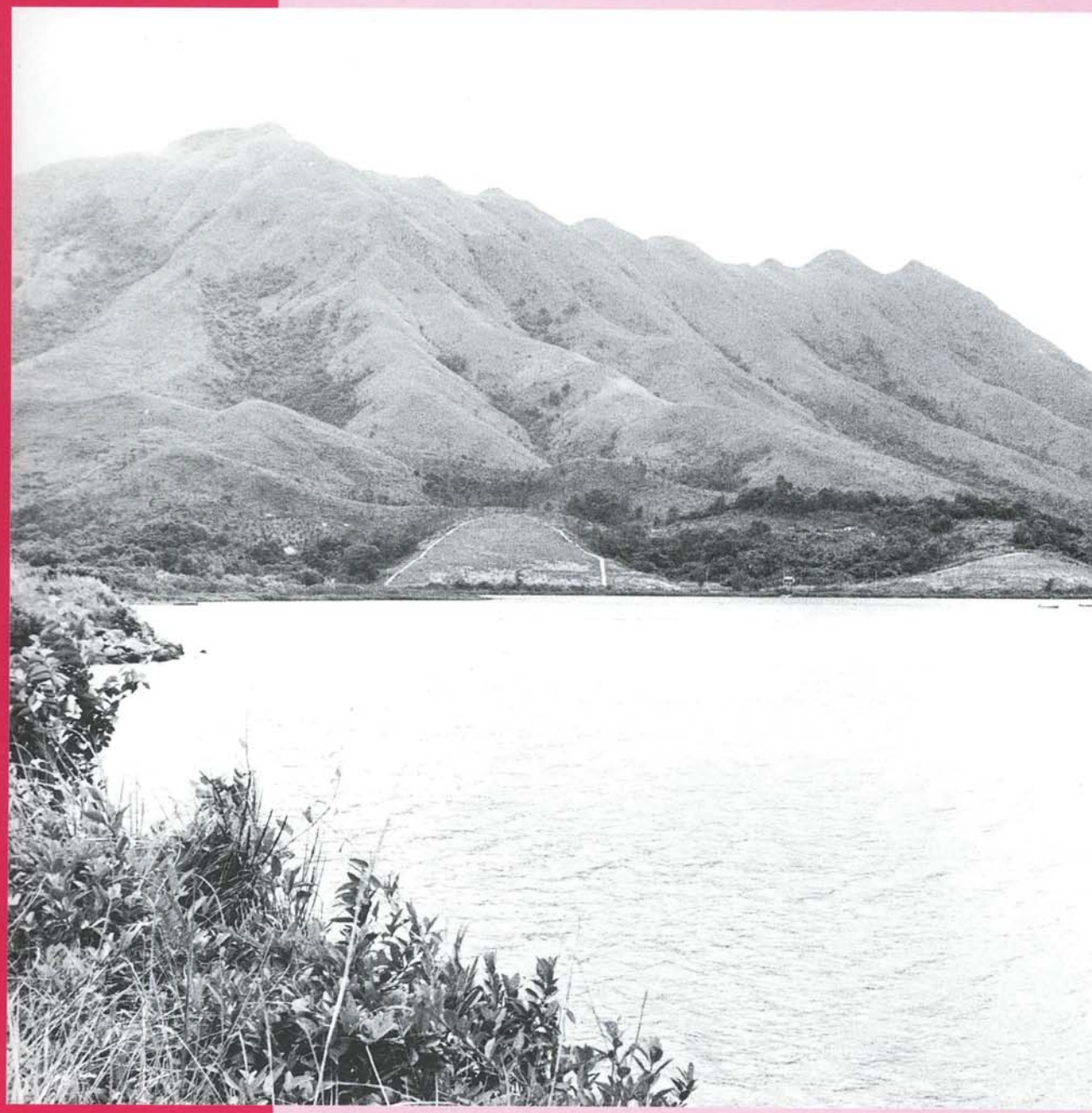
HONG KONG GEOLOGICAL SURVEY *MEMOIR No. 5*

Geology of the Northeastern New Territories



Geotechnical Engineering Office
Civil Engineering Department
HONG KONG

HONG KONG GEOLOGICAL SURVEY *MEMOIR No. 5*

Geology of the Northeastern New Territories

1:20 000 Sheets 3 & 4

K.W. Lai, S.D.G. Campbell & R. Shaw

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Civil Engineering Department
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Foreword

This memoir describes the geology of the Northeastern New Territories. The district stretches from the northern border of the Territory to Chek Mun Hoi Hap (Tolo Channel), with a small area lying to the south of the channel. Many islands along the east coast are also included in the district, the most important of which are Kat O Chau (Crooked Island), Ngo Mei Chau (Crescent Island), Wong Wan Chau (Double Island), Chek Chau (Port Island) and Tap Mun Chau (Grass Island). The isolated island of Ping Chau, which lies about 10 km east-northeast of the mainland, near the eastern border of the Territory within Tai Pang Wan (Mirs Bay), is also described.

The geology described is shown on 1:20 000 scale sheets 3 (Sheung Shui) and 4 (Kat O Chau). The memoir forms part of the published results of a programme of systematic geological mapping undertaken by the Geotechnical Engineering Office (GEO), formerly Geotechnical Control Office (GCO), between 1983 and 1992. The programme has studied the onshore and offshore geology of the Territory in far greater detail than previously attempted. These geological maps and memoirs have enhanced our understanding of Hong Kong's stratigraphy and structure, and helped to establish a geological database necessary for the continuing economic development of the Territory. The mapping programme was undertaken by the Geological Survey Section of the Planning Division of the GEO. The section was led by Mr P.J. Strange, Dr I. R. Basham and Dr C.J.N. Fletcher during the periods of mapping and compilation of this memoir and its accompanying maps; the Division was under the direction initially of Dr A.D.Burnett and latterly Dr R.P. Martin.

Mr K.W.Lai is the principal author of the memoir and he exclusively undertook the onshore geological survey of sheets 3 and 4 from 1988-90. Dr Shaw compiled the offshore geology between 1989 and 1992.

Dr S.D.G.Campbell is the principal author of sections on metamorphism and economic geology. He also assisted Mr Lai in compiling the section on structural geology and with Dr R.J.Sewell, sections on volcanic geology and intrusive rocks. Mr J.A.Fyfe similarly assisted in sections on sedimentary geology. Dr R.Shaw is the principal author of the section on offshore superficial deposits and weathering. Dr Campbell compiled the memoir while he, and Mr Fyfe, were seconded to the Hong Kong Government from the British Geological Survey.

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

The geological field survey benefited from the co-operation of various organisations and many individuals. The Government Flying Service (formerly The Royal Hong Kong Auxiliary Air Force) provided helicopter transport to remote and rugged locations. The Water Supplies Department and The Royal Hong Kong Police supplemented transport in commercial boats used to map the coastline and small islands. Land transport was mostly supplied by the Islands District Office, the City and New Territories Administration, and the Highways Department. The co-operation of Electronic and Geophysical Services Ltd in compiling the offshore geology is also acknowledged.

Thanks are due to Mr M.J.Atherton and Mr C.M.Lee of the Hong Kong Polytechnic University and Mr J.H.Chen, Mr G.X.He and Ms S.Q.Wu of Nanjing Institute of Geology and Palaeontology, Academia Sinica for providing results of their fossil research. Thanks are also due to the technical officers and cartographers of the GEO.

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

A. W. Malone

Principal Government Geotechnical Engineer

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Map and Memoir Series Notes

* This memoir describes the geology of the Northeastern New Territories, including adjacent islands. It should be read in conjunction with 1:20 000 scale Geological Map sheets 3 (Sheung Shui) and 4 (Kat O Chau).

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

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

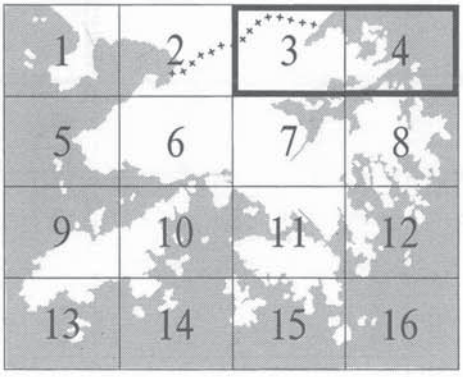
* Grid references are based on the Hong Kong 1980 Metric Grid as shown on the 1:20 000 scale Geological Maps. Ten-figure references indicate positions to within 10 m, with Eastings followed by Northings, e.g. 80342 84432. Eight-figure references indicate positions to within 100 m. For convenience, however, the prefix figures 8, which apply to all eastings and northings in the district, are omitted.

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

* Samples in the Territory-wide rock collection archived by the Hong Kong Geological Survey are prefixed HK followed by a serial number, e.g. HK 7835.

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

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



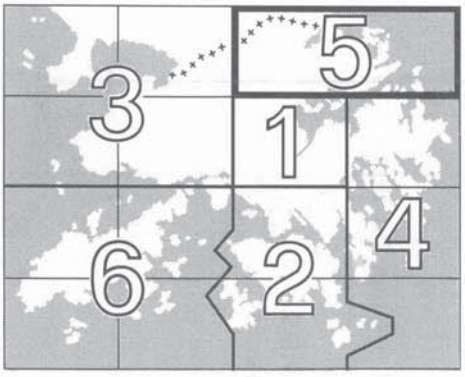


Table 1 — Grain Size Description and Classification of Rocks and Superficial Deposits in Hong Kong

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

Chapter 1
Introduction

Location and Physiography

This memoir describes the geology of 1:20 000 scale map sheets 3 (Sheung Shui) and 4 (Kat O Chau) in the northeastern New Territories. This area is referred to here as the district (Figure 1). Most of the onshore part of the district lies between the northern border of the Territory and Chek Mun Hoi Hap (Tolo Channel). There are also smaller onshore areas on the southeast side of Chek Mun Hoi Hap and on a large number of islands to the east, the largest of which are Kat O Chau (Crooked Island), Wong Wan Chau (Double Island), Chek Chau (Port Island) and Tap Mun Chau (Grass Island). The isolated island of Ping Chau, which lies some 10 km to the east-northeast of the mainland, is also described. The offshore geology included on sheets 3 and 4 is described in detail, and a brief description of the offshore geology east of Sheet 4, within Tai Pang Wan (Mirs Bay), is also presented.

The total land area of the district is approximately 163 km^2, while the offshore area described amounts to about 590 km^2.

The area to the north of Chek Mun Hoi Hap (Tolo Channel) is dominated by east-, east-northeast- and, locally, northwest-trending ridges the highest points of which are Wong Leng (639 m), Shun Yeung Fung (591 m), Lai Pek Shan (550 m) and Hsien Ku Fung (511 m), all in the Pat Sin Leng range in the centre of the district. Other high points include Hung Fa Leng (Robin's Nest, 492 m) in the extreme north, and Kwai Tau Leng (486 m). The eastern part of the district is generally lower-lying although the coastline is often rugged and indented with occasional sandy inlets and bays. There is also an area of low ground in the west of the district, around Sheung Shui.

In the centre of the district, a broadly radial pattern of drainage emanates from the high ground of Pat Sing Leng. Generally, drainage systems are relatively short, with the exception of the Tan Shan Ho, which heads north from its source on the western side of Pat Sing Leng, and on reaching lower ground turns west to join the meandering Ng Tung Ho that continues to Fanling, Sheung Shui and beyond. Although many summits and ridges are grassy and easily traversed on foot, dense vegetation on the lower slopes and in valleys commonly restricts access.

A large part of the district falls within country parks. North of Chek Mun Hoi Hap (Tolo Channel), these include the Pat Sin Leng and Plover Cove country parks in the centre and north of the district, and the Plover Cove Extension Country Park covering the offshore islands to the east. The Sai Kung West and Sai Kung East country parks include that part of the district to the south of Chek Mun Hoi Hap. Future development in the district will therefore be restricted, in the foreseeable future, to the limited areas lying outside the country parks.

The Plover Cove Reservoir occupies a broad embayment bounded to the southeast by a southwest trending peninsula that extends from Fung Wong Wat Teng to Pak Sha Tau Chau.

Kat O Chau (Crooked Island), the largest of the islands in the district, has an unusual Z-shaped outline and covers an area of about 2.5 km^2 . The large village of Tung O is located on its northwest coast. Wong Wan Chau (Double Island), the second largest of the islands, with an area of approximately 2 km^2 , rises to a height of 139 m. Ping Chau, which is isolated near the eastern

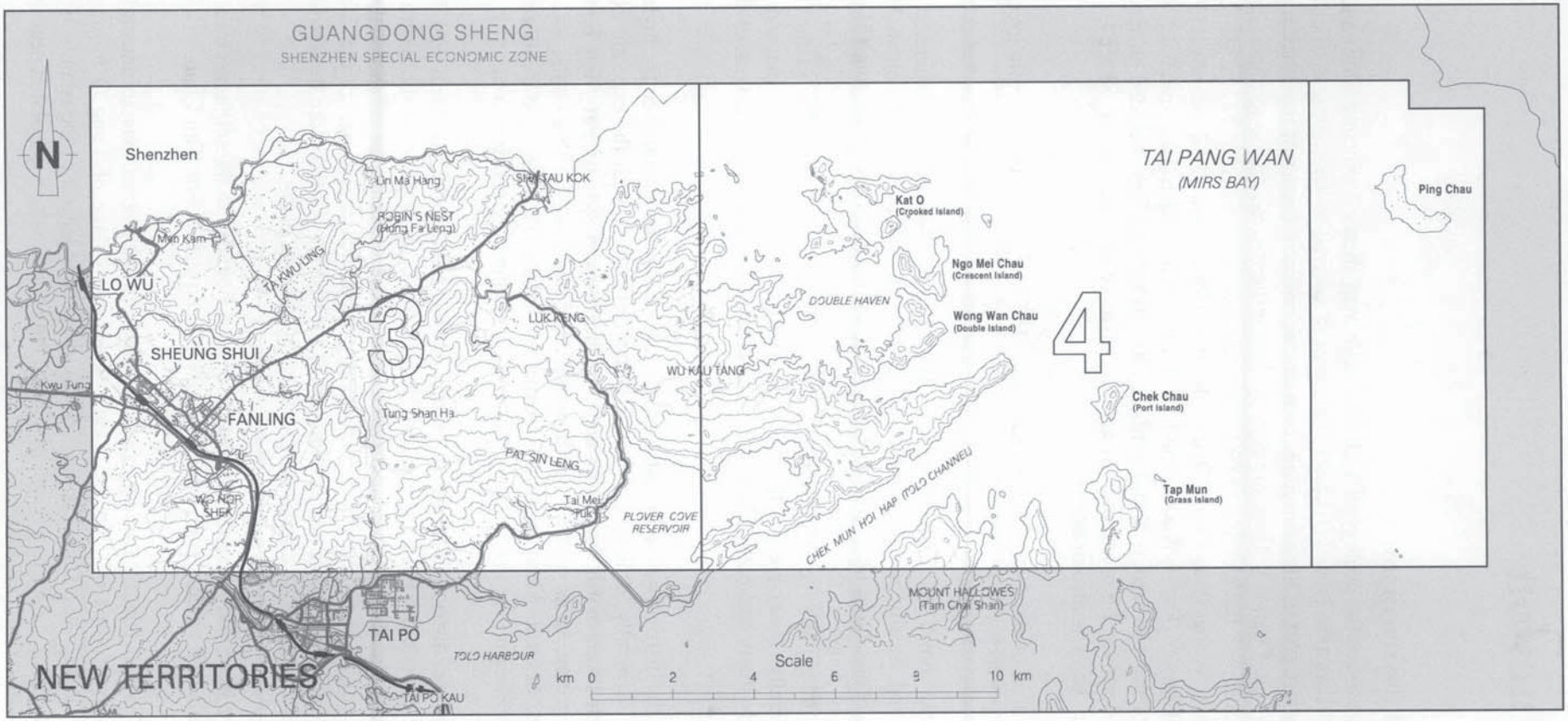


Figure 1 - Principal Topographic Features of the District

edge of the territory in Tai Pang Wan (Mirs Bay) has a crescent-shaped outline and is low-lying with a surface area of just over 1 km^2 and a maximum elevation of only 48 m. Cliffs extend around much of the west coast providing spectacular exposures of the shallowly-inclined sedimentary strata, while there is a wide sandy beach in part of the eastern embayment.

Most of the district is sparsely populated. However, the northern edge of the Tai Po conurbation lies in the southwest, the population centres of Fanling and Sheung Shui are situated on low-lying ground in the west, and the northern border town of Sha Tau Kok sits on the north coast of Sha Tau Kok Hoi.

Previous Work

The earliest geological survey of the Territory was carried out between 1923 and 1927 by Brock, Uglow, Schofield and Williams, under an agreement between the Colonial Office and the University of British Columbia. A map was published at 1:84 480 scale (Brock *et al.*, 1936). This showed the north of the district and adjoining islands, the north coast of Plover Cove, and the extreme southwest, to be composed mainly of volcanic rocks of the Rocky Harbour Formation. Sedimentary rocks across the central part of the district and on Chek Chau (Port Island), and along the northern side of Chek Mun Hoi Hap (Tolo Channel), were assigned either to the Mirs Bay Formation, thought then to be of Eocene age, or the Pat Sin Formation of Jurassic age. The sedimentary rocks on Ping Chau were shown as the Tolo Channel Formation, interpreted to be of early Liassic age. Dykes were mapped locally. Unfortunately, no descriptive memoir was produced to accompany this map, although several related publications (Uglow, 1926; Brock & Schofield, 1926; Williams, 1943; Williams *et al.*, 1945) presented many of the main conclusions related to the mapping. A book, based largely on this earlier work, was written by Davis (1952), and this was followed by a detailed description of the geology of the Territory by Ruxton (1960).

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

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

In the neighbouring Sha Tin district (Sheet 7), Addison (1986) established a detailed lithostratigraphy for the Repulse Bay Volcanic Group, and divided the granites using lithological criteria. His volcanic lithostratigraphy was modified in the adjoining Kowloon and Hong Kong Island districts to the south (Strange & Shaw, 1986), and in the western New Territories (Langford *et al.*, 1989), and has now been extended, in its modified form, into parts of this district. The division of granite intrusions in the district is based on the grain-size classification of Strange (1984). Palaeontological studies (Lee *et al.*, 1990a-d, 1991a-c; Atherton *et al.*, 1990a-d) have greatly improved the constraints on the ages of several of the formations.

Early geological surveys of Hong Kong (Davis, 1952; Allen & Stephens, 1971; Bennett, 1984a) only briefly covered the offshore geology of the Territory, concentrating on the coastal sediments in the littoral and sublittoral zones. Several studies broadly assessed the distribution of offshore deposits in the Territory (e.g. Berry, 1962; Holt, 1962; Lumb, 1977) based on the limited information available at the time. However, it was the undertaking of large offshore engineering projects such as the Kai Tak Runway extension (Henry *et al.*, 1961), the Plover Cove Reservoir, the High Island Reservoir and the Mass Transit Railway within and across limited shallow marine sections that encouraged further detailed studies of the offshore geology (e.g. Fanshawe & Watkins, 1971; Kendall, 1976; Willis & Shirlaw, 1984; Yim, 1984a, b). Offshore mapping was begun by the Hong Kong Geological Survey in 1984 to synthesise the increasing amount of information being produced (Shaw, 1987, 1990; Shaw & Arthurton, 1988).

By the mid-1980s the increasing demand for reclamation fill created problems of supply from the traditional onshore sources. An offshore seismic and borehole study of a large area of Hong Kong waters was initiated by the Geotechnical Control Office to investigate marine fill resources (Cheung & Shaw, 1993). This activity stimulated more interpretive research and specialist meetings (Whyte, 1984; Whiteside & Arthurton, 1986; Whiteside & Wragge-Morley, 1988; Whyte *et al.*, 1988). Information from these and earlier investigations has been used in this memoir and in compilation of the accompanying 1:20 000 scale maps.

Present Survey

Geological field mapping in the district started in 1988 and was largely completed by 1990. Geological information for onshore areas was plotted directly onto 1:5 000 scale topographic base maps. It was then transferred onto 1:10 000 scale maps, and provisional geological maps were prepared at this scale. These formed the bases for the published 1:20 000 scale geological map sheets.

Traverses were made along most roads and footpaths, and accessible stream courses and coastlines (Figure 2). Helicopters, provided by the Government Flying Service (formerly Royal Hong Kong Auxiliary Air Force), enabled access to the more inaccessible and mountainous areas. Islands and remote coastal sections were reached using commercially-hired boats, with some additional assistance provided by the Water Supplies Department and the Royal Hong Kong Police.

Temporary sections were relatively uncommon, except in the urban areas, and ground investigation boreholes (Figure 3) are restricted to only a few parts of the district.

Photogeological interpretation of the distribution of superficial deposits and lineaments in the district was undertaken, mainly using 1963, 1964 and 1983-86 photographs.

High resolution seismic reflection profiling, using a boomer source, was the principal technique employed for offshore surveying. This gave a depth of penetration beneath the sea surface of about 100 metres. The stratigraphy of the superficial deposits was interpreted from continuous seismic records calibrated by the logging of sediment and rock from reconnaissance boreholes. Figure 4 illustrates the geophysical track lines for the records interpreted for this memoir and the accompanying published maps, and also shows the positions of seabed sampling stations.

A Territory-wide gravity survey was also carried out (Busby *et al.*, 1992; Electronic and Geophysical Services Ltd, 1991; Evans, 1990; Busby & Langford, 1994). Marine gravity stations were located on a 2 km grid.

Archival Data

All records from the survey are held in the archives of the Hong Kong Geological Survey (Planning Division, Geotechnical Engineering Office), and are available for inspection. These include: 2238 rock samples of which 983 have thin sections; field notes and photographs; manuscript maps; aerial photographs and related interpretations; analytical data (major and trace elements) for 37 samples (analysed by the Institute of Geological Sciences of Guangdong Province, Guangzhou, P.R.C. and the University of Nottingham, U.K.); and palaeontological details of fossils (identified by the Nanjing Institute of Geology and Palaeontology, Academia Sinica). Ground investigation reports, which were used to study the nature and disposition of onshore and offshore superficial deposits, weathered rocks and rock types, are held in the Geotechnical Information Unit of the Civil Engineering Library.

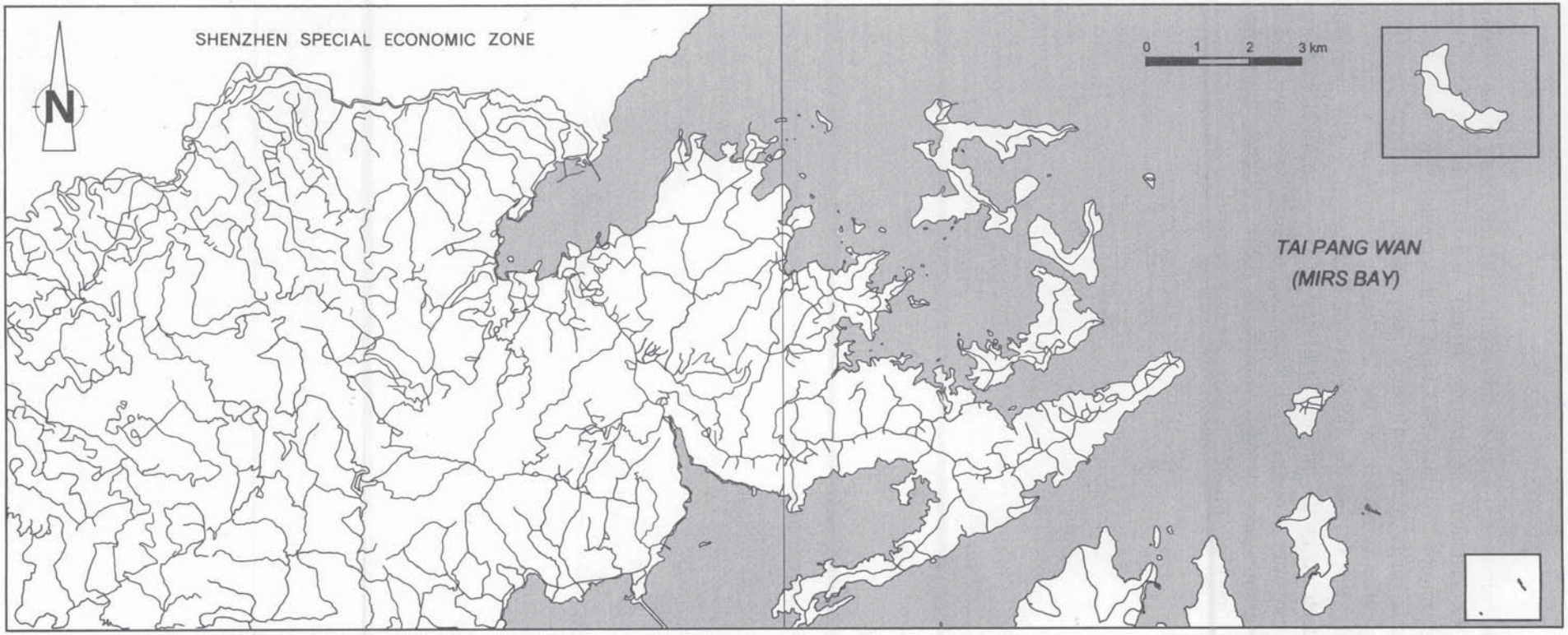


Figure 2 - Traverses Undertaken During Field Survey of the District

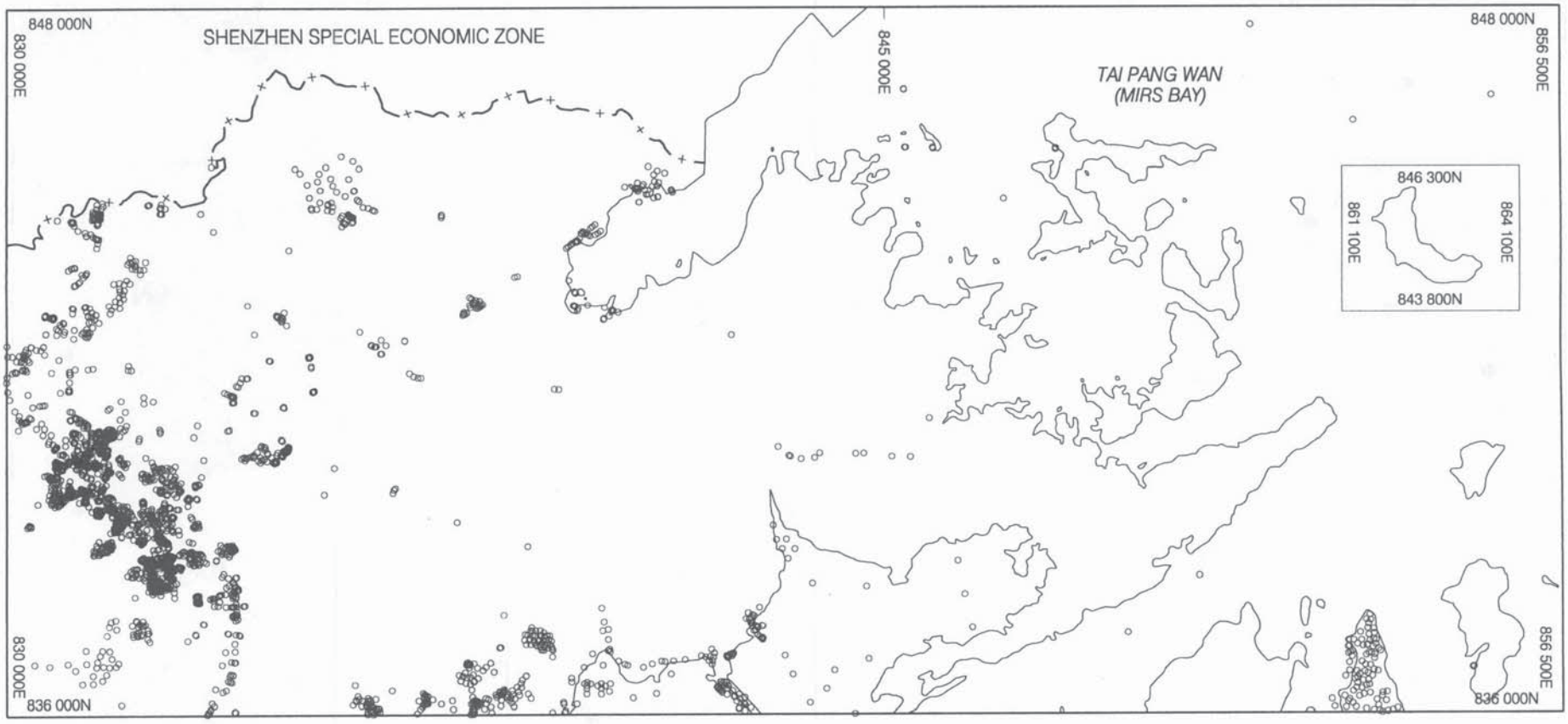


Figure 3 - Location of Boreholes and Cone Penetration Tests in the District

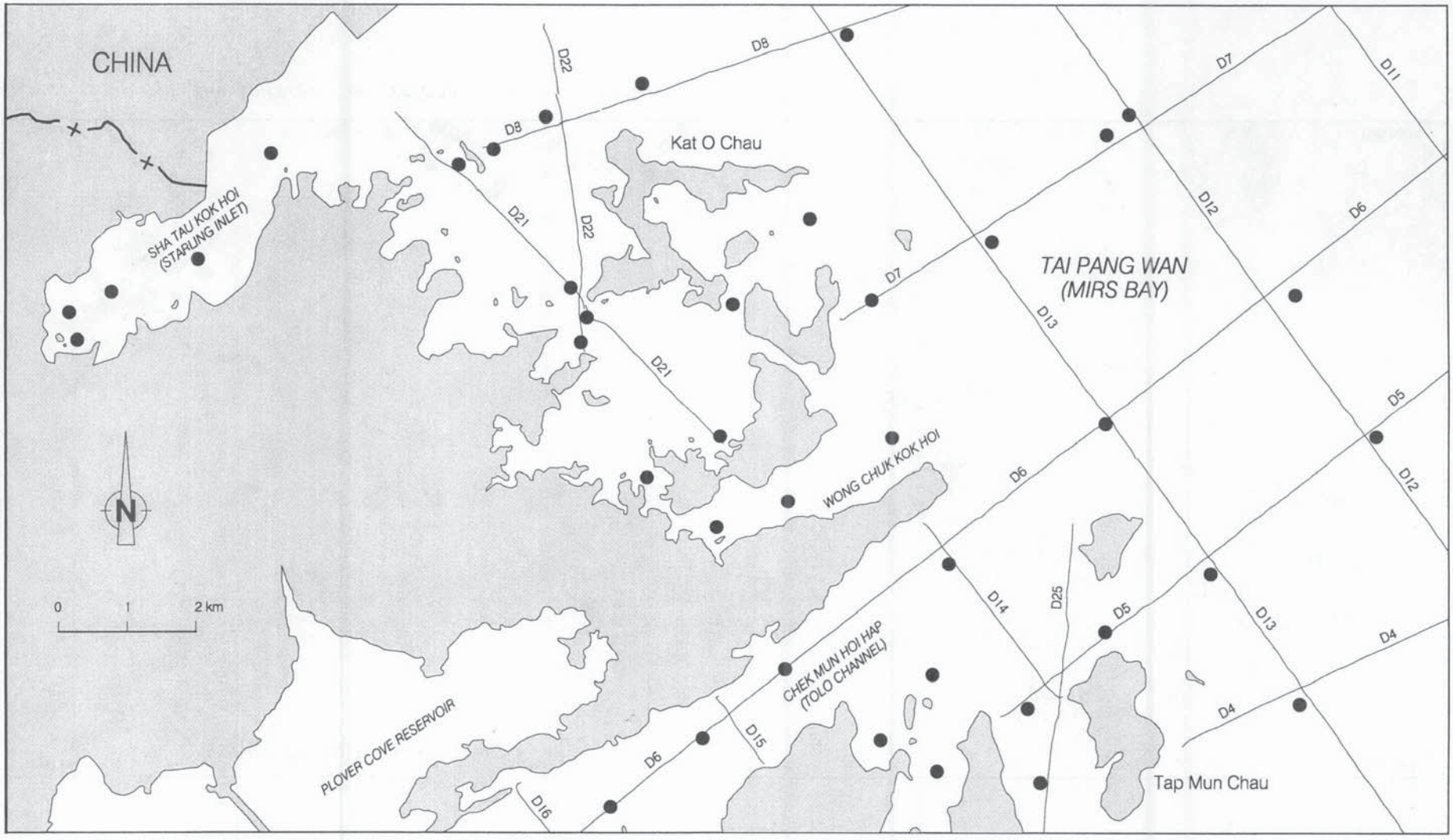


Figure 4 - Location of Seismic Reflection Survey Tracks and Seabed Sampling Stations (Filled Circles) within the District

Chapter 2
Outline of Geology

The solid geology of the district (Figure 5; Table 2) is dominated by Mesozoic volcanic and sedimentary rocks. The volcanic rocks, which comprise tuffs and lavas with intercalated sedimentary rocks, crop out in all parts of the district. Intrusive igneous rocks of Mesozoic age are relatively rare and consist mainly of granodiorite and rhyolitic dykes. Palaeozoic sedimentary rocks crop out within a narrow strip trending northeast along the northern side of Chek Mun Hoi Hap (Tolo Channel), and also occur in the northwest corner of the district. Tertiary sedimentary strata are exposed on Ping Chau in the far east of the district and these extend in subcrop beneath Tai Pang Wan (Mirs Bay). Superficial deposits of Quaternary age (Table 2) form impersistent veneers on hill slopes, but are thicker and more widespread in valleys and lowland areas. Quaternary superficial deposits are extensive offshore.

The Palaeozoic strata comprise the Lower to Middle Devonian Bluff Head Formation and the Lower Carboniferous Lok Ma Chau Formation. The Bluff Head Formation consists of sandstone, conglomerate and siltstone. The formation is exposed within an elongate and narrow, northeast-trending, fault-bounded strip; neither its base nor its top are seen in the district. Mesoscale folding is common within the formation.

The Lok Ma Chau Formation comprises two members that crop out in the extreme northwest of the district where they have been thrust over younger Jurassic volcanic rocks of the Tai Mo Shan Formation. The older of the two, the Mai Po Member, comprises phyllite, metasiltstone with metasandstone, and graphitic schist, whereas the younger Tai Shek Mo Member comprises metasandstone, with metaconglomerate and phyllite.

Mesozoic sedimentary strata lie above and below the main sequences of volcanic rocks. Below the volcanic rocks, only one formation, the Lower Jurassic Tolo Channel Formation, has been recognised. This comprises mudstone and siltstone that are exposed within a fault-bounded strip along the northern coast of Chek Mun Hoi Hap (Tolo Channel). The formation is presumed to lie unconformably on Upper Palaeozoic formations as in adjoining districts.

