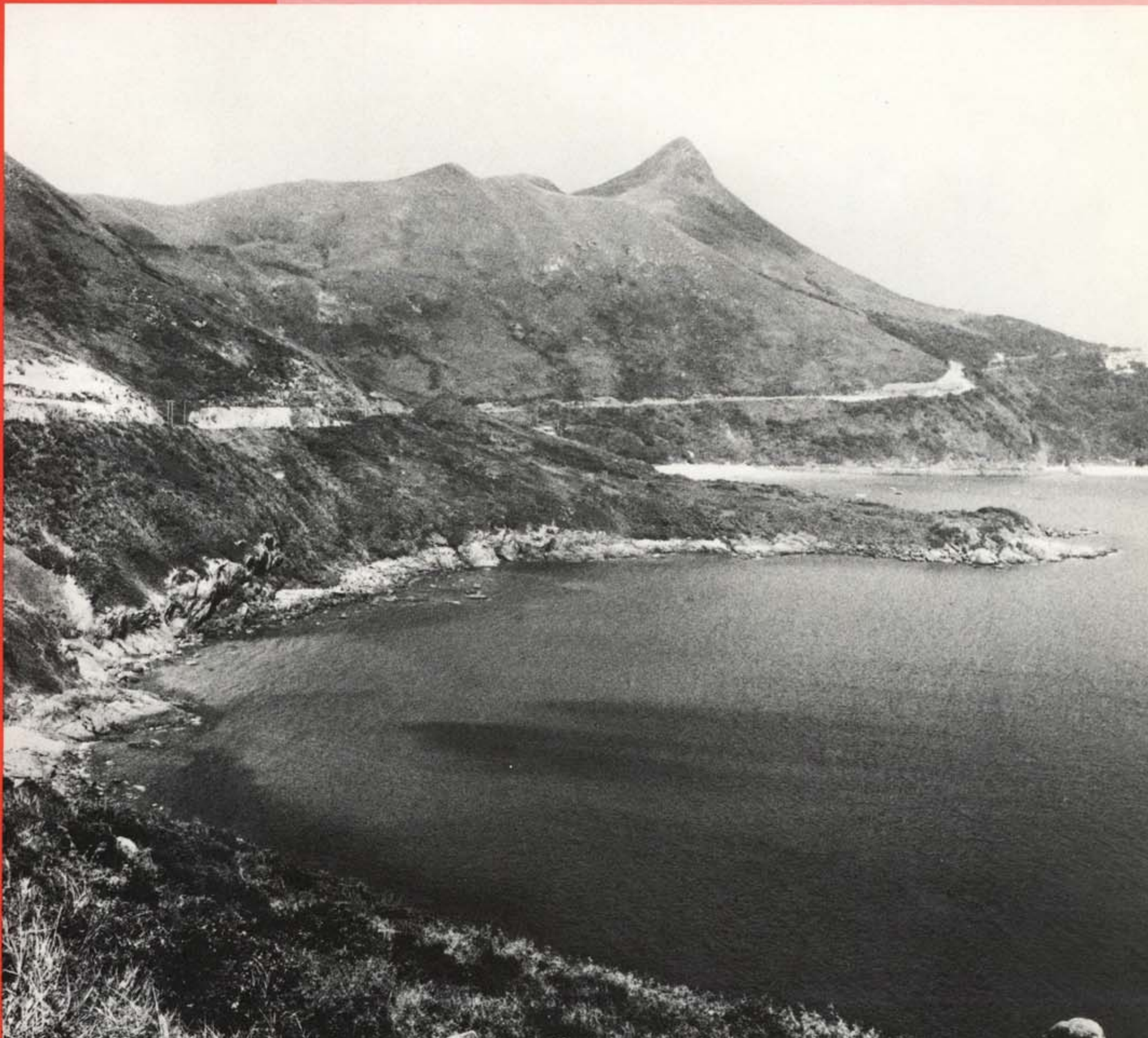
HONG KONG GEOLOGICAL SURVEY *MEMOIR No. 4*

Geology of Sai Kung and Clear Water Bay



Geotechnical Control Office
Civil Engineering Services Department
HONG KONG

HONG KONG GEOLOGICAL SURVEY *MEMOIR No. 4*

Geology of Sai Kung and Clear Water Bay

1:20 000 Sheets 8, 12 & 16

P. J. Strange, R. Shaw & R. Addison

Geotechnical Control Office
Civil Engineering Services Department
HONG KONG March 1990

Published March 1990

Prepared by:

Geotechnical Control Office
Empire Centre, 6th Floor
Tsim Sha Tsui East
Kowloon
Hong Kong

Cover: Clear Water Bay and
High Junk Peak from Tin Ha Shan

This publication is available from:

Government Publications Centre
General Post Office Building
Ground Floor
Connaught Place
Hong Kong

Overseas orders should be placed with:

Publications (Sales) Office
Information Services Department
Beaconsfield House, 5th Floor
Hong Kong

Price in Hong Kong: HK$87

Price overseas: US$13 (including surface postage)

Foreword

This memoir describes the geology of the Sai Kung and Clear Water Bay peninsulas as depicted on 1:20 000 Sheets 8 (Sai Kung), 12 (Clear Water Bay), and 16 (Waglan Island). The Po Toi Islands, falling within the boundaries of Sheet 16 (Waglan Island), have been described in Memoir 2 (Hong Kong Island and Kowloon). This memoir forms part of the published results of a programme of systematic geological mapping that began in 1983. The programme involves the study of the geology of land and sea areas of the Territory in considerably greater detail than has been attempted previously. It is enhancing our understanding of Hong Kong's stratigraphy and structure, and is establishing a geological database necessary for the continuing economic development of the Territory. The mapping programme is being undertaken by the Geological Survey Section of the Planning Division of the GCO. The section was led by Dr R. Addison during the field survey phase, and subsequently by Mr P. J. Strange; the Division is under the direction of Dr A. D. Burnett.

Dr R. Addison conducted the geological mapping of the northwest part of Sheet 8 in 1986, and the remainder of Sheet 8 and Sheet 12 were surveyed by Mr P. J. Strange in 1986–1988. Mr Strange is the principal author of this Memoir. Dr R. Shaw compiled the section dealing with the offshore deposits and with the weathering, and Dr Addison drafted the sections on the Palaeozoic rocks and Tolo Channel and Lai Chi Chong Formations. Both Mr Strange and Dr Addison were on loan to the Hong Kong Government from the British Geological Survey.

The district has been the subject of regional studies (1:20 000 scale) carried out within the Geotechnical Area Studies Programme (GASP). GASP reports covering the Northeast New Territories (GASP VIII), East New Territories (GASP IX) and Clear Water Bay (GASP VII) are available from the Government Publications Sales Centre. They present general geotechnical information on slope gradient, terrain, geomorphology, vegetation, land use, erosion and slope instability. These studies, which were completed before the Geological Survey of Sheets 8, 12 and 16 commenced, were based on the solid rock geology given on the 1:50 000 scale Geological Map produced by Allen & Stephens (1971). This Memoir and the three map sheets supersede both the solid rock geology and the mapping of superficial deposits presented in the GASP reports.

The survey of Sheets 8 and 12 benefitted from the co-operation of various organisations and many individuals. The Royal Hong Kong Auxiliary Air Force, Marine Department and Royal Hong Kong Police provided transport to remote areas, and the Geological Survey Section was grateful for the loan of an inflatable boat from the Environmental Protection Department which was used for access to small islands and otherwise inaccessible coastlines. The Environmental Protection Department also provided seabed sampling data. The Water Supplies Department supplied detailed tunnel logs and geological information relating to the High Island Water Scheme, and also arranged access to the water tunnel network. The co-operation of Electronic and Geophysical Services Ltd is also acknowledged.

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

A. W. Malone
Principal Government Geotechnical Engineer
March 1990

CONTENTS

Page

References

Appendix

Index

List of Tables

List of Figures

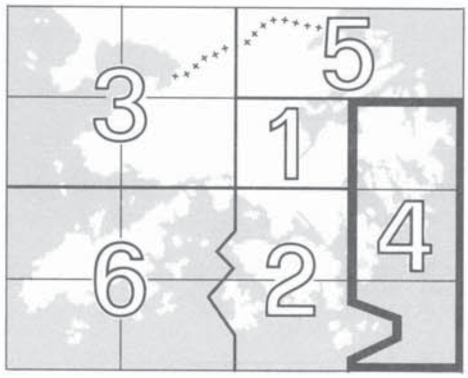
List of Plates

Map and Memoir Series Notes

• This memoir describes the geology of Sai Kung and Clear Water Bay and should be read in conjunction with 1:20 000 Geological Map Sheets 8 (Sai Kung), 12 (Clear Water Bay) and 16 (Waglan Island).

• The Memoir forms 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.

maps



memoirs

• Individual superficial deposits in the onshore area 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. Eight-figure references indicate positions to the nearest 10 metres, with Eastings followed by Northings, e.g. 4515 3590. Six-figure references indicate positions to the nearest 100 metres.

• 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 where available, 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 5881.

• Boreholes are generally referred to by the contractor's number followed by the Geotechnical Information Unit accession number for the relevant ground investigation report e.g 1201D/03412. In some cases there is no report available, and a borehole may be referred to by its number alone, e.g. JBSI/1A.

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

Chapter 1
Introduction

Location and Physiography

This memoir describes the geology of Sheet 8 (Sai Kung), Sheet 12 (Clear Water Bay) and the offshore part of Sheet 16 (Waglan Island). The area covered is referred to in this account as the district (Figure 1). The total land area amounts to approximately 140 sq km and the offshore area described in this memoir totals approximately 400 sq km.

The Clear Water Bay Peninsula is dominated by a major north-south trending ridge which reaches 344 m at High Junk Peak. Although part of the peninsula is set aside for recreational purposes, low density housing has developed on the eastern side. Junk Bay, to the west, is the site of a major new town development. Hong Kong's third university will be located on the northern part of the Clear Water Bay Peninsula.

Sai Kung town, surrounded by many small villages and market gardens, is the main settlement within the district and still remains an important fishing port. The area is, however, increasingly becoming a dormitory area for Kowloon and Hong Kong. Development has been constrained by inadequate road connections to the main urban areas, but a new road in the north, linking Sha Tin and Sai Kung via Nai Chung was opened in 1988.

The islands in Port Shelter and Rocky Harbour are mostly uninhabited, and the area has become a major maritime recreational locality.

The Sai Kung peninsula remains largely unspoilt and most of it has been designated as country park. All roads east of Tai Mong Tsai were constructed as part of the High Island Water Scheme and vehicular access beyond Pak Tam Chung remains restricted. Ferry and kaido services provide regular transport links to the villages along Tolo Channel and around Long Harbour.

Many hills in the Sai Kung peninsula exceed 300 m in height, with Shek Uk Shan (482 m) and Sharp Peak (468 m) the highest points. The topography is influenced by major northwest- and northeast-trending features, controlling the long straight valleys that dissect the terrain. Although many summits and ridges are grassy and easily traversed on foot, dense vegetation is found on the lower slopes and in valleys. The High Island Reservoir, with a capacity of 273 million cubic metres, was completed in 1979, and water is conveyed to Kowloon through a 23 km long tunnel. Much of the Sai Kung Country Park serves as a catchment, with tunnels feeding water from most major stream courses on the peninsula into the reservoir.

Previous Work

The work of Brock, Uglow, Schofield and Williams provides the first descriptions of the geology of the district (Uglow, 1926; Brock & Schofield, 1926; Williams, 1943). These authors regarded most of the volcanic rocks within the district as part of their Rocky Harbour Series. Davis (1952) drew extensively on their unpublished material, producing the first memoir on the geology of Hong Kong.

Ruxton (1960) gave a detailed account of the geology of the district, defining the Bluff Head Formation. Recent fossil evidence (Lee, 1982) has indicated a Devonian age for this strata, which was previously considered to be Jurassic.

The systematic survey of the Territory by Allen & Stephens (1971) of the Institute of Geological Sciences, U.K. resulted in the publication of two 1:50 000 scale geological maps and an accompanying report. They produced a lithological classification of the Repulse Bay Formation recognizing the main rock units present in the district. These remained the definitive work on the geology of Hong Kong until publication of the results of the remapping began in 1986.

Fossil discoveries at Sham Chung (Lee, 1984; Nau, 1984) have proved the presence of Lower Jurassic (Tolo Channel Formation) strata, and plant bearing horizons within the upper parts of the volcanic formations suggest these are of Lower Cretaceous age.

In the neighbouring Sha Tin district (Sheet 7), Addison (1986) established a detailed lithostratigraphic division of the Repulse Bay Volcanic Group, and divided the granites using

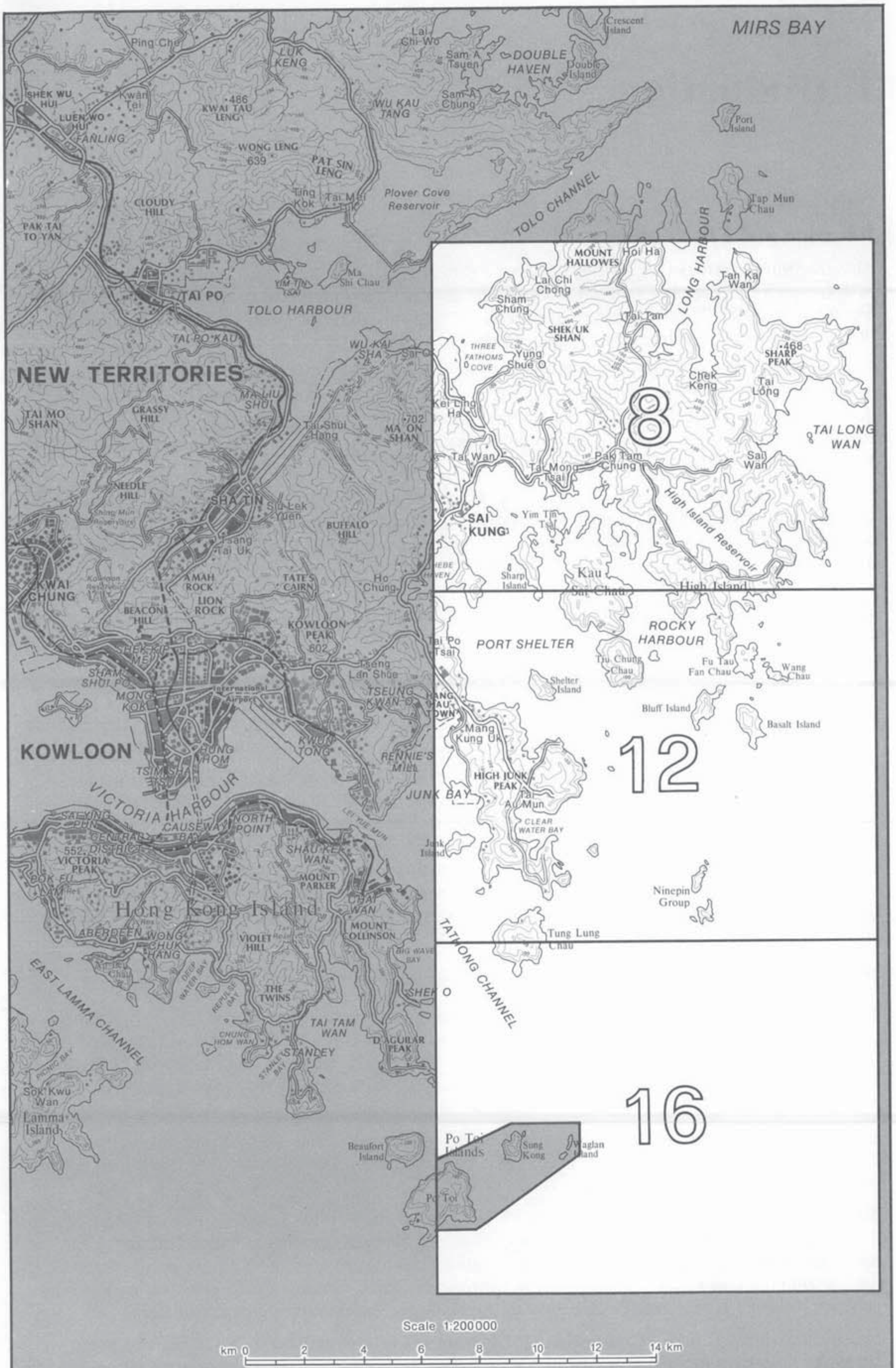


Figure 1 – Principal Topographic Features of the District

lithological criteria. His divisions have been extended southwards into the adjoining Kowloon and Hong Kong Island district (Strange & Shaw, 1986), and eastwards into this district (Sheets 8 & 12).

The present survey

Geological field mapping was undertaken between October 1986 and May 1988. Traverses were made along most roads and footpaths, and accessible coastal sections were mapped. Where possible stream courses were followed, vegetation permitting. Traverse spacings averaged 0.5 km (Figure 2). Access to islands and remote coastal sections was obtained using an inflatable dinghy loaned from the Environmental Protection Department. The Royal Hong Kong Auxiliary Air Force provided helicopter transport to the more inaccessible parts of the Sai Kung peninsula. Most tunnel sections of the High Island Water Scheme were examined and these provided invaluable cross-sections of the district. Borehole information and geological record drawings of the High Island dams revealed important geological data.

A desk study involved the examination of numerous borehole records for the Junk Bay new town development and the Junk Bay controlled tip sites. Seismic traverses provided detailed information on the offshore superficial deposits.

Mapping of the superficical deposits of the district was aided by reference to the Engineering Geology maps produced for the Geotechnical Area Studies Programme (Brand et al, 1982; Geotechnical Control Office, 1988a, 1988b, 1988c).

A photogeological interpretation of the district was conducted using 1963 photographs, but in the Junk Bay area 1985 and 1986 photographs were used. The extent of reclamation shown on the maps is based on data supplied by Survey and Mapping Office, Buildings and Lands Department.

From a total of 929 rock samples collected, 357 were thin sectioned and 34 were sent to the Analytical Chemistry Research Group, British Geological Survey for geochemical analysis of major and trace elements.

For the offshore survey, a total of 194 km of seismic lines have been run in the district, using high resolution Boomer equipment. The resulting seismic profiles have provided the main basis for the stratigraphical interpretation. In addition 24 twelve metre vibrocore holes were drilled along specific seismic lines in the Tathong Channel, Joss House Bay and south, east and northeast of Tung Lung Island (Figure 18, 19 and Appendix). The seismic traverses and vibrocores were completed by the Geotechnical Control Office as part of a project to locate offshore sources of sand (Shaw and Whiteside, 1988; Choot, 1988). 61 seabed grab samples were collected to determine the lithology of the seabed sediments (Figure 17), and a further 12 seabed grab samples, from a programme carried out by the Environmental Protection Department, have assisted with the mapping of Sheet 16.

Although the mapping scale was usually at 1:5 000, the geological information was transferred onto 1:10 000 scale base maps. Provisional geological maps were prepared at this scale, and these formed the bases for the published 1:20 000 scale geological map sheets.

All records from the survey, including rock samples, thin sections, field notes, manuscript maps and analytical data are held by the Geological Survey Section, Planning Division, Geotechnical Control Office, and are available for inspection.

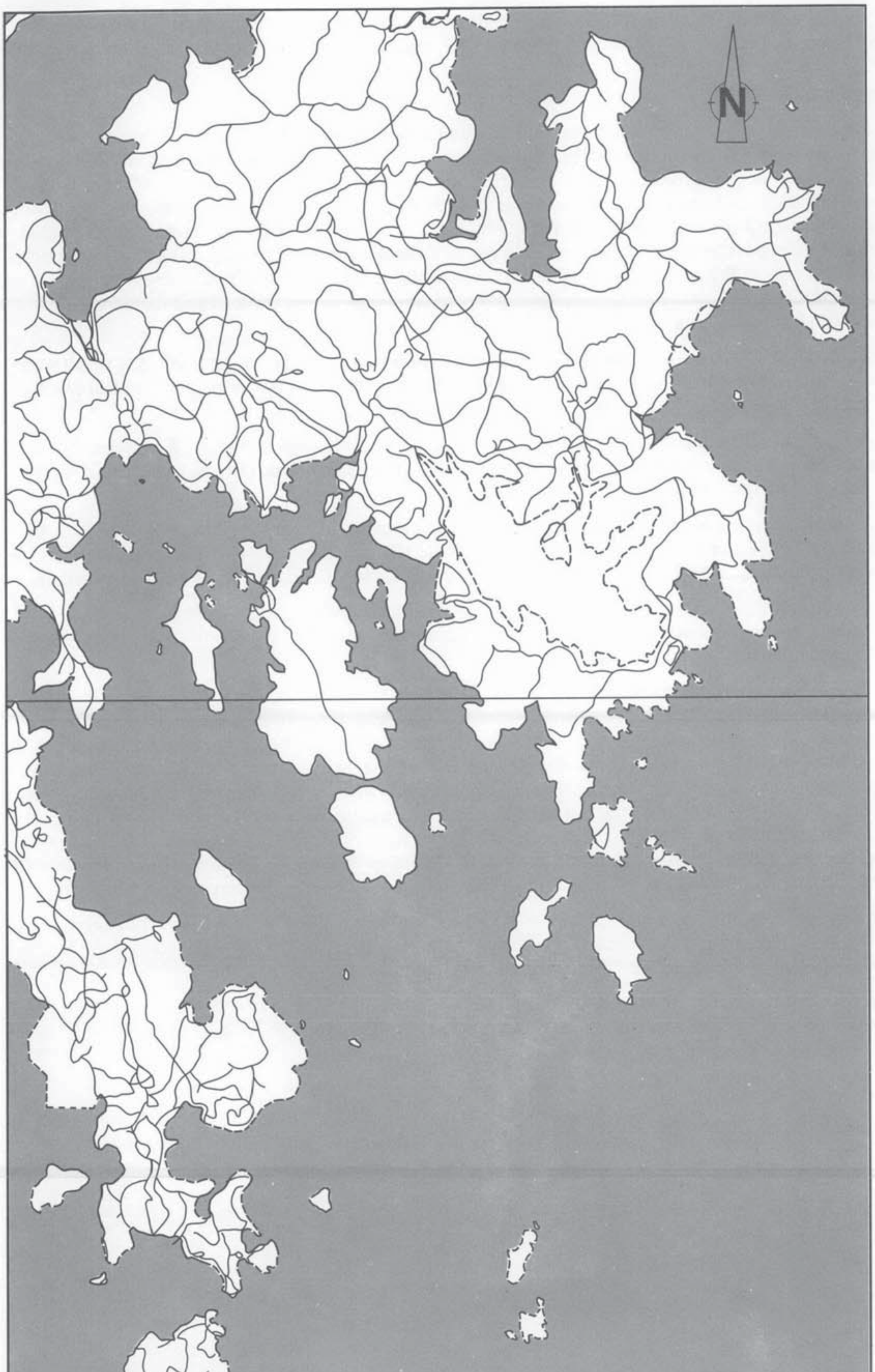


Figure 2 – Traverses Undertaken During Field Survey of the District

Table 2—Solid Rocks and Superficial Deposits of the District

Superficial Deposits (Onshore)

Age		Genetic Classification
Quaternary	Holocene	Fill (made ground) Beach deposits
Quaternary	Holocene and Pleistocene	Alluvium Debris flow deposits, Talus (rockfall) deposits, Mixed debris flow and talus deposits } colluvium

Superficial Deposits (Offshore)

Age		Named Divisions	Principal Materials
Quaternary	Holocene	Hang Hau Formation	Mainly mud
Quaternary	Pleistocene	Chek Lap Kok Formation	Clay, silt, sand and gravel

Solid Rocks

Age		Named Volcanic Divisions		Principal Rock Types
Mesozoic	Upper Jurassic—Lower Cretaceous	Repulse Bay Volcanic Group	Long Harbour Formation	Coarse ash crystal tuff
			Lai Chi Chong Formation	Rhyolite lava, tuff, tuffite mudstone and conglomerate
			High Island Formation	Fine ash vitric tuff
			Clear Water Bay Formation including Tai Miu Wan, Tai Tun and Lan Nai Wan Members	Mainly trachydacite-rhyolite lavas, some tuff and tuffite
			Mang Kung Uk Formation	Tuff, tuffite, and sandstone
			Silverstrand Formation	Eutaxite
			Tai Mo Shan Formation	Coarse ash crystal tuff
			Ap Lei Chau Formation	Fine ash vitric tuff with eutaxite
Mesozoic	Lower Jurassic	Tolo Channel Formation		Siltstone and mudstone
Palaeozoic	Permian	Tolo Harbour Formation		Siltstone and sandstone
Palaeozoic	Devonian	Bluff Head Formation		Sandstone

Intrusive Igneous Rocks

Age		Rock Types
Tertiary	Palaeocene	Basalt
Mesozoic	Upper Jurassic—Lower Cretaceous	Fine-grained granite Quartzphyric rhyolite Feldsparphyric rhyolite Coarse-grained granite Quartz syenite Quartz trachyte

Chapter 2
Outline of Geology

The solid geology of the district is dominated by Mesozoic volcanic rocks of the Repulse Bay Volcanic Group, except in the northwest, where small outcrops of Palaeozoic and Mesozoic sedimentary rocks have been recognized. Small scale plutons and dykes of acidic igneous rocks of Upper Jurassic to Lower Cretaceous age intrude the volcanics. Superficial deposits of Quaternary age are present as impersistent veneers on hill slopes, in valleys and more extensively in lowland areas and offshore.

The Palaeozoic Bluff Head Formation, which in the neighbouring Sha Tin district contains fish fragments of Devonian age, is mainly quartzitic sandtone. These are the oldest rocks of the district and occur only in the vicinity of Tolo Channel. The Tolo Harbour Formation consists of sandstones interbedded with laminated phyllitic siltstones.

The Mesozoic succession comprises the Lower Jurassic Tolo Channel Formation and the Upper Jurassic to Lower Cretaceous Repulse Bay Volcanic Group. The Tolo Channel Formation consists predominantly of marine mudstones and siltstones, which have yielded ammonites. Its outcrop is restricted to the Sham Chung area in the northwest of the district.

The Repulse Bay Volcanic Group has been divided into a number of distinctive lithostratigraphic formations, with two major sequences separated by a major geographical break along the Cheung Sheung—Chek Keng Fault. In the southern half of the district, the oldest rocks of the Repulse Bay Volcanic Group are fine ash vitric tuffs of the Ap Lei Chau Formation. Well defined eutaxite layers that form positive topographic features are present within this formation. The Tai Mo Shan Formation consists of a thick uniform coarse ash tuff sequence. The overlying Silverstrand Formation is composed of fine ash tuff with a prominent eutaxitic fabric throughout. This is overlain in turn by the Mang Kung Uk Formation, which is dominated by well-bedded tuffite, breccia, conglomerate, siltstone and sandstone layers. Impersistent lavas and fine ash tuff bands are also present. The Mang Kung Uk Formation, is succeeded by the Clear Water Bay Formation, containing flow-banded lavas of trachydacite to rhyolite composition. Individual lava flows average 60 to 80 m in thickness in the Clear Water Bay area, with the lowest prominent flow (Tai Miu Wan Member) of trachydacite composition, mappable over a distance of about 5 km. Several fine ash tuff horizons are present between the lava flows, and one feature-forming pyroclastic flow deposit (Tai Tun Member) has a distinctive eutaxitic fabric.

In the uppermost part of the Clear Water Bay Formation, tuffs and tuffaceous sediments (Lan Nai Wan Member) have been delineated in the eastern part of the Sai Kung peninsula. These are overlain by the High Island Formation, consisting of a massive, uniform, fine ash welded tuff, often displaying excellent columnar jointing. In places, this formation oversteps the Clear Water Bay Formation to rest on older volcanic strata where it appears to infill former topographic hollows. In the southern part of the Clear Water Bay Peninsula, fissure vents have been recognized, usually in association with quartz syenite intrusions.

To the north of the Cheung Sheung – Chek Keng Fault (Figure 11), two formations have been identified in the volcanics, namely the Lai Chi Chong and Long Harbour formations. The occurrence of pebbles of flow-banded lava in the Lai Chi Chong Formation indicate that the strata north of the fault are younger than the formations to the south. The Lai Chi Chong Formation rests unconformably on the Lower Jurassic sedimentary strata, and consists of alternations of tuff, tuffite and mudstone, and smaller impersistent conglomerate horizons. The upper rhyolite, a feature-forming unit, separates the formation from the overlying Long Harbour Formation. The latter consists of a thick sequence of coarse ash tuff, which is frequently clast-bearing.

Small plutons of fine-grained granite and fine-grained quartz syenite occur in the southern part of the Clear Water Bay Peninsula. Dykes of quartz syenite and quartzphyric rhyolite are also present, the former containing large enclaves of coarse-grained granite. Quartz syenite bodies also occur in the Sai Kung Peninsula, in particular along the line of the Cheung Sheung – Chek Keng Fault. Basalt dykes of presumed Tertiary age are widespread but small.

It seems likely that the major structural features of the district are related to collapse calderas. One such infilled volcano-tectonic depression is bounded to the west by Junk Bay and to the north by the Cheung Sheung – Chek Keng Fault. The strata north of this line probably represents infilling of another volcano-tectonic depression. Major northeast and northwest striking faults traverse the district.

The impersistent cover of superficial deposits consists mainly of debris flow deposits on hill slopes, usually concentrated into valleys, and alluvial tracts on low-lying ground. Beach deposits fringe the coastline in many localities, especially in sheltered bays. Offshore, the Quaternary deposits are extensive, with the Holocene Hang Hau Formation (mainly marine mud) overlying the complex, stratified, predominantly alluvial sequence of the Chek Lap Kok Formation. Extensive reclamation projects in Junk Bay have disturbed and concealed these deposits.

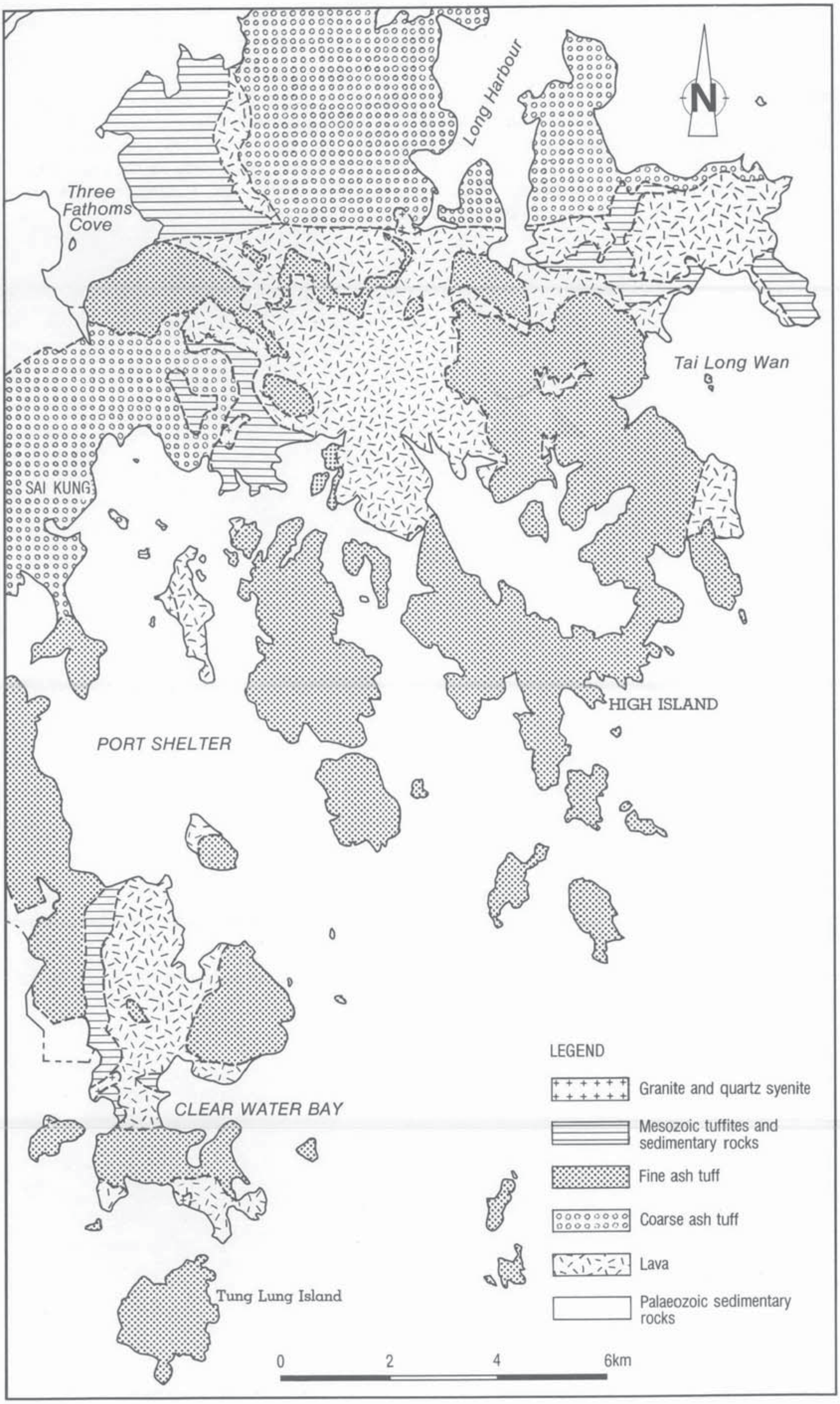


Figure 3 – Generalized Solid Geology of the District

Chapter 3
Palaeozoic Rocks

Classification and Distribution

Within the district, two formations of Palaeozoic age have been mapped. The older unit, the Bluff Head Formation, is Devonian in age, while the younger Tolo Harbour Formation is Permian. Together they form the structurally complex basement on which the Mesozoic sedimentary and volcanic rocks have been deposited. Strata of Carboniferous age, widespread in the north and northwest New Territories, have not been identified in this district.

Ruxton (1960) first defined the Bluff Head Formation, considering the strata to be of Jurassic age. The later discovery of fossil fish remains (Lee, 1982) indicated a Devonian age for the formation. P'an Jiang (Atherton, 1983) compared the Bluff Head with the Devonian Guitou Formation of northern Guangdong Province. Addison (1986) described in detail the fossiliferous localities in the neighbouring Sha Tin district (Sheet 7).

The Tolo Harbour Formation was also first defined by Ruxton (1960), who suggested a probable Permian age, based on palaeontological evidence. The fossils are generally poorly preserved and although none of the assemblages of marine or plant fossils is entirely diagnostic, later identifications suggest a Permian age (Nau, 1980; Yim et al, 1981).

Bluff Head Formation

Stratigraphy

The Bluff Head Formation forms isolated outcrops in the northwest of the district around Three Fathoms Cove and Tolo Channel. Although no fossils have been found in this district, the strata have been grouped with the Bluff Head Formation on structural and lithological grounds. Addison (1986) estimated a thickness of at least 300 m for the sandstones assigned as Bluff Head Formation at Sai O, immediately adjacent to the northwest boundary of Sheet 8.

The lithology consists mainly of pale grey fine-grained sandstones, with occasional siltstones, often displaying cross-bedding structures. The sandstone beds are up to 1 m thick and are internally cross laminated. These beds are lensoidal or dune-like in cross-section, in forms that appear to be megaripples.

Details

Tolo Channel. Exposures of the formation are poor except in road cuttings at Sai Keng (4544 3139), where pale grey to white cross-bedded sandstones are seen. Coastal exposures of Bluff Head Formation are present in the extreme northwest corner of Sheet 8, on the northern side of Tolo Channel. Here (4515 3590) the sandstone strata dip steeply, varying from fine- to coarse-grained, and show cross-stratification.

Sedimentary Environment

The Bluff Head Formation contains mature to very mature quartzitic sandstones, formed from the recycling of sediments from deeply eroded basement rocks. Morton (1988) suggested derivation of the sediments from a low-temperature, high-pressure metamorphic terrain, such as those found at convergent plate boundaries. The sedimentary features such as cross-bedding present in the sandstones indicate a fluvial or deltaic environment.

Tolo Harbour Formation

Stratigraphy

The type area is on Ma Shi Chau in Tolo Harbour (Sheet 7). Within the Sai Kung district, similar strata, but without diagnostic fossils, have been mapped and tentatively regarded as Tolo Harbour Formation (Permian age) on structural and lithological grounds. These strata outcrop on the western and eastern sides of Three Fathoms Cove, on the small islands of Wu Chau and Sam Pui Chau, and on the Sham Chung Kok peninsula.

The formation consists of pale grey, weathering to pale pink, fine- to medium-grained sandstones interbedded with laminated phyllitic siltstones. Individual sandstone beds are generally thinner than 1 m but occasionally reach 2 m in thickness. Both the sandstones and siltstones are foliated, and bedding and foliation are contorted in well-displayed open and tight folds.

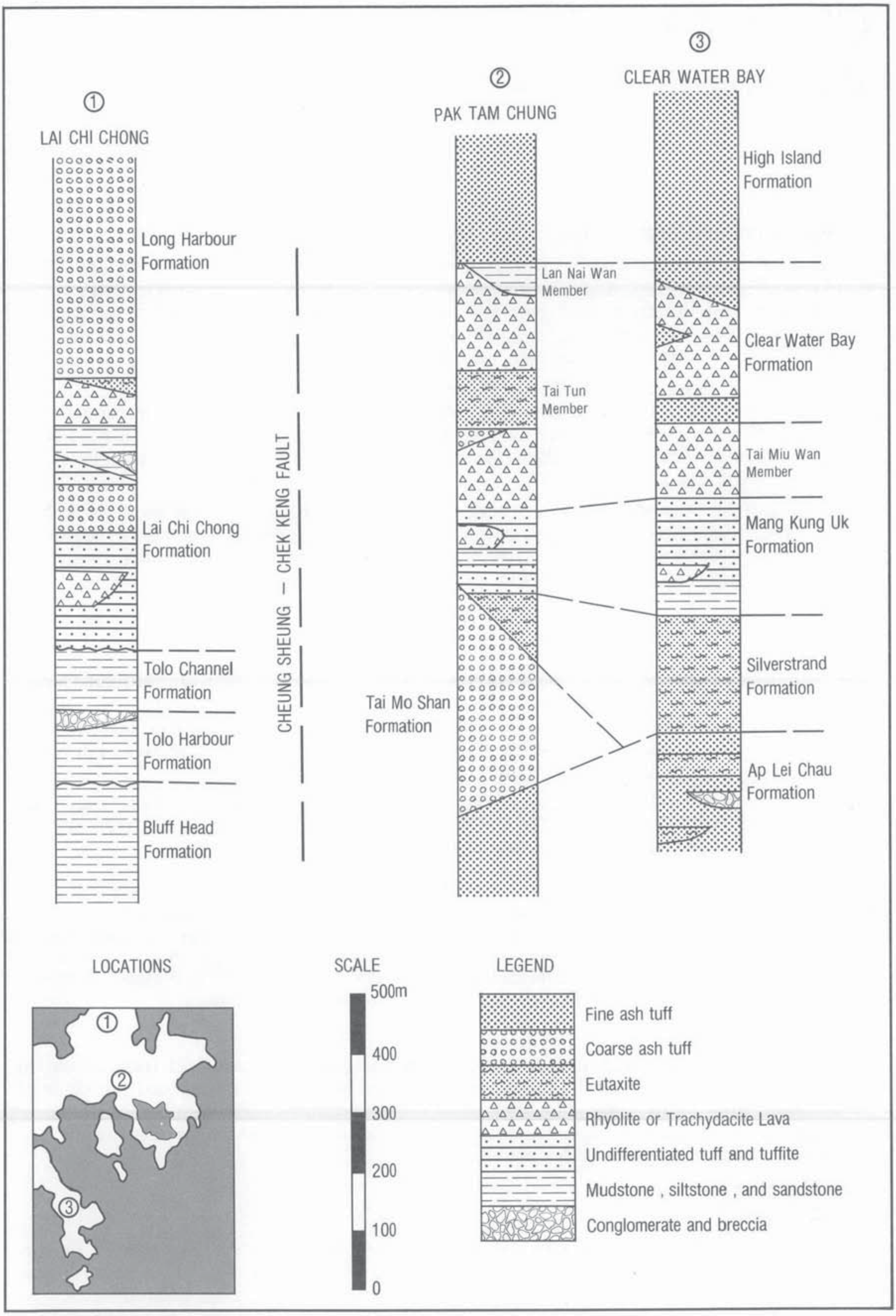


Figure 4 – Generalized Sequences of the Palaeozoic and Mesozoic Sedimentary and Volcanic Rocks

Samples of dark grey laminated siltstone from Sham Chung Kok (HK6167, 4664 3479) were examined for miospores but proved barren.

Details

Three Fathoms Cove. Near the pier on the shore opposite Sam Pui Chau (4583 3243), and on the headland northeast of Che Ha (4565 3278), the strata are cut by faults that exhibit marked shear/breccia zones, some 700 mm in width. On Sam Pui Chau, the strata are tightly folded and exhibit various sedimentary features such as graded sandstone beds with cross-laminated silty tops that imply a westward younging direction on an eastern limb of a syncline (4613 3263).

Sham Chung Kok. At Sham Chung Kok (466 338), pink weathered phyllitic siltstones and sandstones are tightly folded. A thin section of sandstone (HK5769, 4666 3376) possessed a marked metamorphic fabric of sericitic micas. A sample of sandstone collected nearby (HK3681, 4660 3385), analysed for heavy minerals, contained assemblages of zircons similar to those identified from Permian strata on the adjacent Sheet 7 (Morton, 1988).

