver Mine Bay, porphyritic medium-grained granite is characterized by patches of pegmatite. East of Kau Shat Wan (2032 1468), a pegmatite vein typically includes alkali feldspar crystals up to 1 m long by 0.1 m across. These are sometimes separated by long, thin patches of grey crystalline quartz.

On the coast south of Silver Mine Bay, from Shui Teng Wan to Wang Tong, there are xenoliths of medium-grained granite in the feldsparphyric rhyolite dykes. At one locality (1838 1222), the xenolith is 1.5 m wide and over 8 m long, whereas at another (1874 1240), the xenolith is over 15 m long.

Plate 20 - Megacrystic Medium-grained Granite (2059 1749), Discovery Bay

Plate 21 - Pegmatite in Medium-grained Granite (2241 1250), Displaying Graphic Intergrowth Granophyric Texture) in Coastal Exposures on Hei Ling Chau

Plate 22 - Porphyritic Medium-grained Granite (0860 1170), on the North Side of Chi Ma Wan

Plate 23 - Porphyritic Medium-grained Granite (085 050), Siu A Chau , Soko Islands

Pui O Wan. Porphyritic medium-grained granite crops out north of the Chi Ma Wan Road. The granite is cut by feldsparphyric rhyolite dykes and quartz syenite to the north. In deeply weathered areas, the granite produces a fine gravel soil composed of quartz crystals. In fresh exposures, it is pinkish-grey and white, with pinkish feldspar up to 20 mm, white plagioclase between 1 and 5 mm, and pools of quartz aggregates less than 10 mm. Biotite, occurring as single flakes, is 1 to 3 mm.

Chi Ma Wan Peninsula. On the north side of Chi Ma Wan, there are exposures of coarsely porphyritic, medium-grained granite with pegmatitic patches. Dark aphanitic xenoliths are present but scarce. The granite is pinkish-grey, with white plagioclase and prominent black biotite. Tabular phenocrysts of grey alkali feldspar are up to 40 mm long. On the beach to the east of Shap Long San Tsuen (1746 1162) there are many boulders of altered, brecciated and veined medium-grained granite, which have probably been derived from a deeply eroded northwest-trending fault that extends along the adjacent valley.

Pinkish grey and white, porphyritic medium-grained granite, with prominent biotite crystals, from 1 to 3 mm across, is exposed on the ridge (1668 1140) north of Shap Long Kau Tsuen. Although most of the granite in this area is weathered to a coarsely granular soil, this contrasts with the clayey soil of the quartz syenite and feldsparphyric rhyolite dykes. The granite also contains thin aplite dykes and occasional, thin quartz veins. These exposures contrast with the outcrop south of unaltered, pink, equigranular medium-grained granite forming the bedrock of Chi Ma Wan Peninsula.

North of Mong Tung Wan, the granite is pinkish grey, equigranular and medium-grained. Black biotite occurs as single flakes, or in small aggregates of flakes; the individual crystals ranging up to 4 mm. Most of the crystals are 2 to 8 mm, although there are some pink feldspar megacrysts up to 20 mm. Dark xenoliths of quartz microdiorite are common in this area. They are typically rounded, with a diameter of 0.1 to 0.2 m, but can be up to 0.3 m. Aplite dykes, usually around 0.2 m wide, are also common.

On the coast northeast of Lo Yan Shan a rapid textural change can be seen, with equigranular medium-grained granite to the south and a finer variety to the north. The mean crystal size is 2 to 3 mm, with biotite flakes less than 2 mm. The rock is mapped as fine-, to medium-grained granite, although locally it may be medium-grained.

Tung Chung. Porphyritic medium-grained granite has been recorded in offshore boreholes immediately south of Chek Lap Kok. Exposures of similar granite occur on the coast northwest of Lau Fau Sha. The rock is characterised by feldspar megacrysts, in places up to 25 mm long. Dykes of rhyolite and basalt cut the granite, which is often fractured and veined with quartz. Boreholes immediately offshore from Lau Fau Sha have intersected granite with skarn mineralization and fault brecciation, cut by feldsparphyric rhyolite dykes. Although no contact has been observed between the marble-bearing basement and the granite, it is presumed to be faulted.

Sha Chau. The island of Sha Chau and neighbouring Tree Island are dominantly composed of greyish-white, equigranular, medium-grained granite. Part of the outcrop, at the northern end of Sha Chau, includes megacrystic fine-grained granite, but field relations between the varieties cannot be seen. The granite is cut by small aplite and basalt dykes, but the most prominent cross-cutting feature is a zone of mylonitization and quartz veins which trends northeast across the island. A 4 to 5 m-wide zone of mylonitised granite is well exposed on the west coast (0662 2292), and can also be seen on the northeast coast (0680 2309).

Peng Chau. Exposures of medium-grained granite on Peng Chau are generally restricted to slivers between feldsparphyric rhyolite dykes. However, more massive outcrops of granite (2240 1630), displaying distinctive textural variations, are present south of Tung Wan. Boreholes sunk for the indoor recreation centre and library are dominated by pinkish, megacrystic, medium-grained granite. The rock is characterized both by abundant pink megacrysts of feldspar, some up to 30 mm across, and black biotite. Some sections of core (D/004/11189, 21958 16206) also contain fine-grained granite and pegmatite patches, which are thought to be younger intrusions within the relatively uniform, medium-grained granite.

On the north side of the island, there is a progressive transition over 100 m through megacrystic and pegmatite-bearing, fine-grained granite, to fine-grained granite (2243 1635). The fine-grained granite is pinkish grey with no obvious megacrysts and an equigranular groundmass whose grainsize is less than 1 mm. Textural variation also occurs along the coast to the east, as far as the island of Ngan Chan, contrasting with the porphyritic, medium-grained granite with pegmatite and aplite that is typically exposed at Nam Wan in the south.

Sunshine Island (Chau Kung To). Exposures of granite are rare along the coast of Sunshine Island where the dominant rock is feldsparphyric rhyolite. The granite is porphyritic and medium-grained and mainly occurs as slivers between rhyolite dykes. Feldspar megacrysts up to 25 mm long, and biotite flakes from 1 to 3 mm across, are locally abundant and patches of pegmatite sometimes occur with aplite dykes. At one locality (2368 1398) on the north coast, the medium-grained granite is cut by, and partially assimilated by younger, fine-grained granite dykes.

Hei Ling Chau. Porphyritic medium-grained granite, pegmatite and aplite are well exposed on the western and southern coasts of Hei Ling Chau. On the southwest coast (2216 1175), the granite is typically pink and white, mottled black, with pink alkali feldspar phenocrysts up to 40 mm long. The equigranular groundmass contains pink alkali feldspar up to 8 mm and white plagioclase less than 6 mm. Quartz occurs as interstitial crystal aggregates up to 10 mm across. The rock also contains distinctive pegmatitic patches. At a locality (2241 1250) near the southern tip, there are boulders of granite with pegmatite that display perthitic exsolution in the alkali feldspar (Plate 21). About 100 m to the westnorthwest there is a 1 m-wide, subhorizontal aplite dyke with a pegmatitic core.

The presence of dark aphanitic xenoliths, up to 0.5 m across, has been noted in medium-grained granite on the west coast (2163 1242). Close to the jetty (2100 1305), there are exposures of strongly discoloured, finely-fractured and jointed, essentially fine-grained granite. This is megacrystic, and looks in part like medium-grained granite. Further south, there is a swarm of feldsparphyric rhyolite dykes, between which there are slivers of medium-grained granite up to 8 m wide.

Kau Yi Chau. Porphyritic medium-grained granite is exposed on the west coast of Kau Yi Chau (Plate 22). The rock contains alkali feldspar megacrysts up to 30 mm long with abundant biotite crystals and crystal aggregates from 1 to 10 mm. At one locality (2567 1612) in the southwest, the granite is intruded by fine veins of biotite-rich granite and sub-horizontal pegmatite veins from 0.1 to 0.2 m wide.

Siu Kau Yi Chau. Exposures of porphyritic medium-grained granite on this island are limited, the dominant rock type being feldsparphyric rhyolite dykes. Little of the granite country rock is exposed, but where seen, on the western coast, it is medium grained and porphyritic.

Cheung Chau Equigranular medium-grained granite is well exposed on the coast of Cheung Chau, often displaying well-developed honeycomb structure on weathering (Plate 54). The granite is light pink, weathers to a yellowish brown, and is very uniform in texture and appearance over the whole island. Numerous east-, to eastnortheast-trending feldsparphyric rhyolite dykes cut the granite. They often have well-developed chilled margins, for example, on the coast at Italian Beach (Pak Tso Wan) in southwest Cheung Chau (1999 0654), and on the coast south of Fa Peng in southeast Cheung Chau (2208 0720). In addition, the granite is cut by many small aplite (Plate 38) and basalt dykes, and by thin quartz veins. South of the cemetery at Kau Kung Tong (2043 0664), in southwestern Cheung Chau, there is an eastnortheast-trending zone of quartz veins alternating with aplite, up to 20 m wide. Localized kaolinization, probably the result of weathering, can be seen in an isolated exposure northeast of Cheung Kwai Estate (2082 0846).

Shek Kwu Chau Equigranular medium-grained granite with a distinctive pinkish colour in fresh exposures can be seen over most of the island. Only rarely does the rock vary texturally. Mafic xenoliths, up to 0.15m across, occur in exposures on the northwest coast (1634 0666), along with biotite concentrations and small pegmatite patches (1646 0680).

Soko Islands. Porphyritic medium-grained granite (Plate 23) outcrops on both main islands of the Soko Islands group. It is cut by numerous, eastnortheast-trending, feldsparphyric rhyolite dykes.

Petrography

A sample of medium-grained granite from Tai Long Wan (HK8710, 1800 0878) contains pink alkali feldspar crystals up to 10 mm across, white plagioclase and grey quartz, up to 5 mm, and biotite flakes and aggregates less than 3 mm. In thin section, the biotite is pleochroic,and varies from greenish-brown to green in plane-polarised light. Zircon commonly occurs as inclusions in biotite grains, which may be partly altered to chlorite. Other accessory minerals include magnetite, titanite and monazite.

Age Relations

The medium-grained granite in the district has not yet been isotopically dated. However, with the exception of Sha Chau, it is cut throughout the district by rhyolite dykes of the Lantau dyke swarm. These dykes mostly predate volcanic rocks of the Lantau Formation which have a

minimum age of c.145 Ma (see earlier). Therefore, the medium-grained granite is likely to have a minimum age of c.145-147 Ma.

Fine- to Medium-grained Granite

Distribution and lithology

Fine- to medium-grained granite has been mapped in several areas of Lantau Island, Ma Wan and Chek Lap Kok and is regarded as a textural variant of the medium-grained granite. It is typically equigranular and pale pink with equal proportions of plagioclase, alkali feldspar and quartz and scattered flakes of biotite.

Details

Ma Wan. Fine- to medium-grained granite is best exposed on the southeast coast of Ma Wan, around Nam Wan (2470 2288), where it is chilled against an inlier of tuffs, with intrusive contacts dipping gently to the northwest. At the northern edge of the inlier (2366 2392) the contact has a complex structure, suggesting foundering of a polygonally-jointed raft of tuff into the roof of a pluton. Further south, bands of fine-grained granite, within the fine- to medium-grained granite, indicate a flat-lying orientation to the complex (2470 2381, 2450 2372).

Tang Lung Chau. On Tang Lung Chau, the fine- to medium-grained granite forms small outcrops in the west and north of the island. Contacts with fine-grained granite are obscured by feldsparphyric rhyolite dykes.

Sam Chuen. Fine- to medium-grained granite is exposed between Sam Chuen and Tai Chuen, and is found in offshore boreholes at Kap Shui Mun. The granite is non-porphyritic and underlies a subhorizontal sheet of fine-grained granite. Both granites are cut extensively by feldsparphyric and quartzphyric rhyolite dykes.

Silver Mine Bay. Megacrystic fine- to medium-grained granite, with some aplite dykes, is exposed as slivers and narrow belts between the dykes in the Mui Wo area, near Mui Wo Kau Tsuen and Hung Shui. Pink to white feldspar phenocrysts, which are up to 30 mm, are set in a granular matrix of biotite (1-3 mm), quartz (1-8 mm) and feldspar (1-5 mm). Aplite dykes, cutting the granite vary from 0.2 to 0.5 m wide.

Sha Lo Wan. Exposures of megacrystic, fine- to medium-grained granite adjacent to the pier (0814 1711) at Sha Lo Wan contain feldspar megacrysts up to 10 mm and prominent biotite crystals up to 3 mm. The rock is grey or rarely pinkish-grey, and has a groundmass with grainsize between 1 and 2 mm. Numerous quartz veins cut the granite in coastal exposures to the east, and in one locality (0841 1709) this is accompanied by silicification and brecciation of the granite. There is also a 0.3 m wide fault breccia and finely fractured granite exposed 25 m to the east.

Chek Lap Kok (prior to development). Inequigranular, fine- to medium-grained granite, intruded by feldsparphyric and quartzphyric rhyolite dykes, forms much of the eastern part of the island. It is typically light grey, but may be pinkish in some coastal exposures. Feldspar megacrysts up to 10 mm long are common, and may be up to 45 mm. Glomerophyric aggregates of quartz (up to 10 mm) and biotite (up to 7 mm) are also present, set in a fine- to medium-grained groundmass.

Petrography

In thin section, a sample of inequigranular fine- to medium-grained granite from south Chek Lap Kok (HK9236, 1131 1798) contains microperthitic alkali feldspar crystals from 2 to 4 mm. Plagioclase crystals (1 to 4 mm) have incipient sericitization and zoned extinction. Quartz, which is usually strained, is 1 to 2 mm, and rarely up to 4 mm. Subhedral biotite (1-2 mm) is either pleochroic, varying from dark to light brown with streaks of green chlorite, or is completely chloritized. The texture is inequigranular, but not obviously megacrystic, with most crystals 1 to 4 mm across.

Megacrystic fine- to medium-grained granite from a borehole south of Ha Law Wan (HK10518, 11309 17165) contains a few quartz crystals up to 10 mm, but most are around 2 mm (Plate 24). The groundmass (0.6 to 2 mm) is mostly composed of quartz, zoned and sericitized oligoclase, and perthitic alkali feldspar. Biotite is typically chloritized with some epidotization, but when

fresh is pleochroic, varying from light brown to green. Accessory minerals include zircon, titanite and allanite which is commonly altered.

Age Relations

The fine- to medium-grained granite is considered to be a textural variant of medium-grained granite exposed on Lantau Island and is, therefore, presumed to be of similar age. On Chek Lap Kok, the fine- to medium-grained granite probably cooled before the fine-grained granite exposed in the west of the island.

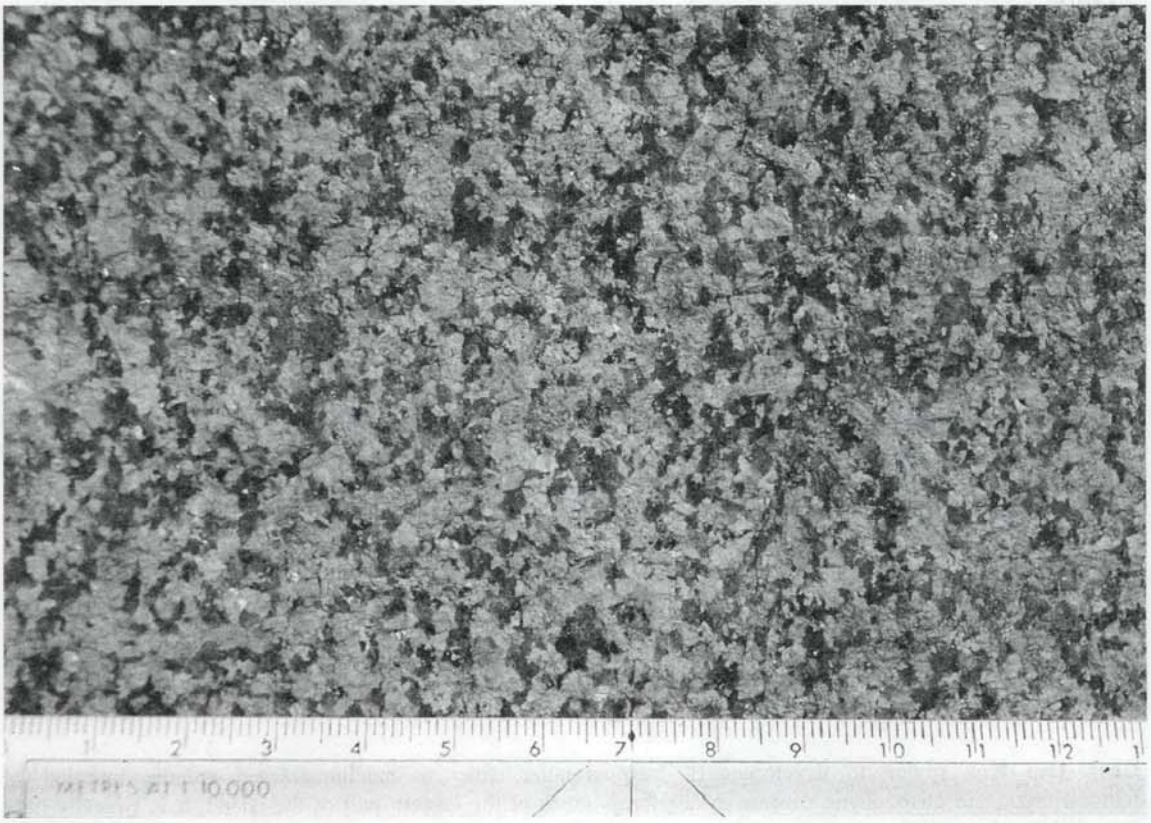


Plate 24 - Fine to Medium-grained Granite (11309 17165), from a Borehole South of Ha Law Wan

Fine-grained Granite

Distribution and Lithology

Fine-grained granite within the district can be divided into megacrystic and non-megacrystic varieties. The richly megacrystic varieties generally occur adjacent to, or within, gradational contact zones with porphyritic, fine- to medium-grained granite and porphyritic, medium-grained granite, whereas the non-megacrystic varieties generally occur as separate intrusive bodies. Megacrystic varieties may also occur as textural variants within feldsparphyric rhyolite dykes.

Fine-grained granite in the district occurs mainly on Tsing Yi, in and around Ma Wan and the northern part of Lantau Island, in central Lantau Island, on Chek Lap Kok and at Sha Lo Wan. Smaller exposures are found on many of the offshore islands.

The granite on Chek Lap Kok is mostly fine grained, and locally includes a noticeably finer-grained microgranite. All the varieties are characterized by an inequigranular groundmass, with a wide range of grainsizes seen in hand specimen and thin section.

Details

Tsing Yi. On Tsing Yi, fine-grained granite occurs either as a chilled margin to the medium-grained granite, or as relatively small, discrete, sheet-like intrusions. In each case the rock is pale pink or pinkish-grey, sparsely megacrystic and hypidiomorphic. In some areas, such as south of Cheung Hong Estate (2860 2313), richly megacrystic, fine-grained granite occurs as textural variants within dykes of feldsparphyric rhyolite which are themselves either richly or sparsely feldsparphyric. Such occurrences were also noted on Ma Wan, for example south of Tung Wan (2461 2327, 2453 2368).

On the peak west of Chun Fa Lok (2863 2190), medium-grained granite is cut by a subhorizontal sheets of fine-grained granite. The fine-grained granite sheets are chilled against the overlying medium-grained granite but grade down, through richly megacrystic fine-grained granite, into typical equigranular medium-grained granite (2871 2177). A number of feldsparphyric dykes intrude the granite to the northeast of Chun Fa Lok (2853 2195) and around Nam Wan (2846 2157) and Nam Wan Kok (2886 2123).

Fine-grained granite forms a relatively thin (c. 25 m) roof contact zone to the medium-grained granite on the main ridge of Tsing Yi, from northwest of Tai Shan Ha (2827 2300) to above Chun Fa Lok (2854 2207) and westwards from there. The contacts are well exposed on the peak (2847 2273), and to the south (2850 2243) where gradations from equigranular medium-grained granite to megacrystic fine-grained can be seen.

Southwest of Nam Wan (2749 2119, 2756 2112, and 2784 2134), megacrystic fine-grained granite forms gently dipping sheets, or dykes, which appear to coalesce when traced eastwards.

South of Cheung Hong Estate, in the centre of Tsing Yi, fine-grained granite, with a markedly megacrystic and inequigranular texture, forms a poorly defined mass that may partly represent the chilled roof margin of a pluton, and partly a dyke-like extension upwards into the overlying country rock. East of these outcrops, sparsely megacrystic fine-grained granite forms a dyke 50 m wide. It cuts the medium-granite along a roughly easterly trend, and is traceable for over 500 m.

In northwestern Tsing Yi, sparsely megacrystic fine-grained granite has been noted in numerous localities. Most outcrops appear to be dykes intruding feldsparphyric rhyolite dykes. In cut-slopes (2801 2272) east of Sai Tso Wan, fine-grained granite dykes are intruded into crystal tuff.

In the southwest of the island, west of the Power Station (2760 2130), and in the north around Cheung Hong Estate, the medium-grained granite has been modified texturally to form richly megacrystic, fine-grained granite along the contact with sparsely megacrystic, fine-grained granite. Modified textures were also noted in the Oil Depot (2924 2244) at Tai Shan Ha.

Ma Wan. On Ma Wan, fine-grained granite is exposed along the shore between Tai Pai Tsui (2415 2264) and Nam Wan (2446 2273), and on the shore east of Pak Nai Shan (2470 2289). The contact between the fine-grained granite and the country rock to the west of Tai Pai Tsui is faulted, whereas to the east it is intruded by a basalt dyke. This margin may also be faulted. A gently dipping intrusive contact is exposed east of Pak Nai Shan but a little further north, fine- to medium-grained granite is in direct contact with the tuff; the contact is sharp and geometrical as if a large polygonal block had foundered in the granite magma. Fifty metres north of this contact, a fine-grained granite dyke intrudes the fine- to medium-grained granite and can be traced offshore onto rocky islets, where it separates the fine- to medium-grained granite from the tuff.

In the north of Ma Wan near Cheung Tsui (2453 2366), Tam Shui Wan (2395 2357) and Shek Tsai Wan (2367 2336) fine-grained granite forms a core facies to sparsely feldsparphyric rhyolite dykes.

The fine-grained granite forms a major part of Tang Lung Chau but the shape of the intrusion is obscure as most contacts with country rocks are faulted, or interrupted by later intrusions.

Sha Chau. Strongly megacrystic, fine-grained granite is exposed north and west of the temple (064 232) on Sha Chau. The granite has tabular feldspar megacrysts, up to 50 mm long, which are set in a fine- to very fine-grained groundmass. Texturally, this granite is similar to that exposed on the east side of Castle Peak (Tsing Shan; Sheet 5).

Penny's Bay. An exposure (2178 1938) on the southwest side of the bay comprises fine-grained granite which is cut by thin, irregular basalt dykes. Both the granite and the basalt are cut by a feldsparphyric rhyolite dyke. About

200 m to the south, there is a irregularly-shaped xenolith of porphyritic medium-grained granite, with feldspar crystals up to 50 mm long. The granite is cut by thin basalt dykes and by feldsparphyric rhyolite.

Discovery Bay. Megacrystic fine-grained granite is exposed in cut slopes (1930 1740) west of the ferry pier at Discovery Bay. The granite is pinkish-white, with alkali feldspar megacrysts up to 40 mm long, and single biotite crystals 1 to 2 mm long. The fine-grained granite is intruded by feldsparphyric rhyolite dykes.

Man Kok - Trappist Monastery Kaido Pier. The country rock around Man Kok is dominantly fine-grained granite and variably megacrystic. The granite is greyish white with pink feldspar megacrysts up to 30 mm. Biotite occurs as single flakes or clusters of crystals up to 3 mm and the groundmass is dominantly 2 to 4 mm. The granite becomes pegmatitic in parts, and commonly contains dykes of aplite. Patches of fine-grained granite occur close to the contact with fine-grained granite near the monastery jetty.

Silver Mine Bay. Between Silver Mine Bay and Chi Ma Wan, there are easterly-trending bands (up to 200 m wide) of altered granite and rhyolite dykes, separated by zones of relatively fresh rock. The altered granite is commonly megacrystic and fine-grained, and is cut by quartz veins along the main ridge of hills (1838 1292).

South of the South Lantau Road there are exposures of equigranular to sparsely megacrystic, fine-grained granite. The rock is typically slightly greenish-white, and weathers to a pale brown. Quartz megacrysts up to 4 mm are prominent on weathered surfaces, and pink feldspar up to 10 mm are also present.

At the east end of Pui O Wan beach, a valley marks a change from equigranular fine- to medium-grained granite in the south, to fine-grained granite in the north. Contact relationships are not exposed. The fine-grained granite at this locality is megacrystic and is cut by feldsparphyric rhyolite dykes.

Hei Ling Chau. The granite on Hei Ling Chau is dominantly equigranular and fine-grained although it may contain patches of medium-grained granite and pegmatite. Although not usually megacrystic, some parts contain prominent quartz and feldspar megacrysts; the feldspar can be up to 30 mm.

Cheung Chau On the northwest coast (2072 0908), there is a small patch of fine-grained granite and pegmatite less than 1m by 3m. The fine-grained granite grades into the adjacent medium-grained granite. Pegmatite veins in the medium-grained granite are exposed out about 120 m to the south, as are thin veins of finer granite and pegmatite in a cut slope (2072 0859) south of Tai Kwai Wan.

Shek Kwu Chau Exposures of megacrystic fine-grained granite are present in the southeast of the island, adjacent to outcrops of medium-grained granite, although the contact between the two is not exposed. Feldspar megacrysts in the fine-grained granite are up to 25 mm long, whereas quartz megacrysts are up to 6 mm across. The megacrysts are set in an equigranular groundmass. Aplite and pegmatite veins cut the granite, and there are localized biotite concentrations. Exposures on the coast, about 120 m east of the jetty (1743 0627), comprise pinkish-grey, megacrystic, fine-grained granite which are cut by aplite dykes up to 0.3 m across. Both the aplite and the granite are cut by a 1 m-wide feldsparphyric rhyolite dyke.

Chek Lap Kok (prior to development). Inequigranular, non-megacrystic to sparsely megacrystic, fine-grained granite crops out west of a line from Sham Wan to Fu Tei Wan. The granite is light pinkish-grey in coastal exposures, and grey when fresh. Quartz megacrysts, up to 5 mm, are only rarely seen. Single flakes of biotite, mostly from 1 to 3 mm, are a prominent feature of the rock. The grains of the groundmass are between 0.2 and 2 mm, but are mostly around 1 mm.

Sample HK8362 (1101 1976) from Cheung Sha Lan is typical, displaying single biotite flakes up to 2 mm. The rock exposures at this locality are relatively free of joints and appear to have been extracted for building stone. Sample HK8363 (1069 1905) from the borrow area for the test embankment is a finer-grained variety of granite (microgranite), and this lithology dominates the borrow. Much of the construction material for the test embankment is fine-grained granite, but blocks of fine- to medium-grained granite, and rarely medium-grained granite, are also present.

San Shek Wan - Sha Lo Wan. At the northern end of the beacon at San Shek Wan (0714 1612), approximately 100 m north of the jetty, there is an exposed contact between granite and metasedimentary rocks. The granite is a megacrystic, fine-grained variety, and the contact with Carboniferous strata to the south strikes eastnortheast and dips 74° south. The contact is marked by a 5 m-wide zone of skarn containing garnet, vesuvianite, diopside and epidote (Peng, 1978). The contact zone also includes quartz syenite and lamprophyre (vogesite) dykes.

Tin Sam. Pinkish-grey, megacrystic fine-grained granite is exposed on the coast west of Hau Hok Wan. Biotite occurs as individual crystals between 1 and 2 mm across, and the rock is cut by thin aplite dykes, numerous thin quartz veins, and occasionally pegmatitic patches.

Southeast of Tin Sam, on the western shores of Tung Chung Wan, fine-grained granite country rock is cut by numerous dykes of feldsparphyric rhyolite, porphyritic microgranite, and basalt. Exposures on the ridge (0993 1627) to the west comprise slightly weathered, brownish-grey, sparsely megacrystic, fine-grained granite. The inequigranular groundmass varies from less than 1 mm to over 3 mm, and rounded quartz megacrysts up to 10 mm across also occur.

Lam Chau. The small island of Lam Chau is dominantly composed of pinkish-grey, inequigranular, fine-grained granite. A notable feature of exposures on the western tip of the island is the abundance of quartz veins. There are also zones of brecciation, epidotization and silicification in the granite. These zones have a preferred east-west trend and are cut by basic dykes (0858 1781). The fine-grained granite is remarkably similar to that seen in northwest Chek Lap Kok and along the north Lantau coast, but includes pegmatitic patches and zones of biotite schleiren, as well as irregular aplitic veins.

Fan Lau. Megacrystic, fine-grained granite is exposed along the coast from the north shores of Fan Lau Tung Wan and Fan Lau Sai Wan, through Heung Chung Au to Peaked Hill (Kai Yet Kok). Alkali feldspar megacrysts, up to 20 mm, quartz megacrysts (20 mm), and biotite crystals are set in a fine-grained groundmass comprising quartz, feldspar, and biotite. 230 m west of the ferry pier at Fan Lau Sai Wan, the fine-grained granite is intruded by quartz syenite.

Soko Islands. Megacrystic, fine-grained granite is exposed on the main islands of Siu A Chau and Tai A Chau and on nearby offshore islands. The granite is cut by feldsparphyric rhyolite dykes, trending variably east or northeast, and aplite and basalt dykes, and may be a textural variant of the medium-grained granite. The megacrystic fine-grained granite (Plate 25) is lithologically similar to that exposed at Fan Lau.

Petrography

Sample HK8362 (1101 1967), from Cheung Sha Lan, is a pinkish-white, inequigranular, fine-grained granite with a groundmass typically between 0.5 and 1 mm. A few alkali feldspar crystals up to 4 mm in size, and rare quartz megacrysts are up to 5 mm. Biotite flakes are less than 2 mm across.

Fine-grained granite from a borehole east of the kaolin mine on Chek Lap Kok (HK 10511, 1114 1904) has a grain size of up to 3 mm, but most grains are less than 1 mm. It comprises quartz, sericitised oligoclase and perthitic alkali feldspar with albitic rims. Plagioclase is zoned, with altered cores, and margins composed of albite. Biotite, fluorite and opaque minerals dominate the groundmass. The biotite exhibits light brown to olive green pleochroism, and is commonly partly chloritized. Late stage muscovite infills interstices within the groundmass.

Age Relations

The fine-grained granite is generally younger than the other granites of the district. On Chek Lap Kok, late stage fluids related to pluton emplacement, locally kaolinized the granite and formed aplite dykes and pods of pegmatite. The fine-grained granite on Chek Lap Kok is cut by quartzphyric rhyolite, basalt, and lamprophyre dykes, but not by feldsparphyric rhyolite dykes suggesting at least two ages of felsic dyke.

Quartz Syenite

Distribution and Lithology

Intrusions of quartz syenite form scattered outcrops in southern parts of the district. The largest outcrop is between Shek Mun Shan and Luk Keng Shan, and the second largest is between Mui Wo and Pui O. Smaller outcrops and dykes occur at Ma Po Ping Prison near Tong Fuk, Fan Lau, Sha Lo Wan and Hei Ling Chau.

Quartz syenite is poorly exposed in inland areas but the landform, abundance of corestones, and soil colour often indicate its presence. Good field relationships are only seen in coastal exposures. The intrusions are generally steep-sided, and some are dyke-like. The quartz syenite is lithologically uniform, porphyritic and has a fine-grained groundmass (Plate 26). Alkali feldspar megacrysts are very prominent and can be up to 40 mm long, but most are less than 15 mm. Plagioclase feldspars are smaller, and white or greenish-white in most exposures, contrasting with the distinctively pinkish alkali feldspar. The proportion of alkali feldspar is much greater than the plagioclase, Grey quartz crystals are infrequent. Visually, the groundmass seems dominated by mafic minerals, but they only constitute a small proportion of the rock.

Details

Luk Keng. The largest quartz syenite body in the district is exposed between Shek Mun Shan and Luk Keng Shan, south of Tong Fuk. The margins of the intrusion are well defined in this area, and the quartz syenite probably extends offshore beneath superficial deposits as far as Cha Kwo Chau, a small island 2 km southeast of Tong Fuk.

On the hillside between Shek Mun Shan and Luk Keng Shan, the syenite forms large corestones up to several metres across. On footpaths and tracks the typically reddish-brown saprolitic soil of weathered quartz syenite surrounds these corestones.

At its northwestern extremity, the Luk Keng Syenite intrudes porphyritic rhyolite lava of the Lantau Formation, although the contact cannot be seen. About 700 m westnorthwest of Shui Hau, a roadside cutting (0856 0946) has rhyolite lava at its base and porphyritic, fine-grained quartz syenite corestones within 20 m. A trachytoid texture occurs in the syenite about 150 m to the eastsoutheast, with feldspar crystals no larger than 6 mm, set in an aphanitic groundmass. About 300 m west of Shui Hau, the lava appears to have been hornfelsed by the intrusion of syenite. Rounded, dark xenoliths are a feature of the quartz syenite, although they are relatively scarce. On the coast (1062 0888) north of Luk Keng Shan, there is a xenolith of dark grey, finely banded lava about 0.3 m across, and 60 m to the southeast is a light grey felsic xenolith, up to 1 m in diameter .Exposures of the quartz syenite can be seen along the road heading south from Shui Hau towards Lo Kei Wan. At the end of the road (098 083), there are exposures of porphyritic, fine-grained quartz syenite with feldspar megacrysts up to 25 mm long. The rock is pinkish-grey, with white plagioclase feldspar and a black biotite-rich groundmass.

Close to the contact (0901 0868) with the volcanics, feldspar megacrysts show distinct flow alignment. This trachytoid texture is also visible in boulders of syenite at Shek Lam Chau (0824 0839). In the absence of an exposed contact, this texture indicates that the syenite at Luk Keng intrudes porphyritic rhyolite lavas of the Lantau Formation. Between Shek Lam Chau and Lo Kei Wan there is an outcrop of granite in fault contact (0852 0777) with the quartz syenite. The contact gives no clear indication of the relative ages of the two intrusive bodies.

On the south side of Shui Hau Wan, the contact between Yim Tin Tsai Formation tuff and the Luk Keng Syenite can be mapped accurately on the basis of morphology, but it is not exposed. Abundant, flow-aligned feldspars can be seen in the syenite (1039 0880). About 80 m to the southwest, the feldspar megacrysts are mostly 2 to 6 mm long, and are set in an aphanitic, possibly trachytic groundmass.

The quartz syenite is interpreted as extending offshore beneath superficial deposits, and is exposed again on Cha Kwo Chau, a small island 4 km south of Cheung Sha. Most of the island is typically composed of grey to pinkish-grey, porphyritic, quartz syenite, containing a few dark xenoliths. On the south side of the island a shear zone has developed along the contact between quartz syenite and granodiorite.

Pui O. The quartz syenite intrusion at Pui O lies on the northeast-trending Pui O-Sha Tau Kok Fault. The quartz syenite is well exposed in cut slopes along the South Lantau Road, near Mui Wo, and at the nearby Water Treatment Works. Elsewhere, exposures are limited to corestones and boulders, often set in a distinctive, reddish-brown saprolitic soil. These boulders are particularly well displayed at Ham Tin Village, near Pui O. The adjacent hillside is littered with syenite boulders, but is also covered in thick vegetation. Closer to Mui Wo, the hillside is more accessible, and the corestones are abundant.

Fresh pinkish-grey syenite is exposed in cut slopes both at the Mui Wo Water Treatment Works and on the adjacent South Lantau Road. The rock can also be seen in its more typical form as corestones between 0.5 and 2 m across, in reddish-brown, saprolitic soil. The contact to the north with the adjacent feldsparphyric rhyolite dykes and medium-grained granite is not exposed, but the outcrop form indicates that it is vertical. To the south of Luk Tei Tong, there are hill top exposures (1690 1340) of laminated tuffaceous siltstone. This outcrop appears to lie on top of the syenite, rather than as a sliver within the intrusion, possibly indicating that the syenite is plug-like in form rather than dyke-like.

About 1 km east of Nam Shan, exposures (1730 1280) of feldsparphyric rhyolite are partly hydrothermally altered within, and adjacent to, the syenite outcrop, indicating that the syenite is younger than the rhyolite dykes.

Tong Fuk. Quartz syenite at Tong Fuk crops out as four discrete bodies. The largest, underlying Ma Po Ping Prison, gives rise to the boulder-strewn hillside, and is well exposed in cuttings on the South Lantau Road. An offshoot of this body occurs on the coast to the south. A third body, north of Tong Fuk, is poorly exposed along the catchwater, and a fourth, very small body is well exposed on the coast west of the prison.

The contact between quartz syenite, with a trachytoid texture, and banded lava cannot be seen on the road to the prison, although both rock types have been observed within a few metres of each other (1068 0987). The syenite also has a fine-grained groundmass, probably resulting from chilling at the margin.

Exposures (1065 0964) of typical, fresh syenite occur on the South Lantau Road, south of the prison. The rock is light grey, with feldspar megacrysts up to 7 mm long, set in a fine-grained groundmass. No xenoliths can be seen, and they have not been observed in corestones in the area either. These corestones are typically set in a reddish-brown, clay-rich saprolitic soil.

Coastal exposures west of the prison (1016 0973) are dominantly composed of sparsely porphyritic, quartz syenite, contrasting with the markedly porphyritic boulders on the shoreline 100 m to the east. The rock is pale grey, with a marked flow-banding in the western part of the exposure. This flow-banded margin, composed of porphyritic trachyte, has sparse quartz phenocrysts, up to 2 mm, and feldspar phenocrysts up to 4 mm long. The contact with the overlying lavas dips 39° southwest. The syenite is intruded by two basalt dykes, respectively 0.1 and 0.3 m wide. These dykes do not cross the adjacent lavas. The trachytic contact clear indicates that the syenite formed a dome-like intrusion in the older lavas.

Fan Lau. Quartz syenite extends from the north shores of Fan Lau Tung Wan and Fan Lau Sai Wan, through Heung Chung Au to Peaked Hill (Kai Yet Kok). A small body also occurs east of Fan Lau Fort. At the northern end of the pier at Fan Lau Sai Wan (0242 0740), the rock is typically pinkish-grey, mottled black, porphyritic, fine-grained quartz syenite. Feldspar megacrysts are up to 15 mm long, although most are less than 8 mm, and the groundmass has a grain size of less than 0.5 mm. Boulder-strewn hill slopes occur to the north, and the edge of the intrusion is marked by the change from cuboidal corestones to rubbly debris on the lower flanks of the hill.

Contact relationships with the adjacent, fine-grained granite can be seen 230 m west of the Fan Lau Sai Wan pier. The contact is sharp, trends southeast, and is marked by a biotite enrichment in the syenite. Quartz veins in the granite do not cross into the quartz syenite, confirming that the syenite is the younger of the two. 300 m further along the coast, there are exposures of partially mylonitized granite close to syenite. The quartz syenite contains large xenoliths, including fine-grained granite, up to 2 m across. About 300 m to the northwest, there is a 0.6 m-wide dyke of quartz syenite, trending eastnortheast, which intrudes the fine-grained granite country rock.

Porphyritic, fine-grained quartz syenite is exposed around high water mark on the northeastern tip (0138 0878) of Peaked Hill (Kai Yet Kok). Flow-aligned alkali feldspar laths, up to 15 mm long, define a trachytoid texture. The quartz syenite is in close proximity to boulders of fractured granite and exposures of fine- to medium-grained granite, and appears to have been intruded along a fault zone within the older granite that trends northwest from Fan Lau to Peaked Hill.

To the east of Fan Lau Tsuen, a contact (0321 0717) between quartz syenite and granite occurs at the northern end of the beach. About 200 m to the east (0344 0725), a trachytoid texture and contact with adjacent metavolcanics has been observed.

No contact relationships were seen in the outcrop near Fan Lau Fort, although at one locality (0286 0658) the syenite has a marked north-south trending trachytoid texture.