The Mesozoic volcanic rocks are divided into two groups: the Tsuen Wan Volcanic Group of middle Jurassic age, and the Repulse Bay Volcanic Group of late Jurassic to early Cretaceous age. The Tsuen Wan Volcanic Group within the district includes the Shing Mun, Tai Mo Shan, Sai Lau Kong and Ngo Mei Chau formations. These crop out mainly in the centre, north and northeast of the district, including exposures on several of the islands along the east coast. The Shing Mun Formation is lithologically varied, and includes fine to coarse ash tuff, tuff breccia, lithic tuff, sandstone, siltstone and mudstone. The main eruptive source of the formation probably lay just to the southwest of the district, but eruptions may also have occurred in the vicinity of Shuen Wan Hoi (Plover Cove). The Tai Mo Shan Formation, which conformably overlie the Shing Mun Formation, consists mainly of coarse ash crystal tuff with subordinate vitric and fine ash tuff and occasional siltstone. The tuffs were probably erupted from one or more sources to the west and southwest of the district. The Sai Lau Kong Formation comprises mainly dacite lavas with intercalated tuff, siltstone and sandstone. These rocks lie directly above the Tai Mo Shan Formation within a restricted northwest-trending outcrop, interpreted as the approximate eruptive source of the lavas and tuffs. The Ngo Mei Chau Formation comprises eutaxitic, fine ash vitric tuff, lithic tuff and rhyolite and has a restricted, partly fault-bounded outcrop on

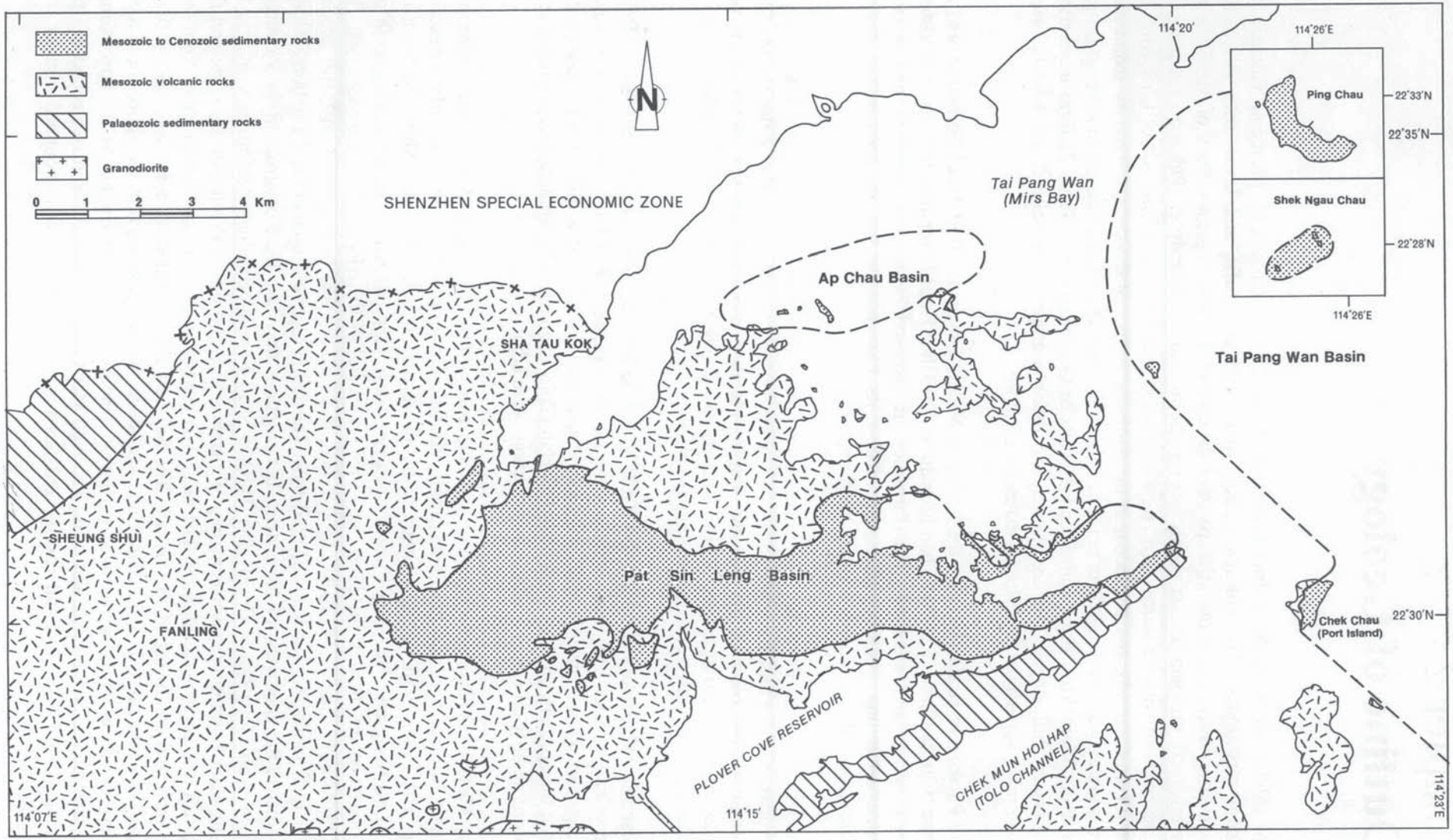


Figure 5 - Generalised Solid Geology of the District

Table 2 - Solid Rocks and Superficial Deposits of the District

Superficial Deposits (Onshore unless specified)				
Age		**Genetic Classification**		**Principal Materials**
Quaternary	Holocene	Fill		Clay, silt, sand and gravel
		Alluvium		Mud and sand
		Estuarine & intertidal deposits		Sand
		Beach deposits		Sand and gravel
		Back beach deposits		Sand and gravel
		Hang Hau Formation (offshore)		Marine mud and sand
		Slope (Debris flow) deposits		Silt, sand, cobbles and boulders
		Talus (Rock fall) deposits		Gravel, cobbles and boulders
	Pleistocene	Terraced alluvium		Clay, silt, sand and gravel
		Slope (Debris flow) deposits		Silt, sand, cobbles and boulders
		Chek Lap Kok Formation (offshore)		Clay, silt, sand and gravel
Solid Rocks				
Age		**Named Divisions**		**Principal Rock Types**
Cenozoic	Palaeogene	Ping Chau Formation		Dolomitic siltstone
Mesozoic	Upper Cretaceous	Kat O Formation		Calcareous breccia
		Port Island Formation		Sandstone and conglomerate
	Lower Cretaceous	Pat Sin Leng Formation		Sandstone, siltstone and conglomerate
	Upper Jurassic	Repulse Bay Volcanic Group	Long Harbour Formation	Coarse ash crystal tuff
			Lai Chi Chong Formation	Fine ash tuff and tuffite
		Tsuen Wan Volcanic Group	Ngo Mei Chau Formation	Fine ash vitric welded tuff
			Sai Lau Kong Formation	Dacite lava
			Tai Mo Shan Formation	Coarse ash crystal tuff
			Shing Mun Formation	Fine to coarse ash tuff with tuffite
	Lower Jurassic	Tolo Channel Formation		Mudstone and siltstone
Palaeozoic	Lower Carboniferous	Lok Ma Chau Formation	Tai Shek Mo Member	Metasandstone with conglomerate
			Mai Po Member	Metasiltstone, phyllite and sandstone
	Lower to Middle Devonian	Bluff Head Formation		Sandstone and siltstone
Intrusive Rocks				
Cenozoic	Tertiary	Basalt		
Mesozoic	Cretaceous to Jurassic	Aplite Quartzphyric Rhyolite Feldsparphyric Rhyolite Granodiorite		

along the east coast. The linear outcrop is interpreted as a fissure-controlled vent complex. The age relationships of the Ngo Mei Chau with other formations within the Tsuen Wan Volcanic Group are uncertain, and it is possible that the formation could be related instead to the younger Repulse Bay Volcanic Group.

The Repulse Bay Volcanic Group is only represented within the district by the Lai Chi Chong and Long Harbour formations that crop out on the south side of Chek Mun Hoi Hap (Tolo Channel). The Lai Chi Chong Formation comprises well-bedded, fine ash tuffs and tuffites whereas the Long Harbour Formation is a thick succession of lithic lapilli-bearing, coarse ash crystal tuffs. The tuffs are interpreted as having been ponded in a volcanotectonic depression created in part by downfaulting on the southeast side of a fault, or faults, along Chek Mun Hoi Hap. The Lai Chi Chong Formation succeeds the Tolo Channel Formation unconformably, and is in turn unconformably overlain by the Long Harbour Formation, although both relationships have only been demonstrated in the adjoining district to the south (Strange *et al.*, 1990).

Mesozoic sedimentary rocks overlying the main Mesozoic volcanic sequences include the Lower Cretaceous Pat Sin Leng Formation, deposited in the Pat Sin Leng Basin, and the Upper Cretaceous Port Island and Kat O formations, deposited in the Tai Pang Wan and Ap Chau basins respectively. Both of the basins are largely preserved offshore. The Pat Sin Leng Formation, which comprises sandstone, siltstone and conglomerate, is present in a broad belt traversing the centre of the district, and extending onto some of the islands along the east coast. The formation unconformably overlies the Tai Mo Shan Formation, by which it is also overthrust. The Port Island Formation is only exposed on islands in the southeast and east of the district. The formation mainly comprises fluvial sedimentary rocks, including channelised sandstones and conglomerates, interbedded with overbank sandstones and siltstones, and siltstone-mudstone units, the latter being typically converted to palaeosols. The largest area of exposure of the formation is on Chek Chau (Port Island) where it unconformably overlies the Long Harbour Formation. The Kat O Formation is restricted to a few small outcrops in the north and northeast of the district, which expose calcareous breccia with conglomerate and sandstone. These outliers unconformably overlie the Sai Lau Kong and Ngo Mei Chau formations.

The Mesozoic and Palaeozoic volcanic and sedimentary rocks are in places intruded by granodiorite stocks, feldsparphyric and quartzphyric rhyolite dykes, and aplite dykes, all of late Jurassic to early Cretaceous age. The granodiorites were comagmatic with the Shing Mun and Tai Mo Shan formations and the location of the intrusions in the southwest of the district is considered to indicate the approximate location of the eruptive source of the Shing Mun Formation. The rhyolitic dykes trend variably to the northeast, north-northeast and east-northeast. These trends closely match the strike of major fault zones in the vicinity of individual dykes. No absolute age dates are available for any of the dykes, but, on the basis of similarities in their whole-rock geochemistry, they are interpreted as being of a similar general age as the late Jurassic to early Cretaceous volcanic rocks in the district.

The Cenozoic is represented only by the Lower Palaeogene Ping Chau Formation. Although the formation is only exposed on Ping Chau in the extreme east of the district, it is interpreted to occur on the seabed around Ping Chau and extends in subcrop under the northern part of Tai Pang Wan (Mirs Bay). On Ping Chau, the formation comprises mainly siltstone and clayey dolomitic siltstone, deposited in chemical and detrital cycles in a brackish lake under tropical and subtropical conditions. The formation also contains an unusual suite of secondary minerals including zeolites and aegirine.

The district is transected by faults trending east-northeast, northeast, and northwest. In addition, important northerly-dipping structures occur in the centre of the district and in the offshore areas to the east, northwest- and north-striking structures are dominant. The structural development of

the district was mainly related to the Yanshanian Orogeny, which affected a broad belt along the southeast coast of China during the Jurassic and Cretaceous periods. Some structures in the northwest are suspected to be pre-Yanshanian but are poorly constrained. The affects of orogeny included fault-controlled volcanism and sedimentary basin development, regional tectonism, and dynamic metamorphism. Early Cenozoic basin development may have been associated with the early stages of Himalayan Orogeny.

In the northwest of the district, a northwest-dipping thrust, the San Tin Fault, has emplaced rocks of Carboniferous age from the northwest onto Jurassic volcanic rocks. Broad zones of shearing and dynamic metamorphism parallel to the thrust are developed in its footwall, which is occupied by Jurassic volcanic rocks. In the centre of the district, Jurassic volcanic rocks have themselves been thrust from the north, onto Cretaceous sedimentary rocks. The deformed sedimentary rocks in the footwall of the thrust may have accumulated contemporaneously with the development of the thrust.

A major north-northeast-trending, subvertical zone of faulting, shearing and dynamic metamorphism transects the area from Sha Tau Kok at the northern limit of the district, to its southwest corner and thereafter across most of the Territory. Much of the faulted zone forms low-lying ground. The fault zone is thought to have had a significant sinistral component of shear but little kinematic evidence has been found to support this. However, this movement sense would be kinematically consistent with the southerly-directed thrusting recognised in the centre of the district.

The laterally extensive Chek Mun Fault Zone runs along the northern side of Chek Mun Hoi Hap (Tolo Channel), and forms part of a fault system that extends across most of the Territory to the southwest of the district. This fault system was probably reactivated several times and with differing movement senses during its evolution. Movement during the eruption of the Tsuen Wan Volcanic Group is likely to have been dextral and extensional, and during the eruption of the Repulse Bay Volcanic Group, mainly extensional also. However, Cretaceous movements are considered to have been mainly sinistral. Evidence of later movement is limited, but an offshore extension of the fault coincides with the northern limit of Ping Chau. In adjoining areas southwest of the district, brittle deformation within the fault zone appears to be related to dextral displacement of pre-existing, north-northwest-trending faults.

Folding is mainly related to the Yanshanian Orogeny. Folds within Palaeozoic rocks are commonly mesoscale, close or tight, and north-northeast-plunging. In contrast, folds within Mesozoic rocks are is generally more open, except where near major faults. Tertiary folding is almost exclusively open in style, and related to the development of sedimentary basins.

Contact (thermal) metamorphism is relatively rare. A notable exception is in the southwest of the district where block-bearing tuff and tuffite hornfels of Jurassic age can be related to the intrusion of granodiorite, also of Jurassic age.

The dominant form of metamorphism within the district is dynamic metamorphism, mainly of late Jurassic and early Cretaceous age. The deformation, expressed as compressional and shear-related foliation is developed extensively in the northwest of the district, in response to large-scale thrusting from the northwest, and within steeply-dipping shear zones. Dynamic metamorphism is also evident in the centre of the district, as a thick zone of sheared rock within the footwall of a northward-dipping thrust, and near the base of the thrust sheet.

Hydrothermal alteration, including silicification and carbonate development, occurs locally, mainly within the Mesozoic volcanic and sedimentary sequences, and particularly adjacent to major zones of faulting and shearing, and within areas of volcanotectonic collapse.

Quartz veins are present in many parts of the district. They trend mostly to the northwest in the west of the district, but are more variably trending in the east, where north and north-northeast trends are also seen.

Superficial deposits of Quaternary age form flat-lying areas onshore, and constitute the sea-bed in most of the offshore area. In hilly terrain, colluvium, including debris flow and other slope deposits, mostly of Pleistocene age, commonly mantles side slopes and lines valleys. Restricted alluvial deposits occur in hilly areas, but alluvium more generally occurs as fans developed downslope of the colluvial deposits. Thick sequences of Pleistocene terraced alluvium are extensively developed in the west of the district, especially around Sheung Shui and Fanling.

Restricted beach deposits of sand, and more common estuarine and intertidal deposits of mud and sand, are developed in front of alluvial deposits and, in some cases, Pleistocene slope deposits, especially in sheltered coastal bays. Pleistocene alluvial deposits also occur offshore, together with slope debris deposits, within the Pleistocene Chek Lap Kok Formation, which generally comprises complex, interbedded red, yellow and grey clay, silt, sand and gravel, with some organic material. The formation is dominantly of fluvial origin, containing probable estuarine and intertidal units within. The Chek Lap Kok Formation is overlain by the extensive Holocene marine deposits of the Hang Hau Formation that comprise mainly dark grey mud with shells, and some sand. Land reclamations at Sha Tau Kok and the dam walls at Plover Cove Reservoir have buried some of the estuarine, intertidal and marine deposits.

A regolith, or mantle of weathered rock, occurs over most of the district. The effects of weathering vary with underlying rock types and this is reflected in topographic relief. For example, granodiorite and Palaeozoic fine-grained clastic rocks are the most deeply weathered and eroded rocks and typically form lower ground. The acidic volcanic rocks are more resistant to deep weathering and erosion, and form rocky hills with boulder fields of large, cuboidal corestones.

Although there are no active mineral workings in the district, lead and zinc, together with by-product silver and gold, have been mined at Lin Ma Hang in the northwest of the district. The age of the mineralization, which is hosted by Jurassic volcanic rocks, is unknown. There are also other occurrences of galena, sphalerite, quartz and graphite, limonite. Locally offshore, in Chek Mun Hoi Hap (Tolo Channel) and in Tai Pang Wan (Mirs Bay), channelised sand bodies within the Chek Lap Kok Formation, but beneath a cover of marine mud, provide a potential resource for construction, but their exploitation has been rejected for environmental reasons.

Chapter 3
Palaeozoic Sedimentary Rocks

Classification and Distribution

Two formations of Palaeozoic age occur within the district: the older Bluff Head Formation is of Devonian age, and the younger Lok Ma Chau Formation is Carboniferous. The Bluff Head Formation crops out on the northwest side of Chek Mun Hoi Hap (Tolo Channel), between Lo Fu Wat in the southwest and Wong Chuk Kok Tsui in the northeast. The outcrop is nearly 10 km long and 0.5 to 1.5 km wide. The Lok Ma Chau Formation occurs in the northwest corner of the district, in a northeast-trending, fault-bounded belt, 4 km long and 2 km wide, which extends into Shenzhen and northeast Guangdong Province. The formation is represented in the district by the Mai Po and Tai Shek Mo members.

The rocks of the Bluff Head Formation were previously known variously as the 'Jurassic Tolo Crest Formation' (Heim, 1929) and 'Mesozoic Volcanic Pat Sin Formation' (Williams *et al.*, 1945) and were referred to by Davis (1952) simply as 'the Jurassic Sediments'. The present name of the formation was first defined by Ruxton (1960), and Allen & Stephens (1971) suggested that the formation was middle Lower Jurassic. Lee (1982), however, discovered placoderm fish fossils at Harbour Island and concluded that the strata were Devonian. More recently, the formation has been confirmed as Lower to Middle Devonian (Lee 1990a & 1990b)[1]. The Bluff Head Formation can therefore be correlated with the Devonian Guitou Formation of northern Guangdong Province. A study carried out by Jones (1995) has defined a number of sedimentary facies associations in this formation.

The Lok Ma Chau Formation is the uppermost formation of the Carboniferous San Tin Group, and was first defined by Williams (1942). Initially thought to be Permian by Heim (1929), the formation was later grouped with Lower Jurassic strata by Allen & Stephens (1971). Lai (1977) compared the formation lithologically with Carboniferous strata in Shenzhen and suggested that they were of the same age, a conclusion subsequently supported by several authors (Ha *et al.*, 1981; Peng, 1983; Lai & Mui, 1984; Bennett, 1984a; and Lee, 1985). Micropalaeontological evidence outlined in Langford *et al.* (1989) has refined the age of the formation to Tournaisian or Namurian-Westphalian.

Bluff Head Formation

The formation consists of pale grey, fine- to coarse-grained quartzitic sandstone, with subordinate reddish brown and purple sericitic siltstone and greyish white, quartz-pebble conglomerate. The formation is generally coarser grained in the lower part, comprising fine- to coarse-grained sandstone, conglomeratic sandstone and up to three beds of conglomerate, and passing up into sandstone with sericite-bearing siltstone, mudstone and lenses of conglomerate.

In the southeast, the base of the formation is faulted along the Chek Mun Fault against the Lower Jurassic Tolo Channel Formation. Near the fault, the strata dip steeply to very steeply and are locally overturned. To the northwest, the regional dip decreases to 30°, but steepens again near the upper, faulted boundary of the formation with the Upper Jurassic Tai Mo Shan Formation and the Lower Cretaceous Pat Sin Leng Formation. The formation is estimated to be 800 m thick,

[1] Based on fossil collections made between 1988 and 1990 by M J Atherton & C M Lee (Hong Kong Polytechnic), J H Chen, G X He & S Q Wu (Nanjing Institute of Geology and Palaeontology, Academia Sinica), P S Nau (Hong Kong University) and K W Lai (Hong Kong Geological Survey).

but neither the base nor the top of the formation are seen, and the effects of faulting and folding are hard to assess.

Details

Cheung Pai Tun. The formation here is best exposed on the northern and southern shores (respectively 3700 3725, 4546 3601) of Cheung Pai Tun. The stratigraphically lower strata are dominantly greyish white, thickly bedded, fine- to medium-grained sandstone with two beds of pebbly conglomerate. The conglomerates, which vary from 8 to 13 m thick, have erosive bases and well-developed trough and planar cross-bedding, and represent channel features. The conglomerate exposed on the southern sea shore is overturned, dipping at 60° to the southeast. Higher in the succession, medium- to fine-grained sandstones are intercalated with siltstone and mudstone. The siltstone varies from reddish brown to reddish purple, greyish white and greyish green. The yellowish brown mudstone and fine-grained sandstone exposed along the northern shore contain bivalve, brachiopod and fish fragments and plant stems. The sedimentary rocks represent a deltaic facies association (Jones, 1995). The formation in this section is 690 m thick, but neither top nor base of the formation are seen.

Wong Wan Tsai to Ngor Kai Teng. The formation is up to 900 m thick in this area. Stratigraphically lower strata are mainly greyish white, quartzitic sandstone with three beds of conglomerate: the lowermost bed, exposed near the base of the formation on the shore of Chek Mun Hoi Hap (Tolo Channel), is a massive, thickly bedded, quartz-pebble conglomerate, 12 m thick; the middle bed is also quartz pebble-bearing and is 3 m thick; and the uppermost bed, 0.5 m thick, is a pale reddish brown, fine-grained, polygenetic conglomerate with subrounded to subangular clasts including quartzite, metasiltstone, and less abundant vein quartz. The upper part of the sequence comprises dominantly medium- to fine-grained, quartzitic and clayey sandstone with intercalated sericitic siltstone, mudstone and two lensoid beds of conglomerate. There are around 40 individual siltstone beds, each being 0.5 to 10 m thick, and the proportion of siltstone in the sequence is nearly 10 %. A thick pebbly conglomerate (4838 3865) occurs 100 m north of Ngor Kai Teng. The pebbles are mainly of quartz, varying from 2 to 150 mm in diameter. A further 1 m thick, fine conglomerate occurs 5 m above this bed.

South of Pak Kok Shan. Between the seashore, 550 m south of Pak Kok Shan (5021 3984) and 400 m northeast of Fung Wong Wat (5078 3920), the formation is 670 m thick. The lower strata are overturned and comprise greyish white sandstone with a thin breccia and a thick conglomerate. These are succeeded by fine-grained quartzitic (Plate 1) and clayey sandstones with subordinate sericitic siltstone and a lensoid conglomerate. These sedimentary rocks are considered by Jones (1995) to be dominantly sheetflood deposits. At Fung Wong Wat (4988 3840), the lower part of the succession includes a 20 m thick unit of well-bedded white sandstone, interpreted by Jones (1995) as including aeolian facies.

Wong Chuk Kok Tsui (Bluff Head). The formation is well exposed (Plate 2) along the shore of Wong Chuk Kok Tsui (527 411), where it is 260 m thick. The lower strata comprise greyish white, quartzitic sandstones with two units of thickly-bedded conglomerate, up to 20 m thick. A quartzphyric rhyolite dyke is intruded into the sandstone. The central part of the formation comprises sandstone with siltstone and a lens of conglomerate, while a series of minor folds is developed in sandstone with siltstone in the upper part. The top of the formation is faulted against tuffs of the Upper Jurassic Tai Mo Shan Formation. These sedimentary rocks are dominantly a channel facies association (Jones, 1995), with several major channels and a number of single and multi-storey minor channels. They are interbedded with palaeosols, which are more common in this locality than elsewhere in the district.

Petrography

Conglomerate. The subrounded, typically clast-supported pebbles in conglomerate beds low in the formation are mainly composed of vein quartz with some quartzite, quartz schist and siltstone clasts varying from 2 to 150 mm in diameter (Plate 3).

Quartz-pebble conglomerate. HK7949 (4889 3792), from 900 m southeast of Ngor Kai Teng, is greyish white, massive with a psammitic-psephitic (sandy-pebbly) texture, and contains (Plate 4) subrounded clasts (65 %) of vein quartz and rock fragments in a sandy, cemented matrix (35 %). Grain size is typically 2 to 4 mm but ranges up to 90 mm. In thin section the rock is seen to be poorly sorted. Vein quartz clasts, comprising 70 % of all of the clasts, are monocrystalline and polycrystalline, subround, and show intragranular cracks and undulose extinction. The rock fragments comprise 30 % of the clasts, are subrounded to subangular, and comprise sandstone and quartz schist. The matrix contains sand size (0.3 to 1.5 mm), subrounded to subangular quartz and quartzite grains (30 % of the whole rock) and some pelite, set in a siliceous cement (5 % of the whole rock) that surrounds the clasts.

Plate 1 - Well-bedded Sandstone and Siltstone with Conglomerate Lenses (5270 4110), and Minor Folds in the Central Part of the Devonian Bluff Head Formation, South of Wong Chuk Kok Tsui (Bluff Head)

Plate 2 - Planar-bedded Sandstone (4780 3720) in the Devonian Bluff Head Formation at Fung Wong Wat 300 m North of Fu Tau Sha on the North Coast of Chek Mun Hoi Hap (Tolo Channel)

Plate 3 - Well-rounded Vein Quartz Cobbles and Pebbles in Conglomerate (5237 4065) within the Devonian Bluff Head Formation, South of Tai Leng on the North Coast of Chek Mun Hoi Hap (Tolo Channel)

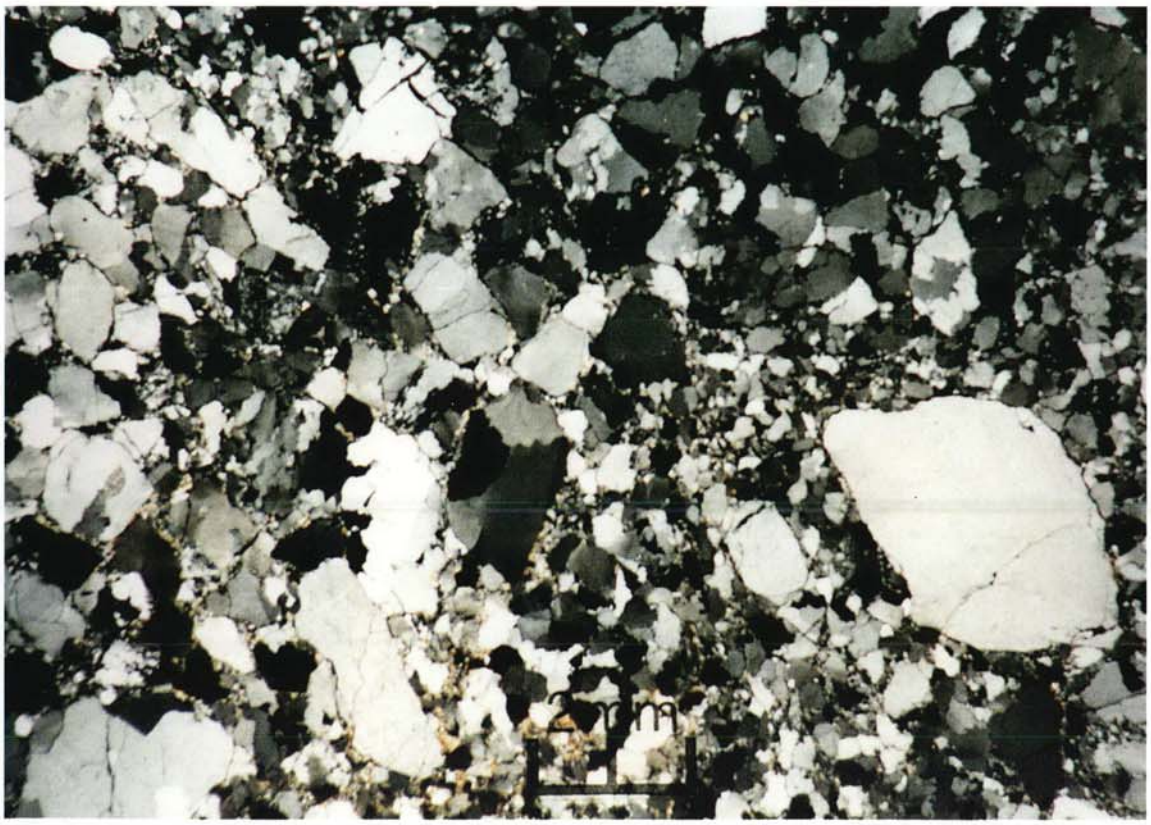


Plate 4 - Thin Section of Quartzose Sandy Conglomerate (HK7949, 4889 3792) in the Devonian Bluff Head Formation, South of Ngor Kai Teng; XPL

Sandstone. Most sandstones are greyish white litharenites containing mainly quartz grains together with 25 to 50 % siliceous rock fragments including quartzite, metasiltstone and quartz schist. However, a few sandstones are quartz arenites or sublitharenites, and a few contain limonite nodules (e.g. HK 8411, 4757 3745).

A hand specimen of sublitharenite (HK7938 from Ngor Kai Teng (4834 3871)), is greyish white, massive, and has a detrital texture. In thin section, it consists of abundant granular quartz (c.85 %) with minor sericite (4 %), sandstone fragments and heavy minerals, including zircon, tourmaline and apatite, and cement (10 %). The subrounded to subangular quartz grains vary from 0.07 to 0.6 mm in diameter but are usually 0.15 to 0.2 mm. They show undulose extinction and subgrain development, both suggesting deformation. The sericite is scaly and curved with grain size in the range of 0.2 by 0.03 mm and 0.4 by 0.08 mm. The cement is mainly siliceous with a minor clayey component that has altered to sericite. Whole-rock chemical analysis indicates that SiO_2 comprises 93.63 % of the rock and Al_2O_3 4.04 %.

Siltstone. Most siltstones are reddish to dark reddish brown, although some are purplish red, purplish grey and grey. Limonite nodules and solution voids may occur. The siltstones comprise mainly quartz and sericite (10 to 35 %). The sericite has formed by metamorphism from clay minerals. Some siltstones are sericite-bearing, such as HK7947 (4888 3801), from 500 m northeast of Wong Wan Tsai, which is reddish brown, thinly bedded and in hand specimen has an aphanitic texture and slaty structure. The sericite has a silky lustre. In thin section, quartz grains vary from 0.01 to 0.02 mm in diameter and comprise 70 % of the rock. The sericite (30 % of the whole rock) is scaly, varies from 0.02 to 0.1 mm by 0.005 to 0.03 mm and is of metamorphic origin.

Palaeontology

Devonian fossils have been found at 23 localities along the south shore of Shuen Wan (Plover Cove) Reservoir stretching between 600 m northwest of Lo Fu Wat (3676 3719) and Siu Kau (4767 3875). About 300 specimens of seven types of fossil have been collected, including bivalves, ostracods, conchostracans, gastropods, crinoids, fishes (Plate 5) and plants (Plate 6) (Lee *et al.*, 1990a, b). The most abundant and diverse of the fossil groups are bivalves, three assemblages of which have been recognised:

1. *Pseudonuculana zhaoi - Deceptrix guangxiensis* assemblage, indicating upper Lower Devonian.
2. *Orthonota guangdongensis - Paracyclas rugosa* assemblage indicative of uppermost Lower Devonian.
3. *Edmondia* aff. *subovata* assemblage comprising *Edmondia* aff. *subovata* Hall, *Edmondia* aff. *phillipi* Hall and *Edmondia* sp., of Middle Devonian age.

Three fossil plant assemblages have been identified at many localities:

1. *Zosterophyllum - Taeniocrada* assemblage indicating Lower Devonian.
2. *Protopteridium* assemblage indicating either uppermost Lower Devonian or lowermost Middle Devonian.
3. *Lepidodendropsis* assemblage which may indicate the lower Middle Devonian and which has never been found in the Lower Devonian.

The Bluff Head Formation can be correlated with the lower to middle Devonian Guitou Group of northern Guangdong Province.

Plate 5 - Fossil Plant (Protopteridium sp., 4 mm Long) from the Devonian Bluff Head Formation on the South Coast (4738 3808) of Plover Cove Reservoir

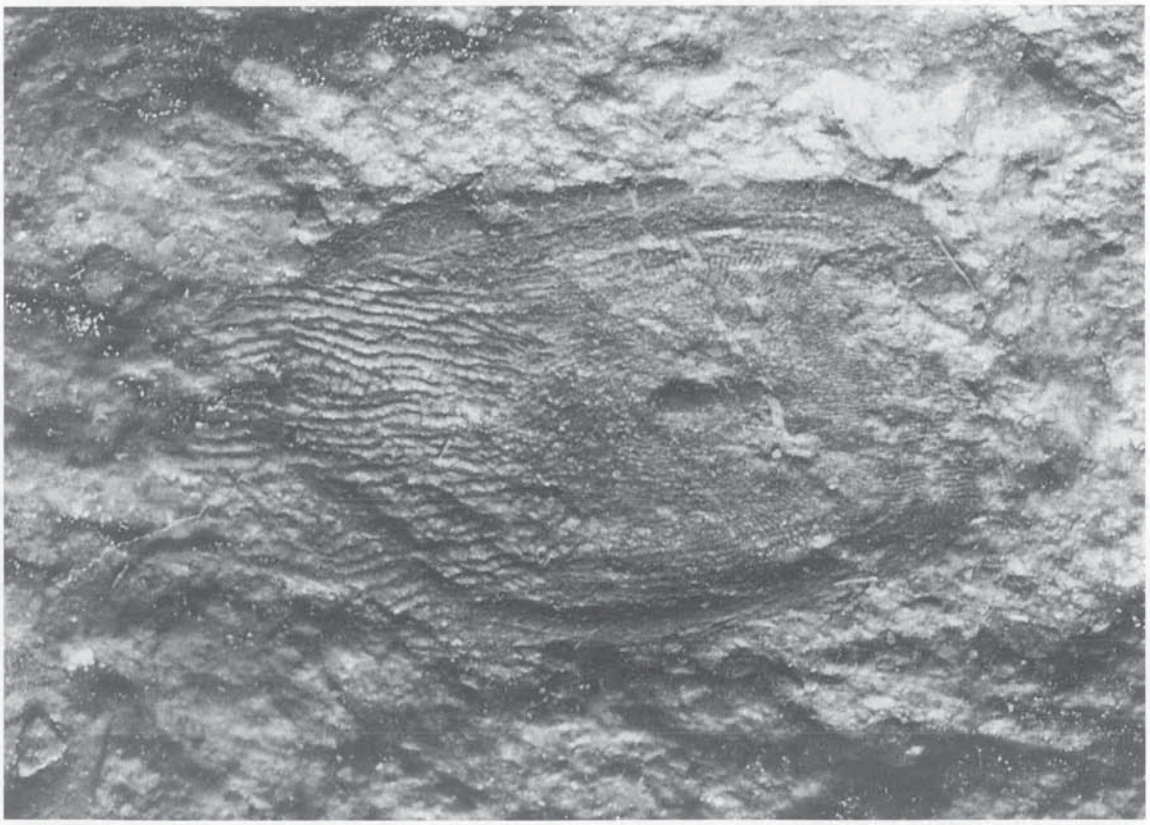


Plate 6 - Fossil Fish Scale (4.5 mm long) from the Devonian Bluff Head Formation on the South Coast (4708 3752) of Plover Cove Reservoir

Sedimentary Environment

Most of the lower and middle parts of the Bluff Head Formation are mainly thickly bedded quartzitic sandstones with pebbly conglomerates. Jones (1995) has identified five main facies associations: channel, sheetflood, palaeosol, deltaic and aeolian. The channel facies is characterized by sedimentary structures typical of high energy environments, including conglomerate-filled channel forms with graded-bedding, cross-bedding, and parallel-laminated to massive sandstone. Both major and minor channel features can be seen and are interpreted as migrating bars and dunes in fluvial channels on an alluvial plain. Sheetflood deposits include laterally-persistent beds of conglomerate and sandstone, typically with erosive bases and exhibiting trough cross-bedding and cross-lamination, interpreted as being deposited as pebble- or sand-laden unconfined sheet floods. Palaeosols, comprising mudstone with solution voids, nodules and desiccation cracks, have been identified at Wong Chuk Kok Tsui (Bluff Head), Fung Wong Wat and Shuen Wan Hoi (Plover Cove). These are commonly interbedded with minor channels and sheetflood sandstones.