Sedimentary Environment

Palaeontological evidence from the adjacent Sha Tin district (Addison, 1986) indicates the presence of marine fossils and fragmentary plant debris. Cross-laminations in the strata from Three Fathoms Cove suggest a shallow marine deltaic environment.

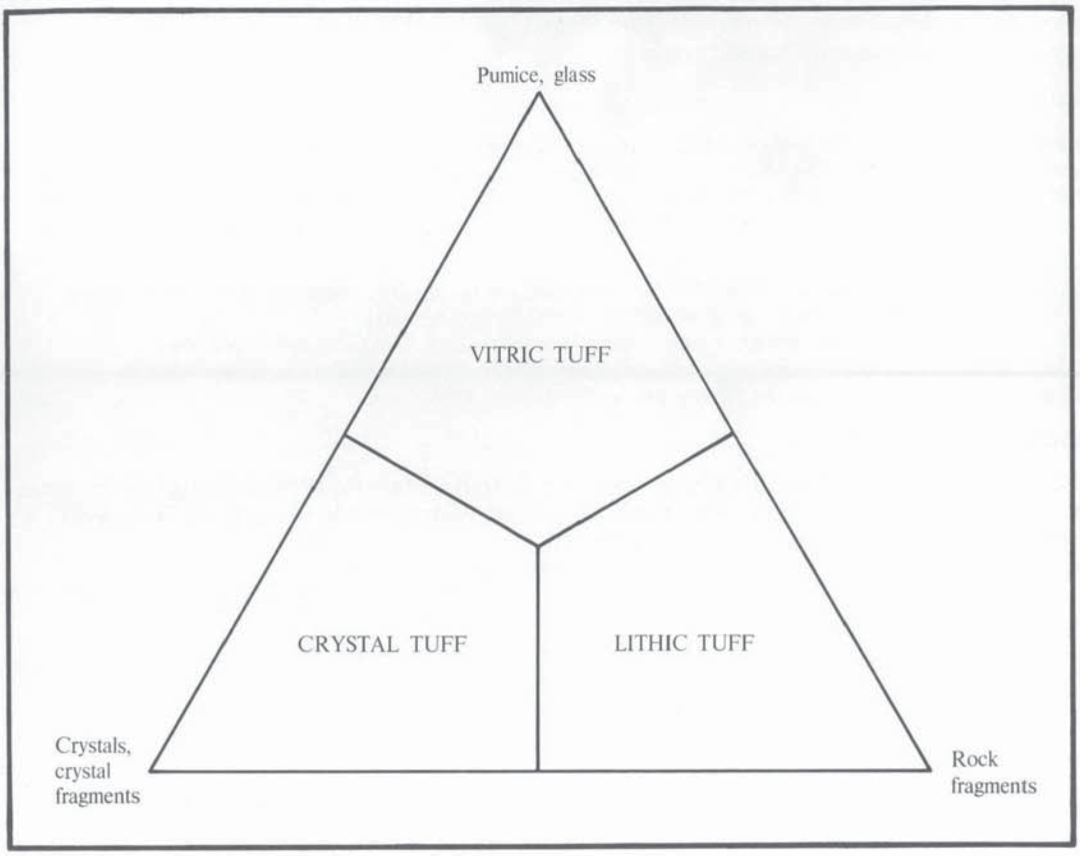


Figure 5 – Classification of Pyroclastic Rocks Based on Composition (after Schmid, 1981)

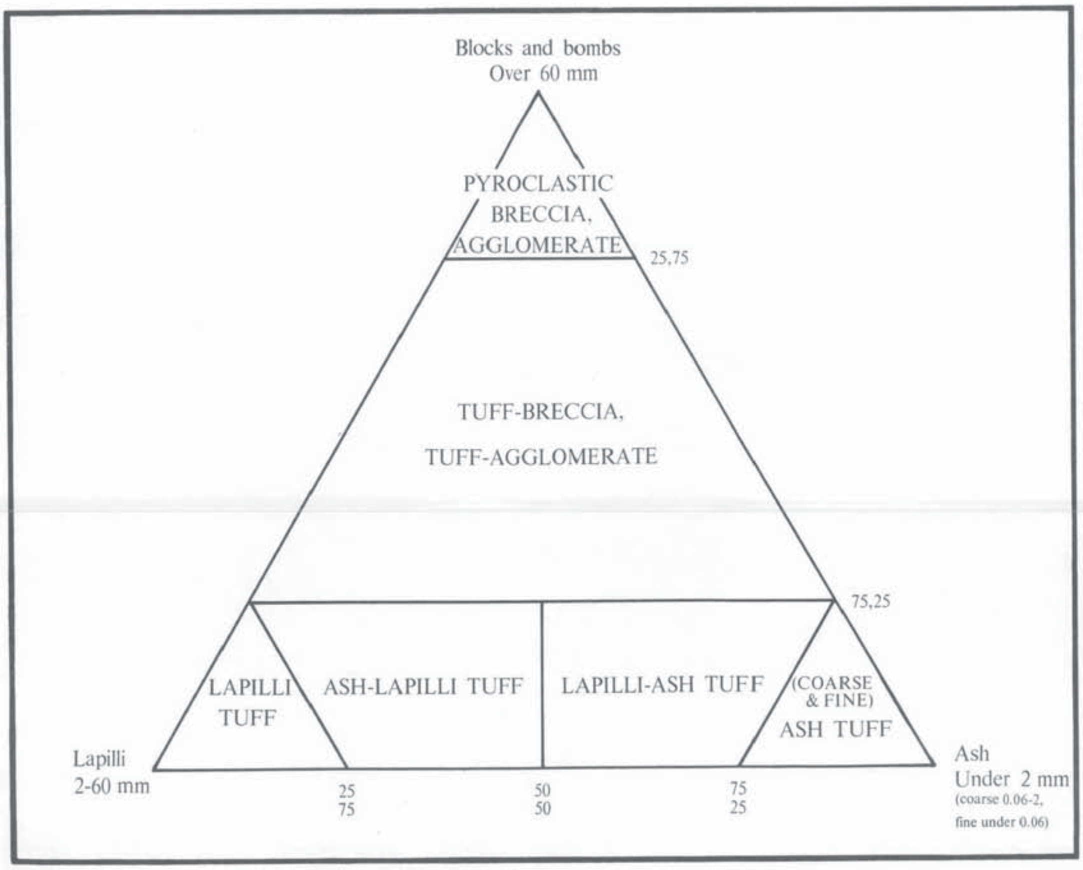
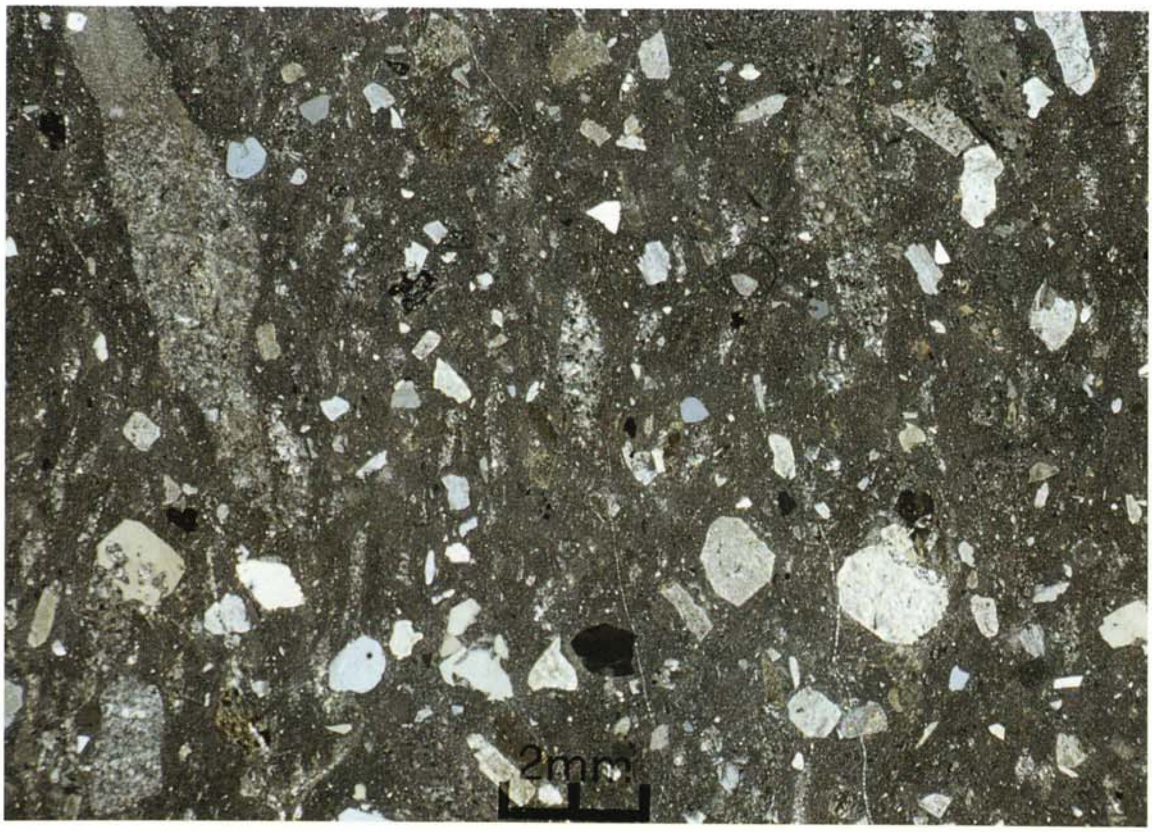


Figure 6 – Classification of Pyroclastic Rocks Based on Grain Size (adapted from Schmid, 1981; Fisher & Schmincke, 1984)

Plate 1 – Eutaxite in Silverstrand Formation. Tung Lung Island (4700 1300)

Plate 2 – Thin Section of Eutaxite in Silverstrand Formation (HK6122) from Silverstrand (4539 2144), XPL × 10



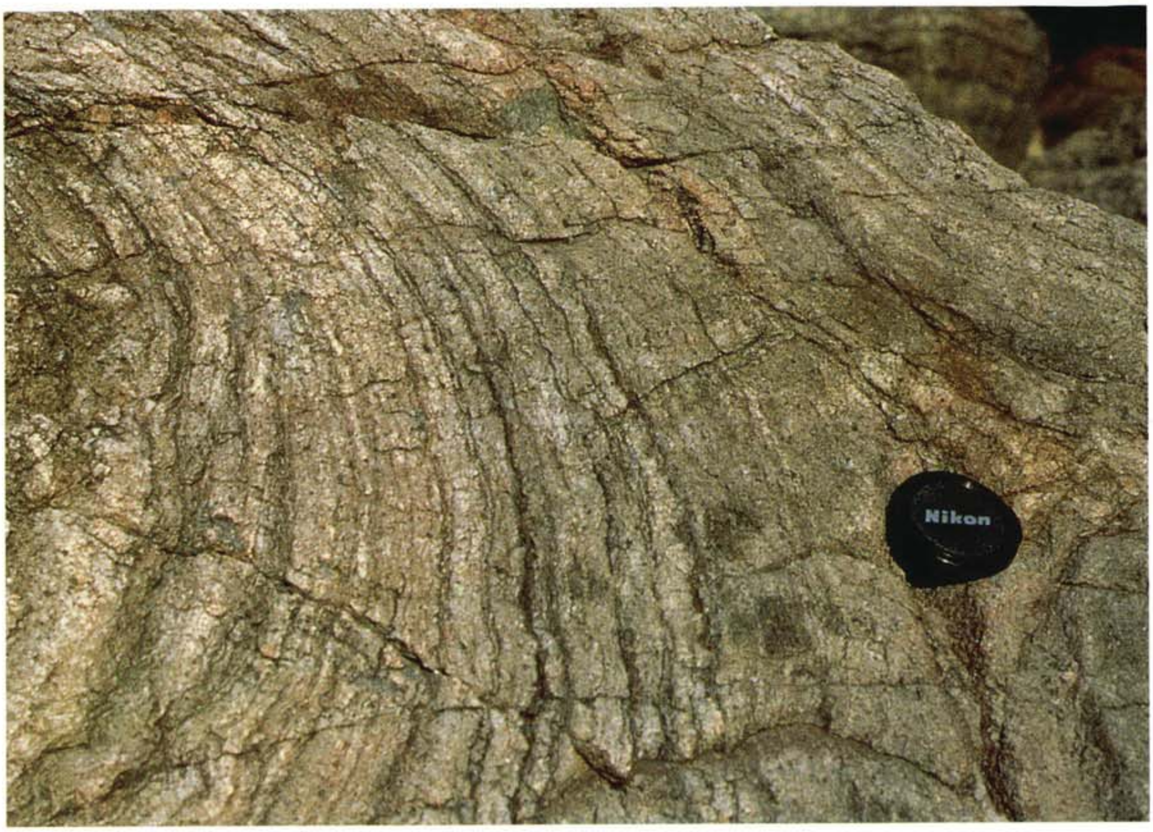


Plate 3 – Flow-banded Trachydacite Lava, Tai Miu Wan Member of Clear Water Bay Formation at Tai Miu Wan (4712 1450)

Plate 4 – Thin Section of Trachydacite, Tai Miu Wan Member of Clear Water Bay Formation (HK6010) from Tai Miu Wan (4763 1609); XPL × 10

Plate 5 – Rhyolite Lava in Clear Water Bay Formation from Sai Wan Road, Pak Tam Chung (536 284); Natural Scale

Plate 6 – Thin Section of Rhyolite Lava in Clear Water Bay Formation (HK6001) from High Island Reservoir (5264 2752); XPL × 10

Plate 7 – Flow-banded Trachydacite to Rhyolite Lava in Clear Water Bay Formation, at Little Palm Beach (4744 2026)

Plate 8 – Autobrecciated Rhyolite Lava, Clear Water Bay Formation, at Bate Head (5940 3300)

Chapter 4
Mesozoic Volcanic and Sedimentary Rocks

Classification and Distribution

The oldest Mesozoic rocks within the district are the mudstone and siltstone of the Tolo Channel Formation of Lower Jurassic age (Lee, 1984b; Nau, 1984b). The strata, ammonite bearing in part, outcrop at Sham Chung on the northeast side of Three Fathoms Cove. Similar but unfossiliferous strata inferred on lithological grounds to be Permian, are exposed on the western side of Three Fathoms Cove and on Sam Pui Chau.

The Tolo Channel Formation is overlain by the Repulse Bay Volcanic Group, a complex succession of tuffaceous sedimentary rock, tuff and lava, which have been divided lithostratigraphically into a number of distinctive formations. It seems likely that the disposition of major volcanic units in the district is closely related to fault movement or collapse calderas, with thick tuff and lava flow sequences confined to an infilled caldera bounded to the west by Junk Bay and Pyramid Hill (Sheet 7) and to the north by the Cheung Sheung–Chek Keng Fault (Figure 11). The strata to the north of Cheung Sheung probably represents infilling of another, later, fault block or collapse caldera. Generalized sequences within the district are illustrated in Figure 4.

The nomenclature and classification of the pyroclastic rocks used in this survey is based on the recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks (Schmid, 1981), and the work of Fisher & Schmincke (1984), which are summarized in Figures 5 and 6.

C.M. Lee (1985) considered the Repulse Bay Volcanics to be equivalent to the Upper Jurassic Gaojiping Group of Guangdong Province. However, fossil plant bearing horizons at Cheung Sheung indicate the presence of strata of Lower Cretaceous age (Atherton, 1989) within the Lai Chi Chong Formation. The overlying Long Harbour Formation may thus represent the highest part of the Repulse Bay Volcanic Group.

Tolo Channel Formation
Stratigraphy

The name Tolo Channel Formation was first proposed by Uglow (1926), with the formation defined by Heim (1929). Although Ruxton (1960) rejected the term, it was re-instated by Allen & Stephens (1971) and restricted to the Lower Jurassic fossil bearing strata. Addison (1986) described the Tolo Channel Formation on Sheet 7, and assigned fossil-bearing siltstone and mudstone at Ma Shi Chau and Nai Chung to the formation.

Lower Jurassic ammonites have been found in the carbonaceous siltstones and mudstones at Sham Chung (Lee, 1984; Nau, 1984), and the outcrop of Tolo Channel Formation in this district is restricted to the eastern side of Three Fathoms Cove.

On the foreshore between Yung Shue O and Sham Chung, outcrops of red breccia have been assigned to the Tolo Channel Formation on lithological grounds, although no fossil evidence is available.

The strata consist mainly of dark grey or pale grey silty mudstone and siltstone, occasionally carbonaceous, which have yielded fossil plants and ammonites. At the base of the succession a 20 m thick conglomerate lies unconformably on highly contorted metasiltstones of presumed Permian age.

Details

Sham Chung Kok. At the base of the formation, at Sham Chung Kok (4673 3374), a conglomerate about 20 m in thickness is overlain by 4 m of siltstone and a 6 m thick sandstone layer, all dipping northeast at about 45° (Plate 9). The conglomerate is pale grey, bleached white in part and consists of rounded pebbles of quartzitic sandstone, vein quartz, pale grey chert and dark grey chert. The base of the conglomerate can be seen on the northern side of Sham Chung Kok (4662 3393) where it lies unconformably on strata presumed to belong to the Tolo Harbour Formation. Higher in the Tolo Channel Formation the rocks are mainly dark grey silty mudstones which have been sheared and indurated in places (4686 3385). They have yielded fossil plants and ammonites at several localities (468 341) (Lee, 1984a; 1984b; Nau, 1984b) (Plate 10).

Plate 9 – Conglomerate at Base of Tolo Channel Formation. Sham Chung Kok (4672 3372)

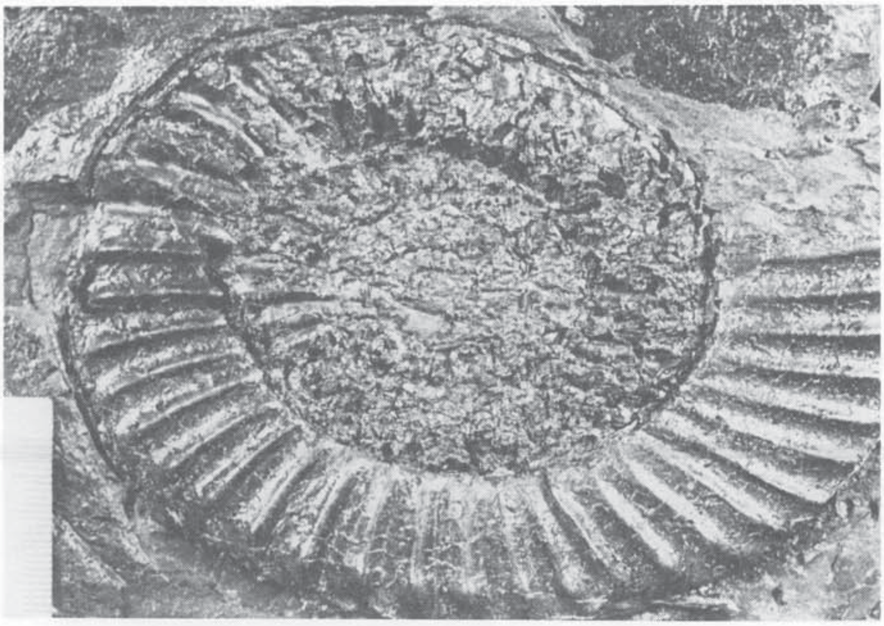


Plate 10 – Fossil in the Tolo Channel Formation; Coroniceras sp (collected by P. S. Nau)

Wong Tei Tong. On the foreshore at Wong Tei Tong below high water mark, (4734 3248) outcrops of red breccia have been assigned to the Tolo Channel Formation. The breccia contains clasts of siltstone, quartzitic sandstone and phyllite, and is inferred to post-date the Permian strata, and the absence of volcanic debris suggests that it pre-dates the Repulse Bay Volcanic Group.

Repulse Bay Volcanic Group

Ap Lei Chau Formation

Stratigraphy

The Ap Lei Chau Formation is considered the oldest tuff division within the Repulse Bay Volcanic Group of this district. Its outcrop is restricted to the western part of the Clear Water Bay Peninsula in the vicinity of Hang Hau, and a small isolated block adjacent to the Sheet 8 margin west of Three Fathoms Cove.

The type locality of the Ap Lei Chau Formation is the southwestern foreshore of Ap Lei Chau, near Aberdeen, on Sheet 15, and has been described in detail in the memoir covering Hong Kong Island (Strange & Shaw, 1986). The maximum thickness of the formation is approximately 2000 m around Junk Bay. The lower part of the formation is not present within the area of Sheet 12, where the strata dip consistently towards the east and pass upwards into the Silverstrand Formation without apparent unconformity.

Much of the Ap Lei Chau Formation consists of fine ash welded tuff interlayered with distinctive pyroclastic flow deposits displaying eutaxitic fabrics (Strange & Shaw, 1986). These eutaxite units form positive topographic features parallel to the general strike of the strata. Within this district, tuff-breccia layers are also present but tuffite and coarse ash tuff, which have been identified elsewhere, are not found.

The eutaxitic fabric provides a guide to the attitude of the strata but since these can become contorted by viscous flow, a number of measurements may be necessary to determine dip and strike directions of the strata.

Chemical analyses indicate that the tuff is of rhyolitic composition (Table 3). Ap Lei Chau Formation has been mapped to the east of Ma On Shan (Sheet 7) and a small faulted block extends on to Sheet 8, west of Three Fathoms Cove. Tuffs of the High Island and Ap Lei Chau Formation are petrographically very similar and it is possible that this outcrop could represent the High Island Formation. However, geochemical analyses from nearby outcrops north of Pyramid Hill (Sheet 7, HK202) show closer similarities to the Ap Lei Chau Formation.

Details

Hang Hau. Extensive excavations 800 m west of Hang Hau have exposed fine ash tuff interlayered with tuff-breccia.This tuff-breccia contains subangular to subrounded clasts of fine ash tuff, aphanitic welded tuff and occasional coarse ash tuff from 30 to 100 mm in diameter. The clasts are set in a pale grey, crystal bearing fine ash tuff matrix which contains occasional pale blue-grey, flattened cherty lenses. On the old coastline (4533 1982) the tuff-breccia passes upwards without apparent unconformity into a fine ash tuff sequence about 30 m in thickness, which in turn is overlain by a fine ash tuff containing abundant fiammé. This eutaxite dips east at approximately 30° and forms a significant positive feature striking northwards roughly parallel to the map sheet boundary. This feature has been dislocated in a number of locations by faulting. When fresh, the eutaxitic fine ash tuff is black and aphanitic, with only a few scattered quartz crystals visible in hand specimen. However, on weathering the rock is white and the prominent eutaxitic fabric stands out.

Southwest of Hang Hau (4580 1952), fine ash tuff is dominant, but includes a more resistant eutaxite unit forming a strong feature at the promontory near the shipyards (456 195). This feature has been traced southwards and is well exposed in the road cuttings (4567 1877) near the controlled tip. Here, fine ash tuff with abundant flattened pumice fragments and small subangular aphanitic clasts forms an extremely hard, black rock with a brittle hackly fracture.

The uppermost part of the formation consists of fine ash tuff which, in the vicinity of Pak Shin Kok (4575 1864) contains abundant angular to subangular clasts averaging 20 mm in diameter. Although most clasts are of tuff, occasional chert and mudstone fragments were noted.

North of Hang Hau, in the road cuttings along Clear Water Bay Road (4537 2095), the same lapilli-bearing fine ash tuff is exposed. This is overlain by the very thick eutaxite sequence which has been separately grouped in the Silverstrand Formation.

Petrography

The Ap Lei Chau Formation is dominated by fine ash vitric tuffs containing scattered crystals of quartz and subhedral feldspar averaging 0.7 mm in diameter. The quartz crystals are sometimes rounded, as for example in HK6862 (4545 2017) from Hang Hau, in which they are deeply embayed, producing the distinctive skeletal shapes so common in the High Island Formation. Scattered lithic fragments up to 8 mm across are common in HK6039 (4542 2084) from Hang Hau. In the recrystallised vitric matrix there are occasional wispy shards and faint fiammé visible under plain light.

Geochemistry

The tuffs of the Ap Lei Chau Formation are relatively high in silica, usually between 74 and 76%, in which respect they are similar to the High Island Formation. The two formations show other similarities in geochemistry in both major and trace element chemistry. It should be noted, however, that the breccia horizons within the Ap Lei Chau Formation show significant variations from the more typical fine ash tuff and resemble the geochemistry of tuffs of the Tai Mo Shan and Shing Mun formations.

Table 3 – Major Element Analyses of Samples from the Ap Lei Chau Formation

Element	Ap Lei Chau Formation		
	Junk Bay Development (45000 20300) HK 5881	Junk Bay Development (45210 19990) HK 6832	Junk Bay Development (45455 20172) HK 6861
SiO_2	67.17	70.47	72.79
TiO_2	0.39	0.42	0.19
Al_2O_3	15.72	14.35	13.31
Fe_2O_3	1.3650	0.6684	0.5964
FeO	2.56	2.53	1.38
MnO	0.13	0.12	0.08
MgO	0.49	0.5	0.09
CaO	1.72	2.26	1.2
Na_2O	2.89	3.15	3.28
K_2O	5.92	4.08	5.26
H_2O^+	1.22	0.95	0.64
H_2O^-	0.16	0.08	0.07
P_2O_5	0.14	0.1	0.04
Total	99.72	99.72	99.87

Volcanic Environment

The welded tuff originates as incandescent (glowing cloud) ash flows, possibly related to calderas (Smith, 1979). Fisher and Schminke (1984), however, considered large volume ash flows could be derived from collapse of a Plinian eruption column. With a thickness of up to 2000 m and a considerable areal extent, this formation should be classed as a large volume ash flow, but no related eruptive centres have so far been identified. Addison (1986) suggested a volcanic source lay in the vicinity of Shek Nga Shan in the Sha Tin district.

Tai Mo Shan Formation

Stratigraphy

Brock & Schofield (1926) and Uglow (1926) named the Tai Mo Shan Formation as a division within their Repulse Bay Volcanics but considered it to be an intrusive porphyry. Ruxton (1960), however, recognized the rocks as extrusive volcanics. Allen & Stephens (1971) divided their Repulse Bay Formation into six lithological units, with the approximate outcrop of the Tai Mo Shan Formation corresponding to their coarse tuff unit.

Addison (1986) has defined the Tai Mo Shan Formation with the type locality at Tai Mo Shan (Sheet 7), where it overlies the Ap Lei Chau Formation. The Tai Mo Shan Formation has been recognized on Hong Kong Island (Strange & Shaw, 1986) where it is composed of coarse ash tuff with thin discontinuous epiclastic layers.

Within this district the formation is present in the Sai Kung area, between Pak Sha Wan and Tai Mong Tsai. No basal contact is exposed in the district, but it is overlain by fine ash tuff of the Silverstrand Formation at Pak Sha Wan, and with angular unconformity by the Mang Kung Uk Formation around Tai Mong Tsai and Kai Kung Shan. In the vicinity of Three Fathoms Cove the High Island Formation oversteps on to the Tai Mo Shan Formation.

The rock is a uniform, greenish grey coarse ash crystal tuff at least 300 m in thickness. Scattered black aphanitic angular clasts averaging 20 mm in diameter are present throughout, and welding fabrics are common. The abundant quartz crystals usually possess a pale brown colouration and often reach 3 mm in diameter. Black shiny biotite flakes are scattered throughout the rock and occasionally these combine to form small clotty aggregations. On weathering the tuffs produce a reddish brown saprolitic soil with large rounded corestones. These often form boulder fields or debris accumulations on hill slopes.

Details

Pak Sha Wan, Sai Kung and Wong Chuk Yeung. To the east of Pak Sha Wan, coarse ash crystal tuff contains small angular aphanitic clasts of vitric tuff and pale grey chert fragments between 10 and 30 mm across. A sedimentary breccia, 400 mm thick, marks the base of the overlying Silverstrand Formation on the east side of the peninsula (4615 2504). Exposures are poor away from coastal sections and inland. For example at Tsui Hang, 1 km south of Sai Kung town (4591 2597), where the coarse ash tuff is deeply weathered with rounded corestones protruding from the reddish brown saprolite. In a former borrow area at this locality the weathered material has been excavated to a depth of 10 m. Similar deep weathering with associated reddish brown soil and corestones of coarse ash tuff is found to the southeast of Wong Chuk Yeung (4595 2896). Large blocks of the tuff form a debris veneer to the hill slopes at Shui Long Wo, particularly well seen at the Star Lookout near the Country Park Management Centre (465 295).

Coarse ash crystal tuff is exposed on the shoreline between Sai Kung and Tso Wo Hang (478 280) and on numerous small islands within Sai Kung Hoi. On Yeung Chau (4689 2679), a north-south striking quartzphyric rhyolite dyke intrudes the tuff. Near Tai Wan Village (4697 2816), abundant lapilli of angular aphanite are set in a crudely banded coarse ash tuff, with faint fiammé. Inland, at Lung Mei (4569 2848), the tuff is finer grained but still possesses the same characteristics of the typical coarse ash tuff. Small felty biotite patches were noted and occasional pink feldspar crystals were scattered through the rock.

Tai Mong Tsai to Kai Kung Shan. Between Tso Wo Hang and Tai Mong Tsai, road cuttings have exposed fresh tuff. 200 m southeast of the Marine Police Base (4795 2799), a thick layer of fine to coarse ash crystal tuff, with a purplish grey colour, is exposed. Angular quartz crystals up to 3 mm across are set in a fine mafic-rich matrix. Further southeast, large fiammé are visible on the weathered rock surface and indicate an easterly dip of 20° (4810 2780). Fiamme are also visible in coastal outcrops near the Outward Bound School (4870 2767), where the coarse ash tuff is overlain by the Mang Kung Uk Formation. The boundary of the two formations can be traced northwards along the eastern side of the Tai Mong Tsai Valley. Fine ash to coarse ash crystal tuff is seen in stream exposures at Shek Hang (4851 2974), where crude columnar jointing was noted. Uniform coarse ash crystal tuff was seen throughout the Water Supplies tunnel extending from Sheet 7 eastwards to Ping Tun (4905 2977).

Petrography

In thin section the rock is essentially a coarse ash tuff as illustrated in Plate 11 of Memoir 1 (Addison,1986). The matrix is very fine, often displaying a welding fabric. Abundant crystal grains vary from angular to subangular, average 1mm in diameter (but can be up to 6 mm), and are poorly sorted. Feldspar crystals (c. 60% of the crystal content) are broken and usually cloudy with albite exsolution. Quartz crystals (c 35%) are invariably angular to subangular, but rare deeply embayed subrounded grains were noted, as for example in HK6657 (4509 2740) from Sai Kung. About 5% of the grains consist of indeterminate lithic fragments.

Geochemistry

Only two analyses of rocks of the Tai Mo Shan Formation are available. These show quite different concentrations of major elements (Table 4), and noticeable differences in the trace elements such as Strontium, vanadium and zirconium. The variations may be due to different eruptive centres. Despite these variations the relative proportions of elements are similar to those exhibited by samples of Tai Mo Shan Formation collected elsewhere in the Territory (Addison,1986; Strange & Shaw,1986).

Table 4 – Major Element Analyses of Samples from the Mang Kung Uk and Tai Mo Shan Formations

Element	Mang Kung Uk Formation	Tai Mo Shan Formation	
	Tai Mong Tsai (49324 27510) HK 6005	Wong Mo Ying (48870 29215) HK 6608	Tai Mong Tsai (47900 28075) HK 6836
SiO_2	75.96	71.64	65.21
TiO_2	0.12	0.3	0.48
Al_2O_3	12.76	13.12	14.99
Fe_2O_3	0.35	1.2153	1.4040
FeO	1.15	1.21	2.3
MnO	0.07	0.06	0.09
MgO	0.07	0.46	0.99
CaO	0.99	1.97	3.3
Na_2O	1.8	2.99	3.22
K_2O	5.08	4.6	4.56
H_2O^+	1.2	1.29	1.34
H_2O^-	0.22	0.15	0.14
P_2O_5	0.01	0.08	0.16
Total	99.87	100.21	100.2

Volcanic Environment

Like the Ap Lei Chau Formation, the Tai Mo Shan Formation was probably deposited from major ignimbritic ash eruptions. The thickness of the deposits and lack of intraformational boundaries or segregations tend to indicate large volume rapid eruptions and confinement of the ash flows, perhaps within a caldera, as described by Francis et al (1983).

Silverstrand Formation

Stratigraphy

The type locality of the Silverstrand Formation is on the shoreline of the southern side of Silverstrand Bay (461 204), where there are almost continuous exposures of welded tuff displaying prominent eutaxitic fabric. The formation is characterised by its uniform eutaxitic nature.

The Silverstrand Formation outcrops over Tung Lung Island and Junk Island, and strikes northwards along the western side of the Clear Water Bay Peninsula as far as Hang Hau, where the outcrop occupies much of the peninsula and is well exposed along the eastern coastline as far as Hebe Haven. From Hebe Haven the formation strikes in a more northeasterly direction and appears to thin rapidly across Inner Port Shelter. At its maximum thickness in the Silverstrand and Hang Hau areas the formation reaches 450 to 500 m in thickness.

The base of the Formation is seen to the south of Hang Hau (458 186) where the eutaxite sits with apparent conformity on fine ash tuffs of the Ap Lei Chau Formation. Although there are similarities between the Ap Lei Chau Formation and the Silverstrand Formation, the latter is characterised by larger fiammé and flattened clasts, and the thick uniform eutaxite contrasts with thinner eutaxitic tuffs within the Ap Lei Chau Formation. To the northeast of Hebe Haven the Silverstrand Formation lies unconformably on coarse ash tuffs of the Tai Mo Shan Formation with no Ap Lei Chau Formation being present. The top of the formation is marked clearly by the abrupt change to the tuffaceous sediments of the Mang Kung Uk Formation. In places, however, for example at Joss House Bay on the southern side of the Clear Water Bay Peninsula, the Silverstrand Formation eutaxites are overlain with marked unconformity by welded tuffs of the High Island Formation. It seems probable that the Mang Kung Uk Formation may have originally overlain the Silverstrand Formation in this area but was eroded away prior to deposition of the later High Island tuffs.

Much of the Silverstrand Formation is considered to be a pyroclastic flow deposit containing the characteristic eutaxitic fabric. This consists of fine ash vitric tuff with abundant fiammé of flattened and stretched pumice fragments. Eutaxite has been described in detail in the description of the Ap Lei Chau Formation (Strange & Shaw, 1986). In several places, lenses of tuffaceous sedimentary rocks, up to 50 m in thickness, have been noted. These usually form negative features on the landscape, as for example at Mau Tin (455 231). One such lens containing tuffaceous mudstone was formerly worked for its clay content at Sha Tsui, Hebe Haven (455 244). These discontinuous interlayered tuffaceous sedimentary rocks may separate individual pyroclastic flow deposits, but no top or base of an individual flow has been noted during the present survey.

Isolated exposures of trachyte lava were noted underlying the Silverstrand Formation tuffs on the southeastern side of Tung Lung Island, and these may represent a minor lava flow within the formation.

Details

Tung Lung Island, Junk Island and Southern Clear Water Bay Peninsula. Silverstrand Formation crops out over Tung Lung Island and the attitude of the strata seem to be fairly gently dipping or roughly horizontal in many places. The eutaxitic fabric is visible everywhere, particularly on weathered surfaces in the coastal exposures. Abundant fiamme are visible in coastal exposures, viz. the cliffs between Nam Tong and the northeast corner of the island at Fat Tong Mun. At Nam Tong (479 130) the fiammé are extremely abundant and make up over 30% of the rock. Small angular to sub-angular clasts of aphanitic pale grey rock possibly chert, are also present in the eutaxite, and these show no signs of flattening. These angular clasts become more abundant towards the western side of the island and in places (471 126) form a tuff-breccia with an average clast size of 20 mm. Along the western coastline the eutaxitic fabric is still present, but in many places the rock is also packed with angular clasts of chert. Several quartzphyric rhyolite dykes are present, the largest striking at 45° across the western side of the island. On the southeastern side of Tung Lung Island a rock of very similar appearance to the trachydacite lava of the Clear Water Bay Formation underlies welded tuff containing a pebbly base.

Junk Island (Fat Tong Chau) and the smaller island of Tit Cham Chau consist of very similar eutaxite to Tung Lung Island. Several quartzphyric rhyolite dykes are found on Tit Cham Chau (466 139) and a number of basalt dykes cut the Silverstrand Formation on Junk Island where the northern part of the island is dominated by a fine-grained granite intrusion with a wide flow-banded quartzphyric rhyolite margin. On the western side of Junk Island, abundant angular and subangular aphanitic clasts are found together with the characteristic flattened fiammé. On the southeast shoreline (455 150), crude columnar jointing was noted perpendicular to the eutaxitic fabric.

The Silverstrand Formation forms the high rugged slopes of Tin Ha Shan between Clear Water Bay and Joss House Bay (Tai Miu Wan). Here, the northerly contact with the lavas of the Tai Miu Wan Member of the Clear Water Bay Formation is fault bounded. 300 m northwest of the Joss House Bay temple (4779 1498), the contact between the eutaxite and the High Island Formation is a marked unconformity. The Silverstrand Formation in this area displays the typical eutaxitic fabric with stretched fiamme up to 50 mm in width and 400 mm in length. 300 m south of Tin Ha Wan (468 151) hillside boulders are rich in angular clasts, similar to those on the western side of Junk Island.

At Shek Miu Wan (4693 1586) and Clear Water Bay Second Beach (4771 1650) isolated outcrops of eutaxite are apparently overlain by tuffaceous sedimentary rock and tuff of the Mang Kung Uk Formation.

Silverstrand and Northern Clear Water Bay Peninsula. The type locality of the formation is at Silverstrand, where a continuous sequence through most of the formation can be seen along the coast to Pik Sha Wan (Bayside Beach). The overlying Mang Kung Uk Formation is found on the east side of Pik Sha Wan Beach. The approximate base of the formation is seen in the road cutting near the junction of Silverstrand Road and Clear Water Bay Road (4573 2058), where feature-forming eutaxite overlies an homogeneous fine ash tuff with no visible welding fabric.

Abundant small fiammé are present in the eutaxite excavated from borrow areas for the Junk Bay Controlled Tip site (461 187), 1 km south of Hang Hau Town. Here the rock is hard and has a brittle fracture. When fresh the eutaxite is black in colour with a very fine glassy matrix; the characteristic fiammé are only faintly visible on fresh surfaces. To the north of Hang Hau, the Kohima Barracks site (now scheduled for development as Hong Kong's third university), has numerous fresh rock excavations into the Silverstrand Formation tuffs. Invariably black when fresh and with a brittle, almost conchoidal glassy fracture, the eutaxite here is typical of the fresh Silverstrand Formation rocks. In places, for example 400 m north of the entrance to the film studios (4517 2175), the eutaxite is crystal rich with patchy concentrations of feldspar laths. Small, sub-angular aphanitic clasts were also noted in places.

At Mau Tin (455 231), a lense of tuffite and weathered fine ash tuff forms a negative topographic feature. The overlying eutaxite displays the characteristic fabric on weathered surfaces in the cliff sections (4565 2330) to the northeast of Camper's Beach where the large fiammé (up to 600 mm by 100 mm) closely resemble those found on the northern side of Tung Lung Island.

Hebe Haven and Inner Port Shelter. On the Ma Lam Wat peninsula, to the east of Hebe Haven, the Silverstrand Formation overlies the coarse ash tuffs of the Tai Mo Shan Formation, where a basal epiclastic breccia, 400 mm in thickness marks the base of the Silverstrand Formation tuff (4613 2506). On the western side of the peninsula, at a similar basal horizon, blocks of streaky parataxitic fine ash tuff are strewn along the coastline (458 248). At Sha Tsui (4540 2434) a tuffaceous lens up to 50 m in thickness is found within the predominantly eutaxitic tuff. The tuffite have been excavated in the past for their clay content, with a processing and tile manufacturing works at the nearby Sha Tsui Pier (454 245). Similar tuffite outcrops along the coast 600 m northeast of Ma Lam Wat where multicoloured tuffaceous sandstone alternates with siltstone layers and thin breccia horizons, very similar in appearance to the Mang Kung Uk Formation strata. These banded rocks dip southeast between 20 and 35° and are overlain by a thick eutaxite sequence (465 246) characterised by small fiammé with abundant sub-angular aphanitic clasts in the vicinity of Pak Ma Tsui (464 235).

Isolated outcrops of Silverstrand Formation occur on the western side of Sharp Island (Kiu Tsui Chau). On Kiu Tau (475 249) a faint eutaxitic fabric is seen, together with abundant small angular aphanitic clasts. A 30 m thick clast rich horizon has been mapped as tuff-breccia (4763 2487), with polymictic clasts including some sandstone and mudstone fragments. 500 m southeast of Kiu Tsui (482 247) clast-rich fine ash tuffs are overlain by alternating tuffaceous sandstone and siltstone of the Mang Kung Uk Formation dipping eastwards at about 45°.

Petrography

Plate 2 (HK6122, 4539 2144) represents a typical thin section of Silverstrand Formation tuff. Quartz and feldspar crystals, angular to subrounded, reach 1.5 mm in diameter and are set in a fine ash vitric matrix, often displaying a eutaxitic fabric. Fiamme up to 12 mm in length and 2 mm width are common. Faint reaction rims around some crystals are visible in specimens from Clear Water Bay Peninsula (HK6021, 4790 1549), and some samples contain subrounded to rounded deeply embayed quartz crystals (HK5899, 4807 1476) resembling thin sections of High Island Formation tuff. The clast and crystal content of the Silverstrand Formation are, however, generally much higher than in fine ash tuff from the Mang Kung Uk and High Island formations.