Sha Lo Wan. The only outcrops of quartz syenite on the north side of Lantau Island are between Tung Chung Wan to the east and Sha Lo Wan in the west. The outcrop consists of two elongate bodies, each over 1 km long but less than 500 m wide, trending westnorthwest along the contact between volcanics to the south, and granite intrusions to the north. In addition, a small syenite dyke lies close to the contact between granite and Carboniferous sedimentary rocks at San Shek Wan.

The largest outcrop of syenite is south and east of Sha Lo Wan Village, but exposures are poor on the steep, thickly vegetated slopes. In a stream bed (0787 1607) south of the village, there are exposures of porphyritic, fine-grained quartz syenite with tabular, euhedral alkali feldspar megacrysts up to 10 mm across. The syenite is also exposed close to fine-to medium-grained granite in a stream 300 m to the east (0618 1616), and on the hillside to the southeast (0640 1597).

Exposures of the eastern outcrop of quartz syenite are very poor, and the strongest evidence for outcrop form comes from the occurrence of a topographic low, rich vegetation and reddish-brown, saprolitic soil on the ridge west of Tung Chung Wan (097 157). To the east, towards Tung Chung, scattered exposures have been noted, and quartz syenite has been recorded close to medium-grained granite at the base of the slope (1846 1539).

On the rocky coast north of San Shek Wan (0714 1611), there is a 3 m-wide, porphyritic, quartz syenite dyke with abundant feldspar megacrysts, up to 6 mm across. The dyke trends eastnortheast, and has a finer-grained, sheared, or trachytic margin against foliated sedimentary rocks to the north.

Hei Ling Chau. Quartz syenite crops out as dykes and small bodies on southern Hei Ling Chau, along the east coast of Hei Ling Chau, and on both east and west Sunshine Island (Chau Kung To). The largest bodies are on the southern ends of both islands, where they are up to 700 m long, and less than 200 m wide.

On southern Hei Ling Chau, the quartz syenite trends northeast with an inferred contact against fine-grained granite. The contact is obscured by boulders, and no age relationships can be determined. However, on the southern tip of Hei Ling Chau (2266 1147), presumably close to the southern margin of the dyke-like intrusion, medium-grained granite and aplite are cut by fine-grained quartz syenite with a trachytoid texture.

On the southwestern tip of Sunshine Island (2306 1325), the quartz syenite has a chilled margin about 50 mm wide against feldsparphyric rhyolite. There is a rapid decrease in the feldspar phenocryst content closer to the contact, whereas the older rhyolite appears unchanged at the contact.

Small dykes of quartz syenite are common along the east coast of Hei Ling Chau. Some have slightly chilled margins against the granite country rock. One dyke (2256 1239) is cut by a flow-banded quartzphyric rhyolite dyke, 10 m wide and trending northeast.

Quartz syenite was only seen exposed on the southwest tip of the island, but its presence is inferred from the abundant, dominant corestones which have toppled onto the beach near the northwest tip of the island (237 138). There, the feldsparphyric rhyolite adjacent to the syenite has been strongly deformed. Feldspar megacrysts are streaked and contorted in a zone over 1 m wide. This is believed to be the result of the younger syenite deforming the hot, plastic dyke rocks.

Abundant boulders of porphyritic quartz syenite disguise the generally deeply weathered outcrop in the southwest. However, in one tumbled block (233 132), the contact between quartz syenite and feldsparphyric rhyolite can be seen. The rhyolite appears to be partially assimilated, or absorbed, by the syenite, and hence is the older rock. The northern margin of the quartz syenite is exposed in a deeply weathered coastal section. It has a chilled margin, about 50 mm wide, in which there is a rapid decrease in the number of feldspar phenocrysts. The older rhyolite has a distinct margin. Boulders of rhyolite on the point to the south (230 132) suggest that the quartz syenite has a complex, dyke-like form, incorporating slivers of older rock.

Petrography

Thin sections of quartz syenite from across the district are texturally and mineralogically similar. For example HK8117 (1765 1368) from the South Lantau Road contains subhedral alkali feldspar phenocrysts 2 to 10 mm long, in a groundmass of alkali feldspar, plagioclase, quartz, mafic and opaque minerals. The groundmass, typically 0.1 to 0.5 mm, forms roughly half the rock. Alkali feldspars comprise 62% of the mineral content, mostly sericitized plagioclase only 15%, and quartz 15 to 25% (e.g. HK10035, 0170 0804). Quartz rarely occurs as phenocrysts or xenocrysts. Mafic minerals include biotite, usually chloritized (c.5% of the rock), and euhedral hornblende (<1%), commonly altered to chlorite and epidote. Opaque minerals usually occur in trace amounts in the groundmass. Relatively high magnetic susceptibilities measured in hand specimen (0.44 cgs units $x10^{-3}$) indicate that they are mainly magnetite.

Age Relations

Quartz syenite is the youngest of the major intrusions within the district and intrudes volcanics of the Lantau Formation in a number of places. Rb-Sr whole-rock isochron ages of 144±6 Ma (MSWD=4.1) and 146±8 Ma (MSWD=1.5) have been obtained on syenite bodies at Tong Fuk and Pui O respectively, (Darbyshire, 1993) suggesting that the quartz syenite is only slightly younger than the Lantau Formation.

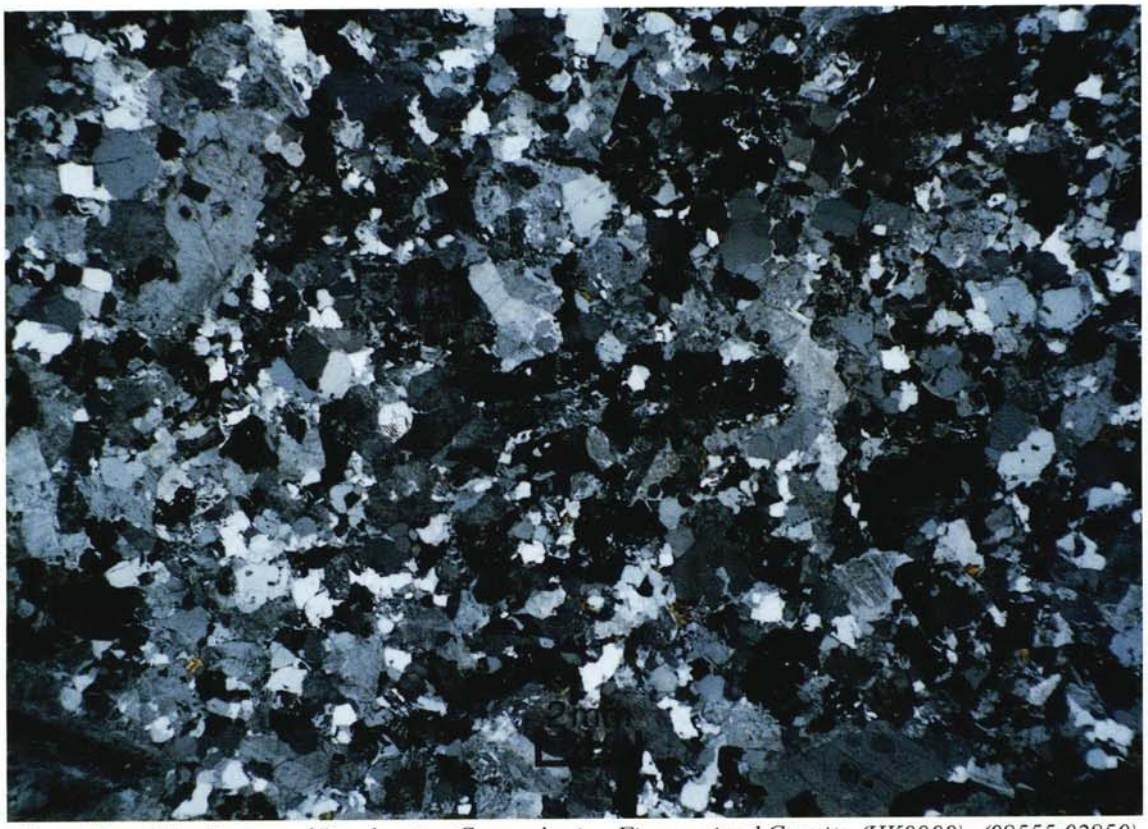


Plate 25 - Thin Section of Porphyritic, Granophyric, Fine-grained Granite (HK9900) (08555 02850), from Tai A Chau ; XPL

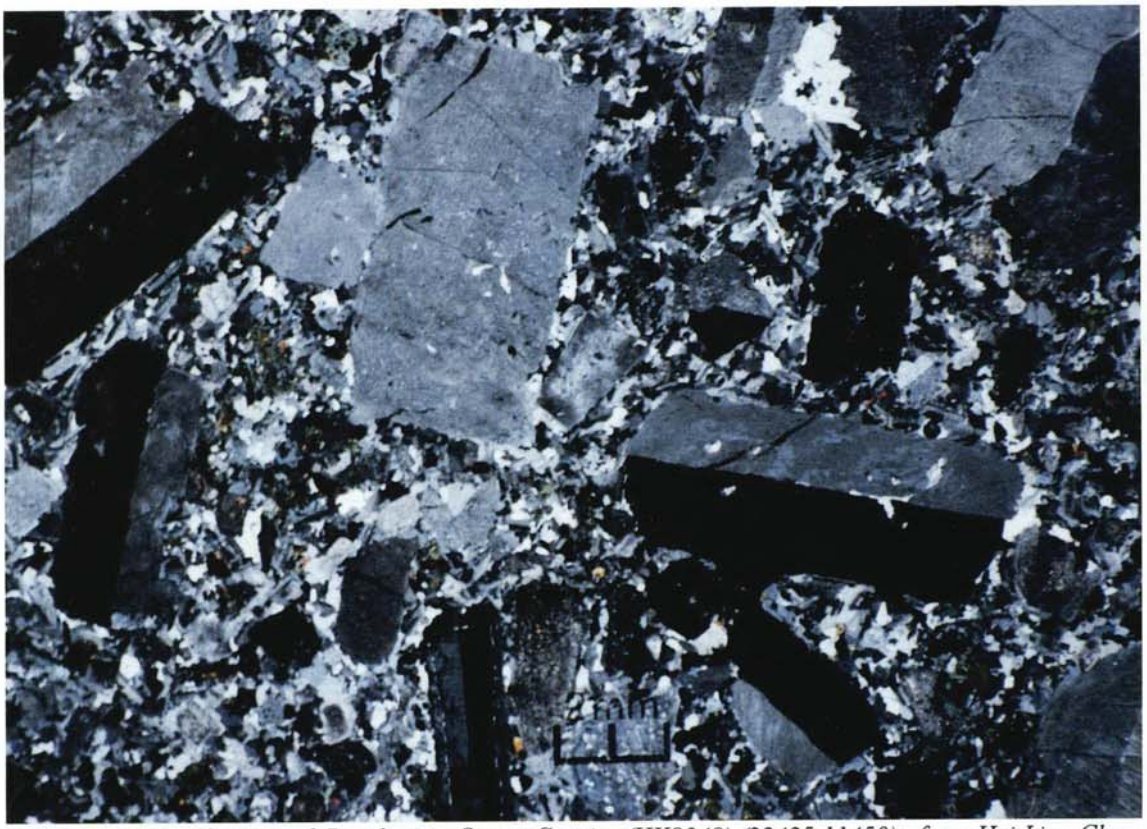


Plate 26 - Thin Section of Porphyritic Quartz Syenite (HK8348) (22425 11450), from Hei Ling Chau; XPL

Plate 27 - Feldsparphyric Rhyolite(2163 2194), Tai Yam

Plate 28 - Feldsparphyric Rhyolite (1851 1339), Barren Hills

Chapter 6
Minor Intrusions

Introduction

The minor intrusions described in this chapter include dykes varying in width from a few centimetres to 200 metres. They are best exposed in coastal sections, and most can only be traced inland for a few tens of metres. However, some have been mapped for more than one kilometre. They are classified using the non-genetic scheme of Streckeisen (1974) and Le Maitre (1989), so that their identification depends on the mineral content of the rocks (Figure 8). Representative whole-rock geochemical analyses of the principal minor intrusions are presented in Appendix 2, although chemical analyses are rarely necessary to confirm the composition of the minor intrusions.

There are eight main types of dyke: feldsparphyric rhyolite, which is the dominant type; quartzphyric rhyolite; quartz syenite; aplite or fine-grained granite; pegmatite; basalt and gabbro; andesite and dacite; and lamprophyre. Quartz syenites and various granitoids which locally form dykes also form larger plutonic bodies and are therefore described in Chapter 5. Dyke swarms mapped by Allen & Stephens (1971) as feldspar and quartz porphyry in north Lantau Island (Lamma porphyry and D'Aguilar porphyry) are reclassified here as feldsparphyric and quartzphyric rhyolite. Allen & Stephens (1971) also identified basic dykes (although none were shown on their map of Lantau Island) and these are renamed as lamprophyre or basalt. Their dolerites have been remapped as basalt or gabbro, while granite and granodiorite porphyry dykes are renamed as rhyolite and rhyodacite respectively. Some multiple quartz veins are large enough to be regarded as dykes, and are shown on the published maps, but most quartz veins are small-scale.

All but the basalt, gabbro and lamprophyre dykes were emplaced during phases of Mesozoic granite plutonism. Allen & Stephens (1971) interpreted the basic intrusions as being significantly younger than the other intrusions and constrained both Upper Cretaceous (syn-plutonic) and Tertiary phases of their emplacement. On the 1:20,000 scale maps, however, basic intrusions have been generalized as Tertiary in age.

Feldsparphyric Rhyolite and Microgranite

Distribution and Lithology

The feldsparphyric rhyolites weather to a grey or brown, and are coarsely porphyritic with an aphanitic matrix. They contain abundant alkali feldspar megacrysts up to 20 mm long (Plate 27), as well as crystals of biotite and quartz up to 2 mm across. In common with the quartzphyric rhyolites, they contain central zones of fine-grained, megacrystic granite. Porphyritic microgranites, by comparison, are less porphyritic and include smaller feldspar megacrysts (<15 mm), sparse quartz crystals, which are up to 2 mm, and rare biotite flakes up to 1 mm. The groundmass, which is pale grey in hand specimen, is usually slightly coarser than that of the feldsparphyric rhyolites, and is often granophyric. Only the presence of common feldspar megacrysts distinguishes the porphyritic microgranites from quartzphyric rhyolites, and both the feldsparphyric rhyolites and the porphyritic microgranites include mesocratic and leucocratic varieties. There are gradations, as well as sharp contacts, between the two rock types, but their inter-relationships are usually too complex for them to be shown separately on the published maps of the district.

Feldsparphyric rhyolites and porphyritic microgranites occur as dykes that vary from a few metres, to hundreds of metres wide. They dominate the geology of northeast Lantau Island, and are distinctive in all granite areas. However, they are rare within the volcanic sequence of central Lantau Island, and do not cut Carboniferous rocks on The Brothers islands, or the granite at Sha Chau. They can form swarms up to 5 km across, and over 10 km long, within which individual dykes can be hard to recognise.

The feldsparphyric rhyolite and porphyritic microgranite dykes show mutually cross-cutting relationships. Most quartzphyric rhyolite and basalt dykes cross-cut them, but only quartz syenite dykes and plutons are consistently younger.

Details

Cheung Chau. On the west side (2135 0712) of Morning Beach (Nam Tam Wan), there is a 30 m-wide feldsparphyric rhyolite dyke trending 080° within medium-grained granite. The dyke has an irregular chilled margin, contains prominent biotite in the groundmass, and includes many melanocratic xenoliths, up to 0.5 m across. A similar (or possibly the same) dyke, exposed on the coast (2225 0747) further east, incorporates numerous, rounded, feldsparphyric xenoliths ranging from 0.02 to 0.3 m.

A multiple dyke is well exposed east (2147 0772) of the Warwick Hotel. Its component dykes, which trend easterly and are less than 50 m wide, include feldsparphyric rhyolite in sharp contact with porphyritic microgranite.

Chi Ma Wan. The eastern part of the Chi Ma Wan peninsula is dominated by feldsparphyric rhyolite dykes, whereas to the west there are only a few, narrow, eastnortheast-trending dykes. On the coast (1921 1047) east of Cheung Sha Wan, a feldsparphyric rhyolite dyke, which is coarsely porphyritic, varies gradationally from north to south towards its centre, into a porphyritic microgranite with abundant small phenocrysts, up to 10 mm across. The dyke intrudes medium-grained granite. Similar gradations also occur along the coast north of Ha So Pai.

Soko Islands. Tai A Chau is dominantly composed of feldsparphyric rhyolite and porphyritic microgranite dykes, which intrude granite. At one locality (0846 0282), west of Pak Tso Wan, feldsparphyric rhyolite grades northwards into porphyritic microgranite. About 50 m to the south, a feldsparphyric rhyolite dyke, trending 020°, cuts an older feldsparphyric rhyolite with a similar texture.

There are very few feldsparphyric rhyolite dykes on the other islands of the group. However, one, which is 2 m wide is exposed on the foreshore (0945 0464) at Sum Wan on Siu A Chau. It trends 020°, and intersects an earlier feldsparphyric rhyolite dyke which probably trends northeastwards. The younger dyke has an aphyric margin, and resembles aplite.

Tong Fuk. The few feldsparphyric rhyolite and porphyritic microgranite dykes exposed on the north and south sides of Shui Hau Wan and Tong Fuk Miu Wan, all intrude tuffs of the Yim Tin Tsai Formation. Exposures are always poor and field relationships obscure.

On the catchwater (0936 0978) north of Shui Hau, light grey feldsparphyric rhyolite intrudes lava of the Lantau Formation. It contains feldspar and quartz phenocrysts, respectively up to 12 mm and 5 mm across, set in an aphanitic groundmass. The dyke, which is probably up to 70 m wide and trends northeastwards, weathers to form corestones in hillside exposures to the southwest. It is one of very few feldsparphyric rhyolite dykes known to intrude the Lantau Formation.

Cheung Sha. Feldsparphyric rhyolite dykes, striking eastnortheast, are exposed between Tong Fuk, Cheung Sha and Pui O. A small group of boulders, exposed 400 m offshore, is an extension of one of these dykes. The country rock is dominantly composed of tuff of the Yim Tin Tsai Formation, but also includes granodiorite, and tuff of the Shing Mun Formation. An eastnortheasterly-trending contact (1387 1049) is exposed near Cheung Sha Village.

Sunshine Island (Chau Kung To) This island is dominantly composed of feldsparphyric rhyolite, which is intruded by younger quartz syenite. At one locality (2334 1323) on the south coast, a feldsparphyric rhyolite dyke contains an aphanitic xenolith with sharp edges and few megacrysts.

Hei Ling Chau. The northern part of the island is dominated by feldsparphyric rhyolite and porphyritic microgranite dykes, mostly trending east or eastnortheast. On the northeast coast (2247 1324), the contact between feldsparphyric rhyolite to the north, and younger porphyritic microgranite to the south, trends 080°.

The microgranite grades southwards into feldsparphyric rhyolite with feldspar phenocrysts up to 40 mm long. A similar relationship also occurs in a dyke trending 085°, which is exposed (2213 1190) on the southwest coast. Numerous, narrow, feldsparphyric rhyolite dykes, separated by screens of medium-grained granite as narrow as 2 m, are well exposed on the coastline (209 129) south of the jetty. The dykes mostly trend eastnortheast, and dominate the outcrop.

Barren Hills. In the Barren Hills, south of Silver Mine Bay, feldsparphyric rhyolite dykes (Plate 28) are dominant and intrude the medium-grained Lantau Granite. They trend eastnortheast. On the coast (1838 1222) between Ngau Kwu Wan and Shui Tseng Wan, the dykes contain large granite xenoliths, up to 1.5 by 8 m across.

Siu Kau Yi Chau. Almost the entire island is composed of feldsparphyric rhyolite and porphyritic microgranite dykes, which locally grade from one to the other. On the south coast (2405 1654), a flow-banded feldsparphyric rhyolite dyke trends 065°, and cuts another feldsparphyric rhyolite dyke. To the east, there are rapid textural changes to microgranite, with abundant small phenocrysts, rarely up to 20 mm long, and then back to feldsparphyric rhyolite, whose texture is dominated by large feldspar phenocrysts set in an aphanitic groundmass.

Peng Chau. On Tai Lei, a small island northwest of Peng Chau, good exposures (2155 1680) of feldsparphyric rhyolite grade, over a width of 2 m, into porphyritic microgranite, but within 5 m the rock texture reverts to feldsparphyric rhyolite. A narrow chilled margin, trending 080°, is developed along the contact with an adjacent dyke.

A feldsparphyric rhyolite dyke, trending approximately eastwards, cuts fine-grained granite east of Tung Wan. The dyke, which is up to 20 m wide, can be traced for 300 m. On the east coast (2278 1642), it has aphyric, flow-banded margins to both north and south, whereas its central zone varies from feldsparphyric rhyolite to porphyritic microgranite. Similar relationships occur elsewhere along the east coast of Peng Chau.

Discovery Bay. Feldsparphyric rhyolites dykes, which intrude medium-grained granite, and porphyritic microgranite dykes, are exposed at numerous localities along the coast around Discovery Bay. Complex, composite intrusive relationships occur between the feldsparphyric rhyolites, with or without small feldspar phenocrysts, and porphyritic microgranites in cut slopes (1948 1646) east of the golf course. The groundmass in the feldsparphyric rhyolites varies locally from aphanitic to microcrystalline.

Between Sam Pak Wan and Sz Pak Wan, north of Discovery Bay, there are good examples of dykes which grade from feldsparphyric rhyolite to porphyritic microgranite. Their margins tend to be coarsely porphyritic, whereas the centres have fewer, smaller phenocrysts.

Siu Ho Wan. Along the coast west of Siu Ho Wan , there are several good exposures of younger feldsparphyric rhyolite dykes chilled against older dykes. In addition, textural gradations occur between light grey feldsparphyric rhyolite, with phenocrysts of feldspar up to 20 mm long, and porphyritic microgranite, with a fine-grained groundmass and phenocrysts of less than 10 mm.

Yam O Wan. A feldsparphyric rhyolite dyke (2036 2181) on the island of Cheung Sok, north of Yam O Wan, contains phenocrysts which are progressively smaller towards the south. It becomes a porphyritic microgranite with abundant quartz and feldspar phenocrysts up to 2 mm across. The northern margin of the dyke, which intrudes tuff of the Shek Lung Kung Member, is flow banded, and contains feldspar crystals up to 20 mm long.

Complex relationships between feldsparphyric rhyolite and porphyritic microgranite occur on the eastern shores of Yam O Wan (209 213). Gradational contacts between the two occur across both wide (several metres) and narrow zones. In addition, multiple dyke contacts are well exposed.

Tung Chung Wan. On the west side of the bay, a feldsparphyric rhyolite dyke, with aphanitic margins and a porphyritic microgranite centre, trends 055°, and intrudes fine-grained granite to the north (1038 1625).

Tsing Yi. Rhyolite dykes, crowded with feldspar megacrysts, are very common on Tsing Yi. They range from a few metres, up to 200 m wide, and extend for up to 1 km. In the north, around Chung Mei (2830 2350), a number of dykes, up to 40 m wide and trending generally eastnortheastwards, intrude tuff, granodiorite and granites. Rhyolite dykes clearly intrude megacrystic, fine-grained granite southwest of Chung Mei (2827 2327), and also tuff to its south (2842 2336), and granodiorite to its east (2844 2347). Further east, near Ko Tai (2905 2345), and southeast at Cheung Ching (2921 2300), feldsparphyric rhyolite intrudes medium-grained granite.

In the southern part of Tsing Yi the rhyolite dykes are generally rich in feldspar megacrysts. They are wider and more extensive than to the north, and trend easterly. A major group of dykes, the largest over 200 m wide, intrudes tuffs and is exposed in road cuts (2785 2216 and 2759 2191) south of Nam Wan. In one outcrop (2777 2205), the rhyolite is intruded by thin dykes of fine-grained granite. This group of dykes can be traced eastwards to the main

ridge of Tsing Yi. The dykes, exposed in cut-slopes and quarries in the southwest of Tsing Yi, are dominantly, richly megacrystic; they are narrower than the dykes south of Nam Wan and more irregular in form. Excellent contact relations are exposed in a quarry (2757 2112), where the rhyolite dyke has a core of sparsely megacrystic, fine-grained granite, and north of the Tsing Yi Road (2785 2133), where the dyke has a core of richly megacrystic fine-grained granite. Rhyolite dykes with abundant feldspar megacrysts occur on the cut-slope (2840 2153) north of the Power Station, and at Nam Wan Kok (2882 2122 and 2883 2167).

On the slopes (2770 2260) east of Sai Tso Wan, richly megacrystic dykes are rather narrow, trend in a northeasterly direction, and are usually cut by northerly-trending faults, although at one locality (2792 2242), a rhyolite dyke deflects along a fault of this trend for a short distance. The dykes on the northern cut-slopes of Sai Tso Wan are wider (up to 60 m) and trend, unusually on Tsing Yi, in a southeasterly direction. Contacts are well exposed at the west end of the cut-slopes (2761 2278), where a richly feldsparphyric rhyolite intrudes tuff and fine-grained granite.

North of Sai Tso Wan, around Liu To, Kam Chuk Kok and Shek Wan, the feldsparphyric rhyolite dykes trend northeasterly and can be very wide. Although most inland exposures are extremely weathered, the distinctive matrix and megacrystic texture of the rhyolites makes their identification relatively easy on the high ground of northwestern Tsing Yi. However, the dykes are best seen in roadside exposures between Sai Tso Wan and on the northwest headland of Tsing Yi. Around Kam Chuk Kok (2700 2300), the rhyolites intrude granodiorite, while further north they intrude tuffs.

Ma Wan. On Ma Wan, richly and sparsely feldspar megacrystic rhyolite dykes occur together throughout the northern and central parts of the island. On the south shore of Tung Wan, there are several rhyolite dykes with feldspar megacrysts up to 15 mm long. One dyke, 8 m wide, has basalt dykes, 1 m wide, along both of its margins (2450 2129), while a thicker dyke to the east (2461 2172) grades into fine-grained granite in its core. Similar gradations between richly feldsparphyric rhyolite and fine-grained granite occur around Cheung Tsui (2469 2368) on the north side of Tung Wan.

On the west coast of Ma Wan, south of Ma Kok Tsui, there are numerous easterly-trending, feldsparphyric rhyolite dykes, but they are narrower than in the outcrops to the north. Several have basalt dykes along their margins (2388 2315, 2390 2293). The presence of basalt xenoliths within the rhyolite suggests that the basalts are older. However, xenocrysts of alkali feldspar occur in the basalt xenoliths. These could have been derived from a parental feldsparphyric magma, but both syenites and quartzphyric dykes in the area also contain feldspar megacrysts.

A dyke complex, exposed on the headland of Ma Kok Tsui (2363 2330), includes richly and sparsely megacrystic rhyolites. The latter often form cores to the former, but richly megacrystic rhyolite also intrudes a large dyke of sparsely megacrystic rhyolite. On the northern shore (2375 2344) of the headland, abundantly feldsparphyric rhyolite, with an accompanying basalt dyke, forms the margin of a major, sparsely feldsparphyric rhyolite dyke, which varies to a fine-grained granite.

North of Shek Tsai Wan, the rhyolite dykes are mostly richly megacrystic, and trend northeastwards across Ma Wan. They have been traced inland through isolated exposures and corestones and in boreholes drilled for the Lantau Fixed Crossing Project.

Chek Lap Kok (prior to development). Feldsparphyric rhyolite dykes are scarce, and are restricted to the south of the island, where most occur in the southern peninsula. Texturally they resemble quartzphyric rhyolites more closely than comparable intrusions in north Lantau Island.

Feldsparphyric rhyolite is exposed in coastal sections south of Kwo Lo Wan, where two small dykes, 0.5 and 3 m wide, contain feldspars only up to 3 mm long. Similar dykes, closer to a quartzphyric rhyolite dyke swarm, have small but prominent feldspars. Abundant boulders of feldsparphyric rhyolite with larger megacrysts (around 20 mm), occur on the beach south of Ha Law Wan, and similar corestones are evident on the adjacent hillside.

Petrography

Feldsparphyric rhyolite (HK9234, 1103 1764), from north of Ha Law Wan, contains subhedral, embayed quartz crystals, up to 5 mm, and smaller feldspars, up to 3 mm, set in a very fine-grained groundmass.

Age Relations

The feldsparphyric dykes intrude tuffs of both the Yim Tin Tsai and Shing Mun formations, and all granite phases in the district except for the granite on Chek Lap Kok . They are rare within

the Lantau Formation, however, and since no dykes are known to cross-cut the fault that forms the eastern side of the Lantau Caldera, it is likely that most predate the main phase of caldera collapse.

The presence of xenoliths of basalt within the rhyolites strongly indicates that the feldsparphyric rhyolites post-date some basaltic dykes. Alkali feldspar xenocrysts within some of these xenoliths may have been derived from a contemporaneous feldsparphyric rhyolite magma, but syenites in the district (and even quartzphyric rhyolites) also contain similar feldspar megacrysts and could be the parental source.

Cross-cutting relationships between individual feldsparphyric dykes indicate that they were intruded over a long period of time. Their gradational relationships with porphyritic microgranite imply broad contemporaneity of the two magmas, which are essentially end-members of a textural, rather than a compositional spectrum.

Some quartzphyric rhyolite dykes, which are described below, cut feldsparphyric rhyolite dykes and are therefore younger. Also, unlike the quartzphyric rhyolites, the feldsparphyric rhyolites do not cut the fine-grained granite on Chek Lap Kok . Some basaltic and lamprophyric dykes clearly cross-cut the feldsparphyric rhyolites and porphyritic microgranites, and these are presumed to be associated with the phase of basaltic intrusion dated, using K-Ar isotopes, as Tertiary by Allen and Stephens (1971). Some quartz veins are also younger.

Quartzphyric Rhyolite

Distribution and Lithology

Quartzphyric rhyolite dykes are relatively rare in the district. They are usually no more than 5 m wide, are pale grey when fresh and are commonly extensively fractured. Typically, the lithology comprises small quartz megacrysts and feldspar phenocrysts, both up to 3 mm, and dark specks of chlorite in an aphanitic groundmass. The margins of these narrow dykes are often flow banded (Plate 29), and may be darker and finer grained than the main body of the dyke.

Quartzphyric rhyolite crops out mainly as northeast- and eastnortheast-trending dykes, which cut the granite country rock. Easterly- and northwesterly-trending dykes also occur locally. They form part of the dyke swarm that dominates north Lantau Island, and their emplacement was probably controlled by major, eastnortheast-trending extensional structures, including the North Lantau Fault.

Details

Cheung Chau. There are a number of thin, flow-banded quartzphyric rhyolite dykes on Cheung Chau, most of which intrude medium-grained granite. At one locality (2170 0897) on Pak Kok Tsui, a strongly flow-banded, quartzphyric rhyolite dyke about 0.5 m wide, trends 030°. It cuts a porphyritic microgranite dyke which has a slightly banded margin (Plate 30). Both dykes intrude medium-grained granite.

Chi Ma Wan. On the east side of the peninsula (2008 1015), a grey, fractured, quartzphyric rhyolite dyke, with quartz crystals up to 2 mm across, is exposed on the coast. It includes a large xenolith of medium-grained granite.

Sunshine Island (Chau Kung To). There are several quartzphyric rhyolite dykes on the south coast of the island. One, which is about 12 m wide, trends 040-050° and can be traced for nearly 200 m along the coast (238 137). It cross-cuts a feldsparphyric rhyolite dyke as well as medium-grained granite.

Kau Yi Chau. On the northeast tip (2618 1644), quartzphyric rhyolite dykes vary gradationally into porphyritic microgranite, and feldspar megacrystic rhyolite. Flow-banded quartzphyric rhyolite, with abundant small quartz phenocrysts, also grades into porphyritic microgranite about 300 m to the west.

Peng Chau. On the northern coast of Peng Chau, and on Tai Lei, there are numerous flow-banded quartzphyric rhyolite dykes. They are typically irregular in form, vary from 0-3 m wide along strike, and trend approximately eastwards. The quartzphyric rhyolite dykes cut both feldsparphyric rhyolite and medium-grained granite.

Tsing Yi. Quartzphyric rhyolite dykes have been recognised only in north and central Tsing Yi. Isolated dykes intrude granodiorite around Cheung Hong Estate (2864 2346 and 2885 2350), while several others, trending northeasterly within tuff, occur in the cut-slopes east of Sai Tso Wan. The main group of quartzphyric rhyolite dykes is exposed on the headland (2632 2387) north of Kam Chuk Kok, and in the roadway (2652 2390) that crosses the ridge. The dykes strike roughly eastwards. A larger dyke is exposed on the crest of the ridge further east (2700 2385), where it has been intensely kaolinized and was formerly worked for china clay.

Chek Lap Kok (prior to development). On the coast south of Ha Law Wan, a grey, quartzphyric rhyolite dyke trends northeastwards. It is flow banded near its irregular contact with the granite country rock. The centre of the dyke, which is around 10 m wide, is slightly coarser. It resembles microgranite and also contains abundant small megacrysts.

At Pak Sha Tsui, there are extensive exposures (110 169) of quartzphyric rhyolite which include several slivers of granite country rock adjacent to the flow-banded margins. These exposures probably form part of a multiple dyke swarm, up to 150 m wide. Most contacts with the granite are very irregular. South of Kwo Lo Wan, the same quartzphyric rhyolite dyke is exposed on the coast. It is cut by lamprophyre (1156 1827), has flow-banded margins, and intrudes granite.

East of Fu Tau Shan, quartzphyric rhyolite dykes occur in swarms up to 100 metres wide. They include prominent quartz crystals, up to 3 mm. Contacts with megacrystic, fine-grained granite are irregular. Individual dykes, trending eastnortheast, vary from 3-30 m wide. Typically (e.g. HK9040, 1180 1897), they are grey and porcellanous, with pinkish feldspar megacrysts, up to 3 mm across, and quartz, dominantly 0.5 to 2 mm.

Exposures of quartzphyric rhyolite west of the Sham Wan-Fu Tei Wan Fault are rare. One occurrence (1069 1840), about 500 metres southeast of the test embankment, is light greenish-grey, and contains megacrysts of quartz and subordinate feldspars, up to 3 mm, in a very fine-grained groundmass. Intrusive contacts with granite are sharp, and abundant quartz veins occur parallel to the margins. A similar dyke, exposed 200 m to the south (1077 1818), is cut by quartz veins and has a lamprophyre dyke and silicified granite along one margin. This same dyke can be traced to the eastnortheast, and was probably intersected in borehole L27/3427A (11069 18226) near the fault.

Petrography

Many small megacrysts, set in a very fine-grained groundmass, are typically seen in thin sections of the quartzphyric rhyolite (Plate 31, HK9040, 1180 1897). The quartz megacrysts are euhedral to subhedral, slightly embayed, and are 0.5 to 1 mm across. Sample HK9233 (1069 1840) has a similar texture and contains microperthitic alkali feldspar, with Carlsbad twins up to 1.5 mm wide. Plagioclase feldspars, of oligoclase composition, can be up to 2 mm across. There are scarce crystals of muscovite, biotite and an opaque mineral, around 0.2 to 0.5 mm. The groundmass is devitrified glass with secondary sericite, 0.02 to 0.05 mm across. Other samples of quartzphyric rhyolite are also devitrified, with radiating quartz needles and granophyric texture occurring as reaction haloes around the megacrysts.

Age Relations

The quartzphyric dykes intrude granite, feldsparphyric rhyolite dykes, porpyhyritic microgranite and the fine-grained granite on Chek Lap Kok. They are in turn intruded by much younger lamprophyre dykes, and are cut by quartz veins. Elsewhere in the Territory, they cut all other Mesozoic intrusive and extrusive rocks.

Basalt, Andesite and Lamprophyre

Distribution

Basic dykes are widespread within the various granites and rhyolitic dykes of the district. They

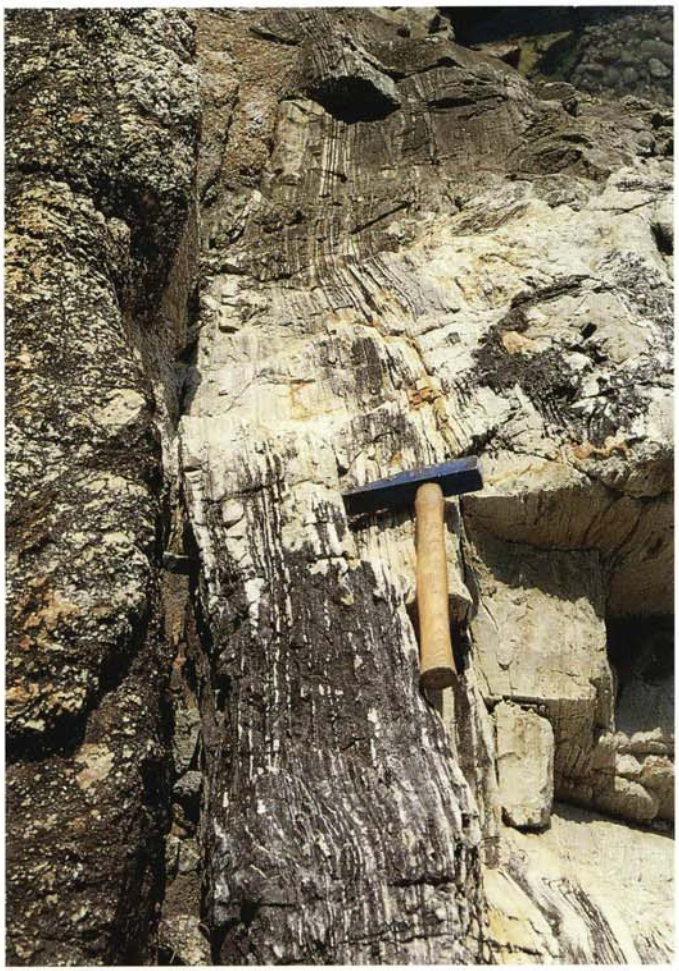


Plate 29 - Flow-banded Quartzphyric Rhyolite (1955 1406), Silver Mine Bay

Plate 30 - Strongly Flow-Banded,Quartzphyric Rhyolite Dyke Intruding a Porphyritic Microgranite Dyke (2170 0897), Pak Kok Tsui

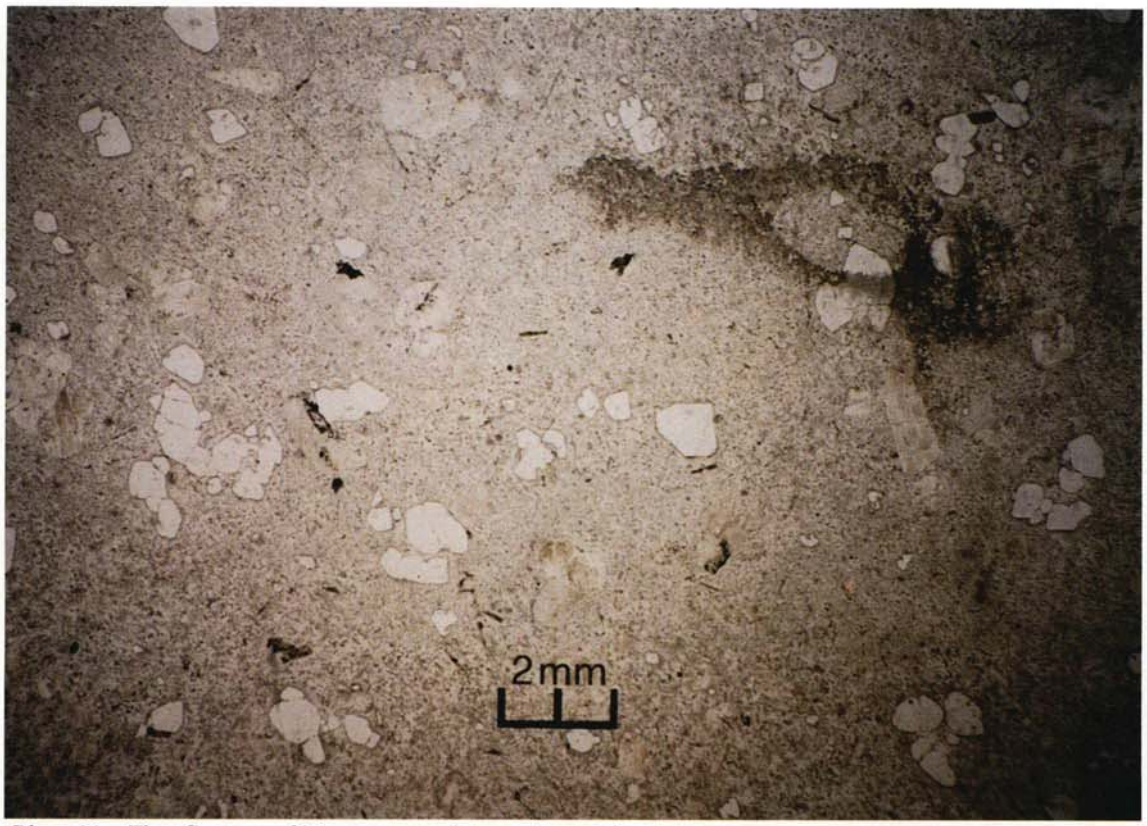


Plate 31 - Thin Section of Megacrystic Quartzphyric Rhyolite (HK9040) (1180 1897), from Chek Lap Kok; PPL

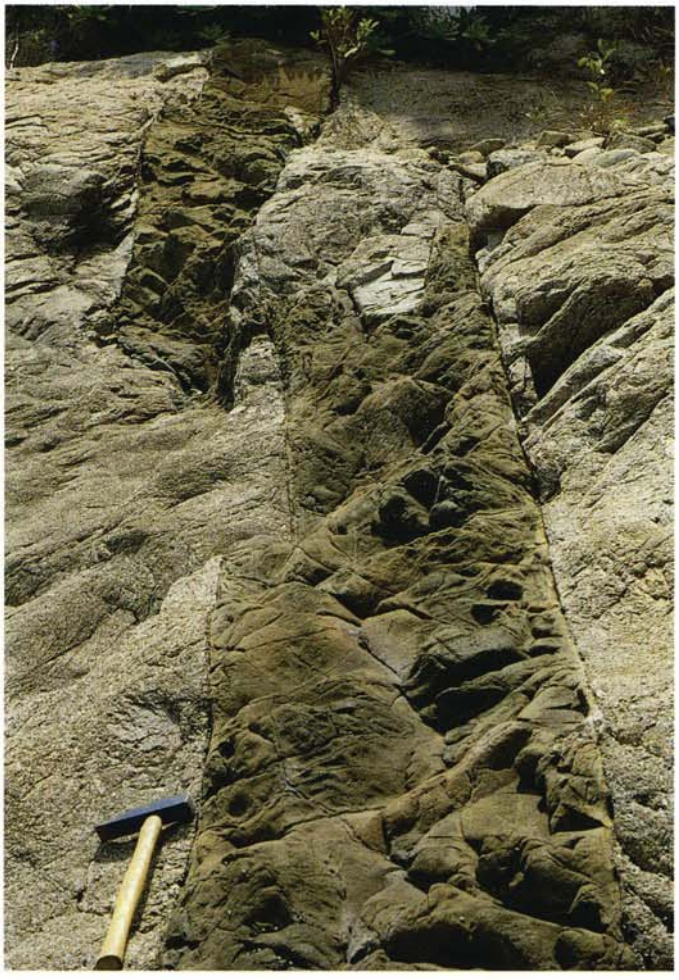


Plate 32 - Basalt Dyke in Granite (2079 1938), Penny's Bay (Chok Ko Wan)

also cut volcanic rocks of the Tsuen Wan Volcanic Group in the east, but not in the west. They have not been recorded either within lavas and tuffs of the Repulse Bay Volcanic Group of central Lantau Island, or in Carboniferous strata of west Lantau Island. They are generally thin, commonly ranging from 0.1 to 0.5 m in width (Plate 32), and are rarely more than a few metres wide. They may persist along strike, but generally, due to their preferential weathering, this cannot be confirmed, and exposures are largely restricted to coastal sections. Most are basaltic, or basaltic andesite in composition. However, they are all strongly altered, and this explains their low magnetic susceptibility, as the fresher lamprophyres have a high magnetic mineral content.