The deltaic facies association is dominated by fine- to medium-grained sandstone and thin siltstone and mudstone beds. A wide range of sedimentary structures, including erosive channel bases, cross-bedding, sometimes grading upwards into ripple lamination, and graded bedding, together with the presence of both plant and marine fossils, indicate a delta to littoral plain environment of deposition (Lee, 1990a; Jones, 1995). The aeolian facies association is restricted to Fung Wong Wat and comprises low-angle, cross-bedded and thinly laminated sandstone with conglomeratic lenses. Foresets consistently dip to the south. The sandstones exhibit a number of typical stratification types, including wind-ripple lamination, and fine, evenly-spaced laminae consistent with grainfall and grainflow. The conglomerates are interpreted as deflation lags.

San Tin Group

The Lok Ma Chau Formation is the only representative of the San Tin Group in the district. Elsewhere in the Territory, the group also includes the older Yuen Long and Ma On Shan formations that consist predominantly of marble. The presence of marble clasts within some volcanic deposits, described below, suggests that older formations in the San Tin Group may occur as subcrop in the district.

Lok Ma Chau Formation

The Lok Ma Chau Formation is exposed in the northeast of Lo Wu, and can be divided lithologically into the Mai Po Member and the Tai Shek Mo Member. The older Mai Po Member comprises mainly metamorphosed siltstone with fine-grained sandstone and carbonaceous siltstone. The younger Tai Shek Mo Member is composed of metamorphosed sandstone with conglomerate. Metamorphism is of low-grade greenschist facies, with dynamic metamorphism producing phyllite, graphite schist and schistose conglomerate within narrow zones. There is possible stratigraphic equivalence between the Lok Ma Chau Formation and the Lower Carboniferous Ceshui Formation which crops out in the Shenzhen and Guangzhou areas.

Palaeontology

Until recently, the only evidence for the age of the Lok Ma Chau Formation came from macrofossils in supposedly equivalent strata in Guangdong. Recent microfaunal identifications by the Guangdong Institute of Geological Sciences and the British Geological Survey, outlined in Langford *et al.* (1989), confirm a Carboniferous age, though this could be either Tournaisian, or Namurian to Westphalian.

Sedimentary Environment

Sedimentary units within the Lok Ma Chau Formation have been interpreted in terms of deposition in neritic swamps within a prograding deltaic environment. Low in the succession, siltstone, fine-grained sandstones and carbonaceous horizons were probably deposited on a deltaic floodplain, the finer grained lithologies representing more distal environments. Some lithologies repeatedly recur but no cyclicity has been established. As the delta advanced, coarser sediments were laid down, culminating in deposition of coarse sand and pebbles in an alluvial environment.

Mai Po Member

The Mai Po Member occurs in a northeast-trending outcrop between the Sheung Shui Water Treatment Works (303 420) and Lo Shue Ling (324 442). The dominant lithologies are light to dark grey metasiltstone, phyllite with metasandstone, thin layers or lenses of graphitic schist. The graphitic schists are dark grey to black when fresh, and have a well-developed schistosity. Their occurrence characterises the member, which is more than 400 m thick. Boreholes suggest that the contact between the Mai Po Member and the underlying marble of the Yuen Long Formation is conformable.

Details

Sheung Shui Water Treatment Works to Cheung Po Tau. The formation is best exposed on the small hill (3062 4224) northwest of the Water Treatment Works and at Cheung Po Tau (3126 4243), where it comprises phyllite and metasiltstone with metasandstone, calcareous metasiltsone and graphitic schist. The latter (HK1151, 3043 4231; HK6984, 3061 4221) occurs in five discrete beds, varying from 0.1 to 2 m in thickness and dipping at 30-40° to the northwest. The calcareous metasiltstone (HK6981) is present in Borehole BH7/5922 (3081 4277). The contact between the formation and the tuff of the Tai Mo Shan Formation is faulted and can be seen at Fu Tei Au Road (3052 4186) and below the service reservoir (3146 4250) at Cheung Po Tau. The metasedimentary rocks are thrust over the tuff, the thrust dipping northwest at 28-40°. Rocks on both sides of the fault are intensely mylonitised.

Kong Nga Po to Lo Shue Ling. All the rocks in this area are metamorphosed, and quartzphyric rhyolite dykes trending 020° that intrude the formation are also foliated. A thin bed of graphitic schist occurs at Kong Nga Po (HK6935, 3186 4288), but the main lithology is phyllite. The outcrop of the formation continues northeast across the Sham Chun River into Shenzhen. At Kong Nga Po, Borehole SL3/6 (GIU report no. 6681, 3192 4291) penetrates metasiltstone (HK3417) overlying mylonitised tuff (HK3418) of the Tai Mo Shan Formation. The contact at 13 m is interpreted as a thrust, with the overlying rocks thrust from northwest to southeast.

Cheung Shek Tsui, Kat O Chau (Crooked Island). Two outcrops occur on Kat O Chau, one north of Tung O Wan (4815 4595) and one south of Cheung Shek Tsui (4830 4603). Both are bounded by faults and comprise dark grey siltstone with thinly-bedded limestones. The latter occur as eight beds between 50 and 200 mm thick, are grey to dark grey with a micritic texture, and have yielded the foramaniniferan *Archaesphaera magna* Suleymanov (identified by Nanjing Institute of Geology and Palaeontology, Academia Sinica). The rocks in this outcrop are believed to belong to the lowermost part of the Mai Po Member.

Petrography

Metasandstone. Most metasandstones are silver-grey to yellowish grey with a blasto-psammitic texture. They comprise dominantly quartz (65-70 %) with minor haematite (5 %), feldspar and heavy minerals including zircon, rutile, epidote, tourmaline, clinopyroxene, magnetite and apatite. The quartz grains are 0.05 to 0.5 mm in size, subangular and often stretched into lenses or ribbons with undulose extinction. Haematite, disseminated throughout the rockmass, may be weathered to limonite, giving the rock a yellowish colour. The matrix (15-30 %) was dominantly clay, but has been recrystallized to sericite which displays a preferred orientation.

Metasiltstone. This has a clastic component mainly of quartz, with a few heavy minerals such as tourmaline and magnetite. The clay matrix has recrystallized to sericite, with dispersed microgranular haematite. Modal analyses of thin sections show 50-60 % quartz, 30-40 % sericite and 1-3 % opaque minerals (haematite and pyrite). The quartz grains are often strained and

flattened, and show undulose extinction. Preferred orientation of sericite defines the schistosity, and in some thin sections there are two foliations.

Limestone. Specimen HK8100 (4826 5605) is grey to dark grey, comprising microcrystalline calcite that makes up to 90 % of the rock. The remainder of the rock comprises disseminated quartz in crystals of 0.02 to 0.04 mm across (5 %), muscovite (1 %), pyrite (3 %) and clay minerals (2 %).

Tai Shek Mo Member

The outcrop of the Tai Shek Mo Member extends from Sha Leng (Sandy Ridge) (300 431) to Muk Wu (318 444) in the northwest of the district. The member is well exposed in a section on Sha Leng. The dominant lithology is greyish white to yellowish white, medium- to fine-grained metasandstone, with metaconglomerate and phyllite.

The contact between the Tai Shek Mo Member and the underlying Mai Po Member is covered by superficial deposits but boreholes have shown that it is transitional. The Tai Shek Mo Member is more than 300 m thick.

Details

Sha Leng (Sandy Ridge). The dominant lithologies in the area are metasandstone and conglomeratic metasandstone with phyllite and metaconglomerate. The sandstone is mainly fine to medium-grained, whereas the sand fraction of the conglomeratic metasandstone is normally coarse. A bed of metaconglomerate, cropping out on a hill 500 m east of Lo Wu (3011 4333) dips at 27° to the northeast.

Muk Wu. The main lithologies in this area are thickly bedded yellowish brown metasandstone and greyish white conglomeratic metasandstone with thinly-bedded metasiltstone, phyllite and sericitic schist. Most of the rocks have been foliated with the structural fabric dipping at between 23° and 40° to the northwest. The rocks of the formation are highly to completely weathered and are widely covered by superficial sediments.

Petrography

Metaconglomerate. The rock is greyish white to yellowish grey and comprises pebbles, mainly subrounded quartzite and vein quartz, varying from 5 to 30 mm in size. The clasts, which make up 40 to 60 % of the rock, are flattened and elongated with a preferred orientation. The matrix comprises grains of quartz, feldspar, muscovite, magnetite and haematite with a microgranular quartz and sericitic cement.

Conglomeratic metasandstone. The rock consists of sub-rounded clasts of flattened quartz grains and elongate quartzite fragments which are strongly foliated. The quartz (60-80 %) has a grain size mostly between 0.1 and 0.2 mm. The larger quartz grains and clasts range from 0.5 to 30 mm, and commonly show undulose extinction. The matrix is composed of sericite (15-25 %) and microgranular quartz.

Metasandstone. Sample HK 6943 (3070 4334) is mainly composed of quartz grains (60-80 %) and haematite (5 % or less), with minor feldspar and pyrite. The grain size varies from 0.07 to 0.3 mm, with a maximum grain size of 0.7 mm. The quartz grains are strongly aligned and show undulose extinction. The matrix (15-25 % of the rock) has been recrystallized to sericite which also displays a preferred orientation.

Chapter 4
Mesozoic Sedimentary and Volcanic Rocks

Classification and Distribution

Mesozoic rocks are the most widespread of any in the district, accounting for about 90 % of the onshore outcrop. They include the Lower Jurassic Tolo Channel Formation, the Upper Jurassic Tsuen Wan Volcanic Group, the Upper Jurassic to Lower Cretaceous Repulse Bay Volcanic Group, the Lower Cretaceous Pat Sin Leng Formation, and the Upper Cretaceous Port Island and Kat O formations.

The Tolo Channel Formation comprises ammonoid-bearing mudstone with sandstone and includes the oldest Mesozoic rocks in the district. The formation occurs impersistently along a narrow, northeast-trending fault zone and extends for more than 6.5 km along the south coast of Pak Kok Shan (5090 3930) as far as Lo Wu Wat (4570 3620), and for more than 150 m offshore. The formation is faulted against sandstone of the Bluff Head Formation to the northwest and volcanic rocks to the southeast.

Allen & Stephens (1971) defined the Repulse Bay Formation as including all Upper Jurassic to Lower Cretaceous volcanic strata in Hong Kong. In the district, this sequence is over 2000 m thick and is equivalent to the Gaoziping Group that crops out to the north in Shenzhen. On early maps of the Hong Kong Geological Survey 1:20 000 scale series, and including Sheet 3 (GCO, 1991), the Repulse Bay Volcanic Group was also used to encompass all volcanic strata. With the publication of Sheet 4 (GEO, 1993), however, the Repulse Bay Volcanic Group was subdivided on the basis of lithology: the lower part of the succession was assigned to the new Tsuen Wan Volcanic Group while the upper part remained as the Repulse Bay Volcanic Group. The nomenclature and classification of the pyroclastic rocks used on the published maps and in this memoir are based on recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks (Schmid, 1981), and the work of Fisher & Schmincke (1984) (Figures 6a and 6b).

The Upper Jurassic Tsuen Wan Volcanic Group is widespread and particularly dominates the west side of the district. It includes four distinctive lithostratigraphic formations. The oldest of these, the Shing Mun Formation, is lithologically variable, and includes ash crystal tuff with minor siltstone intercalations. The overlying Tai Mo Shan Formation comprises predominantly coarse ash crystal tuff with subordinate vitric crystal tuff and fine ash crystal tuff. This is overlain in turn by the Sai Lau Kong Formation, dominated by a dacite lava with tuff and siltstone. The Ngo Mei Chau Formation is confined to a northwest-trending outcrop in the northeast of the district. The outcrop is fault bounded on its western side and is mainly composed of eutaxitic fine ash vitric tuff with lapilli tuff.

The Repulse Bay Volcanic Group, which includes Upper Jurassic to Lower Cretaceous strata, occurs only on the southern side of Chek Mun Hoi Hap (Tolo Channel) where two formations are present: the Lai Chi Chong Formation, composed of fine ash crystal tuff with tuffite, that crops out only at Che Lei Pai (Knob Reef); and the Long Harbour Formation, a lithologically uniform coarse ash crystal tuff.

The Pat Sin Leng Formation is almost 500 m thick and mainly comprises conglomerate, pebbly sandstone, sandstone and siltstone. These occur within a zone that extends for more than 15 km

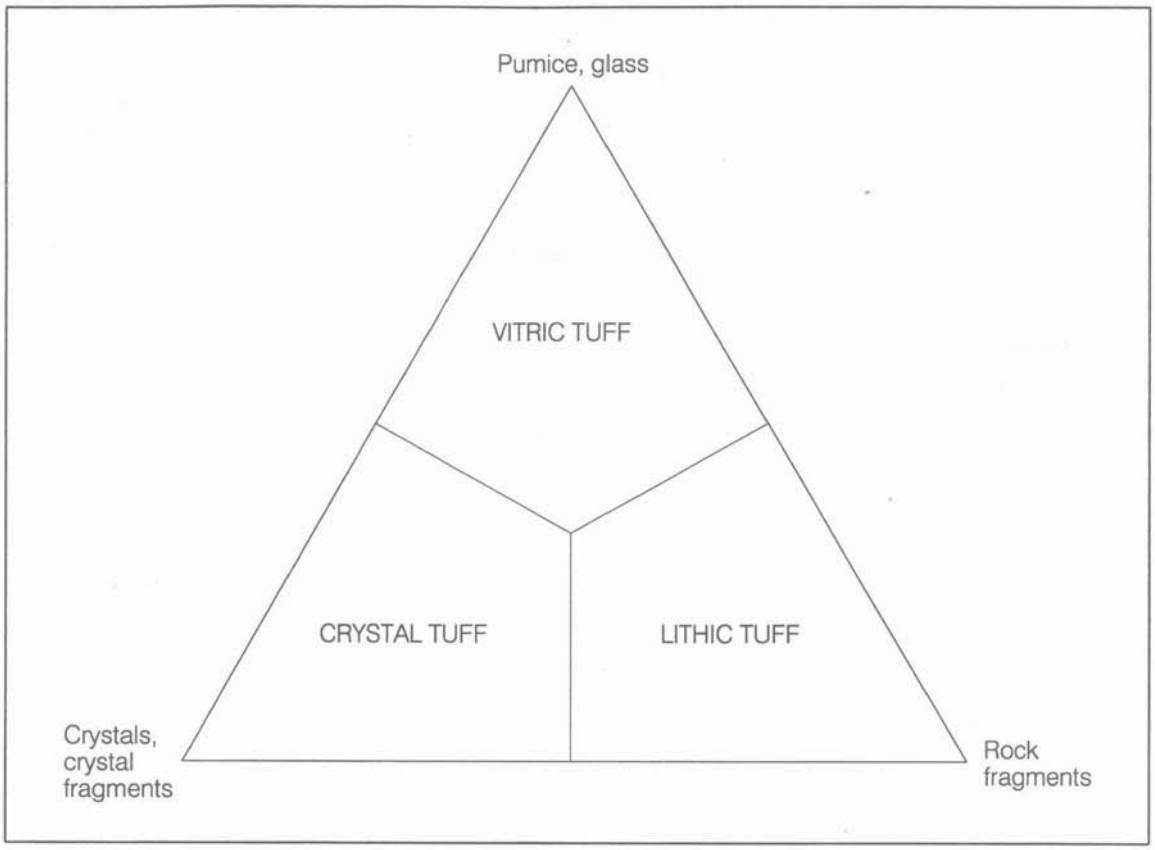


Figure 6a - Classification of Pyroclastic Rocks Based on Composition (after Le Maitre, 1989)

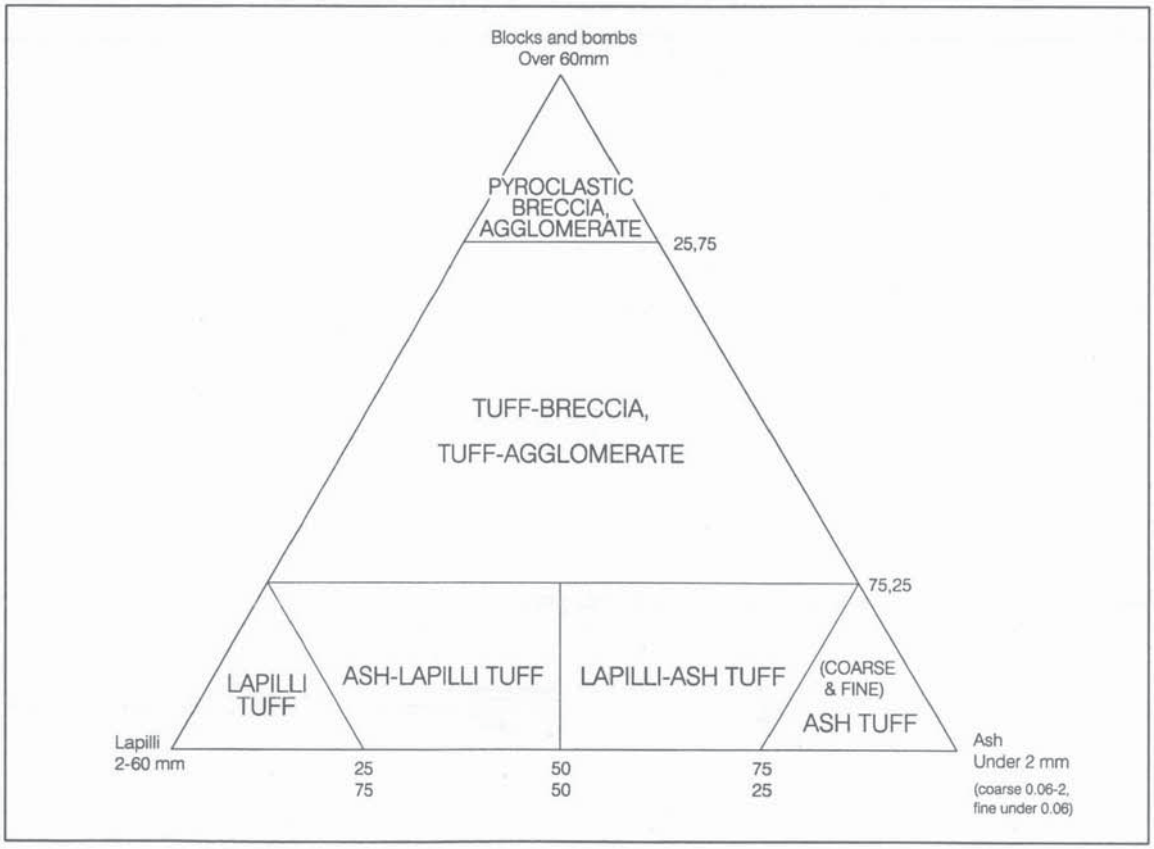


Figure 6b - Classification of Pyroclastic Rocks Based on Grain Size (Adapted from Schmid, 1981 and Fischer & Schminke, 1984)

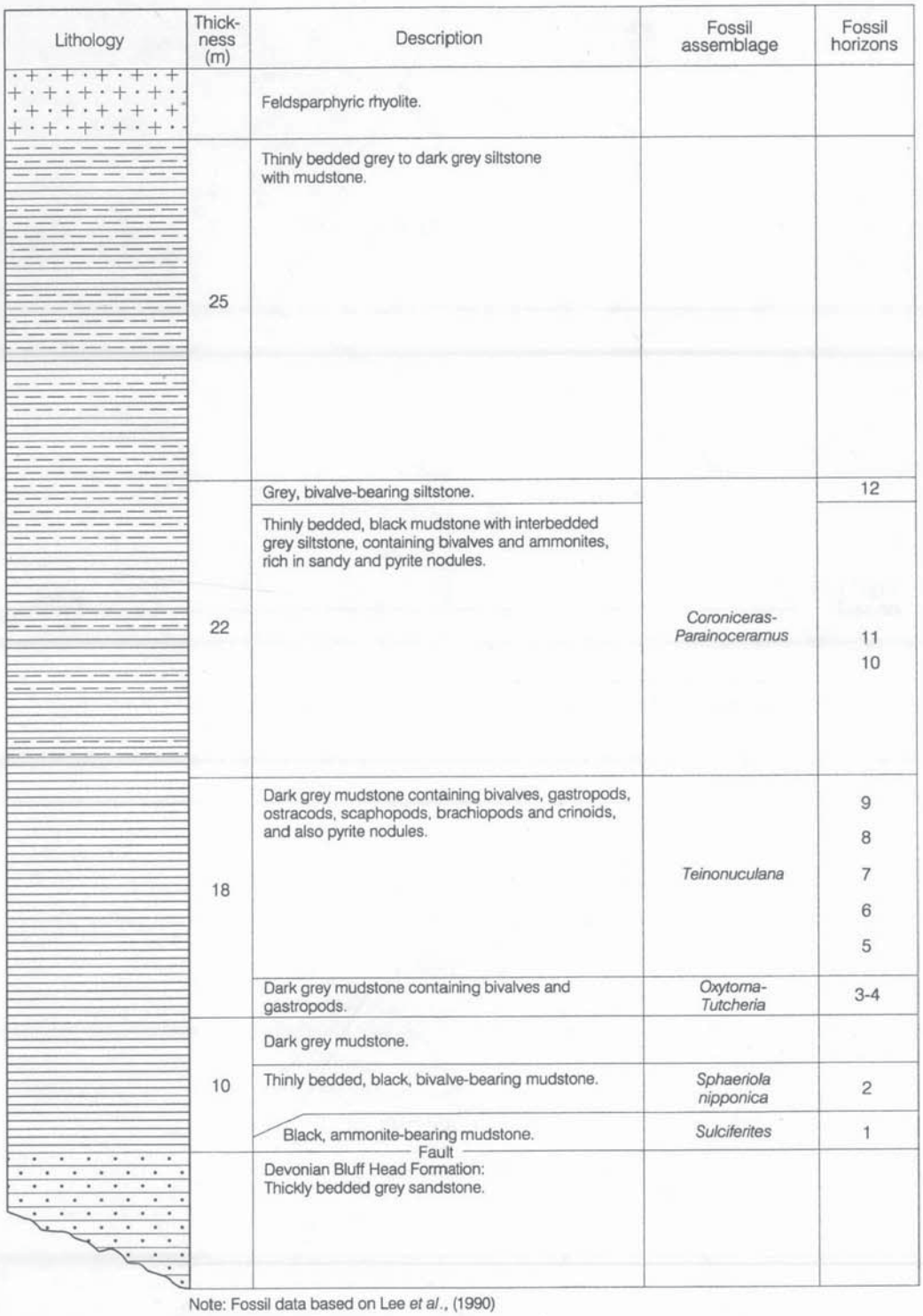


Figure 7 - Stratigraphy of the Tolo Channel Formation

from Bluff Head (524 413) in the east, to the Tan Chuk Hang (370 410) in the west. The formation unconformably overlies the Tsuen Wan Volcanic Group.

The Port Island Formation consists of reddish brown clastic rocks and is over 1200 m thick. Although it occupies an area of some 70 km^2, exposure can only be seen on a few small islands in Tai Pang Wan (Mirs Bay). The Kat O Formation similarly comprises reddish brown, calcareous, coarse clastic rocks but is only approximately 130 m thick, and the outcrop is restricted to about 7 km^2 between Chek Kok Tau (480 462) in the east, to Cheung Pai Tai (Ledge Point) (444 456) in the west. From offshore seismic and borehole data (Borehole VDI/9, 5122 4769), it appears that the two formations are separated by an outcrop of tuffaceous volcanic rock to the northeast of Kat O Chau.

Tolo Channel Formation

The earliest published descriptions of the Tolo Channel Formation by Brock and Schofield (1926) and Uglow (1926) were very brief, but a more comprehensive account was given by Williams (1943). Other descriptions of these strata within the district include those by Grabau (1923), Williams *et al.* (1945), Ruxton (1960) and Allen & Stephens (1971). The ammonite *Hongkongites hongkongensis* was discovered within the formation by Heanley (1924) and recently *Ammonites Coroniceras sp., ?Sulciferites sp.* and the bivalve *Parainoceramus matsumotoi* Hayami have been reported by Lai (1989). Further marine fossils have been recorded by Lee *et al.* (1990), who have assigned the formation to the Lower Sinemurian (Lower Jurassic).

Details

South Coast of Pak Kok Shan. The Tolo Channel Formation crops out in the intertidal zone of a headland on the south coast of Pak Kok Shan (5075 3913). The formation is 75 m thick and consists of thinly bedded black mudstone with grey to dark grey siltstone containing pyritous nodules. The strata dip northwest at 60° but fossil evidence indicates that they are overturned. Biostratigraphical sequences are shown in Figure 7 and Table 3. A feldsparphyric rhyolite dyke, trending northeast, intrudes the succession parallel to the coast. On the south side of the dyke, black mudstones with crushed and silicified sandstone are exposed over a width of 5 m and they extend offshore.

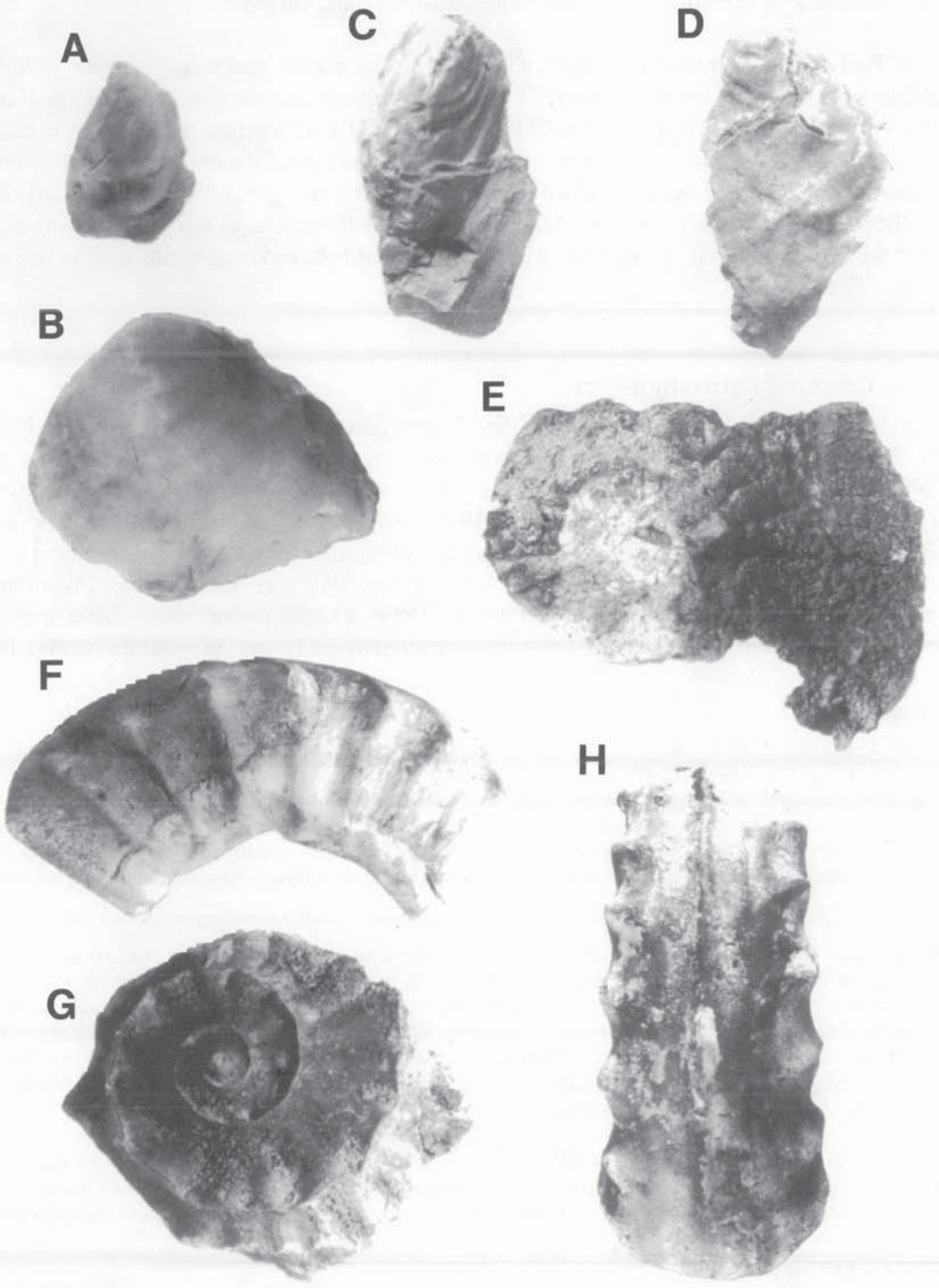
Fung Wong Wat -Wong Wan Tsai. The formation is exposed on the marine platform, at the base of the adjoining hill, and in the intertidal zone. The outcrop is 30 to 120 m wide between Fung Wong Wat (499 385) and Wong Wan Tsai (485 377). The sediments comprise sandstone, which is locally pebbly with angular mudclasts, overlying black fossiliferous mudstone, which contains abundant pyritous nodules, with siltstone and sandstone. The strata dip at 20°. A feldsparphyric rhyolite dyke intrudes the sedimentary rock near the low tide mark. On the adjoining hillside, bedding dips steeply and is contorted along the faulted contact with the Bluff Head Formation. More sandstones occur further southwest along the coast.

Lo Wu Wat. South of To Tau Tsui (4635 3660), the Tolo Channel Formation is exposed at low tide in a narrow outcrop, only 10 m wide, on the foreshore along the north coast of Chek Mun Hoi Hap (Tolo Channel). The thinly bedded siltstone with sandstone is dark grey when fresh, but is yellowish to reddish brown where it is weathered.

Palaeontology

On the south coast of Pak Kok Shan, sparse but very diverse assemblages of fossils have been found in seven beds, containing 13 fossil horizons (Lee *et al.*, 1990 a-e; Figures 7 and 8, Table 3). These include many species of ammonites and bivalves, in addition to gastropods, ostracods, scaphapods, brachiopods and crinoids. A few fossil plant fragments are also present.

Recently, the ammonite *Sulciferites hongkongensis* (previously identified as *Hongkongites* by Wang & Smith (1986)) and the bivalve *Cardinia toriyamai* have been found (Lee *et al.*, 1990) in black mudstone on the foreshore at Fung Wong Wat (4968 3818). This locality is very near to the ammonite-bearing locality described by Heanley (1924). Based on fossil evidence, the Fung



A. *Parainoceramus matsumotoi* Hayami, x 1.9
B. *Parainoceramus matsumotoi* Hayami, x 1.9
C. *Parainoceramus matsumotoi* Hayami, x 5.4
D. *Parainoceramus matsumotoi* Hayami, x 5.4
E. ? *Sulciferites sp.*, lateral view, x 1.5
F. *Coroniceras sp.*, lateral view, x 2.2
G. *Coroniceras sp.*, umbilical view, x 2.2
H. *Coroniceras sp.*, ventral view, x 2.2

Figure 8 - Bivalves and ammonoids from the Tolo Channel Formation, South Coast (5075 3913) of Pak Kok Shan

Table 3 - Fossil Assemblages from Horizons in the Lower Jurassic Tolo Channel Formation along the South Coast of Pak Kok Shan

Fossil Horizon	Fossil Assemblage
12	*Parainoceramus amygdaloides*
11	*Coroniceras* sp., *Parainoceramus matsumotoi*
10	*Parainoceramus matsumotoi, Palaeoneilo* sp.
9	*Limea* ?sp.
8	*Palaeonucula* cf. *navis, Astate* sp., *Parainoceramus* sp., crinoid stems, gastropods
7	*Teinonuculana graphica, Parainoceramus matsumotoi*
6	*Astarte delicata, Entolium* cf. *calvum, Catella* cf. *infraliassica, Teinonuculana elongata, Parainoceramus matsumotoi, P. amygdaloides, Chlamys? subulatus, Palaeonucula* sp., brachiopods, scaphopods, ostracods, gastropods
5	*Astarte subvoltzii, Parainoceramus matsumotoi*, gastropods, brachiopods, scaphopods, crinoids, trace fossils.
4	*Parainoceramus matsumotoi, Chlamys? subulatus,Palaeoneilo galatea, P. jinjiensis, Mesomitltha? shenzhenensis, Veteranella jinijiensis, Catella* cf. *infraliassica, Tutcheria submulticostata*
3	*Lucininola problematica, L. cingulata, Oxytoma inequivalve, Astarte subvoltzii, Parainoceramus* sp., *Tutcheria submulticostata*, gastropods
2	*Sphaeriola nipponica*
1	*Sulciferites?*sp.

Note : Fossil data based on Lee *et al.* (1990)

Wong Wat sequence is equivalent to strata on the south coast of Pak Kok Shan which bear *Sulciferites* assemblages. The fauna clearly shows that the Tolo Channel Formation was deposited during the Lower Sinemurian Stage of the Lower Jurassic, making it a time-equivalent of the Jingji Formation of Central Guangdong (Nau, 1990).

Sedimentary Environment

Fossil assemblages indicate a dominantly shallow marine, sub-littoral environment. Low-energy conditions predominated with the deposition of mud and silt from suspension. Occasional sandier horizons, which are more common in the lower part of the succession, suggest periods of reworking by wave action. The transition from sandstone low in the sequence at Fung Wong Wat to mudstone at higher levels may reflect a marine transgression, consistent with the global trend during the early Jurassic (Hallam, 1981).

Tsuen Wan Volcanic Group

The group is represented in the district by the Shing Mun Formation, the extensive Tai Mo Shan Formation, and the relatively restricted Sai Lau Kong and Ngo Mei Chau formations. The basal formation of the group, the Yim Tin Tsai Formation, is not known within the district.

Shing Mun Formation

The Shing Mun Formation is the most lithologically variable formation of the Tsuen Wan Volcanic Group. It is dominantly comprised of lithic-bearing, coarse ash to fine ash crystal tuff, block-bearing tuff, tuff breccia and intercalated tuffaceous sedimentary rocks, including tuffite and tuffaceous sandstone, siltstone and mudstone. The lithic components comprise block to lapilli-sized fragments of sandstone, siltstone and marble, together with tuffite, tuff and lava.

The formation is up to 350 m thick and crops out in two areas: the largest of the two is west and southwest of Sha Tau Kok Hoi (Starling Inlet), and the other lies on the northwest side of Tai Po Hoi (Tolo Harbour) and Plover Cove Reservoir.

West and southwest of Sha Tau Kok Hoi, the formation is dominated by fine ash to coarse ash crystals tuffs. Intercalations of tuffaceous siltstone and sandstone are rare. The outcrop is at its greatest width of 3.5 km near the northern border of the Territory, from where it trends to the southwest, narrowing and splitting into two, largely fault-bounded slices. The formation is variably tectonised and discrete faults and shear zones, trending mainly northeast to southwest, are present within and alongside the margins of the outcrop. In the central part of the Sha Tau Kok Fault Zone, the formation is strongly mylonitized, but deformation diminishes towards the margins, where the mylonitization is restricted to minor shear zones.

The formation northwest of Tai Po Hoi (Tolo Harbour) and Plover Cove Reservoir displays complex lateral facies variations. Some of these lithofacies are shown on Sheet 3, including fine ash to coarse ash crystal tuffs, block and lapilli-bearing ash crystal tuffs, tuff breccias, tuffites and intercalated beds of sandstone, siltstone and mudstone. Marble clasts occur in block-bearing tuff at several localities around Sheun Wan Hoi (Plover Cove). Siltstone and sandstone beds have been mapped in the upper part of the formation. A substantial area of fine ash tuff has been identified in the Shing Mun Formation of the district; this is unusual as elsewhere the formation is characterized by coarser ash to lapilli grain sizes. However, within the area depicted as fine ash tuff, there are intercalations of coarser volcanic deposits. The contact with the overlying Tai Mo Shan Formation is gradational, but on the southern flanks of Pat Sin Leng, a laterally continuous siltstone has been mapped at the junction between the two formations. Isolated outcrops of medium-grained granodiorite are spatially associated with the Shing Mun outcrop.