Geochemistry

Although the tuffs of the Silverstrand Formation have macroscopic features that distinguish them from the tuffs of the Ap Lei Chau Formation, notably a higher proportion of lapilli and large fiammé, elemental abundancies within the two formations show a considerable degree of similarity. As with the plots of elements from the Ap Lei Chau Formation, plots of elements from the Silverstrand Formation show divided distributions with silica concentrations around 69% or around 75%. Similarly, trace element amounts indicate two groupings; for example the ratio of Zr/Nb concentrated around 25:1 or around 8:1.

Volcanic Environment

The Silverstrand Formation is envisaged as originating from massive ash flow eruptions and plinean column collapse in a similar manner to the Ap Lei Chau Formation. The separation of geochemical types within the Silverstrand Formation may result from variations in the depositional process or possibly from introduction of ash flows into the sequence from two distinct sources.

Table 5 – Major Element Analyses of Samples from the Silverstrand Formation

Element	Silverstrand Formation						
	Clear Water Bay (48071 15240) HK 6014	Kohima Site (45345 21910) HK 6474	Kohima Site (45490 22082) HK 6475	Kohima Site (45130 22300) HK 6476	Kohima Site (45160 21870) HK 6477	Kohima Site (45230 21578) HK 6478	Junk Bay Control Tip (46030 18275) HK 6479
SiO_2	76.32	67.23	75.21	74.47	69.48	70.01	73.49
TiO_2	0.11	0.41	0.16	0.17	0.34	0.31	0.19
Al_2O_3	12.85	15.63	13.01	13.12	14.82	14.76	13.5
Fe_2O_3	0.508	1.0040	0.4219	0.3663	1.0252	1.1941	0.6886
FeO	1.02	2.3	1.24	1.47	1.84	1.58	1.18
MnO	0.06	0.13	0.07	0.09	0.08	0.12	0.09
MgO	0.09	0.37	0.16	0.17	0.31	0.29	0.09
CaO	0.76	2.03	0.69	1.03	1.31	1.62	0.96
Na_2O	2.69	3.61	3.04	3.08	3.73	3.57	3.47
K_2O	5.24	5.67	4.94	4.89	5.57	5.53	5.36
H_2O^+	0.8	0.72	0.88	0.76	0.82	0.68	0.74
H_2O^-	0.13	0.1	0.14	0.1	0.14	0.08	0.08
P_2O_5	0.01	0.16	0.03	0.02	0.11	0.1	0.04
Total	100.59	99.51	99.97	99.78	99.66	99.85	99.9

Mang Kung Uk Formation

Stratigraphy

The Mang Kung Uk Formation has its type locality between Mang Kung Uk Village and the coast at Tai Chik Sha Wan. The formation is also well seen along the Silverstrand coastline 400 m north of Mang Kung Uk Village.

The Mang Kung Uk Formation is dominated by alternations of well-bedded tuffite, epiclastic breccia, conglomerate, siltstone and sandstone layers. Thick fine ash and coarse ash tuff units and impersistent lavas are also present, particularly in the Tai Mong Tsai area where the formation reaches 300 m in thickness.

The Formation sits with no evidence of unconformity on the eutaxite of the Silverstrand Formation in the Clear Water Bay Peninsula, but further north, in the Sai Kung Country Park, oversteps on to the coarse ash tuffs of the Tai Mo Shan Formation. Throughout the district, the Mang Kung Uk Formation is overlain by lava of the Clear Water Bay Formation except on the northern flanks of Sharp Peak, where the Long Harbour tuffs lie unconformably on both the Mang Kung Uk and Clear Water Bay Formations. The Mang Kung Uk Formation represents a significant change in the volcanic environment from the thick pyroclastic flow deposits below, to a lava dominated sequence above.

Details

Mang Kung Uk to Junk Bay. The lower part of the formation is well exposed along the coastline in the vicinity of Tai Chik Sha Wan. On the promontory near the limit of reclamation (4639 1715), interbedded sandstone, tuffaceous siltstone, volcanogenic conglomerate and bedded tuff dip east between 18 and 25°. Bedding is well developed, with the sandstone also exhibiting cross-bedding structures and distinctive graded bedding. Individual graded units vary in thickness from 300 mm to 1.0 m and can be traced laterally for between 20 and 40 m along the shoreline. The conglomerates contain clasts up to 200 mm, the majority being fine ash tuffs, but some siltstone, quartzite and chert fragments were noted. The well stratified units are overlain by a rhyolite lava (465 172) about 25 to 30 m in thickness. This lava is very fine-grained but contains prominent quartz and feldspar phenocrysts, and forms a feature which can be traced over a distance of 1.5 km. A heterolithic tuffite sequence, possible as much as 120 m thick, overlying the lava, has been proved in a number of boreholes at Tai Chik Sha (470 170). This pale grey to pale green rock contains abundant lithic fragments of mudstone, siltstone and welded tuff, averaging 10 mm in diameter. Occasional thin bands of accretionary lapilli have also been noted.

Numerous small exposures of tuffaceous siltstone, tuffaceous sandstone and crystal bearing fine ash tuff are found in the stream bed east of Siu Chik Sha (467 176). Northwards, similar material occupies the wide topographic hollow between Siu Chik Sha and Mang Kung Uk. Soft, grey, flaggy siltstone and sandstone, the basal beds of the formation, sit without apparent unconformity on eutaxite of the Silverstrand Formation, 400 m south of Wo Tong Kong (4640 1898). A pale yellow sandstone band about 25 m in thickness forms a strong north-south striking feature 250 m east of Wo Tong Kong (465 193).

Isolated exposures of the Mang Kung Uk Formation are seen along the coastline between Pik Sha Wan (468 201) and Little Palm Beach (472 203). The lower part of the formation contains breccia and a chaotic assemblage of clasts of all sizes in a tuffaceous siltstone matrix (4679 2010). This melange may possibly represent a lahar flow deposit. Bedded tuffite, exhibiting good graded bedding structures, outcrops further east (4694 2016) and contains thin impersistent epiclastic breccia horizons. Sandstone and mudstone bands with interlayered clast-bearing tuffite dominate the upper part of the formation (4707 2022) and are overlain by extremely contorted flow-banded lava of the Clear Water Bay Formation.

Southern Clear Water Bay Peninsula. Pale greenish grey tuff, tuffite and associated tuff-breccia is exposed on the coast around Shek Miu Wan (469 160). The formation is less than 100 m thick in this area. Similar, soft, weathered tuffite and tuff is found on the southern side of Clear Water Bay Second Beach (477 163) where the strata are intruded by quartzphyric rhyolite dykes and a small fine-grained granite body. The tuffite and tuff is overlain by a thick trachydacite lava flow (Tai Miu Wan Member of the Clear Water Bay Formation).

It is conceivable that the sea channels between Tit Cham Chau and the mainland (467 140), and the Fat Tong Mun Channel (488 134) have been formed in the softer material of the Mang Kung Uk Formation. Large clasts of tuffite with rare accretionary lapilli, siltstone and mudstone, similar in character to the formation, are found in the fissure vents at Fat Tong Kok (4880 1359) and Tai Miu Wan (4707 1463). The material within the vents probably eroded from the vent walls as the eruption broke through the underlying strata, and thus may indicate the presence of Mang Kung Uk Formation at depth.

Sai Kung Hoi and Tai Mong Tsai. The Mang Kung Uk Formation outcrops on a number of small islands in Sai Kung Hoi (Inner Port Shelter). Alternating layers of siltstone and clast rich tuffite are exposed on the southwest side of Sharp Island (482 246). The strata dip eastwards at 45° and are about 40 m thick between underlying fine ash welded tuff and overlying flow-banded lava. In the northern part of Sharp Island, thickly bedded pale greenish grey tuffaceous sandstone contains scattered green mudstone clasts (4832 2627). Thin epiclastic breccia horizons and dark grey mudstone bands are also present (4819 2616). The formation occupies the islands of Pak Sha Chau, Cham Tau Chau, and the smaller islands of Siu Tsan Chau and Tai Tsan Chau. On the latter (4787 2633), laminated siltstone is interbedded with mudstone and sandstone (Plate 11), and dips 20° towards the southeast. Cham Tau Chau (478 266) and Pak Sha Chau (475 262) are composed predominantly of thick coarse tuffite units with occasional epiclastic breccias containing subangular clasts of tuff and siltstone to 200 mm in diameter. Tuff-breccia, similar to the chaotic melange rocks north of Mang Kung Uk, is found on the east side of Pak Sha Chau (4755 2615), and on Cham Tau Chau (4769 2670), where large blocks of black mudstone and pale grey cherty siltstone are found.

Eastward dipping, well-bedded pale grey tuffite is found along the shoreline south of the Outward Bound Training School at Tai Mong Tsai (488 272). Here, a series of minor intraformational unconformities between the tuffite units are exposed between high and low water marks. Black mudstone clasts are present in pale grey siltstone, which is finely laminated in part.

Nearby, penecontemporaneous slumping and small-scale faulting is well seen in laminated beds (4895 2730). A black, fine ash welded tuff (HK6005, 4932 2751) overlies the tuffite sequence. This tuff is in turn overlain by autobrecciated rhyolitic lava, which is exposed on the shoreline 1.2 km southsoutheast of Tai Mong Tsai Village (494 272), where angular to subangular flow-banded lava blocks comprise the autobreccia. The feature-forming lava can be traced northwards as the surface is strewn with flow-banded lava fragments and distinctive blocks of spherulitic rhyolite (494 276). Eastwards to the shores of Tsam Chuk Wan, tuff and tuffite predominate. The soft, white weathering tuffite is frequently crudely layered, and cherty lenses have been noted (4995 2748). Around Tsam Chuk Wan Village and on the small island of Muk Yue Tau (501 278), fine ash to coarse ash tuff occurs, with occasional small fiammé. The nearby islands of Ching Chau (503 278) and Wong Nai Chau Tsai (504 272) consist of well-bedded tuffaceous siltstone and finely laminated mudstone, which on the southwest of Wong Nai Chau Tsai (5042 2720) is seen overlying coarse ash tuff.

The Mang Kung Uk Formation extends northwards from Tai Mong Tsai, but thins rapidly north of Ping Tun, and has not been recognized in the vicinity of Kai Kung Shan (482 305), where both lava of the Clear Water Bay Formation and tuff of the High Island Formation appear to overstep directly on to the coarse ash tuff of the Tai Mo Shan Formation.

At Ping Tun (4897 2982), bedded tuffaceous siltstone and sandstone lie unconformably on an irregular surface of the Tai Mo Shan Formation. Crystal-bearing fine ash to coarse ash tuff, at least 100 m in thickness, overlies the well-bedded tuffaceous sedimentary rocks, and is well seen in the stream course east of Tit Kam Hang Village (493 295). At She Tau (4925 2886), finely laminated, colour-banded siltstone and mudstone are exposed in the footpath leading to Tai Tun.

Finely laminated and banded, white to pale grey tuffaceous mudstone and siltstone rest unconformably on Tai Mo Shan Formation coarse ash tuff to the west and south of Wong Mo Ying. Here, the Mang Kung Uk Formation is about 70 m thick. South of Wong Mo Ying (483 289) the formation is dominantly mudstone and siltstone, and is overlain by a distinctive pyroclastic flow deposit considered to be the Tai Tun Member of the Clear Water Bay Formation.

Chek Keng to Tai Long Wan. Small isolated outcrops of bedded tuffite are found underlying the Clear Water Bay lava in the Chek Keng area. These uppermost beds of the Mang Kung Uk Formation can be seen on the shoreline immediately northeast of Chek Keng Village (542 315). Eastwards to Nam She Au (562 319), a thick sequence of variable tuff, tuffite and occasional mudstone and siltstone layers underlie a hilltop capping of Clear Water Bay lava. The Mang Kung Uk Formation forms subdued topography on the east side of the Tai Long Valley (567 310). Pale greenish grey, fine ash to coarse ash tuff and tuffite is exposed in the footpath from Tai Wan to Tung Wan (575 311).

Plate 11 – Interlayered Conglomerate. Sandstone, Siltstone and Mudstone in Mang Kung Uk Formation on Tai Tsan Chau (4787 2632)

Petrography

Fine ash tuff of this formation has been examined in thin section and is characterised by a very fine vitric matrix with scattered crystals, often broken fragments of quartz and feldspar. Small mafic patches in HK6007 (4964 2739) from Tai Mong Tsai may be magnetite and pyrite, and probably explain the high magnetic susceptibility of the fresh rock. Small fiammé in thin section HK6006 (4955 2725) from Tai Mong Tsai have been partly recrystallised.

Geochemistry

Only one sample of a welded tuff from the Mang Kung Formation has been analysed. This sample (HK6005, 4932 2751) is similar in all respects to the welded tuff of the High Island Formation.

Volcanic and Sedimentary Environment

The Mang Kung Uk Formation succession was deposited under an unstable environment, with sediments and derived volcanic debris being washed into a shallow lacustrine basin, possibly associated with a collapse caldera. The thick tuff sequences accumulated by ash flow from nearby volcanic fissure vents. Impersistent lava flows, interlayered with the pyroclastic and epiclastic strata, were probably derived from local sources, since the viscous rhyolite was unlikely to have flowed more than a few kilometres from its source.

Clear Water Bay Formation

Stratigraphy

This formation is first defined in this memoir, but corresponds approximately to the banded lavas and tuffs (Rbvb) of Allen & Stephens (1971), and in the Sai Kung area to the Lan Nai Wan Division of Watkins (1979).

The formation is well exposed in the Clear Water Bay Peninsula where it overlies the tuffite of the Mang Kung Uk Formation. Here, a basal trachydacite unit, the Tai Miu Wan Member, has been separated. The formation strikes northwards across Port Shelter and outcrops on Shelter and Sharp Islands, and extensively over the Sai Kung Peninsula where a feature-forming eutaxite layer (Tai Tun Member) has been distinguished. In the Sai Kung East Country Park a tuffaceous top to the formation has been recognized (Lan Nai Wan Member) and is overlain by massive fine ash welded tuff of the High Island Formation. The Clear Water Bay Formation oversteps on to the Tai Mo Shan Formation in the vicinity of Kai Kung Shan, but is thin in that area and is absent further west. The formation is at least 300 m thick between Yung Shue Au and Pak Tam Au, but has not been found north of the Cheung Sheung – Chek Keng Fault.

On the Clear Water Bay Peninsula the formation is characterised by several lava flows of trachydacite to rhyolite composition, often autobrecciated, and interlayered with fine ash tuff horizons. In the Sai Kung Country Park, flow-banded rhyolite lava predominates and this is frequently autobrecciated. The three named members will be dealt with in separate sections.

Details

Clear Water Bay Peninsula. Alternating layers of fine ash tuff and autobrecciated trachydacite to rhyolite lava form north-striking dip and scarp features along the main High Junk Peak ridge. The lavas are more resistant to erosion and form isolated crags on the steep west-facing slopes. A common feature of the lava is the highly contorted flow-banding which is well seen on weathered surface blocks and particularly prominent in shoreline exposures, as at Little Palm Beach (4744 2026) (Plate 7). Autobrecciation becomes increasingly common southwards, in the vicinity of Clear Water Bay Second Beach (478 167) and to the southwest of High Junk Peak (473 172). When fresh, the rock is very fine-grained and dark bluish grey, with faint flow-banding and scattered small euhedral feldspar laths. The interlayered fine ash tuff contains small angular aphanitic clasts and in places displays a faint eutaxitic fabric. Within 50 m of the top of the formation, for example at Lung Ha Wan (4892 1897), the tuff and lava take on a mottled purple to pink coloration and are in places deeply weathered. It is possible this horizon represents the top of the Clear Water Bay Formation which was exposed to subaerial weathering prior to the deposition of the overlying High Island Formation.

Ngau Mei Hoi (Port Shelter) and Sai Kung Hoi (Inner Port Shelter). Intensely contorted flow-banding is present in purplish grey lava occupying the northern part of Shelter Island. Similar rocks have been collected underwater at Tai Pai (4843 2259) and are present striking northwards across Sharp Island. On Yim Tin Tsai (4702 2631), purple lava, often autobrecciated, is overlain by High Island Formation tuff.

Sai Kung East Country Park, including High Island and Sharp Peak. The lava exceeds 400 m in thickness to the east of Pak Tam Chung, where a chemical analysis (HK6001, Table 6) indicates it has a rhyolitic composition with some alkali enrichment. The dark grey to black, very fine grained rhyolite has fine flow-banding with sparse euhedral feldspar phenocrysts. The rock gradually changes in colour to reddish purple as the contact with the overlying Lan Nai Wan Member is approached. Near the High Island west col dam (5261 2691) the lava is intensely autobrecciated with fragments of flow-banded rhyolite set in a highly silicified red groundmass. This autobreccia is present in the basal part of borehole DH8 (Figure 8). A continuous exposure of black rhyolite is seen along the length of the water tunnel between Pak Tam Au (5237 3022) and the High Island Reservoir (5264 2843); the rock is flow-banded in places but no autobrecciated layers were observed. Close to the Sai Wan road, 2 km east of Pak Tam Chung (536 284), reddish grey flow-banded lava is exposed in the stream bed (Plate 5). This is overlain by autobreccia consisting of a chaotic assemblage of flow-banded rhyolite blocks of all sizes up to 1.2 m. Flow-banding is also seen in the groundmass separating the large blocks. This rock forms a large tor beside the road (5384 2801) and is overlain by the High Island Formation 100 m to the east.

The Clear Water Bay Formation is present along the valley floors to the west of Sai Wan, the largest outcrop being in the vicinity of Luk Wu (550 292) where flow-banded red and purple lava is exposed in the stream bed. Similar exposures were noted below the high water level on the northern side of the High Island Reservoir,

Plate 12 – Eutaxite in Tai Tun Member of Clear Water Bay Formation, at Wong Yi Chau (5080 2809)

Plate 13 – Thin Section of Eutaxite (HK6621) in Tai Tun Member of Clear Water Bay Formation, from Tai Tun (5033 2884); XPL × 10

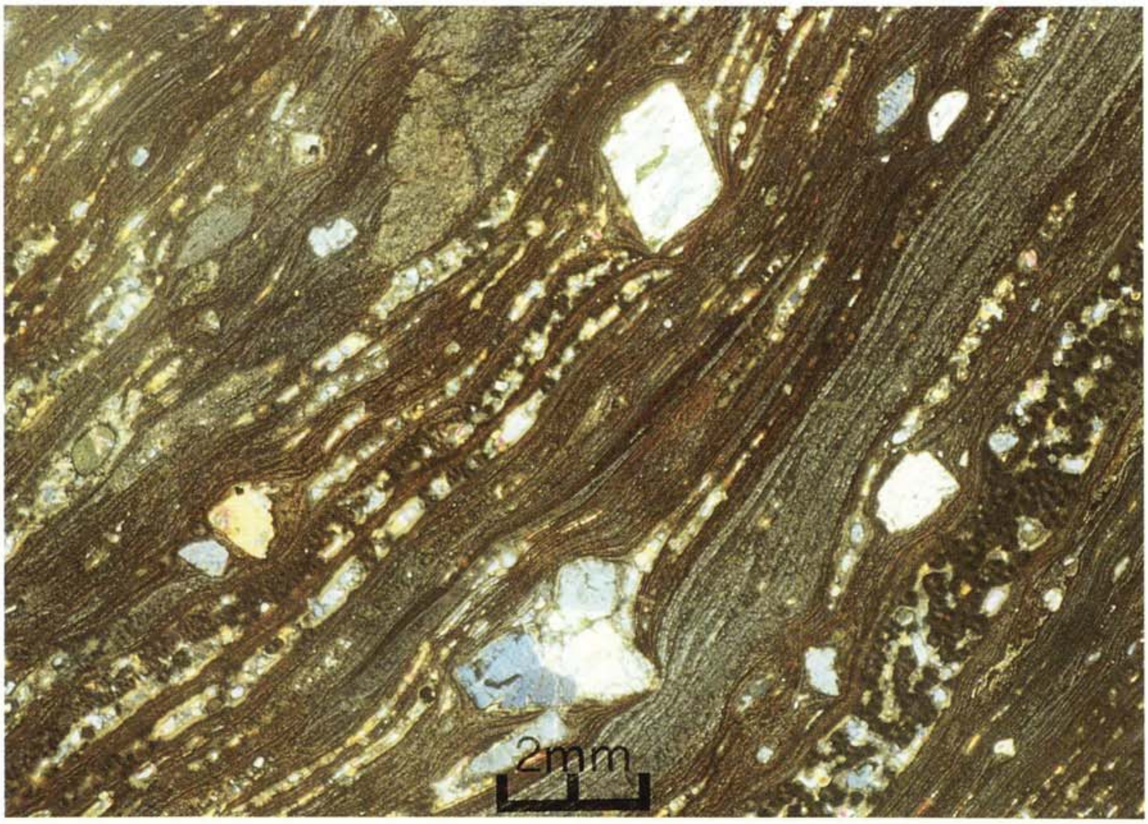


Plate 14 – Fine Ash Vitric Tuff in High Island Formation (HK6003) from High Island East Dam (5663 2502); Natural Scale

Plate 15 – Thin Section of Fine Ash Tuff in High Island Formation (HK6974) from Pai Ngak Shan (5334 3040); XPL plus ¼λ plate × 10

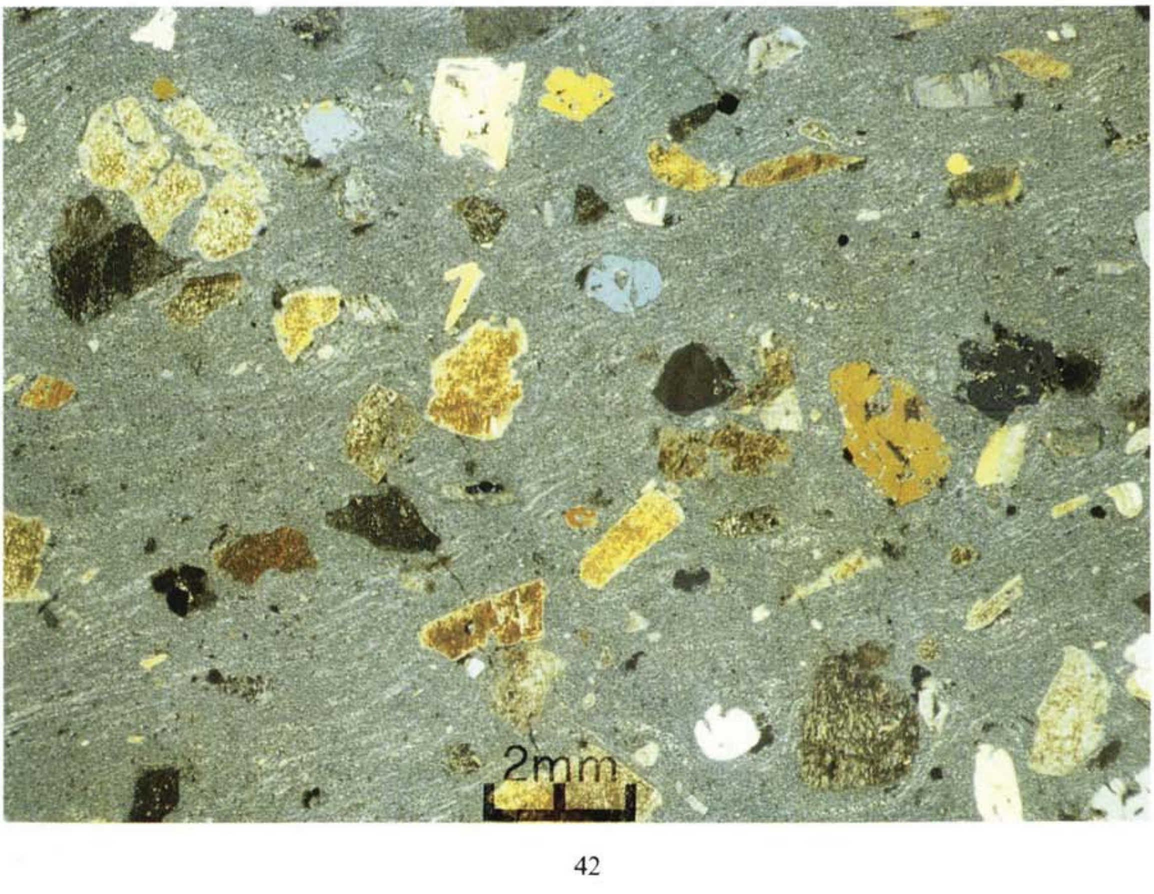


Plate 16 – Columnar Jointing in Fine Ash Tuff of High Island Formation at High Island East Dam (566 250); Note the Basalt dyke intruded along the Kink-Banding

Plate 17 – Basal Conglomerate of Lai Chi Chong Formation at Sham Chung (4662 3392)

Plate 18 – Carbonaceous Mudstone and Banded Tuffite in Lai Chi Chong Formation, near Sham Chung (4716 3294)

Plate 19 – Mudstone Clasts in Coarse Ash Tuff of Lai Chi Chong Formation (4716 3460)

1.5 m southwest of Sai Wan (5485 2738-) (5497 2796). A faulted block of the formation is found on the south side of Tai Long Wan, where tuff, tuff-breccia and eutaxite layers have been noted within the lava sequence. On the nearby island of Tsim Chau (5783 2912) the contact with the overlying High Island Formation is marked by the presence of numerous small vertical silicified veins, apparently injected upwards into the tuff from the flow-banded lava. These may possibly represent late-stage emanations from the cooling lava body which had already been overlain by thick pyroclastic flow material. Autobrecciated reddish brown lava outcrops at Mong Yue Kok (570 301). Altered and silicified lava and tuff are found on Sharp Peak (568 324), where a steeply dipping eutaxite horizon has been delineated. Eastwards, at Bate Head (594 330), autobreccia predominates (Plate 8), with common large blocks to 1.5 m in diameter. At Tung Wan (5785 3138) the lava is markedly spherulitic although traces of the flow-banding are still visible. On the Tai Long Tsui peninsula the lava is overlain by tuff and tuffite of the Lan Nai Wan Member.

Petrography

In thin section the undifferentiated Clear Water Bay Formation lava is very fine-grained, with a low phenocryst content, usually less than 8%. Sample HK6001 (5264 2752) illustrated in Plate 6 is typical, with an indeterminate microcrystalline groundmass enclosing scattered euhedral feldspar phenocrysts up to 3 mm in diameter. Flow-banding is visible in some sections, for example HK6646 (5295 2640), which also contains recrystallisation developing along the flow banding planes. Elongate feldspar laths are flow oriented and occasionally form agglutinated clusters. Some specimens are markedly recrystallised (HK6678, 5203 3089,) and display faint spherulitic structures.

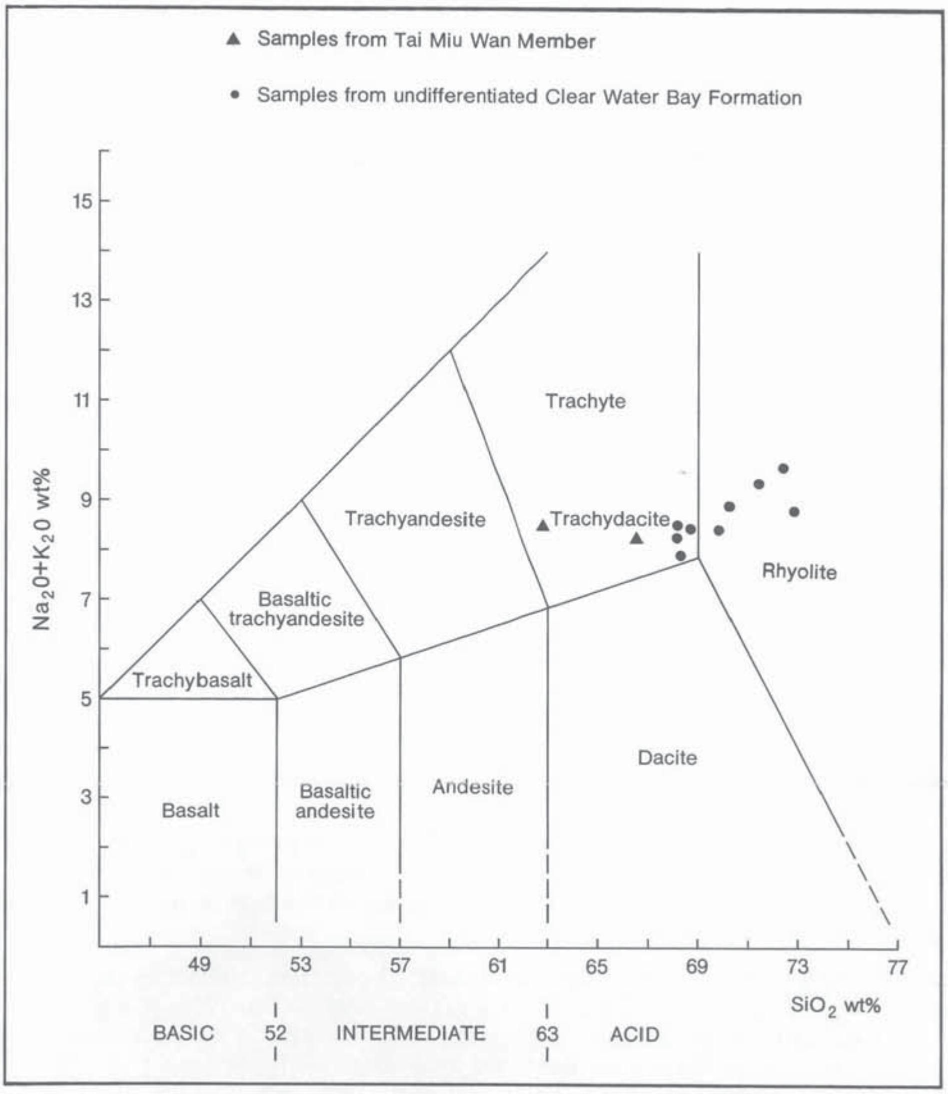


Figure 7 – Chemical Classification of Volcanic Rocks (Total Alkali-Silica Diagram), (after Le Bas et al, 1986); Showing Plots of Samples from the Clear Water Bay Formation

Geochemistry

Despite the numerous common features of the lavas within the Clear Water Bay Formation, geochemically the group comprises two lithotypes, those of trachytic (whether trachyte or trachydacite) and those of rhyolitic aspect. The former includes the rocks of the Clear Water Bay Peninsula, including the Tai Miu Wan Member, and the latter the rocks of the Sai Kung Peninsula. The chemical classification of these rocks has been determined using the total alkali silica method (Le Bas et al. 1986). The plots for the chemically analysed samples are shown in figure 7. It is possible that a geochemical transition or differentiation from trachydacite to the rhyolite occurs, but trace element data suggests that the lavas of the Sai Kung Country Park may have originated from a different source to the equally thick development on the Clear Water Bay Peninsula. The attenuation of the formation in the intervening ground may reflect an original depositional feature.

Table 6 – Major Element Analyses of Samples from the Clear Water Bay Formation

Element	Clear Water Bay Formation							
	Sai Kung (46190 30070) HK 217	High Island (52642 27522) HK 6001	Pak Tam Au (51950 30632) HK 6835	Seung Sz Wan (48100 18677) HK 6839	Little Palm Beach (47690 20100) HK 6840	Clear Water Bay (47473 18296) HK 6863	Clear Water Bay (47380 18718) HK 6864	Kei Ling Ha (45476 30643) HK 6866
SiO_2	71.22	71.84	70.01	68.02	69.76	68.39	68.66	72.43
TiO_2	0.27	0.25	0.26	0.44	0.37	0.42	0.4	0.22
Al_2O_3	14.30	14.70	15.09	14.61	14.09	14.75	14.59	13.76
Fe_2O_3	0.76	0.71	1.2453	1.0718	0.9396	0.8029	1.1074	1.3598
FeO	1.56	1.67	1.12	1.96	2.07	2.22	1.73	0.81
MnO	0.11	0.12	0.18	0.1	0.1	0.11	0.09	0.11
MgO	0.20	0.14	0.12	0.56	0.44	0.62	0.5	0.15
CaO	1.16	0.65	0.86	2.1	1.66	2.64	1.73	1.07
Na_2O	3.39	3.45	2.82	3.05	3.13	2.33	3.2	3.5
K_2O	6.30	6.45	6.39	5.71	5.62	5.82	5.51	5.64
H_2O^+	0.42	0.59	1.16	1.2	1.04	1.2	1.6	0.5
H_2O^-	0.13	0.07	0.38	0.1	0.08	0.14	0.12	0.08
P_2O_5	0.05	0.05	0.03	0.14	0.12	0.13	0.13	0.04
Total	99.87	100.69	100.29	99.84	100.01	100.15	100.04	99.68

Volcanic environment

The Clear Water Bay Formation is dominated by lava flows of types that are typically restricted in their lateral extent to within a radius of less than 10 km from their source. Although it is more than likely, therefore, that the source of these lavas lies within the vicinity of the district, no evidence has been noted of any associated vent.

It is notable that the lavas have been deposited upon a sequence of waterlain mudstones and tuffites and these could conceivably have been laid down within a caldera in which trachydacite and rhyolite lavas were subsequently erupted. If the southeasterly dip of the strata were a result of downsagging of the caldera floor (in the manner described by Walker, 1984), then it is probable that the vent or vents lay somewhere to the southeast. This does not, however, preclude the possibility that rhyolites described by Addison (1986) on Shek Nga Shan could represent an intrusive source of Clear Water Bay Formation lava.

Tai Miu Wan Member

Stratigraphy

The Tai Miu Wan Member forms the basal lava unit of the Clear Water Bay Formation. It is best developed in the southern part of the Clear Water Bay Peninsula, around Tai Miu Wan (Joss House Bay), where it reaches 150 m in thickness and rests on tuffaceous sedimentary rocks of the Mang Kung Uk Formation. The Member can be traced northwards along the western flanks of High Junk Peak as far as Mang Kung Uk, a distance of about 5 km, and is overlain by fine ash tuff.

It has a trachydacite composition, determined from two geochemical analyses (Table 7) (Figure 7). When fresh the rock has a distinctive bluish grey colour. The groundmass is very fine-grained and possesses a finely laminated flow-banding fabric which stands out particularly well on slightly weathered surfaces. Feldspar phenocrysts are scattered throughout the rock, but quartz is rarely visible in hand specimen. Large crude hexagonal columns, some in excess of 2 m diameter, are developed in places (Plate 20).

Details

Tai Miu Wan and Fat Tong Kok. Flow-banded trachydacite forms vertical cliffs in the vicinity of Clear Water Bay Country Club and at Fat Tong Kok (4883 1360), where vertical fissure vents cut through the lavas. The member is overlain at Po Keng Teng (4918 1422) by fine ash vitric tuff of the High Island Formation. The topmost few metres of the trachydacite are purple-stained (4886 1460) and may represent exposure to subaerial weathering prior to deposition of the overlying tuffs. Within the lava flows, at Tai Miu Wan (4798 1450), a 50 m thick tuffite layer has been mapped. Flow-banding in the lavas is prominent, but is frequently highly contorted and is not a useful indicator of the attitude of the strata.

Clear Water Bay (Tsing Shui Wan) and Tai Au Mun. The member outcrops on the promontory immediately south of the main beach (4795 1628), where crude hexagonal columns 2 to 2.5 m in diameter indicate a gentle dip to the south. The trachydacite is greyish blue and is frequently iron-stained due to abundant pyrite crystals scattered throughout the rock, seen for example in the road cutting 250 m south of the bus terminus (4763 1619). On the hill summit, west of the main beach, the trachydacite outcrop is characterised by numerous rounded boulders on the surface, often pitted and iron-stained, and containing prominent feldspar laths up to 8 mm in length. The member produces a significant dip and scarp feature, resulting in crags along the slopes west of High Junk Peak (4695 1723).

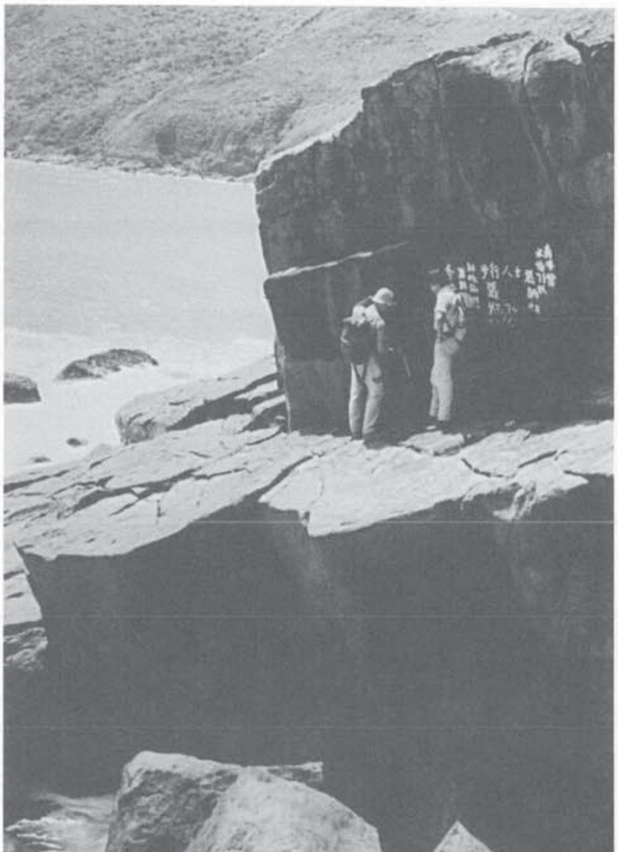


Plate 20 – Columnar Jointed Trachydacite, Tai Miu Wan Member of Clear Water Bay Formation, at Clear Water Bay (4790 1622)

Near the country park management centre at Tai Au Mun (4902 1681), the member is faulted against the High Island Formation. The surface is strewn with boulders of trachydacite, and in the cliffs to the east (4922 1670) prominent crude banding is visible, dipping northeast between 10 and 20°.

Petrography

Plate 4 shows a typical thin section of the trachydacite of the Tai Miu Wan Member (HK6010, 4763 1609). Quartz makes up only about 7% of the total phenocryst content, with plagioclase and alkali feldspars dominant. The feldspar phenocrysts are euhedral to subhedral and average 2 mm in length, but occasional microperthite megacrysts reach 7 mm in length. Magnetite and pyrite are common accessory minerals, together with chlorite and occasional calcite. Sericitised patches are common and indeterminate altered areas in the groundmass are often present.

Geochemistry

Two samples of the member have been analysed and are plotted on the Total Alkali-Silica Diagram (Figure 7) where they fall clearly within the trachydacite field (Le Bas et al, 1986).

Table 7 – Major Element Analyses of Samples from the Tai Miu Wan Member, Clear Water Bay Formation

Element	Tai Miu Wan Member (Clear Water Bay Formation)	
	Clear Water Bay (47625 16090) HK 6010	Clear Water Bay (48300 14420) HK 6011
SiO_2	62.33	65.89
TiO_2	0.58	0.53
Al_2O_3	16.73	15.58
Fe_2O_3	1.19	1.07
FeO	3.4	3.14
MnO	0.15	0.11
MgO	0.1	0.96
CaO	3.22	2.78
Na_2O	2.5	3.27
K_2O	6.12	5.2
H_2O^+	1.64	1.34
H_2O^-	0.15	0.15
P_2O_5	0.21	0.21
Total	99.32	100.23

Tai Tun Member

Stratigraphy

This member occurs within the thick lava sequence of the Clear Water Bay Formation, and consists of a highly distinctive pyroclastic flow deposit. The unusual character was first noted by Allen & Stephens (1971), who described the rock as a lenticulite, and it was grouped within their "mainly banded lavas with some welded tuff" unit on the 1:50 000 scale map.

The member outcrops on Tai Tun, 1.5 km northeast of Tai Mong Tsai, where the hard nature of the rock has resulted in vertical cliffs around the upper part of the hill. It also occurs as isolated outliers northwest of Tai Mong Tsai, resting on Mang Kung Uk Formation sedimentary rocks, and forms a well-defined roughly horizontal feature around the hills in the vicinity of Pak Tam Au. The member is also exposed as steeply dipping strata to the south of Pak Tam Chung and also on Sharp Island. Northeast of Chek Keng the Tai Tun Member forms hill top cappings above the Clear Water Bay Formation lavas.

The rock type is essentially a eutaxite, with a parataxitic fabric in part. The fine ash vitric tuff is packed with fiammé (Plate 12) and occasional angular clasts. The fiammé have formed flow structures around the angular clasts (Plate 12), particularly well seen on weathered surfaces.

Details

Tai Tun and Pak Tam Au. The type locality is at Tai Tun (501 289), where the member forms a hard feature around the summit. Abundant fiammé are present throughout and these indicate a roughly horizontal nature to the strata. The eutaxite rests on soft tuffite at the eastern side of Tai Tun. It is estimated that the member reaches 120 m in this area. To the north of Tai Tun, it reaches a thickness of almost 200 m as a feature-forming, roughly horizontal layer skirting the southern flanks of Ngau Yee Shek Shan. Typical exposures of the member reveal the highly distinctive eutaxitic nature. 800 m north of Pak Tam (5054 3100), the eutaxite forms crags which also display an autobrecciated appearance. Along the Pak Tam Road (5217 3191) the horizontal eutaxite is seen lying on purple rhyolite lava. On Ngau Yee Shek Shan (5136 3087) the eutaxite is overlain by a thick autobrecciated lava.