Details

Tsing Yi. Wide basalt dykes occur at only two localities on Tsing Yi. Around Lo Uk (2816 2376), basalt was intersected in several site investigation boreholes, and a substantial intrusion is inferred to strike northeasterly. To the south, in cut-slopes (2767 2282) north of Sai Tso Wan, a dyke about 8 m wide, with a northeasterly strike cross-cuts southeasterly-trending dykes of fine-grained granite and feldsparphyric rhyolite. In both cases, the basalt dykes vary texturally to fine-grained gabbro in their cores, and it is possible they are parts of the same extensive intrusion.

Elsewhere on Tsing Yi, basalt forms only minor bodies. Thin dykes crop out in shear zones on the cut-slopes (2790 2241) west of Sai Tso Wan, and intersect quartzphyric rhyolite at Kam Chuk Kok (2700 2304). On the headland west of Shek Wan, several thin dykes intrude tuffs and quartzphyric rhyolite, and they are accompanied by a narrow zone of Fe-Cu-Pb mineralization.

Ma Wan. On Ma Wan, basalt dykes are relatively numerous, but they are usually narrow, and intruded parallel to dykes of feldsparphyric rhyolite. Several occur on the west coast (2390 2300) of the island, north of Lung Ha Wan, where basalt dykes, 0.5-1 m wide, form the margins to rhyolite dykes which are up to 10 m wide. The same group of basalt and rhyolite dykes appears to be exposed along strike on the opposite coast of the island, at Tai Lung (2460 2327). It could be inferred that the rhyolite dykes are older than the basalt dykes, but at Lung Ha Wan (2390 2294), they contain xenoliths of basalt, although these in turn contain xenocrysts of alkali feldspar. Hence, in some cases, the two magmas could have been generated broadly at the same time.

Other minor basalt dykes on Ma Wan, occur around Nam Wan (2435 2270), where they intrude along the contact zone of the tuffs and the fine-grained granite. Thin dykes also occur in the north of the island, around Tam Shui Wan (2392 2378) and Pak Wan (2450 2395), where they intrude tuffs of the Yim Tim Tsai Formation.

Sha Chau. A completely weathered, sheared basalt dyke is exposed in the middle of Sha Chau (0659 2304), trending parallel to an earlier quartz vein and mylonitized zone in the granite.

Sha Lo Wan. A basalt, or microgabbro dyke, over 10 m wide and trending eastnortheast, is exposed (0735 1697) on the coast west of Sha Lo Wan. It is mafic-rich, has an aphanitic margin, and contains abundant hornblende, up to 4 mm long, set in a felsic groundmass (HK9309). This basic dyke is cut by a thin aplite dyke. About 90 m to the south, an easterly-trending basalt dyke, about 2.4 m wide, cuts the megacrystic, fine-grained granite. It contains needle-like phenocrysts of amphibole, and quartz amygdales up to 7 mm across, set in a glassy groundmass.

A garnet-bearing, dark green, metabasalt dyke crops out parallel to the eastnortheast-trending contact between megacrystic fine-grained granite and Carboniferous sedimentary rocks at San Shek Wan (0712 1613). The dyke, which intrudes granite, is about 1 m wide. It comprises pseudomorphs after feldspar, up to 3 mm long, set in an aphanitic groundmass. The garnet crystals indicate skarn-type mineralization, and are up to 3 mm across.

Tin Sam. A greenish-grey, eastnortheasterly-trending basalt dyke, 1.5 m wide, cuts weathered, fine- to medium-grained granite on the ridge (0993 1628) south of San Tau. The basalt is poorly foliated, sub-parallel to the dyke margins, and also contains pyrite.

On the coast (0957 1705) northeast of Tin Sam, there is a northnortheast-trending basalt dyke that cuts fine-grained granite. The dyke is 0.6 to 1 m wide, and contains quartz amygdales and small garnet crystals. A small xenolith of altered garnetiferous granite was also noted.

An eastnortheast-trending basalt dyke cuts fine-grained granite country rock on the east side of Hau Hok Wan (0892 1691). It is 2.4 m wide, and greenish-grey, with black augite phenocrysts, up to 3 mm across, set in a felsic groundmass. 80 m to the southwest, there is a dark green, aphanitic, basalt dyke, 0.4-1 m wide, which bifurcates towards the north. It trends northeastwards and is closely jointed.

Lam Chau. An altered basalt dyke crops out on the western side of Lam Chau (0847 1801). It intrudes a fine-grained, partly epidotized segment of the granite on Chek Lap Kok. The dyke is greenish-grey, with altered feldspar phenocrysts up to 2 mm long, set in a chloritized, quartz-sericite groundmass (HK9211). It is 0.3 m wide and trends northnortheast, cutting a thin quartz vein in the granite. There is no apparent displacement of the vein, indicating that the dyke was not intruded along a fault zone.

Tung Chung. In cut slopes 400 m eastnortheast of the ferry pier, there was a temporary exposure (1172 1656) of a completely weathered basic dyke. The dyke, approximately 3 m wide, trends northnorthwest, and cuts the medium-grained granite on Lantau Island. Similar dykes, trending northnorthwest, occur on the eastern side of Chek Lap Kok, near Kwo Lo Wan.

Northwest of Tung Chung (1374 1751), near Kei Tau Kok, a bifurcated, 0.1 to 0.3 m wide basalt dyke cuts feldsparphyric rhyolite dykes. The dyke is grey and aphanitic, and dominantly consists of plagioclase and epidote, with some interstitial quartz (HK8576). It trends eastnortheast, parallel to the dominant trend of the older rhyolite dykes.

Pak Mong. Along the coast (1462 1767) west of Pak Mong, there is an exposed basalt dyke, 0.3 m wide, trending eastnortheast, and parallel to the porphyritic microgranite country rock. The basalt is dark greenish- to bluish-grey, partially epidotized, and varies from aphanitic margins to a porphyritic centre. Feldspar phenocrysts are up to 10 mm long, and quartz xenocrysts are up to 4 mm. There are also chloritized mafic phenocrysts, set in a groundmass dominated by small feldspar laths, but including chlorite and opaque minerals (HK8573).

On a ridge about 1 km southwest of Pak Mong, there is a bluish-grey basalt, or microgabbro dyke, which intrudes feldsparphyric rhyolite. The dyke, whose thickness cannot be determined, probably trends east, varying to southeast, across the ridge. Petrographically, the dyke is not porphyritic, and has a well-developed, sub-ophitic texture of plagioclase and augite. It also contains chlorite and opaque minerals, and small quantities of interstitial quartz. Minor amounts of pyrite can be seen in hand specimens (HK8318).

Yam O Wan. Rarely, basalt dykes intrude the tuffs and rhyolite dykes around Yam O Wan. They do so especially at the contact between these two rocktypes or, between two rhyolite dykes. For example, a 0.3 m wide basalt dyke (2094 2132) occurs along the contact between two northeast-trending feldsparphyric rhyolite dykes on the east side of Yam O Wan.

At Yam Tsai Wan, there are a number of thin basalt dykes cutting both the Shek Lung Kung member tuff and feldsparphyric rhyolite dykes. The basalt dykes are typically 0.3 to 0.5 m wide, and trend generally between northwest and northnorthwest. In a 0.5 m wide, easterly-trending dyke, within tuff (1982 2117), there is a small, medium-grained granite xenolith.

In the hills east of Yam O Wan, there is a 300 m long, 20 to 30 m wide basalt, or lamprophyre dyke (217 212). The hillside is strewn with debris from the dyke, which cuts both tuffs and a rhyolite dyke. The rock is light grey, with a thin, light brown-weathering rind around exhumed corestones. Petrographically, the basalt contains abundant mafic minerals and subordinate plagioclase laths, and includes a small proportion of quartz in the groundmass. The dyke trends roughly east-west, parallel to the dominant dyke trend in the area.

Tai Ho Wan. A swarm of narrow, northerly-trending basalt dykes crops out on the east side of Tai Ho Wan (159 181). The dykes are 0.2 to 1 m wide, and intrude rhyolite dykes. They are typically olive green and aphanitic, with quartz-filled amygdales 3 to 4 mm across. The swarm is probably intruded along the northerly trending fault zone that marks the eastern margin of the Lantau Caldera and which extends through Tai Ho Wan.

Tai Che Tung. A large, easterly-trending andesite, or basalt dyke, crops out on the summit of Tai Che Tung (188 195). The greenish-grey dyke is only seen as hard, well-rounded corestones with exfoliation shells. It contains prominent feldspar laths, up to 1 mm, set in a groundmass with a grain size of around 0.1 mm. The dyke cuts feldsparphyric rhyolite and porphyritic microgranite dykes, which also trend dominantly east to eastnortheast.

Discovery Bay. There are few basic dykes exposed in the Discovery Bay area. Slope formation in 1989, for the Phase IV development at Hai Tei Wan, exposed a deeply weathered, 2 m-wide lamprophyre, or basalt dyke, trending eastnortheast (2061 1741). The rock is bluish grey when fresh, brown when weathered, and cuts fine- to medium-grained granite on Lantau Island.

Hei Ling Chau. Basalt dykes have been recorded at only two localities on Hei Ling Chau. One trends eastnortheast, and is only 0.5 m wide. It is foliated, and contains small granite xenoliths (2242 1328). The other (2263 1264) trends eastsoutheast and is 2 m wide. Both dykes cut granite.

Silver Mine Bay. On the headland southeast of Silver Mine Bay, a 15m-wide basalt dyke cuts feldsparphyric rhyolite dykes. The basalt dyke is exposed on the beach and probably lies in the east- to northeast-trending depression behind the beach. The slightly weathered exposures comprise hard, greenish-brown, equigranular basalt, with a grain size of less than 0.5 mm.

At Man Kok Tsui, at the eastern end of Silver Mine Bay, a wide basalt dyke intrudes feldsparphyric rhyolite. The basalt is hard and bluish-grey when fresh, and weathers to form well-developed corestones in a brown, clayey matrix (Plate 33). The dyke, which trends northeast, is up to 10 m wide.

Peaked Hill (Kai Yet Kok). On the northern shores of Peaked Hill, a thin, foliated basalt dyke cuts an irregular, impersistent, quartzphyric rhyolite dyke. Both dykes cut the medium-grained granite. The basalt trends southeast and is about 0.1 m wide.

Soko Islands. West of Siu A Chau Wan (0851 0457), there is a 5 m wide, northerly-trending basalt dyke cutting coarse-grained granite . The dyke is grey when fresh, and has a sharp, non-foliated margin to the west, and a fractured margin to the east. Petrographically, the rock (HK9562) is dominated by laths of sericitized plagioclase, but also contains augite, biotite, chlorite and opaque minerals. The grain size is generally 0.1 to 0.5 mm, although there are some mafic phenocrysts up to 2 mm across and some secondary pyrite crystals. The even-textured groundmass also contains xenocrysts of quartz, up to 6 mm long.

A 5 m-wide basalt dyke, trending approximately northwards, is exposed on the north coast of Ma Chau (0757 0375), a small island southwest of Siu A Chau. The dyke, dipping 80° to the west, comprises fresh, dark grey corestones set in a deeply weathered matrix. The grain size of the basalt is mostly less than 0.2 mm, and it displays a good ophitic texture in thin section (HK10018).

Chi Ma Wan. Basalt dykes have been noted at a few localities on the Chi Ma Wan peninsula. Most are in the east of the area, where the basalt dykes cut both rhyolite dykes and granite. At Ha So Pai (1984 0968), a 0.6 m-wide, eastnortheast-trending basalt dyke intrudes equigranular, medium-grained granite. The dyke is parallel to a feldsparphyric rhyolite dyke to the north. A thin sliver of medium-grained granite, 0.3 to 1 m wide, occurs between the two dykes.

Near the easternmost tip of the peninsula (1998 1009), an 8 m-wide, dark, greenish-grey basalt, or microgabbro dyke cuts a quartzphyric rhyolite dyke and medium-grained granite. The basalt dyke lies both along the contact between these two older rocks, and cuts across them. The grain size of the basalt ranges from 0.1 to 1 mm, and feldspar laths and augite crystals form a well-developed sub-ophitic texture (HK8351, Plate 34). The rock also contains quartz amygdales, or xenocrysts.

Cheung Chau. A few easterly-trending basalt dykes, cutting medium-grained granite, crop out on the eastern coast of Cheung Chau, and a bluish-grey, aphanitic to very fine-grained basalt dyke, about 1.7 m wide, is exposed on the south coast near Chi Ma Hang (2211 0758). North of Coral Beach (Tung Wan Tsai), there are two, dark grey basalt dykes. The smaller of the two (2165 0909) is only 1.5 m wide, whereas the larger, exposed 110 m to the north, is about 10 m wide. Both dykes have a grain size of 0.05 to 0.1 mm, with plagioclase feldspar laths up to 0.3 mm long. Although there is some augite, the dominant mafic minerals in these slightly altered basalts are chlorite, epidote and opaque minerals.

Chek Lap Kok (prior to development). There are many small basalt dykes which cut granite, and rhyolite dykes on the northeastern end of the peninsula. A spheroidally weathered basalt dyke, 2.5m wide and trending southsoutheast (1156 1827), clearly cuts both megacrystic, fine-grained granite, and a flow-banded, quartzphyric rhyolite dyke that intrudes the granite. About 100 m to the north, a swarm of basalt dykes also intrudes the granite (1151 1738), as well as an easterly-trending feldsparphyric rhyolite dyke. These basalts are dark greenish-grey, cariously weathered, mafic-rich, contain altered feldspar megacrysts, and are 0.5-1.5 m wide. Similar basalt and lamprophyre dykes, about 0.5m wide, crop out on the north coast of Fui Yiu Wan. They trend variably east to eastsoutheast (Plate 35, 1203 1964). The lamprophyre follows the dominant joint trend in the area. Two thin basalt dykes, about 0.3 m wide, and deeply weathered and foliated, cut fine-grained granite west of Fu Tei Wan. They are themselves cut by a small, sinistral fault (1083 1814), with an offset of about 0.3 m (Plate 40). The dykes are also cut by an aplite dyke in the granite.

Petrography

The basaltic dykes are typically very fine-grained and altered, but one sample (HK10684, 1152 1810) (Plate 36) has a slightly coarser-grained groundmass with a grainsize of 0.3 to 0.5 mm. This microgabbro has a well-defined sub-ophitic texture of sericitized plagioclase and pyroxene, and includes phenocrysts of sericitized plagioclase up to 2 mm long.

A typical, finer-grained sample of basalt (HK9237, 1156 1827) from the peninsula south of Kwo Lo Wan is a dark green, very fine grained, and speckled with mafic phenocrysts. The phenocrysts, seen in thin section, are composed of secondary chlorite and calcite, and the groundmass contains abundant hornblende, with plagioclase and epidote.

Lamprophyre dykes in hand specimen can display prominent, dark green, mafic phenocrysts, and overall are mafic-rich relative to the basaltic dykes. A thin section (HK10859, 1117 1986) of the rock contains abundant augite and hornblende, with some plagioclase which is mostly less than 1 mm long (Plate 37). Chlorite replacement of lath-like mafics is common, and there are no feldspar phenocrysts. The composition of the lamprophyre is probably vogesite.

Age Relations

Allen & Stephens (1971) considered that the basalt dykes were emplaced during separate Upper Cretaceous and Tertiary phases. They cut the granite (Late Jurassic-Early Cretaceous) country rock, but are themselves cut by small, northwest-trending faults. The lamprophyre dykes also cut rhyolite dykes and granite, and are considered to be of a similar age to the basalt dykes. At one locality (1051 1920), north of the test embankment, a lamprophyre is cut by a quartz vein about 0.25 m wide.

Aplite and Pegmatite

Distribution and Lithology

Small impersistent dykes of aplite are occasionally found in the granites. For example, they occur in small groups at a number of places around the coast of Chek Lap Kok, where the dykes are leucocratic, with a markedly equigranular grain size of around 0.5 mm. They can be from 25 mm to 5 m wide, but are commonly around 0.25 m. The aplite and granite are closely related in age and genesis. Similarly, aplite dykes occur in medium-grained granite on Cheung Chau (Plate 38).

Pegmatite, or very coarse-grained granite, with crystals over 20 mm across, is rare, and generally occurs as pods or lenses too small to be shown on the published map of the district. However, an irregular, roughly east-west trending pegmatite is exposed west of Fu Tei Wan (1075 1824). Pegmatite is only found within granite, and formed at a late stage during the cooling of the plutons.

Quartz veins

Quartz veins occur in rocks of all types and all ages in the district, but were clearly emplaced during several phases. A vein chronology has not been established in the district, and only the most substantial quartz veins are shown on the published maps.

Details

Chek Lap Kok (prior to development). Quartz veins are widely distributed throughout the island, and mostly trend east to eastnortheast. They cut the granite country rock and most minor intrusions, and are generally narrow, ranging from stringers a few millimetres wide, to veins up to 0.3 m wide. Quartz veins are especially common in and around the kaolinized granite east of the test embankment. The quartz veins commonly form upstanding ribs in the deeply weathered granite. The thin veins tend to separate along cracks on joint faces to produce mosaic-like sheets of quartz. Soil creep bends and displaces these sheets to form debris trails downslope.As well as discrete veins, there are places where the granite country rock has been silicified. To the south of the test embankment, in a coastal exposure (1072 1835), the fine-grained granite country rock has been finely veined and silicified in a zone, at least 1 m wide, which trends southsoutheast.

Petrographically, the veins typically comprise massive white crystalline quartz. Euhedral crystals are rare, although crystal aggregates up to 0.2 m across occur, with individual crystals up to 45 mm across (HK9555, 1091 1912).

Plate 33 - Corestone Development in Basalt Dyke, Intruded into Feldsparphyic Rhyolite (2025 1414), at Man Kok on the Northeastern Side of Silver Mine Bay

Plate 34 - Thin Section of Basalt (HK8351) (1998 1009), from Chi Ma Wan; XPL

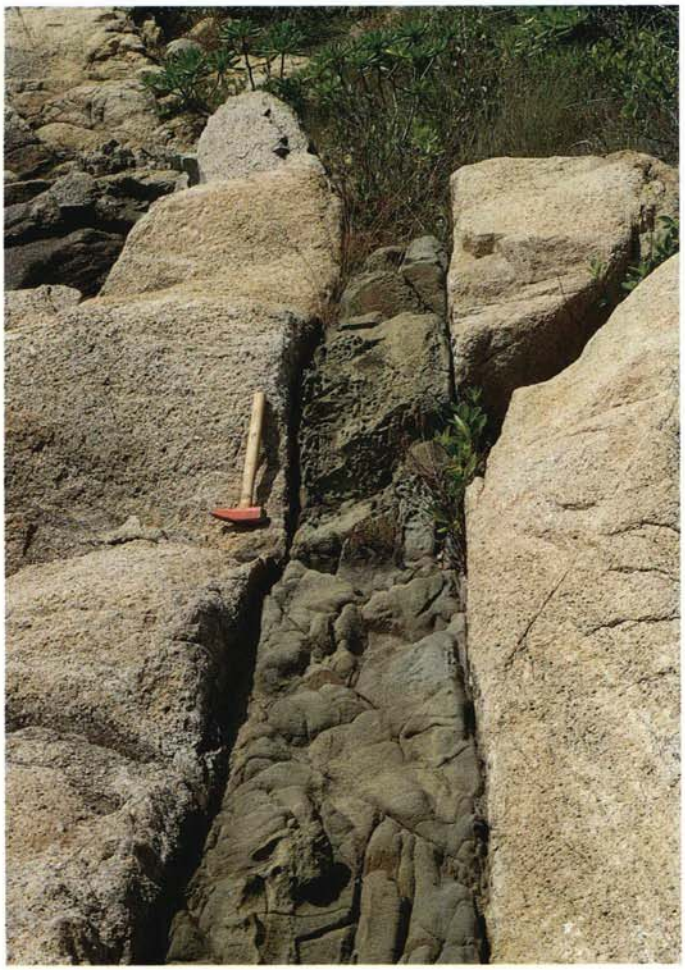


Plate 35 - Lamprophyre Dyke Trending East, Intruding Megacrystic Fine-grained Granite (1203 1964), Fui Yiu Wan

Plate 36 - Thin Section of Very Fine-grained Basalt (HK10684) (1152 1810), from Chek Lap Kok; XPL

Plate 37 - Thin Section of Lamprophyre (HK10859) (1117 1986), Chek Lap Kok; XPL plus ¼λ plate

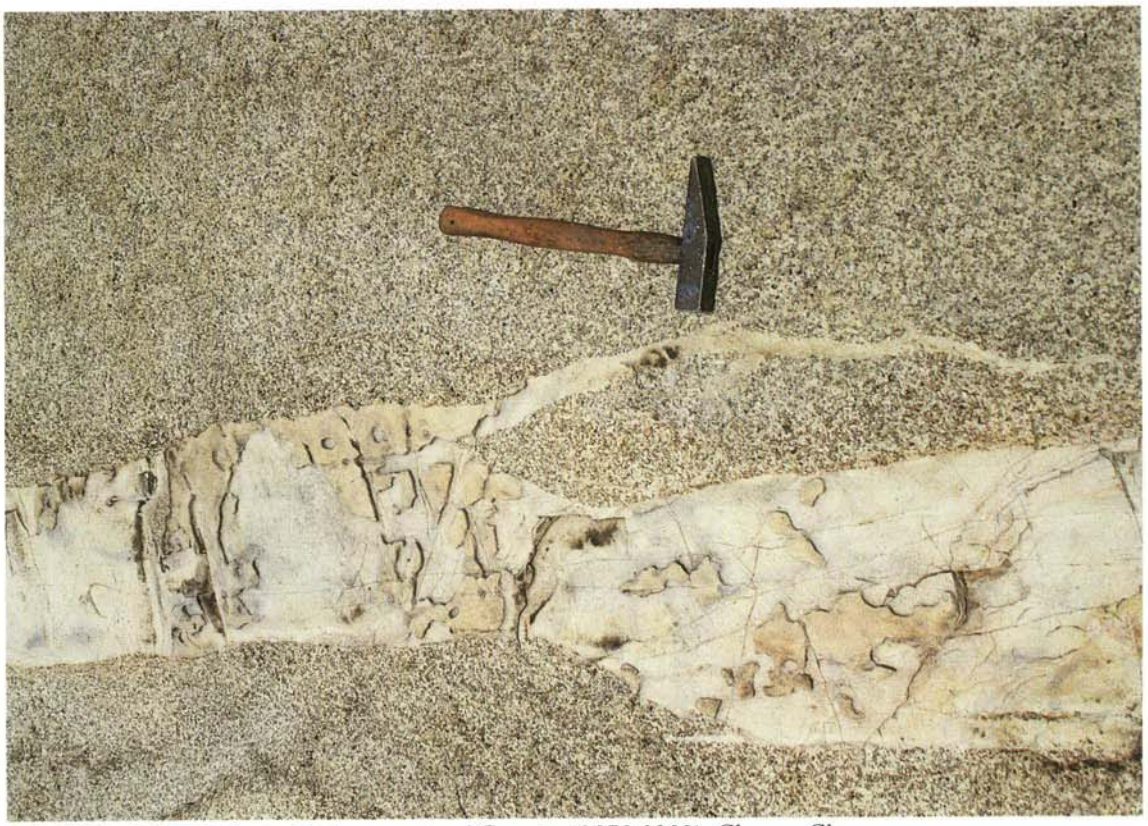


Plate 38 - Aplite Dyke in Medium-grained Granite (2070 0902), Cheung Chau

Chapter 7
Structure

Introduction

The solid geology of the Lantau district is dominated by late Jurassic igneous rocks. The major structural features of the district also date from this period. The magmatism, of which the development of the Lantau Caldera is the most obvious expression in the district, is a local representative of the voluminous silicic volcanic and plutonic zone that extends along the broad coastal belt of southeastern China. The belt is also characterized by a northeast-trending fold and fault zone and includes structurally complex basement terranes. The Jurassic regional tectonism and magmatism are related to the Yenshanian Orogeny which exploited and reactivated basement structures.

The Lantau district, and Hong Kong in general, lie within the major, northeast-trending Lianhua Shan Fault System within the Yenshanian orogenic belt. The fault zone comprises numerous individual faults and shear zones, of which thrusts and sinistral strike-slip faults are the dominant components. They typically have curvilinear traces, tens to hundreds of kilometres long. Post-Yenshanian faulting, which was largely brittle, is also evident on Lantau Island. The main faults in the Hong Kong area are shown in Figure 9.

Most of the major events in the district's structural evolution occurred during a relatively short period in the Late Jurassic, and include the following principal structural elements: reverse faulting involving basement rocks; structures related to Jurassic granitoid plutonism, dyke emplacement and the evolution of the Late Jurassic Lantau Caldera; and post-caldera faulting of three main orientations. The case for and against neotectonics is also briefly examined.

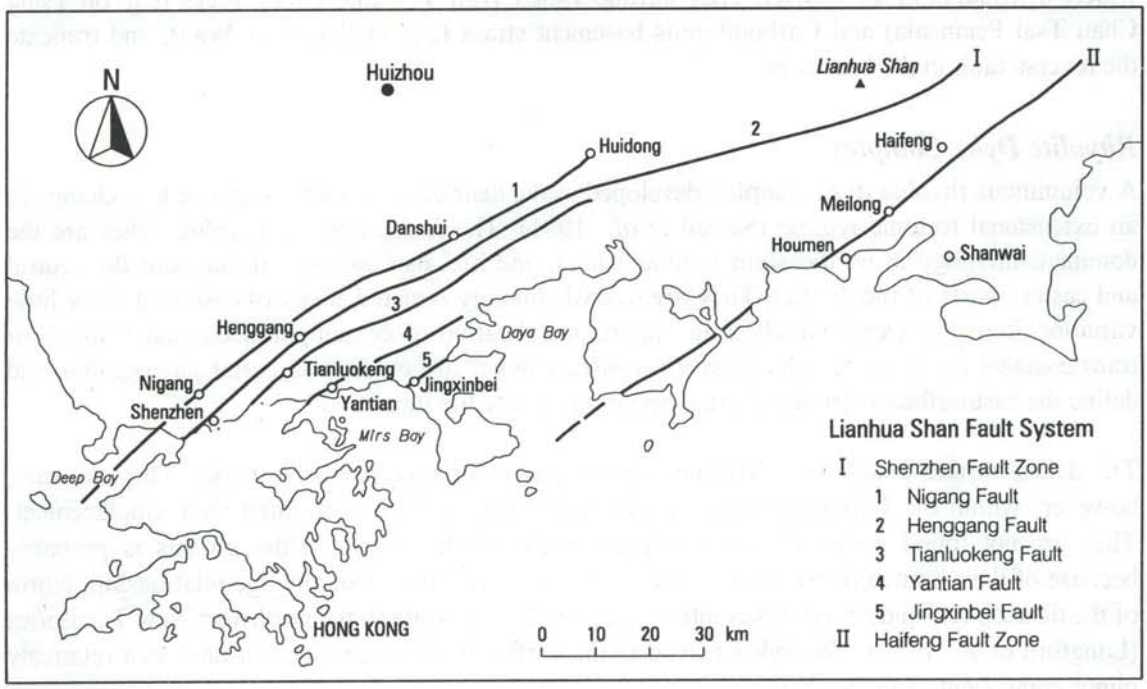


Figure 9 - Main Faults in the Vicinity of Hong Kong (after Lai, 1993)

Pre-Yenshanian Structure

Within the district rocks that pre-date Yenshanian magmatism, are regarded as structural basement. These include the Carboniferous sedimentary rocks, exposed on western Lantau Island and at The Brothers islands, and correlated with the Mai Po Member of the Lok Ma Chau Formation in the northwestern New Territories (Langford *et al.*, 1989).

Pre-Yenshanian folding of basement strata is inferred from limited bedding measurements and younging directions. Details of folds on East and West Brother islands are described below. On Lantau Island, the basement structure is complex, and probably includes tight folding, although this has not been resolved. No consistent pattern of deformation was identified and it seems likely that Yenshanian faulting and pluton emplacement have obscured any earlier trends.

Yenshanian Structural Development

The earliest major structural event recorded in the district is reverse faulting, which placed the Palaeozoic basement over strata of the Jurassic Tsuen Wan Volcanic Group. The contact between the two is the Tai O Fault, exposed between Tai O and San Shek Wan on Lantau Island. Though generally shown as a reverse fault on the published map (Sheet 9), the structure was modified by later development of the Lantau Caldera (see below). The faulted contact between Palaeozoic sedimentary rocks and the volcanic rocks is locally vertical (e.g. 7790 5680). Foliation adjacent to the fault is poorly developed in a zone tens of metres wide.

In the New Territories, Carboniferous rocks have been similarly thrust, along the San Tin Fault, over the Jurassic Tsuen Wan Volcanic Group. Foliation spatially associated with the fault occurs in a very broad zone. The thrust, which was probably directed to the south or southeast, has been interpreted as Yenshanian in age by Langford *et al.* (1989).

Early Intrusive Rocks

Reverse faulting of the basement was followed by an early phase of granite intrusion. These granites, and minor granodiorite, are generally medium- or fine- to medium-grained, and are widely distributed in the district. They intrude Tsuen Wan Volcanic Group rocks (e.g. on Tsing Chau Tsai Peninsula) and Carboniferous basement strata (e.g. at San Shek Wan), and truncate the reverse fault in the basement.

Rhyolite Dyke Complex

A voluminous rhyolite dyke complex developed in the district as an early response to a change to an extensional tectonic regime (Sewell *et al.*, 1991). The feldsparphyric rhyolite dykes are the dominant lithology in northeastern Lantau Island, and are also common throughout the central and eastern parts of the district. They are overwhelmingly oriented eastnortheast, and show little variation from this trend, which is an important indication of contemporaneous extensional, or transtensional orientations. The erosively resistant dykes are evident on aerial photographs and define the eastnortheast structural grain apparent on satellite images.

The dykes intrude Tsuen Wan Volcanic Group and other early intrusive rocks. They are rare, however, within the Lantau Formation, which probably largely post-dated their emplacement. They are not found within the Carboniferous rocks of the district, although this is probably because of their limited distribution to the north and west rather than any age relationship. North of the district, feldsparphyric dykes intrude Carboniferous strata in the northwest New Territories (Langford *et al.*, 1989). The dykes extend to the northeast of the district, but only as a relatively minor component of the geology.

The Lantau Caldera

The clearest structural feature on the maps is associated with the distribution of the Lantau Formation, (assigned to the Repulse Bay Volcanic Group), which occupies most of western Lantau Island. The outcrop of the Lantau Formation is fault bounded in all but the south, where it conformably overlies volcanic rocks of the Tsuen Wan Volcanic Group. Bedding attitudes in sedimentary intercalations are variable, but the regional outcrop pattern suggests that the sequence dips broadly northwards at 20-30°. The steeply faulted northwestern margin, against Carboniferous rocks, has been discussed above. To the north, part of the faulted contact (west of Tung Chung) has been intruded by quartz syenite, but from age relationships it is inferred to have been originally faulted against granite. East of Tung Chung, and along the eastern contact, rhyolite dykes and granite are abruptly truncated by faulting against the outcrop of the Lantau Formation. This largely fault-bounded outcrop pattern is interpreted as a primary volcanotectonic relationship, and the entire structure is inferred to be a caldera (Chapter 4) or similar volcanotectonic collapse structure. From stratigraphic and structural relationships, the caldera is younger than other adjacent volcanic rocks.

The internal structure of the caldera is markedly asymmetrical, and appears to reflect the pattern of bounding faults. Hence, in contrast to the northward-dipping, and conformable succession in the south, the internal structure is more complex northwards, although poor exposure limits the scope of this interpretation. Examples of this complexity include: abrupt changes in bedding orientation, lithology and degree of hydrothermal alteration; folding; local unconformities; and faulting. All of these features are interpreted as primary, and related to the evolution of the caldera, rather than to any later event.

Associated Syenitic Rocks

Four small, fine-grained quartz syenite stocks and several minor dykes ring the Lantau Caldera. In the northwest, contact metamorphism of rocks adjacent to the caldera, indicate that syenite intrusion post-dates the main caldera development.

Late or Post-Yenshanian Faulting

The major faults included in the preceding discussion were generally identified and mapped from displaced contacts in the solid geology. Numerous other faults in the district are mainly inferred rather than observed because of poor exposure. They are located on the basis of minor offsets, lineaments on air-photographs (and other geomorphological evidence), ground investigation data, geophysics, extrapolation from outside the district and, where possible, field observation. Fault traces tend to coincide with Quaternary-filled valleys. However, as the published maps do not show faults beneath Quaternary deposits, they tend to understate their importance. The faults post-date the development of the Lantau Caldera. The structure of offshore areas (i.e. in the northwest and southeast of the district) is poorly known. Correlations with structures in the rest of the Territory are tentative.

The late faults of the district have been subdivided into a number of sets based on their orientation. The sets are apparently related, so are therefore described together. The inter-relationships between sets, including their age-relationships are likely to be complex, so that the relationships suggested below should be considered tentative. Figure 10 presents a sketch of the solid geology, showing faults inferred from all available data.

Northwest-trending Faults

A series of clear, northwest-trending photolineaments are regularly spaced along the length of Lantau Island. The Kap Shui Mun Channel Fault, between Lantau and Ma Wan islands,

separates areas of different lithologies, while other faults in the set offset major geological boundaries; for example the Tung Chung Fault displaces the contact between Tsuen Wan Volcanic Group and the Lantau Formation. This set also appears to offset some other fault trends, including the eastnortheast-trending North Lantau Fault Zone (discussed below).

A magnetic survey of North Lantau Harbour (Electronic and Geophysical Services, 1991) has also identified a series of northwest trends along which anomalies are displaced, and these are interpreted as faults.

Major quartz veins, up to 25 m wide, at Sha Lo Wan, Yam Tsai and Tsing Chau Tsai also trend northwestwards and are likely to be associated with northwest-trending faults. In some places the veins contain breccia of country rock; for example the granite blocks in a quartz vein at Hau Hok Wan

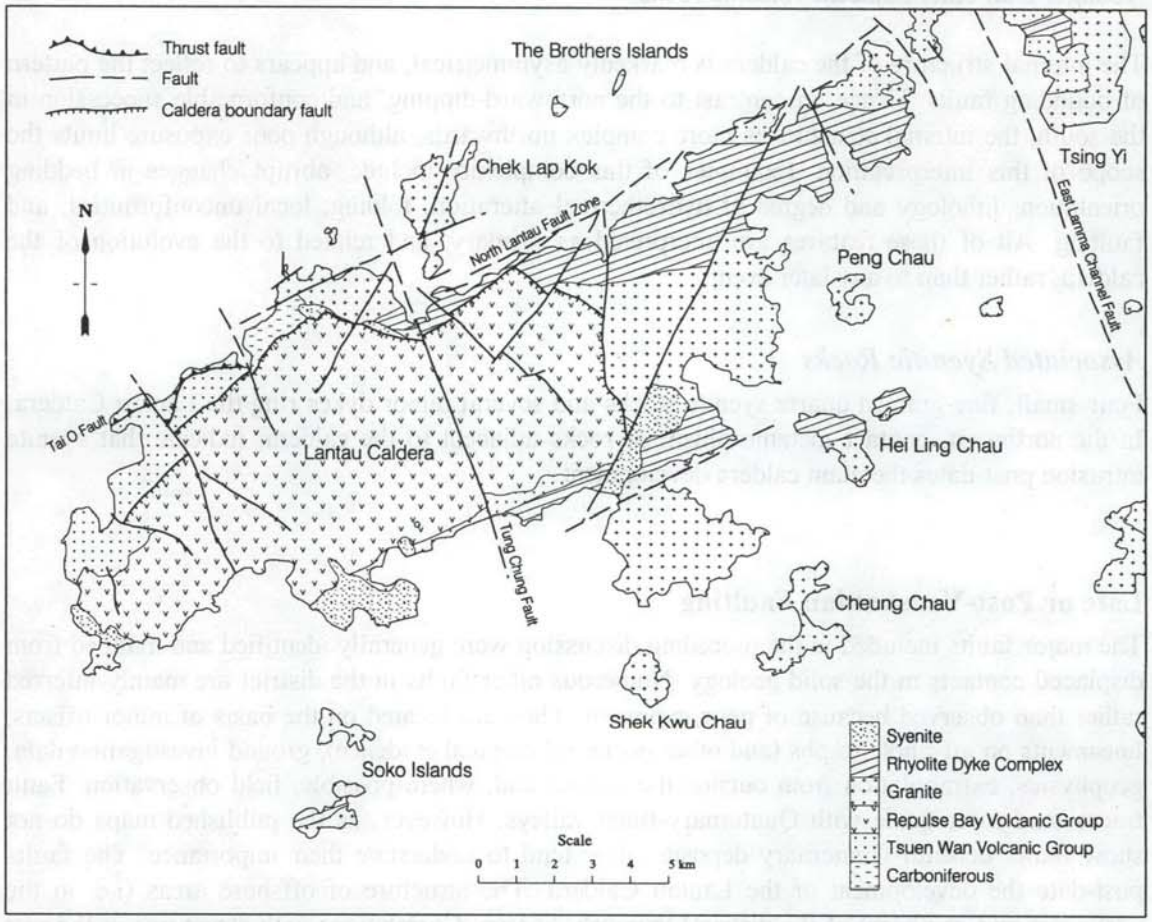


Figure 10 - Solid Geology of the District, Showing the Main Faults Inferred from All Data Sources

Northeast-trending Faults (and photolineaments)

Strong northeast-trending lineaments on air-photographs and satellite images are inferred to be one set of faults. One of the clearest, between Yam O and Pui O, apparently sinistrally offsets granite and syenite contacts by about 1 km. Some similarly-trending, small-scale faults also show apparent sinistral displacements (Plate 39). Other lineaments in this set cross major geological boundaries with no apparent offset, such as the lineament west of Tung Chung which crosses boundaries between granite and syenite, and syenite and Lantau Formation.