Details

Leng Pei Tsuen to Pak Kung Au. From Leng Pei Tsuen (3640 4170) to Pak Kung Au (3920 4620), the formation is grey to dark grey in fresh, unaltered outcrop, but pale grey to greenish grey where metamorphosed. The tuffs are characterized by the abundance and variety of lithic lapilli and large boulders, including sandstone, siltstone and mudstone fragments, typically 50 to 500 mm in size. The matrix is dominated by coarse to fine ash crystals. There are good exposures in a large cut slope at Au Ha (380 410), along a track between the Au Ha cut slope and Hung Fa Chai (380 450), and along the border road from San Kwai Tin (380 460) to Pak Kung Au and Sha Tau Kok. Sandstone and mudstone intercalations occur at Kung Chu Shan (3675 4187 and 3702 4162), 450 m west of Sheung Tam Shui Hang and 200 m northwest of Hung Fa Chai (3785 4495). Large blocks, up to 2 m across, are exposed 450 m southwest of Tong To (3940 4460). The faulted contact with the overlying Tai Mo Shan Formation is well exposed in a road cutting at Au Ha (3805 4295). The northeast-trending fault dips northwest at 40°.

Tung Shan Ha to Hoi Pui Leng. Between Tung Shan Ha (3680 4060) and Hoi Pui Leng (3910 4310), the formation is bounded by northeast-trending faults, along which the tuff is mylonitized. Red beds of the Pat Sin Leng

Formation overlie the tuffs. 500 m south of Sheung Wo Hang (3827 4215 and 3834 4200), the tuff contains lithic lapilli and blocks, and thinly bedded intercalations of light red sandstone and greyish white conglomerate.

Hong Lok Yuen to Fung Yuen Lo Tsuen. The lithic block-bearing, ash crystal tuff in this area surrounds a granodiorite intrusion and has been subjected to contact (thermal) metamorphism. At Hong Lok Yuen (344 360), the tuff is characterized by abundant lithic lapilli and blocks, whereas 600 m northwest of Fung Yuen Lo Tsuen (3600 3600), there are abundant sandstone and siltstone intercalations, 0.5 to 1.5 m thick.

Sheun Wan to Tai Mei Tuk. Between Shuen Wan (392 364) and Tai Mei Tuk (421 366), the coarse and fine ash crystal tuffs are characterized by the abundance and variety of lithic lapilli and blocks, and by intercalations, 0.5 to 3 m thick, of sandstone and siltstone. Marble clast-bearing fine ash tuff occurs 370 m west of Wai Ha (3857 3650) and 870 m west of Ha Tei Ha (3816 3611). The marble clasts are greyish green to dark grey and vary from cobble to gravel size. The fine ash crystal tuff is intruded by small bodies of granodiorite.

Wang Leng Tau to Tai Lung. Exposures on the north side of Plover Cove Reservoir are characterized by abundant lithic blocks in a coarse ash crystal tuff. Blocky lithic clasts and intercalations of sandstone and mudstone occur 450 m south of Tai Lung (4536 3833) and near Wang Leng Tau (4440 3855, 4430 3860 and 4444 3847).

Petrography

In thin section, the crystal tuffs are characterized by angular to subangular quartz crystals (0.1-2 mm), subordinate alkali feldspar and plagioclase crystals (0.5-1.2 mm), and subangular to subrounded rock fragments (1-2 mm) set in a fine ash matrix (Plate 7, HK1880). Accessory minerals include biotite, amphibole, and rare allanite. Altered rocks contain chlorite, epidote, and calcite. In fresh examples, the quartz grains may locally reach up to 5 mm in diameter, in which case the rock is described as lapilli-bearing. Feldspars are generally partly altered to sericite and plagioclase is dominantly andesine in composition. The lithic component includes both volcanic and sedimentary rock fragments. Locally these may be greater than 64 mm in size so that the tuff is described as block-bearing. Sedimentary rock clasts consist mostly of sandstone and siltstone, although marble clasts also occur (e.g. HK10974, 3057 3650; HK7873, 3816 3611). Volcanic rock fragments mostly comprise fine ash tuff, devitrified glass, and lava. Some sedimentary rock fragments are weakly metamorphosed. The tuffaceous strata include crystals of quartz, alkali feldspar and plagioclase, lithic fragments, secondary epidote and sparse chloritized biotite.

In deformed rocks, metamorphic foliation is defined by granulation of fine ash layers and incipient growth of oriented sericite (HK1941). This fabric is typical of local zones of mylonitization close to major shear zones.

Volcanic Environment

The common occurrence of coarse tuffaceous lithologies, including block-bearing tuffs and tuff breccias indicates proximity to the volcanic source, or sources of the deposits. Given the close similarities between the whole-rock geochemistry of samples from the Shing Mun Formation and the granodiorites which intruded the formation, it is likely that the granodiorites represent the primary magma source of the volcanic rocks. The granodiorite outcrops, together with similar granodiorites, referred to collectively as the Tai Po Granodiorite in adjoining areas to the south and southwest of the district (Sheets 5, 6 and 9), are distributed in fairly continuous and gently arcuate chains. These trend variably to the west or west-southwest for about 25 km from Plover Cove Reservoir to the west-southwest of the district. The chains of outcrop are interpreted as following major crustal structures that acted as conduits for the magmas, and controlled the location of volcanic vents.

The tuffaceous sedimentary rocks intercalated with the tuffs are considered to be of volcaniclastic origin deposited in ephemeral lakes, possibly within a caldera, during periods of relative volcanic quiescence.

Age Relationships

The Shing Mun Formation includes the oldest volcanic rocks in the district. The only available absolute age for the formation is based on a K-Ar isotopic determination for biotite from a coarse ash crystal tuff collected south of Tai Lung (3603 3833). This gave an age of 155 ± 4 Ma (Allen & Stephens, 1971), which is equivalent to the late Jurassic. However, recent high precision U-Pb isotopic determinations of zircon crystals from the Yim Tin Tsai and Tai Mo Shan formations, respectively above and below the Shing Mun Formation, and of the Tai Po Granodiorite in the area to the southwest of the district, have indicated that the age of the Shing Mun Formation is 164.5 ± 0.2 Ma (Davies *et al.*, in press). The discrepancy with respect to the K-Ar date is probably due to some loss of argon during deformation of the volcanic rocks.

Tai Mo Shan Formation

The Tai Mo Shan Formation is lithologically uniform and predominantly comprises pale to dark grey, lapilli-ash to coarse ash crystal tuff with subordinate vitric crystal tuff and impersistent layers of tuffaceous sandstone and siltstone. Small lithic fragments, of dark aphanitic volcanic rock or sandstone, are common. The matrix is characterized by euhedral white and grey crystals of feldspar and quartz. The formation conformably overlies the Shing Mun Formation, is at least 600 m thick, although its top is not seen, and is the most voluminous formation within the Tsuen Wan Volcanic Group.

The main outcrop of the Tai Mo Shan Formation dominates the western and northern parts of the district. Other substantial outcrops are present: south of Pat Sin Leng and extending eastwards to Wang Leng and Fung Wong Wat Teng; on the north side of Wong Wan Chau (Double Island); and on the southwest sides of Kat O Chau (Crooked Island) and Ngo Mei Chau (Crescent Island).

Details

Ma Tau Leng to Wong Mau Hang Shan. From Ma Tau Leng (3350 4160) to Wong Mau Hang Shan (3600 4538), the formation comprises rhyolitic, coarse ash lithic crystal tuffs. As the area is bounded by the San Tin and Sha Tau Kok faults (Figure 16), however, the tuffs have been subjected to varying degrees of shearing and metamorphism. Near the San Tin Fault in particular, the tuff is mylonitized. The carbonaceous metasandstone, tuffaceous metasiltstone and phyllite at Wong Mau Hang Shan were deposited in a minor basin that may have been an ancient volcanic crater lake.

Pak Tai To Yan to Lung Shan. In the area of Pak Tai To Yan (3124 3634) and Lung Shan (3454 3904), the rocks are grey to dark grey, lapilli-bearing coarse ash lithic crystal tuff, clasts comprising 50 % and 70 % of the rock respectively. Block-bearing coarse ash lithic crystal tuff occurs on the summit of Pak Tai To Yan. The blocks, comprise siltstone and sandstone and are 250 to 1,000 mm in size, suggesting the proximity of a volcanic vent. Near the Sha Tau Kok Fault Zone, the rocks are foliated and slightly metamorphosed, the rotation of the foliation into parallelism with the fault suggesting sinistral movement.

Kau Lung Hang Shan to Hsien Ku Fung. Lithic clasts comprise 45 to 80 % of the crystal lithic tuff between Kau Lung Hang Shan (3560 3736) and Hsien Ku Fung (4216 3838) at the eastern end of the Pat Sin Leng. Red beds of the Pat Sin Leng Formation overlie the formation in this area. The contact with the underlying Shing Mun Formation is gradational and is defined, as around Kau Lung Hang Shan, on the presence of abundant sedimentary rock intercalations and sedimentary blocks in the Shing Mun Formation but not in the Tai Mo Shan Formation. In the Pat Sin Leng area, the Tai Mo Shan Formation directly overlies a 1 to 5 m-thick siltstone in the Shing Mun Formation. Locally, close to the Sha Tau Kok Fault Zone the tuffs are weakly foliated. A thin, reddish brown siltstone at Hok Tau Reservoir probably represents deposition in a small intermontane lake.

Ma Tau Fung to Wong Chuk Kok Tsui (Bluff Head). Mainly lapilli-bearing coarse ash lithic crystal tuff and some coarse ash crystal lithic tuff are present in a narrow outcrop, 60 to 600 m wide, in the Kwun Yam Shan area, between Ma Tau Fung (4354 3968) and Wong Chuk Kok Tsui. At Wang Leng Tau, the contact (4520 3878) with the underlying Shing Mun Formation is gradational, whereas, a northeast-trending fault separates the formation from the Bluff Head Formation to the southeast. Due to the intensity of erosion, the formation is seen mainly in

small, isolated exposures along streams and in low ground at Shek Tsai Wan (5174 4078) and Wong Chuk Kok Tsui (5230 4125, 5245 4120).

Tiu Tang Lung to Kei Shan Tsui. The rocks between Tiu Tang Lung (4470 4128) and Kei Shan Tsui (4334 4540) mainly comprise lithic crystal ash tuff, with welded tuff and rhyolite lava. Greenish grey, lithic crystal welded tuff is present at Tiu Tang Lung, and there is a porphyritic rhyolite at Pan Pui Teng (4450 4352). The formation is overthrust from the north, by the Pat Sin Leng Formation. The tuff is mylonitized close to the fault zone, from south of Tiu Tang Lung to Fan Kei Tok, and from south of Kwai Tau Leng (3808 4014) to Lo Lung Tin (3870 4080).

Wong Wan Chau (Double Island) to Wong Fong Shan, Kat O Chau (Crooked Island). On the islands in the east of the district, including Kat O Chau (Crooked Island), the northwest of Ngo Mei Chau (Crescent Island), and Shau Kei Pai and Tai Lo Pai, the formation mainly comprises lapilli-bearing coarse ash lithic crystal tuffs with a few lapilli tuffs and occasional rhyolite lava. The lapilli are 5 to 50 mm in size, and quartz crystals are 1 to 5 mm. A whole-rock chemical analysis (HK 9455) confirms that the rock is rhyolitic. The contact with the underlying Pat Sin Leng Formation on Wong Wan Chau is a thrust, and that with the Ngo Mei Chau Formation is a northwest-trending fault.

Petrography

In thin section, tuffs of the Tai Mo Shan Formation show considerable variation in modal mineralogy (Plate 8, HK2016; HK2057, 3289 4198; HK 3716, 3942 3880; HK7405, 4410 3912; HK7409, 4471 4128). The crystal and lithic crystal tuffs contain quartz, varying from 8 to 28 %, plagioclase from 7 to 22 %, alkali feldspar from 4 to 15 %, and biotite from 3 to 6 %. Total crystal content varies from 22 to 50 %. Quartz is commonly less abundant than feldspar. The quartz crystals, 0.1 to 4 mm in size, are euhedral to anhedral and broken, and variably corroded and embayed. Some (e.g. HK2003; 3192 3643) show intragranular cracks, wavy extinction and subcrystal boundaries. Plagioclase, generally 0.3 to 1.2 mm in size but occasionally up to 6 mm, is platy to elongate, shows polysynthetic twinning and may be weakly altered to sericite. Alkali feldspars, including microcline and perthite, are 0.1 to 3 mm in size, angular, platy, are usually strongly clouded and show a slight microperthitic albite exsolution and alteration to sericite and, or, kaolinite, quartz and carbonate. Biotite, 0.2 to 4.5 mm in size, is usually partly chloritized, and sometimes comprises scaly aggregates containing apatite, magnetite and ilmenite.

Lithic clasts (over 10 mm in length) are composed of dark, microcrystalline devitrified glass and may be flattened. Clasts of mudstone and fine-grained sandstone, biotite schist and quartzite are also present. The matrix (c. 50 %) is composed of fine ash crystal debris, epidote and iron oxide minerals, and is variably devitrified and altered to microcrystalline aggregates of feldspar, quartz, flaky aggregates of sericite, and may contain carbonate, biotite, magnetite and zircon.

Volcanic Environment

The uniform lithological character of the formation, dominated by coarse ash tuff, together with its limited stratification and widespread distribution, suggest that it represents the product of very large and relatively continuous eruptions that generated pyroclastic flows. Large volume eruptions of this type are often associated with volcanotectonic collapse and caldera development, which may have occurred southwest of the district around Tai Mo Shan, or west of the district. The tuffaceous sedimentary rock intercalations indicate occasional erosion and redeposition of unconsolidated tuff during periods of quiescence between major pyroclastic events.

Age Relationships

The Tai Mo Shan Formation conformably overlies the Shing Mun Formation, but age relationships with younger formations have not been satisfactorily determined. The Sai Lau Kong and Ngo Mei Chau formations are presumed to be younger formations. Recently obtained U-Pb isotopic determinations of zircon crystals from the adjoining district to the southwest (Davies *et al.*, in press), indicate an imprecise maximum age for the Tai Mo Shan Formation of 164.5 $\pm$0.5 Ma, an age equivalent to the Middle Jurassic.

Sai Lau Kong Formation

The Sai Lau Kong Formation consists mainly of purple, locally flow-banded, dacite lava with crystal-bearing vitric tuffs, tuff breccia, and intercalated tuffaceous sedimentary rocks. The type section is located at Sai Lau Kong (4750 4280) and the formation has an estimated minimum thickness of 300 m.

The formation conformably overlies the Tai Mo Shan Formation but its stratigraphic relationships with other volcanic formations in the district are uncertain.

The formation is exposed in a narrow and elongate, northwest-trending outcrop that includes: the peninsula on the southwest side of Ap Chau Hoi; several small islands in Kat O Hoi (Crooked Harbour); and the promontories on the southwest side of Yan Chau Tong (Double Haven). The formation is not known outside the district.

Details

Sai Lau Kong to Lai Chi Wo. In the southern area of its outcrop, the formation comprises dacite lavas with rhyolite, tuff, and tuffaceous sedimentary rocks. The feldspar-bearing blocky lava, interbedded with reddish brown to dark grey siltstone and mudstone, occurs at the base of the formation south of Sai Lau Kong (4744 4280). Dacite lava of this formation overlying lithic crystal tuff of the Tai Mo Shan Formation is well exposed 300 m southeast of Chung Wan Tsui (HK9350, 4646 4320). Tuff breccia, 100 m northeast of Ngau Shi Wu, is interpreted as infilling a volcanic vent. A tuff breccia dyke, 6 to 20 m wide, is present on both sides of a bay at Lai Chi Wo (4563 4306 to 4508 4317). It may represent the infill of a fissure vent. Some small volcanic fissures infilled by veins of lapilli tuff also occur 300 m east of Lai Chi Wo (HK7577, 4525 4291), and at Lo Chi Pai (4610 4370), Fung Chau (4640 4376) and Tsing Chau (4690 4370). Fine ash tuff, sandstone and siltstone of the formation overlie coarse ash tuff of Tai Mo Shan Formation east of Lai Chi Wo and form the core of a plunging anticline at Chung Wan (4595 4286).

Tai Nim Chau to Sam Kok Tsui. The northern area of outcrop of the formation includes dacite and rhyolite lavas with crystal tuff and siltstone intercalations. Lava occurs between Cheung Shek Tsui (4498 4516) and Sam Kok Tsui (4396 4531) while tuff is exposed on Tai Nim Chau (452 447), Siu Nim Chau (456 443) and Ap Tau Pai (4608 4402). Siltstone occurs west and north of Kau Ma Shek (4556 4374).

Chi Ma Lung to Kai Kuk Shue Ha. Mainly tuffaceous siltstone and sandstone occur at Chi Ma Lung (4352 4551), west of Tai Wan (4168 4371), Fung Hang (4136 4330), and 400 m north (4076 4323) and 600 m northeast (4100 4342) of Kai Kuk Shue Ha. The formation directly overlies a reddish brown palaeo-weathering zone within tuff of the Tai Mo Shan Formation, west of Tai Wan (4182 4380).

Petrography

In thin section, the dacites are commonly weakly flow banded and comprise subhedral to anhedral quartz phenocrysts (1 to 3 mm) together with euhedral to subhedral, altered feldspar phenocrysts (1 to 2 mm) and flakes of biotite (<1 mm), set in a devitrified groundmass of anhedral quartz and feldspar grains (Plate 9, HK9350). Microphenocrysts of amphibole are invariably replaced by aggregates of epidote and iron oxide minerals. The lithic-bearing crystal vitric tuffs are weakly flow banded and are welded in places. Angular to subangular quartz (10 %) predominate with subangular, altered, feldspar pseudomorphs composed of granular quartz (5 %), euhedral to subhedral amphibole pseudomorphs (3 %), and flakes of altered biotite (2 %). Lithic fragments (5 %) are typically rounded to subrounded and consist mostly of siltstone and sandstone, and fine ash crystal tuff. In some rocks, the feldspars have been completely replaced by granular quartz.

Volcanic Environment

The Sai Lau Kong Formation lavas are interpreted as having been erupted from a narrow, northwest-trending rift. The tuff breccia and lapilli tuff indicate some associated pyroclastic volcanism from the same general source area. Sedimentary rocks intercalations between the lava

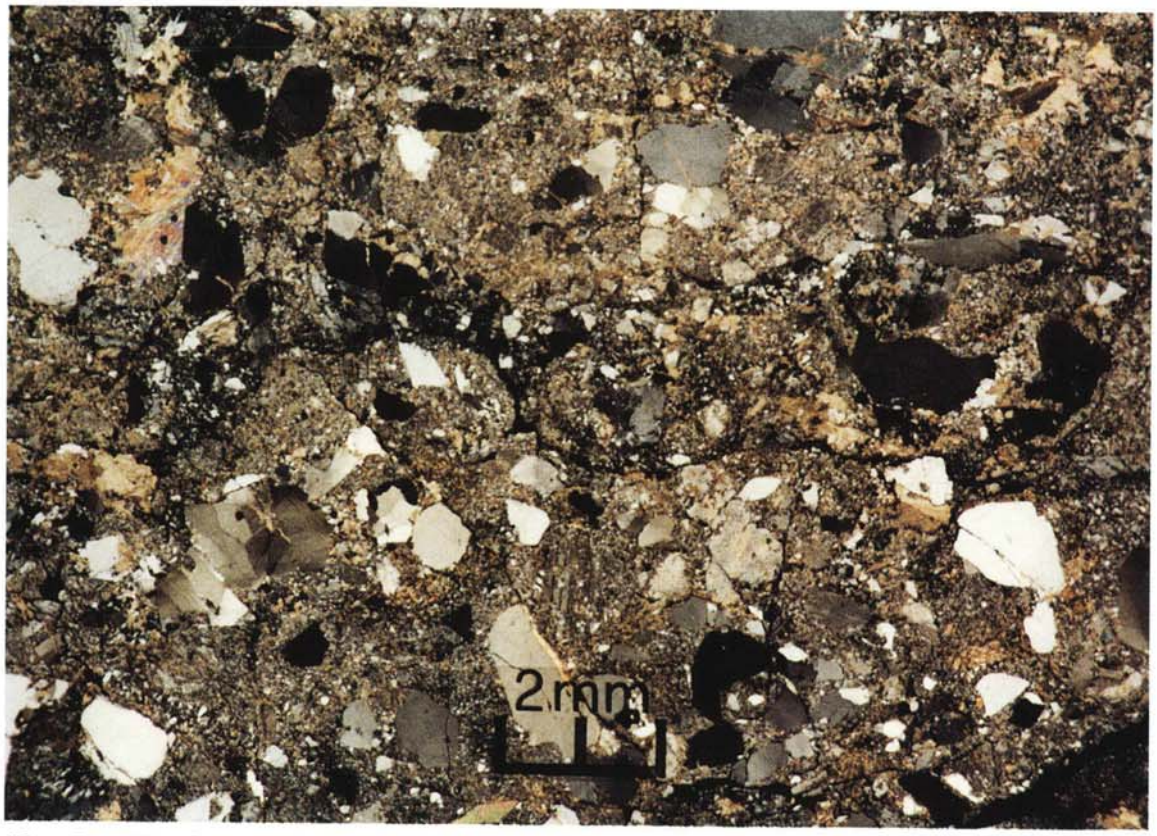


Plate 7 - Thin Section of a Lapilli-bearing Coarse Ash Tuff (HK 1880, 3933 4630) in the Upper Jurassic Shing Mun Formation, Pak Kung Au; XPL

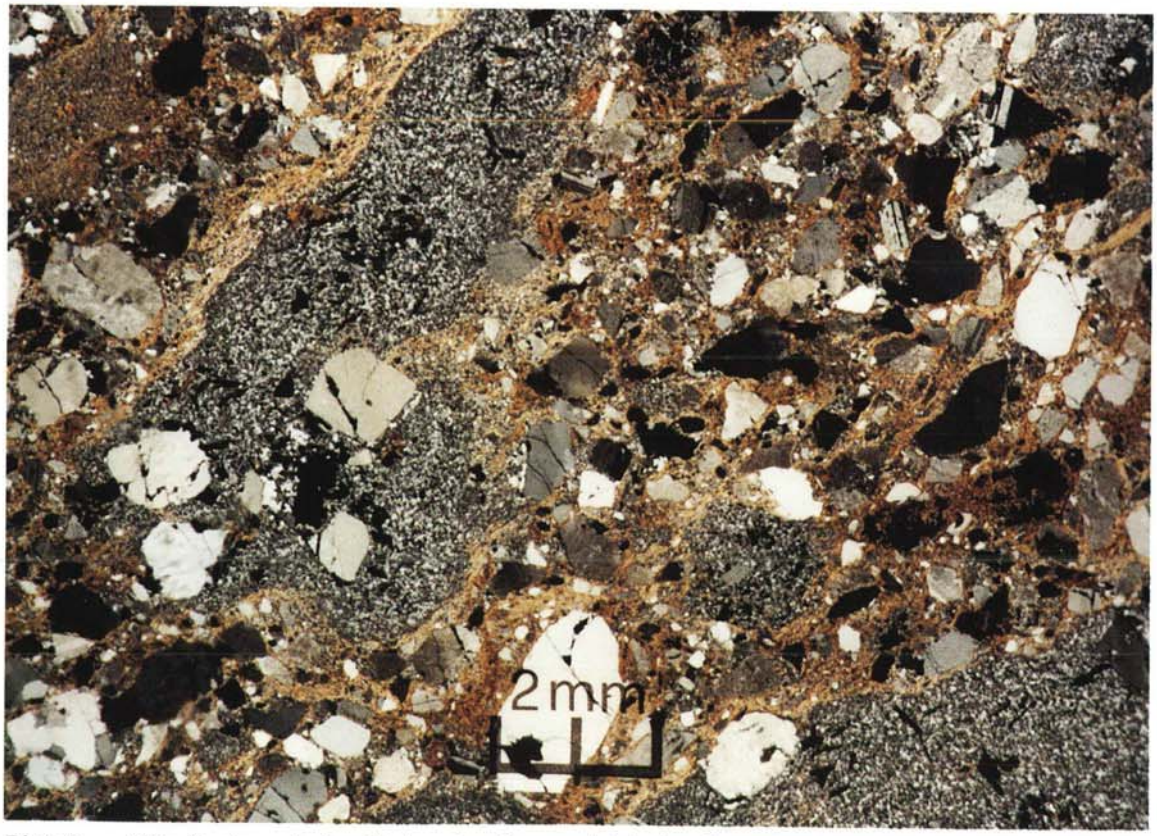


Plate 8 - Thin Section of a Lapilli-bearing Coarse Ash Lithic Crystal Tuff (HK 2016, 3115 3750) within the Upper Jurassic Tai Mo Shan Formation, Kei Lak Tsai; XPL

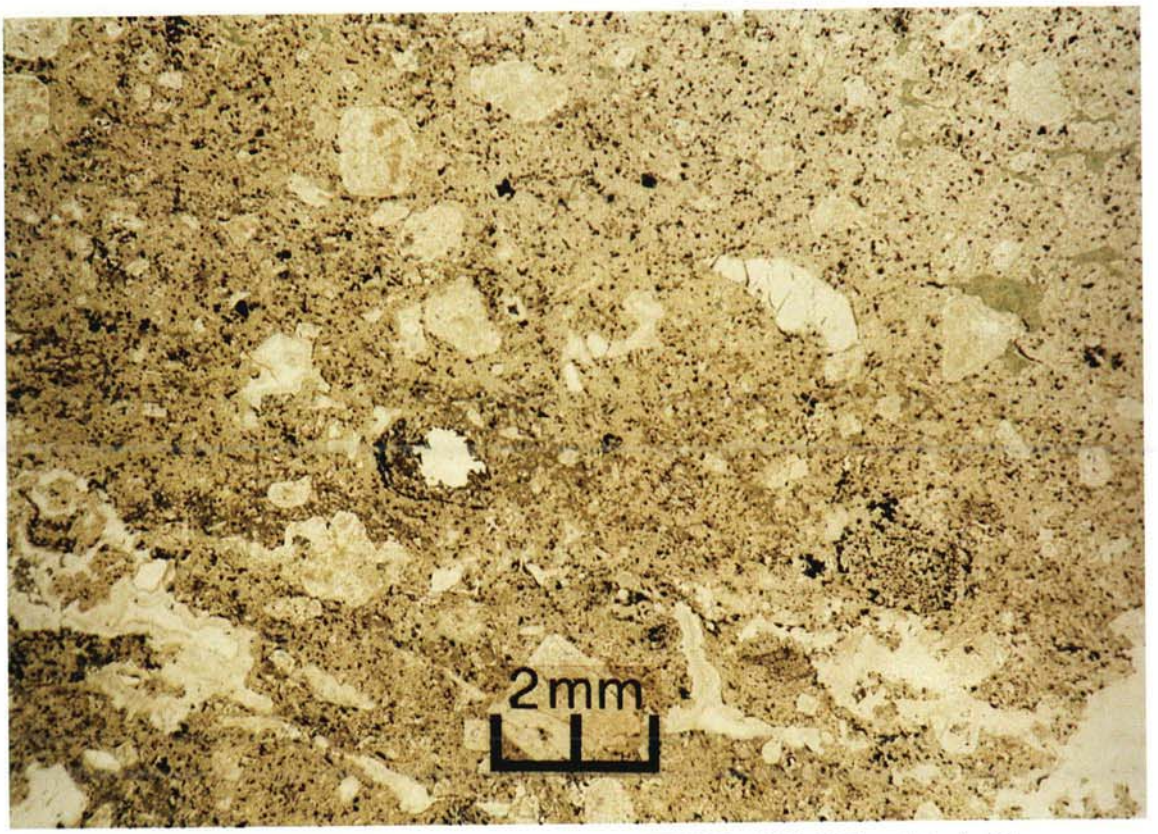


Plate 9 - Thin Section of a Feldsparphyric Dacite Lava (HK9350, 4652 4319) within the Upper Jurassic Sai Lau Kong Formation, Liu Ko Ngam, PPL

Plate 10 - Flow-banding in Feldspar and Lithic Clast-bearing Dacite Lava (4504 4513) within the Upper Jurassic Sai Lau Kong Formation, Cheung Shek Tsui

flows record periods of relative volcanic quiescence during which, silt and mud were derived mainly by erosion of the underlying lavas and were deposited in a lacustrine environment.

Age Relationships

An absolute age for the formation has not been determined. The orientation of stratification and flow banding in the outcrop on the southern side of Ngau Shi Wu Wan, and on islands in Kat O Hoi (Crooked Harbour), suggest that the Sai Lau Kong Formation overlies the Tai Mo Shan Formation. Similarly, the general northeast dip of the flow banding (Plate 10) on the peninsula on the southwest side of Ap Chau Hoi and on small islands in Kat O Hoi also suggests that the Sai Lau Kong Formation is stratigraphically younger than the Tai Mo Shan Formation.

Ngo Mei Chau Formation

The Ngo Mei Chau Formation consists mainly of eutaxitic fine ash vitric tuff (Plate 11), crystal tuff (Plate 12), lapilli tuff and minor intercalated sandstone and siltstone. The type locality is at Hok Wan Tsui (5110 4380) on the northeast coast of Ngo Mei Chau. The formation dips 36-60° to the northeast and has an estimated minimum thickness of 450 m.

The formation crops out on the northeast side of Ngo Mei Chau (Crescent Island), on Tui Min Chau, on the northwestern side of Kat O Chau (Crooked Island), and along the northwestern coast of Wong Wan Chau (Double Island). The limits of the outcrop to the north and northeast of the district beneath Tai Pang Wan (Mirs Bay) are less certain.

The formation is mainly juxtaposed against the Tai Mo Shan Formation along a northwest-trending fault, as on Kat O Chau (Crooked Island) and Ngo Mei Chau (Crescent Island). On Wong Wan Chau (Double Island), however, the formation stratigraphically overlies the Tai Mo Shan Formation with no apparent angular discordance. Sandstone is present at the base of the Ngo Mei Chau Formation and eutaxitic fabric dips in the same direction as the contact. However, it is uncertain whether this contact is conformable or disconformable.

On northern Kat O Chau, narrow, fault-bounded inliers of Carboniferous sedimentary rocks of the Mai Po Member occur within the main outcrop of the formation, but the Tai Mo Shan Formation has not been recognised. This suggests that prior to its eruption, the area now occupied by the Ngo Mei Chau Formation was uplifted relative to the area to the west, along the fault that now separates the Ngo Mei Chau and Tai Mo Shan formations.

Details

Ngo Mei Chau (Crescent Island) and Wong Wan Chau (Double Island). The rocks on Ngo Mei Chau are mainly fine ash vitric welded (eutaxitic) rhyolitic tuff with rhyolite lava, lapilli tuff, lithic crystal tuff and tuffaceous siltstone and sandstone. At Chik Mun Tau (5015 4310), sandstone at the base of the formation is interbedded with lapilli-bearing ash lithic crystal tuff. Sedimentary rocks at Lo Kei Wan and Ngau Mei Wan, dip northeast at 30-40° and include minor plunging folds. Fossil wood is present in the dark grey carbonaceous rocks west of Lo Kei Wan (5066 4285). Rhyolite only occurs (5080 4340) 100 m southwest of Wan Tsai .

The formation also occurs on the northeast coast of Wong Wan Chau (5033 4274, 5064 4230). The base of the formation includes fossil wood-bearing dark grey carbonaceous sandstone and siltstone and overlies coarse ash tuff of the Tai Mo Shan Formation.

Kat O Chau and Tui Min Chau (Yeung Chau). In the north and east of Kat O Chau, and on Tui Min Chau (497 445) and Wong Nai Chau (501 447), the rocks are mainly eutaxitic lapilli-bearing lithic crystal welded tuffs with lapilli-bearing lithic tuffs and a few sedimentary rock intercalations. Fiamme within the eutaxitic bands are 10 to 200 mm long. Lapilli-bearing crystal lithic tuffs at Mun Tsai Wan (491 440), west (484 447) of O Pui Wan, Kai Kung Leng (490 455) and Yung Kok (495 457) mainly comprise pyroclasts (30-60%), including lithic fragments (Plate 11), 10-100 mm across and occasionally up to 800 mm, of rhyolitic lava, crystal tuff, siltstone and sandstone. Sedimentary rock intercalations, including sandstone, siltstone, carbonaceous siltstone and chert, are exposed at Tau Tun (4914 4562), 300 m east (5044 4552) of Chung Wan Teng , and west (4817 4585) of Tung O Wan. The

contact between the Ngo Mei Chau Formation and the Tai Mo Shan Formation is a northwest-trending fault in this area.

Petrography

In thin section, the eutaxitic, lapilli to fine ash crystal vitric tuffs comprise subangular to subrounded quartz pyroclasts (15 %, 0.1 to 4 mm), subangular altered feldspar (5 %, 0.5 to 1 mm), euhedral to subhedral amphibole (3 %, 0.1 to 0.8 mm) set in a devitrified glassy matrix (77 %) (HK8089). Feldspar is almost always completely altered to sericite and amphibole is present only as iron oxide pseudomorphs. Rock fragments are sometimes present and these consist of subrounded lapilli composed of tuffaceous siltstone. Accessory minerals include zircon and apatite. Altered rocks sometimes display spherulitic texture comprising sphericules of recrystallized quartz. Devitrified glassy rocks also occur and may have originally formed flow-banded obsidian. Many of the rocks have been affected by brecciation close to fault zones. These are typically iron-stained and iron-cemented. Rhyolite lava is typically porphyritic with phenocrysts of bipyramidal quartz set in a devitrified glassy mesostasis. Lapilli tuffs are extremely crystal rich with subangular quartz pyroclasts set in a fine-grained ash matrix. Some of the quartz grains are skeletal, indicating post-eruptive crystallisation.

Volcanic Environment

The Ngo Mei Chau Formation marked a renewal of explosive volcanic activity following the sporadic and mainly effusive volcanism of the Sai Lau Kong Formation. The eutaxitic tuff accumulated from pyroclastic flows presumed to have been erupted from a northwest-trending fissure-controlled vent, or vents. The lapilli tuffs were also erupted from the same fissures and probably include vent-fill deposits located along the faulted contact of the formation.

Age Relationships

Interpretation of the stratigraphy of the Ngo Mei Chau Formation is complicated by faulting against other formations, but general structure within the formation is consistent with it being younger than the Tai Mo Shan Formation. Although the formation was assigned to the Tsuen Wan Volcanic Group on the published geological map (Sheet 4), recent age dating using high precision U-Pb isotopic determination of zircon crystals (Davis *et al.*, in press), has yielded an age of 142.7 Ma, suggesting that the formation could alternatively be a constituent of the younger Repulse Bay Volcanic Group, within which eutaxites are far more common.

Fossil wood and sporo-pollen have been found at the north end of Tung Wan (HK8495, 5066 4229) and in carbonaceous sedimentary rocks from the west side of Chik Mun Tau (HK9484, 5034 4274) on Wong Wan Chau (Double Island). Sample HK9484, contains *Classopollis annulatus* (Verb.) Li, *Cingulatisporites* sp., *Cycadopites* sp., *Contignisporites fornicatus* Dettman, *Lycopodiumsporites* sp., *Osmundacidites* sp., and *Reticulatisporites* sp. Miospores dominate the flora which indicates a Late Jurassic age.

Repulse Bay Volcanic Group

The Repulse Bay Volcanic Group, which has a widespread outcrop in the central and southern parts of the Territory, is represented in the district only by the Lai Chi Chong and Long Harbour formations. Both formations are thought to lie stratigraphically in the lower part of the group.