Sharp Island and Wong Yi Chau. The eutaxitic character is well seen in the coastal exposures around Wong Yi Chau (5080 2809), where steep easterly dips are seen in the strata. Occasional aphanitic clasts up to 20 mm across stand out, with the fiammé forming a flow fabric around these clasts (Plate 12). In places the fiammé are stretched out to give a streaky parataxitic fabric. On Sharp Island the Tai Tun Member is steeply dipping and layered between massive flow-banded lavas. The eutaxite is well exposed along the shoreline, where it rests on a brecciated lava surface (4860 2440).

Petrography

This member is highly distinctive in thin section, (Plate 13) (HK6621, 5033 2884). Iron-stained parataxitic flow-banding is contorted around scattered euhedral crystals and larger clasts. Crystals of quartz and feldspar rarely exceed 2 mm and are angular to subangular. Occasionally the fiammé are recrystallised, for example in HK6829 (5091 2819) from Wong Yi Chau, and some reaction rims around the scattered crystals have been noted. Abundant parallel fiammé, in a more typical eutaxite (HK6602, 4836 2879) average 8 mm in length and 1 mm in width and are closely packed.

Lan Nai Wan Member

Stratigraphy

The Lan Nai Wan Division (Watkins, 1979), embraced all the lavas, tuffs and sedimentary rocks comprising the Clear Water Bay Formation, but the newly named member is restricted to tuff, tuffite and sedimentary rock forming the upper part of the formation in the Sai Kung East Country Park. The type locality is at the High Island west col dam, 700 m south of the former village of Lan Nai Wan (now covered by the High Island Reservoir). Boreholes prove 37 m of sedimentary rock, epiclastic breccia, tuffite, tuff and tuff-breccia, overlying red to purple autobrecciated lava. The Lan Nai Wan Member is in turn overlain by the thick fine ash tuff sequence of the High Island Formation (Figure 8).

The member is exposed along part of the northern shore of the reservoir and occupies an extensive area on the Tai Long Tsui peninsula, where it comprises mainly tuff and tuffite.

Details

High Island Reservoir area. At the West Col Dam, three boreholes penetrating the Lan Nai Wan Member were logged in detail (Figure 8). Lithologies include a complex assemblage of green mudstone, siltstone and sandstone, poorly sorted epiclastic breccia, tuffaceous sandstone and purple to green tuff-breccia containing flow-banded rhyolite clasts. To the northeast, on the opposite side of the reservoir (5382 2704), pale grey tuffite with green sandstone bands is exposed 25 m below the high water level. Banded green mudstone underlies the massive High Island tuffs 1200 m west of Sai Wan Village (5498 2820).

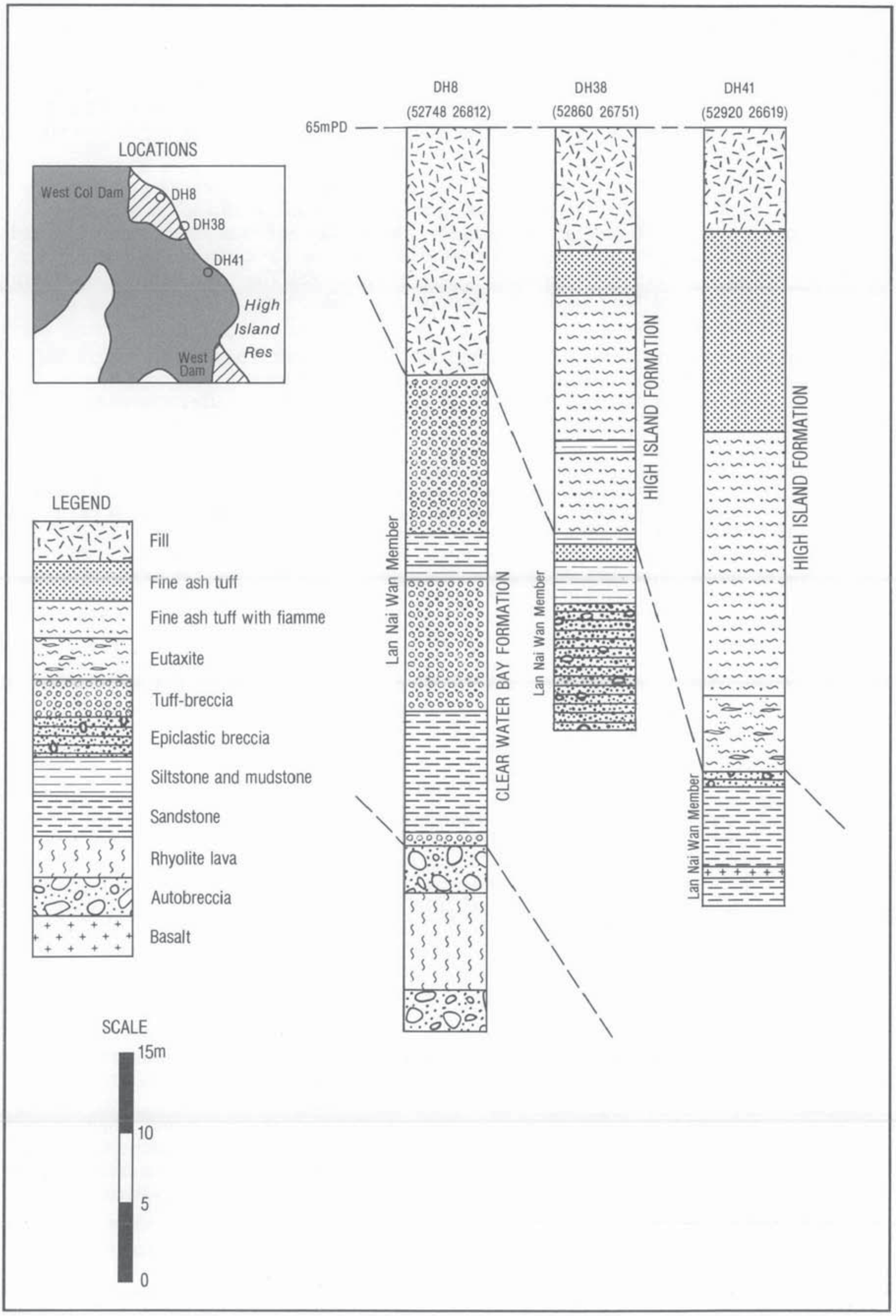


Figure 8 – Geological Sequences in the Upper Part of the Clear Water Bay Formation and Lower Part of the High Island Formation, near the High Island West Dam

Tai Long Tsui Peninsula. The basal beds of the member consist of tuffite and a feature-forming tuff-breccia (5928 3048) about 40 m in thickness. Large rounded clasts of tuff up to 400 mm in diameter are set in a fine ash tuff matrix. This is overlain by a thin fine ash vitric tuff containing small-scale fiammé (5934 3049) and a thick pale green tuffite (5950 3042) at least 120 m thick. The tuffite shows signs of hydrothermal alteration with abundant quartz veining and iron-staining. On the eastern side of the peninsula, polymictic tuff-breccia and clast bearing tuffite contains angular fragments of green mudstone, banded rhyolite and fine ash tuff (5965 3084).

High Island Formation

Stratigraphy

The first geological survey of the Territory by the Canadian geologists (Uglow, 1926; Brock & Schofield, 1926), mapped the majority of the rocks in eastern Sai Kung as the Rocky Harbour Series, regarding the rocks now designated as High Island Formation as rhyolitic lava flows. Ruxton (1960), however, considered these rocks to be part of a quartz porphyry sheet of shallow intrusive origin. Allen and Stephens (1971) concluded the formation was composed of rhyolite lava and thus delineated this on their map (RBv). Tam (1971) was convinced the rocks were ignimbrites, and later detailed examination of numerous borehole cores and thin sections made for investigations into the High Island Water Scheme (Tam & Chan, 1983) confirmed the formation was entirely of pyroclastic flow deposits. The term High Island Division was first used in the High Island Water Scheme (Watkins, 1979), and the High Island Formation as defined in this memoir corresponds to his division, with its type locality in the vicinity of the High Island west dam.

The High Island Formation is lithologically the most uniform major unit within the Repulse Bay Volcanic Group, and consists entirely of massive crystal-bearing fine ash vitric tuff, displaying small-scale eutaxitic fabrics and excellent columnar jointing. The formation occurs as a widespread sheet, reaching 400 m in thickness. It is probably made up of several pyroclastic flows, but these may form one major cooling unit. It is mainly underlain by lava of the Clear Water Bay Formation, but in places oversteps these rocks to rest on older volcanic strata and infills former topographic hollows. Nowhere is the top of the formation seen, and thus its relationship with other volcanic strata north of the Cheung Sheung–Chek Keng Fault, is unknown.

The High Island formation outcrops in southern Clear Water Bay and on adjacent islands, including the Ninepin Group. Northwards, most islands, including the largest, Kau Sai Chau, are composed of the formation. On the mainland, the formation occurs as an extensive outcrop in the area between High Island and Tai Long Wan but windows of the underlying Clear Water Bay Formation are seen in some deeper valleys. The High Island Formation tuff makes up the high ground around Kai Kung Shan and appears to infill an eastwest striking former topographic hollow along the southern part of Three Fathoms Cove.

Preliminary results from rubidium/strontium isotope age-dating of 5 samples from the High Island Formation (HK8664-8668) define an excellent isochron giving an age of 135 ± 8 Ma, suggesting a Lower Cretaceous age (F. Darbyshire, written communication)

Details

Clear Water Bay Peninsula and Ninepins Group. Detailed mapping of the southern Clear Water Bay Peninsula, in the vicinity of Tai Miu Wan and the Clear Water Bay Golf Club, suggests that fine ash vitric tuff of the High Island Formation infills an east-west trending topographic hollow. The formation is well exposed along the coast immediately west of the Tin Hau Temple (437 146), where the characteristic fine ash vitric tuff contains abundant small tabular feldspar crystal and some quartz crystals, set in an almost glassy matrix. Small fiammé are occasionally present, as are small angular aphanitic clasts. The rock is characteristically uniform throughout the coastal section, but is cut by several quartz syenite and basalt dykes, and east-west striking fissure vents. 400 m northwest of the temple (4777 1497), on the northern edge of the outcrop, the fine ash tuff is seen lying with marked unconformity against the eutaxite of the Silverstrand Formation, with the contact surface dipping 60° to the south. On the west side of Tai Miu Wan (4711 1457) the High Island Formation lies with steep unconformity on flow-banded trachydacite of the Clear Water Bay Formation. Abundant small-scale fiammé are seen on the slightly weathered surfaces along the shoreline of Jam Pan Wan (4920 1435). Again, tuff lies with marked unconformity on underlying trachydacite lava.

In the Tai Au Mun area a significant fault can be traced parallel to the coastline, downthrowing the High Island Formation against trachydacite lava. Columnar jointing is well developed, and close to the fault (4877 1705) the columns have been bent through 120°. Between Tai Au Mun (483 173) and Lung Ha Wan (493 189) exposures are few, except along the coast, where columnar jointing is commonly seen in the steep cliffs. The summits of Miu Tsai Tun (472 178) and High Junk Peak (475 174) are capped by columnar jointed fine ash tuff which is very resistant to erosion. In this area the formation rests on soft, pink to purple fine ash tuff presumed to be the uppermost part of the Clear Water Bay Formation.

The Ninepin Islands, Ching Chau (504 153), and the smaller islands to the east of the Clear Water Bay Peninsula are entirely in the High Island Formation. The Ninepins, in particular, display spectacular columnar jointing in the cliff sections.

Port Shelter, Rocky Harbour, High Island and Sai Kung East Country Park. Apart from the smaller islands of Inner Port Shelter (Sai Kung Hoi), the area is composed mainly of High Island Formation fine ash vitric tuffs displaying columnar jointing. Faint eutaxitic fabrics and the attitude of the columns indicate fairly gentle dips in the strata, usually towards the east or southeast. Although the cliffs are sheer and rugged, inland the tuff produces a subdued, rounded topography, with valleys eroded along fracture traces which are particularly clear in aerial photographs.

A number of boreholes sited at the High Island west col dam (528 267) have proved the basal part of the High Island Formation. In borehole DH41 (52920 26619), 42.5 m of the formation rest on epiclastic breccia, tuffaceous siltstone and sandstone of the Lan Nai Wan Member (Clear Water Bay Formation). A small-scale eutaxitic fabric in the fine ash vitric tuff is present in the lower part of the sequence, and this grades into eutaxite with abundant prominent fiammee in the basal few metres (Figure 8). Small tabular feldspar crystals and quartz crystals are scattered throughout the cores, and in places crystal concentrations were noted.

Spectacular columnar jointing is seen in the area of the east dam (Plate 16), with hexagonal columns averaging 1 to 2 m in diameter and extending to depths of at least 80 m. Fiammé lying parallel to the column base, indicate a gentle dip to the southeast. Some kinking of the columns may represent differential laminar shearing associated with post-depositional secondary flow structure (Tam & Chan, 1983).

Along the northern shores of the High Island Reservoir the typical columnar jointed fine ash vitric tuff is well-exposed, with fiammé frequently visible on the slightly weathered rock surfaces. In the valleys to the west of Sai Wan the underlying Clear Water Bay Formation is seen as inliers beneath uniform fine ash tuff of the High Island Formation. Southward dipping fine ash tuff forms the summit of Tai Mun Shan (556 307), and to the south of Chek Keng a faulted block of the formation occupies the high ground.

Three Fathoms Cove to Kai Kung Shan. The High Island Formation, consisting of the typical fiammé bearing fine ash vitric tuff, appears to occupy a roughly east-west striking trough which may represent infilling of a pre-depositional topographic hollow, as has been suggested for southern Clear Water Bay.

In the vicinity of Kai Kung Shan, the formation oversteps the Clear Water Bay Formation and rests unconformably on coarse ash tuff of the Tai Mo Shan Formation. South of Kai Kung Shan (4797 3057), crystal-bearing fine ash vitric tuff with occasional fiammé lies on the coarse ash tuff. Immediately above, a tuff-breccia horizon, several metres thick, contains angular lithic fragments, mainly of fine ash and coarse ash tuff.

Crystal-bearing fine ash vitric tuff is intruded by quartz syenite along the southern shores of Three Fathoms Cove, and this appears to mark the northern boundary of the High Island Formation in this area. To the southwest, road cuttings in the vicinity of Kei Ling Ha Lo Wai (461 303) show aphanitic crystal bearing welded tuffs, often with segregations of abundant crystals (HK6867, 4600 3020), and bounded to the north and the south by flow-banded rhyolite. At the northern contact the rhyolite is reddened as if weathered prior to deposition of the High Island tuffs. Paradoxically, however, the eutaxitic fabric in the tuffs is overturned and dips at 40° towards the contact.

Petrography

In thin section the High Island Formation displays remarkable uniformity throughout the outcrop. The matrix is very fine-grained or vitric, enclosing scattered crystals of feldspar and quartz with only very rare lithic clasts present. Faint, small-scale fiammé are common, and occasionally the rock displays a pronounced eutaxitic fabric with abundant glassy fiammé, as for example in HK6898 (5520 2810) from the water catchment tunnel 1.5 km west of Sai Wan. Here, the parallel fiammé average 4 to 5 mm in length and 0.5 mm in width. Thin wispy shards are common, and flow-banding is disturbed and contorted around the larger crystals. The crystal content is fairly low (c. 20%) comprising small euhedral cloudy alkali feldspars averaging 1 to 3 mm in length, and larger angular feldspars consisting of broken crystal fragments. Quartz crystals are invariably corroded and resorbed, with grains subrounded and deeply embayed with complex skeletal shapes (Plate 15). These embayed quartz crystals average 1.5 mm in size and form the most striking feature in thin sections of the High Island Formation.

Geochemistry

The High Island Formation displays the greatest degree of homogeneity seen in the Repulse Bay Volcanic Group. This must reflect its deposition as a single cooling unit rapidly erupted during a single major volcanic event. Tuffs of the formation show high silica percentages, and are high in potassium and relatively low in alumina in comparison with other pyroclastic formations. In terms of trace elements, the tuffs of the High Island Formation are distinctive in having low concentrations of barium (Ba), strontium (Sr) and titanium (Ti) but relatively high concentrations of niobium (Nb) and yttrium (Y).

Table 8 – Major Element Analyses of Samples from the High Island Formation

Element	High Island Formation					
	Three Fathoms Cove (46515 30370) HK 5740	High Island (56625 25018) HK 6003	Tai Au Mun (58595 17220) HK 6009	Lung Ha Wan (49030 18960) HK 6838	Kei Ling Ha (46050 30260) HK 6865	Kei Ling Ha (46000 30200) HK 6867
SiO_2	76.28	76.14	75.96	75.89	75.79	76.43
TiO_2	0.1	0.1	0.11	0.09	0.11	0.1
Al_2O_3	12.41	12.82	12.76	12.69	12.51	12.41
Fe_2O_3	0.52	0.47	0.51	0.7365	0.9332	0.6632
FeO	1.04	1.01	0.98	0.75	0.6	0.69
MnO	0.08	0.08	0.08	0.09	0.1	0.06
MgO	0.05	0.03	0.04	0	0	0
CaO	0.92	0.68	0.74	0.66	0.73	0.62
Na_2O	3.38	3.16	3.45	3.58	3.73	3.66
K_2O	5.08	5.27	5.11	5.11	5.13	5.22
H_2O^+	0.46	0.6	0.36	0.42	0.39	0.34
H_2O^-	0.06	0.12	0.06	0.07	0.07	0.06
P_2O_5	0.01	0.01	0.01	0.02	0.01	0
Total	100.39	100.49	100.17	100.10	100.02	100.23

Volcanic Environment

The High Island Formation is homogeneous in lithology, petrography and geochemistry. It is up to 400 m in thickness, apparently uniform in thickness in the High Island and Port Shelter islands area, and occupies former topographic hollows around the margins of the district. These factors indicate that its eruption probably occurred as a single cataclysmic event and as such was probably associated with the collapse of a caldera, the margins of which may be defined by the Ma On Shan and Cheung Sheung–Chek Keng fault zones.

Lai Chi Chong Formation

Stratigraphy

The Lai Chi Chong Formation outcrops to the north of the Cheung Sheung – Chek Keng Fault, and its relationship with the volcanic strata to the south is speculative. The presence of some flow-banded lava pebbles in conglomerates within the Lai Chi Chong Formation suggests the latter post-dates the Clear Water Bay Formation outcropping to the south. Since the Lai Chi Chong and Long Harbour formations differ markedly from the other volcanic units south of the Cheung Sheung – Chek Keng Fault, it is suggested that they probably represent infilling of a volcano-tectonic depression. The Lai Chi Chong Formation rests unconformably on the Lower Jurassic sedimentary rocks of the Tolo Channel Formation in the vicinity of Sham Chung; elsewhere the base of the volcanic succession is not seen.

The formation consists of interbedded pale grey cherty tuffite, coarse ash crystal tuff and dark grey silty mudstone. Rhyolite lava units, thin eutaxitic fine ash tuff and several impersistent conglomerate horizons have also been delineated.

No diagnostic macrofossils have been identified from the sedimentary horizons, but fossil plants and tree-trunk remains have been described by Nash & Dale (1984) and Wai (1986). Plant remains collected from Cheung Sheung indicate a Lower Cretaceous age with flora equivalent to the Tuoni Formation of eastern Xizang and the Wealden flora of western Europe (Atherton,1989).

Details

Sham Chung and Yung Shue O. The lowermost unit of the formation is a coarse ash tuff that outcrops along the coast of Tolo Channel northeast of Sham Chung Kok (4687 3415). The pale grey tuff contains clasts of dark grey mudstone, siltstone and sandstone, together with abundant quartz crystals.

These exposures commonly display narrow and sinuous dyke-like structures containing mudstone clasts which may have been formed by vaporization of water from beneath the tuff, resulting in upward streaming of gases which transported the clasts. In places the tuff contains numerous cobbles of quartzite and siltstone (4710 3454). The lowermost coarse ash tuff unit is also exposed south of Sham Chung Wan, where it is characterised by the conspicuous presence of dark grey mudstone clasts (4712 3305). Southwards, on Ngau Yue Tau (4748 3224), the coarse ash tuff contains two subdivisions, the lower one having been stained red and eroded prior to the deposition of the upper bomb- and block-bearing subdivision.

The coarse ash tuff is overlain by thinly bedded tuff and tuffite interbedded with siltstone and mudstone. These are well exposed on the foreshore north of Shek Ngau Tau (4735 3472), where beds of coarse ash tuff up to 20 m in thickness are intercalated with fine ash tuffite and siltstone (Plate 21). The tuffite frequently displays penecontemporaneous deformation by faulting and slumping. These beds can be traced southwards to Sham Chung Wan (4706 3379), and on the coast south of Sham Chung Wan (4716 3294), where sandy tuffite with pumice fragments occupies a shallow channel structure cut into tuff containing accretionary lapilli. Further south (4726 3286) the interbedded fine ash tuffite and mudstone have yielded plant remains. Near Yung Shue O, dark grey siliceous siltstone is indurated and in part contains organic structures which appear to be algal patches.

Rhyolite lava overlies the tuffite sequence, and a thick flow-banded rhyolite member can be traced from Sham Chung southwards to Yung Shue O. The rock is dark grey and aphanitic, but contains abundant euhedral bipyramidal crystals of quartz and less conspicuous crystals of alkali feldspar. Small lithic inclusions are also present. In exposures, the flow-banding is generally planar. The dips are variable and are not regarded as structural indicators. Between Sham Chung and Yung Shue O the rhyolite is overlain by tuffite and fine grained sedimentary rock, and a thick sequence of coarse ash crystal tuff. The latter has been delineated on the map, and extends northwards to the coastline near Shek Ngau Tau (4760 3495). Here, the strata consist of wall-bedded coarse ash tuff with interbedded sandy tuffite that includes beds of accretionary lapilli which in places display cross-bedding. These beds dip east to southeast at about 35°, but their relationship with the underlying rhyolite lava is not seen and the contact may be faulted out of the coastal succession.

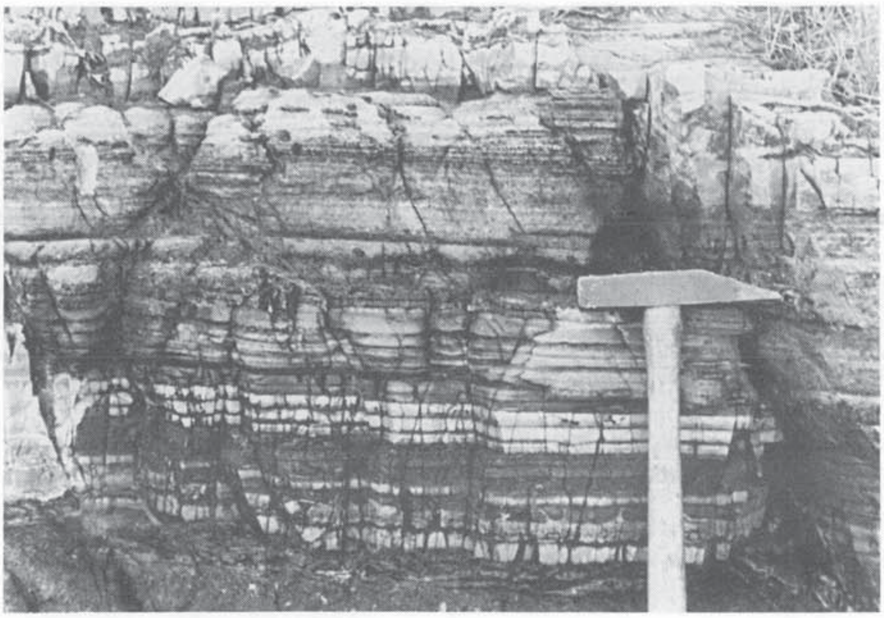


Plate 21 – Bedded Tuffite in Lai Chi Chong Formation, near Shek Nga Tau (4721 3465)

Lai Chi Chong. Coarse ash tuff forms the headland at Pak Kok Chai (4823 3539). The tuff is similar in general appearance to that exposed around the flanks of Shek Ngau Tau (800 m to the southwest), but occasionally possesses a faint eutaxitic fabric dipping east at about 25°. On the headland at Pak Kok Chai the tuff is vertically banded, and this is interpreted as rheomorphic flow-banding. Overlying the coarse ash tuff is a sequence consisting of mudstone, silty mudstone and interbedded tuffite which is in turn overlain by pale grey coarse ash tuff. Within the mudstone, thin fine-grained tuffite layers show classical wet-sediment deformation, usually resulting from slumping or seismic disturbance of unconsolidated strata. One 7 m thick, coarse-grained tuffite bed occurs in this sequence (4865 3519) and contains blocks up to 400 mm across near the base, but is fine-grained and cross-laminated near the top. Plant remains, including large fragments of silicified wood, have been found near Lai Chi Chong Ferry Pier (488 3522) within these mudstones, siltstones and tuffites (Dale & Nash, 1984). In places the strata are highly contorted (Plate 22), but the overall dip is approximately 30° towards the southeast.

Exposures of nodular and structureless chert occur at the river mouth south of Pak Kok Chai (4844 3516). These are identical to exposures on Knob Reef (4800 3600) which are associated with bedded sandy tuffite. South of Lai Chi Chong a distinctive, crudely flow-banded crystal-rich lava can be traced striking southwards and forming a strong feature on the western slopes of Shek Uk Shan (489 333) (Addison & Strange, 1987). 600 m southeast of Lai Chai Chong Village (4948 3422), this rhyolite lava is purple stained and overlain by the massive coarse ash tuff of the Long Harbour Formation (Plate 23).

Cheung Sheung. A thick sequence of coarse ash tuff is overlain to the west of Cheung Sheung by dark grey mudstone containing two significant feature-forming conglomerate layers (Plate 24). The mudstone has yielded abundant plant remains and several fossilized wood logs (4934 3244) (Wai, 1986). Recent detailed examinations of the mudstone localities have revealed abundant plant remains, notably small-size pinnae, conifers with scale-like leaves and many cycadophyles (Atherton,1989). The conglomerate horizons contain rounded pebbles of black aphanitic rock that are commonly finely flow-banded and closely resemble lava of the Clear Water Bay Formation which outcrops to the south of the nearby Cheung Sheung–Chek Keng Fault. Rhyolite lava overlies the mudstone (4932 3252) and is about 35 m in thickness. A fairly thin impersistent fine ash welded tuff with a prominent eutaxitic fabric separates the lava from the overlying coarse ash tuff of the Long Harbour Formation (4940 3260).

Plate 22 – Contorted Tuffite in Lai Chi Chong Formation, at Lai Chi Chong (4884 3524)

Petrography

The rhyolites are characteristically rich in euhedral quartz crystals, with occasional markedly elongate feldspar laths. HK5752 (4722 3359), from Sham Chung Wan, is typical, with flow-oriented microlites and clustering of euhedral quartz and feldspar phenocrysts. Quartz megacrysts reach 7 mm, Alkali feldspar 3mm and plagioclase laths 2 mm. The groundmass is very fine with recrystallisation developed along flow-banding.

Fine ash tuff and tuffite are composed of fine dust and fragments of quartz and feldspar. Occasional accretionary lapilli display concentric banding, seen for example in HK5821 (4771 3481). In other thin sections, for example sample HK5757 (4716 3291), the matrix appears recrystallised and clasts of sericitised pumice, glass and abundant primary muscovite are present.

Sample HK5777 (4810 3541) represents typical lapilli coarse ash tuff, with a recrystallised matrix displaying welding in part, and containing lithic fragments of rhyolite; muscovite is also present.

Volcanic and Sedimentary Environment

The Lai Chi Chong Formation was deposited in a shallow basin that was periodically flooded. The mudstone is presumed to be lacustrine since no marine fossils have been recorded. The conglomerate beds at Cheung Sheung are probably fluviatile, becoming thicker southwards, supporting the inference that they were derived from outcrops of Clear Water Bay Formation lava uplifted on the south side of the Chek Keng–Cheung Sheung Fault. Neither the sedimentary rocks nor the welded tuff, tuffite or lava are represented outside the type area, and it seems likely the basin of deposition was a volcano-tectonic depression, possibly a collapse caldera.

Long Harbour Formation

Stratigraphy

The term Long Harbour Division, covering all the coarse ash tuffs of the Sai Kung area was first used by Watkins (1979). The newly defined Long Harbour Formation consists of fairly uniform, clast-bearing coarse ash tuff, with a widespread outcrop in the vicinity of Long Harbour.

The formation rests with unconformity on a distinctive rhyolite lava with associated overlying impersistent eutaxitic fine ash tuff to the west of Shek Uk Shan, and this boundary can be traced northwards to Lai Chi Chong. The Cheung Sheung–Chek Keng Fault marks the southern boundary of the formation, but in the Sharp Peak area it rests with marked unconformity on Clear Water Bay and Mang Kung Uk Formation strata. The Long Harbour Formation is at least 400 m in thickness, but within the district the top is not seen. On Port Island (Sheet 4), similar coarse ash tuff is overlain by red conglomerate and sandstone of the Upper Cretaceous Port Island Formation.

The formation is characterised by massive coarse ash tuff, usually clast-bearing. These clasts often possess distinctive diffuse-edged margins, similar in some respects to those clasts present in the Yim Tin Tsai Formation (Addison, 1986). The clast content is polymictic, with angular sharp-edged black aphanitic fragments and pink coloured diffuse-edged crystalline clasts, in roughly equal proportions. Fine- and medium-grained granite clasts have been noted within this formation. Abundant pink feldspar crystals give the tuff its distinctive pinkish grey coloration. Crude layering and eutaxitic fabrics have been noted in places, and are particularly well seen on slightly weathered surfaces.

Details

Lai Chi Chong to Cheung Sheung and Ko Tong. To the south of Lai Chi Chong (4945 3422), massive coarse ash tuff rests on weathered purple lava. This contact can be traced southwards to the western flanks of Shek Uk Shan where eutaxitic fine ash tuff lies between the lava and the coarse ash tuff. At Ngo Keng Tsui (4919 3592), at the extreme northern margin of the district, coarse ash tuff rests on easterly dipping tuffite and fine ash welded tuff. The coarse ash tuff extends eastwards to the shores of Long Harbour, and is fairly uniform with occasional angular clasts to 200 mm in diameter. These are polymictic, with dark grey or black aphanitic fragments being the most common. The matrix contains angular bipyramidal quartz grains up to 5 mm across, and abundant pink feldspar crystals, and is speckled throughout with small biotite flakes. A crude bedding and columnar jointing was observed on the tors of Mount Hallowes (5067 3591). Occasional diffuse-edged granitic clasts were noted at Nam Shan Tung (5009 3465). Examination of the High Island Water Scheme tunnels from Nam Shan Tung southwards to Ko Tong (5130 3224) revealed a remarkably uniform body of coarse ash tuff over the entire tunnel length. At Ko Tong the Long Harbour Formation ends abruptly against Clear Water Bay lavas, along the line of the Cheung Sheung–Chek Keng Fault.

Wong Shek Pier and Long Harbour. Excellent exposures of the Long Harbour Formation are seen around the coastline of Long Harbour. A clast-rich zone, in places almost a tuff-breccia, extends from Tai Tan (531 336) southwards to Wong Shek Pier (527 329) and eastwards to include the Tung Sam Kei Peninsula. Within this zone, 600 m north of Wong Shek Pier (5286 3342), 100 to 300 mm diameter clasts of equigranular

Plate 23 – Rhyolite lava in Lai Chi Chong Formation (HK7053) from Shek Uk Shan (4794 3382); Natural Scale

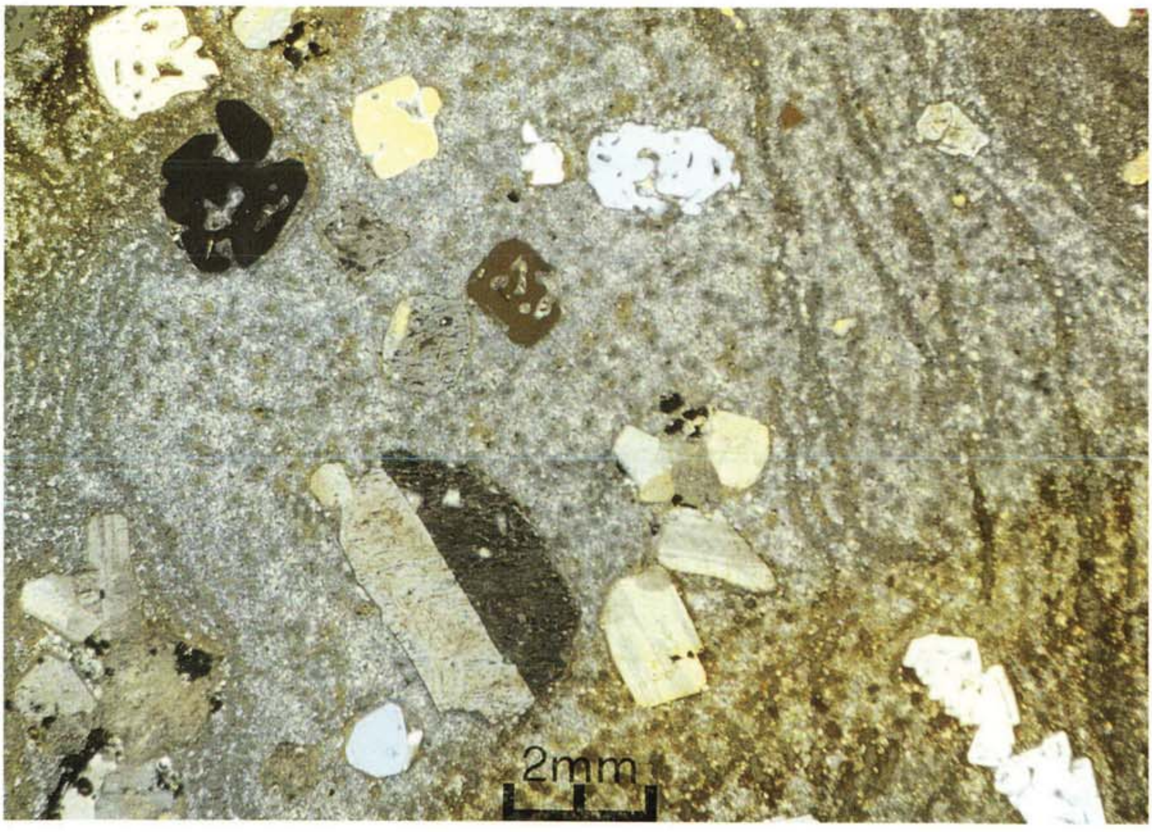
Plate 24 – Aerial View, Looking East, of Conglomerate Escarpments at Cheung Sheung.

Plate 25 – Coarse Ash Tuff in Long Harbour Formation, from Wong Shek Pier (527 329); Natural Scale

Plate 26 – Thin Section of Coarse Ash Tuff in Long Harbour Formation (HK6839), from Hoi Ha (5172 3409); XPL × 10

Plate 27 – Vent Material at Tai Miu Wan (4737 1465)

Plate 28 – Thin Section of Vent Material Matrix (HK6831) at Tai Miu Wan (4732 1467); XPL × 10



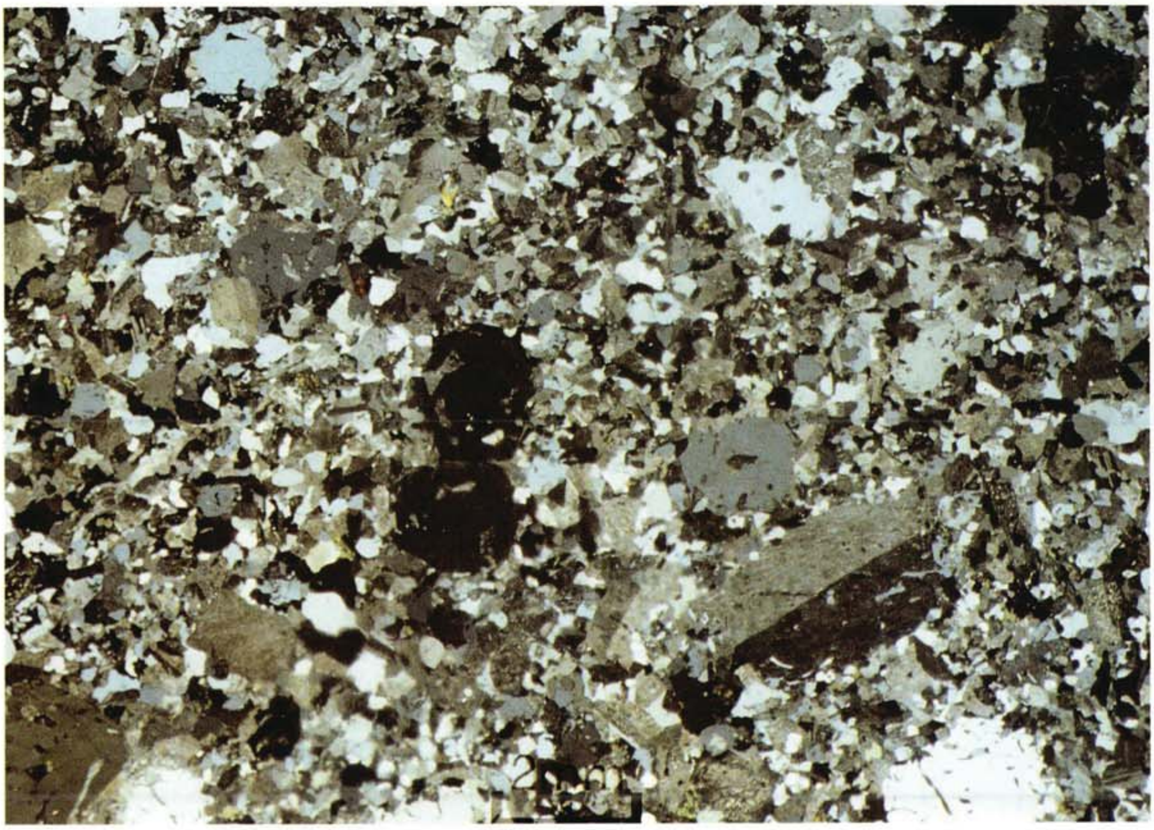
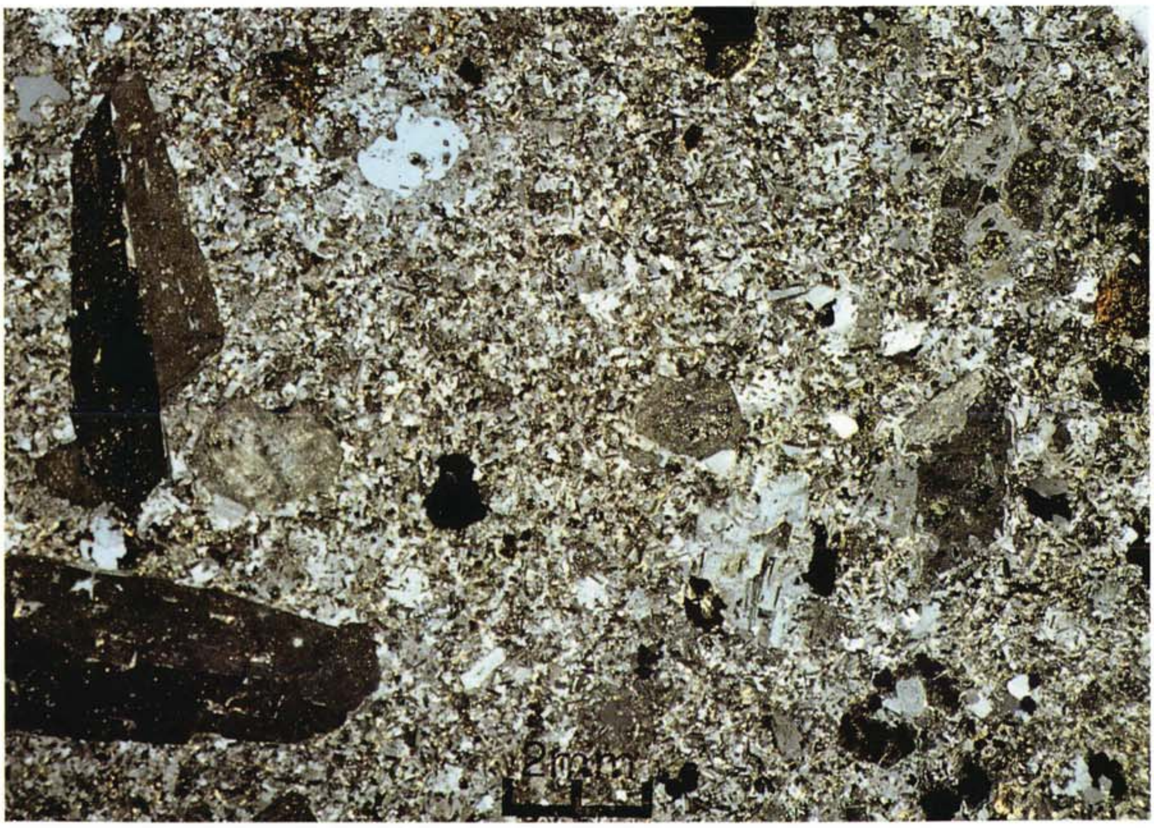


Plate 29 – Thin Section of Quartz Syenite (HK6220) from Shek Miu Wan (4648 1617); XPL × 10

Plate 30 – Thin Section of Quartz Trachyte (HK6584) from Tai Mong Tsai (4974 2735); XPL × 10



medium-grained granite were noted, and nearby, fine-grained granite clasts are also present. Siltstone, sandstone, feldsparphyric rhyolite and welded tuff clasts were noted at Tung Sam Kei (537 333). 400 m northeast of Sz Tei (5320 3418), hexagonal columns, 1 to 2 m in diameter in clast rich coarse ash tuff, suggest the strata here dip eastwards at about 30°. Good exposures of pinkish grey coarse ash tuff, with only occasional clasts, were seen along the coastline from Wong Mau Kok (544 344) to Kau Lo Wan (533 356). Quartzphyric rhyolite dykes cut the tuff, but are usually impersistent. Fiammé, averaging 20 mm in width and 250 mm in length, were seen on weathered rock surfaces 2 km south of Kau Lo Wan (5541 3381).