The northeast- and northwest-trending faults may have been active conjugate structures, moving broadly synchronously. Near Yam O, the northwest-trending fault through Penny's Bay and the northeast-trending Yam O-Pui O Fault define a triangular block of rhyolite dykes from which Tsuen Wan Volcanic Group rocks are largely absent, whereas in adjacent blocks, they are dominant although they are intruded by many rhyolite dykes. It is inferred that the wedge between the two faults has been faulted downwards.

Eastnortheast-trending Faults

Few eastnortheast-trending faults were directly observed during field mapping, but as airport-related developments have proceeded along the northern coast of Lantau Island, cuttings and ground investigations have encountered major fault zones of this orientation.

Excavations on Yam Tsai, for the North Lantau Expressway, intersected an eastnortheast-trending zone, 100 m wide, that is intensely jointed, and includes zones of brecciated rock greater than 10m wide, and deeply weathered zones up to 20 m wide (Franks & Roberts, 1995). The contrasting styles of deformation indicate that the fault set had several stages of development. These faults form part of the North Lantau Fault Zone identified by Langford (1994), which follows the northern coast of Lantau Island. On newly-reclaimed land near Tung Chung, ground investigations revealed similarly complex structures related to this fault zone. They include fault slivers of Carboniferous sedimentary rocks (including marble and skarn), brecciated zones and deep weathering. These faults show the oldest demonstrable activity along the zone, since the Carboniferous strata were incorporated into the fault zone prior to major plutonic activity. Later activity brecciated granite, rhyolite dykes and Tsuen Wan Volcanic Group rocks.

West of Tung Chung, faults striking 070° occur near Sha Lo Wan, and north of Chek Lap Kok. Langford (1994) postulated a further, similarly-trending fault, the Tai O - Sui Lam Fault, and on the southern side of Lantau Island, a strong photolineament trends 070° across the Chi Ma Wan peninsula.

Eastnortheast-trending faults were not active after the development of northwest-trending structures, as offsets at several northwest-trending faults cut the fault zone into segments, and northwest-trending quartz veins cross the fault zone without any displacement (e.g. at Yam Tsai).

North-trending Faults

In the granite headland west of Tung Chung a series of north-trending faults (striking between 000° and 020°) have been mapped, mainly along coastal sections. The faults, which are not associated with well-developed photolineaments, are 1 to 10 m wide, and intensively jointed, with zones of breccia and common quartz veins. The Chek Lap Kok Fault (Langford, 1994) is a northnortheast-trending fault, which has a significant topographic expression (Plate 40) and offsets dykes on Chek Lap Kok.

North-trending faults have not been recognised in other parts of the district, although they are present in the Castle Peak area, in the western New Territories, along a continuation of the trend of the present fault set.

The north-trending faults are offset by a few metres across eastnortheast-trending faults at Hau Hok Wan, and the north-trending fault set is therefore thought to have been active during the last stages of movement on the eastnortheast-trending faults.

Neotectonics

Fault activity in the region around Hong Kong diminished during the Cenozoic. Little evidence of Quaternary faulting onshore was found during fieldwork. Numerous seismic profiles offshore have also failed to identify recent faulting. Raised beach deposits are widely mapped, but their presence is more likely to be caused by storm deposits in the Holocene than tectonic movement.

The Guangdong Seismological Bureau has identified two active, northwest-trending faults in the Pearl River Estuary area (Y.Z.Ding, Guangdong Seismological Bureau, pers. comm., August 1994). One of these, the Humen Fault, lies on the eastern margin of the estuary, and the other lies to the west of Macao. The southsoutheastwards continuation of the Humen Fault is inferred to pass through the district offshore to the northeast of Lantau Island, thence along the Tung Chung Fault, before continuing offshore again, beyond the Territory to the Dangan Islands. Ding stated that Holocene activity had been demonstrated at two sites on the Humen Fault, using seismic profiles. One site is near Shekou Peninsula and the other near the Dangan Islands. At the latter site, the last movement is thought to have occurred between 2000 and 4000 years ago.

Plate 39 - Foliated Basalt Dyke Cutting Fine-grained Granite (1083 1814). The Dyke is Sinistrally Displaced 0.3 m by a Northeast-trending Fault, near Fu Tei Wan

Plate 40 - View Northeast towards Sham Wan along the line of the Chek Lap Kok Fault (11 18), prior to development of Chek Lap Kok

Chapter 8
Metamorphism and Alteration

Introduction

Metamorphism comprises a broad spectrum of post-emplacement fluid, thermal, and mechanical processes which change the primary chemistry, mineralogy and texture of rocks. Alteration processes are similar, but involve less extreme physical and chemical gradients, and are usually more localised. However, there is no clear demarcation between metamorphism and alteration, and they can be regarded as end-members of a continuous spectrum. Metasomatism is commonly used to describe processes of alteration involving the passage of hot fluids, derived internally or externally through rocks, but the term alteration is preferred in the following descriptions.

It is beyond the scope of this memoir to describe comprehensively all forms of metamorphism and alteration in the district. It has, however, been possible on the published sheets to indicate, using overprint, the spatial limits of some areas in which the rocks have, in broad terms, been metamorphosed. In most instances, these rocks have undergone limited mineralogical and chemical changes, and can equally be regarded, therefore, as altered.

Hydrothermal alteration is probably more widespread than any other form of alteration in the district, but examples of contact metamorphism, caused by heat from adjacent intrusions, are also common, albeit generally localised. Regional metamorphism affected limestones, known only in boreholes, and possibly Carboniferous rocks in general. Many rocks have been texturally changed by mechanical processes under the influence of far-field, or local stress, and are therefore dynamically metamorphosed.

Superficial weathering also alters mineralogy and chemistry, but its effects are more appropriately described in Chapter 9, within the context of other surface processes.

Hydrothermal Alteration

Hydrothermal alteration is probably the dominant secondary alteration process in the district. It can be related principally to the evolution of the Lantau Caldera, and to the emplacement of granites during the Jurassic and Cretaceous. In addition, it was associated with the emplacement of other intrusions, including the feldsparphyric rhyolite dyke complex in northeast Lantau Island, and is spatially related to faults in the district. Further types of hydrothermal alteration, resulted in the kaolinization of granites on Chek Lap Kok, and greisenization of granites.

Hydrothermal alteration is extensive within the confines of the Lantau Caldera, and affects all rock types, and has been mapped in several areas. It is depicted on the published maps under the broad category metamorphism and is characterised by silicification, the development of quartz veins, iron staining and recrystallization.

One of the largest mapped areas of metamorphism is to the south and east of Tai O. It occurs within a corridor, up to 2 km wide, which stretches from Fan Lau in the southwestern tip of Lantau Island, northeastwards to Sze Shan (0512 1270), and beyond, tapering rapidly to the southeast of Sham Wat. It affects a wide range of rock types within the Shing Mun and Lantau formations. The northwestern limit of this area of metamorphism coincides in part with the faulted boundary of the Lantau Caldera, but has not been recognised in all Lantau Formation

rocks adjacent to the caldera margin. Hydrothermal alteration has not been recognised within the Palaeozoic sedimentary rocks northwest of the caldera.

Around Pok To Yan (1360 1592) and Por Kai Shan (1397 1633), in the northeastern corner of the Lantau Caldera, an area of alteration up to 2 km across affects all lithologies in the Lantau Formation, including rhyolite lavas, crystal and other tuffs and tuffites and siltstones. The main area of alteration transgresses stratification and faults within the caldera, but has not been recognised in the feldsparphyric rhyolite dykes or in the medium-grained granites adjoining the northeast-, and northwest-trending, caldera-related, faulted contacts of the Lantau Formation. The alteration is therefore broadly controlled by northeast- and northwest-trending faults. Adjacent, subsidiary, northeasterly-trending narrow zones of alteration (141 154, 143 155) may also be crudely stratabound.

A relatively narrow, elongate corridor of alteration (080 157 to 102 153) borders the southerly margin of a syenite dyke along a westnorthwest-trending section of the northern margin of the Lantau Caldera. In addition to alteration in rocks of the Lantau Formation, a small area of medium-grained granite is also affected on the southern side of the syenite. However, the area of alteration does not extend into similar, or other granitic rocks, or feldsparphyric rhyolite dykes north of the syenite. Hence, it is unlikely that the alteration is contact-related to the emplacement of the syenite dyke. A subsidiary, narrow zone of selective alteration (087 157) strikes parallel to the main zone, and to flow-banding within lavas of the Lantau Formation.

Another major zone of hydrothermal alteration extends from Fan Lau, eastnortheastwards along the southern coast of Lantau Island. It splits into discrete, northeasterly-trending lenses, developed within a 3 km wide corridor, and these can be traced towards Nei Lak Shan (088 138), although not beyond its lower, southwestern slopes, and to the southern flank of Lantau Peak (098 123). In both instances, the zones of alteration are truncated by eastnortheast- or northeast-trending faults.

In summary, the hydrothermal alteration is preferentially developed towards the margins of the caldera, most notably in the north and southwest, and along northeast-trending zones within the caldera in the southwest. This distribution can be interpreted in terms of silica-rich hydrothermal fluids being preferentially channelled along the fault system created, or enhanced by development of the caldera. The steep, northeast-trending faults within the caldera, and the caldera-bounding structures, appear to have been the dominant fluid pathways.

Kaolinization

Before reclamation, an area of kaolinized granite occurred east of the former test embankment at Chek Lap Kok, and is sharply bounded to the east by unaltered fine-grained granite, exposed in a stream bed (1112 1901) within 50 m of the kaolinized zone (Langford, 1994). The western boundary of the kaolinization is unclear due to surface workings (see also Chapter 10). Kaolinization also occurred near the northern tip of Chek Lap Kok, east of Sham Wat, where it was mined in association with extensively developed quartz. The white, clay mineral kaolin is an alteration product of feldspar and mica, and formed as a result of the passage of silica-rich hydrothermal fluids through the granite, rather than by surface weathering (Langford, 1994). The fluids were probably derived from the granite itself, during its later stages of cooling (Plate 41).

Contact Metamorphism

Contact metamorphism related to emplacement of granitoid intrusions and dykes is common, but rarely sufficiently extensive to be shown on the published maps of the district. The main reason for this is that

the majority of rocks in the district are of rhyolitic and rhyodacitic composition, and are of similar mineralogy to the main intrusive rocks. Hence, their mineralogy was relatively stable at the temperatures of the intruding magmas. The one notable exception is on Green Island (297 162), in the extreme east of the district, where hornfelsing related to a granitoid intrusion affected coarse ash crystal tuffs of the Mount Davis Formation (but not younger medium-grained quartz syenite dykes).

Ruxton (1957) identified tourmaline, muscovite, iron-stained clinozoisite and incipient andalusite in rocks on The Brothers islands and attributed their presence to contact metamorphism, although no major intrusion is exposed nearby. Allen and Stephens (1971) recorded a similar mineral assemblage in Lok Ma Chau Formation sediments in northwestern Lantau Island, in strata they considered to be 'hard and baked'. They interpreted the assemblage as being due to contact metamorphism related to underlying intrusive rocks at no great depth. However, the spatial relationship with possible overthrusting onto the Jurassic volcanic sequence suggests a dynamic metamorphic association, or hydrothermal alteration associated with the adjacent Lantau Caldera.

Graphite beds which occur on West Brother island were mined from an area in the core of a syncline. There, the graphite has lustrous foliation surfaces and is interpreted as thermally metamorphosed by an unexposed intrusion.

Various examples of skarn mineralization have been noted in boreholes sunk through buried marble east of Tung Chung Wan, e.g. boreholes TC65 (12196 16639), H12/17357 (12112 16599) and east of East Brother island (Borehole NS1/14460, 17111 21750). The skarns, comprising greenish-grey assemblages of magnetite, variously with epidote, chlorite, augite and plagioclase, occur where marble is intruded by feldsparphyric dykes and granites, and is mainly a consequence of contact metamorphism. Skarn, including magnetite, garnet, vesuvianite, diopside and epidote, has also been reported by Peng (1978) at San Shek Wan (0714 1612) in a zone 5 m wide at the contact between foliated sandstones and megacrystic, fine-grained granite.

Regional Metamorphism

Allen and Stephens (1971) considered that regional metamorphism was of greater significance in the Territory as a whole than had earlier workers. They proposed that the Carboniferous Lok Ma Chau Formation had been regionally metamorphosed during the Mesozoic, but prior to granitoid emplacement. Bennett (1984b) interpreted the regional metamorphism of the Lok Ma Chau Formation as of greenschist facies and also suggested the possibility that the formation could have been metamorphosed at an earlier date, before it was tectonically emplaced during the Jurassic.

Regional metamorphism is not widely developed at surface within the district. However, in boreholes to the north of Lantau Island, marble has been recognised, and much of the offshore area to the north of Lantau Island may be underlain by the marble, which also extensively underlies the western New Territories and extends northwards into Guangdong Province. The recrystallization of limestones of Carboniferous age to marble, is therefore a regional-scale metamorphic process.

Regional metamorphism in the western New Territories is primarily associated with thrusting of the Palaeozoic basement onto the Jurassic Tsuen Wan Volcanic Group (Langford *et al.*, 1989). A similar thrust relationship has been interpreted in northwest Lantau Island, although the thrust fault was subsequently modified during development of the Lantau Caldera. However, regional metamorphism related to this structure is less evident in the district than in the New Territories, although the sediments of the Lok Ma Chau Formation have been described on the published

maps as metasandstones and metasiltstones. Foliation is sporadically developed near the faulted contact (Chapter 7) both in the Carboniferous sediments, and in the footwall volcanics of the Lantau Formation. The foliation, or cleavage, has resulted from the preferred alignment of mainly micaeous minerals, due to their physical rotation, and, or to growth of secondary minerals (especially sericite and biotite). Allen and Stephens (1971) considered, alternatively, that the Palaeozoic sediments had been contact rather than regionally metamorphosed.

Mylonites have been observed mainly on an exposure scale within granitoid country rocks, parallel and subparallel to eastnortheast-trending feldsparphyric rhyolite dykes in the east of Lantau Island. Occasionally, zones of mylonitic rocks are sufficiently wide, and laterally continuous, to be shown on the published maps of the district. These rocks were formed where extremely high stresses or strain rates, typically within a shear zone, caused wholesale and extreme fragmentation, as well as new mineral growth.

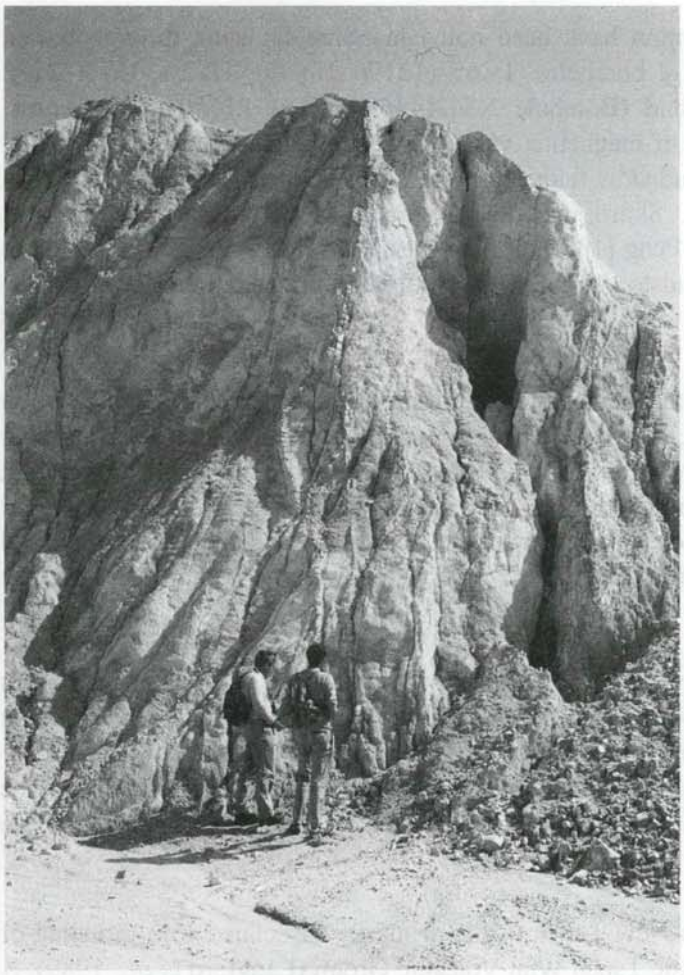


Plate 41 - Deeply Weathered and Highly Kaolinitized Granite Intruded by Thin Quartz Veins, in an Old Kaolin Mine (1104 1901), East of the Test Embankment, Chek Lap Kok (Prior to Development).

Chapter 9
Superficial Geology

Introduction

The superficial deposits of the district form two broad categories: widely distributed, stratified units, characteristic of the offshore area and more restricted and irregular onshore deposits (Figure 11). Estuarine deposits and mud flats of the intertidal region are included with the onshore deposits. The boundary between onshore and offshore deposits is taken arbitrarily at the pre-reclamation, or natural coastal low water line, and the relationship between the two is shown in Figure 12. Available evidence suggests that the superficial deposits in the district accumulated during the Quaternary period.

The most important onshore superficial sediments in the district are fluvial and colluvial, including mass wasting deposits. These deposits continue offshore, usually beneath marine deposits. This chapter also describes weathering both of the common rock types and superficial deposits.

Onshore Superficial Deposits

Classification and Distribution

The onshore superficial deposits are classified according to their inferred mode of formation. Bennett (1984a) recommended the division of onshore transported superficial deposits into the layered, fluviatile sequences, which include alluvium, and mass wasting deposits (colluvium). Mass wasting deposits can be subdivided into slightly transported and substantially transported categories, although the former are unmappable at the scale of the present survey. They include creep deposits, minor landslip features and virtually *in situ* boulder fields. The substantially transported category has been separated into slope deposits and talus (rockfall deposits).

The onshore alluvium and slope deposits are of Pleistocene, or Holocene age, and are differentiated on the map. Slope deposits occur in isolated upland valleys, and as more extensive accumulations on lower slopes, where they usually merge imperceptibly into the alluvium. Both deposits are composed of clay, silt, sand and gravel in varying proportions, while the slope deposits generally also contain cobbles and boulders. Talus or rockfall deposits have a very limited distribution in the district, the largest deposits being found near Lantau Peak, with minor occurrences below small free faces and sea cliffs at several other locations. They are dominantly composed of angular boulders.

Beach deposits are laterally extensive accumulations of sand and gravel, extending inland from the low water mark. They are found in sheltered areas along most coastlines. Boulder beaches occur on exposed coasts where erosion has winnowed the fines from a weathered cliff talus or slope deposit, leaving a coarse lag. In places, it has been possible to differentiate raised beaches as a distinct feature, rising up to 6 mPD. These may have formed during a period of slightly higher sea level, but in most cases they are probably storm beaches related to typhoon conditions. In the absence of beach sand there is usually a distinctive line between rock and offshore deposits that can be seen on aerial photographs. A darker mottled phototone formed by irregular, marine

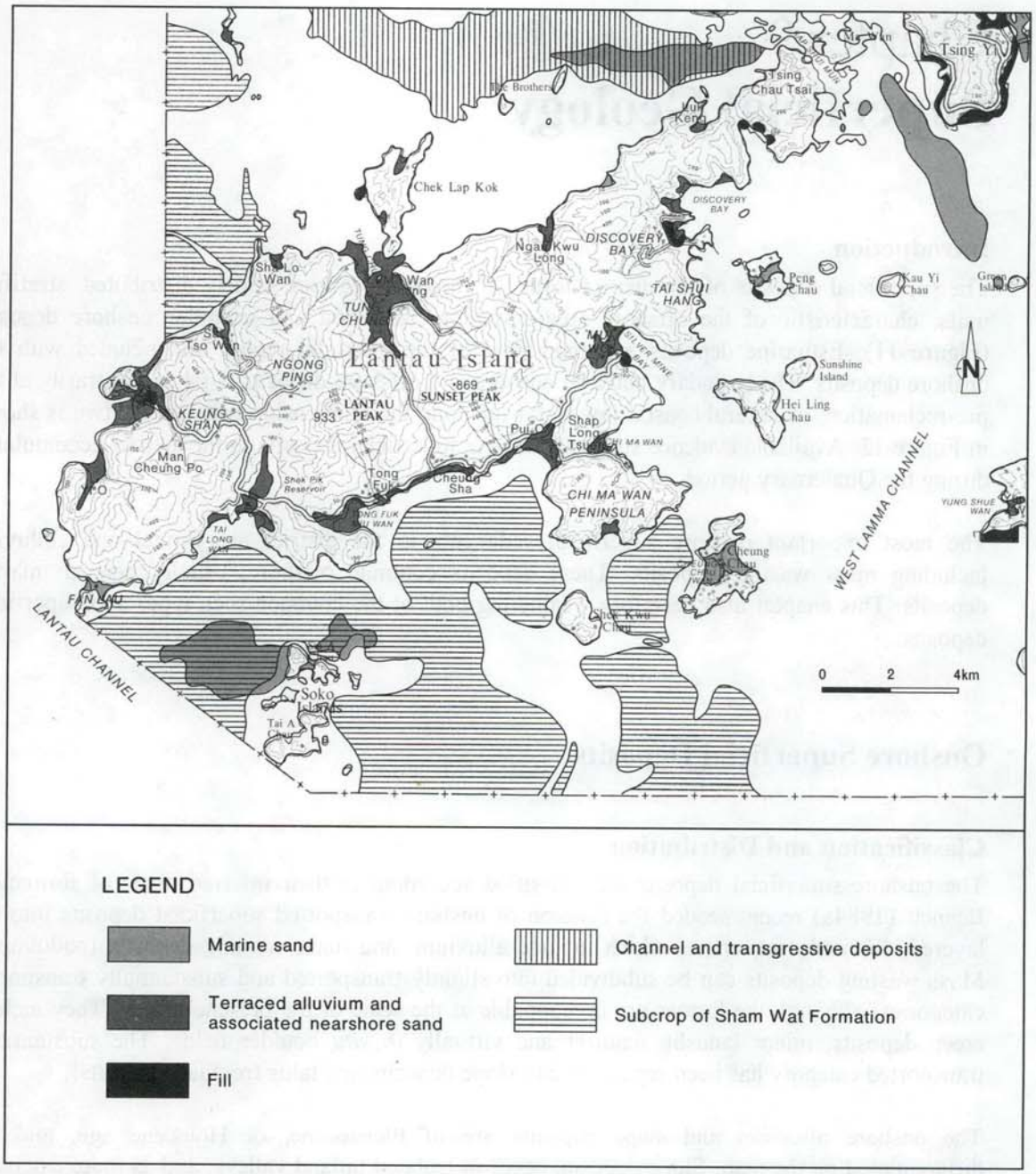


Figure 11 - The Distribution of Onshore and Offshore Superficial Deposits in the District

vegetation-covered rock has a sharp boundary with smooth bare marine mud at the edge of the littoral zone (low water mark).

The onshore area has been substantially extended by reclamation, particularly around Tsing Yi and, most recently, along the north Lantau Island coast and around Chek Lap Kok, in relation to the new airport development. Fill bodies have been mapped separately, both where they cover the pre-reclamation coastline, and where they are associated with major engineering projects such as dams and roads.

Alluvium

Alluvium is rarely seen in section in the district, and can usually only be described from site investigation boreholes and auger holes. The deposits consist mainly of well-sorted to semi-sorted clays, silts, sands and gravels.

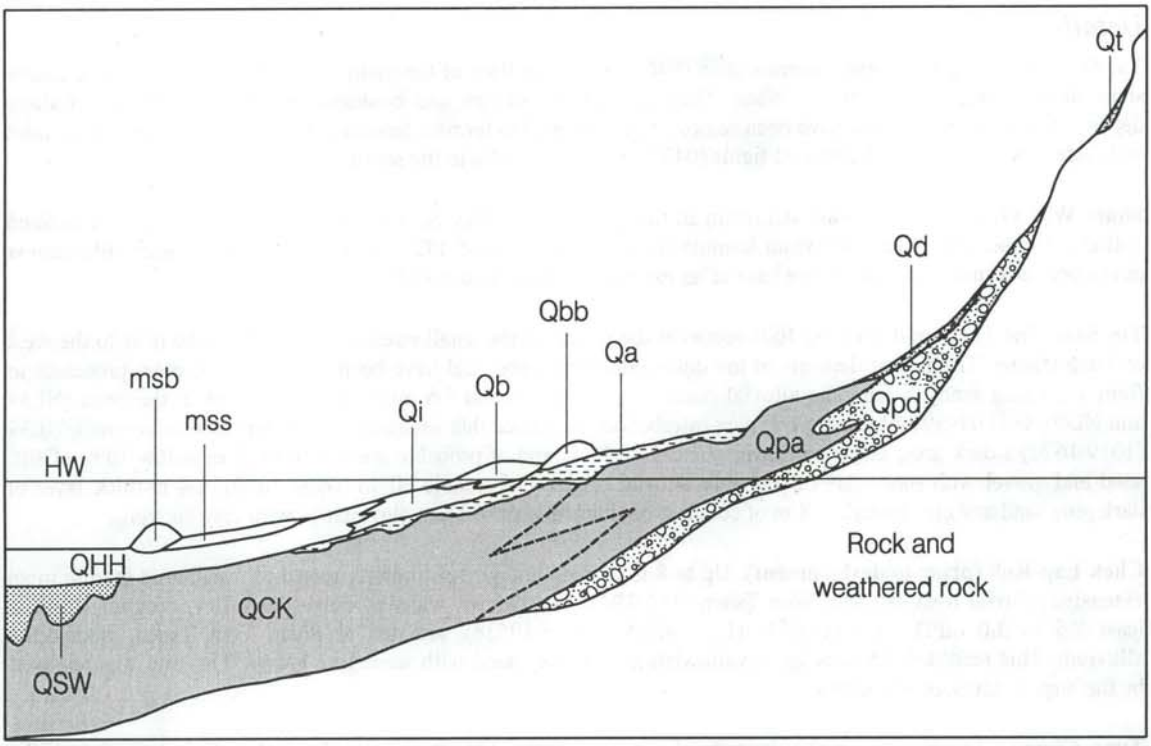


Figure 12 - Schematic Section Relating Onshore to Offshore Superficial Deposits.

Colours vary from grey to yellowish-brown, depending on the nature and proximity of the bedrock source and the degree of weathering. Where the source is granitic or dyke rocks, sand-size material predominates, while clayey, clast-rich alluvium derives from volcanic rocks.

Two ages of alluvial deposits are recognised. The late Pleistocene deposits are found in extensive, elevated, fluvial terraces, with the Holocene alluvium largely confined to the recent stream courses that are incised by up to 7 m into the terrace surface. The lithofacies of the late Pleistocene fluvial terrace deposits vary across the outcrop. Near the foot of hills, the deposits consist mainly of semi-sorted, yellowish-brown to orange, gravelly, silty sand which is probably derived by slopewash from the adjacent slopes. In the upper valley sections these deposits commonly pass laterally into more bouldery Pleistocene slope deposits. In the distal plains the fluvial terrace deposits are characterized by mottled red, yellow, brown and white, well-sorted clayey sandy silt with some sand layers.

In general, deposits of Holocene alluvium are relatively low-lying, reaching a maximum height of c.10 mPD, and are usually narrow, cutting into the surrounding Pleistocene terraced alluvium. The deposits comprise gravelly sand in the upper stream courses with some subrounded boulders, and yellowish-brown, well-sorted clayey sand, or silt, in the lower courses. At several localities along the coast, the streams are dammed by sand bars or spits, behind which lagoonal deposits have formed, as for example at Pui O. Small patches of hillside alluvium have also been mapped. These occur in narrow valleys in restricted areas, are generally only 50 to 100 m wide, and are less than a kilometre long.

Because of the steep, rugged topography which characterises the district, alluvium tends to be only locally developed. Lantau Island is characterised by short, steep valleys, mostly choked with bouldery debris deposits. With the exception of the Tung Chung and Shek Pik valleys, alluvium is generally limited to small deposits at seaward ends of valleys, occurring either as short linear valley fills, or wide fans along the coastal zone.

Details

Tai O. Alluvial deposits form a narrow strip (046 128) on the floor of the main valley at the base of an extensive sheet of slope deposits below Sze Shan. They are rich in cobbles and boulders, being mostly reworked slope deposits from which the fines have been removed. Alluvium also forms a terrace (039 131) in the west of the inlet and underlies a large area of enclosed fields (042 123) as a fan delta to the south.

Sham Wat Wan - Sha Lo Wan. Alluvium in the Sham Wat Valley occurs as a very narrow strip, with isolated outliers of raised Pleistocene alluvium forming flanking terraces (065 142). In the Sha Lo Wan Valley, alluvium is developed as a small fan delta at the base of an extensive debris deposit (079 167).

Tin Sam. The Tin Sam delta (101 167) occurs at the mouth of the small stream draining from the hills to the west of Tung Chung. The fluvial deposits of the delta extend offshore, and have been modified by coastal processes to form a fringing sandy beach. The alluvial plain is mostly at around 5.5 mPD. Two boreholes in the delta (NL39 and NL40, GIU 04459) intersect a complex interbedded sequence that includes marine deposits. In borehole NL39 (1019 1670) a dark grey, clayey silt layer about 3 m thick, and of probable marine origin, lies below 10 m of silt, sand and gravel with some clay of probable alluvial origin. In borehole NL40 (0990 1690), a 4 m-thick layer of dark grey sand and clay underlies 8 m of cobbles, boulders and gravel in a clay matrix with clay horizons.

Chek Lap Kok (prior to development). Up to 8 m of sand and gravel formerly rested on weathered granite in an extensive alluvial tract at Sham Wan Tsuen (115 194). The deposit widened down the valley, dropping from at least 7.5 to 3.0 mPD. One borehole (L15/3427A, 11508 19528), situated at Sham Wan Tsuen, intersected alluvium. This recorded 7.5 m of light, yellowish-grey ,clayey sand with some fine gravel. This site was removed by the airport development works.

Tung Chung. The most extensive deposits of alluvium in the district occur in the east and west streams of the Tung Chung Valley. Pleistocene alluvium infills the western valley to form a raised terrace from 400 to 500 m wide, and extending inland for about 2000 m. It reaches an elevation of almost 20 mPD, forming an extensive, northerly-inclined surface covered with fields on the valley floor. The terraces grade up into coarse, bouldery debris on the surrounding slopes and, except where there is a marked break in slope, the boundary is difficult to distinguish. Few sections expose the deposit, but away from the foot of the hillslopes, where the material is coarse and contains cobbles and boulders, the deposit is mottled red and yellow sandy silt with some sand lenses and layers. Holocene alluvium form a series of narrow strips, less than 100 m wide, adjacent to the modern stream channel incised in the older terrace by up to 3 m.

Alluvium in the eastern valley is very restricted. A thin, continuous strip of alluvium lines the modern channel with detached remnants of the Pleistocene alluvium forming isolated terraces along the valley sides. The combined deposits are less than 100 m wide.

The alluvial fan at Ma Wan (113 150) comprises the eluviated distal extremities of adjacent slope deposits. It is dominated by cobbles and boulders, and has been incised by a recent stream. The deposit is narrow, and is fringed by Holocene beach sand and mangroves. The surface of the fan is exposed in the intertidal region. It is probably of late Pleistocene age.

West Brother island (prior to development). The southern tip of the island was dominated by a cobble beach (246 211), which formed the reworked part of a debris fan from the centre of the island. The slope deposit, possibly fluvial in part, was well exposed near the mine, where it was preserved beneath a concrete platform.

Pak Mong. An extensive area of flat, coastal alluvium (150 176) grades inland into slope deposits that feed down the two valleys.

Ngau Tau Wan - Tai Ho Wan. Behind the eluviated, raised sandy beach is a mangrove swamp that merges southwards into an alluvial flat (159 172). The boulder-strewn river channel cuts down into this flat by 2 m or more. A sharp break of slope indicates the base of the surrounding slope deposits.

Yi Pak - Discovery Bay. Very few mappable deposits of alluvium occur on the northeastern end of Lantau Island. Several minor deposits were identified at Tso Wan (237 218), Fa Peng (237 213), Pa Tau Kwu (236 203), Penny's Bay (225 204 and 215 209) and Sam Pak (199 191). The largest are at Yi Pak (194 185) and Discovery Bay (194 178). At Yi Pak, the deposit is a fan at the seaward end of an extensive, dendritic valley-fill debris deposit that has accumulated behind a raised bar feature at the back of the bay. The stream has an outlet against the hillside. Similarly, at Discovery Bay, the alluvium is backed up behind a raised bar, the stream flowing southwards at the foot of the hillslope behind, and parallel to the bar. Tributary valleys are filled with debris deposits. The deposit has now largely been covered with fill as part of the Discovery Bay residential development.

Mui Wo. Extensive alluvial flats occupy the valley floor (177 147) at Mui Wo. Borehole records indicate that the alluvium is 9 to 13 m thick, and comprises gravel, cobbles and boulders in a sandy silt, or sandy matrix. This alluvial deposit is the distal portion of the slope deposits filling the valley behind Mui Wo, and it thins rapidly to the east, ranging from 4 to 13 m in thickness. It is dominated by gravel, cobbles and boulders, but also contains sand layers. The sand and silty sand matrix is greyish-brown to yellowish-grey. The clasts are dominantly rounded to subrounded, weathered volcanic rocks derived from the slopes of Lin Fa Shan. The alluvium north of Luk Tei Tong (174 138) is a brownish-grey to pale brown sand. The stream bed is wide, covered in boulders and cobbles, and is inset 2-3 m into the surrounding alluvium.

Pui O - Tong Fuk. Several thin and isolated deposits of alluvium occur along the steep stream courses that drain the southern slopes of Sunset Peak.

Shek Pik. An extensive alluvial deposit fills the valley occupied by the Shek Pik Reservoir. A series of coalescing lacustrine fans mantle its eastern slopes, which are commonly exposed during periods of low water level to be eroded and reworked. The material is a coarse gravelly sand, with some pebbles and cobbles, although sparse boulders occur.

Slope Deposits

Slope deposits are defined as accumulations of mass-transported material, formed by water-mobilised, gravitational processes (Varnes, 1978). These mass movement deposits include creep debris, rock falls, debris slides and debris flows. Previously in Hong Kong, they have been collectively referred to as colluvium, although this term has not been rigorously defined and embraces the full range of slope deposits (Lai, 1982). They are diverse in composition and typically poorly sorted. Depending on the original topography, source rock and distance travelled, they comprise variable mixtures of silt, sand, gravel, cobbles and boulders. Most commonly, the slope deposits consist of boulders and cobbles embedded in a gravelly, sandy silt matrix. Boulders up to 10 m occur, but they average around 0.5 m across. They vary considerably in roundness, depending on the parent rock type and age of the deposit. Lai & Taylor (1983) presented criteria for the subdivision of colluvium into three classes, based on superposition, differences in clast-matrix ratios and the degree of decomposition of the clasts. They discussed the probable ages of the deposits, suggesting Early Pleistocene for the older debris flows and a Holocene age for the younger deposits. During the present survey it was found that the representation of the three classes of slope deposits was impractical at the mapping scale. Generally, the fine debris occurs on the gentle slopes and in the upper sections of low gradient valleys, whereas the boulder deposits lie at the foot of steep slopes, or fill the heads of steep valleys. The thickest accumulations usually occur at the base of steep slopes, lining upland valley floors and filling lower valleys, with significant deposits often more than 20 m in thickness.

Slope deposits are very extensively developed on the lavas and tuffs of the Lantau Formation. They have a more restricted occurrence on the granites of the Chi Ma Wan peninsula, and occur only as isolated patches on the feldsparphyric rhyolites of northeastern Lantau. Quaternary slope debris is manifested in several morphological forms. It develops as isolated linear fills in the upper sections of minor drainage lines, such as on the northern and southwestern slopes of Nei Lak Shan (087 138). It also occurs as more complex, digitating but isolated networks below ridge lines and at the head of larger drainages, such as at the inception of the Sham Wat drainage west of Nei Lak Shan (080 142), or north of Sunset Peak (130 138). The deposits also occur as laterally extensive sheets, indiscriminately blanketing hillsides, for example on the western slopes (045 132) of Sze Shan above Tai O, and on the lower, northwestern slopes (125 165) of Por Kai Shan, crossing the coast near Lau Fau Shan. However, the thickest and most extensive deposits fill entire valley systems from their headwaters to the coast, as major dendritic accumulations with fingers reaching up to the ridge crests. Of particular note are the deposits feeding down to Tung Chung from Nei Lak Shan (095 146), Tung Chung Au (121 116) and Sunset Peak (127 144). Boulders tend to accumulate in drainage lines, either by rafting and rolling down from the adjacent slopes, or as a result of eluviation of the fines by stream action, to form linear boulder

trains. The regolith on most steep slopes has crept to some degree. This is visible in section as outcrop curvature of quartz veins, or debris trails from outcropping marker bands.

The Holocene slope deposits are generally soft to firm, light yellowish-brown, slightly clayey, sandy silt to gravelly silty sand. Included clasts are slightly to moderately weathered, subangular to angular cobbles and boulders. The weathering rind on large boulders is never more than a few millimetres thick. Pleistocene slope deposits have a mottled, reddish-brown or white matrix, which is firm, stiff, or indurated, and clasts that are more highly weathered in places.

Details

Tai O - Sha Lo Wan. Between Tai O and Sha Lo Wan the hillsides are characterised by extensive slope deposits. These grade downslope into alluvial fans as seen at Tai O (045 127) and at Sha Lo Wan (079 165). East of Tai O fluvial and slope deposits of presumed Pleistocene age are exposed along the foreshore, unconformably overlying Carboniferous sedimentary rocks of the Lok Ma Chau Formation (Plate 42). These superficial deposits are onshore lateral equivalents of the Chek Lap Kok Formation, identified in offshore seismic records and boreholes.