Lai Chi Chong Formation

The Lai Chi Chong Formation within the district consists, in the limited exposure available, of predominantly greenish grey, fine ash crystal tuff with tuffaceous sedimentary rocks and black chert. The formation was first described by Strange *et al.* (1990) in the adjoining district to the

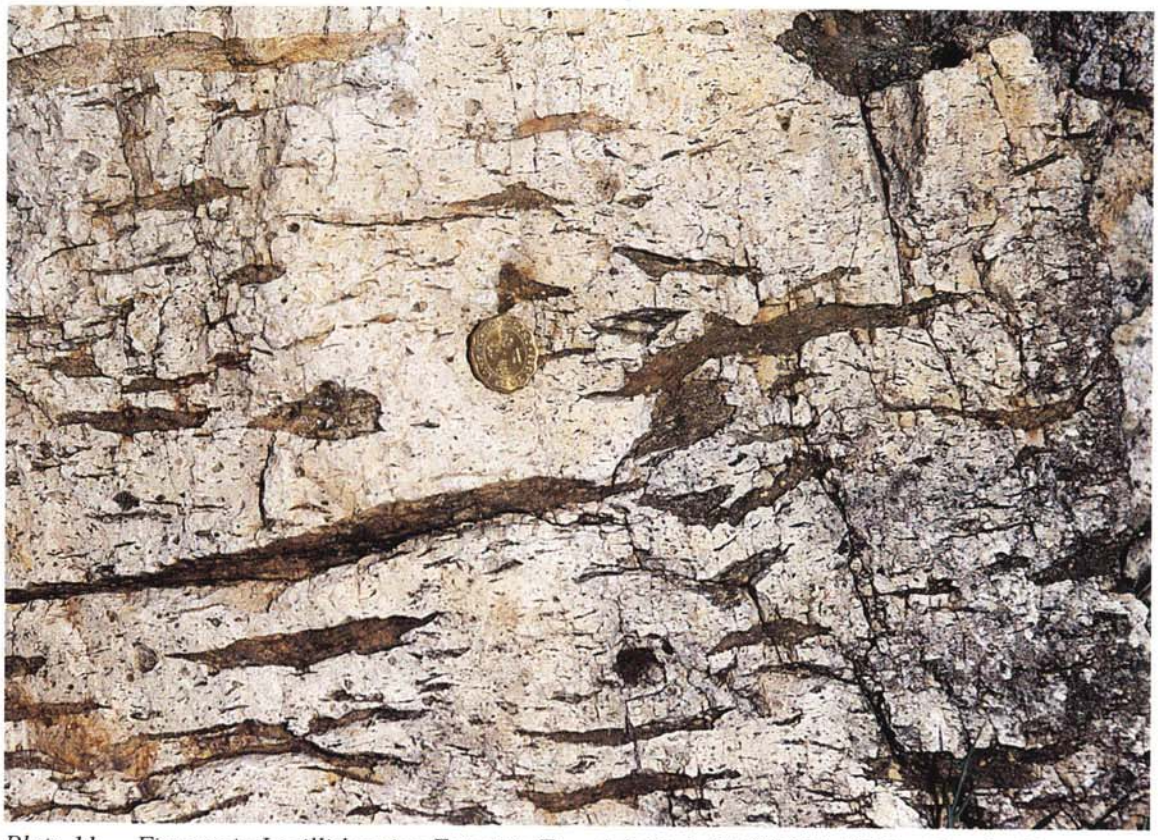


Plate 11 - Fiamme in Lapilli-bearing Eutaxitic Fine Ash Vitric Tuff (5084 4372) within the Upper Jurassic(?) Ngo Mei Chau Formation, Wan Tsai on Ngo Mei Chau (Crescent Island)

Plate 12 - Rhyolite Block in Lithic-bearing Lapilli-Coarse Ash Crystal Tuff (4869 4466) within the Upper Jurassic (?) Ngo Mei Chau Formation, on Kat O Chau (Crooked Island)

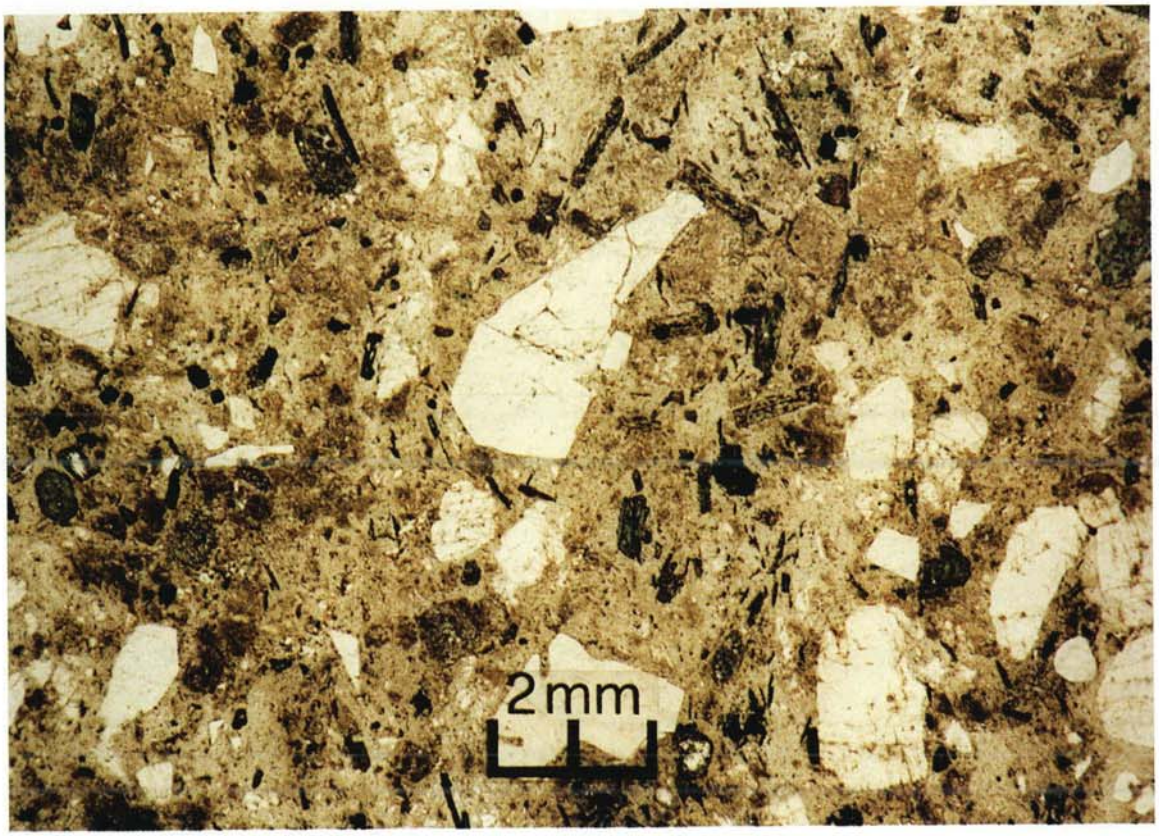


Plate 13 - Thin Section of Coarse Ash Crystal Tuff (HK5159, 5552 3800) within the Lower Cretaceous Long Harbour Formation, Che Wan; PPL

Plate 14 - Coarse-grained Granite Block in Coarse Ash Crystal Tuff (5486 3968) within the Lower Cretaceous Long Harbour Formation, below the Unconformity with Conglomerates of the\ Port Island Formation, near Hung Ying Tsui on the South Coast of Chek Chau (Port Island)

south where it comprises interbedded greenish grey to yellowish fine and coarse ash crystal tuff, tuffaceous sedimentary rocks including pale grey cherty tuffite, and dark grey silty mudstone and black chert. Rhyolite lava units, thin eutaxitic fine ash tuff and impersistent conglomerates also occur in the area to the south and soft sediment deformation is a common characteristic of the formation.

The formation is exposed only on the northern side of Che Lei Pai (Knob Reef) where the very steep easterly dip is likely to reflect proximity to a fault offshore. However, the formation is presumed to occur in subcrop also, covered by superficial sediments, on the southern side of Chek Mun Hoi Hap (Tolo Channel), and may have many of the lithological characteristics of the formation as described by Strange *et al.* (1990) in the area to the south.

Details

Che Lei Pai (Knob Reef). The outcrop on the northern side of this small island comprises predominantly poorly-bedded, pale greenish grey, fine ash crystal tuff. The outcrop is largely massive, though crudely defined bedding, dipping vertically, is seen on its western side. To the east, the bedding is thinner, dips at 70-80° to the northeast, and includes thin laminae of coarser crystal tuff containing lapilli and blocks up to 350 mm across.

Volcanic and Sedimentary Environment

The Lai Chi Chong Formation is thought to have accumulated in a lacustrine basin, bounded by an east-northeast-trending fault on its northwest side that runs along Chek Mun Hoi Hap. The tuffs and tuffaceous sedimentary rocks were deposited mainly as turbidites, though some of the tuffs could represent primary airfall deposits that settled through the water column.

Age Relationships

In the adjoining area to the south, the Lai Chi Chong Formation unconformably overlies the Lower Jurassic Tolo Channel Formation (Strange *et al.*, 1990).

Diagnostic macrofossils, identified from sedimentary horizons, include plant remains indicative of an Early Cretaceous age with flora equivalent to the Duoni Formation of eastern Xizang and the Wealden flora of western Europe (Atherton, 1989).

Long Harbour Formation

The Long Harbour Formation is a lithologically uniform, lithic-bearing coarse ash tuff containing characteristic, abundant pink alkali feldspar crystals. Clasts consist of fine ash tuff, rhyolite lava and rare, fine to medium-grained granite. The formation has a minimum thickness of 400 m.

The term Long Harbour Division was first used in a general sense in the Sai Kung area by Watkins (1979), but was modified to Long Harbour Formation by Strange *et al.* (1990) to describe only a sequence of fairly uniform, lithic lapilli-bearing coarse ash tuff in the adjoining area to the south of the district.

The Long Harbour Formation crops out widely in the southeastern corner of the district. It is restricted to the southern side of Chek Mun Hoi Hap (Tolo Channel), and crops out around Tai Leng Tun and Heung Lo Kok, as well as on Tap Mun Chau (Grass Island), the west of Chek Chau (Port Island) and several other small islands in the vicinity of Long Harbour. The formation is also present in subcrop beneath superficial deposits on the southern side of Chek Mun Hoi Hap.

The formation rests unconformably on a rhyolite lava within the Lai Chi Chong Formation, although the contact is not exposed within the district. The relationship of the formation to younger volcanic formations in the Territory can not be directly established as the Long Harbour

Formation is fault bounded. However, isotopic age dating (see below) suggests that the formation predates most of the other volcanic formations within the Repulse Bay Volcanic Group.

Details

Ngau Kwo Lo and Tai Leng Tun. Mainly lithic-bearing lapilli-coarse ash crystal tuff with lithic tuff and lithic vitric tuff are exposed between Ngau Kwo Lo (511 362) and Tai Leng Tun (Goliath Hill) (534 362). Sample HK8401 (5019 3697), from Ngau Kwo Lo, contains mainly crystals (52 %), including plagioclase, alkali feldspar, quartz and biotite, and also rhyolite (3 %) and vitric (15 %) clasts. The cement (30 %) is volcanic dust, recrystallized to a microcrystalline aggregate of feldspar and quartz. Fine ash vitric tuff at Chuen Lo Kok Tsui, represented by sample HK8407 (5211 3683), contains 64.5 % vitric pyroclasts, 10.5 % crystal tuff and 25 % fine ash matrix. A quartzphyric rhyolite dyke intrudes the formation at Chuen Lo Kok Tsui.

Tap Mun Chau (Grass Island), Chek Chau (Port Island) and Kung Chau. The rocks mainly comprise lapilli-bearing coarse ash lithic crystal tuff with crystal lithic tuff and crystal vitric tuff. Sample HK7996 (5466 4003) from 100 m south of Tai Wan, is a vitric crystal tuff, containing 52 % crystal pyroclasts, including plagioclase, alkali feldspar, quartz and biotite, vitric clasts (24 %), rock fragments (4 %), and cement (20 %). Rock sample HK8000 (5487 3969), from 80 m north of Hung Ying Tsui, is a grey to pale grey, lapilli-bearing vitric lithic tuff containing almost equal proportions of rhyolite and tuff clasts, vitric clasts, crystals, and cement. Columnar joints are always evident. A reddish brown palaeo-weathering crust, up to 12 m thick, is developed in the tuffs at the top of the formation, which is overlain by red beds of the Upper Cretaceous Port Island Formation.

Petrography

In thin section, the Long Harbour Formation is typically packed with angular to subangular quartz (20 %), subangular altered feldspar (10 %), subangular fresh to slightly altered green amphibole (5 %), chloritised biotite (3 %) and euhedral minerals of iron oxide (<1 %) (Plate 13, HK5159). These crystals are set in a poorly sorted granular matrix (61%) comprising mostly quartz and feldspar. Subrounded lithic fragments are common and these are composed mostly of porphyritic lava lapilli, although sandstone and rare granite clasts are also present (Plate 14). A common feature of the Long Harbour Formation is the presence of skeletal quartz crystals indicating post-eruptive crystallisation. Some quartz crystals may reach 10 mm in diameter. Accessory minerals include zircon, apatite, and allanite.

Volcanic Environment

The Long Harbour Formation represents a major phase of explosive volcanism with emplacement of deposits largely from large-volume pyroclastic flows. The formation is confined to a fault-bounded block interpreted as a volcano-tectonic depression. The depression lies on the southeast side of the Chek Mun Fault and southwest of the Kat O Fault. South of the district (Sheet 8), the formation is restricted to the area north of the Chek Keng-Cheung Sheung Fault. This phase of volcanotectonism reflected more general extension across the Chek Mun Fault, one of the local components of the regional Linhua Shan Fault System.

Age Relationships

The age of the Long Harbour Formation has recently been established (Davis *et al.*, in press), using high precision U-Pb isotopic determination of four single zircon fractions: they yielded concordant or near concordant data points that define an age of 142.9 $\pm$ 0.2 Ma, close to the lower limit of the Cretaceous (144 Ma).

Although formerly thought by Strange *et al.* (1990) to be the youngest stratigraphic unit in the Repulse Bay Volcanic Group in the Sai Kung area, the U-Pb dating of the formation, and of other formations to the south of the district, indicates that it probably predates most of the formations in the Repulse Bay Volcanic Group. The only exceptions to this are the Lantau and Lai Chi Chong formations. Strange *et al.* (1990) suggested that granite clasts within the formation were lithologically similar to granites of the Kowloon Pluton. However, U-Pb dating has demonstrated that the pluton is significantly younger than the Long Harbour Formation.

Pat Sin Leng Formation

The Pat Sin Leng Formation occupies a fault-bounded block, the northern side of which is bounded by a thrust, and the southeast flank by a normal fault. The thrust on the north side is part of a broad and complex zone of deformation which affects Cretaceous and older rocks in the northern and western parts of the Territory. The southern boundary is preserved as a fault only from Tai Leng (458 393) to Pak Kok Shan (385 392). To the southwest, the formation lies unconformably on volcanic rocks of the Tai Mo Shan Formation. Boulders of conglomerate belonging to the Pat Sin Leng Formation are found on the hillside some distance from the present outcrop, suggesting that the unconformity has only recently been exposed and that before the recent erosion, the formation was in faulted contact with the Bluff Head Formation to the south. The formation (Figure 9) is thickest (500 m) at the centre of the block, between Wang Leng (458 393) and Sam A Tsuen (459 421), and thins to both the east and west.

The formation comprises conglomerate, breccia (Plate 15), pebbly sandstone, sandstone (including greywacke and litharenite), siltstone and mudstone, and it unconformably overlies the Tai Mo Shan Formation. The formation has been divided into three parts, the lowest of which consists of grey to dark grey, very thickly bedded conglomerate with greyish white, tuffaceous sandstone, and thinly bedded siltstone. Clasts in the conglomerate typically range in size from 2 to 50 mm, though some are up to 600 mm. Pebbles and subrounded boulders form 40 to 60 % of the rock and include tuff and lava of the Tsuen Wan Volcanic Group, and sandstone, siltstone of older formations, and vein quartz; the matrix is generally pelitic and silty.

The middle part is composed of pale greyish red sandstone with purplish red siltstone and occasional conglomerate, this being greyish to reddish purple, or moderately red to dark red. The pebbles, cobbles and boulders dominantly comprise red and brown volcanic rocks that are subrounded to subangular, mostly 5 to 60 mm in size, with some up to 500 mm. The upper part of the formation is composed of reddish purple, clayey siltstone with sandstone. The sandstones at the margin of the block are mostly greyish white to brownish grey, tuffaceous greywacke, whereas at the centre, they are mainly reddish brown litharenite.

Details

Ping Fung Shan to Luk Keng and Bride's Pool. Only the lower part (80 m thick) of the Pat Sin Leng Formation occurs west of Bride's Pool (4248 4038). At the base of the formation, a very thickly bedded conglomerate with sandstone, overlying tuff of the Tai Mo Shan Formation, is exposed in a steep cliff. The basal conglomerate thins to the east and is locally absent. In the west, it is generally 25 m thick, but varies from 10 to 30 m. The lower strata are rich in tuffaceous clasts towards the west. Three beds of conglomerate are present at Bride's Pool, but to the west, at Ping Fung Shan (3870 3922), there is only one. Some of the pebbles are pale greyish red, in contrast to the typically grey to dark grey matrix. The sandstone is variably greyish white, or pale grey to greyish red towards the top of the section.

The formation has largely been removed by erosion at Hsien Ku Fung (4215 3837), and to the west, only a few outcrops remain as outliers on peaks such as Shun Yeung Fung (4110 3856) and Lai Pek Shan (4023 3894). The scarp from Wong Leng (3946 3884) to Nam Shan (3744 3988) marks the unconformable contact with the underlying Tai Mo Shan Formation. Further to the north, fault-bounded isolated outcrops occur 500 m east of Tan Chuk Hang (371 413), west of Nam Chung (390 426), and along the beach between Wu Shek Kok (400 439) and Pok Tau Ha (396 435). On the hill top (3900 4280) west of Nam Chung the strata are less than 40 m thick and dip to the southeast. To the north (394 415, 400 413, 405 416), three very deeply-dissecting streams locally expose the underlying tuff.

Chek Ma Tau to Tiu Tang Lung. From Bride's Pool (4248 4038) east to near Hung Shek Mun (474 397) the formation is up to 500 m thick (Figure 10). The basal strata are characterized by a 25 m thick conglomerate and sandstone unit which caps the hill top and forms a lengthy, steep cliff on the south side of the slope. Higher in the sequence, sandstone predominates, with subordinate tuffaceous sandstone and greyish red clayey siltstone, and there is a gradual transition upwards into greyish red clayey siltstone with sandstone.

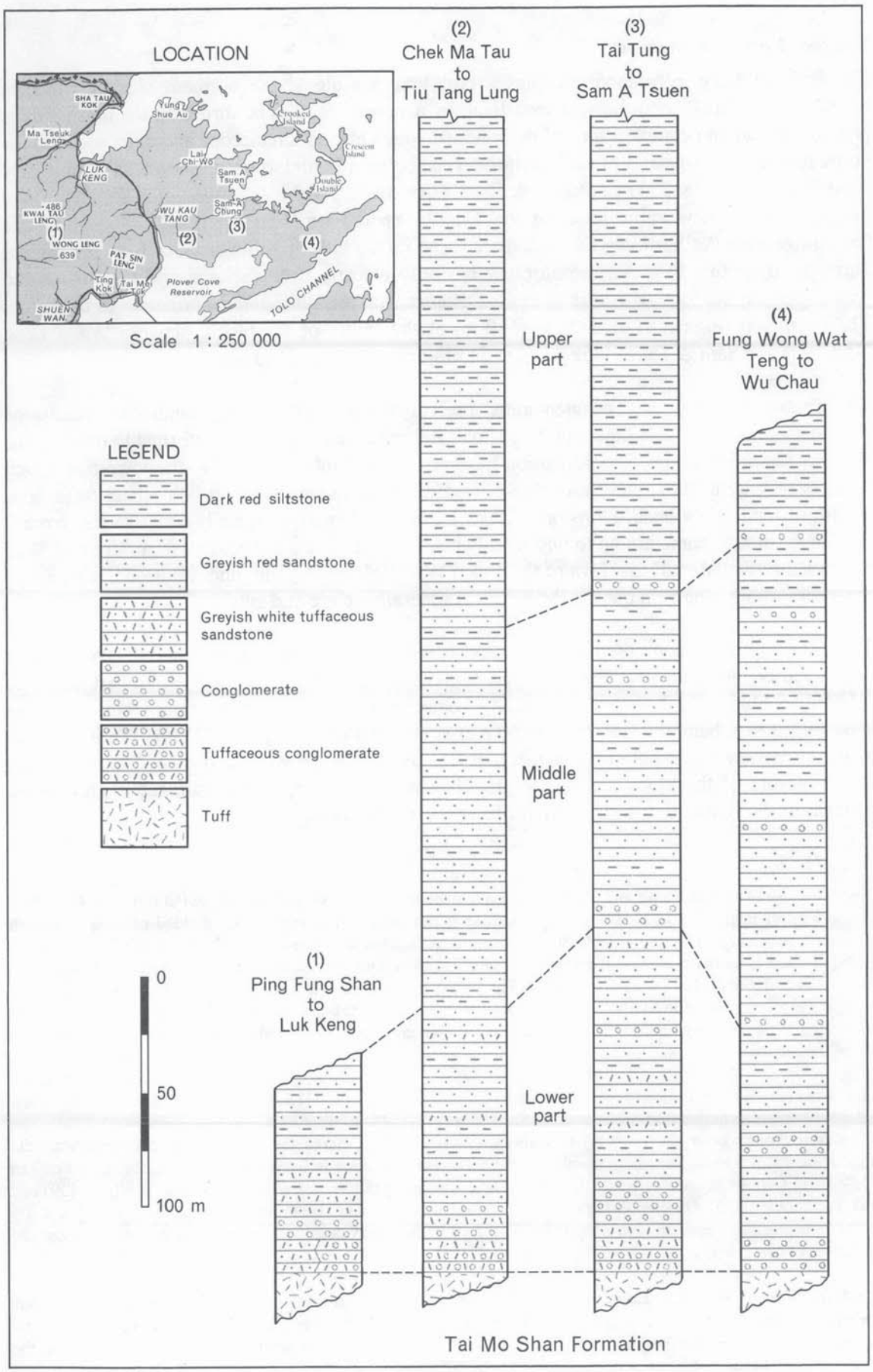


Figure 9 - Generalised Vertical Sections through the Pat Sing Leng Formation

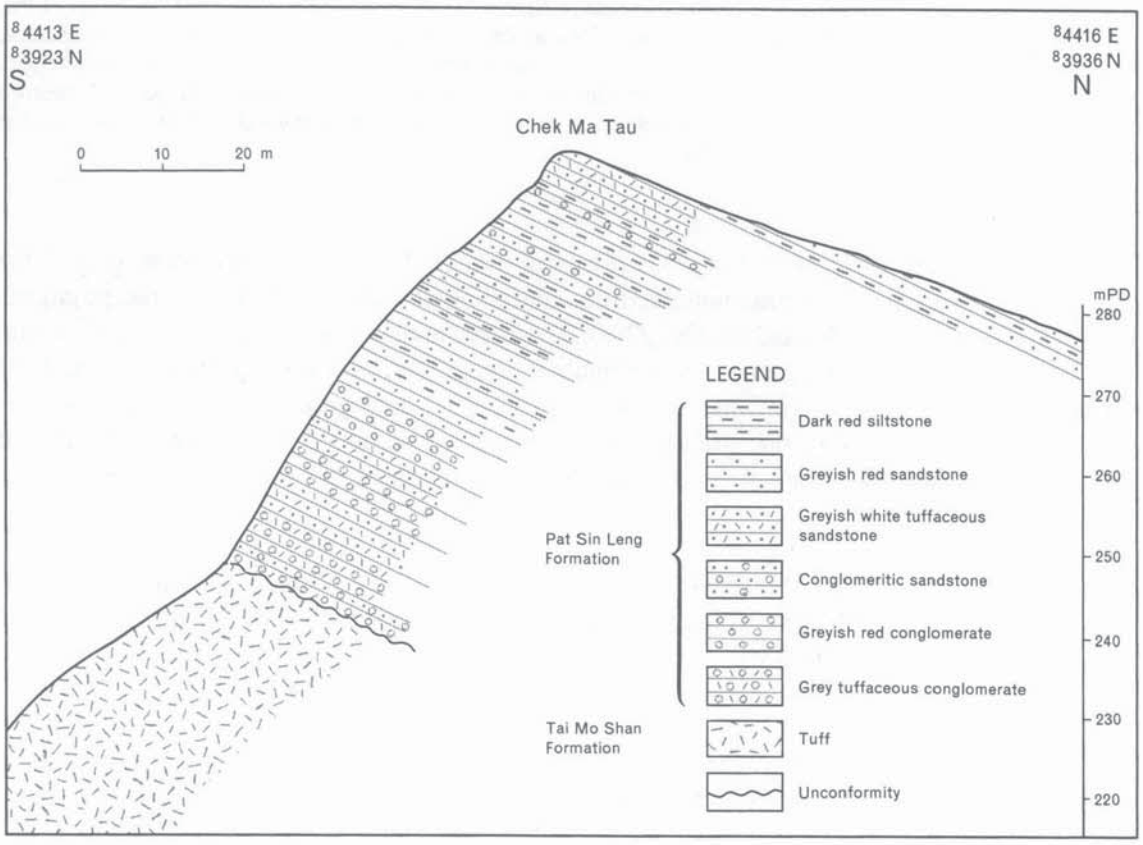


Figure 10 - Geological Cross-section of the Pat Sin Leng Formation at Chek Ma Tau

A typical profile of the lower strata exposed at Chek Ma Tau (4410 3928) is presented in Figure 10. The sequence is 64.5 m thick and sedimentary cyclicity is evident. Each of the 11 cycles, where complete, includes conglomerate, sandstone and siltstone. The base of the formation comprises mainly pinkish grey, very thick, tuffaceous conglomerate and very light grey or pale red tuffaceous sandstone. Overlying rocks include reddish siltstone which in each cycle are 1 to 3 m thick.

In the middle of the formation, near Sheung Miu Tin (447 403), sandstone predominates, with subordinate tuffaceous sandstone and greyish red, clayey siltstone. Strata from the upper part of the southern slope of Tiu Tang Lung (447 412) comprise 120 m of thick, greyish red to reddish, clayey siltstone with four beds of greyish white to reddish purple sandstone, 0.5 to 1 m thick. To the north, thrusting along the Tiu Tang Lung Fault has caused repetition of strata and the development of minor folding at Wu Kau Tang (437 407).

Tai Tung to Sam A Tsuen. The lower part of the formation is exposed between Tai Tung (462 395) and Kwun Yam Tung (4693 3979) and consists of 26 m of very thickly bedded pinkish grey to light grey tuffaceous sandstone with conglomerate and a subordinate siltstone. This passes upwards into a sequence dominated by sandstone with siltstone and conglomerate at Sam A Chung and then into siltstones from Sam A Wan (463 415) to Sam A Tsuen (460 421). The strata are steeper in the south, dipping at 35° to the north, compared with dips of 17° to the northeast in the central part of the basin at Sam A Chung (456 407). At Au Yue Tsui (4672 4156) and north of Ma Niu Shui (467 410), the sequence is thrust-faulted and is repeated north of the thrust plane.

Fung Wong Wat Teng to Wu Chau. The strata to the north of Fung Wong Wat Teng (497 391) are approximately 350 m thick and have been intensely eroded. On the sea shore opposite Wu Chau (493 401), underlying yellowish grey tuff with a 20 mm-thick, brick red weathered zone is exposed and is overlain by reddish brown conglomerate of the Pat Sin Leng Formation. The proximity of northeast-trending faults parallel to the coastline has led to a steepening of the bedding on the south shore of Wong Chuk Kok Hoi and dips up to 45° to the north are recorded. At Wong Wan Sai Teng (410 490), tuff of the Tai Mo Shan Formation is thrust over the Pat Sin Leng Formation.

Pak Kok Shan to Wong Wan Chau (Double Island). The strata on the peninsula from Pak Kok Shan to Wong Chuk Kok Tsui (Bluff Head) are cut by northeast and northwest-trending faults forming a series minor fault blocks. The strata become very steep and are even overturned adjacent to the southeastern marginal fault. The formation here is relatively thin, and the underlying tuff is exposed at Wong Chuk Kok Tsui (Bluff Head) (5244 4130, Plate

16), Shek Tsai Wan (5172 4080), the beach northwest of Ngong Chong Shan (5100 4046) and northwest of Pak Kok Shan (5050 4000). The formation at and west of Wong Chuk Kok Tsui comprises conglomerate, sandstone, and mudstone. The conglomerate has subangular to rounded clasts up to 150 mm across, with some intraformational mudstone clasts. The sandstone is poorly sorted, fine to coarse-grained, cross-bedded with poorly-developed small-scale channels. On Wong Wan Chau, the northern limit of the formation is marked by a thrust zone and is overlain by tuff of the Tai Mo Shan Formation.

Petrography

Sandstone. Specimen HK7406 (4405 3928) from Chek Ma Tau is a brownish grey lithic greywacke (Plate 17) with a psammitic texture, consisting of quartz (50 %), volcanic fragments (23 %), phyllite clasts (5 %) and matrix (22%). The heavy minerals are dominated by zircon with rare clinopyroxene, epidote, garnet and tourmaline. Quartz grains are generally coarse and are subrounded to subangular. Tuff and lava fragments are medium grained and angular, whereas phyllite clasts are generally fine grained and subangular, commonly comprising aggregates of fine, flaky sericite. The matrix is pelitic, having been completely sericitized, with a fine lepidoblastic texture.

Specimen HK8231 (4028 4279) from Luk Keng is a light brown sublitharenite with a psammitic texture. The majority of the grains are very fine to fine-grained quartz, which makes up 85 % of the rock. The matrix is pelitic with an aphanitic texture. Occasional pyrite crystals are present, but have been largely weathered to limonite, giving the rock its brown colour.

Siltstone. Specimen HK7415 (4458 4089) from Tiu Tang Lung is a reddish brown phyllitic siltstone. The sediment is poorly-sorted and comprises quartz (40 %), kaolinite and hydromica (40 %), muscovite (15 %) and heavy minerals (5 %). The quartz is angular to subangular, and mostly of coarse silt grade. Kaolinite and hydromica aggregates with relict feldspar pseudomorphs are colourless or brown, and 0.01 to 0.05 mm in size; muscovite grains with phyllitic texture range from 0.005 to 0.1 mm in size. Heavy minerals include ilmenite, magnetite, zircon, apatite, tourmaline, amphibole and monazite. The matrix is composed of pelite, metamorphosed to sericite; dust-sized haematite gives the rock its reddish brown colour.

Tuffaceous siltstones vary from pale red to brick red with increasing haematite content. Tuffaceous siltstone from Luk Wu Tung (HK7962, 4815 3929) contains 30 % pyroclastic fragments. The siltstones may contain a few crystals of albite, chlorite and biotite. Some have been metamorphosed to phyllite, as at Ping Fung Shan (HK3720, 3933 3988) and Chek Ma Tau (HK7404, 4402 3918).

Sedimentary Environment

The formation occupies a basin referred to here as the Pat Sin Leng Basin. The form of the basin is uncertain, partly because of thrusting along the northern outcrop margin of the formation. Sedimentary rocks at the base of the formation contain large subangular to subrounded boulders and fill large-scale channels. The clasts are of volcanic rocks, presumed to have been locally derived, and the lower part of the formation is considered to have been deposited in a piedmont and fluvial environment. Locally, reddish brown siltstone and mudstone are pedogenically altered to form palaeosols. The sandstone and siltstone beds in middle and upper parts of the formation are unconfined sheetflood deposits and represent floodplain, fluvial and lacustrine deposits. Desiccation of the bioturbated siltstone horizons indicates drying out of the plains following flood events. Changes in rock colour throughout the sequence from pale grey at the base to dark red at the top suggest a fluctuating climate but, overall, a semi-arid environment is indicated.

Plate 15 - Breccia (52375 41275) within the Pat Sin Leng Formation, West of Wong Chuk Kok Tsui (Bluff Head)

Plate 16 - Unconformity (5244 4130) with Cross-bedded Sandstones and Conglomerates (to Left) of the Lower Cretaceous Pat Sin Leng Formation overlying Tuffs of the Upper Jurassic Tai Mo Shan Formation (to right), Wong Chuk Kok Tsui (Bluff Head)

Plate 17 - Thin Section of Lithic Greywacke (HK7406, 4405 3928) within the Lower Cretaceous Pat Sin Leng Formation, Chek Ma Tau; XPL

Plate 18 - Well-bedded Conglomerate, Sandstone and Siltstone (553 405) within the Upper Cretaceous Port Island Formation, on the North Coast of Chek Chau (Port Island)

Port Island Formation

The Port Island Formation was named by Ruxton (1960), who included within his definition the red beds of Pat Sin Leng, now considered as a separate formation. The Port Island Formation consists of well-bedded (Plate 18) and cross-bedded (Plate 19) reddish brown conglomerate and sandstone with siltstone and crops out on many of the islands of Tai Pang Wan (Mirs Bay) including Pak Sha Chau (Round Island) (520 446), Chek Chau (Port Island), Cham Pai (Channel Rock) (5556 3896), a reef (5626 3833) northeast of Kung Chau , Shek Ngau Chau (621 363) and Breaker Reef (6130 3577). Boreholes and seismic interpretation have shown that the formation is widespread over most of Tai Pang Wan (Mirs Bay) subcropping the superficial deposits. The formation is also exposed at Xiasha in the Shenzhen Special Economic Zone on the east side of Tai Pang Wan, forming a gentle synclinal basin 24 km long and 13 km wide. The formation is more than 1200 m thick at its maximum development (Figure 12).

Details

Chek Chau (Port Island) to Kung Chau. The type locality of the formation forms the outcrop on the eastern coast of Chek Chau. An 8 m-thick conglomerate and conglomeratic sandstone overlies tuff of the Long Harbour Formation, dipping 30° to the east-northeast (Plate 20). The overlying rocks are mainly very thickly to thickly bedded, reddish sandstone. Underlying the unconformity, a 10 to 12 m-thick, dark reddish brown, weathered tuff is exposed on both sides of Hung Ying Tsui (5488 3976, 5500 3970) and on the north coast of the island at Lau Shui Hang Tam (5518 4056). Some subrounded pebbles, similar to those in the overlying Port Island Formation, are embedded in the weathered tuff, suggesting that the tuff was still not lithified when the conglomerate was deposited. The remainder of the formation comprises mainly interbedded, very thickly to thickly bedded conglomerate and sandstone with thickly to thinly bedded, reddish siltstone. The strata are cut by normal faults trending east-northeast and west-northwest. At low tide, reefs are exposed at Cham Pai (Channel Rock) (5556 3896) and to the northeast (5626 3833) of Kung Chau, and comprise reddish brown conglomerate and conglomeratic sandstone, dipping 25° to the northeast. The western side of a submarine rock high (553 390) has been interpreted from seismic data (line D5, fix 2250) as a fault between the Port Island Formation and tuff. This is shown on a cross-section on Sheet 4, but is now thought more likely to represent a scarp formed by a change in lithology, similar to that on Port Island itself where an unconformity is clearly visible.

Pak Sha Chau (Round Island). The island is situated in the northwest of Tai Pang Wan (Mirs Bay). The lithology in the lower part of the sequence, in the southwest of the island, is a dominantly reddish brown, thickly to very thickly bedded, coarse-grained sandstone with conglomerate. In the northeast of the island, the upper part of the sequence comprises interbedded coarse-grained sandstone and conglomerate, dipping 30-40° to the east-northeast and southeast. Depositional cycles, including conglomerate and sandstone, vary from 30 to 50 mm. Two sets of faults are developed: one trending 320°, parallel to the southwest coast, containing fault breccia and dipping 60-80°; the other trending 340° and dipping 75-85°, forming large fault scarps. Proximity to faults explains the very steep to locally overturned bedding in the northeast of the island.