Sharp Peak. The Long Harbour Formation rests with angular unconformity on Mang Kung Uk Formation tuffite and Clear Water Bay Formation lava along the northern flanks of Sharp Peak. Massive, pinkish grey coarse ash tuff, with only rare clasts, outcrops along the coast from Nam She Wan eastwards to Mun Wan (587 329). The tuff appears to be banked up against the lava, and crude bedding suggests northerly dips of up to 40° in the Long Harbour Formation. Similar crudely bedded tuff was seen on Wong Mau Chau (5865 3432).

Petrography

A typical thin section of the Long Harbour Formation (HK6834, 5172 3409) from Hoi Ha is illustrated in Plate 26. The rock is packed with angular to subangular crystal fragments, with quartz and feldspar in proportions of 60% and 40% respectively. The matrix is poorly sorted, with abundant lithic clasts varying from fine ash tuff fragments to rhyolitic and granitic clasts. Granite clasts consist of equigranular fine-grained and medium-grained varieties, very similar to those described from the Kowloon Peninsula (Strange & Shaw, 1986). Diffuse boundaries around clasts and some corrosion of crystals suggests the tuff was deposited as a hot ash flow.

Table 9 – Major Element Analyses of Samples from the Long Harbour Formation

Element	Long Harbour Formation		
	Wong Shek Pier (5270 3290) HK 6004	**Hoi Ha (51710 35540) HK 6833**	**Hoi Ha Road (51720 34090) HK 6834**
SiO_2	73.58	72.94	74.43
TiO_2	0.25	0.28	0.21
Al_2O_3	13.09	13.14	12.22
Fe_2O_3	0.9720	0.6074	0.6320
FeO	1.15	1.73	1.15
MnO	0.06	0.06	0.06
MgO	0.32	0.5	0.34
CaO	1.48	1.94	1.9
Na_2O	3.2	3.04	2.94
K_2O	4.9	4.68	4.86
H_2O^+	0.74	0.94	0.65
H_2O^-	0.22	0.1	0.15
P_2O_5	0.06	0.06	0.04
Total	99.86	100.24	99.84

Geochemistry

The tuffs of the Long Harbour Formation show no overall similarities to any of the other tuffs analysed from the Repulse Bay Volcanic Group. In silica content they are closest to the High Island and Ap Lei Chau formations, but in their content of calcium, potassium and sodium oxides they begin to show differences and on trace element concentrations, particularly of barium, yttrium, zirconium and strontium, they show a closer similarity to coarse ash tuff of the Yim Tin Tsai and Tai Mo Shan formations.

Volcanic environment

The deposition of the Long Harbour Formation represents a return to major volcanic eruptions with the emplacement of the formation as essentially one ash flow unit. As with the Lai Chi Chong Formation, the Long Harbour Formation is confined to the volcano-tectonic depression lying to the north of the Chek Keng–Cheung Sheung Fault. It is likely this formation represents the last major eruptive phase of the Repulse Bay Volcanic Group within the Territory.

Fissure Vents

Stratigraphy

Fissure vents have been recognized in the southern part of the Clear Water Bay Peninsula. They are defined as the opening at the earth's surface of a volcanic conduit having the form of a crack or fissure (Bates & Jackson, 1980).

The fissure vents vary in width from 10 m to more than 35 m and are roughly vertical. The parallel sides of the fissure were seen to widen upwards at Fat Tong Kok, a characteristic not uncommon in fissure vents (Ekren & Byers, 1976). The vents are found cutting the volcanic strata of the Clear Water Bay Formation (Tai Miu Wan Member) (Strange, 1988) and the lower part of the High Island Formation, and therefore post-date the early part of the High Island tuff deposition.

The vent material comprises a heterolithic assemblage of material with fragments of sandstone, tuffite, tuff and lava ranging from lapilli to block size, set in a variable tuff matrix (Plate 27). Similar tuffs infilling a volcanic vent have been recognized in Korea (Reedman et al, 1987) and in Nevada (Ekren & Byers, 1976). The fragments are angular to rounded in shape, and probably represent material excavated from the vent walls, or possibly, at the cessation of eruption, debris that has partly collapsed back into the fissure. Many of the tuffite and sandstone clasts resemble the rock occurring in the Mang Kung Uk Formation, which stratigraphically underlies the strata outcropping in the Tai Miu Wan and Fat Tong Kok areas.

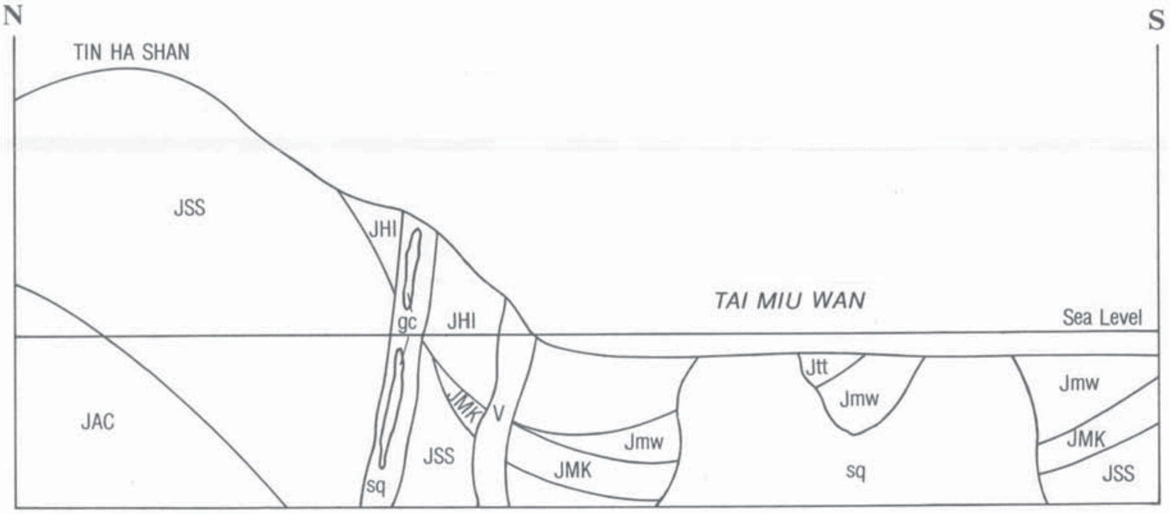


Figure 9 – Generalized Geological Section Across Tin Ha Shan and Tai Miu Wan, Showing Relations of the Volcanic Strata. Dykes and Fissure Vents.

Quartz syenite and quartz trachyte are intimately associated with the fissure vents and patchy intrusions of syenitic material are ubiquitous within the vent matrix. The quartz syenite, with its characteristic trachytoidal texture, produces contorted flow-banding which can be seen infiltrating the tuff matrix in the vent.

Details

Tai Miu Wan (Joss House Bay). A fissure vent outcrops along the shoreline west of the temple (4737 1465), where it strikes roughly east-west and is approximately 20 m in width (Strange, 1988). The vent is filled with large blocks of eutaxite, sandstone and tuffite (Plate 27). All are set in a tuff matrix. Quartz syenite has invaded the matrix, producing a distinctive flow-banded overprint. Similar material is exposed along the beach on the western side of the bay (4707 1464), and is probably part of the same vent. Here, it reaches 35 m in width, and contains numerous small intrusions of quartz trachyte and basalt.

Fat Tong Kok (Clear Water Bay Country Club). A fissure vent, striking roughly northeast, outcrops in the cliffs immediately west of Fat Tong Kok (4881 1359). Large blocks of eutaxite and rafts of sandstone and mudstone are supported by a matrix of lapilli tuff. A thin, 400 mm wide quartz syenite dyke intrudes the matrix. On the eastern side of the peninsula (4900 1374) the vent is vertical and approximately 10 m wide near the base of the cliffs but widens upwards to 30 to 35 m on the summit. Similar upward widening of fissure vents was identified in Nevada (Ekren & Byers, 1976).

Petrography

Plate 28 illustrates a typical thin section of the vent material (HK6831, 4732 1467). Deeply embayed subrounded quartz grains and corroded feldspar grains up to 4 mm in diameter are surrounded by an indeterminate groundmass exhibiting a flow-banded fabric. In specimen HK6830 (4899 1376) from Fat Tong Point the flow fabric is prominent around the larger crystals, producing a very similar appearance to the Tai Tun Member pyroclastic flow deposits (Plate 13). Reedman et al (1987) noted similar material in thin section from volcanic vents in South Korea. They described the fluidal planar parataxitic fabric as a welded tuff intrusion, resulting from agglutination along the vent walls serving as a feeder for extrusive ignimbrites.

Chapter 5
Intrusive Igneous Rocks

Classification

No large granitic plutons are present within this district, and the intrusive igneous rocks occur as small plutonic bodies, or as dykes varying from a few tens of millimetres to 75 m in width. These consist of fine-grained granite, quartz syenite, quartz trachyte, quartzphyric rhyolite and basalt. All, except the basalt dykes, are related to the Mesozoic granitic emplacement of Late Jurassic—Early Cretaceous age. The basalt is considered to be of Tertiary age (Allen & Stephens, 1971).

The nomenclature of the granitoid rocks used by Allen & Stephens (1971) was based on the system proposed by Steckeisen, whose updated nomenclature (Streckeisen, 1974) has been adopted here. However, the system of named units has not been used in the present survey (Addison, 1986; Strange & Shaw, 1986; Langford et al, 1989).

The rhyolite and trachyte correspond to the porphyry dykes of Allen & Stephens (1971), the quartz syenite to their quartz monzonite (Strange, 1987), and the basalt corresponds to their dolerite. Hatch et al (1972) recommended use of the rhyolite, trachyte and basalt on non-genetic grounds for the minor intrusions and volcanics alike. Streckeisen (1974, 1980) made recommendations for the classification of these rocks to the IUGS Subcommission on the Systematics of Igneous Rocks, and his divisions are used in this survey (Figure 10). Thus it is possible to correctly identify a rock from thin section or hand specimen even though field relationships may be uncertain and mode of occurrence unknown.

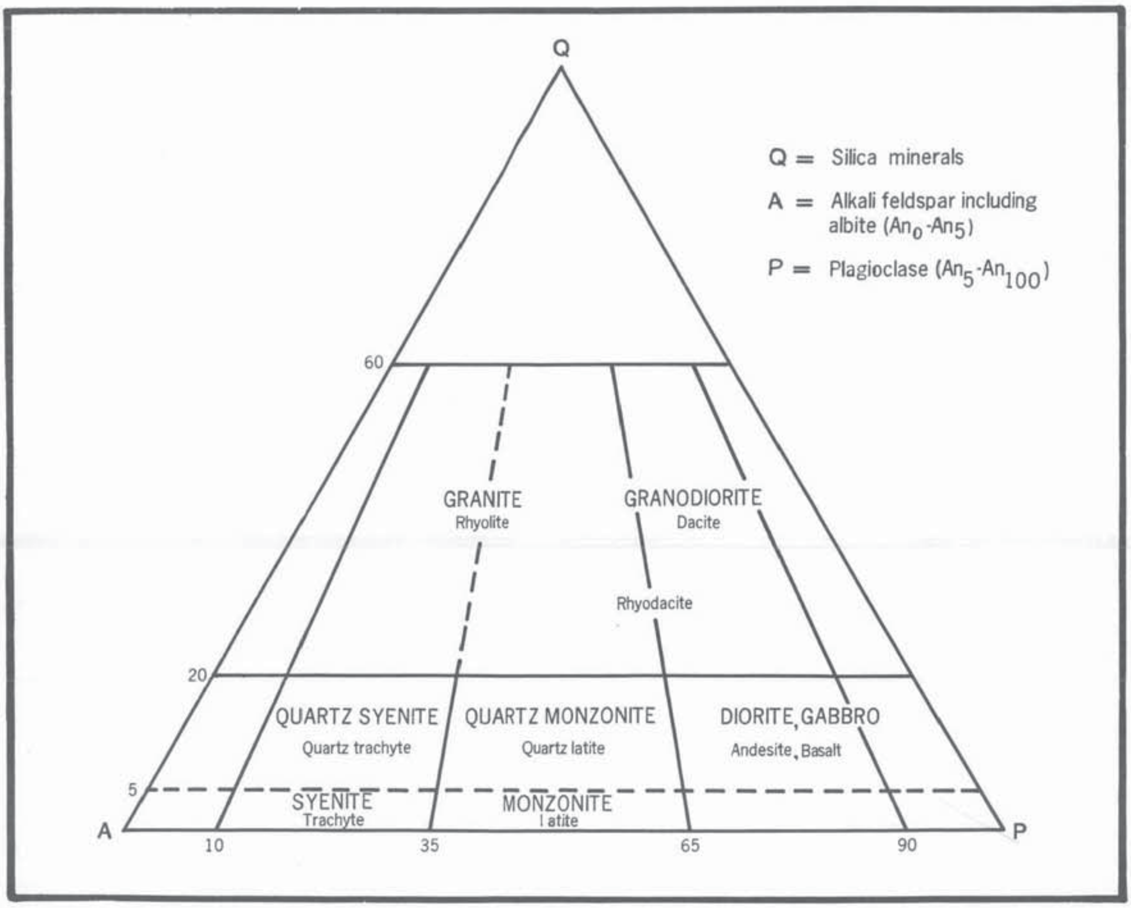


Figure 10 – General Classification and Nomenclature of Major and Minor Intrusive Rocks (after Streckeisen, 1974)

Fine-Grained Granite

Distribution and Lithology

The fine-grained granite outcrop is restricted to the southern part of the Clear Water Bay Peninsula, where it occurs as small elongate plutonic bodies, striking east-northeast, intruding the Repulse Bay Volcanic Group. A wide, very fine-grained margin (quartzphyric rhyolite) is associated with these intrusions, suggesting a closer affinity to granitic dykes.

The granite has a fairly equigranular fine-grained groundmass averaging 1 mm in grain size, but possesses abundant alkali feldspar megacrysts up to 6 mm and occasional smaller quartz megacrysts. This rock resembles the quartz syenite (Strange, 1987; 1988) apart from the slightly greater abundance of quartz which places it within the granite field (Figure 10). The alkali feldspar megacrysts are sometimes aligned, exhibiting a trachytoid texture, a feature common in the quartz syenites.

Details

Junk Island and Clear Water Bay Peninsula. On Junk Island the fine-grained granite is bounded by flow-banded quartzphyric rhyolite and the contact appears gradational (4560 1579). Megacrysts of alkali feldspar, often aligned, are abundant, and average 3 by 6 mm in size. Smaller quartz grains are present, as are single flakes of biotite. The groundmass averages less than 1 mm and is pinkish grey in colour. At Shek Miu Wan (4650 1616) the granite is pink and the feldspar megacrysts average 4 mm in length. Small felty clots of biotite were also noted in hand specimen. The fine-grained granite outcropping in the roadside cuttings near the bus terminus at the Clear Water Bay Second Beach possesses a groundmass bordering on the very fine-grained (rhyolite). Pink alkali feldspars to 7 mm in length and smaller quartz crystals to 3 mm are common.

Coarse-Grained Granite

Distribution and Lithology

The rock occurs only as enclaves or screens some 5 m in width and 60 to 80 m in length within a quartz syenite dyke at Tai Miu Wan, southern Clear Water Bay Peninsula. There are no other outcrops of this rock within the district but it closely resembles the coarse-grained granite outcropping in the Lai Chi Kok and Sha Tin areas (Sheets 11 and 7). The rock has an average groundmass grain size between 5 and 7 mm, with occasional aggregations of quartz crystals up to 15 mm across and alkali feldspar megacrysts up to 18 mm in length. Biotite, present as concentrations of small black single flakes creating the appearance of felty blotches, constitutes less than 2% of the rock.

Quartzphyric Rhyolite

Distribution and Lithology

This rock occurs as dykes and also as margins to the small scale fine-grained granite plutons. Quartzphyric rhyolite dykes are found throughout the district but are usually laterally impersistent and unrelated to major dyke swarms. They vary in width from 200 mm to 50 m. The largest dyke, striking north-south through Sharp Peak, averages 40 m in width and extends over 2 km. It is not typical, however, since abundant quartz veining has infiltrated the rock. The majority of dykes strike between north and east.

In hand specimen, the quartzphyric rhyolite is light grey or pinkish grey in colour and very fine-grained, with occasional scattered quartz megacrysts up to 4 mm across. Near the dyke margins, a distinctive flow-banded fabric is seen, roughly parallel to the contact.

Details

Clear Water Bay Peninsula, Junk Island and Tung Lung Island. A northeast-striking quartzphyric rhyolite dyke reaches 90 m in width near Lam Tong (4758 1278). The pale grey to pink rhyolite is homogeneous but contains small scattered quartz and feldspar megacrysts. Distinctive flow-banding, striking 65°, is prominent in the weathered coastal exposures. The dyke forms a well-defined positive topographic feature inland. Small quartzphyric rhyolite dykes averaging 2 m in width, are seen in a number of coastal sections cutting Silverstrand Formation tuff on Tung Lung Island, Tit Cham Chau and at Tin Ha Shan.

Flow-banded quartzphyric rhyolite forms a wide margin to a small elongate fine-grained granite pluton on Junk Island (45485 1581). This intrusive body can be traced northeast on to the mainland at Shek Miu Wan (4648 1617). On the north side of Junk Island the rhyolite margin reaches 100 m in width, with distinctive flow-banding throughout. The megacryst content increases gradually towards the granite, where the boundary is gradational. A raft of tuff-breccia, 2 m by 500 mm was noted in the centre of the rhyolite body.

Sai Kung and Kau Sai Chau. A 40 m wide quartzphyric rhyolite dyke with prominent flow-banded margins strikes north through Tai Mo Shan Formation tuff on Yeung Chau (469 268). One rhyolite dyke was identified at Kwai Tau Tam, northern Kau Sai Chau, striking roughly east-west and cutting the High Island Formation tuff.

Long Harbour and Sharp Peak. A number of quartzphyric rhyolite dykes cut coarse ash tuff of the Long Harbour Formation. Many parallel the east-west striking Cheung Sheung – Chek Keng Fault, as for example at Chek Keng Hau, but others strike northeast on the Kau Lo Wan peninsula in the same direction as numerous parallel photolineaments. All these dykes are impersistent and, although they may reach 20 m in width, rarely extend laterally for more than 200 m. In all cases the rhyolite is pale grey and flow-banded with sparse quartz megacrysts. Immediately west of Sharp Peak (5665 3234) a feature-forming rhyolite dyke strikes north-south and averages 40 m in width. This dyke bifurcates near the coast east of Nam She Wan (5670 3323) and several branches are seen cutting Long Harbour Formation tuff in the cliffs. The rhyolite is atypical in that it is high in silica and abundant quartz veining is present. It seems probable that there has been later injection of silica rich fluids along the dyke. To the east of Sharp Peak, quartz veins parallel this major dyke (590 329).

Quartz Syenite

Distribution and Lithology

The quartz syenite corresponds approximately to Allen & Stephens' (1971) quartz monzonite category. Davis (1952) had grouped the quartz syenite of the district into his Rocky Harbour Granite-Syenite unit, and provided a geochemical analysis from Sharp Island showing the rock falls clearly within the syenite field.

Quartz syenite is distinguished from the fine-grained granite of the district by the lower quartz content, although both rocks possess many similarities, including trachytoidal textures and very fine-grained flow-banded margins. The quartz syenite is usually pinkish grey and fine-grained, with prominent alkali feldspar megacrysts. Within the dykes of southern Clear Water Bay Peninsula, long enclaves or screens of coarse-grained granite occur; coarse-grained granite does not outcrop elsewhere within the district.

The rock occurs mainly as dykes and small plutons in southern Clear Water Bay Peninsula, on Sharp Island, and around Tai Mong Tsai, and is closely associated with the Cheung Sheung – Chek Keng Fault. The quartz syenite also appears intimately associated with the fissure vents of southern Clear Water Bay Peninsula, where infiltration of syenite possessing the characteristic aligned trachytoid texture is common in the vent material matrix.

Details

Southern Clear Water Bay Peninsula. On the eastern side of Tai Miu Wan (480 144) a small quartz syenite pluton surrounded by a chilled margin of quartz trachyte is exposed in coastal sections. Here, rounded syenite corestones stand out in the weathered cliff exposures (Plate 35). The rock is essentially fine-grained and pinkish grey, with abundant alkali feldspar megacrysts which are often aligned to form the characteristic trachytoid texture. Striking east-west across the southern slopes of Tin Ha Shan is a quartz syenite dyke that reaches 60 m in width and contains several long enclaves or screens of coarse-grained granite (4750 1475) (4772 1477). In places, the dyke appears to bulge, as for example at the helicopter landing site above the Tin Hau Temple (4773 1475) (Strange, 1988).

Sharp Island and Tai Mong Tsai. Quartz syenite outcrops on the western side of Sharp island. The rock is pink, fine-grained or fine- to medium-grained, with abundant euhedral alkali feldspar megacrysts. Similar rock occurs on the small island of Tai Tsan Chau (479 263) where it is seen intruding tuffaceous sedimentary rocks of the Mang Kung Uk Formation. In the northern part of Sharp Island the outcrop of quartz syenite is marked by abundant rounded boulders along the shoreline (4806 2608). In the vicinity of Tai Mong Tsai village (490 283) a small pluton of quartz syenite and quartz trachyte intrudes tuff and tuffaceous sedimentary rocks. Boulders of quartz syenite and quartz trachyte are scattered across the surface and exposures are poor.

Three Fathoms Cove and Long Harbour. Small isolated outcrops of quartz syenite have been noted intruding High Island Formation tuff along the shoreline southwest of Yung Shue Au (472 315). It seems probable that this coastline parallels a southwestward extension of the Cheung Sheung – Chek Keng Fault. A quartz syenite body some 200 m by 100 m in outcrop is exposed in the catchwater excavations (4727 3141) (4735 3146).

Small irregular-shaped quartz syenite bodies form discontinuous outcrops between Uk Tau, Wong Shek Pier (525 322), To Kwa Peng (531 322) and Chek Keng Hau (545 324), along or parallel to the line of the Cheung Sheung – Chek Keng Fault. There is no evidence to show that the quartz syenite is faulted. The rock has widely spaced joints, and it seems probable that the intrusions postdate the main fault movements. The intrusions at To Kwa Peng vary between fine-grained and medium-grained, with abundant alkali feldspar megacrysts up to 20 mm in length. At Chek Keng Hau the rock has a fine-grained pink groundmass with feldspar megacrysts averaging 10 mm in length and quartz up to 6 mm across. Single fresh biotite flakes are scattered throughout.

Petrography

A typical thin section of quartz syenite (HK6220, 4648 1617) is illustrated in Plate 29. The average groundmass grain size is about 0.2 mm, with scattered larger quartz grains to 1.2 mm and alkali feldspar laths to 4 mm in length. Apart from the lower quartz percentage and the predominant alkali feldspar megacrysts, the fine-grained groundmass is similar to the fine-grained granites occurring within the district. In HK5683 (4581 3056) the groundmass is dominated by intergrown laths of alkali feldspar with strongly zoned plagioclase crystals and altered remnants of amphibole.

Quartz Trachyte

Distribution and Lithology

Quartz trachyte is the very fine-grained equivalent of Quartz syenite (Figure 10). Allen & Stephens (1971) grouped these intrusions under their more general porphyry dykes category. The present survey, however, has attempted to differentiate between the rhyolite and trachyte, mainly on the basis of their close association with the more clearly defined coarser grained equivalents, granite and quartz syenite.

The quartz trachyte occurs as margins to the small plutonic quartz syenite intrusions and also as small impersistent dykes, often displaying trachytoid texture. The rock is occasionally flow-banded as with the quartzphyric rhyolite, but the megacryst content is dominated by alkali feldspars with little or no quartz visible in hand specimen.

Outcrops of quartz trachyte are found in the southern Clear Water Bay Peninsula and in the Sai Kung Country Park around Tai Mong Tsai.

Details

Clear Water Bay Peninsula. Quartz trachyte forms a 30 m wide chilled margin to the small quartz syenite pluton outcropping along the shoreline southeast of the Tin Hau Temple at Tai Miu Wan (4792 1446). Scattered alkali feldspar megacrysts to 10 mm in length stand out against a very fine-grained grey groundmass. Along the southern margin of this pluton (4818 1420), the quartz trachyte is markedly flow-banded. Elsewhere in the southern part of the Clear Water Bay Peninsula, quartz trachyte occurs as impersistent dykes, usually less than 2 m in width. One small dyke is found within a fissure vent at Fat Tong Kok (4900 1374). The dyke is flow-banded, containing aligned alkali feldspar megacrysts to 10 mm in length and occasional small quartz crystals, and meanders through the dominantly tuff vent material.

Tai Mong Tsai and Sharp Island. On the coast 1.2 km southeast of Tai Mong Tsai village, quartz trachyte forms a 100 m wide dyke striking northeast. Vertical flow-banding, more apparent near the dyke margins, together with aligned feldspar megacrysts, are seen in the shoreline outcrops.

On Sharp Island (4823 2622), intrusions of quartz trachyte into tuffaceous siltstone of the Mang Kung Uk Formation are related to a small quartz syenite pluton. The quartz trachyte has a very fine-grained pale grey groundmass containing scattered alkali feldspar megacrysts.

Petrography

Sample HK6584 (4974 2735), illustrated in Plate 30, displays the typical characteristics of the quartz trachytes present in this district. The very fine-grained groundmass is dominated by minute feldspar laths with scattered quartz grains. Megacrysts of alkali feldspar up to 7 mm in length are scattered throughout the section, with occasional smaller quartz grains, often corroded and embayed, averaging 1 mm in diameter. Quartz and biotite together total less than 10% of the section.

Basalt

Distribution and Lithology

The term dolerite, as used by Allen & Stephens (1971), is replaced in the present survey by the classification recommended by Streckeisen (1980), and the term basalt is used for the minor basic intrusions within this district (Figure 10). The basalt is found only as dykes, usually less than 2 m in width and impersistent, extending laterally less than 200 m in length.

The dykes are small but widespread, cutting most rock types found within the district. The basalt is a very fine-grained black rock with a groundmass of euhedral feldspar laths and abundant amphibole, biotite and magnetite. Alteration products of chlorite and sericite are common. On weathering the rock produces a distinctive reddish brown soil, and in coastal outcrops the weathered basalt is easily eroded to form sea caves.

Potassium-argon age determinations (Allen & Stephens, 1971) indicated similar dykes found elsewhere within the Territory were of early Palaeocene age (Tertiary).

Details

Clear Water Bay Peninsula. Basalt dykes are usually less than 2 m in width and are laterally impersistent. They are found cutting most rock types and usually strike roughly north-south. At Tai Miu Wan (4763 1468), several basalt dykes, less than 400 mm in width cut High Island Formation tuff. A 4 m wide dyke with a northerly strike outcrops along the shoreline 500 m south of Clear Water Bay Second Beach (4770 1597). At Tai Chik Sha (4661 1677) a basalt dyke has been dislocated by a northeast striking fault.

Sai Kung Country Park. Basalt dykes have been noted cutting most volcanic strata, but are usually only seen in coastal exposures, especially in the High Island area where they are usually less than 1.5 m in width. One well-exposed dyke at the High Island east dam (Plate 16) intrudes the columnar jointed tuffs following a well defined kink band. Another dyke was exposed in the foundation excavations for the west dam, where it has been dislocated some 30 m by a westnorthwest-trending fault.

Chapter 6
Structure

The structure of the solid rocks of the onshore areas of the district is shown in Figure 11. The attitude of the strata appears largely related to the original depositional environment. It is postulated that the geology of the district was dominated by two major collapse calderas, with an infilled caldera some 20 km across bounded to the west by Junk Bay and to the north by Three Fathoms Cove and the Cheung Sheung – Chek Keng Fault. The strata north of this line probably represent the infilling of another collapse caldera. The strata on the Clear Water Bay Peninsula thus dip eastwards towards the probable centre of the former caldera basin. Subsequent infilling of the basin by ignimbritic tuff has led to roughly horizontal or gently dipping strata in the central area. The subsequent collapse of another caldera produced an east-west escarpment feature along the line of the Cheung Sheung – Chek Keng Fault resulting in northward dipping strata which include conglomerate layers at Cheung Sheung. Fracturing and injections of igneous rocks at the caldera margins may explain the presence of granite and syenitic intrusions at Clear Water Bay and in the Shek Nga Shan – Pyramid Hill areas on the adjoining Sheet 7, and along the line of the Cheung Sheung – Chek Keng Fault. Some of the quartz syenite intrusions post-date the major faulting activity in the vicinity of Chek Keng.

Major northeast- and northwest-striking faults dissect the district, and these stand out particularly well as negative photolineaments, especially in the more widespread uniform rock types such as the High Island Formation tuff. Polygonal columnar jointing in the latter has resulted in characteristic coastal exposures around High Island and adjacent islands of Port Shelter (Plate 16).

Circular histograms of faults and photolineaments within each quarter sheet quadrant are shown in Figure 12.

Details

Clear Water Bay area (Sheet 12). The volcanic and associated sedimentary strata strike roughly north-south through the northern and central parts of the Clear Water Bay Peninsula, with eastward dips of between 10 and 40°. In the southern part of the peninsula, however, dips are variable and the strata appear folded along east-west axes. This may be related to the granitic and syenitic emplacements. On Tung Lung Island the eutaxitic fabric in the Silverstrand Formation has provided a rough indication of the attitude of the strata. Here the tuff has been gently folded in several minor northnorthwest-striking anticlines and synclines. Vertical columnar joints in the Ninepins Island Group and on the islands of Port Shelter and Rocky Harbour, including Basalt and Bluff Islands, indicate an approximate horizontal disposition to the tuff.

Northeast- and northwest-striking faults on Tung Lung Island and southern Clear Water Bay Peninsula do not appear to have large throws, but significant east-west faults show considerable displacements. One of these displaces the lower part of the Clear Water Bay Formation against High Island Formation tuff at Tai Au Mun; this can be traced along the coastline to the east.

A circular histogram of the dykes for Sheet 12 is shown in Figure 13. The acidic intrusive dykes associated with the Mesozoic igneous activity generally trend in an east-west direction and are often cut by faulting. However, the basalt dykes, of presumed Tertiary age, trend roughly north-south and are also in places dislocated by faults.

Sai Kung area (Sheet 8). The Cheung Sheung – Chek Keng Fault is the dominant structural feature of the area, separating two markedly different volcanic successions. It was first mapped by Allen & Stephens (1971) and is described by Burnett & Lai (1985), who considered the fault (referred to as the Yung Shue Au – To Kwo Peng Fault) to be part of a major lineament some 32 km in length extending westwards to Tai Po. Several small quartz syenite intrusions at Chek Keng appear to post-date the main faulting activity. The Water Supplies tunnel at Ko Tong (5130 3212) passed through a 27 m wide fault zone along the line of this fault and the tunnel has been concrete lined at this location.

Most fault zones intersected in the High Island Water Scheme tunnels varied between 2 m and 30 m in width but occasionally much wider zones were logged. At Shui Long Wo (468 295) the tunnel passed through the O Tau Fault which consisted of a 140 m wide zone of shattered and very closely jointed rock. Although not exposed at the surface, this fault zone coincided with a strong northwest-striking valley feature. Similarly, in other locations along the tunnel route, most faults encountered are related to significant negative photolineaments, as for example at Pak Tam Au (5196 3078) where Watkins (1979) noted that the tunnel, shaft and intake locations were carefully chosen to avoid faulted ground.

Most dips in the volcanics and their associated sedimentary rocks are fairly gentle, and Figure 11 shows the regional dip of the strata.

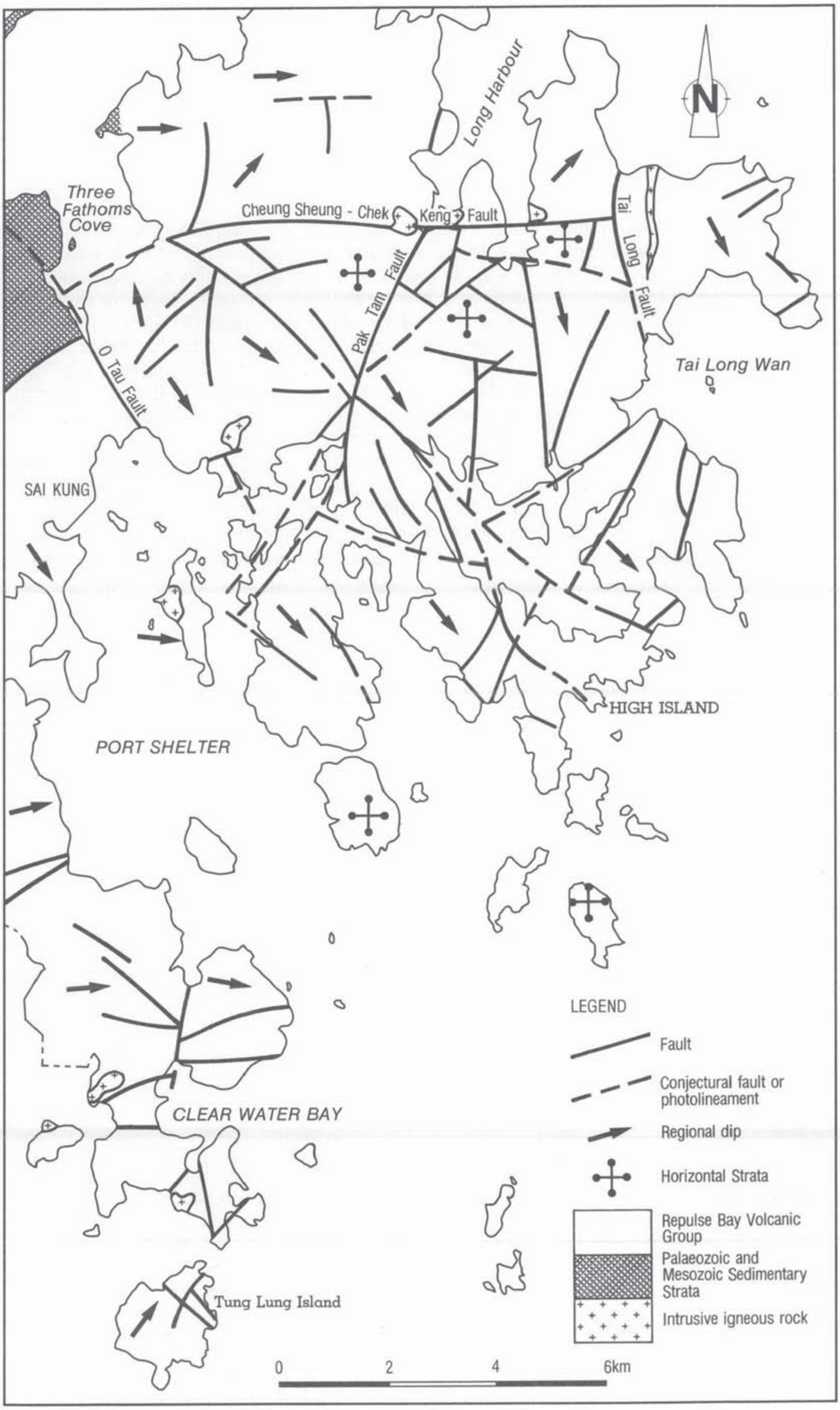


Figure 11 – Principal Structural Features of the District

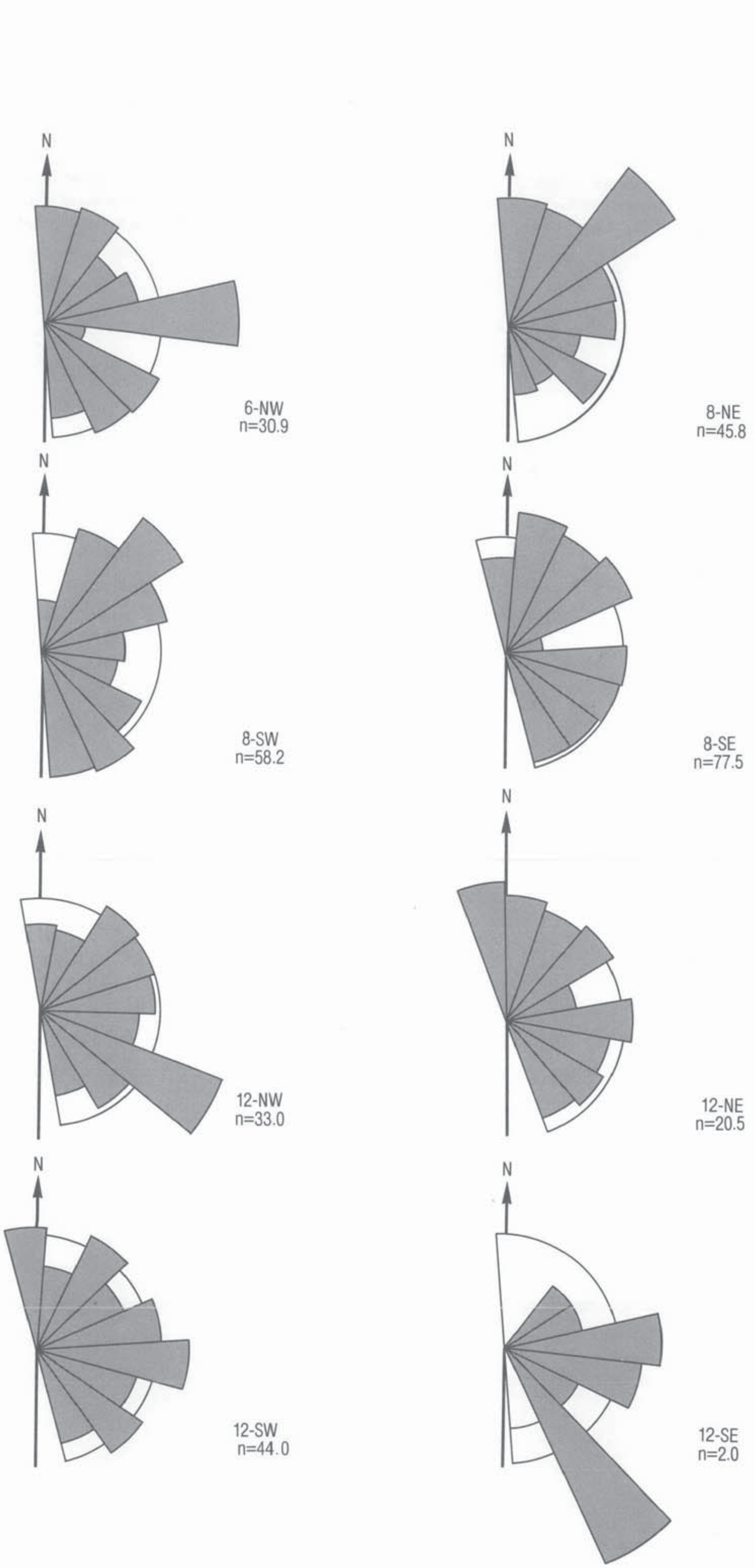


Figure 12 – Circular Histograms of Faults and Photolineaments on Sheets 8 and 12

North of the Cheung Sheung – Chek Keng Fault, most dykes are quartzphyric rhyolite and these strike northeast, coinciding with similar trending photolineaments. In the Sharp Peak area, quartzphyric rhyolite dykes and large quartz veins strike north. The quartz veins of the Tai Long Tsui peninsula (5948 3096) have been dislocated by numerous small faults. Basalt dykes in the High Island area follow the dominant joint directions, and at the east dam (5668 2502), basalt has been injected along a kink in the columnar jointed tuffs (Plate 16).