Above Sham Wat Wan, Pleistocene slope deposits form a large, lobate mass (065 137) on the flanks of Cheung Shan. The deposits display a mottled, reddish-brown and white matrix, and clasts which are partially weathered *in situ*. The beach in front of the slope deposits is dominated by boulders and cobbles of both sedimentary and volcanic rocks. The Lok Ma Chau Formation to the northeast and southwest of Sham Wat Wan produces a sharp ridge line, which is a surface expression of the hard sedimentary rock. These hills are free of coarse slope deposits, but the volcanic rocks south of Sham Wat Wan have, in places, extensive spreads of boulder debris.

San Shek Shan (071 158) is dominated by an extensive sheet of slope deposits from the adjacent steep hills. The lower slopes of these hills are underlain by the Lok Ma Chau Formation, and are therefore relatively debris free, but the steep upper parts are in the volcanic rocks that are the source of much of the debris.

Tung Chung. The most extensive debris deposits in the district occupy the western streams of the Tung Chung Valley. A dendritic network of Pleistocene debris deposits feeds eastwards, from the flanks of Nei Lak Shan (097 147) and adjacent hills, and a continuous valley lobe (121 125) feeds northwards for 2500 m from Tung Chung Au. The material is predominantly a coarse bouldery deposit, with well weathered boulders and cobbles in a stiff, mottled, sandy silt matrix. Downslope, the debris grades into extensive, partially indurated Pleistocene alluvial terrace deposits. Holocene debris deposits fill many of the minor valley heads, forming minor dendritic networks that are not contiguous with the Pleistocene debris.

A dendritic system of Holocene debris deposits fills the eastern valley (127 144) below Shek Sze Shan and the northern slopes of Sunset Peak (136 146), receiving feeder lobes from Wo Liu Tun (122 149) and Pok To Yan (126 157). The material is mostly cobbles with a predominantly sandy, unweathered matrix.

Chek Lap Kok (prior to development). The largest area of slope debris occurred at Fu Tei Wan (111 181). Before the island was levelled, there was extensive agricultural terracing in the deposit, which was a relatively smooth, steeply inclined accumulation of boulders and cobbles in a silty matrix. Sections were not seen, but one borehole (L27/3427A, 11069 18326) passed through 4 m of yellowish-brown, clayey sand with gravel before passing into the underlying weathered bedrock. Artificially-terraced slope deposits occurred upslope of beach deposits at Cheung Sha Lan (111 197), and marginal to the large alluvial tract (115 195) at Sham Wan Tsuen. At Cheung Sha Lan the surface of the deposit comprised fine gravel and sand, with quartz vein debris prominent.

The distribution of slope deposits were largely determined by surface morphology. They were generally restricted to thin mantles on some of the steeper slopes, feeding narrow valley fills. The material appeared to be formed predominantly by soil creep and slopewash, and contained few boulders. The largest areas of slope deposits are along the two valleys connecting Fu Tei Wan and Sham Wan. Elsewhere they formed small patches in steep hollows on hillslopes.

Lau Fau Sha - Tai Ho Wan. Extensive trains of boulder debris occur in most valleys on the northern flanks (124 164) of Pok To Yan and Por Kai Shan. These usually originate from rock ribs and ledges formed by upstanding dykes. Near Tai Ho Wan , very extensive debris deposits choke the valley system (159 169) to the south. To the east, the side of the un-named hill (164 174) clearly displays coarse boulder streams, which are probably debris flow deposits from which the fines have been eluviated. Further east, narrow boulder debris streams are also well developed (Plate 43, 177 170) to the southwest of Lo Fu Tau.

Tai Che Tung. Extensive, linear boulder streams are well developed, filling valleys on the north slopes (188 198). Near the summit, small waterlogged hollows have formed in the deposits, most of which are boulder-free.

Plate 42 - Fluvial and Slope Deposits of Presumed Pleistocene Age, of the Chek Lap Kok Formation, Resting Unconformably on Carboniferous Sedimentary Rocks (0401 1334), East of Tai O

Plate 43 - Boulder Debris in Narrow Streams (177 170), Southwest of Lo Fu Tau

Plate 44 - Boulder Debris on the Southern Flanks of Lin Fa Shan (1520 1395)

Plate 45 - Boulder Beach, Dominantly Composed of Banded Lava Boulders(025 072), Sam Shak Wan

Yam O Wan - Yi Pak Wan. Small, isolated debris deposits occupy short valleys on the northern flanks of Lai Pik Shan (206 201) and Tai Shan (208 205, 213 204), with large developments on their southern flanks (208 200). A long lobate deposit fills the valley (188 193) behind Yi Pak Wan, below Tai Che Tung. The material generally comprises a coarse, blocky-weathering debris, derived from the feldsparphyric rhyolite, set in a sandy, silty matrix.

Boulder streams occupy the upper slopes. These are fed by narrow boulder trails that extend down incipient drainage lines from the ridge crests. Downslope, the streams feed extensive debris sheets which have, in several areas, been eroded to expose boulders, separated by matrix-rich debris lobes between gully lines. The boulders are typically small, but occasionally exceed 20m. Locally, the deposits extend to the coast, where they either form fans, at the bottoms of narrow valleys, or truncated lobes. The deposits are widespread and on a large scale in this area. Trains of debris leading downslope from rock outcrops on ridges are common. Subsequent incision of the deposits has exposed bedrock in the deeper stream courses.

Lin Fa Shan - Mui Wo. Extensive sheets of boulders occur on the steep upper flanks of Lin Fa Shan (Plate 44), except on the steep eastern slope on which bare rock is exposed. Lower down the gentler slopes, debris streams appear and a thin veneer of debris is continuous from around the Forestry Office to Luk Tei Tong.

Silver Mine Bay - Tung Wan Tau. The hills have a thin cover of debris. Slopewash deposits have accumulated in the gentle valleys, although alluvial fills are rare. Boulder streams are uncommon, but debris is widely developed.

Chi Ma Wan. Debris deposits are very restricted on the granitic rocks of the Chi Ma Wan peninsula, largely comprising a thin litter of isolated boulders on the open slopes and eluviated boulder trains in the valleys.

Tong Fuk. Coarse, bouldery slope deposits choke the short, steep valleys on the southern slopes of Sunset Peak and Lantau Peak. The largest deposit (106 106) occurs above Tong Fuk, where an extensive dendritic system feeds down from Lantau Peak to the coastal fan. A thin mantle of sandy, silty slope deposits cover the valley sides, large areas of which were mobilised as shallow debris slides, or long linear, debris flow-slides in minor tributaries during the November 1993 rainstorms, leaving hundreds of fresh scars over these slopes.

Shek Pik. On the southwestern flanks of Lantau Peak, and below Muk Yue Shan and Sze Tsz Tau Shan, the dendritic drainage lines converge on the Shek Pik valley. They are all occupied by slope deposits, consisting of cobbles in a sandy matrix, which feed into the alluvial fan at Shek Pik.

Tai Hom Shan - Sham Hang Lek. Slope deposits have a restricted development in the short valleys draining off the peaks of southwestern Lantau Island. They are predominantly narrow, linear streams, composed of sandy, gravelly debris with some boulders.

Talus (Rockfall Deposits)

Talus predominantly consists of angular rock fragments, often large, derived from, and lying at the base of, a cliff or very steep rocky slope (Bates & Jackson, 1987). The fragments have been transported downslope by a combination of falling, sliding, or rolling. They commonly overlie Pleistocene slope deposits in the district, and are still accumulating.

The talus is restricted to very confined deposits, which are mostly unmappable at the 1:20,000 scale. The composition is very variable, but generally comprises an unsorted mass of gravel, pebbles, cobbles and boulders, with only a sparse sandy matrix

Details

Lantau Peak. Small talus accumulations occur below several small, free faces in the lavas and tuffs of Lantau Peak, the largest forming a linear scree (091 125) on the western flanks. The deposit comprises large, angular boulders with no visible matrix, occurring as a jumbled pile.

Beach Deposits

Beach deposits are narrow, laterally extensive features composed of unconsolidated, predominantly sand-sized material extending landwards from the low-water mark to a cliff line, or storm beach, that marks the upper limit of wave action. These deposits are laterally continuous with the littoral and sublittoral sands of the Hang Hau Formation. The beach deposits in the district mostly consist of clean, pale yellow sand, and several, such as Cheung Sha Beach are

gazetted for recreational purposes. Sandy beaches are generally found only in sheltered bays and inlets, with the largest extent of beach deposits at Cheung Sha, Silver Mine Bay and Discovery Bay. On more exposed coasts, they are composed of pebbly or gravelly, silty sand with shell fragments, but can include cobbles and boulders. The pale phototone of beach sand, forming a narrow fringe around the natural coastline, is clear on aerial photographs. This phototone can usually also be detected beneath shallow water

Raised beach deposits, or high level storm beaches, occur behind the contemporary sand beach and are composed of gravelly coarse sand with scattered pebbles. The beaches attain a maximum elevation of 6 mPD. There is no unequivocal evidence in the district for former, higher sea levels. In places, the deposits form sand barriers across river mouths, resulting in the formation of freshwater lagoons with extensive alluvial tracts inland. Boulders, cobbles and pebbles constitute the beach deposits on more exposed coasts. These have been distinguished from the beach sands.

Details

Tai O. The south side of Tai O Island has a fringe of alluvial and beach deposits (032 128) adjacent to extensive intertidal mud flats. Beach bars occur east of the Police Post and in the middle of the town (040 128). The original settlement was established on sand bars in the estuary.

Sham Wat Wan - Tin Sam. Along this northeastern coast, with the exception of the extensive boulder beaches on the exposed coast between Tai O and Sham Wat Wan (044 139 and 054 146) the beaches are restricted, and largely confined to narrow, curved back beaches in the deeply indented, sheltered bays of Sham Wat Wan (065 144), Sha Lo Wan (079 168) and Hau Hok Wan (087 168). A narrow sand beach has developed along the coastal margin of the Tin Sam delta (103 167). A boulder beach occurs in the shallow bay at Sam Shek Wan (Plate 45, 070 158), lying on a rock platform cut in the underlying Lok Ma Chau Formation.

Tung Chung. The bay (Tung Chung Wan) east of San Tau contains extensive sand bars and sand banks that are exposed at low tide.

Chek Lap Kok (prior to development). The largest deposits were formed in sheltered bays, particularly at Sham Wan and Fu Tei Wan. High back beach deposits, rising to 5.5 mPD, occurred behind the sand beach at Sham Wan Tsuen. The beach sand at Sham Wan (116 197) filled much of the shallow bay, extending from low water mark to a height of about 3 mPD. The sand formed a broad dune, through which a stream was incised. Sand bars characterized the tidal zone. The material forming the beach was light brown and varied from coarse sand to fine gravel, with some mud. Pebble-sized fragments of rock littered the surface of the beach. They probably resulted from recent stone cutting around the bay. The beach at Fu Tei Wan (110 180) extended inland for 100 m from the high water mark. It was intersected by a shallow borehole (89/3955, 10992 17950) that showed sand with 3 to 16% mud and a trace of shell fragments at least 3.8 m thick. The deposit was contiguous with marine sand deposits. The beach rose to 4 mPD, and was backed by partially eluviated slope deposits. The form of the beach was largely determined by extensive sand digging this century. The beach at Cheung Sha Lan (110 197) was composed of light brown coarse sand with some shell fragments.

Archaeological excavations in back beach deposits at Sham Wan revealed a layered sequence of coarse to medium sand, interspersed with remains dated to the both the Tang Dynasty (c. 1 000 years old) and Late Neolithic (3 500 -5 000 years old) (W Meacham, oral communication, 1993). A similar investigation at Sham Wan Tsuen revealed a basal coarse beach sand resting on bedrock at about 3 mPD. Artefacts found in the sand were over 5 000 years old (W Meacham, oral communication, 1991). Overlying this was 3 m of fine sand and soil containing remains ranging from Late Neolithic, through the Tang Dynasty, to the Ching Dynasty.

Tai Ho Wan - Yam O Wan. This section of the coast has been extensively modified by cutting and reclamation associated with the building of the North Lantau Expressway. However, prior to the development, the beaches from Tai Ho Wan to Ngau Tau Wan consisted of sand and cobbles, with areas of clean sand exposed that were characterized by a sharp break in the gradient near high water mark. Boulder streams from the adjacent slopes extended into the coastal zone. The beaches from Siu Ho Wan to Sham Shui Kok and Tai Pang Po were dominantly a mixture of sand, cobbles and boulders. The sand was either exposed as a narrow strip above high water mark, or was completely obscured by cobbles. In most of the intervening areas, the slope deposits were eroded and either reworked into beach deposits, or entirely removed, exposing bare rock.

Penny's Bay. Prior to reclamation for the shipyards, extensive sandy beach deposits occurred along the sheltered northeastern shore of Penny's Bay.

Sz Pak Wan - Sam Pak Wan - Yi Pak Wan. The sand beaches in Discovery Bay are well developed and slightly elevated, indicating that they are probably storm beaches. They are composed of coarse sand and shell debris, with a transition offshore to grey mud with shells. A lagoon has developed behind the beaches, and mangrove flats are established on the tidal creeks.

Peng Chau. Boreholes in Tung Wan (GIU 05202) revealed a succession of grey mud or sand overlying weathered rock. Most of the bay is underlain by grey marine sand, 4 to 8 m thick, with shells and coral fragments. This deposit is contiguous with the thin beach deposits around the bay. Weathered rock generally underlies the sand, although mud is recorded in places.

Man Kok Tsui - Kau Shat Wan. The beaches along this promontory are sandy, with few boulders or cobbles. Storm beaches have formed up to 2 m above sea-level at the backs of the bays.

Silver Mine Bay - Mui Wo. A wide sand beach encircles the back of the bay, behind which a lagoon has formed. This is now being reclaimed. West of the sandy beach at Mui Wo, boreholes have proved 5 to 7 m of dark grey sand with shell fragments. This marine deposits overlies alluvium. It dies out 120 m west of the high water mark. Boreholes sunk in the new river channel (GIU 02444) show that it is underlain by grey silty sand with gravel, and some shell fragments. Inland to the west, these marine sands pass into brownish-grey, silty alluvial sand with gravel. In the east, the sand has been reworked and the fines removed to form a beach. Bedrock is generally at shallow depth, ranging from -12.6 mPD at the river mouth, to -2.5 mPD about 1 km inland. Many boreholes intersect, or were terminated at boulders, believed to be the relict of extensive slope deposits beneath the alluvium and marine deposits. The marine sands are generally thin, ranging up to 7.5 m thick, and are underlain by up to 4 m of brownish-yellow, alluvial silty sand. About 1 km southeast of the ferry pier, the marine deposit comprises about 7 m of dark grey silty sand with shell fragments, overlying thin mottled alluvium or weathered bedrock.

Cheung Chau. The two granite islands are connected by a raised sand bar, or tombolo, forming a textbook example of dumbbell islands. The sand composing the bar has a coarse, gravelly texture, and rises up to 4 mPD at its crest.

Pui O Wan. The area between Pui O village and the beach is dominated by low-lying alluvium, rising gently inland from 2.9 to 4.8 mPD. Much of the area immediately behind the beach is waterlogged. Aligned westnorthwest across the alluvial plain, about 200 m behind the present beach, is a sand bar 300 m long and 50 m wide. This bar has been stranded by alluviation of the lagoon (Plate 46). The crest of the present beach is at 4 to 4.5 mPD, and is composed of clean white sand. The beach slopes gently seawards and becomes progressively muddy below high water mark (Plate 47). Seven boreholes in the raised bar at +4.5mPD (GIU 06626) intersected 2.5 to 4 m of loose, light brown, fine sand with some shell fragments, overlying 7 to 9.5 m of grey marine sand. The base of the succession is at about -7mPD. Below these sands are 10 to 20 m of alluvium, comprising clayey silty sand with gravel and boulders, which is yellowish-brown, and poorly stratified, lying on tuff bedrock.

Cheung Sha. An extensive sandy beach at Cheung Sha extends along the gently embayed coast for almost 3 km. It is composed of clean, pale yellow sand, is up to 50 m wide, and shelves gently below low water mark.

Tai Long Wan - Fan Lau Tung Wan - Fan Lau Sai Wan. Long sandy beaches occur at Tai Long Wan, Fan Lau Tung Wan and Fan Lau Sai Wan at the back of wide, sweeping bays in the steep coast (Plate 48). The beach at Tung Wan has been modified by the construction of a breakwater and the Shek Pik Prison. All the beaches along this coast are composed of well sorted, fine- to medium-grained, clean quartz sand.

Intertidal Deposits

Holocene estuarine intertidal deposits are of mixed alluvial and marine origin. They generally consist of grey clayey silty sand with plant remains, and dark grey, organic clayey silt with shell fragments, and accumulate as mud flats in wide embayments, between the high and low water mark. Mud on wide interfluves between branching distributaries is commonly rippled. Channels generally have a sandy bed, and sand splays and ribbons cross the flats. Mangroves characteristically grow on the flats and channel margins. The deposits predominantly consist of grey, clayey silty sand in the channels, and dark grey, organic, clayey silt with plant remains and shell fragments on the flats. Flaser bedding is common. Intertidal deposits are most extensive at Tai O and Tung Chung.

Details

Tai O. Extensive intertidal deposits occur in the sheltered creek at Tai O. They are almost 1 km wide to the south of the town, although the landward side has been bunded and ponds constructed (038 125) and reclamation fill placed over the central area to construct an extension to the town (042 128). The creek is tidal and mangroves persist in places, although many have been cleared. To the north of the town (041 132), the deposits are reclaimed for agriculture and a pattern of fields has been established.

Sham Wat Wan. The intertidal deposits of Sham Wat Wan are about 200 m wide. Numerous boulders and cobbles on the surface have been exhumed from the underlying slope deposits by wave action. The deposits are fringed by mangrove, particularly on the southeast side of the bay. Small sand bars have formed near the high tide level between the alluvium of the valley and the intertidal sediments.

Tung Chung. Intertidal deposits in Tung Chung Bay are up to 400 m wide and form a fringing strip about 2400 m long. They are characterized by extensive sandy splays and mangrove-lined channels.

Chek Lap Kok (prior to development). There was an unusual development of intertidal deposits, an extensive, shallow fan, largely derived from excavations at the kaolin mine and adjacent test embankment (105 186). The deposit consisted of fine sand and silt, produced by washing of the kaolinized granite to the east.

Yam O Wan. Prior to construction of the North Lantau Expressway, in Yam O Wan, a northeast-trending inlet, grey, silty intertidal mudflats, up to 300 m wide, fringed the seaward end of coastal slope deposits that extended seawards into the bay.

Shui Hau Wan. In this sheltered east-facing bay, very extensive intertidal mudflats, up to about 700 m wide, have developed as a seaward extension of the low-lying, alluviated valley at Shui Hau. Mangrove-lined creeks are a feature of the flats. The deposits are relatively sandy.

Tung Wan. A restricted development of intertidal deposits occurs in the southern bay at Tung Wan, south of the Country Park Management Centre. The area has been modified by development.

Yi O. Intertidal mudflats, up to 400 m wide, cover the floor of the shallow bay at Yi O. The deposits consist of a grey, sandy silt, with numerous cobbles on the surface, indicating they they are probably a winnowed slope deposit, being a seaward extension of the low gradient slope deposit from the adjacent valleys.

Ngau Tau Wan - Tai Ho Wan. Tai Ho Wan consists of a tidal mud and sand flats, fringed by mangroves. The clean sandy beach is marked by a sharp break in slope near high water mark.

Offshore Superficial Deposits

Classification and Distribution

The Hong Kong Geological Survey has previously subdivided the offshore superficial deposits into the Hang Hau and Chek Lap Kok formations, based on lithological and palaeontological evidence from boreholes, and on interpretations of seismic characteristics (Strange & Shaw, 1986; Langford *et al.*, 1989; Strange *et al.*, 1990). The Hang Hau Formation is younger than the Chek Lap Kok Formation. A new formation, the Sham Wat Formation, has been recognised on seismic profiles from the district. Stratigraphically, it lies below the Hang Hau Formation and, within the district, above the Chek Lap Kok Formation. It has a diagnostic seismic signature and appears, from limited borehole evidence, to have recognisable sedimentological and palaeontological characteristics.

A distinctive seismic sequence of very limited extent has been recognised above the rockhead reflector in the Brothers - Ma Wan Channel. This sequence is interpreted as older than the Chek Lap Kok Formation and has been designated as pre-Chek Lap Kok Formation deposits, but it has not been given formational, or member status. In addition, Channel and Transgressive Deposits

Plate 46 - Raised Sand Bar or Dune behind the Present Sandy Beach at Pui O (156 113). Mangrove and Swamp Lie behind the Beach, Adjacent to the Tidal Stream Channel, Pui O Wan

Plate 47 - Sandy Beach with a Broad Intertidal Zone Composed of Muddy Sand (1562 1125), Pui O Wan

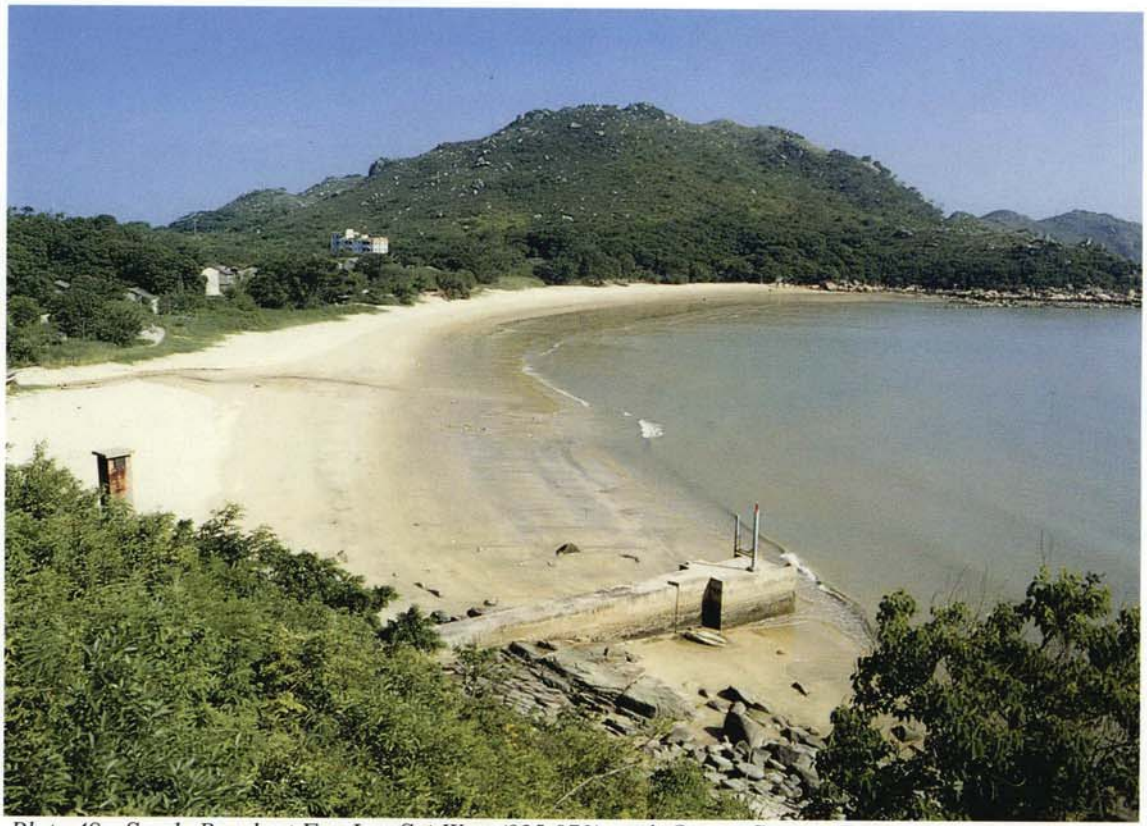


Plate 48 - Sandy Beach at Fan Lau Sai Wan (025 073), with Quartz Syenite Exposed near the Jetty, and Fine-grained Granite on the Hills to the South

of uncertain stratigraphical significance have been recognised, associated principally with large-scale erosional and depositional events during the last sea-level lowstand and the succeeding transgression. However, the basal part of this unit may include sediments that pre-date these events.

The major formation- or sequence-bounding reflectors have been correlated with borehole, cone penetration test, and vane test data. The reflectors generally correspond to significant changes in a number of parameters, including lithology, geotechnical properties, palaeontology and geochemistry. However, difficulties of interpretation and correlation arise where minor variations in facies and lithology occur laterally across, and vertically through a deposit, but these changes are not clearly displayed on the seismic records. These subtle changes within and across formation and sequence boundaries have led to the inclusion of two facies within the offshore deposits that are based on their genetic character; marine sand sheets and marine sand banks.

Within the Pearl River (Zhujiang) Estuary, a twofold stratigraphical division has been described by Long and Huo (1990), comprising a lower Zhongshan Formation (40 000 to 12 000 BP) and an upper Shunde Formation (12 000 BP to Present). Both formations have been subdivided into three units. From the limited published descriptions, the lower unit of the Zhongshan Formation appears to be the equivalent of the Chek Lap Kok Formation, the middle unit of the Zhongshan Formation matches the features of the Sham Wat Formation, and the middle and upper units of the Shunde Formation are similar to those of the Hang Hau Formation (Shaw & Fyfe, 1992).

Over most of the offshore area of the district there is a thick mantle of superficial deposits, with rock exposures at the sea bed confined mainly to shoals such as Pun San Shek (2510 2030), to nearshore exposures, and to areas swept by currents with relatively high velocities, such as the narrow channels of Kap Shui Mun (2400 2230) and around Tsing Yi (2630 2300). The superficial deposits generally lie on a rock surface that is steeply inclined near the coast, continuing the generally steep coastal slopes. The slopes tend to flatten out at c. -20 to -30 mPD, although in some places close to the coastline they descend to lower than -50 mPD. Away from the coast, the superficial deposits commonly infill broad, relatively smooth depressions, although there are areas, such as around Sha Chau and The Brothers islands, where the superficial deposits onlap and thin over local rock highs.

A number of factors control the thickness of the superficial sediments. These include the form and elevation of the rock surface, tidal currents, the sediment sources and their depositional environment. These are in turn influenced by the proximity of the coastline. For example, in a relatively narrow tidal channel north of Lantau Island, between Ma Wan and Sha Chau, superficial sediment thickness varies from zero around Ma Wan to about 50 m at the Territory's boundary west of Chek Lap Kok. Within the central part of the tidal channel, superficial sediments can be relatively thin (<5 to 15 m). This is mainly attributable to non-deposition rather than major erosion within the area of relatively high current velocities.

South of Lantau Island, towards the southern limit of the Territory, superficial sediment thickness increases into the Dangan Channel. Along this southern margin, the superficial sediments exceed 80 m in thickness. Further north, sediments more than 60 m thick fill the West Lamma Channel. Around the Soko Islands, tidal currents have determined the form and thickness of the superficial sediments. A large sand bank built up west of the islands but has been subsequently dredged for fill.

Pre-Chek Lap Kok Formation Deposits

These deposits are of limited areal extent, and are defined solely on their seismic character. They have not been assigned formation or member status. The lithology of the deposits is not known, but their seismic character suggests that they are likely to be sand and gravel rather than finer grained sediments. The sequence displays well-developed, relatively strong reflectors parallel to the base of the unit. Within the main Brothers - Ma Wan Channel they have a trough-like form, but become horizontal over the platform, or terrace, at its margins. The top of the sequence is defined by a planar, horizontal reflector marking the base of the overlying Chek Lap Kok Formation.

Details

The Brothers islands - Ma Wan. These sediments have a very limited areal extent in the centre of the Brothers - Ma Wan Channel northwest of Yam O Wan (Figure 13). They cover an area of approximately 300 m by 500 m and fill a small channel, or basin, aligned parallel to the modern channel. The deposit has a maximum infill of about 15 m beneath the overlying Chek Lap Kok Formation. The deepest part of the deposit has a symmetrical, V-shaped cross-section about 180 m wide, and its base is below -50 mPD. The southern margin is characterized by a 5 m-thick platform, or terrace, with a horizontal base.

Age and Sedimentary Environment

An over-deepened fluvial or estuarine channel is the most probable environment of deposition. The exact age of the deposit is uncertain.

Chek Lap Kok Formation

The type section of the formation is the continuously sampled borehole, B13/B13A (10292.8 18701.5), drilled on the test embankment at Chek Lap Kok (Strange & Shaw, 1986). Five other boreholes, B15, ESC17, A5/1, A5/2 and B2/1, all penetrating sediments assigned to the Chek Lap Kok Formation, have also been logged and analysed in detail (Figure 13). Of the offshore Quaternary formations, it is the most complex and heterogeneous physically, lithologically and seismically. Sequences that are internally complex on seismic records and in boreholes are generally classed as Chek Lap Kok Formation. However, there are several diagnostic characteristics which help to identify it, such as complex, small-scale channelling on seismic records, intense oxidation, and the presence of organic and plant debris in borehole samples.

The Chek Lap Kok Formation is widely distributed throughout the area. Lithologically, it comprises a wide range of grain sizes, from gravel to clay, and sediment type varies extensively both laterally and vertically throughout. Clays tend to be firmer than in overlying formations, with unconfined compressive strengths ranging from 30 to 90 kPa. Deposits have a variety of forms, including upward-fining sequences from basal gravels through to silts and clays with abundant organic debris. The organic material, which includes comminuted plant debris as well as wood fragments, can occur either within the silt or clay matrix, or as thin beds within silt, clay and sand. Upward-coarsening sequences are also a feature, as are massive, moderately sorted sands. Interbedded with the sandy deposits, firm silts are common, some of which are massive, though many contain thin flaser laminae and lenses of sand and silty sand.

Oxidized horizons are characteristic of the formation, and oxidized palaeosols commonly occur at the top of the formation. Around Chek Lap Kok, the top of the formation is a deeply oxidized palaeosol, extending to 1.0 m below its upper surface in Borehole B13/B13A (Shaw *et al.*, 1986) and to 4.4 m in Borehole B15. However, the palaeosol is absent where the upper surface of the formation has been channeled by erosion. Palaeosols also occur lower in the sequence, as for example, in Borehole A5/1, near the Soko Islands at -32.8 m PD, and at -74.80m PD in Borehole A5/2 in the West Lamma Channel (Owen *et al.*, 1995). Oxidation is not confined to clay and silt

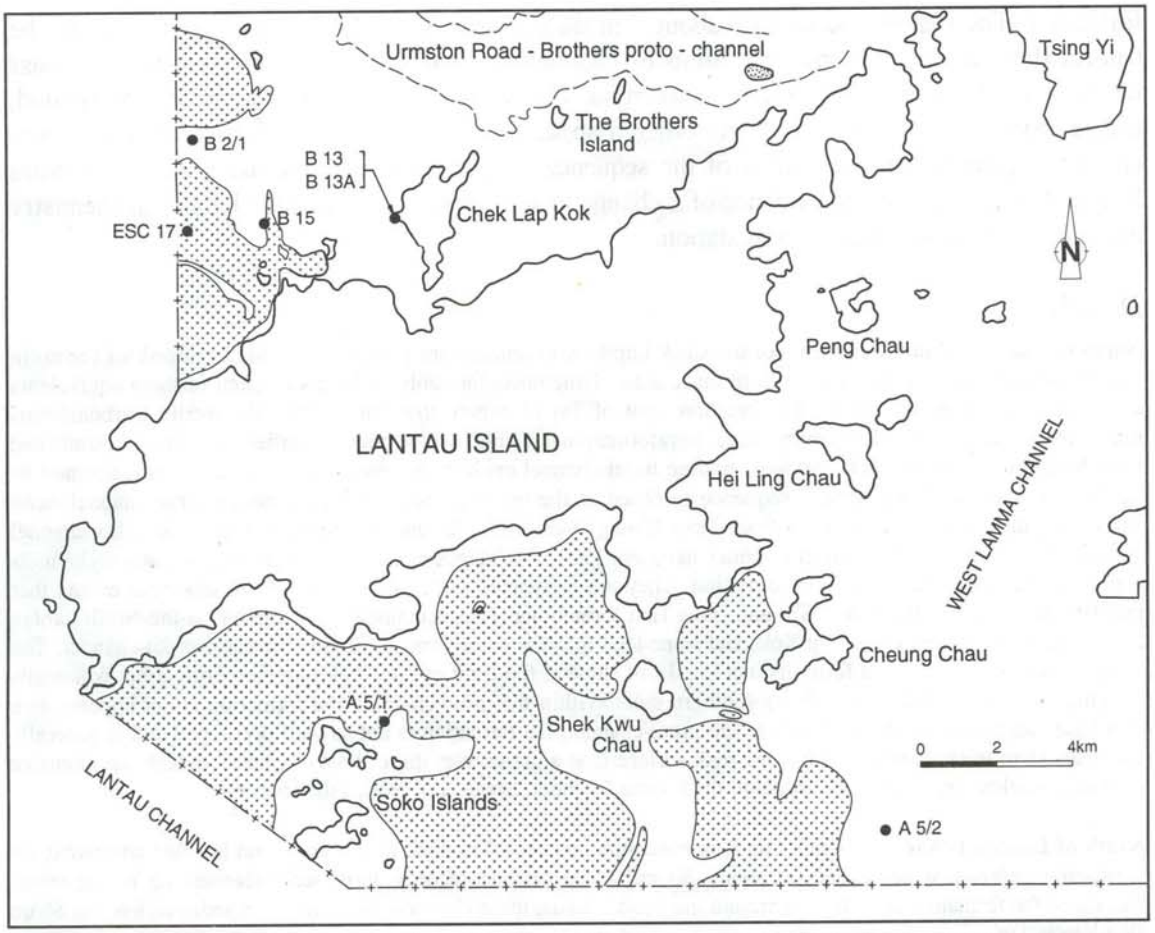


Figure 13 - Subcrops of Pre-Chek Lap Kok Formation Deposits and Sham Wat Formation (Stippled), and Locations of Boreholes A5/1, A5/2, B2/1, B13, B13A, B15 and ESC 17, Containing Type and Other Sections Through Offshore Superficial Deposit Formations.

palaeosols, but can also be seen at depth in massive sands and flaser sand lenses. The oxidation in these sandy sequences probably results from percolating iron-rich groundwater rather than direct subaerial exposure.

Bulk X-ray diffraction analyses on a number of samples in Borehole ESC17 indicate that the Chek Lap Kok Formation sediments are composed of quartz, kaolinite and illite, with subordinate calcite, siderite and feldspar. In samples from the Chek Lap Kok airport site, Tovey (1991) found that illite is the most common clay mineral, comprising 44 to 50% of the clays. Kaolinite is also present at a concentration of 29 to 36%, and smectite comprises only about 5%. Quartz is the main component of the >2μm fraction.

The seismic character of the formation confirms the complexity of the lithologies and facies associations. Generally, there is low acoustic impedance contrast and poor to non-existent reflector development in much of the underlying rock, so that the base is commonly difficult to delineate accurately. The formation appears to have no single, diagnostic seismic character. Relatively short, laterally impersistent, truncated bounding reflectors and channel forms are common, with large variations in background seismic tones and internal reflector characteristics. However, on a local scale, correlation can be made between the seismic reflectors and lithologies in the Chek Lap Kok Formation. For example, the units of clayey silt and sand and gravel seen in boreholes B15, A5/1 and A5/2 can be matched crudely to changes in seismic character and laterally persistent reflectors. Seismic features such as lateral accretion foreset reflectors, can be correlated with sand sequences in boreholes B15 and A5/2. On some seismic records, a sequence of sub-horizontal, relatively persistent, high amplitude reflectors occurs near the top of the

formation. The sequence is usually about 5 m thick, but may reach 10 m locally. It can also be truncated by more than one generation of channelling, and be laterally impersistent, or pass laterally into the ambient chaotic reflector style. The sequence appears to be predominantly mud, and is characterized by the relatively ordered appearance of its reflectors compared to the more chaotic sequences beneath. Much of the sequence is commonly well oxidized, as in boreholes B15 and A5/2. There is no evidence of a change in seismic character due to changes in chemistry and mineralogy associated with oxidation.

Details

North of Lantau Island. Sediments of the Chek Lap Kok Formation are particularly well developed off the north Lantau coast, where sequences over 40 m thick occur, lying unconformably on bedrock. Their onshore equivalents are locally well exposed behind the foreshore east of Tai O, where they unconformably overlie Carboniferous sedimentary rocks (Plate 42). Several large, intraformational channels have been identified on seismic records and from boreholes. West of Chek Lap Kok, a large basal channel evident on seismic records, has been confirmed by the well-developed, fining-upward sequence recorded at the base of Borehole B15. Another large channel, with sub-horizontal reflectors, runs north from Tung Chung Wan (105 170) and merges into a more complex channel system with overlapping bars north of Lam Chau (090 190). Two stages of extensive erosion have incised channels deep into the upper surface of the formation. They are associated with the low base-level erosional events that pre-date deposition of the Sham Wat and Hang Hau formations. These channels are common off the North Lantau Island coast and around Chek Lap Kok, and some feed into the main Urmston Road - Brothers proto-channel. The margins of the proto-channel form distinct breaks of slope at the limit of the Chek Lap Kok Formation, which sits as a high sub-horizontal terrace on its southern side. Within the proto-channel, the formation either appears as a thin basal deposit, or is absent. North of the proto-channel, the formation is not as well developed and is generally less than 15 m thick, mainly because the rock surface is at a higher elevation. West of Chek Lap Kok, an intensive channel complex, draining westwards into the Lantau Channel, has deeply eroded the formation.

South of Lantau Island. The Chek Lap Kok Formation is over 40 m thick in this area, and lies unconformably on weathered bedrock, which occurs at about -80 mPD. On seismic records, large-scale channelling of the upper surface of the formation is clear, and around the Soko Islands, these channels are filled with sediments of the Sham Wat Formation.

West Lamma Channel. The formation ranges in thickness from a few metres, near the coasts and bedrock highs, to over 80 m thick near the southern part of the West Lamma Channel. On seismic records, the formation has a characteristically confused and chaotic pattern of high amplitude, generally discontinuous reflectors that contain several, distinctly cross-bedded, or channel-form units, confirming the fluvial origin of the sediments. The formation lies with major unconformity on a weathered rock mantle that is commonly 10 m, or more, thick. The bedrock surface is a gently undulating, or almost planar, surface, that suggests significant erosional planation prior to deposition of the Chek Lap Kok Formation.

Characteristically, bedrock appears on the seismic records near the coasts or islands, and commonly crops out on the seabed. Away from the coasts, the bedrock surface slopes gently. Sediments of the formation fill what appears to be a deep and broad channel into the underlying bedrock. Over most of the southern part of the West Lamma Channel, bedrock occurs at more than 75 m to 85 m below seabed, or greater than -95 mPD.

Further north, bedrock appears at about 65 to 70 m below seabed, or at about -75 to -80 mPD. This indicates a low gradient valley with a southwards fall of about 20 m in 7 km. The surface of the formation falls gently from north to south. It is intensely channelled, indicating extensive erosion. The channels are up to 350 m wide and 15 m deep, and form a dendritic pattern that converges southwards. Near the top of the formation, the seismic records are characterized by laterally continuous, sub-parallel, high amplitude reflectors in a sequence up to 10 m thick. The sediments in Borehole A5/2 generally comprise a muddy sequence with sand laminae and bands, and organic fragments, and indicate deposition in an estuarine environment.

Age and Sedimentary Environment

Sedimentary features recognised from seismic profiles include channel-fill, exhibiting truncation and overlapping during vertical accretion, and lateral accretion foresets associated with migrating channels. Sediment onlap across the underlying rock surface is apparent in a number of areas, and indicates vertical accretion. The poorly developed, laterally persistent reflectors noted in some areas in the upper part of the formation may indicate sedimentation in relatively extensive and undisturbed water, although subject to currents that were capable of cutting and

filling channels and transporting sandy sediments. These sediments in Borehole A5/2 are very organic,

with cosmopolitan diatoms and sponge spicules present in low numbers, and were deposited (Owen *et al.*, 1995) in a brackish, coastal marsh setting succeeded by shallow mud flats, or possibly estuarine conditions.