Shek Ngau Chau to Breaker Reef. The formation on these islands in the southern part of Tai Pang Wan (Mirs Bay), comprises reddish brown conglomeratic sandstone and fine to coarse-grained sandstone with conglomerate dipping at 20-26° to the northeast. The strata are cut by minor high-angle normal faults trending 015-128°. Quartz veinlets infill joints along the fault zone.

Tai Pang Wan. Based on interpretation of seismic data and 18 boreholes logs (Geotechnical Information Unit No. 12915), the Port Island Formation extends across most parts of Tai Pang Wan (Mirs Bay) and infills a structure referred to here as the Tai Pang Wan Basin, which is 24 km long and 13 km wide. The main lithologies seen in boreholes are reddish brown siltstone, sandstone and conglomerate. The dip of the sedimentary rocks in the centre of the basin is gentle (14-18°), though near the basin margins is steeper (20-28°). The centre of the basin is located beneath a small Tertiary basin at Ping Chau.

Petrography

Conglomerate. Conglomerate usually fills channels and is generally clast-supported. The matrix comprises medium- to coarse-grained sandstone. Sorting is generally poor and crude graded bedding is present in some channels. Clasts vary from subangular to rounded and comprise mostly volcanic rocks, the rounded clasts often being quartzose.

Sandstone. Specimen HK7328 (6207 3634) from Shek Ngau Chau, Tai Pang Wan, is a reddish purple tuffaceous litharenite with psammitic texture. The grains are rounded and moderately well

sorted, dominantly 0.5 to 1 mm but occasionally 0.1 to 0.5 mm in size. The grains form 90 % of the rock and comprise clasts of devitrified tuff (40 %), rhyolite (30 %), quartz (15 %), biotite and heavy minerals (5 %). The heavy minerals include abundant zircon and apatite, with rare magnetite, limonite, clinopyroxene, epidote, garnet, tourmaline and rutile. The matrix (10 %) is made up of pelite, silt, quartz and limonite.

Specimen HK8042 (5487 3961) from Chek Chau, Tai Pang Wan, is a reddish tuffaceous sandy siltstone with a psammitic silty texture. The grains are subrounded, mostly 0.003 to 0.05 mm, with a few 0.02 to 1 mm in size. Clasts comprise tuff, rhyolite, quartz and feldspar, and rare magnetite and zircon. All feldspar grains are metasomatized to a scaly sericite aggregate. The matrix (20 %) consists of clayey minerals and limonite.

Sedimentary Environment

An environmental interpretation of the Port Island Formation by Jones (1996) identified two sedimentary facies associations representative of channel and floodplain fluvial environments. The succession is considered to be a distal alluvial fan or proximal braidplain. A 12 m-thick, reddish brown weathered zone developed in the underlying tuff indicates a period of quiescence following the volcanic activity.

The channel-fill conglomerates indicate high-energy conditions and channel depths of up to 6 m have been inferred. The sandstone of the middle and upper parts of the formation are widespread in the Tai Pang Wan Basin and represent unconfined sheetflood sediments deposited in a floodplain environment. Periods of reduced sedimentation, when channel sedimentation ceased, resulted in the finer-grained floodplain facies and the deposition of silt on the floodplain. Complete cessation of sedimentation led to calcrete development on the abandoned fan. In the lower part of the formation, this change in lithology follows a cyclical pattern, and probably resulted from rapid tectonic movement flooding the area with coarse detritus. Subsequent upward-fining of the sedimentary rocks reflects adjustment to the tectonic process (Jones, 1996).

Kat O Formation

The Kat O Formation was first named by Ruxton (1960) and comprises calcareous breccia, conglomerate and coarse sandstone, with calcite as a very common component of the rock. The formation fills the Ap Chau Basin (Figures 5 & 16), a small depositional basin bounded by east-northeast and northwest-trending faults in Ap Chau Hoi and Kat O Hoi (Crooked Harbour). Seismic interpretation suggests that this basin is 6.4 km long and 1.6 km wide. The formation overlies eutaxite and lapilli tuff of the Ngo Mei Chau Formation and the basal unconformity is seen at the Chek Kok Tau (480 461). The breccia and sandstone that make up the formation dip at 5° to the north and are estimated to be 100 m thick. The formation occurs at Ap Chau (Robinson Island) (Plate 21), Sai Ap Chau, Ap Lo Chun, Pak Tun Pai, Cheung Pai Tau (Ledge Point) and Chek Kok Tau (North Point).

Details

Cheung Pai Tau. The formation here comprises calcareous breccia with coarse sandstone. Bedding dips very gently, at 5°, to the north. A 15 m-wide fault zone, marking the southern margin of the basin, dips at 48° to the north. There is a block-bearing tuff within the fault zone that includes blocks of limestone, black mudstone, lava and tuff. The limestone is dark grey to light grey and pink, and is commonly cut by small veins of calcite (Williams, 1943). Fossils of *Fusulina* and *Fusulinella* of Permian age were recovered from one limestone clast (Lee, in Williams, 1943). A quarry where the limestone was extracted is now disused and flooded.

Ap Chau (including Sai Ap Chau, Ap Lo Chun, Ap Chau Pak Tun Pai and Ap Chau Mei Pak Tun Pai). The Kat O Formation on these islands is mainly reddish brown, thickly bedded breccia with thinly bedded

Plate 19 - Cross-bedding in Sandstones and Subordinate Conglomerates (5506 3967) within the Upper Cretaceous Port Island Formation, on the South Coast of Chek Chau (Port Island)

Plate 20 - Conglomerate (5500 3970) within the Upper Cretaceous Port Island Formation Unconformably Overlies Tuff of the Long Harbour Formation with a Thickly Bedded Palaeo-weathering Zone, South Side of Chek Chau

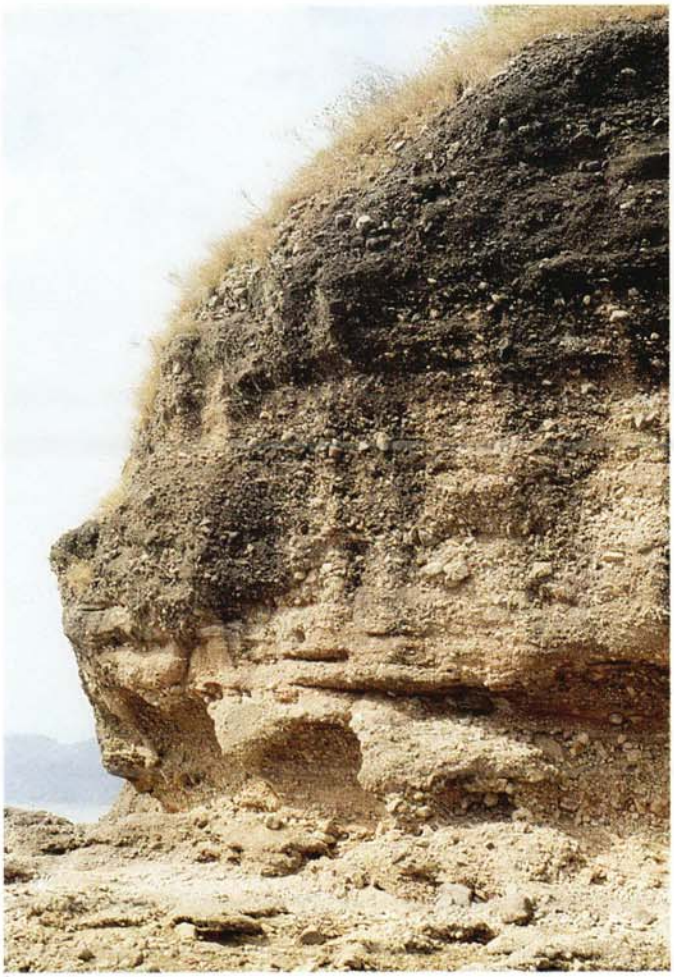


Plate 21 - Bedded Tuffaceous Breccia (4597 4558) within the Upper Cretaceous Kat O Formation, with a Well-developed Wave-cut Notch at the Base of the Cliff, on ApChau

Plate 22 - Thin Section of Calcareous, Tuffaceous, Fine-grained, Brecciated Sandstone (HK8245, 4597 4558) within the Kat O Formation, Ap Chau; XPL

coarse-grained sandstone, cemented with a calcareous and clayey matrix. Some veins are characterized by large crystals of calcite. Lithic clasts contain tuff, rhyolite and vein quartz and are 30 to 600 mm across. The bedding is gently dipping at 5-10° to the north. The strata are cut by minor normal faults. The calcareous minerals in the rocks are susceptible to marine erosion leading to the formation of sea caves, cliffs, arches and wave-cut platforms (Plate 21). A large sea arch occurs at Kau Tau Shek (4563 4603), north of Ap Chau (Plate 42).

Chek Kok Tau. This headland, on the northern coast of Kat O, exposes a widespread, reddish brown breccia and overlies pale green lapilli tuff of the Ngo Mei Chau Formation. Fine-grained detrital rocks, locally occurring near the base of the formation are seen only on the sea shore (4795 4614). Grey to greyish white breccia and coarse sandstone, 1.5 m thick, lie directly on the tuff, passing upwards into 1 m of grey sandy siltstone, 0.5 to 1 m of greyish white soft mudstone, and 1 to 2 m of greyish white sandstone. This sequence is overlain by the thickly bedded calcareous reddish brown breccia and coarse-grained sandstone that make up the rest of the headland.

Petrography

Calcareous tuffaceous breccia. Specimen HK8245 (4597 4558) (Plate 22) from Ap Chau, is purplish red with subangular to angular clasts, dominantly 3 to 5 mm in size, with a few up to 15 mm, that constitute up 75 % of the rock. Clast types include rhyolite (25 %), devitrified tuff (35 %), felsite and quartz grains (15 %). The heavy minerals are dominantly zircon and apatite, with rare rutile, tourmaline, garnet, epidote and clinopyroxene. The matrix and cement make up 25 % of the rock and consist of ash tuff, and clayey and calcareous minerals including sericite, calcite, limonite and felsitic aggregate. Calcite fills intergranular space or forms veinlets. Chemical analysis has shown that the breccia is very rich in CaO (21.24%, Table 4).

Sedimentary Environment

The formation fills a small, closed, intermontane basin, surrounded by volcanic rocks, and was deposited mainly in a piedmont and fluvial environment, with locally-derived clasts. The reddish brown colour and carbonate development suggest an arid palaeoclimate.

Table 4 - Major Element Analyses of Cretaceous Sedimentary Rocks

Element	Pat Sin Leng Formation							Port Island Formation			Kat O Formation
	White Sandstone		Red Sandstone	Red Siltstone				Red Sandstone			Red Conglom. Sandstone
	HK 7804 Lai Pak Shan (4010 3920)	HK 8167 Luk Keng Lam Uk (3980 4190)	HK 9397 Ngong Chong Shan (5180 4050)	HK 7967 Kwun YamYung (4700 3970)	HK 8463 Pak Kok Shan (5010 4000)	HK 9364 Shek Tsai Wan (5140 4070)	HK 9376 Ham Yue Ching (4830 4060)	HK 8045 Chek Chau (5520 3990)	HK 8321 Shek Ngau Chau (6210 3630)	HK 10084 Pak Sha Chau (5210 4450)	HK 8244 Ap Chau (4590 4560)
SiO_2	82.50	77.96	83.84	70.57	72.45	68.70	71.69	82.25	80.92	75.26	45.15
TiO_2	0.19	0.24	0.19	0.62	0.64	0.63	0.62	0.14	0.30	0.23	0.26
Al_2O_3	9.66	12.81	9.18	15.50	14.86	16.72	14.95	8.57	10.13	8.98	8.49
Fe_2O_3	1.68	1.70	1.67	4.58	4.45	4.87	4.75	1.45	2.44	1.72	2.15
FeO	0.16	0.08	0.08	0.08	0.08	0.04	0.04	0.04	0.20	0.16	0.04
MnO	0.02	0.02	0.03	0.02	0.02	0.09	0.03	0.04	0.04	0.07	0.16
MgO	0.41	0.54	0.28	0.02	0.42	0.09	0.68	0.22	0.56	0.56	0.54
CaO	0.07	0.06	0.07	0.07	0.08	0.08	0.07	0.12	0.09	4.23	21.24
Na_2O	0.00	0.00	0.00	0.09	0.06	0.18	0.16	0.03	0.00	0.07	0.17
K_2O	3.50	4.42	2.85	5.18	4.38	5.24	4.48	2.60	3.20	3.92	2.92
P_2O_5	0.03	0.00	0.04	0.04	0.04	0.03	0.03	0.05	0.09	0.04	0.04
LOI*	1.64	2.04	1.58	2.36	2.27	2.52	2.38	1.46	1.94	4.66	19.00
Total	99.81	99.87	99.78	99.82	99.76	99.71	99.89	99.96	99.82	99.91	100.15

Notes: 1. LOI : Loss on ignition; mainly CO_2 and H_2O

2. All samples were analysed by the University of Nottingham using the XRF fusion bead method

Chapter 5
Intrusive Igneous Rocks

Classification

Intrusive igneous rocks are relativelt rare within the district. They comprise small exposures of granodiorite, isolated dykes of feldsparphyric rhyolite and quartzphyric rhyolite, and sporadic veins of aplite. These rocks have been classified on the basis of their texture (after Strange, 1984) and modal mineralogy (Figure 11). Occasional quartz veins also occur.

Whole rock major and trace element data for one sample of granodiorite (HK 8932) from Tung Tsz are included in Appendix 1.

Granodiorite

Distribution and Lithology

Medium-grained granodiorite is exposed in five areas along the southern margin of the district and has also been recorded in several offshore boreholes. These scattered exposures form part of a large suite of intrusions, mainly developed to the south of the district, and collectively referred to as the Tai Po Granodiorite.

The granodiorite is typically dark grey, medium grained, and porphyritic in hand specimen with prominent euhedral to subhedral alkali feldspar, subhedral to anhedral quartz and subhedral plagioclase. Biotite is present in crystal aggregates and single crystals of amphibole are scattered throughout the matrix.

Granodiorite intrudes block-bearing tuff and tuffite of the Shing Mun Formation to the east (369 360) and west (358 360) of Mak Uk. The host rocks are thermally metamorphosed to hornfels within 100 m of the granodiorite contact at both localities. Granodiorite also intrudes fine ash tuff of the Shing Mun Formation north (3910 3720, 3925 3730) and west of (3820 3665) Shuen Wan, and on the coast at Shuen Wan Chim Uk (3960 3610). Granodiorite is further exposed on the northern tip of Yuen Chau (4095 3605) in Shuen Wan Hoi (Plover Cove) and has been recorded in offshore boreholes near Wong Chuk Tsuen (e.g. BHTK2/18, 4189 3696, BHTK2/19, 4195 3690).

Petrography

In thin section, phenocrysts of euhedral plagioclase (10 to 40 %, 1 to 5 mm) and subordinate bipyramidal quartz (20 to 30 %, 1 to 3 mm) are set in a medium-grained granular matrix (10 to 20 %) of quartz, feldspar, and mafic minerals (Plate 23, HK7876). Large (10 to 12 mm), subhedral megacrysts (5 to 10 %) of K-feldspar (orthoclase) typically have poikilitic rims enclosing matrix minerals. Plagioclase (labradorite to oligoclase) phenocrysts are strongly zoned, commonly with sericitised, calcium-rich cores and sodic rims. Euhedral brown amphibole (2 %) and pleochroic green to brown biotite (3 %), frequently altered to chlorite and epidote, are the chief mafic constituents. Accessory minerals include zircon, allanite, apatite, titanite, and magnetite.

Age Relationships

Medium-grained granodiorite within the district has not been isotopically dated. However, it intrudes block-bearing tuff and tuffite, and fine ash crystal tuff of the Shing Mun Formation, and

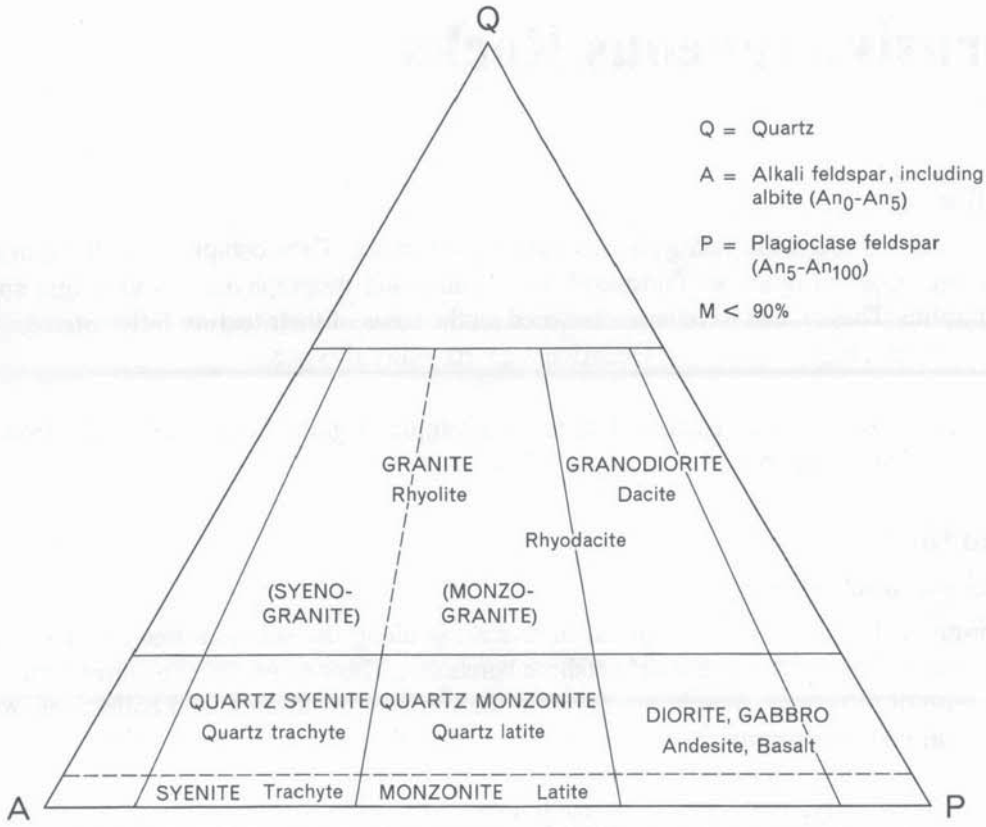


Figure 11 - General Classification and Nomenclature of Major and Minor Intrusive Rocks (after Streckeisen, 1974)

on the basis of geochemical similarities, can be correlated with formations of the Tsuen Wan Volcanic Group.

Feldsparphyric Rhyolite

Distribution and Lithology

Dykes of feldsparphyric rhyolite have only been observed at two localities, near Pak Kok Shan (5080 3912) and at Wong Wan Tsai (4850 3770), both of which are on the northern coast of Chek Mun Hoi Hap (Tolo Channel). At both localities, the northeast-trending dyke, 5 m wide, intrudes black mudstone and siltstone of the Tolo Channel Formation. The feldsparphyric rhyolite is rather weathered and consists of phenocrysts of euhedral alkali feldspar and subhedral quartz in a fine-grained granular matrix.

Petrography

In thin section, the rock is characterized by large (3 to 5 mm) euhedral to subhedral, altered, alkali feldspar phenocrysts and quartz (2 to 7 mm) phenocrysts (5 %) set in a fine intergranular matrix dominated by quartz and feldspar. Relict biotite grains are strongly chloritised (Plate 24, HK8918).

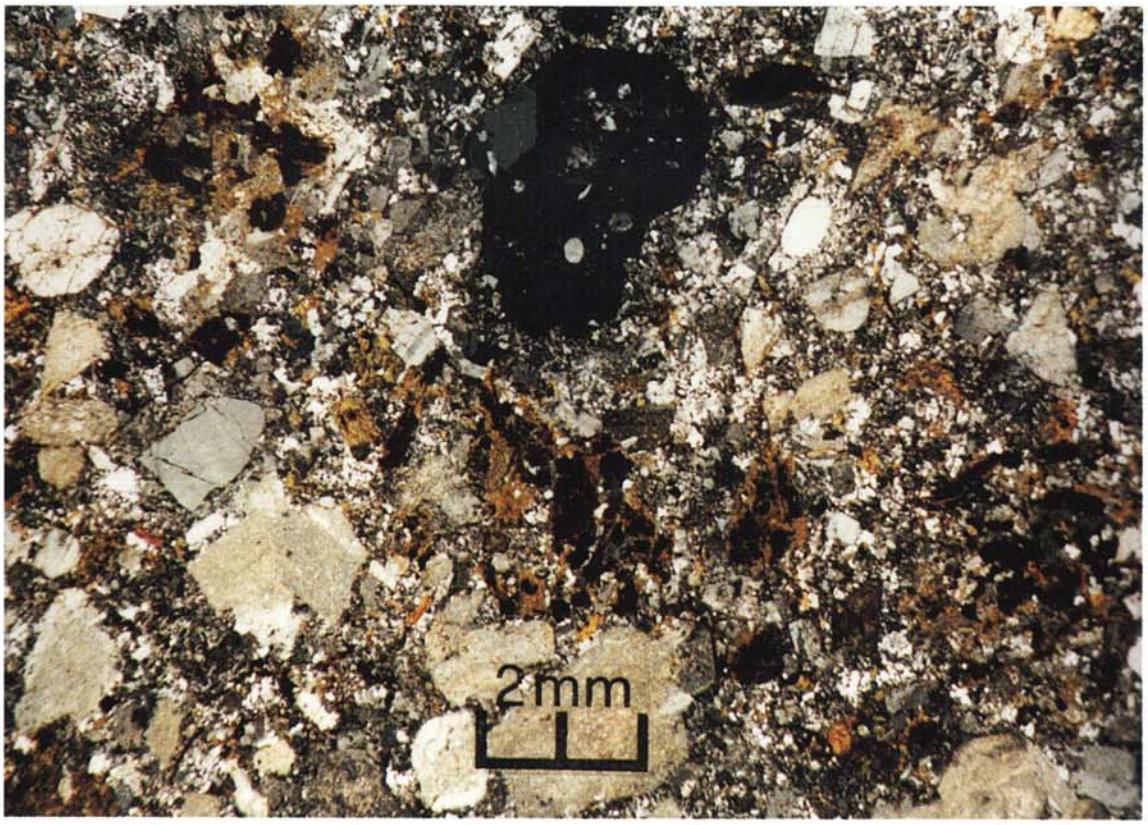


Plate 23 - Thin Section of Granodiorite (HK7876, 3810 3664), Shuen Wan; XPL

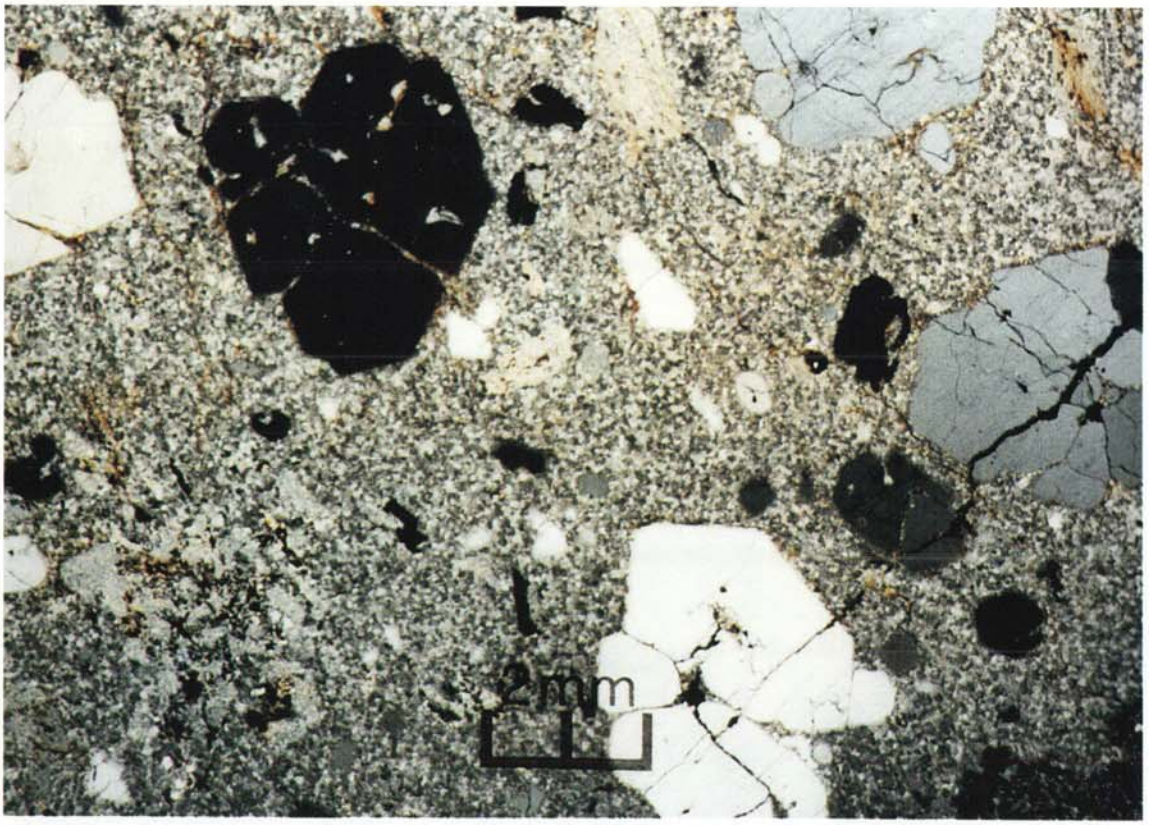


Plate 24 - Thin Section of Feldsparphyric Rhyolite Dyke (HK8918, 4873 3781), Wong Wan Tsai; XPL

Plate 25 - Quartzphyric Rhyolite Dyke (4972 3826) Intruded into Mudstone, Siltstone and Fine-grained Sandstone of the Tolo Channel Formation, in a Fault Zone near Fung Wong Wat on the North Coast of Chek Mun Hoi Hap (Tolo Channel)

Plate 26 - Thin Section of Quartzphyric Rhyolite Dyke (HK2022, 35755 3787), Cloudy Hill; XPL

Quartzphyric Rhyolite

Distribution and Lithology

Sporadic quartzphyric rhyolite dykes occur throughout the district, intruding a variety of volcanic and pre-volcanic lithologies, but have not been observed in Lower Cretaceous and younger clastic sedimentary rocks in the district. The dykes are generally northeast trending and generally range in thickness from 2 to 5 m, although rarely they can be up to 60 m thick.

In hand specimen, the lithology is characterized by prominent subhedral to anhedral quartz phenocrysts and subordinate alkali feldspar phenocrysts, both of which are set in a fine-grained granular matrix.

The most prominent quartzphyric rhyolite dyke in the district, which is up to 60 m wide, can be traced for nearly 1 km, extends from near Kong Nga Po (320 432) towards the north-northeast (3224 4381). The dyke intrudes Carboniferous metasedimentary strata of the Mai Po Member of the Lok Ma Chau Formation and can be traced close to (319 429), but not apparently as far as, the thrust-faulted contact between the metasedimentary rocks and the underlying Jurassic volcanic rocks of the Tai Mo Shan Formation. A minor dyke occurs within metasedimentary rocks further to the southwest (3100 4260). North of the main dyke outcrop, a photolineament of similar trend continues for about 1 km, albeit offset slightly to the west, and there is also a more northeast-trending dyke (3236 4390).

The Tai Mo Shan Formation is intruded by quartzphyric rhyolite dykes at two localities. At one locality, on the northern flank (3578 3781) of Kau Lung Hang Shan, the dyke strikes in the same general direction as metamorphosed zones in the area, although its strike is slightly oblique to the nearest such zone shown on the published map (Sheet 3). The other dyke also obliquely intrudes a metamorphosed zone west (3494 3988) of Lau Shui Heung. These dykes also intrude the Shing Mun Formation south of Pak Kung Au (3955 4545) and the Long Harbour Formation at Chuen Lo Kok Tsui (Tide Pole Point) (5210 3690).

Dykes striking variably northeast to east-northeast, and extending for distances of up to several hundred metres, occur at several localities between Wong Wan Tsai and Wong Chuk Kok Tsui on the northern side of Chek Mun Hoi Hap (Tolo Channel). The most laterally extensive of these dykes intrudes black mudstone and siltstone of the Lower Jurassic Tolo Channel Formation on the coast between Wong Wan Tsai (4890 3777) and Fung Wong Wat (4974 3827) (Plate 25). Subparallel dykes intrude the Devonian Bluff Head Formation further to the north (4844 3847, 4890 3886) and northeast (5020 3930), and on the coast southeast (5270 4093) of Wong Chuk Kok Tsui (Bluff Head).

Petrography

In thin section, the lithology comprises euhedral to subhedral phenocrysts (3 to 5 mm) of bipyramidal quartz (5 to 8 %), and subhedral (1 to 3 mm), altered alkali feldspar (3 to 6%) set in a fine-grained granular matrix (85 to 90 %) of quartz, feldspar and chloritised biotite (Plate 26, HK2022). Accessory minerals in the matrix include apatite and zircon.

Aplite

Distribution and Lithology

Thin (1-2 m) discontinuous dykes of aplite are widespread in northeastern parts of the district where they mainly intrude the Ngo Mei Chau Formation at Ngo Mei Chau (5018 4309), Tui Mun Chau (4970 4430) and Kat O Chau (4911 4561, 5001 4569, 4973 4431). However, they also

intrude the Tai Mo Shan Formation at Chung Wan (4632 4300), Ah Kung Tsui (4304 4558) and at Plover Cove Reservoir (4334 3750). The dykes are leucocratic and aphyric with an average grain size of 0.5 mm. The aplite dykes generally have a northeast-southwest trend.

Quartz Veins

Details

Quartz veins are ubiquitous throughout the district but are particularly common within Cretaceous strata. Although they can be found in any orientation, there is a tendency for them to have a preferred north-south trend. Quartz veins are also found in association with shear zones.

Plate 27 - Well-bedded Calcareous Siltstone and Dolomitic Siltstone (6336 4445) of the Ping Chau Formation, Kan Lau Shek on Ping Chau

Plate 28 - Soft-sediment Deformation of Laminated Siltstone and Fine-grained Sandstone (6260 4490) within the Ping Chau Formation, Ping Chau

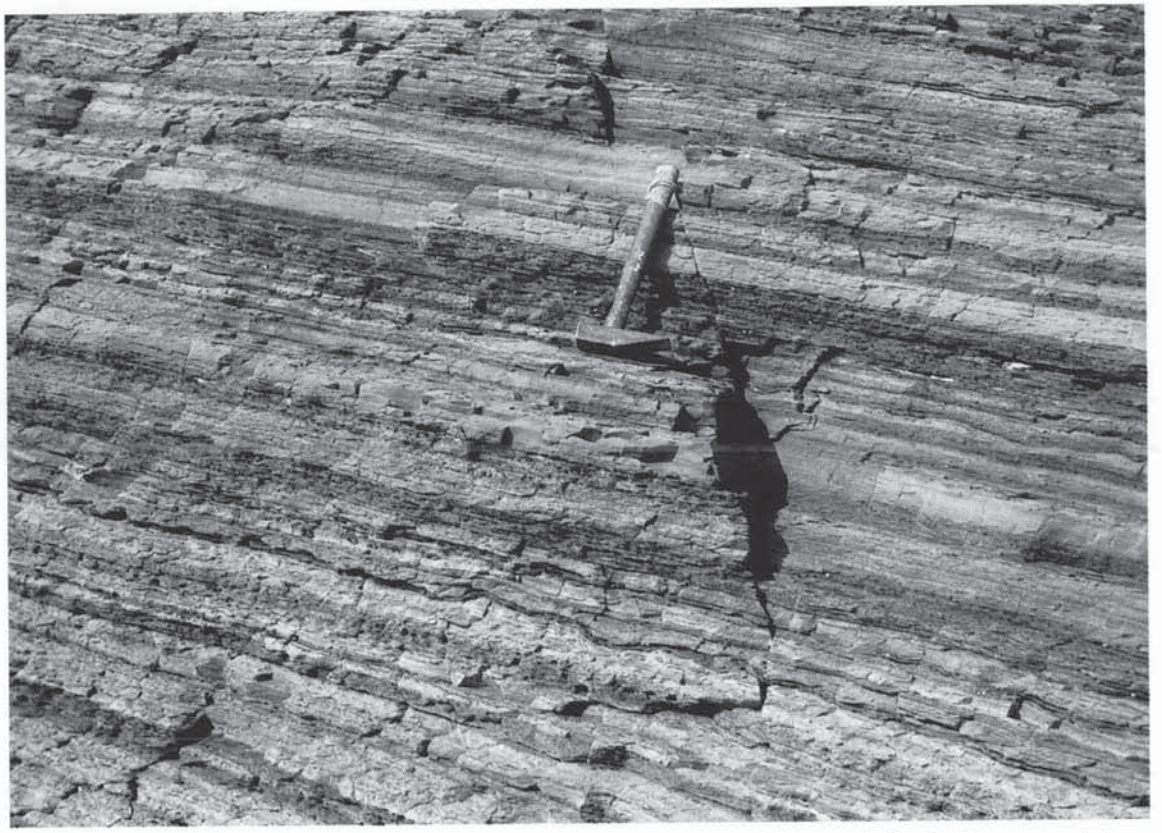


Plate 29 - Well-developed, Very Thinly Interlaminated Detrital and Chemical Cyclic Deposits of the Ping Chau Formation, Nan Kao Shui (6334 4440) on Ping Chau

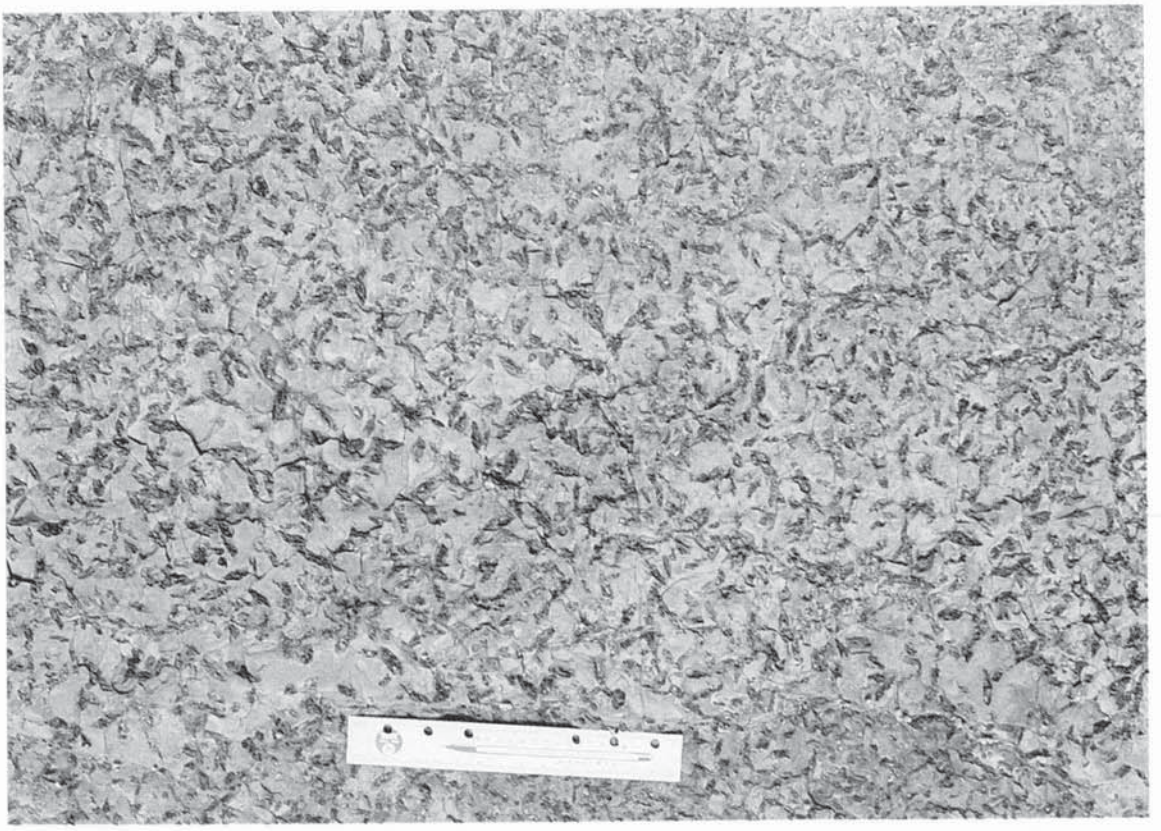


Plate 30 - Aegirine-filled (with Calcite and Pyrite) Pseudomorphic Crystals, Possibly after Gypsum (6185 4570), within the Ping Chau Formation, Ping Chau

Chapter 6
Cenozoic Rocks

Classification and Distribution

The Ping Chau Formation is the only Cenozoic sedimentary sequence in Hong Kong. It crops out on Ping Chau, an island of low relief, 600 m long and 200 m wide, in the northeast of Tai Pang Wan (Mirs Bay). Offshore, the Ping Chau Formation can be identified on boomer seismic profiles as forming an open syncline (Figure 12). Much of the formation crops out on the sea floor or is overlain by a thin layer of of Quaternary sediments, less than 5 m thick. The formation overlies gently-dipping, coarse-grained, sedimentary rocks of the Port Island Formation.