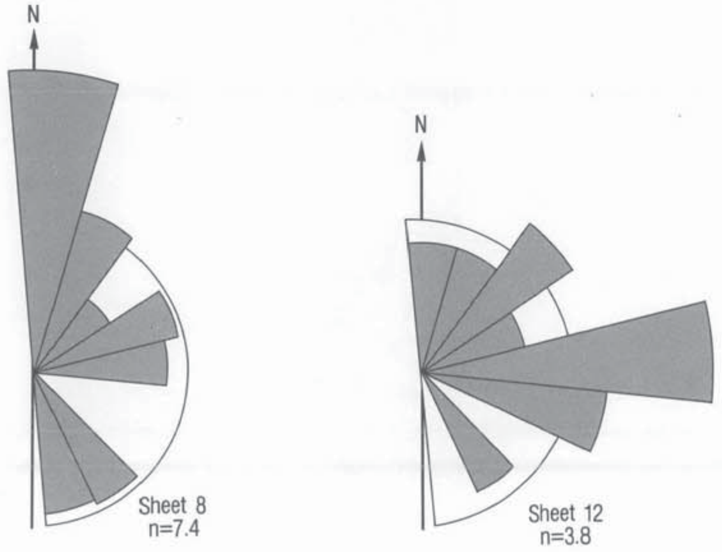


Figure 13 – Circular Histograms of Dykes on Sheets 8 and 12

Plate 31 – Debris Flow Deposit on Northern Coast of Tung Lung Island (4820 1320)

Plate 32 – Northeasterly Oriented Fault-line Valley in High Island Formation; Note the Sand Bar Impounding a Lagoon at Sai Wan (562 284)

Plate 33 – Tors, Scattered Corestones and Boulder Trains in Coarse Ash Tuff of the Long Harbour Formation, Northern Flanks of Mount Hallowes (506 358)

Plate 34 – Erosion Scars and Gullying of the Weathered Mantle in Coarse Ash Tuff of Long Harbour Formation, Southern Flanks of Mount Hallowes (501 349)

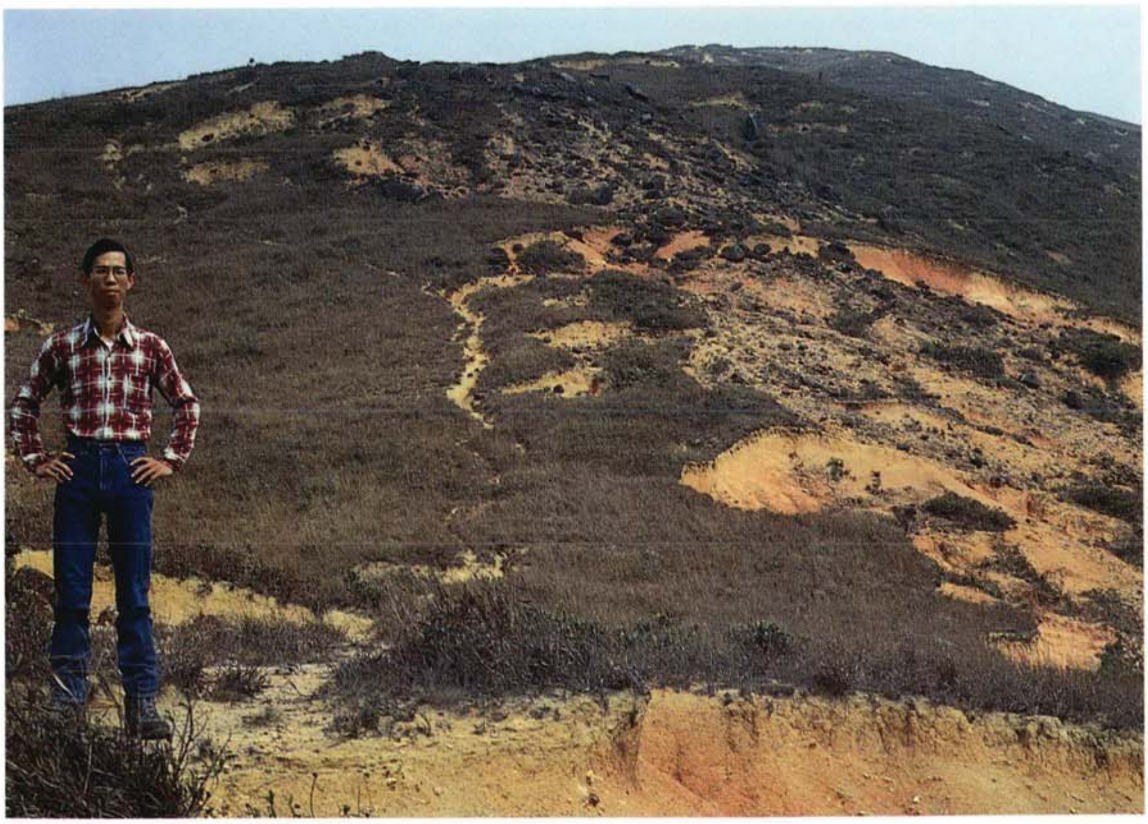


Plate 35 – Well-developed Corestones in Quartz Syenite, at Tai Miu Wan (4804 1424)

Plate 36 – Concentric Exfoliation Shells around a Remnant Corestone in Coarse Ash Tuff of Long Harbour Formation, at Mount Hallowes (5010 3472)

4531 3432 28/67/3/2/-/-/-/-

5469 2127 4/4/24/48/16/3/1/-

4527 2507 10/84/3/1/1/1/-/-

4863 1547 2/1/20/71/6/-/-/-

5235 2361 6/31/59/3/1/-/-/-

5508 2093 4/7/1/27/48/12/1/-

5747 2533 5/10/72/11/2/-/-/-

5054 1856 3/4/2/13/53/21/4/-

EXPLANATION

Grid Reference

Percentage: clay/silt/fine/medium/coarse (sand)/fine/medium/coarse (gravel)

0 5 10 15mm

Plate 37 – Samples of Seabed Sediments Showing a Gradation from Shelly Mud to Sand and Gravel

Chapter 7
Metamorphic Rocks

The metamorphic rocks of the district are limited in extent, but can be divided into three categories, namely regional metamorphism, thermal (contact) metamorphism and metasomatism.

Davis (1952) discussed the development of schist in Hong Kong, but it was Allen & Stephens (1971) who first emphasised the regional metamorphism of the Territory. They also described in detail the effects of thermal metamorphism around the granitic intrusions. Ruxton (GCO, 1982) produced a detailed examination of the thermal metamorphic products of the Victoria Peak area (Sheet 11), and his four grades of thermal metamorphic facies have been adopted in the present survey (Strange & Shaw, 1986).

Regional Metamorphism

Although the main belt of regional metamorphism extends northeast across the northern New Territories (Allen & Stephens, 1971), Langford et al (1989) have defined a larger area which is affected by dynamic metamorphism and hydrothermal alteration primarily associated with the overthrusting of Palaeozoic basement onto Jurassic volcanics. It had been generally assumed such metamorphism did not affect the district covered by this memoir, but siltstones of presumed Palaeozoic age occurring beneath the Lower Jurassic Tolo Channel Formation in the Three Fathoms Cove area possess a phyllitic fabric with contorted foliations and small-scale kink bands. The overlying Jurassic volcanic and sedimentary rocks are not affected.

Thermal (Contact) Metamorphism

The majority of volcanic rocks that constitute the country rock surrounding the granitic intrusions are of rhyolitic, rhyodacitic or trachydacitic composition, possessing mineral assemblages stable at temperatures as high as those of the intruding rocks. Therefore, except within a few metres of the contact, few megascopic signs of thermal metamorphism are evident.

Within the district the granitic and syenitic intrusions are of limited size, and a metamorphic aureole has only been mapped at one locality, Shek Miu Wan (471 166), where tuff of the Mang Kung Uk Formation and trachydacite lava of the Tai Miu Wan Member have been altered by a fine-grained granite intrusion. Within 50 m of the contact the rocks have been recrystallized, with small crystals of quartz, pyrite and garnet scattered throughout the aphanitic groundmass. These metamorphosed rocks fall within the medium-grade (hornblende-hornfels) facies (Strange & Shaw, 1986). The rock is hard and forms a well-defined low ridge feature parallel to the granite contact. In other localities, as for example at Tai Miu Wan (4800 1450), tuffite has been baked and recrystallised within a few metres of the igneous contact, but is not significant enough to be identified on Sheet 12.

Metasomatism

Metasomatism is the chemical alteration of rock by fluids and gases emanating from a cooling igneous, usually granitic, intrusion. In the eastern part of the Sai Kung Peninsula, around Sharp Peak and Tai Long Tsui, the country rock displays unusual patchy alteration which represents hydrothermal infiltration and metasomatism. These are usually associated with numerous quartz veins, and tuffite of the Lan Nai Wan Member in particular has been affected. In the vicinity of Tai Long Tsui the country rock is markedly altered close to quartz veins with quartz infilling vughs and iron-stained patches scattered throughout the brecciated rock.

Chapter 8
Superficial Geology

The superficial deposits have been divided into two categories; those widely distributed, stratified units that are characteristic of the offshore deposits and the more restricted irregular onshore deposits. The boundary between onshore and offshore deposits is taken at the pre-reclamation or natural coastal low water line, and the relationship between the two is shown in Figure 14.

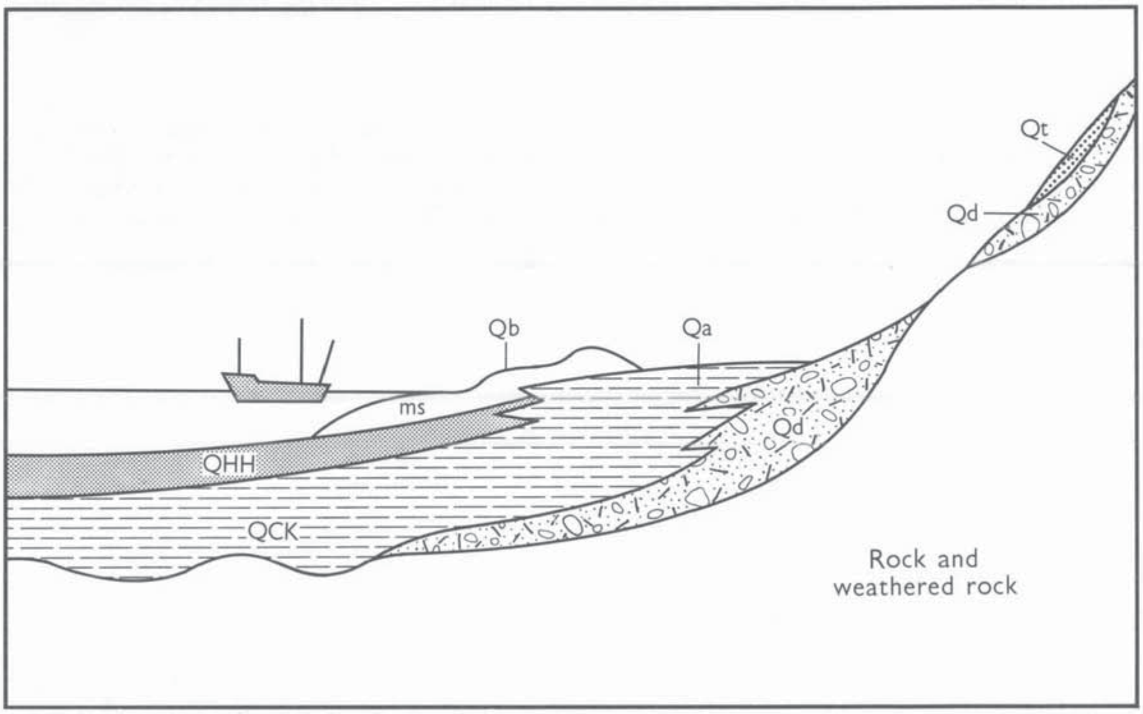


Figure 14 – Schematic Section Showing the Relationship between the Offshore and the Onshore Superficial Deposits

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 transported superficial deposits onshore into a layered, fluviatile sequence that includes alluvium, and deposits of mass wasting (colluvium) that in turn can be subdivided into slightly transported and substantially transported categories. The former are regarded as unmappable at the scale of the present survey and include minor landslip features and almost in situ boulder fields. The substantially transported category has been separated into talus (rockfall deposits) and debris flow deposits. Occasionally the two are so closely associated that they have been delineated on the map as mixed debris flow and talus deposits.

Beach deposits have been mapped and these include beach material, usually sand, extending inland from the low water mark, and also blown sand that has accumulated to heights of up to 8 m above sea level. Raised beach deposits, related to former higher sea levels, have not been recognized in the district.

Extensive reclamation has taken place around Junk Bay and to a lesser extent at Sai Kung town. A major controlled tip site is located at Junk Bay and a second landfill site is under construction at nearby Tai Chik Sha.

Alluvium

Stratigraphy

The alluvium consists mainly of well-sorted to semi-sorted clay, silt, sand and gravel, with the colour and composition of the material reflecting the underlying solid geology of the drainage basin.

Alluvium is present in the lower reaches of most river valleys, but is also found in upland areas, especially where valley constrictions, caused by geological factors, have acted as barriers across the stream courses. Along the coast, particularly on the eastern seaboard, a number of valleys have been dammed by beach deposits (Plate 32), and here lacustrine sediments have filled freshwater or brackish lagoons which formed behind the sand bars.

Although older terraced alluvium is extensive in the western, northern and central parts of the New Territories, it has not been recognized within this district, due probably to the limited extent of the alluvial tracts and the intensive agricultural terracing which has obliterated any natural terrace features.

Details

Sai Kung and Sai Kung Peninsula. Immediately west of Sai Kung town an extensive alluvial tract merges into gently sloping debris flow deposits. Intense agricultural terracing has obscured the boundaries of the alluvium, particularly around Sha Kok Mei (459 277). At Long Keng (470 288), further north, a wide flat area of waterlogged alluvium comprising brownish grey silt and clay covers the valley floor at a height of 15 to 16 m above sea level. In the hills north of Sai Kung, alluvium floors upland hollows at Wong Chuk Yueng (456 296). Here, the alluvium forms a very gently sloping plain between 195 m and 205 m above sea level. The stream course is constricted downstream by a band of hard rhyolite, effectively creating a natural dam across the valley.

On the west side of Three Fathoms Cove, a wide, gently sloping plain of both debris flow material and alluvium surrounds low hills of sedimentary rocks. Similar material in the neighbouring Nai Chung area (Sheet 7) has been described in detail by Addison (1986). Alluvium is present at Yung Shue Au and Sham Chung, and although extensive near the coast, it only continues inland for 1 km. Upland alluvium occupies the topographic hollows marking the trace of the Cheung Sheung–Chek Keng Fault between Cheung Sheung and Wong Chuk Long (501 322).

At Tai Long Wan, Ham Tin and Sai Wan, alluvium has accumulated behind sand bars. Freshwater lagoons and waterlogged silty clay ground are a feature of the alluvial tracts at these localities (Plate 32).

Clear Water Bay Peninsula. Alluvium is restricted to small valleys in this area. Most stream courses are short and steep, and the narrow alluvial tracts only extend for a few hundred metres.

Debris Flow Deposits

Stratigraphy

Debris flow deposits are defined as accumulations of mass-transported material formed by water-mobilised gravitional processes (Varnes, 1978). In Hong Kong, these complex deposits have been generally referred to as colluvium. Lai (1982) outlined criteria for the subdivision of colluvium into three classes based on the evidence of superposition, differences in clast-matrix ratios and the degree of decomposition of the clasts. During the present survey it was found that the representation of the three classes of debris flow deposits is impractical at the 1:20 000 scale.

In places, debris flow deposits may include a component of talus (rockfall) origin, and have thus been delineated on the map as mixed debris flow and talus deposits (Qdt).

Typically, the debris flow deposits consist of boulders, cobbles and pebbles supported by a gravelly clay matrix. Boulders up to 10 m occur, but they usually average 0.5 m across. They vary considerably in roundness depending on the parent rock type and age of the deposit. For example, round boulders more commonly develop from the coarse ash tuff and angular blocks from the polygonal jointed fine ash tuff.

The debris flow deposits are found on hill sides, with the thickest accumulations in valleys and at the base of steep slopes. The deposits also commonly line upland valley floors and are found filling lower valleys, with significant deposits often more than 20 m in thickness.

The deposits have a widespread distribution within the district. They are more commonly derived from coarse ash tuff, and found to a lesser extent in areas underlain by fine ash tuff of the High Island Formation. Lai & Taylor (1983) discussed in detail the probable ages of the deposits, suggesting Early Pleistocene for the older debris flows and a Holocene age for the younger deposits. Langford et al. (1989) distinguished the older debris flow material (Qpd) in the Western New Territories, but there is insufficient evidence within the Sai Kung and Clear Water Bay district to allow a similar chronological subdivision.

Details

Sai Kung and Sai Kung Country Park. Extensive debris flow deposits mantle the hill slopes to the west and north of Sai Kung town. These consist largely of rounded and sub-rounded boulders, some up to 3 m across set in a gravelly clay matrix. The boulders in the debris flows occurring west of Sai Kung are composed largely of fine ash tuff, flow-banded rhyolite, quartz syenite and quartz monzonite derived from the Ngong Ping and Ma On Shan areas. In the narrow stream courses, as for example northwest of Wo Tong Kong (452 283), the debris flow deposits rarely exceed 3 m in thickness and solid rock is often exposed in the river beds. In the lower reaches, the debris flows are more extensive and form low gradient slopes. There are few exposures in this material but stream banks often reveal a thickness greater than 7 m. At Nam Shan (453 277) the low angle debris flow slope has encircled a raised outcrop of coarse ash tuff. In the vicinity of the Star Lookout at Shui Long Wo (466 295), the hill slopes are mantled by a veneer of debris flow deposits dominated by large rounded boulders of coarse ash tuff. These boulders are up to 5 m in diameter and are typical of the underlying Tai Mo Shan Formation. Extensive debris flow deposits are derived from this rock type and tend to blanket many slopes without necessarily following present day stream courses, as for example at Ngong Wo (475 293).

The coarse ash tuff of the Long Harbour Formation tend to produce similar large rounded blocks which have been transported downslope to form mixed talus and debris flow deposits on the upper slopes and true debris flow deposits on lower slopes. This is well seen in the Pak Sha O Valley, where thick deposits mantle the hill side in the vicinity of Hoi Ha (516 357). Around the shores of Long Harbour, as for example near Tung Sam Kei opposite Wong Shek Pier (533 327), debris flows dominated by large rounded boulders of coarse ash tuff extend down to the shoreline.

Subangular to subrounded blocks of eutaxite and flow-banded lava set in a silty matrix comprise the debris flow deposits of the Pak Tam valley (506 305). Numerous small bedrock exposures on the valley sides indicate that the deposits are not more than 10 m in thickness.

Fine ash tuff of the High Island Formation crops out over a wide area of southeastern Sai Kung Country Park and the adjacent islands; debris flow deposits have only a limited development. Small isolated patches of debris flow material, as for example at High Island (544 245), are restricted to valley floors. The deposit consists of angular to subrounded blocks, usually less than 300 mm in diameter, set in a clay matrix.

Clear Water Bay Peninsula and Tung Lung Island. Debris flow deposits are most extensive on the western and eastern slopes of Sheung Yeung Shan (470 189) and High Junk Peak (475 154). Although largely restricted to valley floors, these flows have in places formed a thin veneer of debris on hill slopes away from the stream courses. On Tung Lung Island, near Nam Tong (4817 1317), debris deposits derived from Silverstrand Formation tuff mantle the cliffs along the shoreline (Plate 31) and can be traced inland along small stream courses.

Talus (Rockfall) Deposits
Stratigraphy

Talus consists of predominantly angular rock fragments, often large, derived from and lying at the base of a cliff or very steep rocky slope (Bates & Jackson, 1980). The blocks have been transported downslope by a combination of gravitional sliding, falling or rolling. Mixed debris flow and talus deposits (Qdt) include a component of both, as for example in the Hoi Ha area of Long Harbour.

The extent of talus is limited to very small areas, which are often unmappable at the 1:20 000 scale. They have, however, been delineated at Tai Long Wan and Hoi Ha in Sai Kung Country Park, and on the western side of High Junk Peak (4715 1766) on the Clear Water Bay Peninsula. In every case the talus consists of an unsorted mass of gravel, pebbles, cobbles and boulders, with only a sparse sandy matrix present.

Beach Deposits
Stratigraphy

Beach deposits are defined as unconsolidated predominantly sand-sized material formed by marine action, extending landwards from the low-water line to a cliff line or storm beach limit. They are usually found only in sheltered bays and inlets, with the largest extent of beach deposits present along the shores of Tai Long Wan.

The beach deposits usually consist of clean, pale yellow sand, and many of the beaches in the district are gazetted for recreational purposes. Deposits of beach sand are found inland of the high water mark and tidal zone and rise to heights of 8 m above sea-level. These are considered to be storm beach deposits. There is no evidence in the district for former higher sea levels. The deposits often form sand barriers across river mouths, resulting in the formation of freshwater lagoons and extensive alluvial tracts inland (Plate 32). In places, boulders, cobbles and pebbles constitute the beach deposits, particularly on more exposed coastal localities; where possible, these have been distinguished from the beach sands.

High-level beach rock, similar to that occurring on Hong Kong Island (Strange, 1986), has not been recognized within the district. However, a small area of low-lying beach rock occurs just above the high water mark at Kiu Tau in Inner Port Shelter.

Details

Clear Water Bay Peninsula. In the sheltered inlet of Clear Water Bay (Tsing Shui Wan), the main beach (Clear Water Bay Second Beach) (477 165) consists of clean fine sand. Small sandy beaches are also found at the First Beach (480 169) and Tai Wan Tau (484 168).

A coarser, shingle beach is developed at the western end of Tai Miu Wan. The sandy bays at Tai Chik Sha Wan (466 170) and Siu Chik Sha Wan (464 176) have now been covered by reclamation. Small beach deposits facing Port Shelter occupy sheltered coves, as for example at Silverstrand (461 204).

Inner Port Shelter (Sai Kung Hoi), and Rocky Harbour. Beaches of clean sand are found occupying sheltered bays at Sam Sing Wan (457 243), Hap Mun (482 242) and Tai Sha Wan (530 238) and are popular recreational localities. Kiu Tau is joined to Sharp Island by a 30 m wide causeway (4771 2514) exposed at low tide and consisting of pebbles and cobbles of locally derived volcanics and quartz syenite. On Pak Sha Chau (4756 2626) a sand spit has developed on the northern side of the island. Between Sharp Island and Sai Kung, sand is abundant just below sea level and in places sandy patches are exposed above the low water mark; these small areas are however included in the marine sand category. On the northern tip of Shelter Island (483 214), rounded boulders, cobbles and pebbles of rhyolite form a spit extending seawards for 100 m, and rising inland to 7 m above sea level. Similar coarse deposits of cobbles and pebbles occur on the north side of Basalt Island (556 202) and the west coast of Bluff Island (544 205).

Three Fathoms Cove, Long Harbour and Tai Long Wan. The coastline of Three Fathoms Cove and the shores bordering Tolo Channel are fringed by beach sand deposits of limited extent, usually less than 10 m in width. Similarly, Long Harbour has only scattered beach deposits, as for example in the sheltered bay at Tan Ka Wan (553 347). Extensive sandy beaches are present at Tung Wan, Tai Wan, Ham Tin and Sai Wan in Tai Long Wan. The sand extends inland for 200 m at Tai Wan (569 306) and rises to 6.5 m above sea level. This forms a barrier across the Tai Long valley and on the inland side a wide alluvial tract has developed, at a height of between 2.4 and 4.5 m above sea level. Similarly, at Sai Wan (5625 2863), the village is built on the beach sand deposit at an average height of 5 m above sea level, whereas inland the sand barrier has created a lagoon and waterlogged alluvium some 2 to 4 m above sea level has accumulated.

Offshore Superficial Deposits—Classification and Distribution

Two offshore formations have been defined. The oldest is the Pleistocene Chek Lap Kok Formation (Strange & Shaw, 1986) consisting of silt, clay, sand and gravel, largely of alluvial origin. The formation is up to about 30 m in thickness and is widespread throughout the Territory. It rests with major unconformity on rock in various states of weathering. Overlying it, generally with minor unconformity or non-sequence, is the Hang Hau Formation (Strange & Shaw, 1986) which underlies the seabed over most of the district. The formation is Holocene in age and of marine origin, consisting predominantly of mud with subordinate sand but becoming entirely sand in areas of stronger current activity. The formation exceeds 30 m in thickness in parts of the district but more commonly is from 10 m – 20 m thick.

Chek Lap Kok Formation

Stratigraphy

The Chek Lap Kok Formation has a widespread distribution but is concealed by the Hang Hau Formation everywhere except between Beaufort Island and Po Toi Island in the southwest of the district. Its thickness is generally in the range of 10 to 50 m. It is absent around parts of the coastal fringe, between the islands such as Fat Tong Mun, Sor See Mun, Sam Chau Mun, and over the many submerged bedrock outcrops. The type section of the formation is a continuously sampled borehole (B13/13A) at Chek Lap Kok (Sheet 9) (Shaw, 1985, 1987; Shaw et al 1986). The stratigraphy of the formation is complex. Samples from vibrocore and drill holes in the district indicate that the formation is lithologically diverse, consisting mainly of firm to stiff clay, with silt, dense sand and gravel and occasional boulders. Some of the clays and silts are laminated and some include grey or dark grey organic layers with wood fragments. The more typical colours are cream and light bluish grey to light grey, with yellow, brown and intense red mottling.

The seismic signature of the formation is generally distinctive. The reflectors in the Chek Lap Kok Formation are commonly impersistent and chaotic and usually have a higher amplitude than the weak, continuous, sub-parallel reflectors that characterise the seismic records of the marine mud of the overlying Hang Hau Formation (Plate 38). The formation rests unconformably on weathered rock. On the seismic profiles the unconformity at the base of the formation is not everywhere well-defined, particularly at depths of about 70 m below seabed, but usually becomes clearer where rock approaches or crops out at the seabed. The unconformity is generally irregular and the formation may thin out against, or be confined to, depressions or channels in rock or weathered rock. Its base is probably markedly diachronous, but in the absence of continuous seismic reflectors and of documented stratigraphically marked horizons such diachronism remains unproved. The formation extends to below -95 mPD at the southern boundary of the district; seismic records from there do not encounter rock at that depth, the practicable working limit of the boomer seismic equipment. Northwards, the formation is thinner, the proliferation of islands and common appearance of bedrock outcrops on the seabed indicating that bedrock is generally nearer the surface.

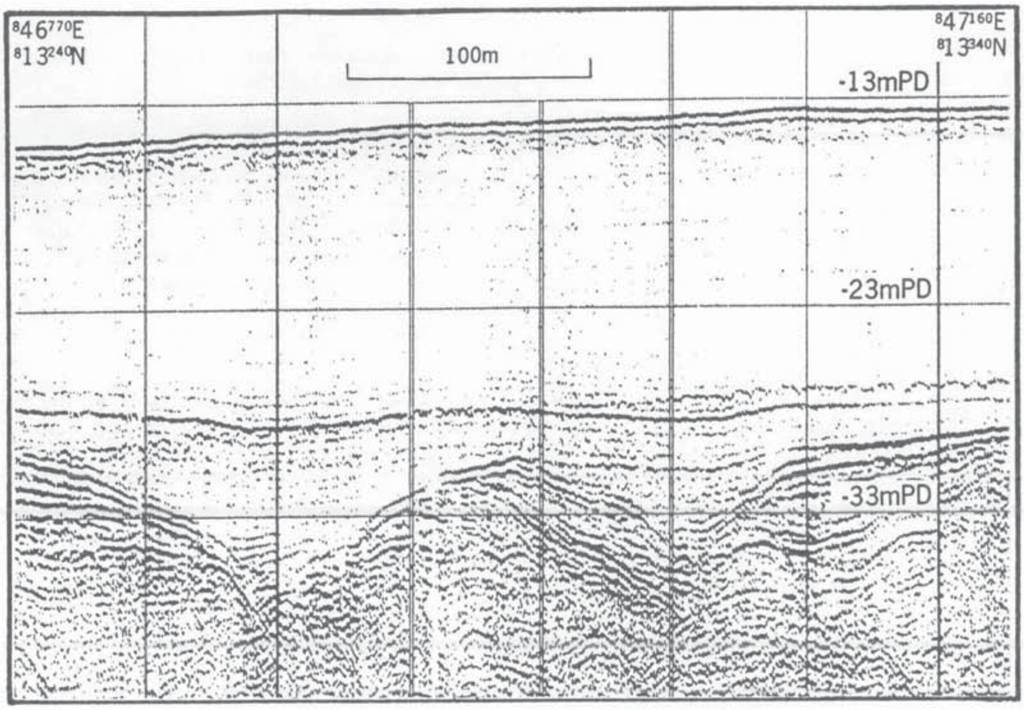


Plate 38 – Seismic Profile Illustrating the Contrast Between the Seismic Character of the Hang Hau and Chek Lap Kok Formations: Note the Gullied Surface of the Latter Formation (Seismic Line C6)

The top of the formation is a former subaerial drainage surface that was inundated by the Holocene marine transgression. Contouring of this surface (Figure 15) reveals a dissected plain falling gently southwards from around −20 mPD to −40 mPD. A dendritic pattern of channels incise this surface to a maximum depth of −65 mPD at the southern limit of the district (Figure 15). A similar pattern is recognised in the Western Harbour area (Sheet 11) (Strange & Shaw, 1986; Shaw & Arthurton, 1988) and in Urmston Road (Sheets 5, 6, 9 and 10) and the West Lamma Channel areas (Sheets 10 and 14) (Shaw, 1988, 1990).

Details

Three Fathoms Cove, Tolo Channel and Long Harbour. In Three Fathoms Cove the formation ranges from about 3 m to 10 m thick, resting on an irregular surface of weathered bedrock that falls northwestwards from about −17 mPD at the head of the cove to about −32 mPD near the mouth. The formation is characterised by a complex seismic signature that comprises a dense and confused pattern of discontinuous and intersecting reflectors. The strong multiple reflection generated by the surface of the formation suggests that the formation is sandy. The top of the formation falls from around −10 mPD at the head of Three Fathoms Cove to −20 mPD at the mouth. An axial channel is eroded into the upper surface, directed towards Tolo Channel.

In Tolo Channel the formation is from about 4 m to 12 m thick forming a broadly lenticular body that infills a channel in the bedrock. The centre of the bedrock valley lies at about −29 mPD off Three Fathoms Cove and falls northeastwards to −42 mPD at the northern boundary of the district. Seismically the formation is complex displaying a confused pattern of high amplitude, discontinuous reflectors. In the centre of Tolo Channel the surface of the formation lies at −30 mPD, the contoured surface indicating an axial channel, the sides of which rise to about −15 mPD close to the present coast.

The formation is up to 10 m thick in Long Harbour. Off Stoke's Point (537 334) the formation is absent over a bedrock high, that rises 6 m above its upper surface, and rapidly thickens to about 6 m on its flanks. Northwards the formation thickens to about 10 m on an irregular bedrock surface that falls from −13 mPD on top of the bedrock high to −42 mPD in the centre of the channel west of Boulder Point (543 357). The formation exhibits a characteristic confused and chaotic seismic response. In Long Harbour the surface of the

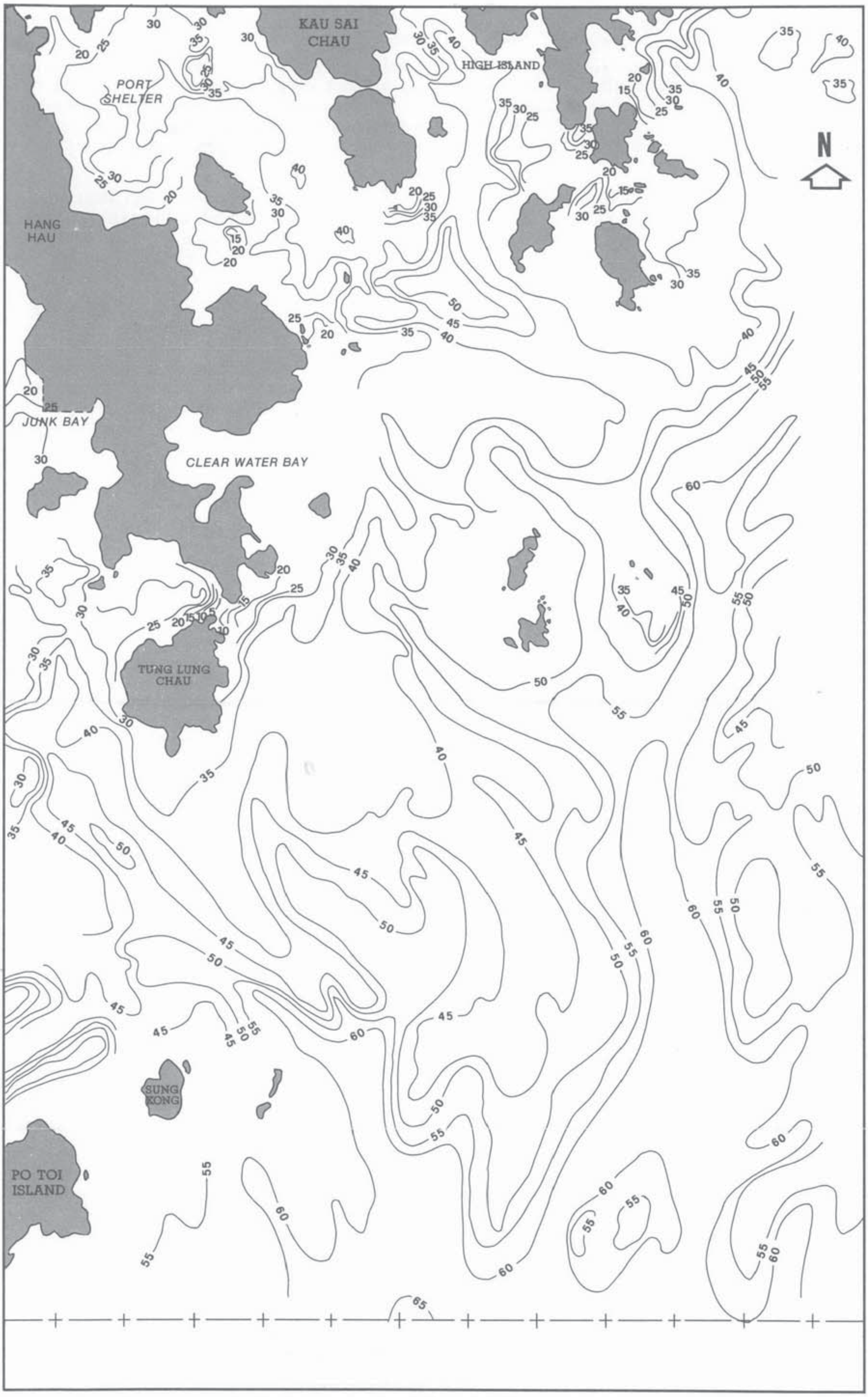


Figure 15 – Contours on the Surface of the Chek Lap Kok Formation (in metres below Principal Datum)

formation falls northwards from −15 mPD off Stoke's Point to −30 mPD west of Boulder Point. On the seismic records it has an irregular upper surface which suggests extensive channel erosion.

Mirs Bay and Tai Long Wan. The formation is up to 15 m thick in Mirs Bay. It is absent over a bedrock high, which rises almost 13 m above the top of the formation off the Tan Ka Wan peninsula (564 350). Eastwards the formation thickens rapidly, thereafter maintaining a fairly uniform thickness of about 10 m on a regular bedrock floor at about −49 mPD. A chaotic and confused seismic signature characterises the formation. The upper surface of the formation is irregular and channelled, falling from about −25 mPD near the coast to −45 mPD to the east.

In Tai Long Wan the formation ranges from about 1 m to 12 m thick, filling depressions on an irregular bedrock floor that declines southeastwards from −14 mPD to −54 mPD. Seismically the formation displays a chaotic seismic signature, which has a pattern of high amplitude reflectors distinguished by many hyperbolic reflectors, suggesting the presence of cobbles or bounders in the sediments. The surface of the formation declines from around −25 mPD near the coast to −45 mPD at the eastern bouldary of the district.

High Island and Rocky Harbour. Under the site of the present High Island Reservoir, originally the Kwun Mun Channel, investigations revealed that the Chek Lap Kok Formation was lenticular in form, ranging in thickness from 2 to 8 m across the area (Kendall, 1975). Well-defined layers of botanical residues were found along the former course of a meandering channel at about −20 mPD. The channel sediments comprised clays and lenses of sand and silt intercalated between beds of sandy-gravel. Evidence of considerable scouring and floodplain ponding was observed on the surface of the deposit. At the site of the east dam (565 249) up to 13 m of Chek Lap Kok Formation deposits were located on a bedrock surface at about −28 mPD. The sediments were found to be predominantly sandy with gravels and some cobbles and thin clay beds. Yim (1984) reported the existence of a marine layer within the formation at this site. Southeastwards the formation thickens from almost 18 m at 0.5 km from the east dam to over 25 m at about 4 km away on an irregular bedrock surface that slopes from −48 mPD to almost −60 mPD (600 225). Seismically the formation exhibits a dense, chaotic signature. The top of the formation has an undulating upper surface, falling from about −20 mPD to −35 mPD within 1.5 km of the coast.

In Rocky Harbour the formation varies from a thin veneer to up to 12 m thick on a highly irregular bedrock surface with a relief amplitude of up to 20 m. At the northern end of Rocky Harbour a 1 m to 7 m thick cover of Chek Lap Kok Formation sediments overlie an irregular bedrock surface at about −25 mPD. Southwards the formation thickens slightly to about 10 m to the west of She Wan Kok (530 230), on a bedrock surface at about −48 mPD. In the centre of the Bay off Sor See Mun the formation thickens to 25 m on a bedrock surface at −49 mPD (550 213). Southeastwards the formation thins as the bedrock surface becomes more irregular and then rises to crop out at the seabed off Yuen Kong Chau (558 205). Southeastwards the formation again thickens to between 20–25 m on a bedrock surface that descends from the seabed at around −15 mPD to about −63 mPD at 2.5 km southeast of Basalt Island (585 185). The formation exhibits the typical seismic signature of dense, chaotic reflectors that have a uniformly irregular appearance except in the area to the north of Wai Kap Pai (537 218) where there is the suggestion of a lower channelled unit within the formation.

Port Shelter and Inner Port Shelter. In Inner Port Shelter and the eastern side of Port Shelter the formation varies from a thin veneer to more than 30 m thick, on a highly irregular bedrock surface with a relief amplitude of up to 25 m. It is absent on many bedrock highs, against which the formation thins rapidly. Between Sharp Island and Pak Ma Tsui (475 235) the surface of the bedrock is not clearly defined on the seismic records but appears to be below −60 mPD. The formation is greater than 30 m thick in this area. Southwest of Wong Wan Pai (500 205) the surface of the bedrock is at −60 mPD and the formation has thinned to about 25 m. Southeast of Table Island (515 190) the bedrock surface has descended to −66 mPD, the formation maintaining a thickness of about 25 m.

At the mouth of Hebe Haven (452 243) the formation is from 2 to 10 m thick on a very irregular bedrock surface that undulates between −16 and −30 mPD. Southwards the formation thins as bedrock approaches to within 2 m of the seabed west of Pak Ma Tsui Pai (463 233). The formation thickens to 20 m northeast of Silverstrand bay on an irregular bedrock surface at about −50 mPD. The formation occurs only as isolated pockets between 5 and 15 m thick to the southeast. The upper surface of the formation descends generally southeastwards from −20 mPD south of Yeung Chau (464 255) to −40 mPD east of Table Island (514 192) (Figure 15).

Junk Bay, Joss House Bay (Tai Miu Wan) and Tathong Channel. Eastwards from Fat Tong Mun the Chek Lap Kok Formation ranges in thickness from 20 to 45 m on a bedrock surface with a relief amplitude of over 20 m. On the eastern side of Junk Bay (463 196) the surface of the Chek Lap Kok formation is fairly uniform in elevation, but the thickness varies from around 20 m over the bedrock highs to 45 m over the bedrock depressions. At the northern end of the Tathong Channel the formation ranges in thickness from a minimum of 7 m over a bedrock high west of Tit Tam Chau (461 137), to 40 m in a bedrock depression near the southern boundary of the district. Seismic records of the formation from the area display a characteristic chaotic and confused seismic signature that comprises discontinuous, high amplitude reflectors. The upper surface of the formation falls from −20 mPD in Junk Bay and near the head of Joss House Bay to −30 mPD at the northern end of the Tathong Channel from where the surface is incised by a well-defined valley that descends southwards to reach −40 mPD at the southern boundary of the district (Figure 15).

Southeastern Approaches and the Ninepin Group. From the east of Trio Island (520 180) southwards the formation is absent over several bedrock highs, and ranges between 15 to 40 m thick between them.

Southwards the formation thickens to over 60 m. Conditions are similar in the western part of the area where the formation commonly exceeds 50 m in thickness. The formation thins considerably around the islands and island groups, with bedrock rising to near the seabed or cropping out at several locations between the islands of the Ninepin Group. Thicknesses of up to 20 m occur in depressions between the bedrock highs. Up to three broad seismic units can be distinguished on the seismic records form the area. Three continuously sampled boreholes indicate that the formation is predominatly sandy (Appendix). Overall the upper surface of the formation forms a wide plain that falls from −40 mPD in the north to −60 mPD in the south (Figure 15).

Age and Sedimentary Environment

Three radiocarbon dates are available from the Chek Lap Kok Formation within the district. At High Island, one sample gave a date of 36 600 yr BP, and two others were determined to be greater than 40 000 yr BP (Kendall, 1975), the limit of the technique. Several dates from within the formation at Chek Lap Kok ranged from 16 420 ± 660 to 36 480 ± 830 yr BP (RMP Encon, 1982) and a date of greater than 40 000 yr BP was obtained from the formation at the base of the type borehole (Strange & Shaw, 1986). This evidence suggests a Late Pleistocene age for the proximal parts of the formation.

Palynological analyses of samples from the formation in the type borehole at Chek Lap Kok (Shaw et al, 1986) and from the type borehole of the Hang Hau Formation at Junk Bay (Strange & Shaw, 1986) indicate a predominantly fluvial origin, with subsidiary lacustrine horizons. A marine origin for some deposits within the formation at other locations has been suggested (Yim, 1984; Wang & Yim, 1985; Howat, 1985). It is considered that the bulk of the formation probably accumulated, or was reworked, during the lower sea-levels of the Pleistocene glacial periods, during which times the deposits were subaerially weathered giving rise to the distinctive oxidation and mottling of the sediments (Shaw & Arthurton, 1988; Shaw, 1987, 1990).