Within the Chek Lap Kok Formation diatoms, foraminifera, ostracods and sponge spicules are absent or sparse and, where present, are of very low diversity (Shaw *et al.*, 1986; Owen *et al.*, 1995). The foraminifera are generally planktonic forms (Wilkinson, 1990). Palynologically, the formation in Borehole B15 contains a large preponderance of terrestrially-derived organic material and dinoflagellate cysts are scarce (Harland, 1990). The sediments are characterized by cysts of *Protoperidinium* with *Spiniferites* spp. and *Polykrikos*. Terrestrial pollen in Borehole A5/1 (Appendix 4a), which lies just to the east of the Soko Islands, comprises a number of palynofloral associations (Jolley, 1992a). These include mangrove pollen, such as *Sonneratia caseolaris,* as well as the marine microplankton *Spiniferites ramosus* and *Pterosperma* spp. *Castanopsis/Lithocarpus* and *Quercus* pollen, derived from a mixed mesophytic forest community (Wang, 1961), are the background pollen in some of these associations that are dominated by *Alsophyla* spp, graminids and *Pteris*-type spores. There is also an association characterized by common specimens of *Liquidamber formosana* type and frequent specimens of *Rhizophora* type.

The lack of calcareous microfauna in sediments analysed from the Chek Lap Kok Formation does not entirely preclude a marine influence during some period of deposition; decalcification could account for the lack of fauna (Yim, 1984, 1994). Mangrove and other pollen associations, at depth in boreholes A5/1 and B13/13A (Shaw *et al.*, 1986), suggest a littoral or sublittoral environment in a restricted estuary with a significant marine influence. The sediments within Borehole A5/1 may record a cycle of rising and falling sea level, with intertidal deposits at the base of the formation passing up into massive estuarine sands that were subsequently oxidized by percolating groundwater during subaerial exposure. From Borehole WB7 (23999.4 08000.2) in the West Lamma Channel, two lower marine units, separated by terrestrial deposits, have been described (Yim & Yu, 1993). Fluvial and supralittoral environments are also indicated by local, well-channelled architecture, upward-fining sedimentary sequences in boreholes B15 and A5/2, and extensive interbedded plant and organic horizons, which probably formed as overbank deposits in a fluvial system. The formation was deposited in an environment that varied in time and place from submarine to subaerial in an estuarine, intertidal to fluvial setting. Changes in local base level were likely, leading to changes in the location of sediment sources and sinks and a diversity of sediment lithology and architecture.

There are various problems in determining the age of the formation. They stem largely from trying to reconcile the seismic evidence for two regional base level changes and sediment accretion cycles, which deposited the overlying Sham Wat and Hang Hau formations, with radiometric dates obtained from material within the Chek Lap Kok Formation in the district. Dates range from 16,420 years BP to more than 41,000 years BP (around the maximum age of resolution of the ^{14}C method). Three dates were obtained near the top of the formation in Borehole A5/2 (Owen *et al.*, 1995), in the seismic unit characterised by poorly developed, laterally persistent reflectors. A radiocarbon date from a wood fragment, 6.6 m below the top of the formation, gave an age of 35,000 $\pm$ 1250 years BP. An Optically Stimulated Luminescence (OSL) date of 80,000 $\pm$ 9000 years BP and a Thermoluminescence (TL) date of 78,000 $\pm$ 850 years BP were obtained 5 cm and 10 cm respectively below this level. Further dating of sediments within a well established seismic stratigraphy is needed to resolve the absolute chronology.

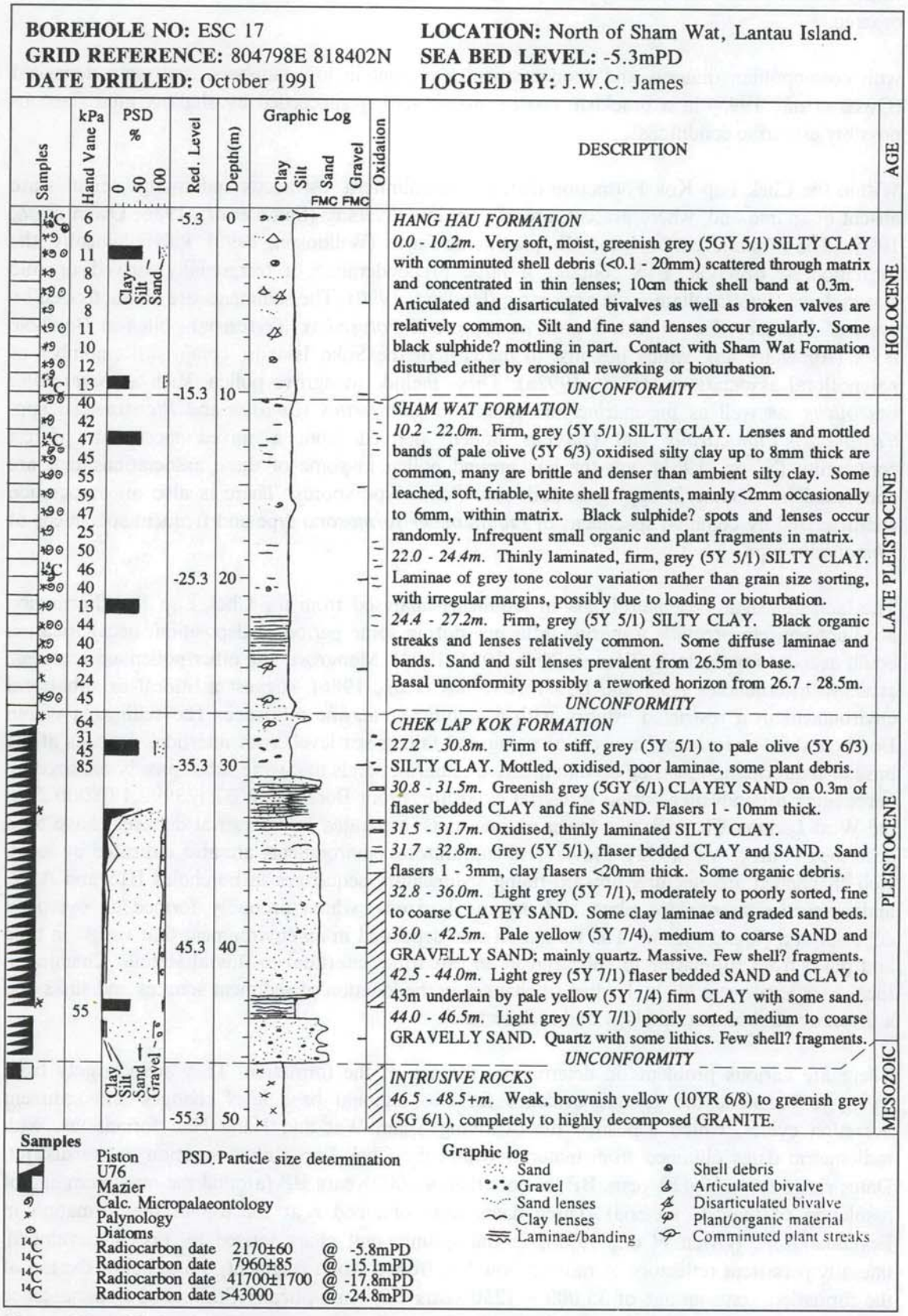


Figure 14 - Geological Log of Borehole ESC17, Containing the Type Section Through the Sham Wat Formation

Sham Wat Formation

The Sham Wat Formation is a newly-defined formation (James, 1993; Fyfe & James, 1995), named after the locality of Sham Wat (0620 1500) on the northwest coast of Lantau Island. The type section of the formation is the continuously sampled Borehole ESC17 (04798 18402) (Figure 14) located north of Sham Wat. The borehole sampled thick deposits of the Sham Wat Formation which are overlain by Hang Hau Formation sediments and underlain by thick Chek Lap Kok Formation sediments. At this site, the formation is bounded by reflectors interpreted as erosional unconformities. The borehole was sited on the intersection of two seismic lines, B35 and B39, allowing the formations and their bounding unconformities to be traced north-south and east-west. Borehole B2/1, to the north, and Borehole A5/1 (Figure 15), which lies to the east of the Soko Islands, also intersected these formations.

The Sham Wat Formation is very restricted in its occurrence, with a total subcrop area of 96 km^2 in the district. The most extensive deposits are confined to the west of the area, both north and south of Lantau Island (Figure 13). The formation is not exposed at sea bed, as it is always overlain by Hang Hau Formation sediments.

The diagnostic morphology of the formation includes the form of its lower bounding surface. In this district, this distinctive lower surface has a high-density, deeply-channelled form (Figure 16). Channel separation varies from 35 to 150 m, with depths of less than 5 m to greater than 20 m. The floors of the channels may reach a level of -54 mPD. On seismic records, the channels are generally symmetrical in cross-section, commonly with deep, V-shaped forms and convex margins. Because of the high channel density many of the channel interfluves are no more than rounded humps, but in some areas they may be planar, with the line of an older erosion surface discernible across the interfluves. Conversely, the upper bounding surface is a planar sub-horizontal erosive contact, although some channelling at the base of the Hang Hau Formation has occurred locally and this has incised the upper surface of the Sham Wat Formation.

The channelled morphology of much of the Sham Wat Formation has controlled the distinctive seismic character of the formation in this district. The primary reflector style is of continuous, sub-parallel units that drape over channel interfluves and down into channel deeps. In the deeper channels the reflectors are parallel, U-shaped infills that onlap the channel margins and across the interfluves. In some channels, especially the widest and deepest, there is evidence of reflector overlap and truncation due to erosion and current activity. A transparent, monotonous seismic response characterises the basal infill of some channels, but these are covered by thick sequences of well-developed, parallel-draped reflectors. The draped nature of the sequence suggests that consolidation of the sediments occurred since initial deposition. Although some consolidation is likely, the absence of significant thinning between the principal reflectors over most channel margins, suggests it is not the principal cause (James, 1993). The drapes are probably primary phenomena resulting from siltation in shallow waters. The sub-parallel draping is generally continuous to the top of the formation, although there is some decrease in the amplitude of the drapes.

Few boreholes penetrate the thick sequences of the Sham Wat Formation around the Soko Islands and north of Sham Wat. The most complete sequence proved is in the type borehole, ESC17 (Figures 13, 14 and 16). The formation comprises generally firm (undrained shear strength 40 - 60 kPa), grey clayey silt. Lenses and mottled bands of brittle and denser, pale olive, oxidized, clayey silt up to 8 mm thick, are common. Leached, soft and corroded white shell fragments, generally less than 2 mm, but occasionally up to 6 mm, occur and very small disarticulated bivalves, up to 6 mm across, are also present. Black spots and lenses occur randomly, as do infrequent, small, organic fragments. Within the upper part of the channel, at the base of the

BOREHOLE NO: A5/1 **LOCATION:** East of Soko Islands.
GRID REFERENCE: 809935E 805580N **SEA BED LEVEL:** -10.0mPD
DATE DRILLED: September 1989 **LOGGED BY:** J.W.C. James

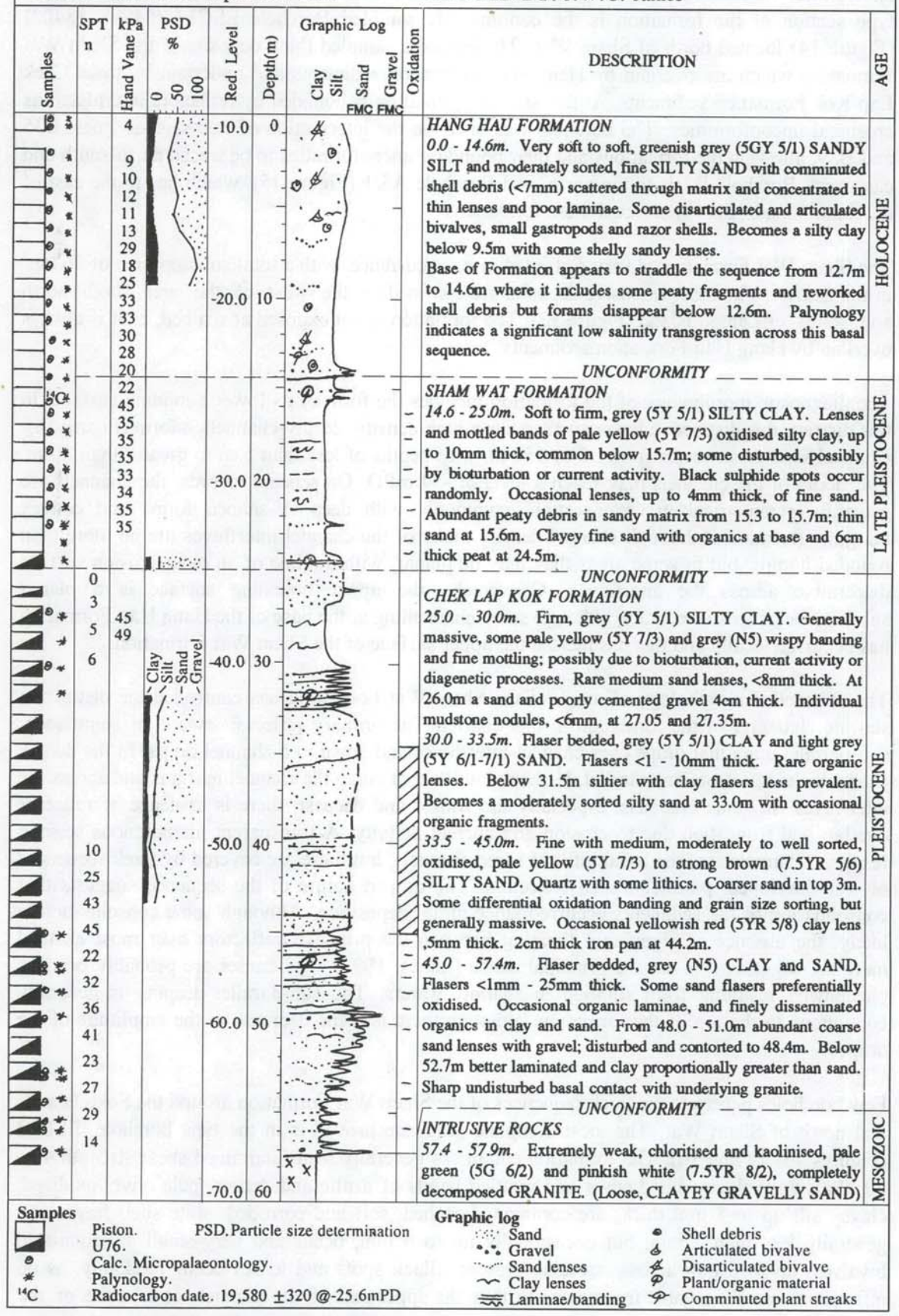


Figure 15 - Geological Log of Borehole A5/1

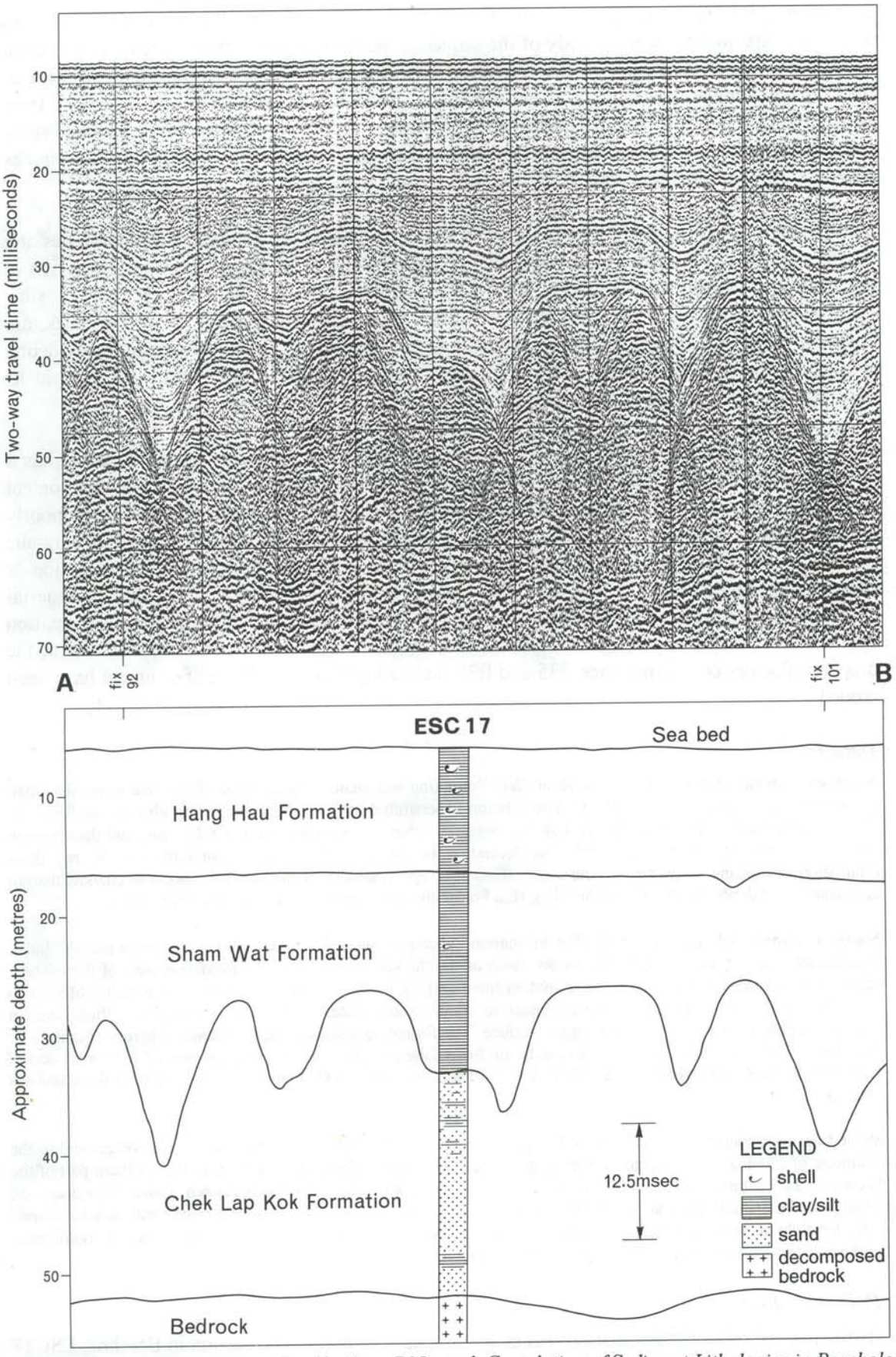


Figure 16 - Boomer Seismic Profile Line B35 and Correlation of Sediment Lithologies in Borehole ESC17 with Interpretation of the Seismic Character.

formation, thinly laminated clays occur at a depth of -27.3 to -29.7 mPD. Plant fragments and debris are rare within the main body of the sequence, but thin organic streaks are more prevalent below -29.7 mPD. The base of the formation lies at a reworked horizon around -32.5 mPD, where sand laminae and beds become dominant. Bulk XRD analyses of two samples from Borehole ESC17 showed major concentrations of quartz and kaolinite with minor mica and some smectite; subordinate calcite, feldspar and pyrite were also noted. The fractions of the samples less than 2μm are predominantly composed of kaolinite with minor smectite and mica.

In Borehole A5/1 (Figures 13 and 15), east of the Soko Islands, the top of the formation lies at a depth of about -24.6 mPD. Some reworking of the top may have occurred during deposition of the overlying Hang Hau Formation muds. The sediments are soft to firm, grey clayey silts. Lenses and mottled bands of pale yellow, oxidized clayey silt, which are up to 10 mm thick, are common below -25.7 mPD, as are occasional lenses of fine sand. There is abundant peaty debris in a sandy matrix near the top of the formation. Sand and organic fragments also occur at its base in association with a 60 mm thick peat.

It is clear from the lithologies described in these boreholes that the Sham Wat Formation has a few diagnostic features. The formation is firmer (40 - 60 kPa) and has a lower moisture content (<80%) than the overlying Hang Hau Formation. It is also greyer and has some very poorly oxidized bands. There are only a few carbonate shells and these are poorly preserved. Organic streaks and lenses may occur near the base of the formation. Although no intense oxidation or palaeosol is apparent at the top of the formation in ESC17 or A5/1, a period of subaerial exposure is likely to have post-dated its deposition. The erosion noted at the top of the formation could have removed any evidence of such features. This is evident from the truncation of the draped reflectors on seismic lines B35 and B39, indicating that up to 10 m of sediment have been eroded.

Details

North of Lantau Island. In this area, Sham Wat Formation sediments subcrop west of the line from Sha Chau (0600 2600) to Lam Chau (0850 1800). The subcrop is separated by an east-west trending channel infilled with Hang Hau Formation sediments (Figure 13). The northern subcrop has an area of about 4.25 km^2 and the southern subcrop an area of about 10.30 km^2. The formation is about 20 m thick in Borehole ESC17, but thins rapidlynorthwards and eastwards. To the east of these subcrops, remnants of the formation occur as channel margin or channel floor deposits, underlying the Hang Hau Formation or Channel and Transgressive Deposits.

South of Lantau Island. The Sham Wat Formation subcrop is well developed around the Soko Islands, but a considerable area of acoustic turbidity masks much of the thicker sequences of the formation west of the islands. Eastwards, towards Cheung Chau, the formation thins and, as in the area north of Lantau, it is more difficult to recognise. It attains its maximum development in southwestern waters, where it is over 35 m thick, with a well-developed, deep palaeosol on its upper surface. The formation occurs as three distinct subcrops (Figure 13). One has an area of 61.80 km^2 and surrounds the Soko Islands. The second, with an area of 5.40 km^2, occurs between Cheung Chau and Shek Kum Chau. The third subcrop, south of Cheung Chau, is about 10 m thick and has an area of 14.00 km^2.

West Lamma Channel. A continuous subcrop of unequivocal Sham Wat Formation sediments wedges out to the southeast of Cheung Chau, on the western edge of the West Lamma Channel. However, in the southern part of the West Lamma Channel, channels in the surface of the Chek Lap Kok Formation, between 5 and 15 m deep, are filled with laminated sandy silts and silty sands. In the larger channels, these have a wavy, sub-parallel draped reflector style on seismic records, analogous to the Sham Wat Formation. The age and stratigraphical significance of these extensive channel-fills in this part of the district have not been resolved.

Palaeontology

Distinctive palynofloral associations occur in sediments from the type section in Borehole ESC17 (Appendix 4b) (Jolley, 1992b). *Pteris*-type spores are relatively abundant and dominate much of the sequence, from a depth of -30.8 to -15.7 mPD, as do other polypodiaceous fern spore-types

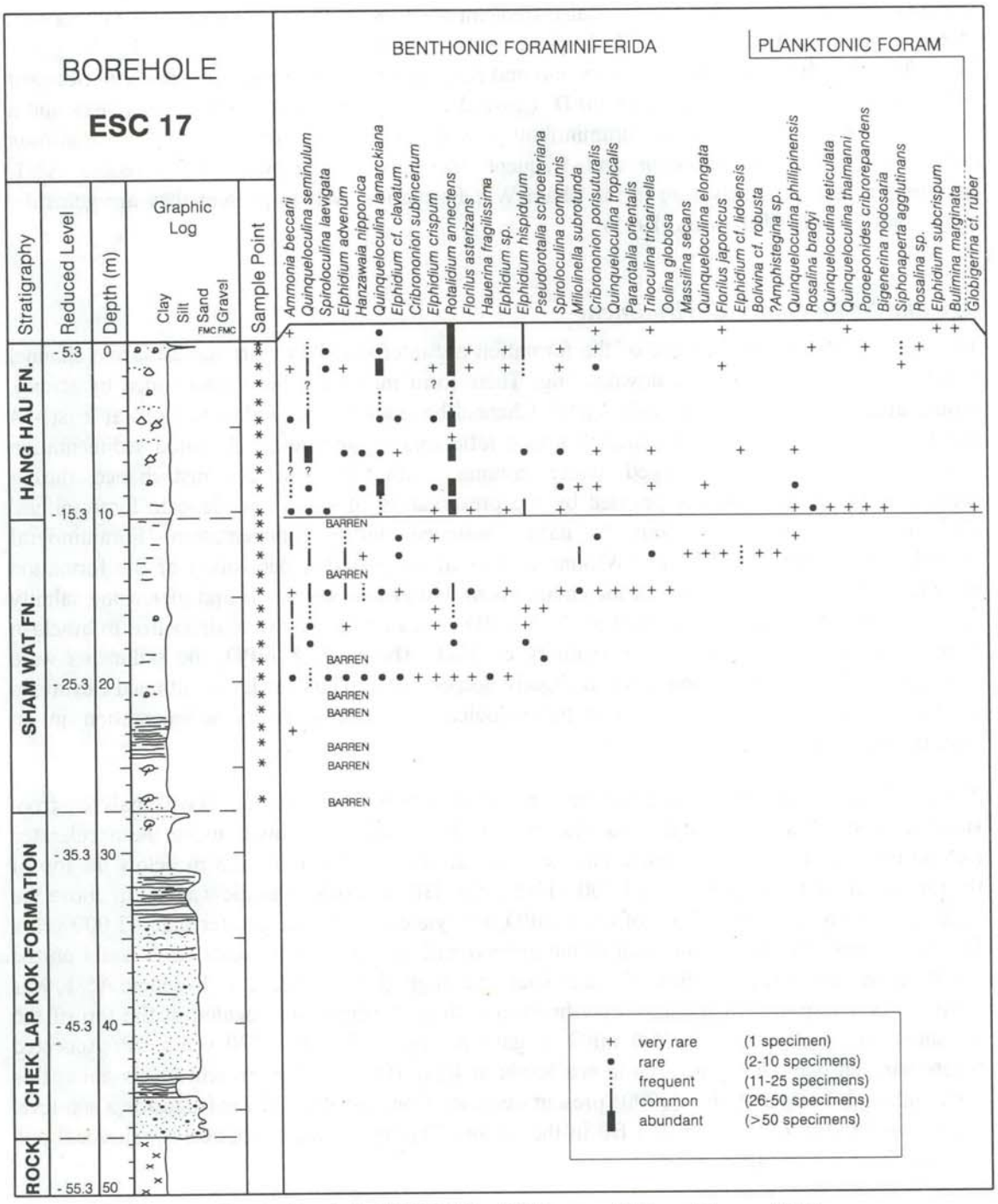


Figure 17 - Foraminifera in Borehole ESC17 (after Wilkinson, 1991 and James 1993)

such as *Alsophyla*, *Ctenitis* and *Selaginella*. The broad-leaved, evergreen forest taxa *Castanopsis/Lithocarpus, Quercus, Liquidamber formosana* type and *Corylopsis* are present in various abundances throughout, and have an inverse relationship with the ferns. Microplankton, such as *Spiniferites cf. bellerius, Achomosphaera ramulifera, Protoperidinium* spp., *P. leonis, P. conicum, Lingulodinium machaerophorum* and *Spiniferites* spp. also occur. Although mangrove pollen is not recorded in the basal 5 m of the formation, both *Rhizophora* type and *Acrostichum aureum* occur between -25.8 and -18.8 mPD.

Foraminifera are present, although not common. Eight of the sixteen samples analysed from Borehole ESC17 (Figure 17) were barren of foraminifera, including the whole sequence below -25.3 mPD (Wilkinson, 1992a). The lowest productive sample, at -24.8 mPD, is dominated by

Quinqueloculina seminulum, which is also frequent at -20.8 mPD and common in the upper part of the formation. Although individual species were recorded rarely at -24.8 mPD, the genus *Elphidium* is well represented and *Ammonia* and *Rotalidium* are also present. *Ammonia beccarii* is common between -22.8 and -20.8 mPD. Upward from these depths, diversity increases and a number of miliolids and other foraminiferal species appear, including common *Rotalidium annectens*, *Elphidium advenum* and frequent *Hanzawala nipponica*. In Borehole A5/1, foraminifera are extremely rare in the Sham Wat Formation. Where present they are generally agglutinated forms (Wilkinson, 1991).

Age and Sedimentary Environment

The incised channels at the base of the formation are interpreted as marginal estuarine channel systems associated with rapid downcutting. Their form may have been maintained by strong, semi-diurnal tidal streams and high runoff. Channel base levels are eroded down to at least -54 mPD. The well-developed, sub-parallel draped reflectors suggest relatively rapid sedimentation from a highly sediment-charged water column, with little current disturbance during sedimentation; a conclusion supported by the preservation of small and delicate foraminifera. High terrestrial runoff is likely to have continued during sedimentation. Foraminiferal assemblages in Borehole ESC17 (Wilkinson, 1992a) suggest that deposition of the formation occurred within an estuarine to marine environment, with rising sea levels and increasing salinity through time. Analyses of sediment at -24.8 mPD indicate that they were deposited in brackish water in depths of less than 20 m (salinity c.30‰). Above -22.8 mPD, the sediments were deposited in fully marine conditions and slightly deeper water. Thus sea levels attained elevations comparable to the present day. The palynological evidence supports sedimentation in an estuarine environment.

Three ^{14}C dates have been obtained from material within the formation. Two analyses from Borehole ESC17 were of small, less than 6 mm, disarticulated bivalves using the accelerator (AMS) method. The highest sample analysed was at -17.8 mPD, about 2.5 m below the top of the formation, and gave a date of 41,700 ±1700 years BP. The other sample was 7.7 m above the base of the formation, at a depth of -24.8 mPD, and yielded a date of greater than 43,000 years BP. Both dates are close to the limit of the method and the large error factor casts doubt on the result. In addition, the possibility of contamination is high. The third date, in Borehole A5/1, was from a wood fragment in a sandy clay horizon with peat fragments, located at the top of the formation at an elevation of -25.6 mPD. It gave an age of 19,580 ±320 years BP. Accepted Quaternary chronologies place world sea levels at least 100 m below present levels about this time, although Long and Huo (1990) present evidence from the Pearl River Delta for a sea-level high from 28,000 to 21,000 years BP in the region. The age of the formation is equivocal and requires further resolution.

Channel and Transgressive Deposits

These deposits form a distinctive sequence of sediments within what has been interpreted as a proto-channel of the Pearl River system, and occur only in a limited area. Consequently, they are of indeterminate stratigraphical status. They are composed predominantly of sand, although there is variability both laterally and vertically throughout. Interbedded sequences are common, and include fine to coarse sand, some with gravel and cobbles, silty fine sand and sandy clayey silt.

The deposits are characterized by distinctive high amplitude reflectors. They most commonly occur as sets of shallow-angled, dipping clinoforms and sub-parallel reflectors about 3 to 4 m thick, with continuous high amplitude planar reflectors at the bottom and top of these sets. The clinoforms, particularly on the cross-channel sections, can dip in opposite directions and in some areas minor channelling and truncation is evident. Along the channel, the planar sets have a high degree of continuity, with foresets appearing to have a dominant down-channel dip to the east.

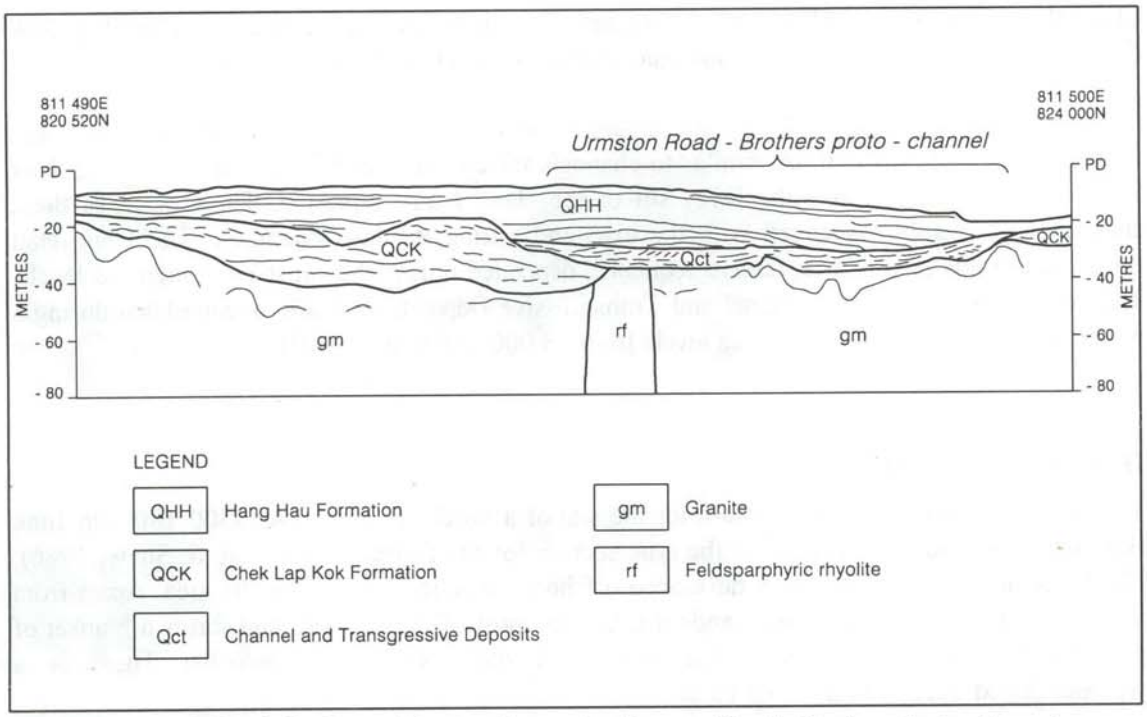


Figure 18 - North-South Geological Section Across the Urmston Road - Brothers Proto-channel

Details

Urmston Road. The deposits occur as a basal infill of the buried Urmston Road - Brothers proto-channel (Figure 18). The alignment of the proto-channel follows the modern bathymetric channel north of The Brothers islands to Kap Shui Mun. The southern limit of the proto-channel enters the district from the north, about 2km east of Sha Chau, continues towards the north tip of Chek Lap Kok, then is directed north of both The Brothers and across to the Lantau Island coast at Cheung Sok Tsui (2030 2200). North of Chek Lap Kok, the proto-channel is about 2km wide. Its northern limit swings north out of the district and returns east of The Brothers islands where it narrows towards Kap Shui Mun. The proto-channel has incised deeply into the Chek Lap Kok Formation. Its southern margin forms a prominent break of slope, with extensive Chek Lap Kok Formation sediments remaining as a high terrace between the proto-channel and the Lantau Island coast. Thicknesses vary from less than a metre at the margins of the channel, to almost 15 m near the centre. Around The Brothers islands there are some rock highs over which the deposit thins. One of the most notable features of the unit is the planar sub-horizontal style of its base. Its top is similarly planar, and the deposit therefore has an almost constant thickness of less than ten metres.

Age and Sedimentary Environment

Strong planar reflectors, with well-developed foresets, are clearly displayed on the seismic records, suggesting that lateral accretion was a prominent process. These structures are common in large fluvial systems, but they can also develop in estuarine conditions with high runoff and weak tidal currents. The proto-channel is likely to have been a major distributary channel of the proto-Pearl River. The cutting of the proto-channel would have been associated with a major, eustatic, low sea-level stand, with the bulk of sedimentation probably occurring during and after the subsequent transgression. However, remnants of low-stand accretionary sediments cannot be discounted at depth within the channel.

The deposits deeply erode the Chek Lap Kok Formation, but there may be some remnants of it at the base of the proto-channel. There is little evidence of a direct association with the lithologically and seismically dissimilar Sham Wat Formation, which does not extend as far east as the Urmston Road to Kap Shui Mun area. Remnants of sequences with a draped seismic reflector style, characteristic of the Sham Wat Formation, have been noted on the proto-channel margin east of Sha Chau. These remnants have been truncated by the basal surface of the

Channel and Transgressive Deposits. Stratigraphically, both are younger than the Chek Lap Kok Formation and both are overlain by the mud blanket of the Hang Hau Formation.

On some seismic sections, there are channel incisions into the top of the Channel and Transgressive Deposits that are similar to channels which cut elsewhere into the Chek Lap Kok Formation; all are infilled with clayey silt of the Hang Hau Formation. The erosion of these channels is probably associated with the lowstand during the last glaciation. The Hang Hau Formation in this area is a regressive sequence, deposited during the subsequent high sea levels. The bulk of the underlying Channel and Transgressive Deposits probably accumulated during a period of relatively rapidly rising sea levels from 18,000 to 8,000 years BP.

Hang Hau Formation

The Hang Hau Formation is named after the site of a borehole, JBS1/1A (4500 1800) in Junk Bay, which has been designated as the type section for the formation (Strange & Shaw, 1986). The formation is the most widely developed offshore superficial deposit in the area. Apart from areas of rock outcrop and littoral sands it underlies most of the sea bed, and forms a blanket of predominantly muddy sediment that covers all older superficial deposits. There is a well-developed unconformity at its base.

There are two principal controls on its nature and distribution. The first is the form of its basal surface, the major features of which were formed during the low stand of the last glaciation and the marine transgression associated with the subsequent deglaciation. An extensive dendritic network of channels was eroded across the area during the low stand. They vary in depth from less than 3 m to about 15 m. They are not as abundant as the channels at the base of the Sham Wat Formation, nor are they as deeply incised. There are many relatively narrow channels with widths of less than 200 m, and they generally have V-shaped profiles. These channels are particularly well developed east of Chek Lap Kok. The narrower channels feed into larger channels, with widths over 2 km, such as the Urmston Road - Brothers proto-channel, the West Lamma Channel and a large channel south of Sha Chau. All of the channels have been infilled with sediments of the Hang Hau Formation. Isopachs for the formation illustrate the drainage pattern (Figure 19). The distribution of acoustic turbidity within these sediments, originating from decaying organic matter at the base of the channels, also indicates their trend.

The second major control on sedimentation has been the strength and distribution of tidal currents in the area. One of the main tidal pathways of the Pearl River estuary runs down the Urmston Road Channel, through Kap Shui Mun and south through the East Lamma Channel. The higher velocities of currents within this tidal pathway reduced sedimentation in its main course and precluded it in the narrows of Kap Shui Mun. However, large marginal banks of muddy sediment have built up in response to the decreasing current velocity gradient away from the tidal pathway. Large sand banks have also developed on either end of the Kap Shui Mun gap, in the centre of the tidal channel. Over 25 m of sediment has accumulated above the larger incised channels, with 10 to 15 m on the interfluves. These interfluves are generally planar, and any thickness variations above them are due to the form of the sea bed. The marginal, tidal channel banks can be underlain by up to 25 m of sediment.

Other minor controls on sediment thickness include thinning towards the coastal margin, which tends to be very rapid because of the steep coastal slopes. Some rock highs were exposed during the last sea-level low stand, especially around The Brothers islands. They subsequently acted as obstructions to currents, creating turbulence and scouring during deposition of the Hang Hau Formation. Current scouring and turbulence next to prominent headlands, such as north of Lam Chau and Sha Lo Wan, creates small depressions in the sea bed and thinning of the sediments.