The Ping Chau Formation was formally defined by Peng (1978, 1983), although the sedimentary rocks were first described by Williams (1943), who assigned them mainly to the Jurassic, and possibly Lower Jurassic. Allen & Stephens (1971) considered the formation to be Middle to Lower Jurassic. With the discovery of numerous, well-preserved fossils on Ping Chau and detailed studies of the sequence, a late Cretaceous to early Tertiary age now appears more likely. Recent interpretations of the age include Lower Cretaceous (Zhou *et al.*, 1990), late Early to early Late Cretaceous (Wu & Nau 1989; Nau *et al.*, 1990), and Upper Cretaceous (Peng, 1983; Lee *et al.*, 1990a). Based on the fossil evidence now available, and interpretation of lithology, structure and palaeoclimate (Lai, 1991; Lee *et al.*, 1990b), Early Tertiary is preferred here.

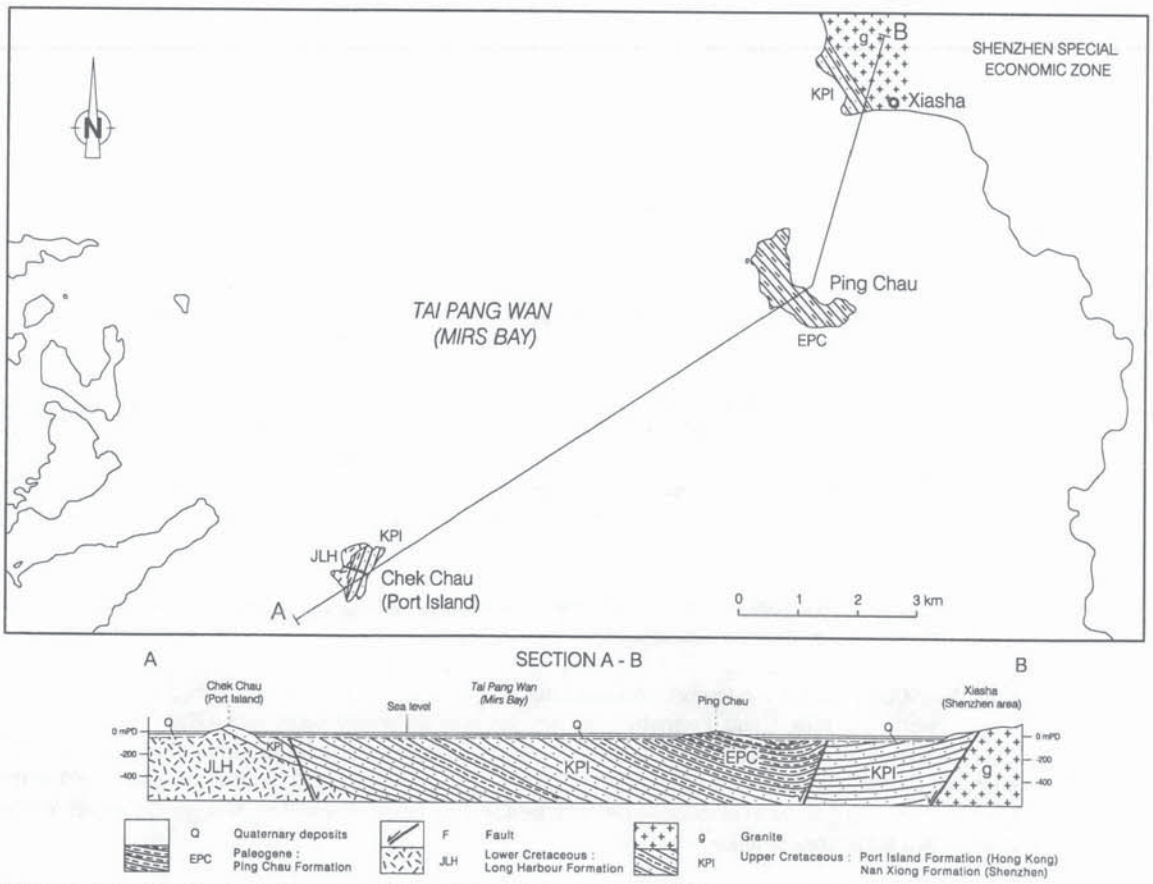


Figure 12 - Geological Cross-section of the Cretaceous and Tertiary Basins in Tai Pang Wan (Mirs Bay)

Ping Chau Formation

The Ping Chau Formation has been divided into three members, the middle of which crops out on Ping Chau, where it has been further sub-divided into three units. This lithostratigraphy (Figure 13) may be correlated with that of the nearby Shanshui Basin in Guangdong Province (Figure 14). This indicates that the middle stratigraphic member of the Ping Chau Formation is equivalent to the Second Formation of the Eocene Buxin Group.

The Ping Chau Formation consists predominantly of dark grey, thinly bedded siltstone with clayey dolomitic siltstone (Plate 27), together with a layer of chert. All of these rocks are rich in dolomite, calcite and feldspar (mainly albite) with variable amounts of aegirine, zeolite, illite, quartz, pyrite, apatite, bitumen and carbonaceous matter (Peng, 1967, 1971, 1978). The strata exhibit a variety of sedimentary structures such as ripple marks, sub-aqueous and sub-aerial shrinkage cracks, cross-bedding, loading and slump structures (Plate 28), and the development of pyrite nodules.

Details

Ping Chau. The strata on Ping Chau belong to the middle stratigraphic unit of the formation. The formation is characterized by thinly bedded strata. In general, each of the beds is only 2 to 6 cm wide but can be traced laterally for a distance of several hundred metres. Most beds are composed of very thin, alternating planar laminae, each less than 1 mm thick, of detrital and chemical sedimentary rocks (Plate 29). The lowest unit of the member consists of dark grey, thinly bedded aegirine-bearing siltstone with clayey dolomitic siltstone and a layer of chert and exceed 60 m in thickness. Intercalated, pale yellowish brown, dolomitic siltstone is well exposed at Cham Keng Chau (617 454) and Chau Bei (625 444). There are also several thin layers containing coarse calcite aggregates that crop out at Hok Ngam Teng beach (6320 4430). Calcite veinlets, 0.5 to 1 cm thick, fill minor faults at Cham Keng Chau (6180 4540). Aegirine, calcite and pyrite crystals, some possibly pseudomorphic after gypsum, occur locally (6185 4570) (Plate 30). Bitumenized plant remains are abundant on bedding planes or scattered within beds as carbonaceous fragments. A large fossil tree branch, some 60 cm in length, was found at the beach near Tsau Uk (6190 4510). Sedimentary structures, including sub-aqueous and sub-aerial shrinkage cracks, ripple marks and the development of pyrite nodules are common. Cross-bedding, load structures and other forms of soft-sediment deformation (Plate 28) also occur. A greyish white, massive chert forms a well-defined marker bed along the west coast (Plate 31) and creates a hard and narrow ridge about 1 m thick (Plate 32). Northwards, this horizon thins from 1.2 to 0.6 m.

The middle part of the member is 46 m thick, and comprises dark grey, thinly bedded siltstone with intercalated dolomitic siltstone and mudstone. Laminae within each of the siltstone beds are also very thin but contain more detrital minerals. Pyrite is abundant, ranging in size from 0.1 mm cubic crystals to 120 mm nodules. Shrinkage cracks, cross-bedding, rain pitting prints and trace fossils (Fyfe, 1991) are present in the rocks, and fossil plants are also abundant. A fossil palm leaf, 60 cm long and 50 cm wide, occurs at Nan Kwo Shui (6365 4445).

The upper part of the member is 92 m thick and consists of dark grey, thinly bedded, zeolite- and aegirine-bearing siltstone (Plate 33). The zeolite-bearing siltstone is well developed along the east coast between Wong Ye Kok (627 449) and Lam Uk (627 446). The zeolite includes natrolite and analcime, and occurs as abundant, rosette-shaped crystal aggregates lying on bedding planes, or forms prismatic and granular crystal aggregates that fill cracks and "birds eye" structures. Pyrite is present as subspherical nodules and laminae. Cross-bedding is common at Wong Ye Kok.

At Chau Mei Kok (623 460), the rocks display a lithofacies change to dark grey, thinly bedded calcareous and dolomitic siltstone, showing a conspicuous decrease of sodium-rich minerals (aegirine and zeolite).

Seabed West of Ping Chau. Seismic interpretation indicates that rock is exposed on the seabed within 200 m of the island. Further west, the Ping Chau Formation is overlain by Quaternary sediments. The seismic profiles suggest that the formation offshore comprises mainly thinly bedded, gently dipping strata that resemble the siltstones exposed on Ping Chau. The strata offshore, estimated as being more than 150 m thick, are assigned to the lowermost member of the Ping Chau Formation. They overlie the Port Island Formation, though the nature of the contact between the two formations is unknown.

Seabed East of Ping Chau. The upper member of the Ping Chau Formation is overlain by Quaternary sediments except near the coast, and is presumed to be dominated by siltstone. The thickness of the sequence is more than 100 m in this area.

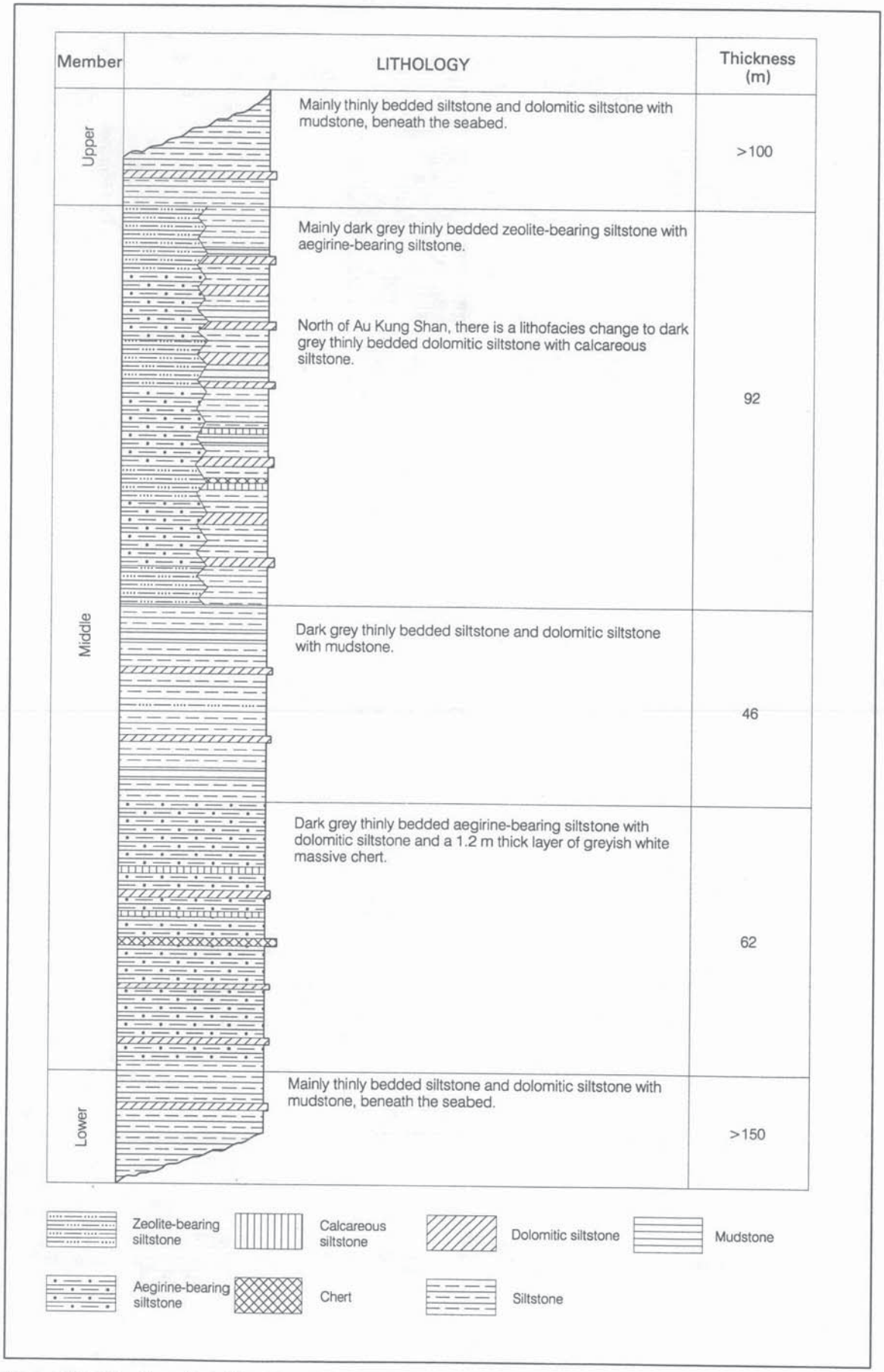


Figure 13 - Stratigraphy of the Ping Chau Formation

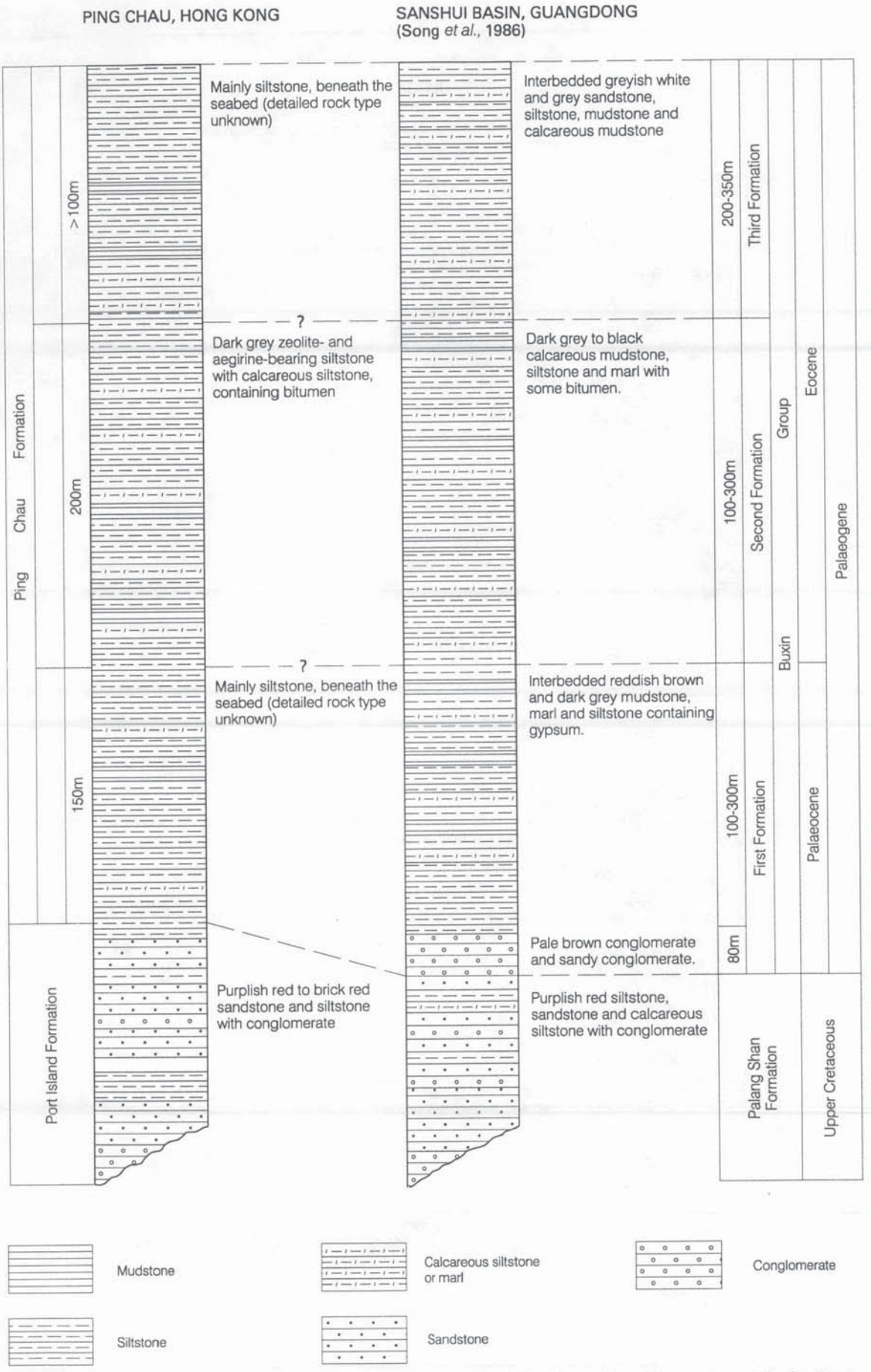


Figure 14 - Lithostratigraphic Comparison (Not to Scale) of the Ping Chau Formation with the Buxin Group of the Sanshui Basin, Guangdong

Plate 31 - Greyish White Chert within the Ping Chau Formation, Ngai Kok (6186 4577) on Ping Chau

Plate 32 - White Chert, Well-bedded Calcareous Siltstone and Dolomitic Siltstone (6210 4460) of the Ping Chau Formation, Lung Lok Shui on Ping Chau

Plate 33 - Thin Section of Aegirine-bearing Laminated Siltstone (HK7314, 6190 4482), within the Ping Chau Formation, Nam Tong on Ping Chau; XPL

Plate 34 - Thin Section of Chert with Stylolitic Horizon (HK9115, 6276 4422), within the Ping Chau Formation, Chau Tau, Ping Chau; XPL

Petrography

Dolomitic siltstone HK 7318 (6271 4486) is composed mainly of dolomite, calcite with quartz, illite, albite and pyrite. The grain size ranges from 0.01 to 0.03 mm. The albite forms subhedral crystals whereas the dolomite is euhedral. The rocks generally contain approximately 10 to 45% dolomite. In thin section, they are characterized by very thinly interlaminated detrital deposits, feldspathic siltstone, mudstone and carbonaceous matter, with chemical sedimentary rocks, mainly clayey dolomite. The laminae vary from 0.05 to 0.035 mm thick.

Aegirine-bearing dolomitic siltstone is dark grey and thinly bedded. It contains mainly subhedral albite and euhedral dolomite associated with accessory calcite, illite, quartz, pyrite and carbonaceous matter. The rock often contains 10-20 % dolomite and the grain size varies from 0.005 to 0.02 mm. The most distinctive feature is the presence of 2-8 % aegirine seen in samples HK 9107 (6183 4561) and HK 7314 (6190 4482) (Plate 33). The aegirine occurs as sheaves, or radiating aggregates, of green to bluish green needles less than 1 mm in length, which together with calcite, dolomite and albite filling shrinkage cracks and 'birds eye' structures, or densely scattered along bedding planes. These siltstones contain Na_2O: 4.95-6.14 % and MgO + CaO: 8.27-10.02 % (Table 5).

Zeolite-bearing siltstone is dark grey and thinly bedded. Each bed comprises laminae that are 0.1 to 0.35 mm thick. In thin section (HK7318, 6270 4485), the main minerals are dolomite with calcite (5-35 %), illite, albite, pyrite, asphalt and carbonaceous matter. The rock contains Na_2O: 4.80-5.53 % and MgO + CaO: 10.04 - 13.95 % (Table 5), while grain size is 0.005 to 0.02 mm. A distinctive feature is the presence of zeolites (5 - 10 %), including natrolite and analcime. These occur as abundant, rosette-shaped crystal aggregates lying on bedding planes, or

forming prismatic and granular crystal aggregates up to 4 mm long, filling cracks, cavities and "birds eye" structures.

Chert is greyish white, massive, and very hard with stylolitic structures (Plate 34). In thin sections HK 9108 (6188 4576), HK 7313 (6212 4460), and HK 9115 (6276 4422), it consists mainly of anhedral intergrowths of fine to very fine-grained quartz (75-84 %), that was probably recrystallized from opal. Rhombs of dolomite and ankerite (5.0-9.5 %) also occur and are a secondary development of late diagenetic origin. Scattered clastic grains of albite (0.015 mm) quartz and accessory zircon form 3-6.5 % of the rock. Occasional zeolite and aegirine crystals are dispersed throughout in dolomitic crystalline patches. The chemical composition is shown on Table 5.

Palaeontology

Numerous fossils have been recovered from the Ping Chau Formation, including specimens of some fossil plants (Lee *et al.*, 1990b) and insects (Figure 15). Identifications of fossil insect material of Cretaceous to Tertiary age (including one fossil specimen and 36 photographs of fossils) by Q.B.Lin (Nanjing Institute of Geology and Palaeontology, Academia Sinica) confirms the presence of *Tettigarctidae gen. et sp., Gyrinidae gen. et sp., Cicadellidae gen. et sp., Coleoptera sp., Bibiorridae gen. et sp.*, and *Cupididae gen. et sp.* These identifications agree with Cockerell's original opinion (in Williams, 1943), suggesting that the age of the insect fossil *Otiorhynchites williamsi* Cockerell from Ping Chau is Cretaceous, Eocene or younger. *Otiorhynchid* weevils are particularly numerous and widespread in the Eocene (Williams, 1943).

A total of 35 fossil plant genera have been recognized from the Ping Chau Formation (Appendix 2), including 17 angiosperms, 15 gymnosperms and 3 pteridophytes (Lee *et al.* 1990b). Ten sporo-pollen samples were studied by the Geology Department of Zhongshan University, Guangdong Institute of Geological Sciences and Nanjing Institute of Geology and Palaeontology,

Table 5 - Major Element Analyses of Samples of Sedimentary Rocks from the Ping Chau Formation, Ping Chau

Major Oxides	Aegirine-bearing siltstone	Zeolite-bearing siltstone	Chert
	HK 7316 Tsau Uk (6190 4510)	HK 9679 Wong Ye Kok (6270 4490)	HK 7313 Lung Lok Shui (6220 4460)
SiO_2	50.8	47.05	78.54
TiO_2	0.47	0.35	0.03
Al_2O_3	16.19	14.41	11.04
Fe_2O_3	4.88	3.76	0.68
MnO	0.11	0.1	0.07
MgO	2.32	2.34	0.23
CaO	5.95	7.7	0.94
Na_2O	6.14	5.53	5.9
K_2O	3.54	3.76	0.63
P_2O_5	0.07	0.12	0.01
LOI*	9.38	14.69	1.58
Total	99.85	99.81	99.65

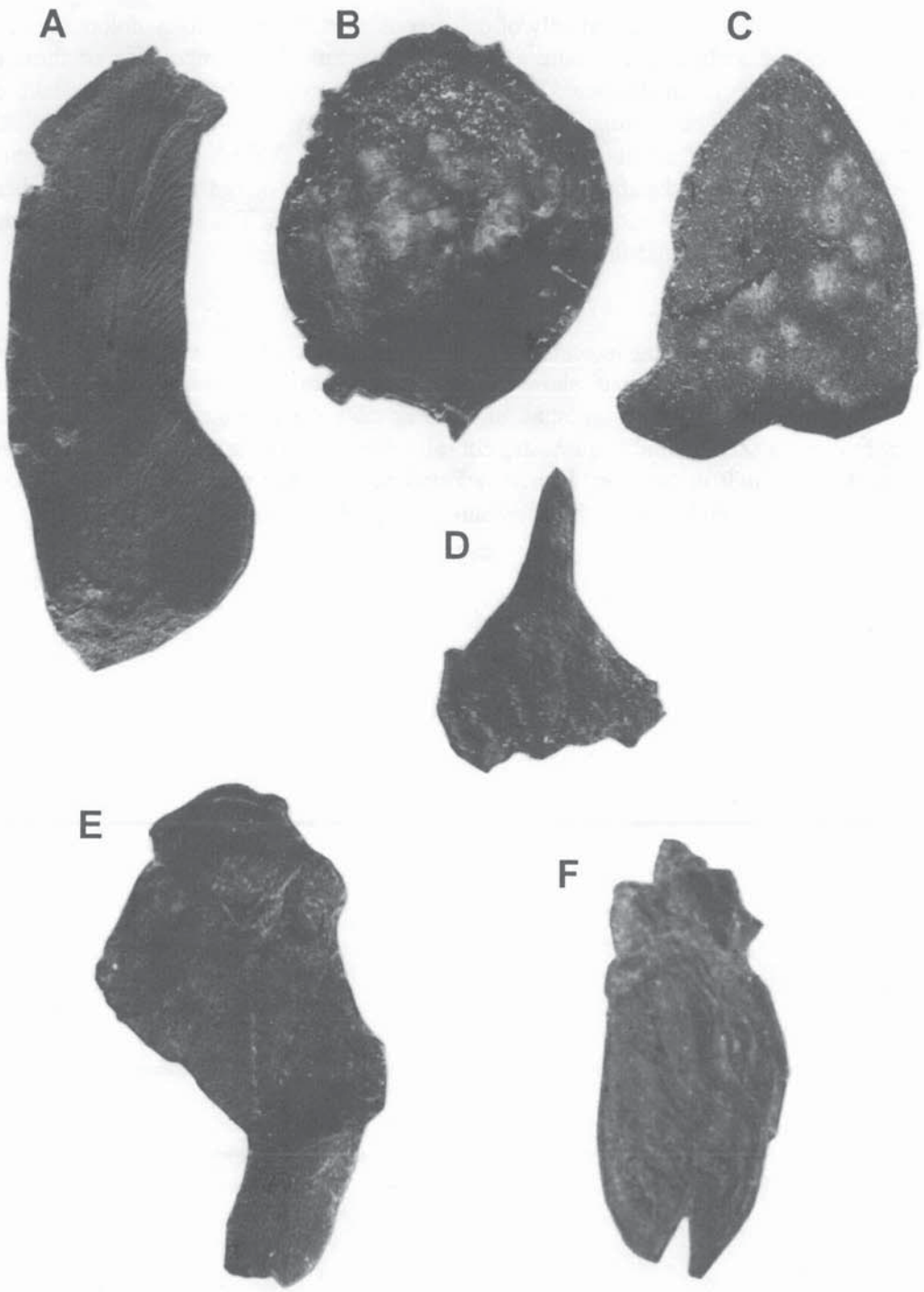
Note 1. LOI : Loss on ignition; mainly includes CO_2 and H_2O

2. Samples were analysed by the University of Nottingham using the XRF fusion bead method.

3. Total iron calculated as Fe_2O_3

Academia Sinica. Among the total of 115 genera (Appendix 3), 55 are angiosperms, 21 % are gymnosperms and 39 are pteridophytes. Angiosperms have been more dominant since the Upper Cretaceous, and are especially common in the Cenozoic. Moreover, some of the macroplants such as *Sabalites sp.*, *Cinnamomum sp.*, *Cercis sp.*, *Trapa sp.* and sporo-pollen such as *Plicapollis granulatus, Quercordites sp.*, *Engelhardtioidites punctatus* and *Ulmipollenites minor* are restricted to the Tertiary.

The sporo-pollen assemblage from the Ping Chau Formation comprises *Pterisisporites, Verrutetraspora, Inaperturopallenites, Ulmipollenites, Ulmoideipites, Subtriporopollenites* and *Plicapollis*. Palynological comparison of the Ping Chau Formation with strata in the Shanshui Basin, Guangdong (Appendix 4) indicates that the Ping Chau Formation is similar to the Palaeogene Buxin Group but differs markedly from the Cretaceous Dalang Shan Formation, which is dominated by *Pterisisporiter, Schizaeoisporites, Gabonisporis, Exesipollenites, Classopollis* and *Sporopollis*.



A	*Otozamites sp.*	(P129)	15mm*1	D	*? Cone scale*	(P149)	6mm
B	*Carpolithus sp.*	(P145)	15mm	E	*Tettigarctidae, gen. et. sp. cf. Liutaiprosbole sp.*	(P712)*2	5mm
C	*Carpolithus sp.*	(P135)	8mm	F	*Gyrinidae, gen. et. sp.*	(DB8)	5mm

Note *1 All fossils identified by Nanjing Institute of Geology & Palaeontology, Academia Sinica. Specimen length in mm.

*2 Collected by P.S. Nau

Figure 15 - Fossil Plants and Insects from the Ping Chau Formation, Ping Chau

Sedimentary Environment

The Ping Chau Formation consists mainly of calcareous siltstone with clayey dolomitic siltstone and possesses a high sodium-rich zeolite and aegirine content. The composition of these rocks indicates that they have been deposited in a tropical to subtropical brackish water lake under semi-arid conditions. The formation is characterized by well-developed, very thinly interlaminated, detrital and chemical cyclical deposits. In the detrital cycles, the presence of carbonaceous matter and feldspathic siltstone reflect a relatively humid period. In the chemical depositional cycles, the clayey carbonate rocks indicate dry periods. The interlaminated rocks are interpreted as reflecting seasonal fluctuations of water level and salinity.

Ripple marks and cross-bedding indicate a shallow water environment whereas the rain pitting and subaerial desiccation polygons show that the surface of the sediments was subaerially exposed. The presence of pyrite suggests a high water table creating a reducing environment in the sediment column. Zeolite and aegirine are considered to have crystallised during deposition of the sediments. Although no gypsum has been found in the rocks exposed on Ping Chau, the possible presence of pseudomorphs after gypsum (Peng, 1971) suggest that this mineral may have occurred.

Chapter 7
Structure

Introduction

The major structural features of the district (Figure 16), are dominated by northeast-trending faults, shear zones and fold axes, with subordinate northwest- and east-trending faults. The most laterally extensive of the northeast-trending faults are: the San Tin Fault, a part of the Lo Wu-Tuen Mun Fault Zone, that extends northeast of the district to Shenzhen and Wuhua in east Guangdong Province, and beyond into Fujian; the Sha Tau Kok Fault Zone; and the Chek Mun Fault Zone.

The volcanism in the district evolved in relation to the Yanshanian Orogeny, which occurred during the Jurassic and Cretaceous, and coeval, voluminous, silicic volcanism and plutonism extended along a broad coastal belt in southeast China. The belt is also characterized by northeast-trending folds and faults and includes structurally complex basement terranes.

Hong Kong lies within the major, northeast-trending Lianhua Shan Fault System, a part of the Yanshanian orogenic belt. The fault system is characterized by numerous individual faults and shear zones, of which thrusts and sinistral strike-slip faults are the dominant components. They typically have curvilinear traces and are up to hundreds of kilometres long. The main faults in the district are shown in Figure 16.

Earlier structural development, referred to here as Pre-Yanshanian is possibly related to the Indosinian Orogeny and are thought to have affected Palaeozoic rocks in the northwest of the district. Basin development during the Cenozoic post-dated the Yanshanian orogeny, and was possibly related to the Himalayan orogeny.

Pre-Yanshanian Structures

Pre-Yanshanian structures are thought to occur in the extreme northwest of the district, affecting Carboniferous rocks of the Mai Po Member that lie within the Lo Wu-Tuen Mun Fault Zone, and in the southwest, affecting Devonian rocks of the Bluff Head Formation in the Chek Mun Fault Zone. However, due to the intensity of subsequent Yanshanian structural and metamorphic overprint, these early structures, possibly including folds with northeast-trending fold axes, are hard to define.

Yanshanian Structural Development

Yanshanian structural development affected the entire district during the Jurassic and Cretaceous, causing movement along northeast-trending faults, and subsidiary east- and northwest-trending faults within the Linhua Shan Fault Zone. Activity on these faults influenced contemporaneous volcanism and basin development, and widespread foliation and folding also developed.

Folds

Folds in the district are commonly hard to identify as they are often obscured by intense faulting, the effects of magmatism and metamorphic overprint. Lack of exposure, especially in low-lying areas covered by superficial deposits, also limits their identification.

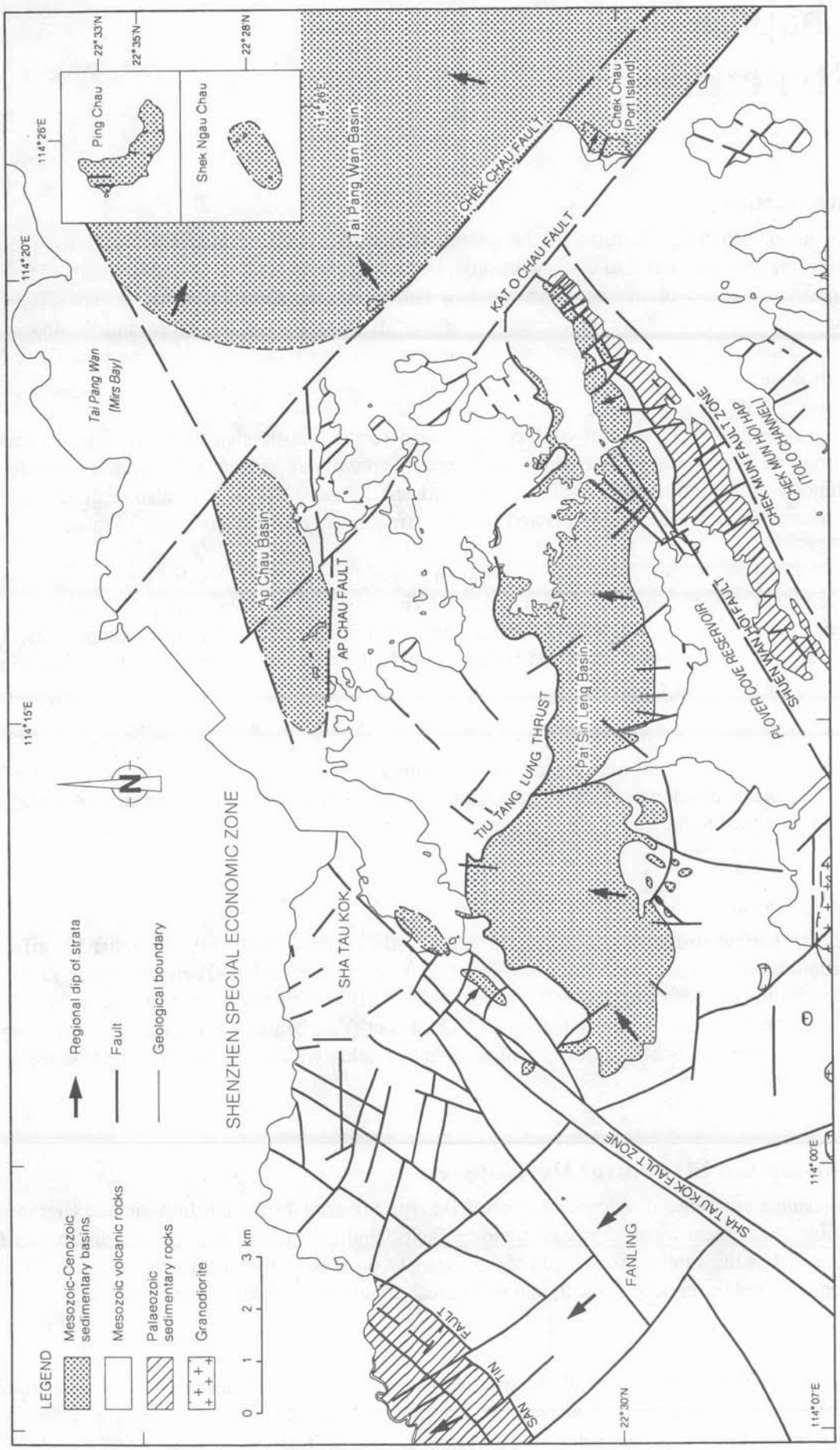


Figure 16 - Principal Structural Features of the District

Folds are commonly seen within sedimentary rocks of the Bluff Head Formation. Along the northwest shores of Chek Mun Hoi Hap (Tolo Channel), for example, they are typically close and asymmetric, and their axes trend north-northeast or northeast, but the axial zones are generally disrupted by faulting. Open to close parasitic folds (Plate 35) also occur within the Bluff Head Formation 200 m south of Bluff Head (5248 4119, 5262 4117, 5250 4118), on the south shore of Plover Cove Reservoir (4602 3715, 4708 3743, 4709 3759), and at Lo Fu Wat (4660 3685). The axes of these minor synclines plunge variably towards 207-235°, whereas axes of minor anticlines plunge towards 028-042° and occasionally 230°.