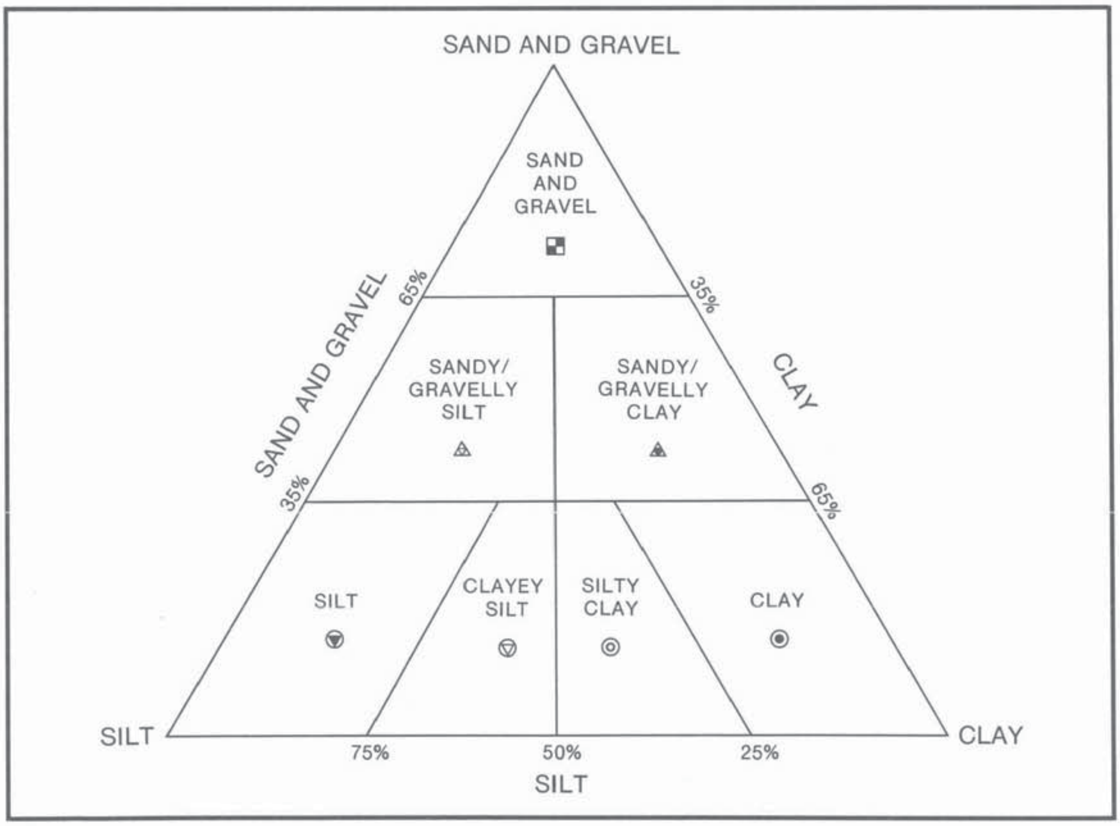


Figure 16 – Classification of Sediment Mixtures (Modified from the British Soil Classification System for Engineering Purposes BS 5930: 1981)

Hang Hau Formation

Stratigraphy

The formation is widespread and underlies the seabed over most of the district. It is thin or absent in restricted areas between many of the islands, such as Fat Tong Mun and Sor See Mun, or over bedrock highs such as around the islands of the Ninepin Group and to the west of Shelter Island.

Lithologically the formation comprises predominantly soft to very soft, olive-grey to bluish grey mud with shells (Plate 37). It is typically 10 to 20 m thick, but ranges from less than 5 m at the heads of bays and between islands, to more than 30 m where it fills valleys incised into the surface of the underlying Chek Lap Kok Formation. The type section of the formation is a continuously sampled borehole (JBS 1/1A) in Junk Bay (Sheet 11) (Strange & Shaw, 1986). The mud is generally shelly; characteristically the shells are uniformly distributed, although very shelly layers, not unusually as bands of comminuted shell debris, are recorded as well as shell-free intervals of 1 m or more. Bivalves dominate the faunal assemblage, but gastropods are locally abundant; sparse echinoid and scaphopod fragments also occur.

Particle size distribution plots show that the mud is composed dominantly of silt (around 80%) with subsidiary clay and minor fine sand components (Figure 17). The sand content increases in areas of higher current activity and in the littoral and sub-littoral zone. No sedimentary structures or discontinuities within the mud have been recorded from vibrocores or continuously sampled boreholes in the district. However, well-marked and extensive subparallel reflectors commonly characterize the seismic signature (Plate 39). The formation commonly comprises two clearly-defined units on the seismic profiles. The lower seismic unit displays strong reflectors, that may be curved and downlapping. In many localities the surface of the unit has a bank-like form, or the surface may be eroded by channels. Above this denser basal unit the reflectors of the overlying unit are weaker. In the southern part of the district the reflectors indicate the existence of at least three transparent units above the dense basal unit, separated by distinct discontinuities (Plate 41).

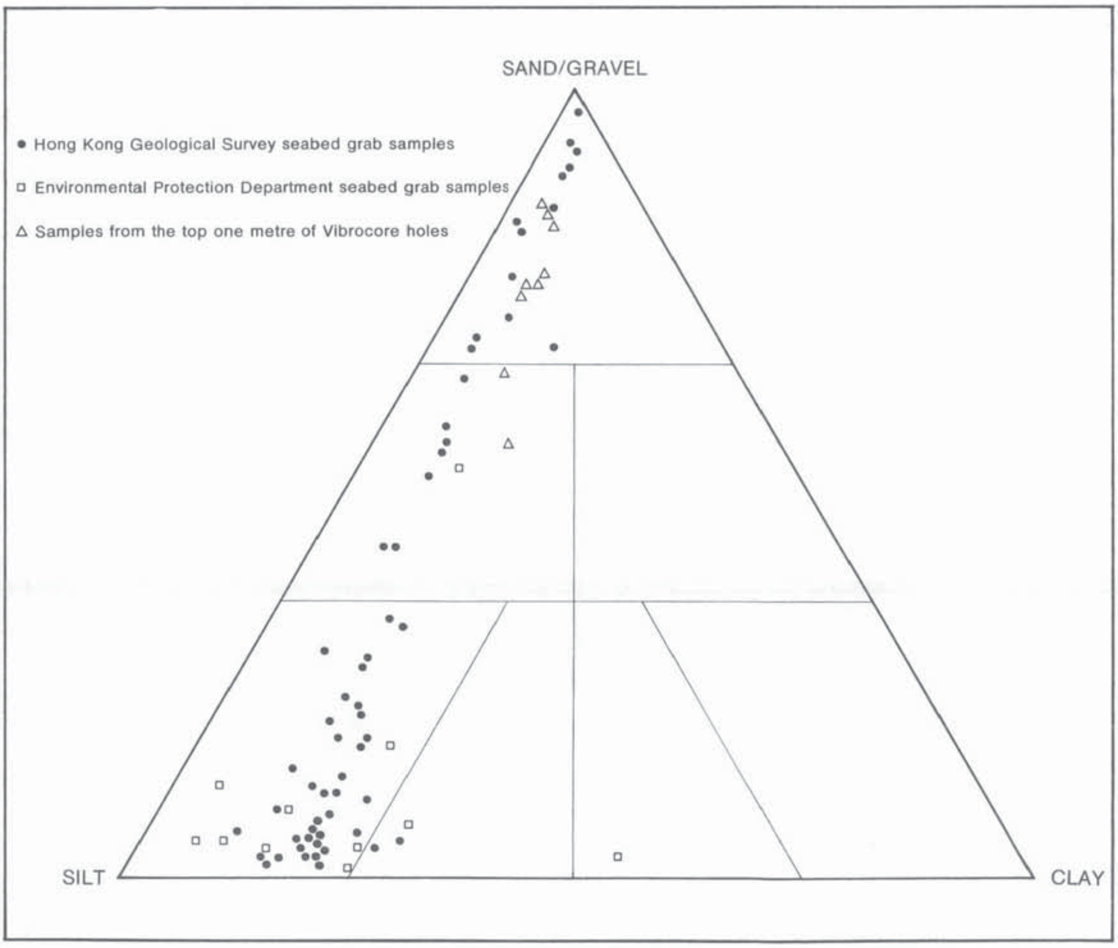


Figure 17 – Triangular Plot Showing the Particle Size Distribution of Seabed Sediment Samples from the District (Classification Fields from Figure 16)

The Hang Hau Formation is unconformable on the Chek Lap Kok Formation (Plate 38), and locally overlaps it to rest on rock or weathered rock (Plate 40), particularly at the heads of bays or against submarine outcrops. Ambiguity about the base of the formation exists on many of the seismic profiles, particularly where the base of the formation is sandy and displays cross-cutting or gully-infill structures. The formation is usually distinguished on the basis of the clearer, more continuous seismic signature. Over large areas the Hang Hau Formation sediments fill and overlap gullies and channels incised into the surface of the underlying Chek Lap Kok Formation (Plate 38) (Figure 15).

Sand or muddy sand is present within the formation fringing the present and pre-reclamation coasts. Extensive seabed and intertidal sands are developed in Inner Port Shelter, and wide sandy beaches occur in sheltered bays such as Clear Water Bay and Silverstrand. The majority of the coastline of the district comprises steep and high cliffs, therefore the development of littoral sands is narrow but there is an almost ubiquitous narrow fringe of sub-littoral sands along most coastlines. Sand deposits are also associated with areas of stronger current activity, such as in the Tathong Channel, to the east of the Sheung Sz Mun Channel, around the islands of Ninepin Group and adjacent to restricted inter-island gaps. The larger sand bodies, such as in the Tathong Channel, comprise predominantly quartz sand with subordinate feldspar and shell fragments, as do the majority of the littoral and sub-littoral deposits. In contrast, the sands and gravels occurring in the inter-island narrows, such as the South Channel (Long Harbour) and between Wong Chau and Basalt Island consist predominantly of comminuted shell debris. Sor See Mun is floored with a lag deposit of cobbles and pebbles.

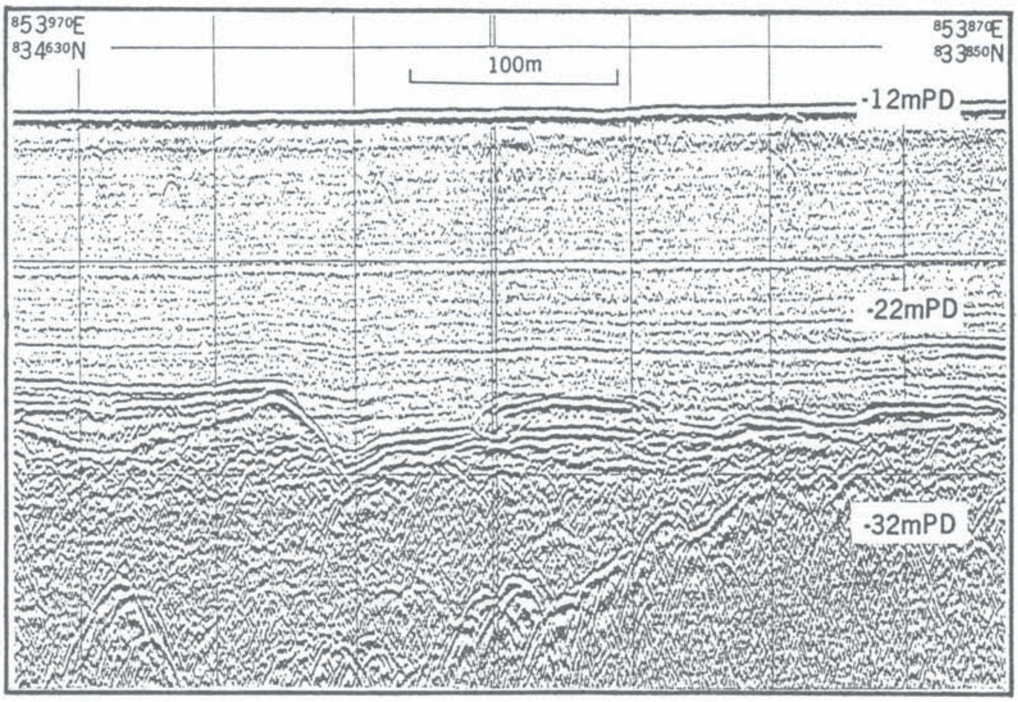


Plate 39 – Seismic Profile Showing a Discontinuity within the Hang Hau Formation muds in Long Harbour (Seismic Line D25)

Details

Three Fathoms Cove, Tolo Channel and Long Harbour. The formation ranges from less than 5 m thick at the head of Three Fathoms Cove to almost 15 m near the mouth, filling a shallow channel eroded into the upper surface of the underlying Chek Lap Kok Formation. Seismic records indicate that the formation comprises two distinct units. A lower basal unit up to 5 m thick is characterised by high amplitude, continuous seismic reflectors. This early marine unit is laterally discontinuous. The upper, seismically transparent, unit forms an unbroken cover. Shorewards the reflectors increase in amplitude as the unit becomes more sandy. Grab sampling demonstrated that at the head of the bay the formation is sandy at seabed (Figure 18), with a narrow zone of sub-littoral sand around the perimeter of the cove. Mud underlies the seabed over the remainder

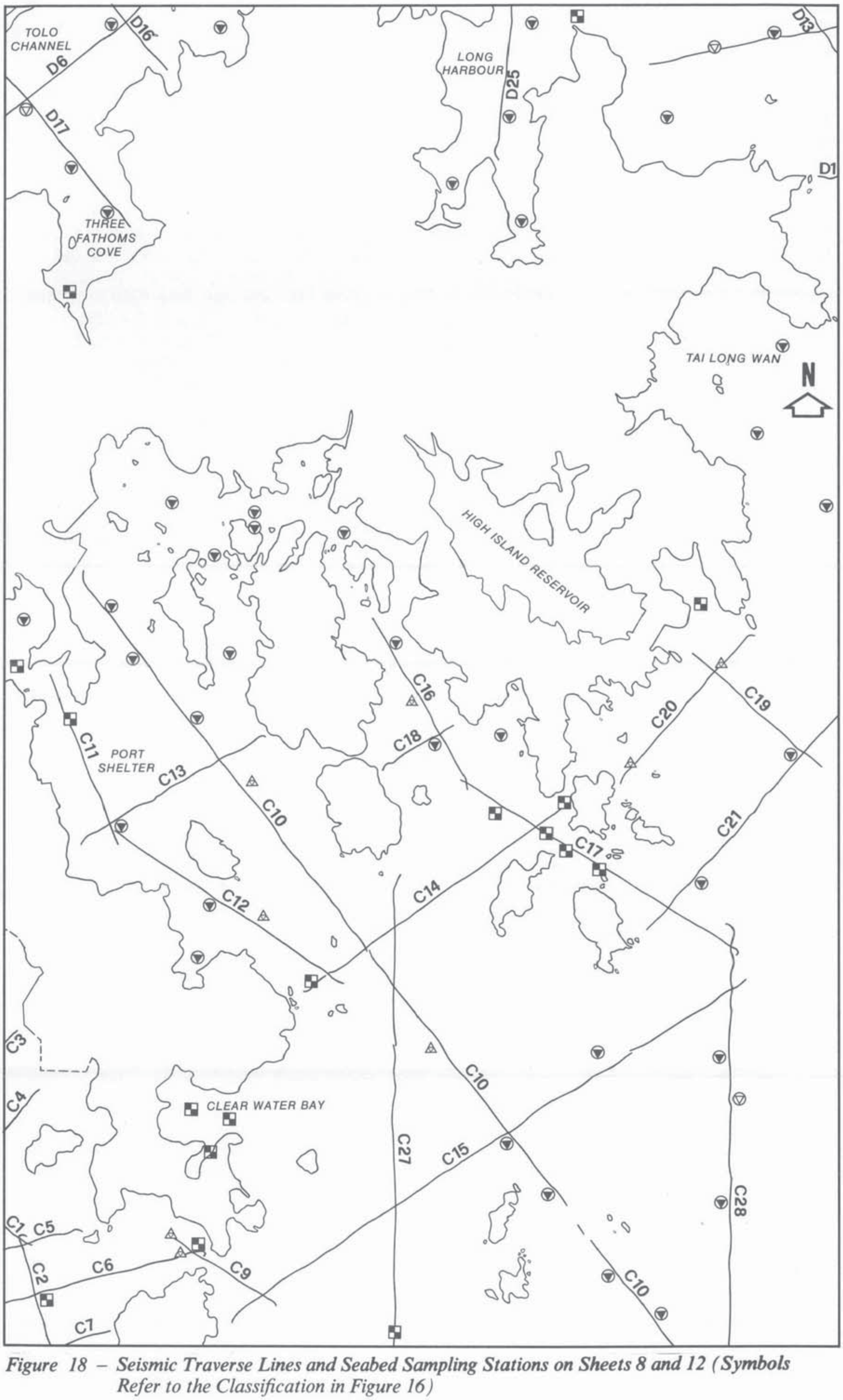


Figure 18 – Seismic Traverse Lines and Seabed Sampling Stations on Sheets 8 and 12 (Symbols Refer to the Classification in Figure 16)

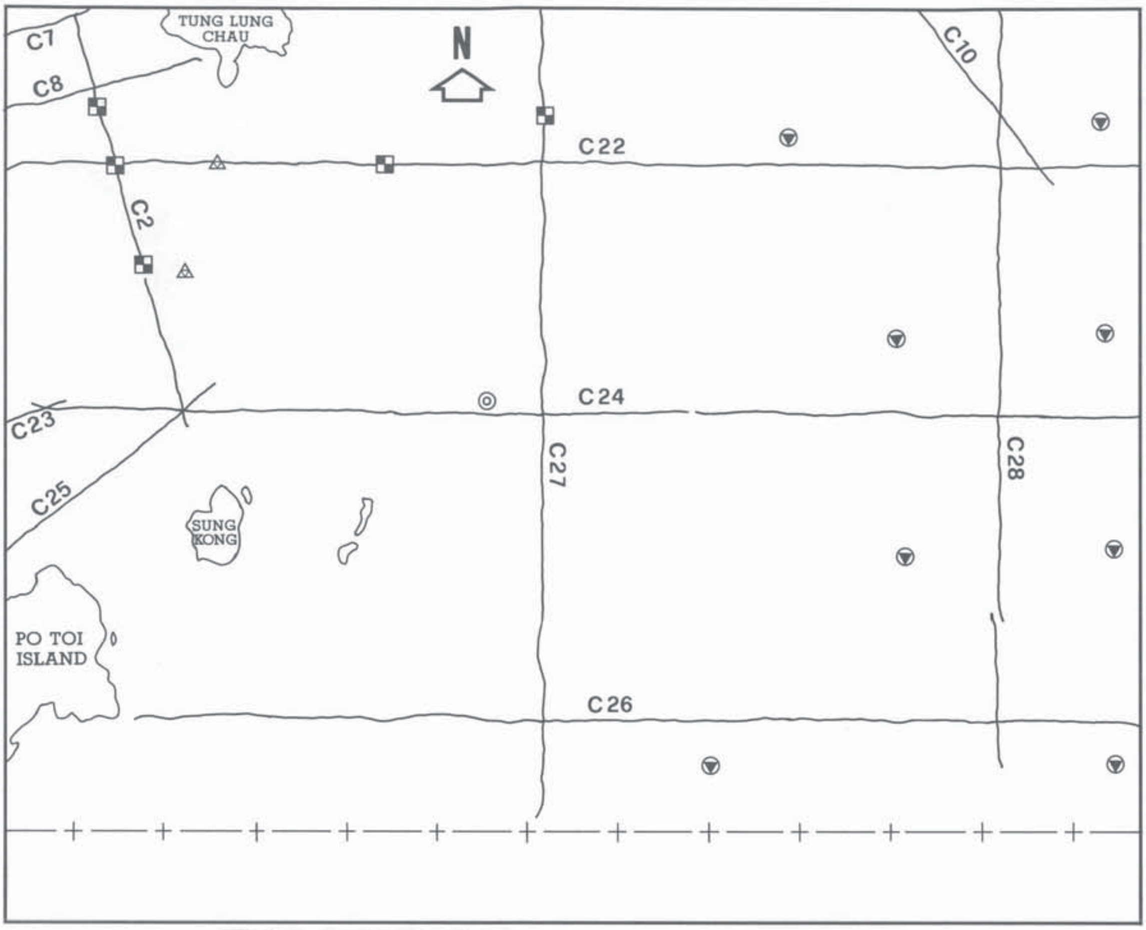


Figure 19 – Seismic Traverse Lines and Seabed Sampling Stations on Sheet 16 (Symbols Refer to the Classification in Figure 16)

of the cove. On the floor of the Tolo Channel the formation is from about 10 m to almost 20 m thick and is muddy at the surface (Figure 18). The mud is bluish grey and shelly (Plate 37). Seismic profiles indicate the existence of a basal unit from 3 to 7 m thick filling channels eroded in the underlying surface. The reflectors in this unit are continuous and have a higher amplitude than those in the unit above. At several locations (454 345) (461 350) (470 359) are mound-like features, containing strong, curvilinear seismic reflectors, that are probably sandbanks formed at an early stage of the marine incursion into Tolo Channel. This basal unit is complex displaying cross-cutting relations and evidence of channel erosion. The upper muddy unit is almost seismically transparent. To the south of Flat Reef (475 353) a discontinuity in the upper unit indicates the presence of a late infill unit on the floor of the modern bathymetric channel.

In Long Harbour the formation is from about 3 m to 18 m thick. It is typically a clayey silt on the seabed over most of the area (Figure 18) but becomes sandy with minor gravel in the East Arm. A narrow zone of sub-littoral sand occurs at the heads of the West and East Arms. On seismic profiles the formation can be seen to comprise a basal unit up to 5 m thick filling minor gullies in the surface of the underlying Chek Lap Kok Formation. A dense, complex pattern of seismic reflectors characterise the unit which displays on its upper surface low amplitude bedforms, banks or ridges of from 2 to 3 m high. The upper unit is horizontally bedded with continuous, low amplitude reflectors. A discontinuity is apparent within the upper transparent unit and in places a second discontinuity is indicated suggesting at least three sub-units (Plate 39).

Mirs Bay and Tai Long Wan. A thin deposit of slightly silty, gravelly sand with an abundance of shells and shell fragments floors the South Channel between Long Harbour and Mirs Bay (552 358). In Mirs Bay the formation ranges from less than 5 m to almost 25 m thick. At seabed the formation comprises clayey silt in Nam She Wan (568 338) (Figure 18), but becomes more sandy north of Wong Mau Chau (575 353). A wide zone of sub-littoral sand floors the head of the bay of Nam She Wan. Seismic records indicate that the formation comprises a basal, possibly sandy, unit up to 13 m thick. It is characterised by strong seismic reflectors. Near the coast the upper surface of the basal unit displays bank-like forms developed during the early stages of the marine transgression. Eastwards the unit becomes complex with a well defined cross-bedding thickening to the northeast. The upper transparent unit is up to 23 m thick, comprising continuous, weak and sub-parallel reflectors.

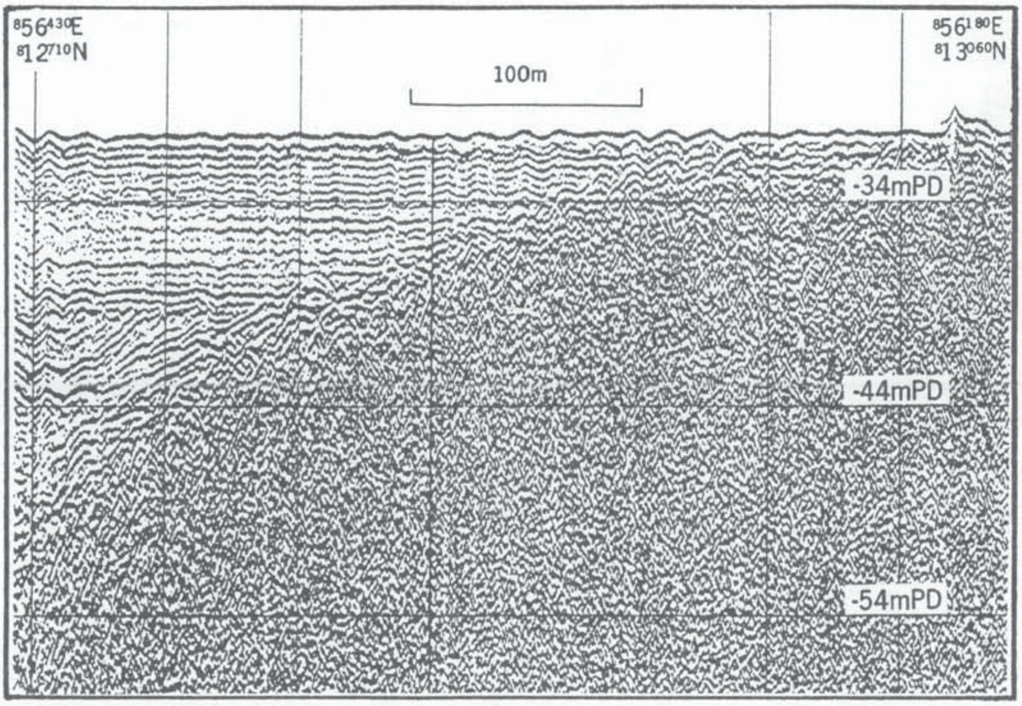


Plate 40 – Seismic Profile Showing a Bedrock Rise and Overstepping of Hang Hau Formation Mud Units (Seismic Line C10, Southeast of the Ninepin Group)

In Tai Long Wan the formation is from 6 to 13 m thick. Against the shore of this high energy coast wide and extensive littoral sands pass into a broad sub-littoral sand that grades to slightly sandy mud on the seabed east off Tsim Chau (Figure 18). Sandy mud covers the seabed to the east of Tai Yue Ngam Teng (595 274) (Figure 18). Seismic records indicate the existence of a denser basal unit up to 5 m thick, overlain by a more transparent unit about 8 m thick.

High Island and Rocky Harbour. Excavations for the High Island Reservoir determined that the formation was from 10 to 18 m thick down the centre of the Kwun Mun Channel (Kendall, 1975). At the site of the east dam the formation was from 7 to 8.5 m thick and comprised grey shelly and silty sands with gravel and cobbles (Yim, 1984). To the north, in Long Ke Wan, the formation is less than 5 m thick, consisting of a slightly silty fine sand at the seabed. The formation thickens to the southeast, reaching 20 m to the southeast of Wong Nai Chau (567 227). On the seabed the formation is a silty sand to about 1 km offshore but becomes muddy about 3 km offshore. The formation is sandy at seabed between Wong Nai Chau, Kong Tau Pai and Hole Island (Wang Chau).

In Rocky Harbour the formation thickens southwards from about 8 to 30 m, attaining a maximum thickness of 31 m in the centre of the channel off She Wan Kok (531 225). The formation thins to the southeast and is absent between Tung Sam Chau and Basalt Island (558 205) where bedrock crops out on the seabed. On the seismic profiles at least two distinct seismic units can be distinguished. The lower basal unit is characterised by a stronger seismic signature than the overlying unit. It is from 5 to 18 m thick. Several rounded, bank-like features with curved internal reflectors appear on the records in the northwest of the inlet. These are probably early marine sand banks. To the southeast the surface of the lower unit is distinctly channelled, with channels, up to 4 m deep and 80 m wide. Over these channels a thin unit, up to 5 m thick, appears between the lower and upper units. This intermediate unit has a high amplitude seismic signature with continuous reflectors that downwarp into the gullies, a feature indicating the effects of post-depositional consolidation of this probably sandy gully infill unit. The upper unit ranges from about 8 m to 18 m thick. It has a weak seismic signature with continuous reflectors typical of marine mud. The seabed is muddy in the upper reaches of Rocky Harbour north of Urn Island. Southwards the formation comprises a sandy mud between Tiu Chung Chau and She Wan Kok (530 225). Off Datum Beach the seabed is a muddy fine sand (528 238) and mud occurs at the seabed in the mouth of Chau Tsai (540 232). On the seabed the formation becomes increasingly sandy towards the north of Basalt Island. A silty sand occurs off Kei Tau Kok Teng (548 217), which rapidly becomes coarser southeastwards. Grab sampling north of Basalt Island yielded only a sparse recovery of fine sand and shell fragments, suggesting that the rock floor of this channel was largely swept clean by the strong tidal currents. Conversely, samples recovered from the floor of Sor See Mun include barnacle-encrusted pebbles and cobbles, up to 150 mm long, consisting of fine-ash vitric tuff in a sparse matrix of sand, gravel and shell fragments. Southeast of Basalt Island the formation rapidly thickens to more than 20 m. The formation is more than 25 m thick in the channel between Tiu Chung Chau and Bluff Island (530 205) where it fills a channel in the surface of the underlying Chek Lap Kok Formation.

Port Shelter and Inner Port Shelter. The formation is less than 5 m thick in Inner Port Shelter. On the eastern side of Port Shelter the formation thickens from less than 5 m to a little over 20 m. Three distinct units can be identified on the seismic records. The lower unit has a high amplitude seismic signature with curved and cross-cutting reflectors. It infills channels eroded on the upper surface of the Chek Lap Kok Formation. The middle unit has strong reflectors that are horizontal, parallel and continuous. The upper unit is seismically transparent. A maximum thickness of over 20 m is attained to the north and east of Shelter Island (Figure 20). Here the formation is a slightly sandy mud at seabed. Extensive littoral and sub-littoral sands are developed in this area, although the axial zones of the inter-island channels have mud at the seabed. The centres of the bathymetric channels to the east of Lo Fu Ngam (472 245) and at the northern end of Sam Nga Hau (497 270) have sandy silts on the seabed.

On the western side of Port Shelter the formation is thinner, generally being less than 15 m thick. Seismically the formation is transparent to the northwest towards Hebe Haven. West of Pak Ma Tsui (459 236) a lower unit with stronger continuous reflectors appears below it. It is up to 5 m thick. This unit extends to the southeast to overlie and infill channels in the upper surface of a third seismic unit which appears on the seismic records to the east of Pak Shui Wan (465 224). This basal unit displays denser, curved reflectors suggesting a possible early marine sandbank or sand sheet. The upper surface of this unit is eroded by channels up to 7 m deep. In Hebe Haven the formation is muddy at the seabed, but the narrow mouth is sandy. Here the formation reaches 10 m in thickness resting on a gullied surface of the underlying Chek Lap Kok Formation. To the west of Shelter Island the formation is less than 10 m thick, thinning against and over numerous seabed outcrops and bedrock highs. At seabed the formation becomes coarser southeastwards from Silverstrand towards Pak Pai (Duck Rocks). In Seung Sz Wan (484 187) the formation is less than 10 m thick (Figure 20) and is a slightly sandy silt at seabed. To the southeast of Pak Pai (503 186) thin sand and gravel covers bedrock.

Junk Bay, Joss House Bay and Tathong Channel. A bedrock threshold, devoid of any superficial deposits, floors Fat Tong Mun (487 134). Westwards the formation thickens rapidly to about 15 m (Figure 20). On the eastern side of Tai Miu Wan (Joss House Bay) the formation is a silty sand at seabed. Two 12 m long vibrocore holes have proved that this sand extends to between 1.5 m (VC 1/12) and 5 m (VC 1/11) below seabed, below which the formation is more muddy. The sand is coarse near Fat Tong Mun and only begins to fine about 750 m to the west.

The formation is up to 25 m thick in the eastern part of Junk Bay (Figure 20). Borehole evidence, including the type borehole of the Hang Hau Formation (4500 1800) (Strange & Shaw, 1986), indicates that the formation is muddy.

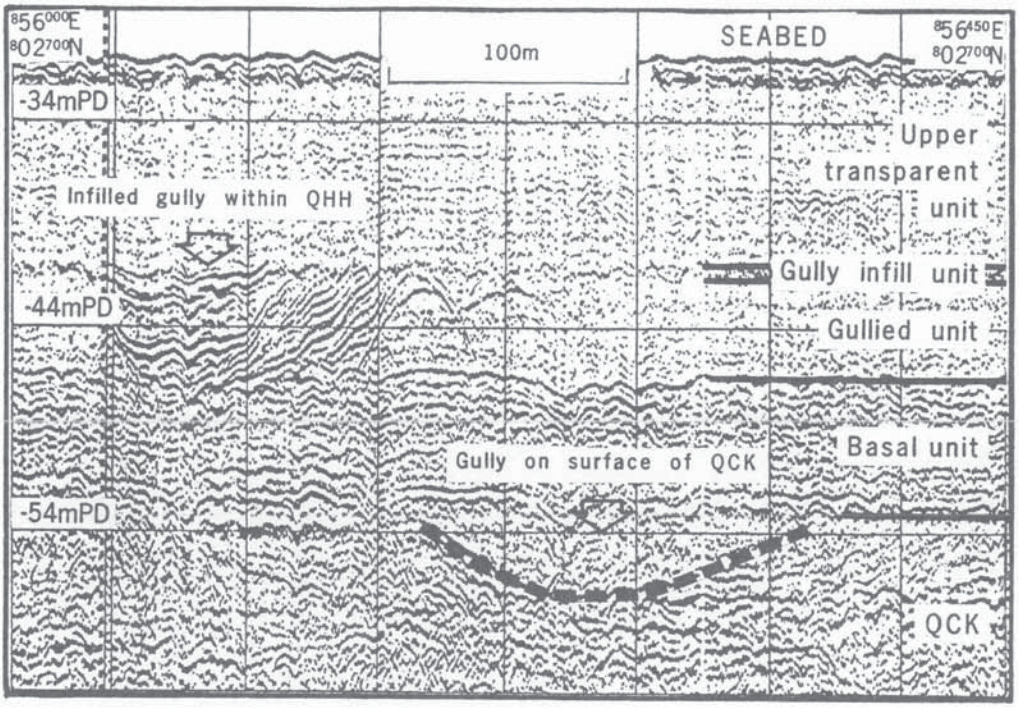


Plate 41 – Seismic Profile to Illustrate the Four Seismostratigraphic Units of the Hang Hau Formation (Seismic Line C26)

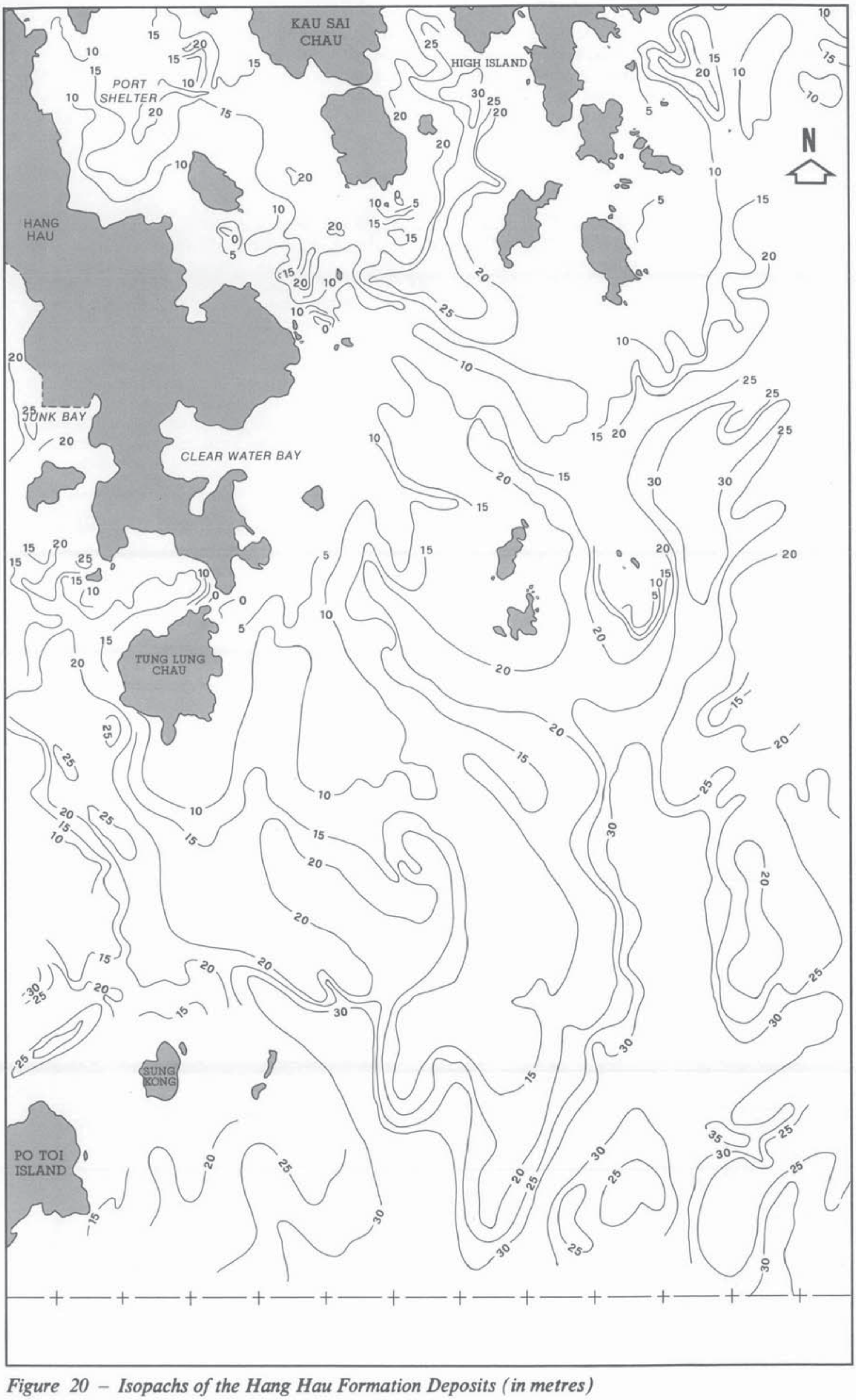


Figure 20 – Isopachs of the Hang Hau Formation Deposits (in metres)

In the Tathong Channel the formation is from 15 to 25 m thick, filling a channel in the surface of the underlying Chek Lap Kok Formation. Vibrocore evidence shows that the formation is a sandy silt to the west of Tit Cham Chau in the southern part of Junk Bay (VC 1/10), but becomes increasingly sandy southwards. Records from ten 12 m vibrocore holes in the Tathong Channel show that the sand varies from 1.3 m to at least 12 m thick and that the sand is predominantly medium to coarse with an appreciable content of fine gravel.

Southeastern Approaches and the Ninepin group including Clear Water Bay. In the western part of this area the formation thickens from 15 m to the southeast of Ching Chau (Steep Island) to 30 m southeast of Sung Kong Island (Figure 20). In the east the formation thickens rapidly from 15 to 20 m to the east of Basalt Island to 30 m to the east of the Ninepin group. In both cases the formation infills valleys in the surface of the underlying Chek Lap Kok Formation (Figure 15).

In Clear Water Bay, the formation is less than 5 m thick (Figure 20), and is dominated by sand on the seabed. To the southeast of Trio Island the formation is sandy at seabed. Southwest of the Ninepins a vibrocore (VC 1/27) has proved over 4 m of sand below the seabed, and two other holes (VC 1/23 and VC 1/26) have proved up to 7 m of sand below less than 1 m of mud. Southeast of the Ninepins the mud is sandy (33%).

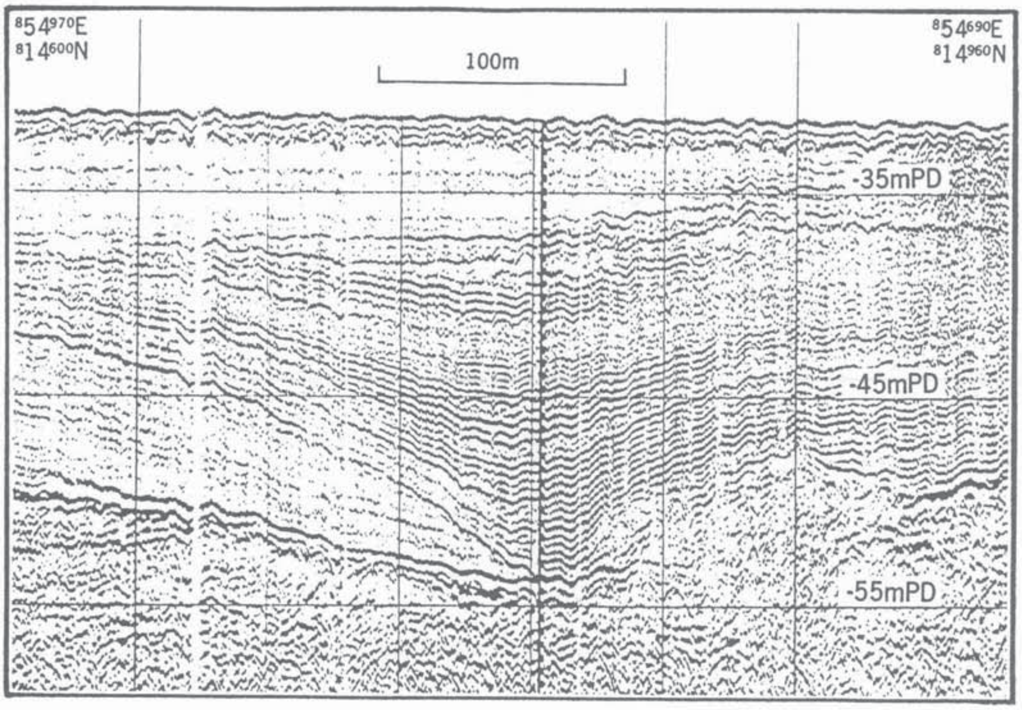


Plate 42 – Seismic Profile Showing a Deep Channel in the Hang Hau Formation, near the Ninepin Group (Seismic Line C10)

Over the remainder of this part of the district seven 12 m vibrocores, six seabed grab samples collected by the Hong Kong Geological Survey and eleven seabed grab samples collected by the Environmental Protection Department have confirmed that the seabed is muddy.