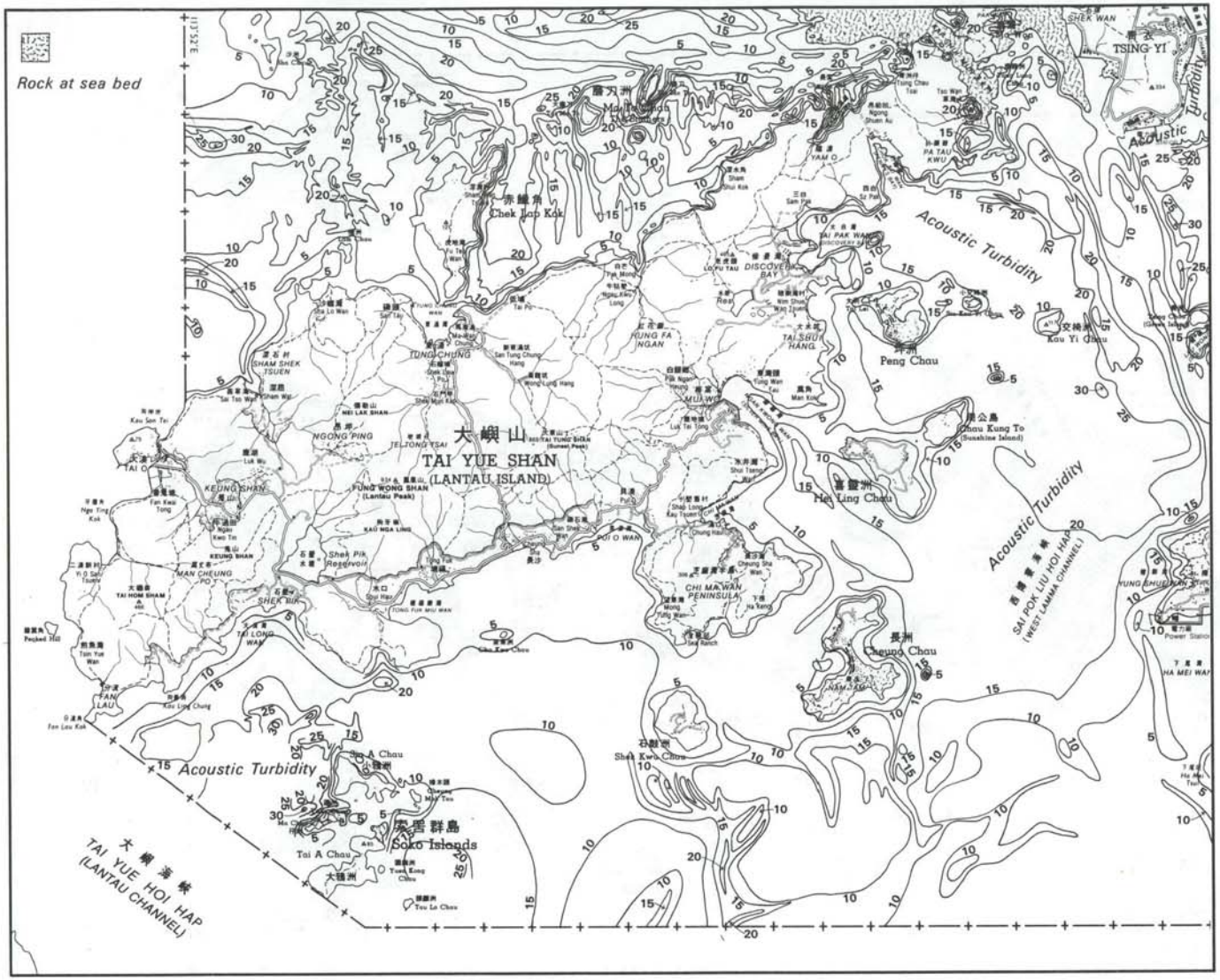


Figure 19 - Distribution and Thickness (Isopachs) of the Hang Hau Formation Muds in the Distict

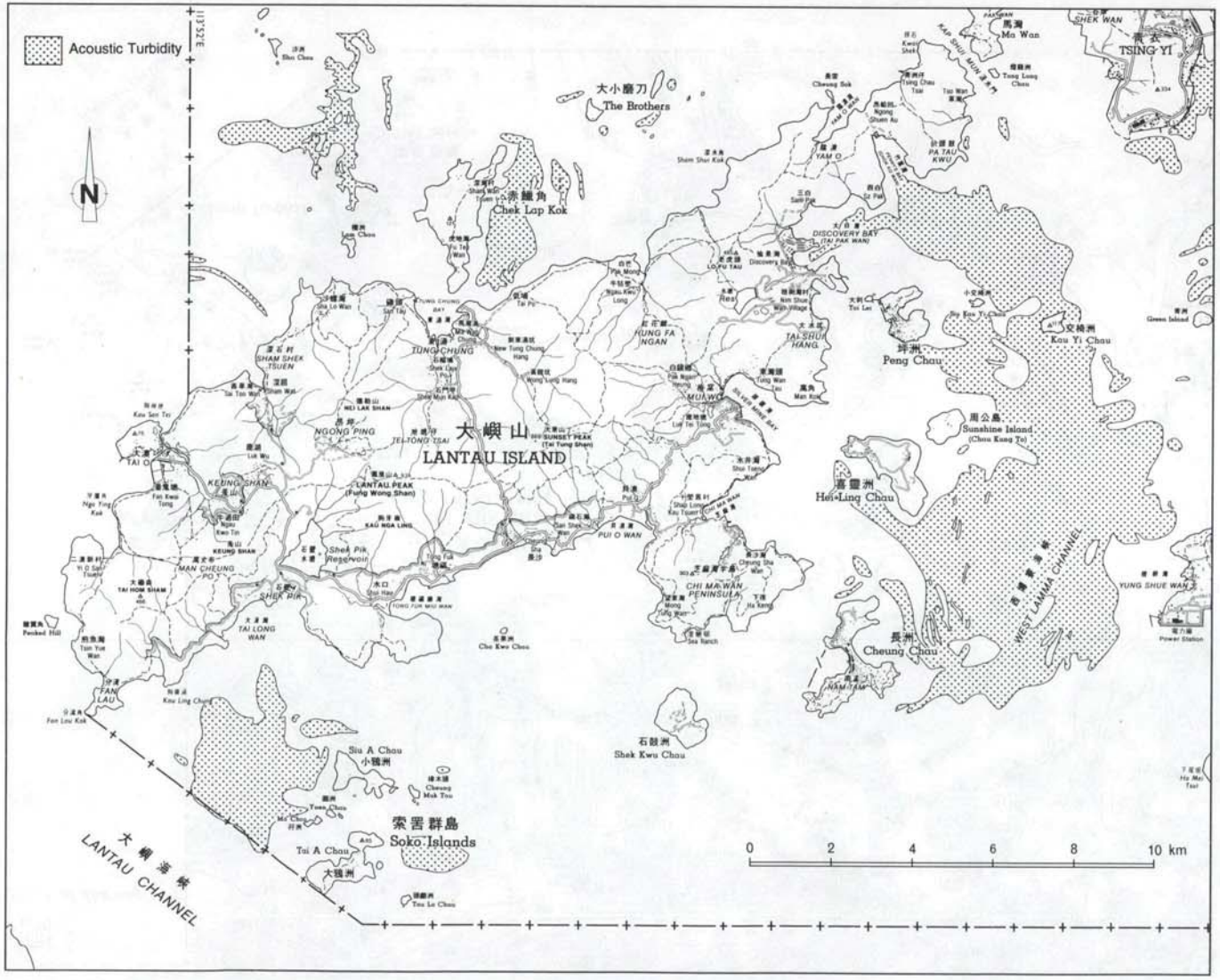


Figure 20 - Areas of Acoustic Turbidity (Stippled) in Offshore Areas of the District

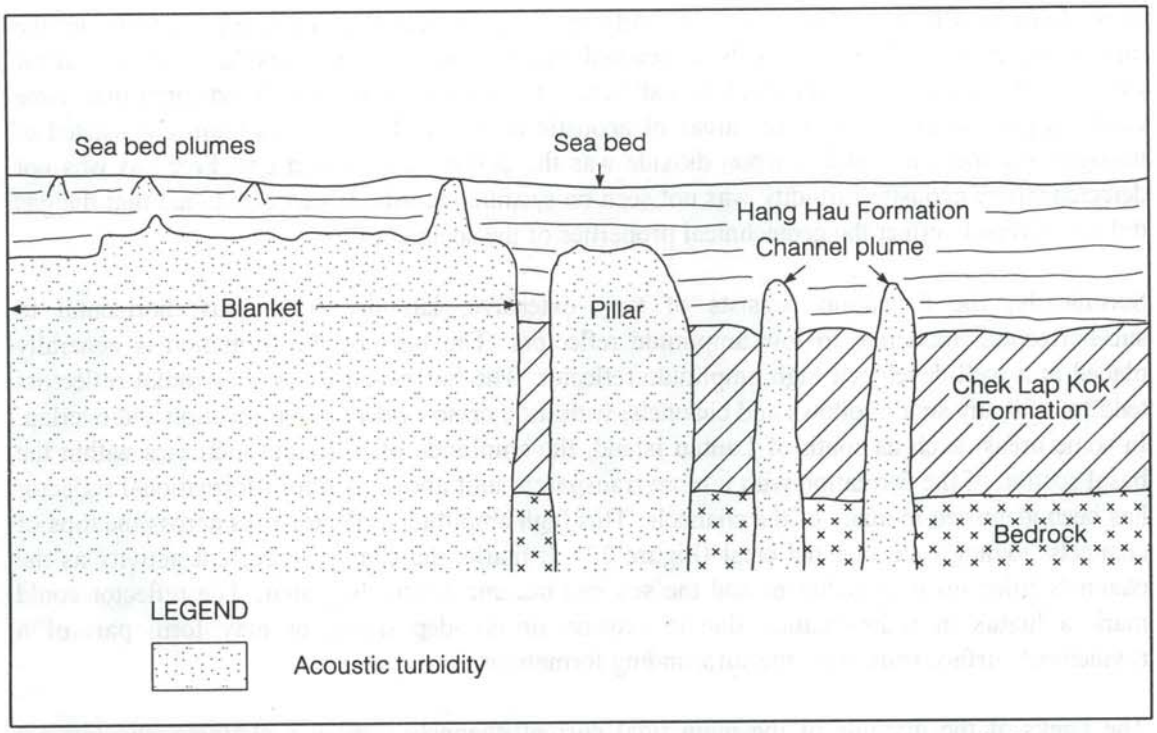


Figure 21 - Morphology of Acoustic Turbidity on Seismic Profiles in the District (Not to Scale)

The formation is relatively homogenous lithologically, consisting of very soft to soft, olive grey clayey silt. Undrained shear strengths range from less than 3 to 20 kPa. Disarticulated and articulated bivalve shells are relatively common. Comminuted shell debris, ranging in size from less than 0.1 to 20 mm, is scattered throughout the matrix, but is sometimes concentrated in thin beds and lenses. Silt and fine sand lenses also occur regularly throughout the sequence and some black mottling has been noted. The sediments are commonly coarser towards, and at, the base of the formation.

Acoustic turbidity (acoustic blanking or gas blanking) appears on seismic records as zones of chaotic reflectors that obscure or obliterate any other reflectors within or beneath these zones. It results from gas within the sediments causing absorption and, or, scattering of the acoustic pulse (Judd, 1989). This creates significant attenuation of the return signal, and a relatively dramatic drop in acoustic velocity (Gardner, 1987). Shallow, biogenic gas within sediments is produced by anaerobic bacteria feeding at depth on a source of carbon such as decaying organic matter.

Extensive areas of acoustic turbidity have been identified, along the West Lamma Channel, and around the Soko Islands and Chek Lap Kok (Figure 20). The major occurrences of acoustic turbidity generally begin within the Hang Hau Formation and mask reflectors in the underlying Sham Wat and Chek Lap Kok formations and rock. However, west of the Soko Islands some acoustic turbidity occurs at depth in the Sham Wat Formation, and does not affect the overlying Hang Hau Formation. The morphology of the turbidity on seismic records takes a number of forms (Figure 21), including wide extensive blankets, such as in the West Lamma Channel and around the Soko Islands. This turbidity is also associated with infilled channels at the base of the Hang Hau Formation. Channel plumes tend to lie across the channels, with their upper surface generally at depths of 7 to 10 m beneath the sea bed. The turbidity picks out the branching plan of many channel systems but does not always extend along the entire length of all the channels in which it occurs. There is little evidence of columnar plumes reaching the sea bed, or of gas escape or gas pressure features at the sea bed. Sea bed morphology associated with shallow gas, such as pockmarks (Hovland & Judd, 1988) have not been noted in Hong Kong. Localized doming of up to one metre of the sea bed, has been seen on some pinger seismic records in the

West Lamma Channel. These may be attributed to increased pore (gas) pressure in the underlying sediments, or, more likely, to sea bed dumping. A study to assess the effect of shallow gas on the engineering properties of sediments (Premchitt *et al.*, 1990) indicated that some occluded gas bubbles exist in the areas of acoustic turbidity. The free gas mainly consisted of nitrogen and methane, while carbon dioxide was the dominant dissolved gas. Free gas was not detected where acoustic turbidity was not seen on seismic records. It was concluded that the gas did not adversely effect the geotechnical properties of the sediments.

Seismically, the formation consists of very extensive, laterally continuous, horizontal to sub-horizontal, moderate to low amplitude reflectors. The base of the formation is generally placed at a well-developed high amplitude reflector. The horizontal to sub-horizontal reflectors tend to infill any small hollows and channels, with little or no evidence of truncation and overlap. In some areas, such as south of Lantau Island, the amplitude of reflectors increases within the basal section of the formation with a more transparent unit above. An intra-formational reflector has been identified in many of the channels. This high amplitude reflector runs across the tops of channels, joining each channel crest (Figure 22). It marks the change in current activity as the channels filled up with sediment and the sea bed became relatively planar. The reflector could mark a hiatus in sedimentation due to erosion or non-deposition, or may form part of a ravinement surface truncating the surrounding formations.

The banks at the margins of the main tidal current channels display a characteristic internal reflector style. Long, low-angled reflectors predominate, with low-angled truncations formed by reactivation. An extensive, prominent reflector with a very long, sinuous wavelength has been identified south of the Urmston Road - Brothers proto-channel. This reflector may be the result of a major hiatus or a change in current activity. South of Sha Chau, the formation exhibits strong clinoform reflectors dipping to the south. These are inclined at a high angle directly above the basal reflector of the formation. The whole formation in this area is virtually one foreset and topset unit, with no bottomset development, indicating very rapid sedimentation.

Details

North and east of Lantau Island. Over most of the area, the sea bed comprises soft, clayey silts of the formation. Coarser sandy sediment is associated with the tidal current pathway that runs along the Urmston Road - Brothers Channel through Kap Shui Mun (240 225) and southwards past Green Island (290 160). Tidal current velocities exceed 1 m s^{-1} in Kap Shui Mun where the sea bed is floored by rock. As the current velocity gradient decreases to the west and south of Kap Shui Mun (Figure 23), so sedimentation has occurred, firstly as sand banks, and with continuing loss of velocity the sand has given way to the ubiquitous mud blanket. A sand bank occurs off the northeast coast of Lantau, to the north of which the sea bed is rock floored. This sand bank widens and thins westwards to be concealed by a thickening cover of marine mud. A second sand bank occurs immediately south of Kap Shui Mun, that is subsumed southwards by a thickening mud cover. A third sand bank occurred southwest of Tsing Yi, extending under a mud cover to Green Island, but was removed for reclamation fill. Considerable modification of the sea bed has taken place in this area. Much of the sand from the Kap Shui Mun bank has been dredged for reclamation fill, the Urmston Road Channel is regularly dredged for navigation, and the site of the new Chek Lap Kok airport has had most of the marine mud removed, and replaced by reclamation fill. A number of large seabed pits have been dredged east of Sha Chau as a repository for dredged, contaminated marine mud and most of the northeast Lantau coast and littoral zone has been extensively modified by reclamation works for the North Lantau Expressway.

South Lantau Island. To the south of Lantau Island, the sea bed is a layer of marine mud that is generally up to c.15 m thick. A sand bank, which has now been dredged, occurred west of the Soko Islands, and there is some sand at the seabed immediately to the east of the Soko Islands. Both of these occurrences are related to accelerating tidal currents passing the islands, keeping finer material in suspension while sandier material is deposited on the lee side. A large gazetted dumping ground to the south of Cheung Chau (Sheet 1A) has received a variety of dumped waste, and most recently the dredged mud from the Chek Lap Kok airport and other reclamations throughout the Territory. A former sea bed dumping ground (240 170) is located north of Siu Kan Yi Chau.

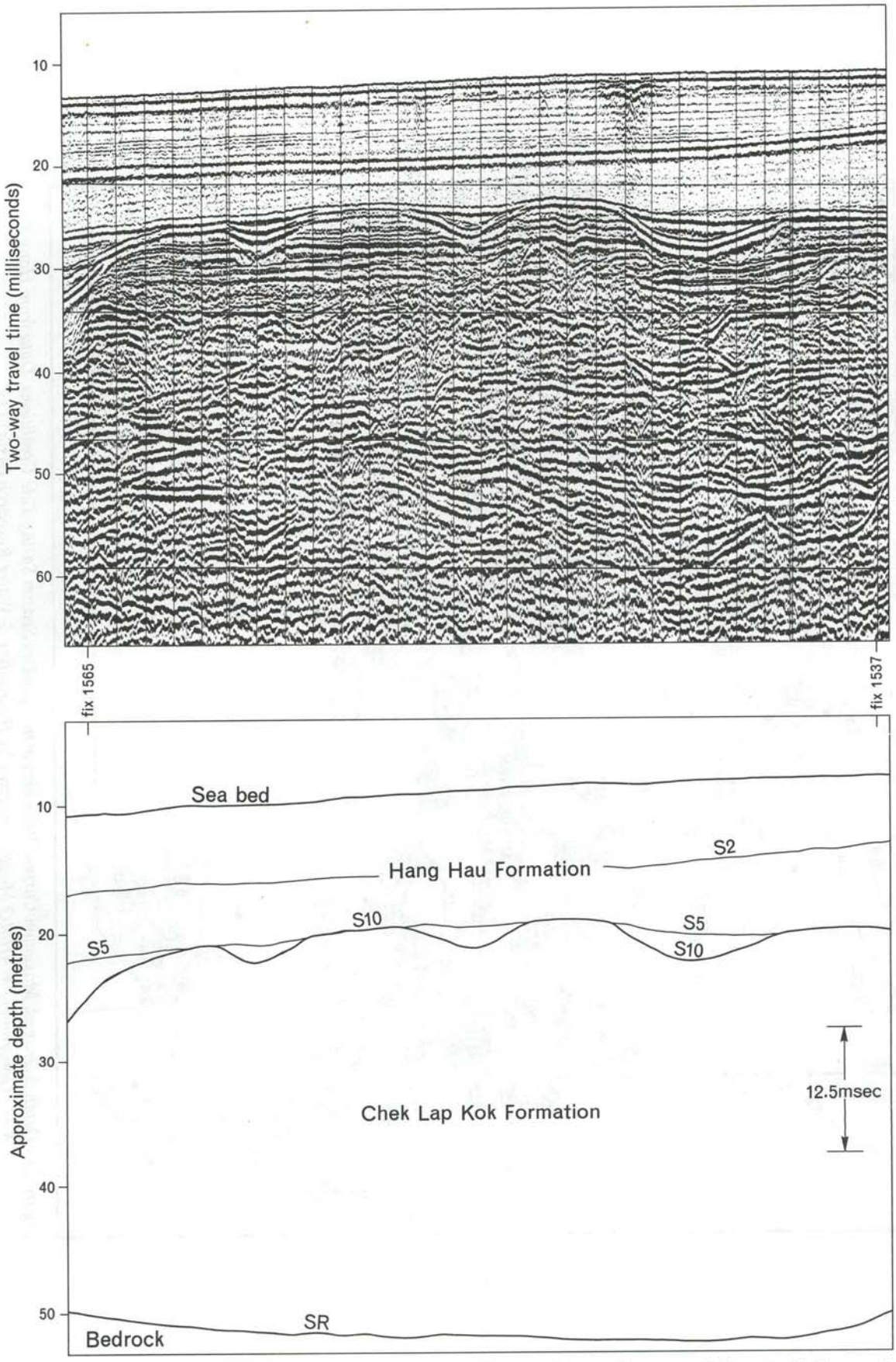


Figure 22 - Boomer Seismic Profile along Line NL3 Showing Major, Interpreted Seismic Reflectors in the Area West of The Brothers Islands, and Highlighting a High Amplitude Reflector, S5,within the Hang Hau Formation, which Runs across the Channel Tops, and Joins the Channel Crests.

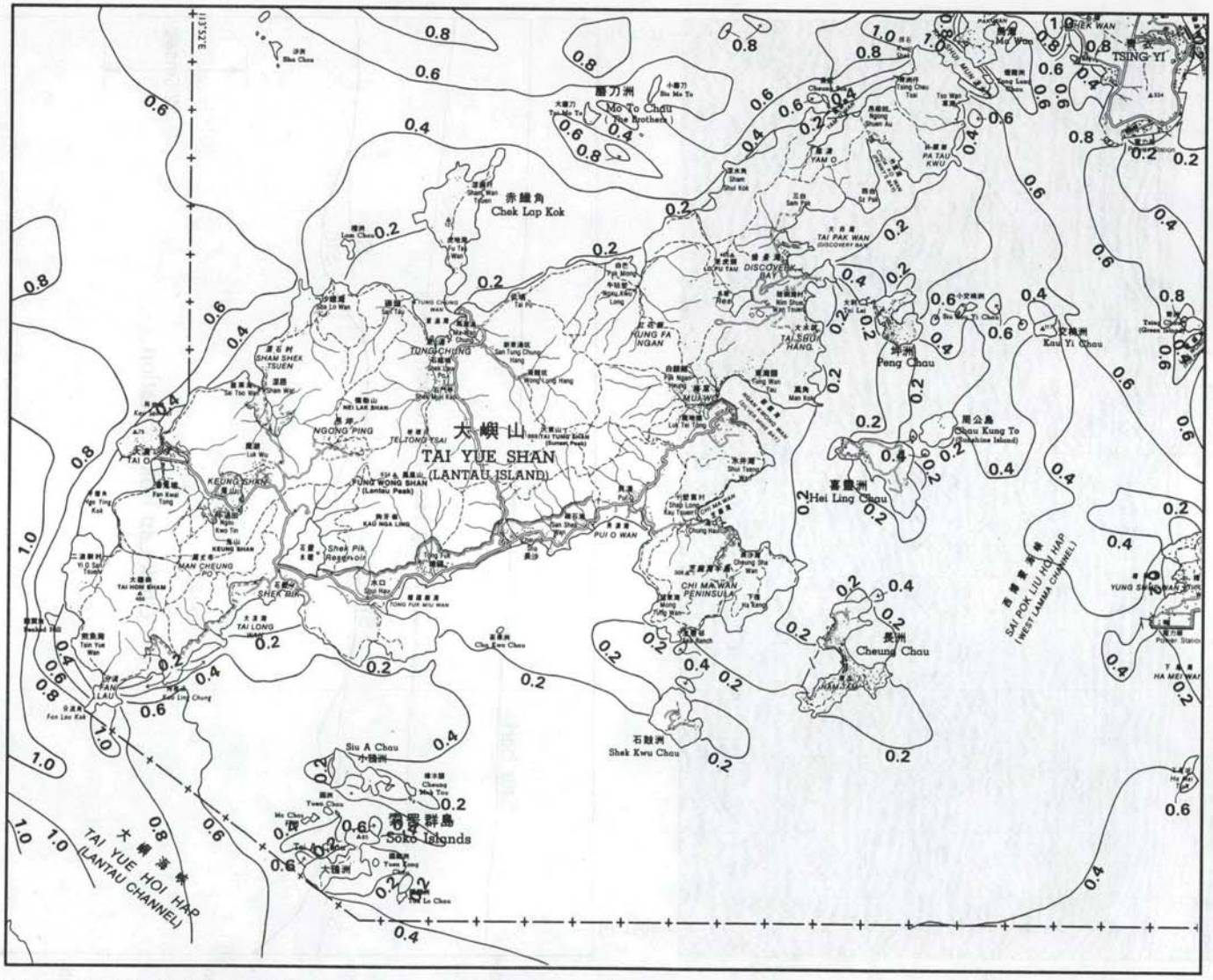


Figure 23 - Depth-Averaged, Maximum Current Velocities in ms^{-1} for Dry Season Spring Tide Conditions. Data from Hong Kong Government WAHMO Model. Analyses by Hydraulics & Water Research (Asia) Ltd.

West Lamma Channel. The Hang Hau Formation forms a thick blanket over the entire West Lamma Channel area. It ranges in thickness from 6 to 20 m, being thickest in the north and thinning southwards towards the southern limits of Territorial Waters. The base of the formation, as seen on the seismic records, is fairly uniform, or gently undulating, It forms an almost horizontal plain, falling gently from about -25 mPD in the north to about -30 mPD in the south. A thick accumulation of Hang Hau Formation muds occurs southeast of Cheung Chau, filling a channel which runs northwest to southeast between Hei Ling Chau and Cheung Chau. Near the southwestern end, a thicker channel-fill tongue of Hang Hau Formation muds is situated between Hei Ling Chau and the northern end of Lamma Island. The thinnest area of Hang Hau Formation muds, about 7 m, occurs at the southern limit of Territorial Waters. Acoustic turbidity, or occluded gas bubbles, affect almost 50 km^2 of the muds in the West Lamma Channel.

The surface of the formation declines gently southwards, and the sea bed forms a wide, shallow channel. Water depths shelve to 5 m deep within 0.5 km of the coastlines. To the east of Hei Ling Chau, the floor of the West Lamma Channel is less than 10 m deep, reaching 10 m between Cheung Chau and Lamma Island, 15 m south of Lamma Island and 20 m near the limits of Territorial Waters. The smooth-surfaced, gently southward-shelving sea bed indicates the lack of strong currents or erosive tidal streams in the West Lamma Channel. This is in contrast to the rock-floored Kap Shui Mun Channel to the north and the East Lamma Channel, which is 30 m deep and scoured to 40 m in places. This quiescent picture is also emphasised by the thick, uniform mud deposits that floor the channel, which slowly settled out from suspension in the water column.

Age and Sedimentary Environment

The formation contains abundant macro- and microfauna. Calcareous disarticulated and articulated bivalves are common, with some gastropods, scaphopods and echinoids. There is a rich diatom flora (Owen *et al.*, 1995) and a varied foraminiferal fauna, although diversity is moderate. A bimodal distribution of *Elphidium hispidulum* is evident (Wilkinson, 1990, 1992a and 1992b) and the population is also dominated by *Rotalidium annectens, Quinqueloculina seminulum, Ammonia beccarii, E. advenum and Cribonion tikutoensis* (Figure 17). A similar range of calcareous microfauna was noted by Shaw *et al.* (1986) and also by Yim & Yu (1991).

Wilkinson (1990) found the ostracod fauna to be generally of a lower diversity compared with the foraminifera, with very little variation through the sequence analysed in Borehole B15. The species were euryhaline. *Sinocytherida impressa, Keijella hodgii* and *Stigmatocythere spinosa* dominate the assemblage. In Borehole ESC17, diatoms were rare to moderately common (R.B.Owen, written communication, 1992) with a restricted fauna dominated by *Cyclotella striata*. In Borehole A5/2, Owen *et al.*, (1995) distinguished five diatom zones in the Holocene sequence, and related them to sea level variations, and the fluctuating influence of fresh and brackish water at the site.Shaw *et al.* (1986) and Yim *et al.* (1987) recorded palynoflora dominated by *Castanopsis* and *Quercus*, although Yim *et al.* (1987) emphasised the Rhizophoracean component in the formation. Jolley (1992a and b) found a comparable record in boreholes ESC17 and B15 (Appendices 4a and 4b) with *Castanopsis/Lithocarpus* and *Quercus* occurring, commonly accompanied by pollen of the Rhizophoraceae. *Cibotium barometz*-types were also regularly recorded.

The seismic, lithological and palaeontological evidence suggests a regressive estuarine to marine sequence, with most of the sediment probably derived from the Pearl River. There are likely to be thin sequences at the base of the formation associated with the Holocene marine transgression, but the bulk of sedimentation occurred in water depths at, or rising towards, those of the present day. The relatively homogenous nature of the sediments down to the base of the formation and thick foreset developments in some areas, suggests rapid initiation of sedimentation with tidal current streams similar to the present regime prevailing throughout the sedimentation cycle.

Palaeontological evidence indicates fluctuations in marine influence during sedimentation with variations in salinity due to increased flows of fresh water in the system. Whether these indicate annual monsoonal influx of fresh water or short term climatic oscillations has not been resolved.

The formation is Holocene in age. Two ^{14}C radiocarbon dates have been obtained from foraminifera in Borehole ESC17 (Appendix 5). The first was near the base of the formation at -15.1 mPD and gave an age of 7,960 ±85 years BP. The second was 0.5 m below sea bed at -5.8 mPD and yielded an age of 2,170 ±60 years BP. The older date accords well with a date of 8,080 ±130 years BP for the base of the formation at -19.70 mPD in the type section (Borehole JBS1/1A) near Hang Hau (Strange & Shaw, 1986). Two radiocarbon dates were determined from shells within the formation in Borehole A5/2 (Owen *et al.*, 1995). The first date, of 3,950 ± 95 years BP, was obtained from 3.29 m below the seabed at -21.60 mPD, and the second, of 7,840 ± 120 years BP, was from 6.21 m below the seabed, or 1.09 m above the base of the formation, at -24.43 mPD. Elsewhere in Hong Kong, ^{14}C dates of 10,060 to 6,580 years BP have been obtained within the formation.

Weathered rocks and sediments

A widespread regolith, of variable thickness, covers the solid rocks of the district. This weathered mantle results from the differential breakdown of minerals in the bedrock. It comprises resistant minerals, mainly quartz, within a matrix of clays derived from the decomposition of ferromagnesian and feldspathic minerals. Regolith thickness depends mainly upon the underlying rock type, its structure and the prevailing slope angle.

In general, the volcanic rocks are the most resistant to weathering and thus form, or cap, the highest summits of Lantau Peak (934 m), Sunset Peak (869 m), Lin Fa Shan (766 m), Nei Lak Shan (751 m) and the surrounding uplands. The granitic rocks are lower lying, and form subdued, rounded hills, reaching a maximum elevation of 306 m at Lo Yan Shan on the Chi Ma Wan peninsula.

The paucity of urban development on Lantau Island compared with the Hong Kong and Kowloon districts (Strange & Shaw, 1986) has meant that there are fewer cut slopes in which deep weathering profiles can be observed. However, some sections are exposed in road cuts, catchwater slopes and stream sections around the island, and major excavations associated with the North Lantau Expressway and the airport at Chek Lap Kok provided valuable temporary sections.

An abundance of tors (Plate 49), boulder fields and boulder streams throughout the district confirms that deep weathering and corestone exhumation (Plates 50 and 51) has proceeded both in the volcanic rocks, and the intrusive igneous rocks. In extreme cases, this results in the formation of pedestal rocks, where completely isolated corestones have been left resting on joint or contact surfaces. Examples occur on hillsides south of Lo Fu Tau, and along coasts, as at Hei Ling Chau (Plate 52). The volcanic rocks have weathered to form elongate, ridge-like crests. Steeply inclined, dendritic drainage systems have developed on their flanks, with sharp interfluves characterised by boulder accumulations, or ridge crest tors, with minor mass movements in the shallow weathering profile. Minor free faces, with thin talus slopes of blocky weathering debris, occur sporadically below ridge summits, usually near the heads of steams. Many channels are choked with boulder debris that has either rafted down from the adjacent slopes, or has been concentrated, by fluvial eluviation of the fines, from the weathering profile along the stream lines. The Chi Ma Wan peninsula is the largest granite outcrop in the district. It displays a distinctive landscape of summit and spur end tors, rounded granite corestones littering the slopes and sandy, eroded ridge crests. The topography is generally more rounded than in the volcanic areas with gentler, shallower valleys that are commonly choked with valley trains of

corestone boulders. Granite cliffs and exposed sheeting joints (Plate 53) are characteristic of the coast and in several places vertical and sub-vertical joints have been selectively weathered and eroded by wave action, to form narrow joint caves.

The sandstones and siltstones of the Lok Ma Chau Formation have been differentially weathered and eroded to form minor escarpments, the more resistant sandstones producing sharp ridgelines standing above the vales in the softer, interbedded siltstones. Both rock types generally weather to sand or silt sized material and produce very little coarse debris. Scarps are particularly well developed along the coastal strip (066 153) northeast and southwest of Sham Wat Wan.

In the northeast of Lantau Island the feldsparphyric rhyolite dyke complex has differentially weathered to create a very lineated topography, which is dominated by upstanding ribs, ridges and ledges oriented in a westsouthwest to eastnortheast direction. The topographical grain is very clear on high level aerial photographs, which show that the drainage pattern has a subparallel, trellis-like geometry that contrasts with the dendritic, radiating patterns on the other hills. The chilled margins of the dykes have been preferentially weathered out to leave the central, relatively less weathered, portions of the dykes upstanding. The ridges weather out to produce coarse blocky debris which topples and collapses to feed debris sheets and streams on the adjacent slopes. This weathering phenomenon is clearly displayed on the slopes (465 m) (181 179) of Lo Fu Tau. To the south, granite rocks crop out. The more readily weathered granites form a lower, less angular topography, as exemplified by the area around the low col (180 m) (170 156) near Wo Sheung Au, where the sharper and higher peak is developed on the feldsparphyric rhyolite.

At outcrop scale, there are many examples of differential weathering, particularly in the volcanic rocks. The clearest example is the distinctive weathering-out of the finer-grained matrix of the Sunset Peak Member, leaving the more resistant blocks protruding from weathered faces. This is well displayed on boulders on the flanks of Lin Fa Shan (Plate 16). Less pronounced, but still evident, is the etching out of the softer bands in the finely flow-banded lavas of the Lantau Formation. These produce sub-parallel, ridged surfaces with interspersed, raised cross-joints (Plate 8) or irregular, wavy banding, emphasising primary flow features (Plate 10). Pitting is well developed in the lapilli-bearing tuffs in which flattened, aligned lapilli are preferentially weathered leaving a honeycombed surface (Plate 17). On the granitic rocks, weathering pits on the upper surfaces of boulders, as on the Chi Ma Wan peninsula, and, more rarely, pseudo-karren flute the sides of some boulders and ridge top tors. Alveolar weathering, which is restricted to the granites, is rare in the district, but an extremely well developed example occurs on a coastal outcrop at Ha So Pai (Plate 54).

The effects of weathering are important in distinguishing the ages of the transported superficial deposits in the district. Late Pleistocene alluvium occurs as high fluvial terraces that have been incised by contemporary streams. The alluvium comprises weathered, oxidised, mainly yellowish-brown to orange debris. Similarly, the older Pleistocene debris flow deposits are oxidised and stained red and brown, or dark yellowish-brown to orange-red. Large clasts display rinds up to about 50 mm thick which must result from post-depositional weathering as they are too fragile to have survived transport. Weathering of the matrix has caused cementing in some deposits, and, where the matrix is silty or clayey, it has been dessicated to produce a stiff to very stiff material.

A weathered mantle, of variable thickness, also occurs beneath offshore superficial deposits of the district. This feature can be recognised on seismic profiles on which the fresh to moderately weathered rock usually has high amplitude reflectors, whereas the overlying, highly to completely weathered rock material of the weathering profile is characterised by more moderate amplitude reflectors. The rock surface has an undulating topography similar to that developed onshore but with a lower amplitude, and in places the weathered mantle is thin or discontinuous.

Boreholes (A5/1, A5/2, B2/1, ESC17 and B15; see above) drilled through the Chek Lap Kok Formation sediments show that they were mainly deposited subaerially. The effects of their subaerial weathering range from sporadic orange oxidation mottles and streaks, to intensive weathering to a deep red colour and the development of nodular concretions. The latter are associated with palaeosols on former exposed surfaces. Generally, the intensity of weathering decreases downwards for about 2 m, below which it is usually represented by intermittent yellow or orange brown streaks and mottles. The weathering occurred during, or soon after deposition, and prior to deposition of the overlying grey, reduced, marine muds of the Hang Hau Formation. The Sham Wat Formation is weathered to a limited extent. It still retains its grey groundmass colour but this is superimposed with sparse orange-yellow mottles and streaks. It is also firm and relatively dewatered, and macroscopic shells are soft and slightly corroded, suggesting subaerial exposure of the sediments.