Seismic evidence indicates that the formation in this part of the district comprises at least four identifiable seismo-stratigraphic units (Plate 41). A basal unit with a fairly dense seismic signature is succeeded by a unit that is characterised by a uniform and continuous pattern of reflectors; the surface of this unit is gullied. A thin unit overlies the gullied unit, infilling the gullies. Finally, a fourth unit with a transparent seismic signature forms a cover up to 10 m thick in the south and east. Borehole evidence demonstrates that the basal unit comprises two lithological sub-units. A lower predominantly silty layer with sandy intercalations containing plant and black organic fragments is succeeded by an olive grey shelly sand. Together these sub-units represent respectively the intertidal deposits and basal transgressive sands of the Holocene marine transgression. The three overlying seismic units are muddy. The upper unit thins westwards and northwestwards, becoming more sandy in this direction. Deep channelling within the formation is clearly displayed on the seismic profiles in the area around the islands of the Ninepin Group. Here channels up to 10 m deep have been scoured and subsequently infilled with denser, probably sandy, sediments (Plate 42).

Age and Sedimentary Environment

Four radiocarbon dates have been determined for material from the Hang Hau Formation within the district. Two wood and two shell fragments were dated respectively at 6640 ± 100, 7830 ± 140, 7790 ± 90 and 7920 ± 110 yr BP from between −16.13 and −17.43 mPD (Kendall, 1975), confirming a Holocene age. Dates are available from other parts of the Territory. Organic material from near the base of the formation (−21.32 mPD) in the type borehole in Junk Bay has been dated at 8080 ± 130 yr BP (Strange & Shaw, 1986), and from the same horizon in a continuously sampled borehole in Deep Bay at 10060 ± 130 BP (Langford et al, 1989). Dates of 6520 ± 130 yr BP and 6580 ± 130 yr BP were obtained from the formation in Victoria Harbour (Meacham, 1978), and dates ranging from 520 ± 112 yr BP to 5475 ± 155 yr BP were recorded from the formation at sites in the northwestern New Territories (Langford et al, 1989).

Borehole and vibrocore evidence has indicated that, as in other parts of the Territory, the early stages of the Holocene marine transgression were characterised by the penetration of marine influences up the valleys eroded into the surface of the Chek Lap Kok Formation, depositing intertidal organic muds with sandy intercalations (Shaw, 1988, 1990; Shaw and Whiteside, 1988). This initial phase was succeeded by a period of strong tidal streaming that deposited and distributed basal marine sands or sandy muds, commonly as sand banks or sand sheets, before the deepening waters gave way to widespread mud deposition in the more open marine areas, and zones of sand and sandy mud in areas of stronger current activity.

Foraminiferal analyses of samples from the muds of the type borehole indicated four phases of marine deposition. The initial marine transgression was followed by a period of stable sea-level that was interrupted by a minor regression before a return to the prevailing shallow marine conditions (Strange & Shaw, 1986). Seismic evidence in the district indicates a four-fold subdivision of the formation in places, particularly in the southeast of the district (Shaw, 1990) (Plate 41). The existence of a gullied horizon within the formation suggests a change in conditions consistent with a minor regression. A similar erosional hiatus within the formation has been observed on seismic profiles from the East Lamma Channel (Strange & Shaw, 1986) and Urmston Road (Shaw, 1988).

Weathered Rocks and Sediments

An extensive residual mantle of weathered rock overlies the fresh rock of the district and effectively masks much of the solid geology. Only the minerals resistant to weathering survive. Thus the weathered mantle consists predominantly of quartz combined with the weathering alteration products of ferromagnesian and feldspathic minerals; most commonly in the form of limonitic and clay minerals respectively. The extent to which this mantle is developed depends upon the relative resistance to weathering of the different rock types, their relative position in the landscape and the geological structure.

The effect of weathering upon the different lithologies is broadly reflected in their relief. Fine-grained volcanic rocks tend to form higher and sharper peaks with fewer surface boulders, granite forms lower and more rounded peaks with surface boulders, exhumed corestones, more common. In general the fine-grained granites are more resistant to weathering than the coarser varieties.

Viewed on aerial photographs the topography of the district has a more rectilinear appearance than other areas of the Territory. Straight stream courses, long and continuous ridge crests and straight sections of coast are common. This is a reflection of the geological structure of the area, exploited by weathering and emphasised by erosion.

In general, weathering depths are comparatively shallow in the district in contrast to the deep profiles that occur over the granites in other parts of the Territory. As a result the deep and extensive gullied badland erosion that occurs in the northwest New Territories (Langford et al, 1989), in the Tai Mo Shan area (Addison, 1986) and on the hills of north Kowloon (Strange & Shaw, 1986), is virtually absent here and only isolated examples can be observed an aerial photographs. Corestones are largely restricted to the coarse ash tuffs of the Long Harbour and Tai Mo Shan Formations. The weathering characteristics of the district are largely confined to the topographic expression of the different rock types, reflecting their relative propensity to weathering. For example, the Clear Water Bay Formation contains resistant lava bands that produce well-defined escarpments, protecting the softer and more easily weathered tuffs. The development of multiple scarps is clearly displayed along the Clear Water Bay Peninsula. Between Mang Kung Uk and High Junk Peak a series of at least four west facing tiered scarps occur.

The coarse ash tuffs of the Tai Mo Shan and Long Harbour Formations are corestone forming. Corestones up to 3 m in diameter cover the northeastern and eastern slopes of Wong Chuk Yueng (462 295). Similarly the northern slopes of Mount Hallowes are littered with subrounded corestones (Plate 33). The ridge crests are surmounted by tors, which commonly have the appearance of imbricated piles of rectilinear blocks, and the valley floors are choked with corestones forming clast-supported boulder streams. In contrast the southern slopes of Mount Hallowes are almost completely devoid of corestones and the homogeneous weathered mantle is characterised by numerous mass movement scars (Plate 34).

Hydrothermal alteration of the lavas forming Sharp Peak has silicified the rock, producing extensive quartz veining which has resulted in the altered lavas being more resistant to weathering. The fine ash tuff of Kau Sai Chau has also been altered. In this area a 2 m to 6 m thick kaolin-rich weathered profile overlies soft rock.

The restricted outcrops of quartz syenite at the southern end of the Clear Water Bay Peninsula display weathering profiles that contain corestones (Plate 35). The matrix of the profile is generally bleached to cream or white with extensive staining by red oxides of iron.

A large variety of features of weathering interest occur at the macro-scale. For example the volcanic rocks of the High Island Formation exposed on the beach at Tai Miu Wan (478 146) display a wide range of sizes of weathering pits on boulder surfaces as well as upstanding resistant quartz veins. Differential weathering has picked out the structures and constituents of other volcanic rocks in the district. Autobrecciation in the rhyolitic lavas of the Clearwater Bay Formation is emphasised by differential weathering at Bate Head (Plate 8).

Flow-banding is commonly emphasised in lavas (Plates 3 and 7) as is the banding of the eutaxites (Plate 1). Fiammé in eutaxites are weathered-out to leave a honeycombed surface (Plate 1) with larger clasts standing above the surface. Differential weathering of vent agglomerate at Tai Miu Wan has clearly emphasised the constituent elements of the rock fabric (Plate 27). Corestones in granite are almost ubiquitously associated with curvilinear exfoliation shells. The same association can be observed in the coarse ash tuff of the Long Harbour Formation (Plate 36) and the quartz syenite (Plate 35), where concentric shells encase the fresher corestone nucleus.

Weathering has also affected the transported superficial deposits in the district. Many of the debris flow deposits display extensive weathering of the matrix, resulting in a secondary cementing. The constituent boulders commonly have weathered and exfoliating shells that can only have developed after transport as they are too fragile to have survived attrition during flow.

Offshore seismic profiling has demonstrated that a weathered mantle is developed on the surface of the rock below the superficial deposits but, in common with the onshore part of the district, this mantle appears to be thin and discontinuous. This is in marked contrast to the thick and extensive weathered profiles developed on the granites onshore (Strange & Shaw, 1986).

Three continuously sampled boreholes have been drilled through the Chek Lap Kok Formation sediments in the district (Appendix). As elsewhere in the Territory many of the clayey and silty sediments of the formation are strongly weathered and mottled (Shaw, 1985, 1986; Strange & Shaw, 1986; Langford et al, 1989). This is a penecontemporaneous or post-depositional process, indicating exposure to sub-aerial weathering either during or after deposition.

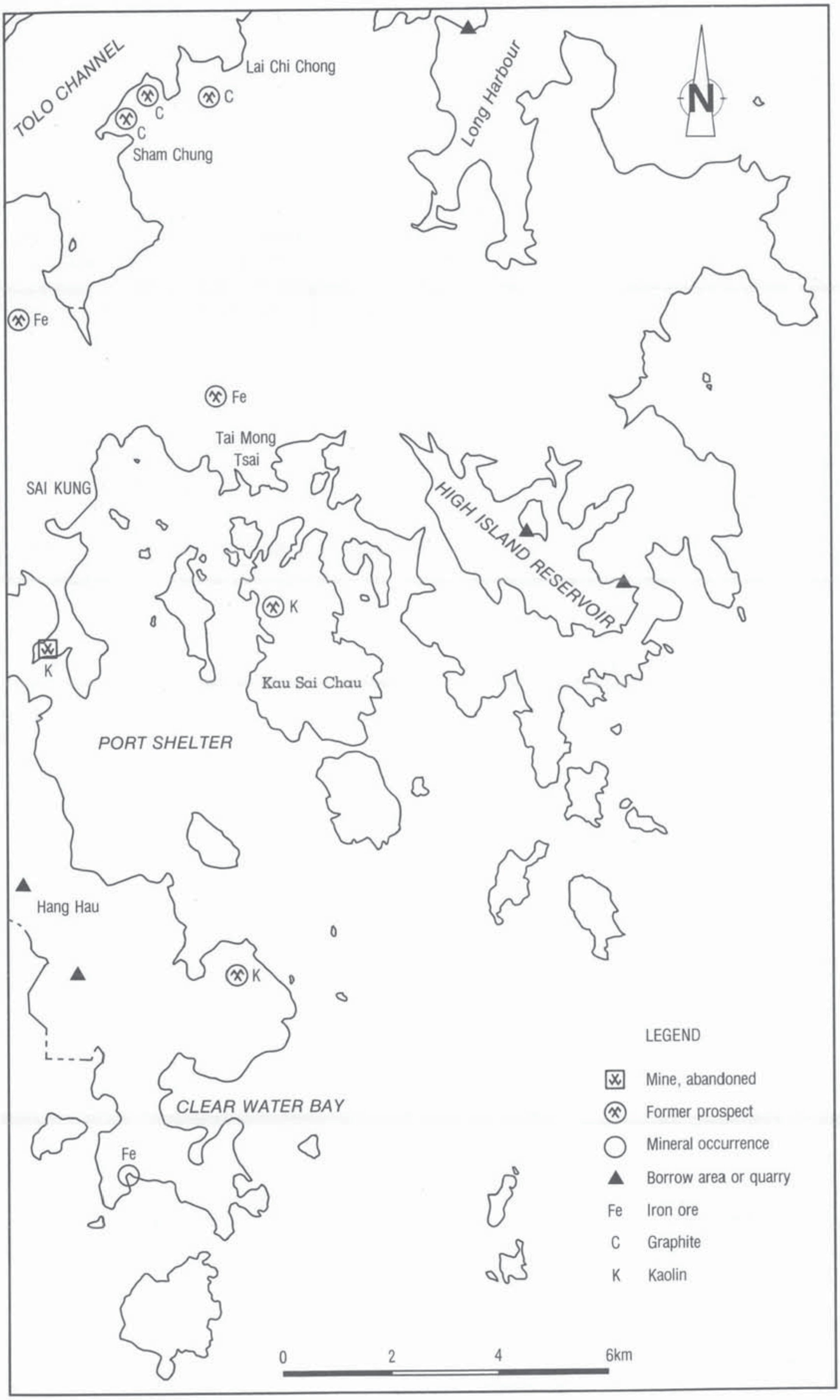


Figure 21 – Economic Geology of the District

Chapter 9
Economic Geology

Classification

This account of the economic geology of the district consists of two sections, dealing with metalliferous and associated minerals for which mining or prospecting licences were issued, and bulk minerals worked for borrow material or construction aggregates.

Metalliferous and Associated minerals

Metalliferous minerals and associated minerals such as feldspar, kaolin and quartz are covered by the Mining Ordinance and permission to prospect or work these deposits is granted in the form of prospecting or mining licences respectively.

Kaolin and Clay

Clay was formerly worked at Ma Nam Wat (445 244), where a 50 m thick highly weathered tuffaceous mudstone layer within the Silverstrand tuffs provided material for a tile manufacturing works at Sha Tsui Pier (454 245). Although the mining licence included permission to work quartz, there is no evidence of significant quantities of quartz in the rock.

On the western side of Kau Sai Chau (495 255), prospecting for kaolin was carried out in an area of deeply weathered High Island Formation tuff. Patchy weathering to a depth of 8 to 10 m in this fine ash tuff has produced a white clay. Similarly weathered High Island tuff was prospected near Lung Ha Wan (492 188), Clear Water Bay Peninsula, but no mining has taken place.

Graphite

Mining licences were formerly granted for the working of graphite between Lai Chi Chong and Sham Chung, presumably from the carbonaceous-rich sedimentary rocks of the Tolo Channel Formation and the carbonaceous-bearing horizons within the Lai Chi Chong Formation. No significant excavations were noted during the present survey and there is no evidence to support any economic quantities of graphite being present in these rocks.

Iron

A prospecting licence for iron ore was issued for the area between Wong Mo Ying and Tai Mong Tsai (487 287), but there are no signs of iron mineralisation in the area except for heaps of iron slag along the shoreline near the Outward Bound School (4863 2782). There is a possibility that some haematite mineralisation is associated with the nearby quartz syenite intrusion, similar to that at Tai Miu Wan (4714 1476), where haematite crops out on the beach adjacent to a quartz syenite intrusion.

With the discovery of the large magnetite ore body at Ma On Shan (Sheet 7), a series of prospecting licences was extended northeastwards to the shores of Three Fathoms Cove, in the vicinity of Shap Sz Heung (453 306). No mineralisation of the skarn type, as found at Ma On Shan, has been reported however.

Bulk Deposits—Borrow or Aggregate Workings

A borrow area at Nam Fung Shan (535 359), on the northern side of Long Harbour, extracted large quantities of weathered coarse ash tuff of the Long Harbour Formation for use in the Sha Tin area reclamation projects. The material was shipped by barge to Tolo Harbour. The workings have now been reinstated and landscaped.

The High Island Water Scheme required considerable quantities of rock for the dam constructions, which mostly came from quarries in High Island Formation tuff on the northeast side of the reservoir site (544 267), (565 254). Since the columnar-jointed tuff only produced blocks up to 1.2 m in diameter, it was necessary to import some larger blocks of granite from Turret Hill Quarry, Sha Tin, for sea wall construction.

Around Junk Bay, major reclamation works have necessitated the extraction of large quantities of rock, mostly from fine ash tuff of the Ap Lei Chau Formation. The hard fresh fine ash vitric tuff has been quarried extensively to the west of Hang Hau Town (454 199). South of Hang Hau the reclamation projects, including the Junk Bay Controlled Tip site, were constructed using material removed from hill top borrow areas near Pak Shin Kok (461 186). Here, the weathered tuff together with fresh eutaxitic tuff of the Silverstrand Formation comprise the dominant lithology.

References

Addison, R. (1986). *Geology of Sha Tin, 1:20 000 Sheet 7*. Geotechnical Control Office, Hong Kong, 85 p. (Hong Kong Geological Survey Memoir, No. 1).

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

Atherton, M.J. (1983). Devonian fish experts visit Hong Kong. *Geological Society of Hong Kong Newsletter*, vol. 1, no. 3, 1 p.

Atherton, M.J. (1989). Palaeontologists from the Nanjing University Institute of Geology and Palaeontology: Recent Fossil Finds in Hong Kong. *Geological Society of Hong Kong Newsletter*, vol. 7 no. 2, pp 42–43.

Bates, R.L. & Jackson, J.A. (1980). *Glossary of Geology*. American Geological Institute, Falls Church, Virginia, 749 p.

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

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

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

Berry, L. (1962). The physical background to Hong Kong soils. In: *Symposium on Hong Kong Soils*, P. Lumb, editor, Hong Kong Joint Group of The Institutions of Civil, Mechanical and Electrical Engineers, Hong Kong, pp 1–8 (plus 1 drg).

Berry, L. & Ruxton, B.P. (1959). Notes on weathering zones and soils on granitic rocks in two tropical regions. *Journal of Soil Science*, vol. 10, pp 54–63.

Berry, L. & Ruxton, B.P. (1960). The evolution of Hong Kong Harbour basin. *Zeitschrift fur Geomorphologie*, vol. 4, no. 2, pp 97–115.

Brand, E.W. (1988). *Bibliography on the Geology and Geotechnical Engineering of Hong Kong to December 1987*. Geotechnical Control Office, Hong Kong, 149p. (GCO Publication No. 1/88).

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

Brock, R.W. (1943). Weathering of igneous rocks near Hong Kong. *Bulletin of the Geological Society of America*, vol. 54, pp 717–738.

Brock, R.W. & Schofield, S.J. (1926). The geological history and metallogenetic epochs of Hong Kong. *Proceedings of the Third Pan-Pacific Science Congress*, Tokyo, vol. 1. pp 576–581.

Brock, R.W., Schofield S.J., Williams, M.Y. & Uglow, W.L. (1936). *Geological Map of Hong Kong (1:84 480)*. Ordnance Survey, Southampton.

British Standards Institution (1981). *Code of Practice for Site Investigations, BS 5930:1981*, British Standards Institution, London, 147 p.

Burnett, A.D. & Lai, K.W. (1985). A review of photogeological lineaments in Hong Kong. In: *Geological Aspects of Site Investigation*, I. McFeat-Smith, editor, Geological Society of Hong Kong Bulletin, no. 2, pp 113–131.

Chalmers, M.L. (1984). Preliminary assessment of sedimentation in Victoria Harbour, Hong Kong. In: *Geology of Surficial Deposits in Hong Kong*, W.W.S. Yim, editor, Geological Society of Hong Kong Bulletin, no. 1, pp 117–129.

Cox, K.G., Bell, J.D. & Pankhurst, R.J. (1979). *The Interpretation of Igneous Rocks*. George Allen and Unwin, London, 450 p.

Dale, M.J. & Nash, J.M. (1984). The occurrence of silicified wood in the Repulse Bay Formation sediments at Lai Chi Chong, New Territories, Hong Kong. *Geological Society of Hong Kong Newsletter*, vol. 2, no. 3, pp 1–4.

Davis, S.G. (1952). *The Geology of Hong Kong*. Government Printer, Hong Kong, 231 p. plus 14 plates and 3 maps.

Ekren, E.B. & byers, F.M. (1976). Ash-flow fissure vent in west-central Nevada. *Geology*, vol. 4, pp 247–251.

Evans, C.D.R. (1986). Holocene marine sedimentation and erosion in Hong Kong—evidence from seismic profiles. In: *Sea-level Changes in Hong Kong during the Last 40 000 years*, Geological Society of Hong Kong and University of Hong Kong Abstracts, no. 3, pp 37–38.

Evans, C.D.R. (1987). Seismo-stratigraphy of early Holocene sandbanks. In: *Marine Sand and Gravel Resources of Hong Kong*, P.G.D. Whiteside & N. Wragge-Morley, editors, Geological Society of Hong Kong, pp 45–52.

Fisher, R.V. & Schmincke, H.U. (1984). *Pyroclastic Rocks*. Springer-Verlag, New York, 472 p.

Francis, P.W., O'Callaghan, L., Kretzchmar G.A., Thorpe, R.S., Sparks, R.S.J., Page, R.N., de Barrio, R.E., Gillou, G. and Gonzalez, O.E. (1983). The Cerro Galan ignimbrite. *Nature* 301, 51–3.

Geotechnical Control Office (1982). *Mid-levels Study: Report on Geology, Hydrology and Soil Properties*. Geotechnical Control Office, Hong Kong, 2 vols, 266 p. plus 54 drgs.

Geotechnical Control Office (1988a). *Guide to Rock and Soil Descriptions (Geoguide 3)*. Geotechnical Control Office, Hong Kong. 189 p.

Geotechnical Control Office (1988b). Geotechnical Area Studies Programme—Clear Water Bay. *Geotechnical Control Office, Hong Kong, GASP Report* no. VII, 144 p. plus 4 maps.

Geotechnical Control Office (1988c). Geotechnical Area Studies Programme—North East New Territories. *Geotechnical Control Office, Hong Kong, GASP Report* no. VIII, 144 p. plus 4 maps.

Geotechnical Control Office (1988d). Geotechnical Area Studies Programme—East New Territories. *Geotechnical Control Office, Hong Kong, GASP Report* no. IX, 141 p. plus 4 maps.

Grant, C.J. (1960). *The Soils and Agriculture of Hong Kong*. Government Printer, Hong Kong, 154 p.

Hatch, F.H., Wells, A.K. & Wells, M.K. (1972). *Petrology of the Igneous Rocks*. George Allen and Unwin, London, 531 p.

Heanley, C.M. (1924). Notes on some fossiliferous rocks near Hong Kong. *Bulletin of the Geological Society of China*, vol. 3, no. 1, pp 85–87.

Heim, A. (1929). Fragmentary observations in the region of Hong Kong, compared with Canton. *Geological Survey of Kwangtung & Kwangsi, Annual Report*, vol. 2, pp 1–32 (plus 1 p. errata).

Howat, M.D. (1985). A nearshore colluvial deposit in Western District, Hong Kong Island. *Geological Society of Hong Kong Newsletter*, vol. 3, no. 6, pp 6–12.

Huang, T.K. (1960). The main characteristics of the structure of China: preliminary conclusion. *Scientia Sinica*, vol. 9, no. 4, pp 492–44.

Huang, T.K. (1978). An outline of the tectonic characteristics of China. *Eclogae Geologica Helvetica*, vol. 71, pp 611–635.

Kendall, F.H. (1975). High Island—a study of undersea deposits. *Journal of Hong Kong Archaeological Society*, vol. 6, pp 26–32.

Kingsmill, T.W. (1862). Notes on the geology of the east coast of China. *Journal of the Geological Society of Dublin*, vol. 10, pp 1–6.

Lai, K.W. (1982). Discussion on the colluvium of Hong Kong. *Hong Kong Baptist College Academic Journal*, vol. 9, pp 139–158.

Lai, K.W. (1986). A review of the Late Cretaceous Palaeogene fault basins around Hong Kong. *The Geography Bulletin (Hong Kong)*, no. 17, pp 38–47. (In Chinese).

Lai, K.W. & Taylor, B.W. (1983). The classification of colluvium in Hong Kong. In: *Geology of Surficial Deposits in Hong Kong*, W.W.S. Yim, editor, Geological Society of Hong Kong Bulletin, no. 1, pp 75–85.

Langford, R.L., Lai, K.W., Arthurton, R.S. and Shaw, R. (1989): *Geology of the Western New Territories, 1:20 000 Sheets 2, 5 and 6*. Hong Kong Geological Survey memoir No. 3, Hong Kong Government Printer, 140 p.

Le Bas, M.J., Le Maitre, R.W., Streckeisen, A. and Zanettin, B. (1986). A Chemical Classification of Volcanic Rocks Based on the Total Alkali-Silica Diagram. *Journal of Petrology*, Vol 27, Part 3, pp 745–750.

Lee, C.M. (1982). The occurrence of a Devonian Placodermi fish fossil in Hong Kong. *The Geography Bulletin* (Hong Kong), no. 16, pp 101–103 (Chinese), 104–106 (English), and 117–118 (plates). (Abstract reprinted in *Geological Society of Hong Kong Newsletter*, vol. 1, 1983, no. 4, 2 p).

Lee, C.M. (1984a). Lower Jurassic fossil assemblages at Sham Chung, New Territories, Hong Kong. *Geological Society of Hong Kong Newsletter*, vol. 2, no. 6, pp 1–5.

Lee, C.M. (1984b). Preliminary studies on Lower Jurassic fossil assemblages from Sham Chung, NT, Hong Kong (Abstract). *Abstracts of the Conference on Geological Aspects of Site Investigation*, Hong Kong, pp 28–29. (Published as *Geological Society of Hong Kong, Abstracts* no. 2, edited by W.W.S. Yim & I. McFeat-Smith, 1984).

Lee, C.M. (1985). Explanatory notes by C.M. Lee on his stratigraphic column in Table 1. *Geological Society of Hong Kong Newsletter*, vol. 3, no. 4, pp 8–9.

Lumb, P. (1962a). General nature of the soils of Hong Kong. In: *Symposium on Hong Kong Soils*, P. Lumb, editor, Hong Kong Joint Group of The Institutions of Civil, Mechanical and Electrical Engineers, Hong Kong, pp 19–31.

Lumb, P. (1962b). The properties of decomposed granite. *Geotechnique*, vol. 12(3), pp 226–243 (plus 2 plates).

Lumb, P. & Lee, C.F. (1975). Clay Mineralogy of the Hong Kong soils. *Proceedings of the Fourth Southeast Asian Conference on Soil Engineering*, Kuala Lumpur, pp 1.41–1.50.

Meacham, W. (1978). Sham Wan, Lamma Island : site formation and geohistory. *Journal Monograph III, Hong Kong Archaeological Society*, pp 51–56.

Meacham, W. (1979). Dates on kiln sites in Hong Kong. *Journal of the Hong Kong Archaeological Society*, vol. 7, p 117.

Meacham, W. (1986). Archaeological evidence of higher sea-levels in Hong Kong. In: *Sea-level Changes in Hong Kong during the Last 40 000 years*, Geological Society of Hong Kong and University of Hong Kong Abstracts, no. 3, pp 31–33.

Morton, A.C. (1988). A preliminary assessment of the potential application of heavy mineral analysis to lithostratigraphic problems in Hong Kong. *British Geological Survey Stratigraphy Series Technical Report* WH/88/67R, 16 p.

Nan, Y. (1979). *Stratigraphy of Guangdong*. Guangdong Institute of Geology, Guangzhou, pp 25–31. (In Chinese).

Nau, P.S. (1980). Fossil plant from Ma Shi Chau Island, Hong Kong—a preliminary note. *Annals of the Geographical, Geological & Archaeological Society, University of Hong Kong*, no. 8, pp 27–32.

Nau, P.S (1984a). Note on Ammonites (Arietitidae) from Sham Chung, Tolo Channel. *Geological Society of Hong Kong Newsletter*, vol. 2, no. 6, pp 6–8.

Nau, P.S. (1984b). Note on Lower Jurassic marine strata along shoreline north of Sham Chung Wan, Tolo Harbour, H.K. *Annals of the Geographical, Geological & Archaeological Society, University of Hong Kong*, no. 12, pp 74–85.

Nau, P.S. (1986a). Upper Triassic strata along the shoreline at Nai Chung ferry pier, Nai Chung, New Territories, Hong Kong. *Geological Society of Hong Kong Newsletter*, vol. 4, no. 1, pp 7–12.

Nau, P.S. (1986b). Discussion on the age of the rock sequence on the coast north of Lai Chi Chong, New Territories, Hong Kong. *Geological Society of Hong Kong Newsletter*, vol. 4, no. 3, pp 1–4.

Parham, W.E. (1969). Halloysite-rich weathering products of Hong Kong. Proceedings of the International Clay Conference, Tokyo, vol. 1, pp 403–416.

Peng, C.J. (1978). *Hong Kong Minerals*. Hong Kong Government Printer, 80 p. (English version and Chinese version).

Reedman, A.J., Park, K.H., Merriman, R.J. & Kim, S.E. (1987). Welded tuff infilling a volcanic vent at Weolseong, Republic of Korea. *Bulletin of Volcanology*, vol. 49, pp 541–546.

Ruxton, B.P. (1960). The geology of Hong Kong. *Quarterly Journal of the Geological Society of London*, vol. 115, pp 233–260 (plus 2 plates & 1 map).

Ruxton, B.P. (1968). Measures of the degree of chemical weathering of rocks. *Journal of Geology*, vol. 76, pp 518–527.

Ruxton, B.P. (1980). Slope problems in Hong Kong a geological appraisal. *Hong Kong Engineers*, vol. 8, no. 6, pp 31–39.

Ruxton, B.P. & Berry, L. (1957). Weathering of granite and associated erosional features in Hong Kong. *Bulletin of the Geological Society of America*, vol. 68, pp 1263–1291 (plus 1 plate).

Ruxton, B.P. & Berry, L. (1959). The basal rock surface on weathered granitic rocks. *Proceedings of the Geologists' Association*, vol. 70, part A, pp 285–290.

Ruxton, B.P. & Berry, L. (1961). Weathering profiles and geomorphic position on granite in two tropical regions. *Revue geomorphologie Dynamique*, vol. 12, pp 16–31.

Schmid, R. (1981). Descriptive nomenclature and classification of pyroclastic deposits and fragments: Recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks. *Geologische Rundschau*, vol. 70, pp 794–799.

Shaw, R. (1985). Preliminary interpretations of the Quaternary Stratigraphy of the eastern part of the Pearl River esturary. In: *Marine Geology of Hong Kong and the Pearl River Mouth,* P.G.D. Whiteside & R.S. Arthurton, editors, Geological Society of Hong Kong, pp 61–65.

Shaw, R. (1987). Offshore Quaternary Geology in Hong Kong. In: *Progress in Quaternary Geology of East and Southeast Asia,* F.W. Wezel & J.L. Rau, editors, CCOP, pp 283–292.

Shaw, R. (1988): The nature and occurrence of sand deposits in Hong Kong Waters. *Proceedings of the Seminar on Marine Sources of Sand*, Geological Society of Hong Kong, Hong Kong, pp 33–43.

Shaw, R. (1990) : Recent advances in Late Quaternary stratigraphical interpretation of Hong Kong's offshore area. *Proceedings of the First International Conference on Asian Marine Geology*, Shanghai (In Preparation).

Shaw, R. & Arthurton, R.S. (1988). Palaeoenvironment interpretation of offshore Quaternary sediments in Hong Kong. In: *The Palaeoenvironment of East Asia from the Mid-Tertiary*, University of Hong Kong, pp 138–150.

Shaw, R. and Whiteside, P.G.D. (1988): *Sources of Sand and Gravel in Hong Kong Waters : Final Report* Planning Report PR 1/88, Geotechnical Control Office, Hong Kong Government, 70 p.

Shaw, R., Zhou, K., Gervais, E. & Allen, L.O. (1986). Results of a palaeontological investigation of the Chek Lap Kok Borehole (B13/B13A), North Lantau. *Geological Society of Hong Kong Newsletter*, vol. 4, no. 2, pp 1–12.

Smith, R.L. (1979). Ash-flow magmatism. *Geological Society of America Special Paper No. 180*, pp 5–27.

Sparks, R.S.J. & Wilson, L. (1976). A model for the formation of ignimbrite by gravitational column collapse. *Journal of the Geological Society of London*, vol. 132, pp 441–451.

Strange, P. J. (1985). Towards a simpler classification of the Hong Kong granites. Geological Aspects of Site Investigation. In: *Geological Aspects of Site Investigation,* I. McFeat-Smith, editor, Geological Society of Hong Kong Bulletin, no. 2, pp 99–103.

Strange, P.J. (1986). High level beach rock on Hong Kong Island. *Hong Kong Geological Society Newsletter*, vol. 4, no. 2, pp 13–16.

Strange, P.J. (1987). Petrological aspects of the Hong Kong quartz syenites. *Geological Society of Hong Kong Newsletter*, vol. 5, no. 2, pp 3–8.

Strange, P.J. (1988). The geology of Tai Miu Wan (Joss House Bay), Clear Water Bay. *Geological Society of Hong Kong Newsletter*, vol. 6, pp 33–38.

Strange, P.J. & Shaw, R. (1986). *Geology of Hong Kong Island and Kowloon*. Geotechnical Control Office, Hong Kong, 134 p. (Hong Kong Geological Survey Memoir No. 2).

Streckeisen, A. (1967). Classification and nomenclature of igneous rocks. *Neues Jahrbu Miner. Abh*, vol. 107, pp 144–240.

Streckeisen, A. (1974). Classification and nomenclature of plutonic rocks. Recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks. *Geologische Rundschau*, vol. 63, pp 773–786.

Streckeisen, A. (1980). Classification and nomenclature of volcanic rocks, lamprophyres, carbonatites and melititic rocks: IUGS Subcommission on the Systematics of Igneous rocks. *Geologische Rundschau*, vol. 69, pp 194–207.

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

Tam, S.W. & Chan, Y.M. (1982). Late Jurassic ash-flow tuffs in the eastern part of Hong Kong, South China. *Chinese University of Hong Kong, Department of Geography, Occasional Paper* no. 34, 41 p.

Tam, S.W. & Chan, Y.M. (1983). Late Jurassic ash-flow tuffs in the eastern parts of Hong Kong, South China. *Asian Geographer*, vol. 2, no. 1, pp 47–69.

Tam, S.W. (1970). *Landform in Sai Kung Peninsula and the Adjacent Islands*. MA Thesis, Hong Kong University, 240 p.

Uglow, W.L. (1926). *Geology and mineral resources of the Colony of Hong Kong*. Government of Hong Kong, Legislative Council Sessional Papers for 1926, pp 73–77.

Vail, A.J., Lee, G.A. & Robertson, I.R.S. (1976). Some aspects of the construction of the High Island Scheme. *Hong Kong Engineer*, vol. 4, no. 4, pp 53–63.

Varnes, D.J. (1978). Slope movement types and processes. *Landslides, Analysis and Control. Transportation Research Board, National Research Council, Special Report No. 176*, edited by R.L. Schuster and R.J. Krizek, pp 11–33.

Wai, C.C. (1986). A note on the discovery of fossil wood found in the Repulse Bay Formation sediments at Cheung Sheung, Sai Kung, New Territories, Hong Kong. *Geological Society of Hong Kong Newsletter*, vol. 4, no. 3, pp 5–7.

Walker, G.P.L. (1984). Downsag calderas, ring faults, caldera sizes, and incremental caldera growth. *F. Geophys. Res.* 89, 8407–16.

Wang, P. and Yim, W.W.S. (1985). Preliminary investigation on the occurrence of marine microfossils in an offshore drillhole from Lei Yue Mun Bay. *Geological Society of Hong Kong Newsletter*, vol. 3, no. 1, pp 1–5.

Watkins, M.D. (1979). Engineering geological mapping for the High Island water scheme in Hong Kong. *Proceedings of the Symposium on Engineering Geological Mapping*, Newcastle-upon-Tyne. (Published in *Bulletin of the International Association of Engineering Geology*, no. 19, pp 166–175).

Williams, M.Y. (1943). The stratigraphy and palaeontology of Hong Kong and the New Territories. *Transactions of the Royal Society of Canada*, third series, vol. 37, sect. IV, pp 93–117.

Williams, M.Y., Brock, R.W., Schofield, S.J. & Phemister, T.C. (1945). The physiography and igneous geology of Hong Kong and the New Territories. *Transactions of the Royal Society of Canada*, third series, vol. 39 sect. V, pp 91–119.

Workman, D.R. (1985). An exposure of welded tuff at Mount Kellett. *Geological Society of Hong Kong Newsletter*, vol. 3, no. 4, pp 3–7.

Yim, W.W.S. (1983). A sedimentological study of the sea-floor sediments exposed during excavation of the East Dam site, High Island, Sai Kung. *Proceedings of the Meeting on Geology of Surficial Deposits in Hong Kong*, Hong Kong, pp 131–142. (Published as *Geological Society of Hong Kong, Bulletin* no. 1, edited by W.W.S. Yim, 1984). (Abstract published in *Geological Society of Hong Kong, Abstracts* no. 1, 183, pp 28).

Yim, W.W.S. (1984). Evidence for Quaternary environmental changes from sea-floor sediments in Hong Kong. *The Evolution of the Asian Environment*, vol. 1, pp 137–155.

Yim, W.W.S., Nau, P.S. & Rosen, B.R. (1981). Permian corals in the Tolo Harbour Formation, Ma Shi Chau, Hong Kong. *Journal of Palaeontology*, vol. 55, pp 1298–1300.

Appendix

Continuously Sampled Boreholes through Offshore Superficial Deposits

The following are abridged logs of boreholes sunk by the Geotechnical Control Office for the SEAMAT study, a Territory-wide investigation to locate offshore deposits of sand and gravel for reclamation fill and aggregates.

Borehole	Southwest of the Ninepin Group C2/1
Grid Ref.	5155 1000
Surface level	–29.36 mPD
Superficial deposits	69.45 m
Bedrock	Not reached
Date drilled	August, 1989

Geological Classification	Lithology	Thickness, m	Depth in Hole, m	Reduced Level, mPD
Hang Hau Formation	SILT; clayey, fine sand, shelly (shells mostly broken), olive grey; soft	4.45	4.45	–33.81
	SAND; fine to medium, clayey, silty, with silty clay bands, shell fragments, sparse plant remains, olive grey to yellow brown; dense to very dense	15.45	19.90	–49.26
	SILT; clayey, fine sand bands, olive grey; firm to stiff	4.05	23.95	–53.31
Chek Lap Kok Formation	SAND; medium to coarse, yellow brown; dense	0.95	24.90	–54.26
	CLAY; silty, fine sand in bands, blue grey; firm to stiff	6.50	31.40	–60.76
	SAND; fine, clay, silty (silty clay bands up to 1.00 m), blue grey with brown and red patches; medium dense	6.80	38.20	–67.56
	CLAY; silty, fine sand, olive grey with brown mottles; firm to stiff	2.25	40.45	–69.81
	SAND; fine to coarse, silty, sparse gravel, whitish grey; dense	5.20	45.65	–75.01
	CLAY; silty, fine to medium sand, white with red mottles; very stiff	5.55	51.20	–80.56
	SAND; medium to coarse, silty, clayey, creamy white to light brown; very dense	3.05	54.25	–83.61
	CLAY; silty, sparse fine sand, white with yellow brown and red mottles; stiff to very stiff	13.40	67.65	–97.01
	SAND; fine to medium, clayey, silty, yellowish brown; dense	1.80	69.45	–98.81

*Base of the Formation was not reached

Borehole	Southwest of the Ninepin Group C2/2
Grid Ref.	5799 1117
Surface level	–30.41 mPD
Superficial deposits	73.80 m thick
Bedrock	–104.21 mPD
Date drilled	July/September, 1989

Geological Classification	Lithology	Thickness, m	Depth in Hole, m	Reduced Level, mPD
Hang Hau Formation	SILT; clayey, fine sand (Sand increasing lower down), olive grey, shelly (shells mostly broken); soft becoming firm lower down	11.80	11.80	–42.21
	SAND; medium to coarse with fine sand layers, silty, olive grey, shelly; very loose to medium dense	4.15	15.95	–46.36
	SILT; clayey, olive grey, interlaminated with fine sand bands, black organic fragments; firm	4.35	20.30	–50.71
Chek Lap Kok Formation	SAND; fine to medium with layers of coarse sand and fine gravel, silty with silty clay pockets and bands, rare plant fragment bands, yellow brown to grey brown, mottled; loose to very dense	13.50	33.80	–64.21
	CLAY; silty, dark blue grey to olive grey, layers and pockets of yellow brown fine sand; firm	5.75	39.55	–69.96
	SAND; fine to medium with some coarse sand layers, silty with clayey silt pockets and layers, bands of sparse plant fragments, yellow brown with light grey and creamy white horizons; medium dense to dense	34.25	73.80	–104.21
Granite?	GRANITE?; medium-grained rock with quartz megacrysts in yellow-brown clay; completely weathered	1.15	74.95	105.36

Borehole	North of the Ninepin Group C2/3
Grid Ref.	5384 1606
Surface level	–28.70 mPD
Superficial deposits	53.85 m thick
Bedrock	–82.55 mPD
Date drilled	July, 1989

Geological Classification	Lithology	Thickness, m	Depth in Hole, m	Reduced Level, mPD
Hang Hau Formation	SILT; clayey, shelly (shells mostly broken), olive grey; soft to firm	4.45	4.45	–33.15
	SAND; fine, silty, shelly, olive grey, medium dense	3.75	8.20 m	–36.90
	SILT; clayey, fine sand bands, shelly, olive grey; soft	10.15	18.35	–47.05

Geological Classification	Lithology	Thickness, m	Depth in Hole, m	Reduced Level, mPD
Chek Lap Kok Formation	SAND; fine to medium, silty, clayey with silty clay pockets, sand becoming coarser lower down, light grey to brownish grey; dense to very dense	8.40	26.75	–55.45
	CLAY; silty, fine to coarse sand as pockets and bands, rare bands of plant and wood fragments, blue grey to brownish grey with brown mottles; firm to stiff	17.95	44.70	–73.40
	SAND; medium to coarse, clayey, sparse gravel, grey to brownish grey; medium dense to dense	1.45	45.15	–74.85
	CLAY; silty, medium to coarse sand, scattered plant remains, blue grey to olive grey with brown patches; firm to stiff	2.65	48.80	–77.50
	SAND; medium to coarse, silty clay pockets and bands with rare plant remains, sparse gravel, brownish grey; very dense	5.05	53.85	–82.55
High Island Formation	TUFF; fine ash, quartz crystals in a grey white silty clay; completely weathered	1.10	54.95	–83.65

Index

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

HK$87 (US$13 including surface postage)
P59120004E0
ISBN 962-02-0083-7

Printed and Published by the Government Printer, Hong Kong 185918—26L—3/90