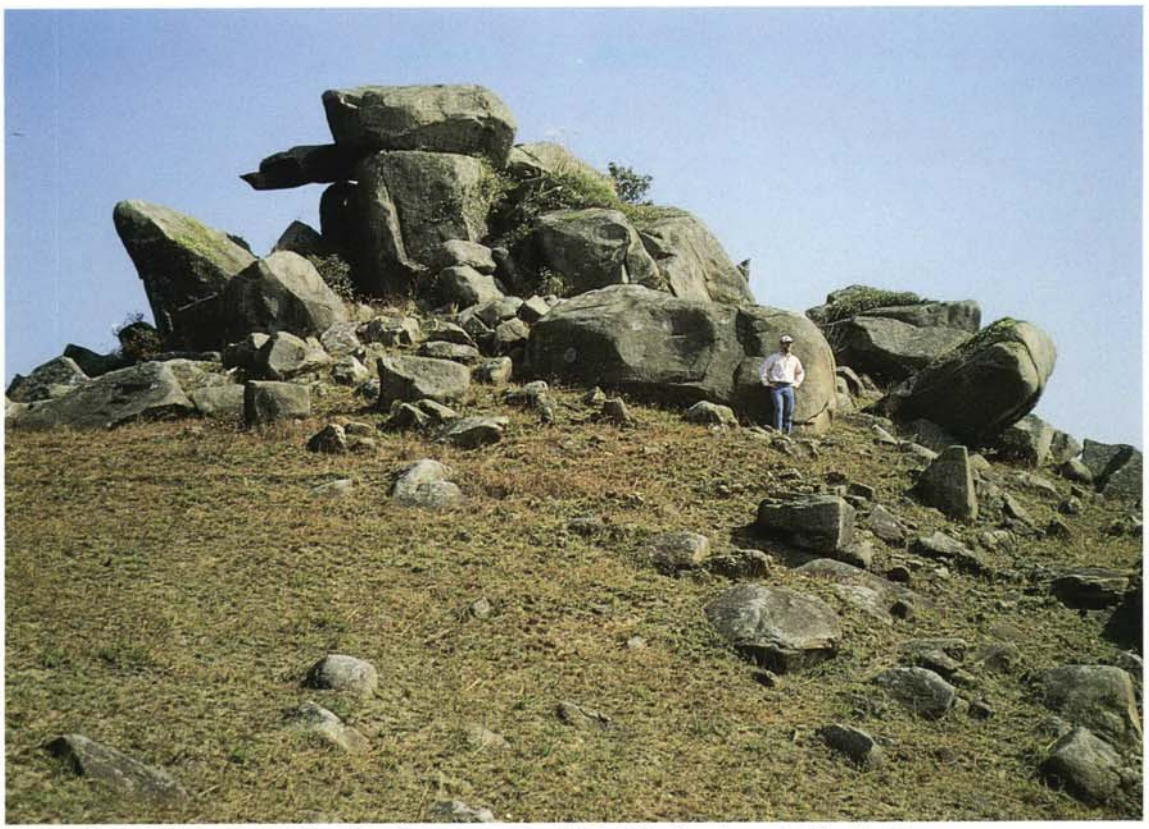


Plate 49 - Feldsparphyric Rhyolite Corestone Tor (176 171), Southwest of Lo Fu Tau

Plate 50 - Corestone Development (Spheroidal Weathering) in Fine-grained Gabbro (1999 1089), East Chi Ma Wan Peninsula

Plate 51 - Deep Weathering Profile with Relict Corestones (Spheroidal Weathering) in Feldsparphyric Rhyolite (2058 1933), Sz Pak Wan

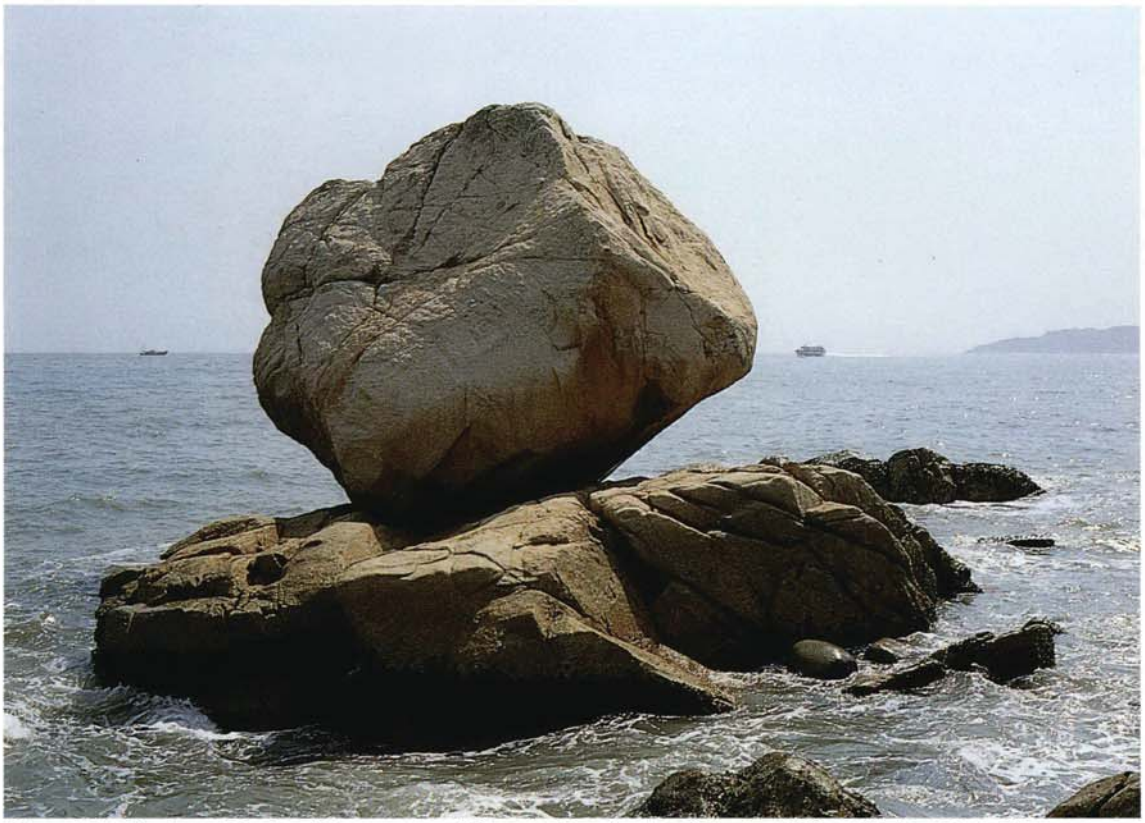


Plate 52 - Pedastal Rock of Fine-grained Granite Perched on Syenite (229 119), Hei Ling Chau

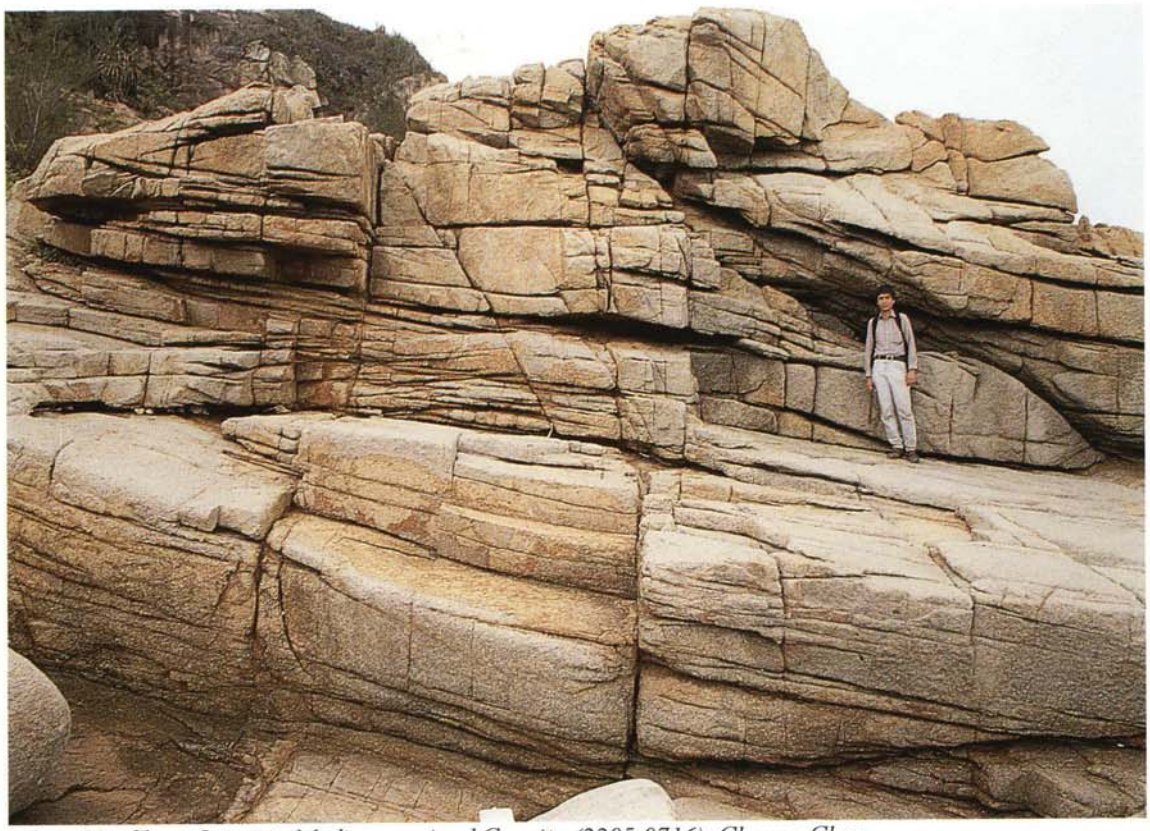


Plate 53 - Sheet Joints in Medium-grained Granite (2205 0716), Cheung Chau

Plate 54 - Alveolar Weathering in Medium-grained Granite (1979 0967), Ha So Pai

Chapter 10
Economic Geology

Introduction and classification

There are no active mineral workings in the district, but lead, silver, tungsten and graphite have all been mined in the past and there are occurrences of zinc, tin, fluorite and beryl. Quartz and clay, which occur within intrusive, and interleaved volcanic rocks, have also been mined on a small-scale at numerous locations. Although there are no active quarries, there are large borrow areas on Tsing Yi, and smaller borrows in northeast Lantau Island. As part of the new airport development, Chek Lap Kok was largely levelled and during the preparation of this memoir it became the biggest borrow area in the district. The Brothers islands were similarly levelled and exploited.

The economic geology is divided into three sections; metalliferous minerals, non-metalliferous minerals, and construction materials. The mineral deposits (Figure 24) include those mined, or prospected for, and other significant mineral occurrences[1]. The construction materials include freestone and aggregate quarries, and borrow areas.

Metalliferous Minerals

Metalliferous mineral deposits usually occur as narrow fissure veins, infilled by precipitates from high temperature, mineralized fluids. These fluids were probably mainly derived from Mesozoic granite bodies at a late stage during their emplacement. Two abandoned mines are known in the district; one at Silver Mine Bay, and another at Sha Lo Wan.

The mine which lends its name to Silver Mine Bay is about 1km northwest of Mui Wo. It was active until 1896, and produced galena, from which lead and small amounts of silver were extracted. The only visible remnants of the mine, are a large tailings fan, adjacent to an adit which is sealed with a concrete wall (17085 14965). The adit was driven along an easterly-trending fault, which separates a silicified feldsparphyric rhyolite dyke, with traces of galena along the northern wall of the adit, from medium-grained granite, seen in the roof.

The wolframite (tungsten oxide) mine at Sha Lo Wan (0901 1584, 0896 1564, 0885 1570) was active until the 1960s. It exploited extensive mineralization in a stockwork of quartz veins and shears, commonly cut by thicker, typically southsouthwest-dipping, quartz-filled, and, or, pegmatitic, shear-veins, joints and fractures. The mineralization is located at, or near, the locally westnorthwesterly-striking contact zone between granitic intrusions to the north, and volcanic rocks infilling the Lantau Caldera to the south. Fine-grained quartz syenite is intruded along this contact zone near the mine workings. Ruxton (1957) recorded sporadic ore minerals in the stockwork, including molybdenite, chalcopyrite, arsenopyrite, wolframite and pyrite. He also noted very minor occurrences of ore minerals in the cross-cutting quartz veins.

The area was extensively trenched prior to the 1950s, although there are no records that wolframite was mined. However, wolframite ore was extracted in 1952 and 1953, and in the late 1950s, the Far Eastern Prospecting and Development Corporation started a large-scale working

[1] Metallifereous minerals, together with associated non-metalliferous minerals, are subject to the provisions of the Mining Ordinance. Permission to prospect for, or work these deposits, is granted in the form of prospecting or mining licences respectively.

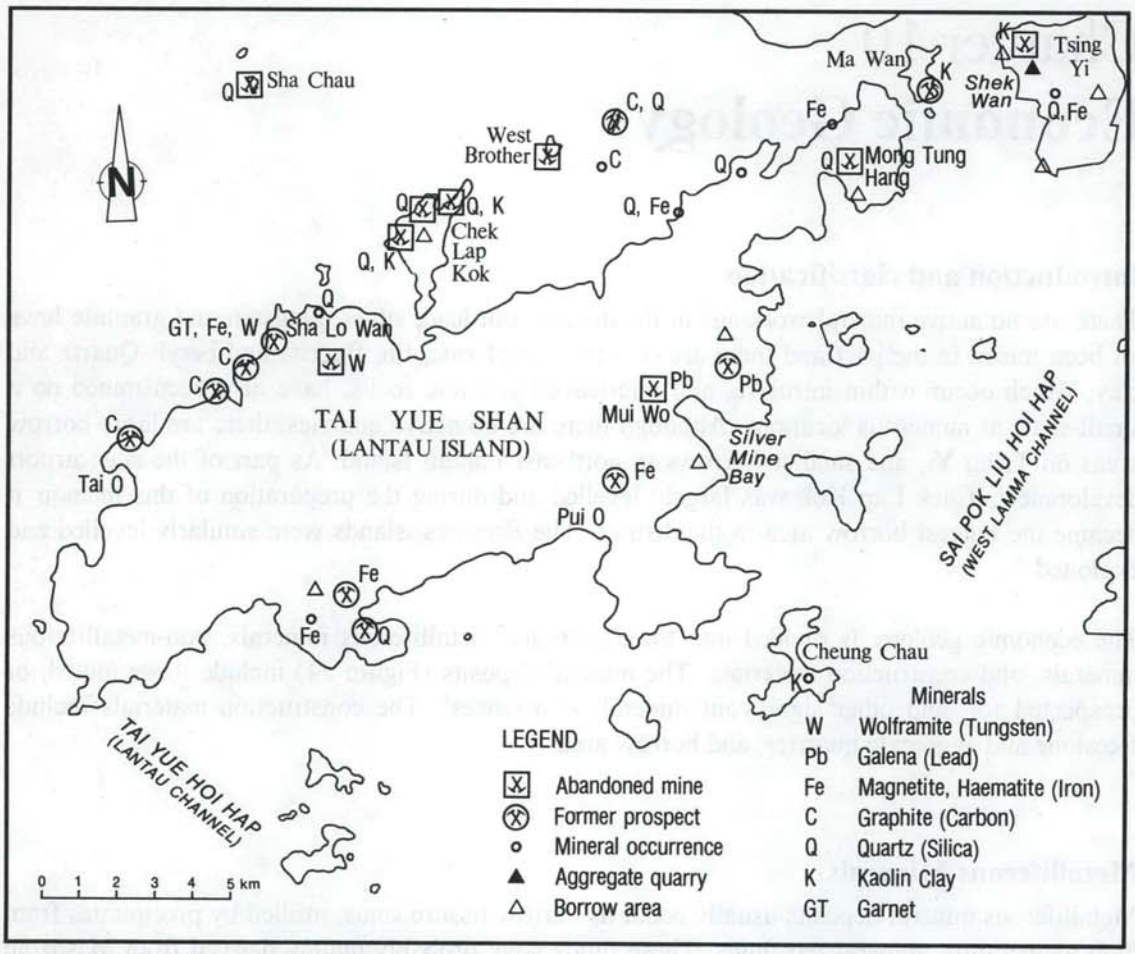


Figure 24 - Distribution of Mineral Deposits in the District

(Ruxton, 1958). The disused mine office (0907 1616) and remains of processing facilities 140 m to its south, are about 1 km east of Sha Lo Wan village. 500 m south of the office, there are extensive heaps of spoil and surface workings (089 157), from which trenches extend west for 500 m. Mining licences were in force for the Sha Lo Wan deposit between 1954 and 1961, although Ruxton (1957) saw little activity at the mine. Aerial photographs show that the mine buildings were occupied in 1963, but that all activity had ceased prior to 1973. Further prospecting for tungsten mineralization has taken place in central and northeast Lantau Island, and on Ma Wan and Tsing Yi, but no further significant mineralization has been recorded.

Prospecting for iron ore, principally magnetite, took place in part of west Lantau Island, but only minor occurrences have been noted (Peng, 1978; Weld, 1915; Tegengren, 1923), including magnetitic veins about 560m westnorthwest of San Tau. Magnetite is also a constituent of skarn mineralization. It is locally abundant in marbles, encountered in a few boreholes sunk on the reclamation east of Tung Chung Wan, near Lau Fau Sha (e.g. boreholes TC65, 12196 16639, H12/17357, 12112 16599) and east of East Brother island (Borehole NS1/14460, 17111 21750). The skarn is commonly greenish-grey and in addition to magnetite, can include epidote, chlorite, augite and plagioclase. It occurs where the marbles are intruded by feldsparphyric dykes and granites, and is mainly related to contact metamorphism. A skarn deposit has also been recorded at San Shek Wan (0714 1612) (Peng, 1978), where it comprises a zone, about 5 m wide, at the contact between foliated sandstone and megacrystic, fine-grained granite. It includes garnet, vesuvianite, diopside and epidote, in addition to scattered magnetite. To date, none of the occurrences of skarn mineralization have been shown to contain economic quantities of any mineral.

Non-metalliferous Minerals

Fissure veins of quartz are common throughout the granitic rocks, particularly on Chek Lap Kok and in northeast Lantau Island. They typically strike northnorthwest or eastnortheast, although other trends, including more northerly, and northeasterly veins, also occur. There have been numerous small workings of quartz veins, for some of which mining licences were granted. The three most important areas of these workings are at Mong Tung Hang near Penny's Bay, and on northern Chek Lap Kok and Sha Chau.

Mining at Mong Tung Hang (223 206) took place between 1969 and 1974 along a northnorthwest-trending vein, up to 6 m wide. However, quantities of quartz mined must have been relatively small. Vestiges of the workings are still visible.

Quartz vein mining on Chek Lap Kok (Langford, 1990) was concentrated in small, easterly-trending trenches south of Cheung Sha Lan (111 195). The extensive workings were licenced between 1959 and 1963, but may have had a longer history of mining. The area may have been a source of quartz crystal for spectacle lenses produced in Guangzhou in the nineteenth century (P. Bruce, oral communication, June 1990). Quartz veins were also mined in northeast Chek Lap Kok, at Miu Wan (1213 1986), from where kaolin was also extracted (see below). The mine operated from the early 1950s until the early 1970s.

A large quartz vein, trending northeastwards across the centre of Sha Chau (067 230), and associated with brecciated and mylonitized granite, was mined briefly under licence after 1969.

Kaolin has been worked in two areas: northeast Tsing Yi and on north Chek Lap Kok. The mining on northeast Tsing Yi, at Shek Wan (272 238), was in an altered quartzphyric rhyolite dyke. It started in 1976, and continued, albeit illegally, between 1981 and 1983. Kaolin (and vein quartz) was mined in granite at Miu Wan (1213 1986) in northeast Chek Lap Kok. A second mine on the island operated between 1981 and 1988. It produced only small amounts of kaolin, and concentrated on production of the washed sand by-product. Production figures for kaolin and quartz are available for both mines (Langford, 1990).

Graphitic siltstone beds, up to several metres thick, occur throughout the Lok Ma Chau Formation, but the graphite is generally subeconomic. However, on West Brother island (Tai Mo To) high grade graphite ore (1456 2117) was mined (Ruxton, 1957; Woods & Langford, 1991). The soft, dark grey, graphite-bearing sedimentary rocks, now largely obliterated following the levelling of the island, were generally highly erosive and poorly exposed. The graphite which was mined probably came from the axial zone of the northeast-plunging syncline which forms the island. The rock has lustrous foliation surfaces, and was probably thermally metamorphosed. Mining started in late 1952, and production was around 3 500 tons a year in the early 1960s. The Ng Fuk Black Lead Mining Co. Ltd ceased production in 1971, and the licence expired in 1973. Mining, which was entirely underground, extended to 90 m below sea level, yet did not reach the bottom of the succession, which may be over 300 m thick. Some of the workings have now collapsed. Other notable occurrences of graphitic siltstone include: a 2 m thick unit, exposed on the headland west of San Chau, a 3 m-thick, tightly-folded graphitic bed north of Sham Wat Wan (0626 1526), and on Reef Island.

Construction Materials

Freestone quarrying was carried out along the granitic coastline of Lantau Island, and the surrounding islands, up to the 1950s. Islands such as Chek Lap Kok provided large amounts of building stone prior to the Second World War, and there is ample evidence of cutting and

dressing on the foreshore of Sham Wan (1156 2000). Stone cutting can also be seen in coastal granite exposures on islands such as Kau Yi Chau, Cheung Chau and Siu A Chau. The Chi Ma Wan peninsula, with outcrops of even textured medium-grained granite, has been extensively exploited along its coast. Both Sha Chau and Tree Island in the northwest of the district have also been sources of building stone.

Aggregate production for construction has been confined to a small, temporary quarry at Sham Wan on northwest Tsing Yi. The quarry was active during construction of the road across the island, and is now moribund.

Borrow areas in the district were, until recently, restricted. They can be found on east and south Tsing Yi, and in the Barren Hills near Mui Wo. Urban and golf course development at Discovery Bay, and shipyard development in Penny's Bay, have resulted in borrows in these areas. The largest borrow area in the district involved the reduction of Chek Lap Kok to about 8 mPD for the airport development. The borrow started in 1991, and the project also resulted in additional borrows on The Brothers islands, in northwest Tsing Yi and in northeast Lantau Island.

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Appendix 1

Microfossils identified from samples of the Carboniferous Mai Po Member by China Corelab (CC), Shekou, Shenzhen, and Guangdong Institute of Geological Sciences (GIGS)

HK 7250, 14600 21150, West Brother Island (CC)

Calamospora breviradiata
Calamospora sp.
Densosporites annulatus
Triquitrites trivalvis
Laevigatosporites sp.
Leiotriletes sp.

HK 9284, 02765 13075, Tai O, Lantau Island (GIGS)

Gorgonisphaeridium ? sp.
Knoxisporites litheratus (Waltz) Playford
Knoxisporites sp.
Laevigatosporites sp.
Lycospora sp.
Lycospora pusilla (Ibrahim)

The organic residue recovered from this sample contained a few miospores. *Knoxisporites litheratus*, *Lycospora pusilla* and *Gorgonisphaeridium* sp. indicate a Carboniferous age in South China.

HK 8433, 13245 13350, Sunset Peak (GIGS)

In No. 8433 some badly preserved inside cores were found and identified as *Bairdia* sp., *Cytherellina* sp., *Amphissites* sp. and *Parapachites* sp. The latter three genera may be Late Palaeozoic in age.
Age: ?Late Palaeozoic

Appendix 2

Selected Whole-rock XRF Geochemical Analyses of Volcanic and Intrusive Rocks from the District. Major oxides in wt%, trace elements in ppm

Sample	HK9847	HK8206	HK9861	HK8547	HK9311	HK8563
SiO2	71.43	73.28	73.23	77.73	76.75	73.74
TiO2	0.41	0.24	0.25	0.17	0.08	0.09
Al2O3	13.66	13.38	13.72	12.22	12.07	14.98
Fe2O3*	3.16	2.08	1.59	1.06	1.45	1.27
MnO	0.07	0.09	0.05	0.02	0.03	0.07
MgO	0.82	0.51	0.24	0.14	0.09	0.05
CaO	2.37	2.89	1.42	0.44	0.63	0.67
Na2O	2.80	0.82	3.43	3.00	3.83	2.11
K2O	4.37	5.69	4.93	4.43	4.09	6.11
P2O5	0.09	0.05	0.06	0.01	0.01	0.01
Total	99.18	99.03	98.92	99.22	99.03	99.10
LOI	0.68	0.96	0.70	0.61	0.65	0.98
Cr	22	26	11	29	43	19
Ni	11	9	6	7	13	13
Co	6	6	3	5	2	3
Sc	-	-	-	-	-	-
V	41	-	23	-	-	-
Cu	5	1	8	1	1	1
Pb	33	33	56	27	38	31
Zn	48	23	35	18	39	29
Sn	6	-	11	-	-	-
W	6	3	3	1	6	4
Mo	-	2	3	2	1	1
S	-	32	-	22	76	49
As	-	7	-	2	3	3
Rb	213	293	264	203	301	315
Ba	466	448	448	132	7	42
Sr	182	164	181	53	12	101
Ga	-	13	-	12	14	17
Nb	13	15	14	16	39	28
Zr	140	130	132	142	160	107
Ti	-	1439	1499	1019	480	540
Y	39	45	43	32	96	55
Th	27	37	40	31	42	32
U	5	8	11	4	7	7
La	38	22	38	51	44	6
Ce	57	66	55	101	76	53

HK9847	Lapilli-bearing coarse ash crystal tuff, Yim Tin Tsai Formation, Ma Wan	23930 22870
HK8206	Ash crystal vitric tuff, Shing Mun Formation, Cheung Sha	12760 10695
HK9861	Coarse ash crystal tuff, Shek Lung Kung Member, Shing Mun Formation, Yam O	20365 21840
HK8547	Porphyritic rhyolite lava, Lantau Formation, Tung Chung Road	11915 12590
HK9311	Tuffite, Lantau Formation, Lantau Peak	09555 11855
HK8563	Eutaxitic coarse ash crystal tuff, Cheung Shan Member, Lantau Formation	11975 10575

Appendix 2 (continued)

Sample	HK9913	HK8426	HK8007	HK5531	HK8200	HK8029
SiO2	76.30	72.87	73.61	63.60	75.90	74.51
TiO2	0.14	0.27	0.24	0.73	0.07	0.22
Al2O3	14.62	13.23	13.31	15.01	12.60	13.21
Fe2O3*	1.70	2.33	2.22	6.81	1.27	1.64
MnO	0.01	0.03	0.06	0.12	0.08	0.03
MgO	0.23	0.41	0.40	2.79	0.07	0.28
CaO	0.14	1.05	1.47	4.45	0.71	1.20
Na2O	0.10	2.72	3.09	2.64	3.39	2.47
K2O	4.47	5.03	4.95	2.79	5.27	5.30
P2O5	0.02	0.09	0.07	0.14	0.02	0.05
Total	97.73	98.03	99.42	99.08	99.38	98.91
LOI	2.09	1.58	0.43	2.54	0.68	0.65
Cr	22	20	23	49	47	11
Ni	10	12	2	10	5	10
Co	2	6	4	19	1	2
Sc	-	-	-	20	-	-
V	-	-	-	106	3	-
Cu	1	1	-	7	39	1
Pb	16	23	43	18	18	36
Zn	5	35	33	69	10	18
Sn	-	-	-	2	5	-
W	4	1	5	2	1	1
Mo	5	1	1	2	-	1
S	184	47	101	-	-	338
As	17	1	5	-	-	1
Rb	268	232	188	140	300	286
Ba	79	491	854	513	18	193
Sr	4	161	127	229	25	120
Ga	18	15	16	17	10	14
Nb	28	19	17	9	25	11
Zr	181	173	314	185	115	84
Ti	839	1619	1439	4376	420	1319
Y	35	54	40	34	36	20
Th	46	30	27	16	39	32
U	6	5	4	3	9	9
La	14	57	65	30	8	12
Ce	72	107	159	65	41	32

HK9913	Metatuffite, Pak Kok Member, Lantau Formation, Pak Kok	05600 08180
HK8426	Lapilli-ash crystal tuff, Sunset Peak Member, Lantau Formation, Yi Tung Shan	14385 13175
HK8007	Eutaxite, Mount Davis Formation, Kau Yi Chau	26150 16175
HK5531	Granodiorite, Tsing Yi, Cheung Hong Estate	28925 23465
HK8200	Medium-grained granite, Chi Ma Wan	19160 10595
HK8029	Porphyritic fine- to medium-grained granite, Mui Wo	19275 12620

Appendix 2 (continued)

Sample	HK5570	HK9988	HK8555	HK9767	HK9841	HK9855
SiO2	75.57	76.79	68.32	75.12	77.81	51.57
TiO2	0.10	0.07	0.47	0.18	0.05	1.36
Al2O3	12.57	12.13	14.25	12.84	12.52	16.49
Fe2O3*	1.43	1.75	4.96	1.83	0.26	9.95
MnO	0.03	0.10	0.09	0.02	-	0.14
MgO	0.20	-	0.56	0.16	-	4.29
CaO	0.87	0.16	1.87	0.39	0.12	8.30
Na2O	3.16	3.88	3.19	3.24	3.26	2.67
K2O	5.09	4.82	5.30	5.83	5.13	1.74
P2O5	0.02	0.01	0.14	0.03	-	0.41
Total	99.04	99.71	99.15	99.64	99.15	96.92
LOI	1.03	0.30	1.22	0.45	0.83	2.77
Cr	6	15	104	12	6	21
Ni	-	10	9	4	11	9
Co	2	8	7	3	3	25
Sc	-	-	-	-	-	-
V	3	1	11	7	2	192
Cu	-	1	37	1	1	18
Pb	31	33	23	28	27	14
Zn	21	77	29	21	3	80
Sn	1	5	3	2	2	1
W	6	5	2	4	9	1
Mo	-	-	-	-	-	2
S	-	-	-	-	-	-
As	-	-	-	-	-	-
Rb	303	341	201	218	354	74
Ba	175	23	554	315	8	472
Sr	52	14	200	80	22	532
Ga	18	-	12	-	-	-
Nb	20	43	11	16	67	9
Zr	149	171	189	183	111	140
Ti	600	420	2818	1079	300	8153
Y	49	74	34	38	83	30
Th	39	47	25	34	47	3
U	7	8	4	4	8	2
La	31	30	63	63	4	18
Ce	62	65	120	127	7	56

HK5570	Fine-grained granite, Tsing Nam Wan	27955 21330
HK9988	Porphyritic fine-grained syenite, Tong Fuk Mui Wan	10165 09730
HK8555	Feldsparphyric rhyolite, Discovery Bay	20125 17330
HK9767	Porphyritic microgranite, Pa Tau Kwu	23425 20060
HK9841	Quartzphyric rhyolite, Penny's Bay	21575 20435
HK9855	Basalt, Sam Pak	19160 19655

Appendix 2 (continued)

Sample	HK10547	HK9739
SiO2	54.65	74.19
TiO2	1.48	0.18
Al2O3	14.76	13.88
Fe2O3*	10.57	1.88
MnO	0.19	0.02
MgO	3.91	0.19
CaO	7.20	0.24
Na2O	0.93	2.14
K2O	3.44	6.17
P2O5	0.29	0.04
Total	97.42	98.93
LOI	1.82	1.06
Cr	26	4
Ni	14	7
Co	26	3
Sc	-	-
V	-	9
Cu	8	2
Pb	21	34
Zn	211	29
Sn	-	2
W	1	8
Mo	1	-
S	-	-
As	-	-
Rb	507	365
Ba	409	1024
Sr	388	167
Ga	20	-
Nb	17	14
Zr	178	209
Ti	8873	1079
Y	35	37
Th	3	-
U	3	8
La	30	56
Ce	82	129

HK10547	Lamprophyre, Tsing Yi	26575 23830
HK9739	Aplite, Yi Chuen	23760 22315

Appendix 3

Microfossils identified from Mesozoic mudstones by Guangdong Institute of Geological Sciences (GIGS)

HK 9314, 09276 10860, Kau Nga Ling (GIGS)

Cibotiumspora sp.
Cicatricosisporites sp.
Cyathidites mesozoicus (Theirgar) Potonie
Deltoidospora sp.
D. irregularis Pflug
Granulatisporites sp.
Lycopodiumsporites sp.
Lygodiumsporites subsimplex Bolchovitina
Lophotriletes sp.
Neoraistrickia sp.
Pterisisporites sp.
Reticulatisporites changningensis Bai
Toroisporis sp.
Laricoidites ? sp.
Pinuspollenites sp.
Piceaepollenites sp.

Miospores dominate the organic residue recovered from this sample. Significant numbers of *Reticulatisporites changningensis*, *Lycopodiumsporites subsimplex*, *Cyathidites mesozoicus*, *Deltoidospora* and *Lophotriletes* sp., *Granulatisporites* sp., *Cibotiumspora* sp. and others indicate a Mesozoic age in South China.
Age : Jurassic.

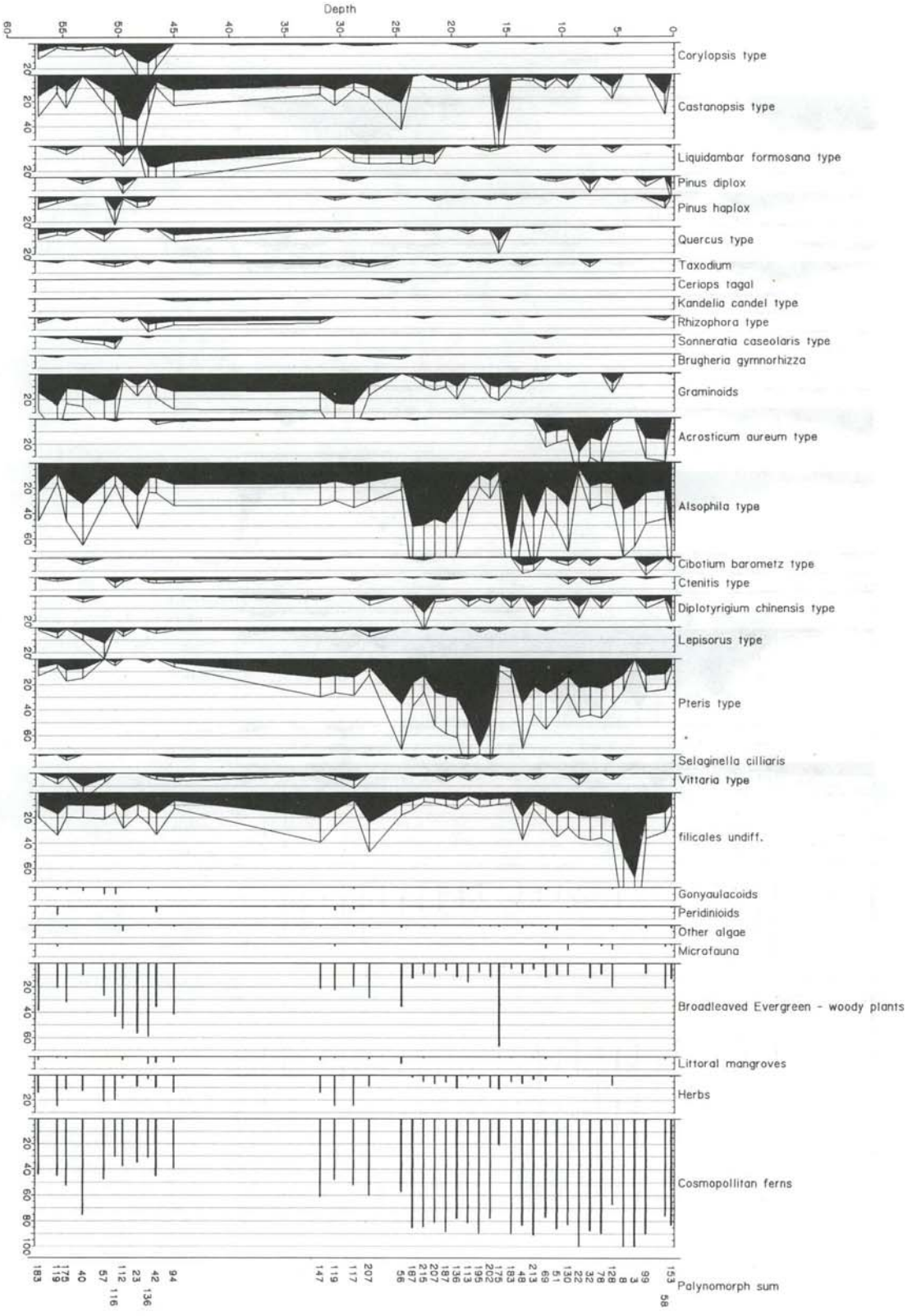
HK 9329, 10320 12245, Lantau Peak (GIGS)

Classopollis sp.
C. annulatus (Verbitskaja) Li
C. parcus (Brenner) Xu & Zhang
Cerebropollenites sp.
Psophosphaera sp.
Psophosphaera minor (Verb.) Song & Zheng
Protoconiferus sp.
Cycadopites sp.
C. nitidus (Balme) Pocock
Deltodospora sp.
Leiotriletes sp.
Lophotriletes sp.
Osmundacites elegans (Verb) Xu & Zheng
Pterisisporites sp.
Verrucosisporites granatus (Bolchovitina) Gao & Zhao

Classopollis annulatus, *Psophosphaera minor*, *Cycadopites nitidus*, *Osmundacites eleganus* and *Verrucosisporites granatus* usually confirm a Mesozoic age in South China. *Classopollis annulatus* and *Psophosphaera minor* dominate the sample and indicate the Late Jurassic.
Age : Late Jurassic.

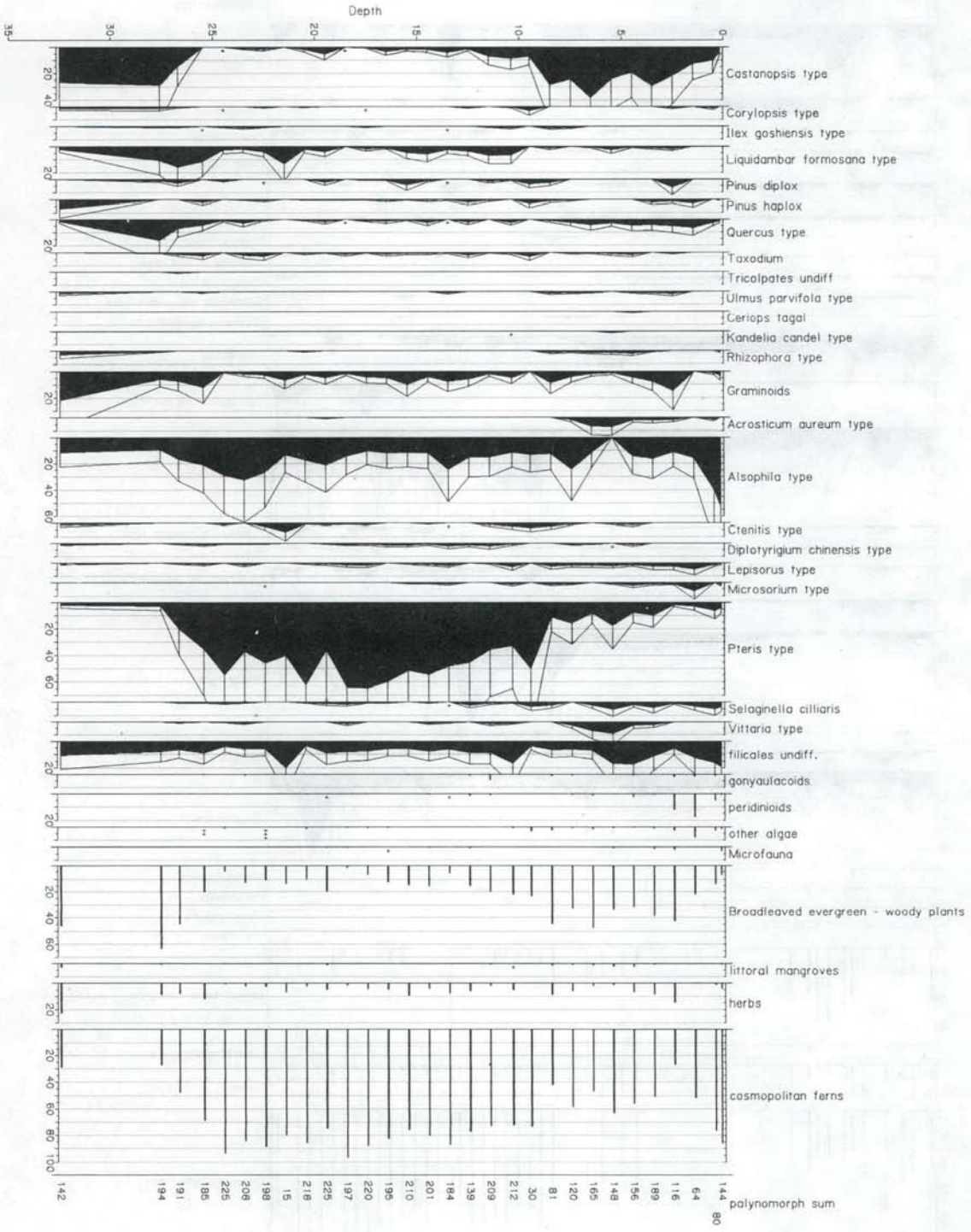
Appendix 4a

Selective normalized palynology plot of Borehole A5/1



Appendix 4b

Selective normalized palynology plot of Borehole ESC17



Appendix 5 - Radiocarbon and Other Dates from Offshore Superficial Deposits

Borehole number	Location	Co-ordinates		Formation	Sample Type	Depth metres	Elevation mPD	Age in yrs BP
		Easting	Northing					
ESC17	North of Sham Wat	804,798	818,402	Hang Hau Fm	Foraminifera	0.5	-5.8	C^{14} 2 170±60
ESC17	North of Sham Wat	804,798	818,402	Hang Hau Fm	Foraminifera	9.8	-15.1	C^{14} 7 960±85
A5/2	S. of West Lamma Channel	823,108	802,705	Hang Hau Fm	Shells	3.3	-21.6	C^{14} 3 950±95
A5/2	S. of West Lamma Channel	823,108	802,705	Hang Hau Fm	Shells	6.1	-24.4	C^{14} 7 840±120
ESC17	North of Sham Wat	804,798	818,402	Sham Wat Fm	Shells	12.5	-17.8	C^{14} 41 700±1700
ESC17	North of Sham Wat	804,798	818,402	Sham Wat Fm	Shells	19.5	-24.8	C^{14} >43 700
A5/1	Soko Islands	809,935	805,580	Sham Wat Fm	Wood	15.6	-25.6	C^{14} 19 580±320
B2/1	North of Sham Wat	804,800	819,856	Chek Lap Kok Fm	Wood	17.5	-24.2	C^{14} 20 760±480
B15	Chek Lap Kok	806,800	818,600	Chek Lap Kok Fm	Peat	13.9	-20	C^{14} >41 600
B13/B13A	Chek Lap Kok	810,293	818,702	Chek Lap Kok Fm	Wood	31.4	-28.4	C^{14} >40 000
A5/2	S. of West Lamma Channel	823,108	802,705	Chek Lap Kok Fm	Wood	13.8	32.1	C^{14} 35 000±1250
A5/2	S. of West Lamma Channel	823,108	802,705	Chek Lap Kok Fm	Sands	13.9	-32.2	OSL 80 000±9000
A5/2	S. of West Lamma Channel	823,108	802,705	Chek Lap Kok Fm	Sands	14	-32.3	TL 78 000±8500
M14	Chek Lap Kok	809,482	817,266	Chek Lap Kok Fm	Wood	20.9	-23.3	C^{14} >35 230
M20	Chek Lap Kok	808,287	817,332	Chek Lap Kok Fm	Wood	10.4	-15.8	C^{14} 16 420±660
M28	Chek Lap Kok	808,251	817,629	Chek Lap Kok Fm	Wood	20.5	-24.2	C^{14} 37 590±1590
M28	Chek Lap Kok	808,251	817,629	Chek Lap Kok Fm	Wood	21.8	-25.5	C^{14} 26 770±840
M35	Chek Lap Kok	810,012	818,636	Chek Lap Kok Fm	Wood	23.7	-26.5	C^{14} 33 440±1740
M55	Chek Lap Kok	810,309	819,496	Chek Lap Kok Fm	Wood	12.3	-20	C^{14} 18 220±440
M59	Chek Lap Kok	809,183	819,427	Chek Lap Kok Fm	Wood	31.3	-36.5	C^{14} 36 480±830
M64	Chek Lap Kok	812,379	818,560	Chek Lap Kok Fm	Wood	35	-37.5	C^{14} 20 000±270
M67	Chek Lap Kok	808,938	817,346	Chek Lap Kok Fm	Wood	22.1	-25.5	C^{14} 27 660±590

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Page numbers in **bold** refer to major sections on the topic. Page numbers in *italics* refer to plates, figures and tables.

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