Folds affecting Upper Jurassic and Lower Cretaceous volcanic and interbedded sedimentary rocks are typically open. The Cretaceous red beds, by contrast, are gently folded at most.

Faults

The main northeast and northwest fault trends (Figure 16) are well illustrated by circular histograms (cf. Cheeney, 1983) (Figure 17). The northeast trend is dominant on Sheet 3, but on Sheet 4, northwest trends are of greater importance.

Northeast-trending faults are the most laterally continuous structures onshore in the district. They vary in strike between 040-060° and include the San Tin Fault, and the Sha Tau Kok Fault Zone. The Chek Mun Fault Zone, which lies just offshore in Chek Mun Hoi Hap (Tolo Channel), is also of similar trend. The other main structure onshore is the Tiu Tang Lung Thrust which trends nearly east-west. Major northwest-trending faults mainly occur offshore in the east of the district, and include the Kat O Chau Fault on the southwest side of the Tai Pang Wan (Mirs Bay).

Fault activity was complex and constraining the time of individual phases of movement is, in many cases, uncertain. The main faults were reactivated during both compressional and extensional phases and the northeast-trending faults show evidence of both vertical and horizontal displacements. Zones of dynamic metamorphism, including foliated, schistose, mylonitized, brecciated and cataclastic rocks, are also typical of the fault zones. Generally, the ductile shear fabrics can be interpreted as having formed in deeper crustal environments, possibly at the end of the late Jurassic and early Cretaceous, whereas brittle structures mainly developed at a later stage, during or after the early Cretaceous.

Northeast-trending Faults

The main northeast-trending faults in the district (Figure 16) are the San Tin Fault in the northwest, the Sha Tau Kok Fault Zone, the Shuen Wan Hoi Fault Zone, and the Chek Mun Fault Zone. The San Tin Fault is a moderately inclined thrust, but by contrast, the other main northeast-trending fault zones in the district are very steeply inclined.

San Tin Fault. The San Tin Fault (Figure 18) occurs in the northwest of the district, where it extends from Fu Tei Au Road (3041 4180) through Cheung Po Tau (3145 4244) to west of Pak Fu Shan (3462 4645). To the southwest of Cheung Po Tau this fault trends 050°, and dips northwest at angles varying from 20-32°. The fault has thrust Carboniferous sedimentary strata southeast over Jurassic tuff of the Tai Mo Shan Formation. This relationship is exposed in roadside sections (3040 4180) on the Fu Tei Au Road, and south of a service reservoir at Cheung Po Tau (3146 4244). Northeast of Cheung Po Tau the fault trend changes to 040°, although it continues to dip to the northwest. From Chow Tin Tsuen (3300 4404), southwest of Pak Fu Shan, the fault runs along the Shum Chun River and extends thereafter into the Shenzhen area. Tuff in the footwall of the fault, on its southeast side, is mylonitized within a zone ranging from tens of metres to one kilometre wide. This zone grades laterally into a slightly sheared zone that

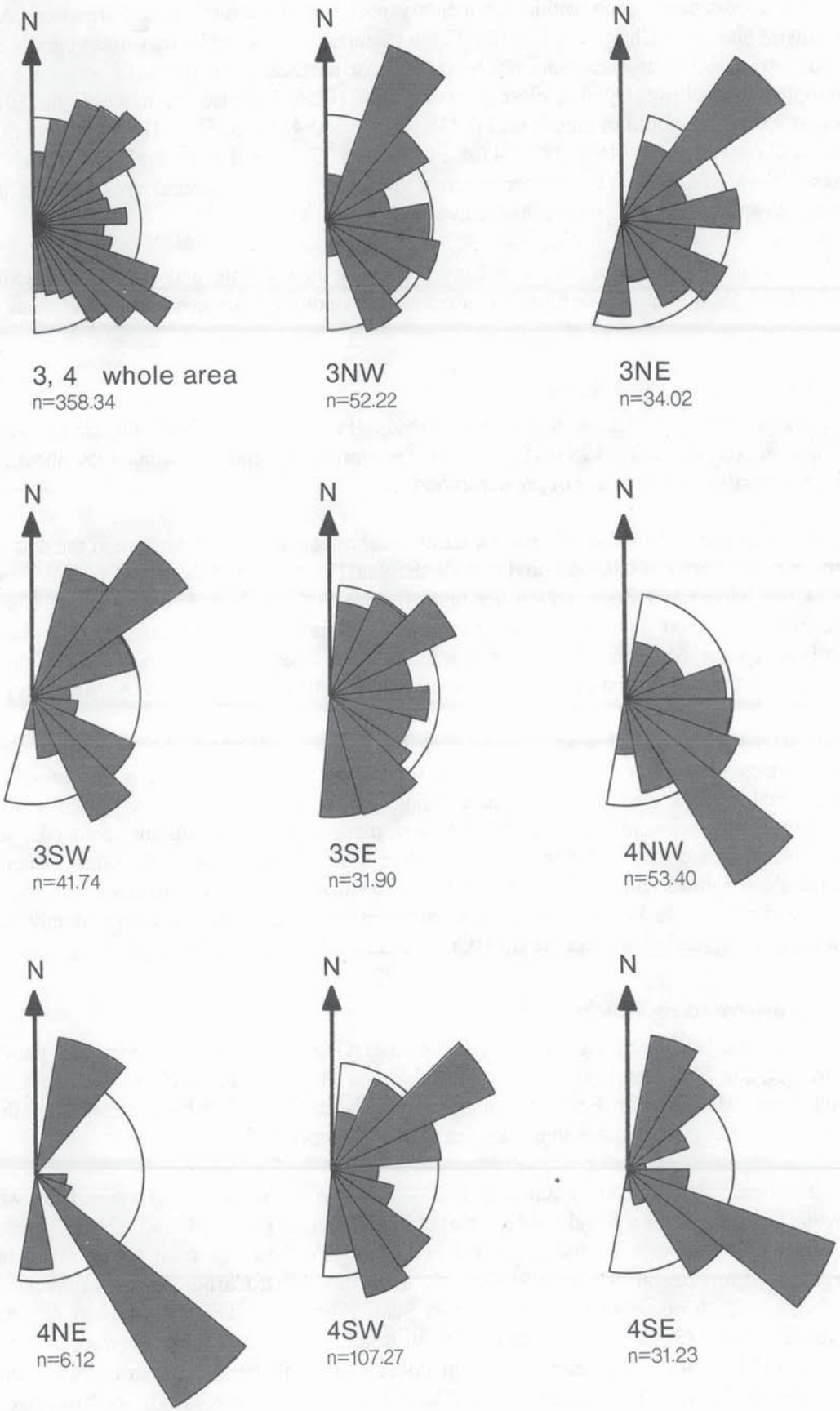


Figure 17 - Circular Histograms of Orientation and Length of Faults for the District. Histograms Are Shown by Sheet Number; the Total Length of Each Fault Is Plotted in Kilometres (after Cheeney, 1983)

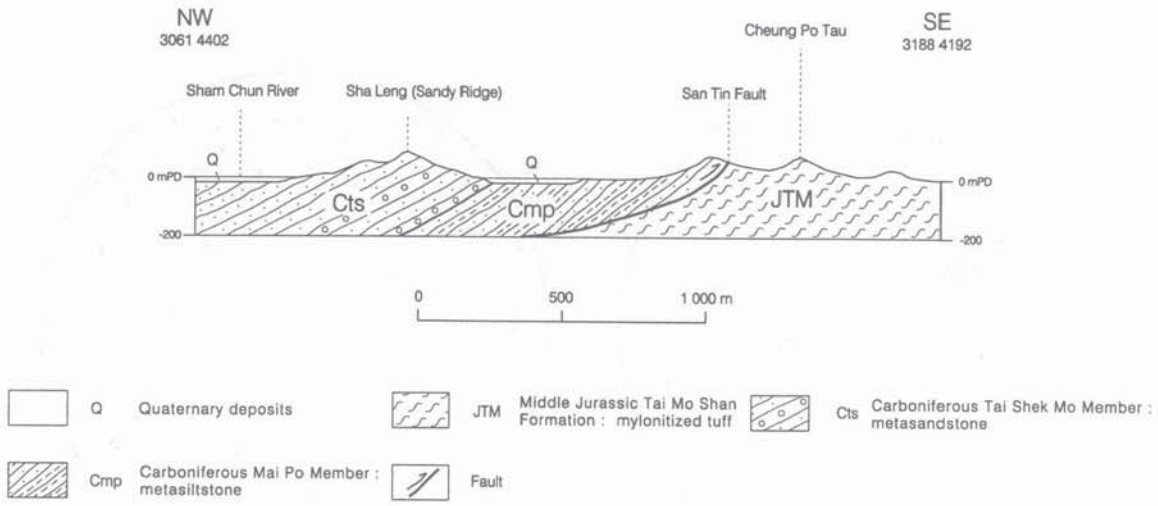


Figure 18 - Geological Cross-section across the San Tin Fault

can be traced for up to six kilometres from the fault. Mylonitized rock is also present in the hangingwall.

Sha Tau Kok Fault Zone. The fault zone stretches from Wai Tau Tsuen (332 360), through Tan Chuk Hang (366 412) and along the northwest coast of Sha Tau Kok Hoi (Starling Inlet) into Shenzhen. The fault zone within the district is 13 km long, between 0.5 and 1.5 km wide, and comprises zones of slightly metamorphosed rock with two to four individual faults that dip to the northwest at 40-70° and along which there are narrow zones of mylonitic schist and intensely crushed or mylonitized rocks, varying between 5 and 20 m wide.

The orientation of foliation within the fault zone is complex and has yet to be resolved in detail. In many instances, it is either parallel to the northeast trend of the zone, dipping northwest, or more oblique to the zone and dipping to the north-northwest. Locally, however, the foliation strikes almost at right angles to the zone, and dips northeast. The foliation is generally moderately inclined, in contrast to the subvertical orientation of the fault zone. The variable strike of the foliation relative to the fault zone suggests strike-slip, and probably sinistral movement. Similar foliation variations occur between the San Tin Fault and the Sha Tau Kok Fault Zone, defining very large-scale Z-shaped inflections up to 5 km across and may also indicate regional sinistral shear.

Foliation orientation data for the district as a whole are presented in Figure 19. The strongly preferred concentration of data emphasises the dominance of moderately inclined, northwest dipping foliation in the west of the district in particular.

The fault zone dissects Cretaceous strata of the Pat Sin Leng Formation at localities 700 m northeast of Tan Chuk Hang (3450 3910), 600 m west of Kwai Tau Leng at Pak Tau Ha (3960 4350), and at Wu Shek Kok (4000 4400). Alternating bands of schistose and undeformed tuff occur at Lung Shan (Birds Hill) (3450 3910). A 2 m-wide fault zone, containing crushed and chloritized tuff, crops out in a cutting (3810 4294) on the Sha Tau Kok Road near Au Ha.

Shuen Wan Hoi Fault. The fault can be traced from 700 m southeast of Siu Kau (4720 3840), through Fung Wong Wat Teng (4972 3940) and Pak Kok Shan (507 400), to Wong Chuk Kok Tsui (Bluff Head) (5250 4122). In this part of the area the fault can be regarded as part of the

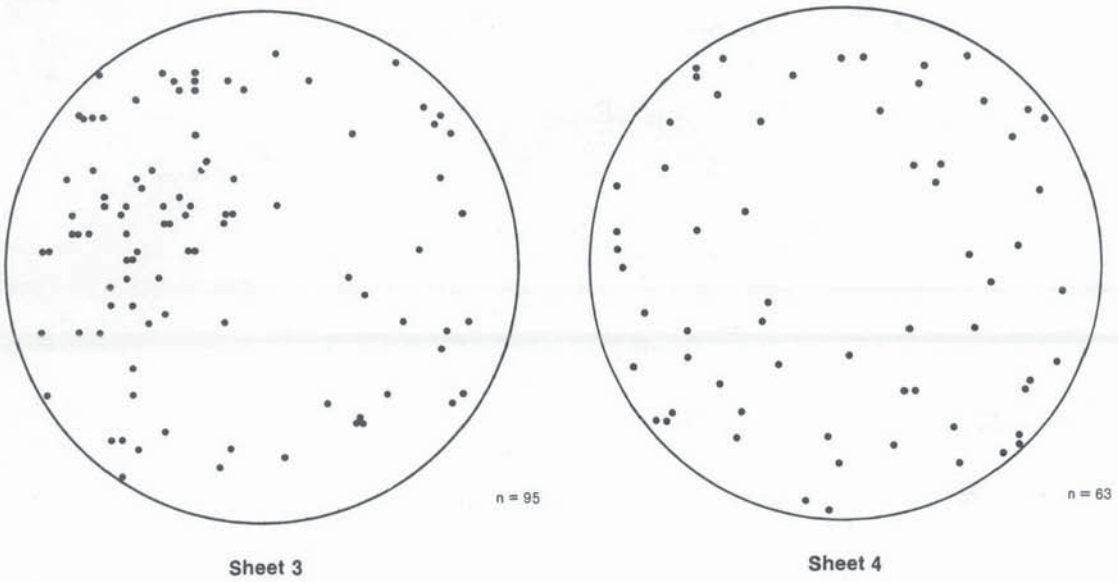


Figure 19a - Equal-area Point Plots for Joints in Volcanic Rocks of the District

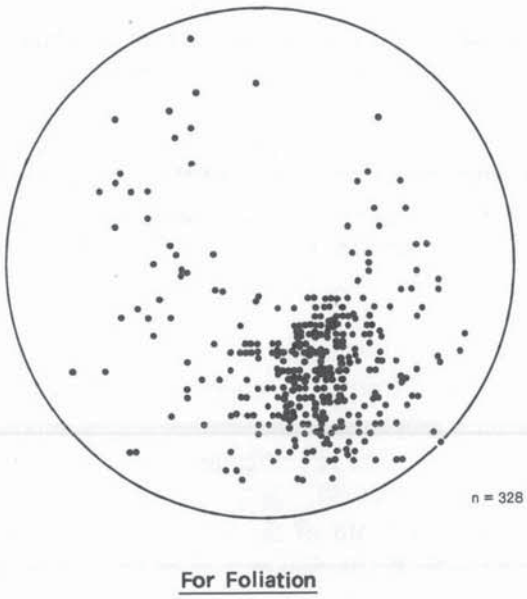


Figure 19b - Equal-area Point Plots for Foliation in Volcanic and Sedimentary Rocks in the Northwest of the District

Plate 35 - Anticline, Plunging Northeast, in Sandstone and Siltstone of the Bluff Head Formation, on the Coast (5250 4118) South of Wong Chuk Kok Tsui (Bluff Head)

Plate 36 - Fault Zone (5250 4122), 1.5 m Wide, Separating Sandstones of the Devonian Bluff Head Formation (to the Left) from Coarse Ash Tuff of the Upper Jurassic Tai Mo Shan Formation (to the Right), Wong Chuk Kok Tsui (Bluff Head)

Plate 37 - Faulted Contact (5080 3917) between White Sandstone and Reddish Siltstone of the Devonian Bluff Head Formation and Dark Grey Siltstone of the Jurassic ToloChannel Formation, Pak Kok Tsai, North Coast of Chek Mun Hoi Hap (Tolo Channel)

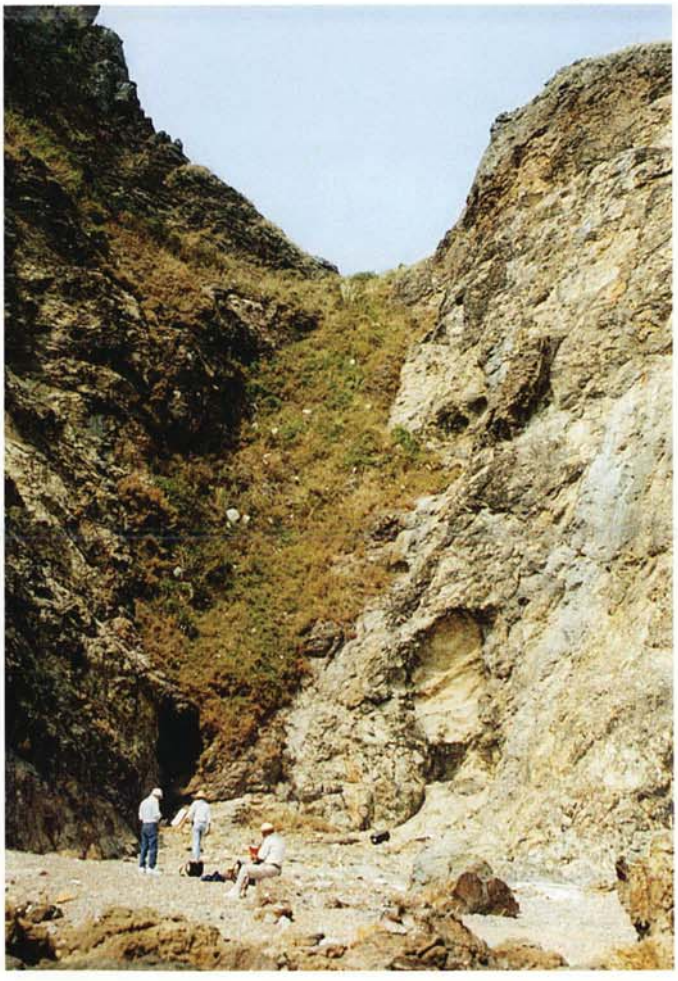


Plate 38 - Northwest-trending Fault (5040 4550) within the Ngo Mei Chau Formation, Fei Shu Ngam, East of Kat O Chau

subparallel Chek Mun Fault Zone, that lies to the southeast. However, further southwest, and beyond the district, the fault is more easterly trending and appears to be a linking fault between the Chek Mun and Sha Tau Kok fault zones. Southwest of Pak Kok Shan, the Shuen Wan Hoi Fault juxtaposes tuff of the Upper Jurassic Tai Mo Shan Formation and sedimentary strata of the Devonian Bluff Head Formation. The fault is interpreted as a mainly reverse fault, dipping at 68-73° towards the east-southeast, with the Bluff Head Formation having been thrust from the southeast, onto the tuff. Northwest of Pak Kok Shan, the fault zone forms the margin of the Cretaceous Pat Sin Leng Basin, with the Bluff Head Formation on its southeast side, and here, the fault zone has a normal displacement and dips northwest at 80°.

At Wong Chuk Kok Tsui (5250 4122), the fault again separates tuff of the Tai Mo Shan Formation from sedimentary strata of the Bluff Head Formation. The fault comprises a 1.5 m-wide zone of brecciated rocks, including tuff and sandstone clasts (Plate 36). Siltstones form minor, close folds, and sandstones occur as tectonic lenses on the southeast side of the fault. The tuff on the opposite side of the fault is intensely jointed within a zone 80 m wide.

The Shuen Wan Hoi Fault Zone may have influenced the emplacement of granodiorite intrusions during an extensional phase of movement in the late Jurassic. Both the Shuen Wan Hoi and Chek Mun fault zones, which are both high angle structures, had phases of further extension, reverse movement, and, on the basis of the form of S-C microfabrics, sinistral displacements, though the ages of these movements are not well constrained.

Chek Mun Fault Zone. The fault zone (Figure 20) is composed of two faults that border a narrow, elongate graben, subparallel to the north coast of Chek Mun Hoi Hap (Tolo Channel). The graben extends from southeast of Wong Chuk Kok Tsui (Bluff Head) to Lo Fu Wat (4600 3635). Lower Jurassic strata of the Tolo Channel Formation largely infill the graben, together with some Upper Jurassic volcanic rocks. The width of the graben varies from approximately 50 to 100 m. Some acidic dykes occur within the graben, striking parallel to its axis.

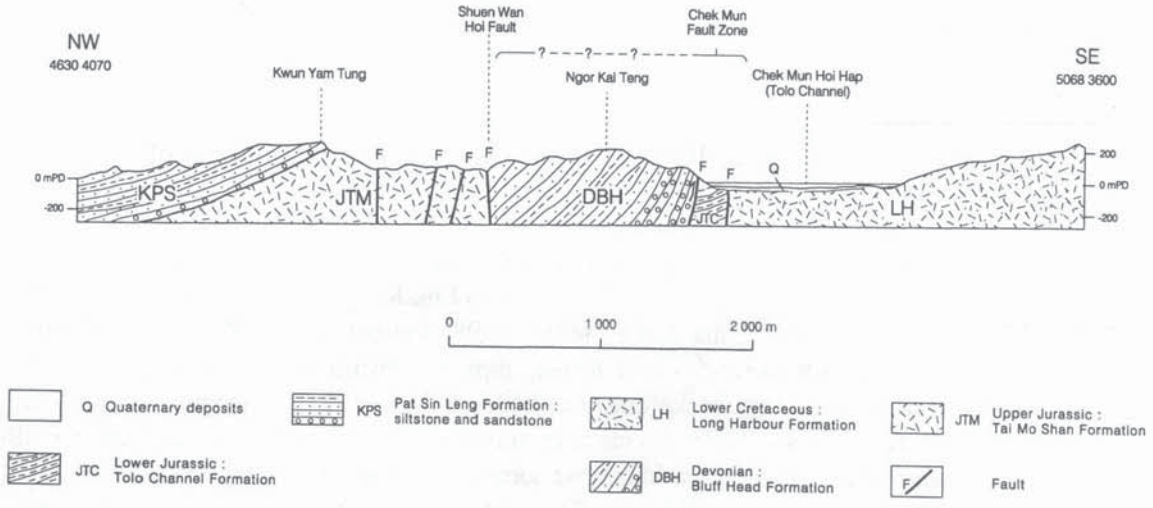


Figure 20 - Geological Cross-section across the Chek Mun Fault Zone

The fault between the Devonian Bluff Head and Tolo Channel formations is a high angle reverse fault, dipping northwest at angles varying from 82°, at 100 m south of Fung Wong Wat, to 85°, 500 m south of Pak Kok Shan (Plate 37). The fault also shows evidence of sinistral movement. Sedimentary strata of the Bluff Head Formation are steep to overturned adjacent to the fault zone, but further away from it, they are inclined more gently (30-50°) and are cut by strike-slip faults parallel to the main fault zone.

Northwest-trending Faults

Northwest-trending faults (trend varying to north-northwest, Figure 16), including the Chek Chau and Kat O Chau faults, have a high angle of dip and contain narrow crush zones. Generally, they displace the more laterally continuous northeast-trending faults. During the late Jurassic, some northwest-trending faults acted as conduits for fissure-controlled volcanism. They also controlled the margins of late-Yanshanian sedimentary basins (see below) during the Cretaceous and a small post-Yanshanian basin during the Tertiary, indicating that they were dominantly normal faults during this time. Elsewhere in the Territory, there is evidence of significant dextral and occasionally sinistral displacement along faults of this orientation, but within the district, there is little constraint on lateral movement.

Kat O Chau Fault. The fault trends 310° and can be traced from Sham Chung (4823 4460) on Kat O Chau, passing west (4972 4368) of Hung Fa Leng on Ngo Mei Chau (Crescent Island) and offshore along Chik Mun Tau Channel to the west of Chek Chau. A 2 m-wide brecciated zone can be seen within the fault onshore on both sides of Wang Mun Hoi Channel (4973 4365, and 4948 4383). Aplite dykes have been intruded along the fault at Wong Kok Teng (4947 4386) and on the east shore (4824 4457) of Sham Chung on Kat O Chau. Complementary northwest-trending faults occur parallel to the southwest coast of the Taipang Peninsula at Xiasha. Minor northwest-trending faults on the east side of Kat O Chau (Plate 38) and east of Pak Kok Shan (5080 3980) offset northeast-trending faults. An aplite dyke has been intruded parallel to these faults at Chung Wan Teng (5020 4560) on Kat O Chau.

Chek Chau Fault. The Chek Chau Fault can be clearly detected on seismic reflection profiles, lying offshore to the east of Kai Kung Tau (507 456) on Kat O Chau (Crooked Island). Towards the southeast, it passes west of Pak Sha Chau (Round Island) and east of Chek Chau. The fault, which trends 310° and is downthrown on its northeast side, forms the bounding margin of the Tai Pang Wan Basin.

East-trending Faults

East-trending faults include (Figure 16) the Tiu Tang Lung Thrust in the centre of the district, and the Ap Chau Fault.

The Tiu Tang Lung Thrust (Figure 21) trends roughly east-west across the central part of the district, westwards from Kwai Tau Leng (3771 4063), to Luk Keng (4000 4227), Wu Kau Tang (4352 4115), and south of Tiu Tang Lung (4468 4098) towards Wong Wan Chau (Double Island) in the east. The southerly-directed thrust, dips northward at a low angle, and has emplaced Upper Jurassic volcanic rocks onto red beds of the Lower Cretaceous Pat Sin Leng Formation (Figure 21). The southerly direction of thrust movement is broadly consistent with north and northeast-plunging elongation lineations seen in the footwall of the thrust and towards the base of the overlying hanging wall block. The southerly movement sense is also consistent with evidence of sinistral displacements on the main northeast-trending fault zones in the district. The thrusting could post-date the Lower Cretaceous. However, it is also possible that the Pat Sin Leng Formation was deposited in a basin (the Pat Sin Len Basin, Figure 16), at the toe of the thrust, and this basin was continuously overridden by the thrust as it advanced.

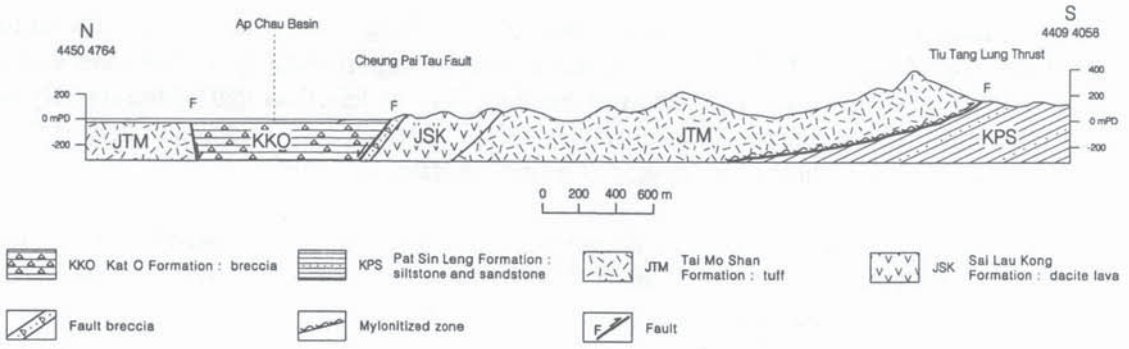


Figure 21 - Geological Cross-section across the Cheung Pai Tau and Tiu Tang Lung Faults

The Ap Chau Fault trends 098°, dipping north at 48-62°, and extends eastwards from Cheung Pai Tau (Ledge Point), passing to the south of Ap Chau and to the north of Kat O Chau. The fault downthows the Kat O Formation against dacite of the Upper Jurassic Sai Lau Kong Formation. A crush zone is developed along the fault and is 5 to 10 m wide generally. Locally, the fault is up to 45 m-wide and contains brecciated and silicified block-bearing lapilli tuff, raising the possibility that the fault had also acted as a conduit for volcanism. The lithic clasts include Upper Jurassic tuff and lava and Permian limestone.

Sedimentary Basins

The three sedimentary basins identified in the district are thought to have formed during the late Yanshanian and Himalayan orogenies. They are (Figure 16) the Lower Cretaceous Pat Sin Leng Basin, which is preserved mainly onshore, and the Upper Cretaceous Tai Pang Wan and Ap Chau basins, both of which are preserved largely offshore. The Cenozoic Ping Chau Formation overlies the Upper Cretaceous sedimentary rocks of the Tai Pang Wan Basin, without any marked stratigraphic break. However, it is uncertain whether the Ping Chau Formation is the youngest manifestation of Yanshanian orogeny in the district or, as is more likely, a consequence of Himalayan orogeny.

Pat Sin Leng Basin. The basin is fault-bounded with the southern boundary occurring along a fault stretching southwest from Wong Chuk Kok Tsui (Bluff Head) to Siu Kau, Ma Shi Chau and possibly beyond. The Sha Tau Kok Fault Zone truncates the basin on its west side. Some isolated outcrops of Pat Sin Leng Formation red beds occur within the fault zone, e.g. capping the hill south of Hoi Bei Leng (3900 4280), at Pak Tau Ha (3960 4350), at Wu Shek Kok (4000 4390), and 0.8 km east (3705 4132) of Tan Chuk Hang. On the north side of the basin, the red beds are overlain along the Tiu Tang Lung Thrust by the Upper Jurassic Tai Mo Shan Formation (Figures 16 and 21).

Tai Pang Wan Basin. Sedimentary strata within this basin include the Upper Cretaceous Port Island Formation, exposed on Pak Sha Chau (Round Island), Chek Chau (Port Island), and Shek Ngau Chau, and the Cenozoic Ping Chau Formation, exposed on Ping Chau. Lithofacies on both margins of the basin indicate deposition as piedmont alluvial fans onto an intermontane plain,

while at the centre of the basin, deposition was within a brackish water lake. The Chek Chau Fault, which trends 130° and is downthrown on its northeast side, forms the bounding margin of the Tai Pang Wan Basin (Figure 12).

Cenozoic strata form a very gentle syncline beneath Tai Pang Wan (Mirs Bay), with strata dipping at 5-20° (Figure 12). The Cenozoic basin, which is approximately 10 km long and is truncated on its northeast side by a northwest-trending fault, is less than that of the underlying Upper Cretaceous basin. The depositional centre of the Cenozoic basin is approximately at Ping Chau, and the basin as a whole is interpreted as an asymmetric half-graben.

Ap Chau Basin. This basin is situated on the northern side of Kat O Hoi (Crooked Harbour), and extends from Cheung Pai Tau (Ledge Point) (4438 4556) to Ap Chau and North Point on Kat O Chau (Crooked Island), a distance of 5 km. The basin contains reddish brown calcareous breccia of the Upper Cretaceous Kat O Formation and is bounded by east-trending faults. Of these, the Ap Chau Fault is the southern marginal fault of the basin.

Joints

In general, joints are much more pronounced in the volcanic rocks than in the older sedimentary rocks. Joint orientation data for the district as a whole are presented in Figure 19a, but data are insufficient to define consistent joints sets for the district as a whole.

Chapter 8
Metamorphism & Alteration

Introduction

Metamorphism comprises a broad spectrum of fluid, thermal, and mechanical processes which change the primary chemistry, mineralogy and texture of rocks. Alteration processes are similar, but involve less extreme physical and chemical gradients, and are usually more localised. However, there is no clear demarcation between metamorphism and alteration, and they can be regarded as end-members of a continuous spectrum. Superficial weathering also alters mineralogy and chemistry, but its effects are more appropriately described in Chapter 9, within the context of other surface processes and involving low temperature fluids as opposed to the high temperature fluids typically associated with hydrothermal alteration and metamorphism.

Dynamic metamorphism is the most commonly recognised form of metamorphism in the district and its development is extensively shown on the published 1:20 000 scale maps (Sheets 3 and 4), mostly designated as slightly metamorphosed rock, but more locally as schist or mylonite. These variably deformed rocks are most widespread in the northwest of the district where they often occur in northeast- and east-trending zones affecting the Upper Jurassic volcanic rocks of the Tai Mo Shan Formation. Given the widespread occurrence of dynamic metamorphism affecting Carboniferous and Jurassic rocks, it could be regarded as form of regional metamorphism but it has been preferred to emphasise the specific association with faulting in this account. Regional metamorphism is however described in relation to low grade metamorphism observed in Devonian sedimentary rocks in the area.

In most parts of the district, intrusive igneous rocks are uncommon and typically comprise only small-scale dykes. Consequently, contact metamorphism associated with these intrusions is insignificant at the scale of the published maps. However, in the south of the district, a more widespread area of contact metamorphism, developed around a granodiorite intrusion, is shown on Sheet 3.

Limited hydrothermal alteration is probably widespread within the district, especially in the vicinity of volcanic centres, intrusions, faults and shear zones. However, the effects of hydrothermal alteration are hard to distinguish, particularly from those of dynamic and contact metamorphism. As a result, no attempt has been made to distinguish areas of hydrothermal alteration on the published maps. The most significant hydrothermal alteration observed in the district occurs in, and around the Lin Ma Hang Mine, on the northern border of the Territory in the northwest of the district.

Dynamic Metamorphism

Dynamic metamorphism encompasses a wide spectrum of deformational features, the most common of which in the district are foliation, schistosity and the development of mylonitic fabrics. Areas of slightly metamorphosed rock, characterized by foliation, are common to the northwest of the Sha Tau Kok Fault Zone. The foliation results from the preferred alignment of mainly micaceous minerals, due to their physical rotation, and growth of secondary minerals (especially sericite and biotite). The foliation occurs mainly in zones that strike variably northeast to east-northeast. Where foliation occurs, the rocks tend to erode preferentially, forming low-lying topography bounded by ridges composed of relatively undeformed rocks. The foliation

within these slightly metamorphosed areas mostly dips at moderate angles (20-65°, although locally foliation is subvertical) to the northwest or north-northwest.

In the extreme northwest of the district, the foliation becomes more schistose and mylonitic and tends towards subparallelism with the base of the San Tin Fault, which comprises dynamically metamorphosed mylonitic schists dipping at about 30° to the northwest. Foliation also occurs in the hanging wall of the fault, within the Carboniferous sedimentary rocks of the Lok Ma Chau Formation, which comprises metasandstones, metasiltstones, phyllites, metaconglomerates and graphite schists. These rocks could all be regarded as the product of regional metamorphism but similar Carboniferous sedimentary rocks in adjoining areas of Guangdong Province lying beyond the main zones of faulting and shearing are not metamorphosed. This suggests that the metamorphism is more local and dynamic than regional. Although similar metamorphism in the adjoining district to the west was described as regional metamorphism by Langford *et al.*, (1989), they also considered that the metamorphism was primarily associated with thrusting, i.e. dynamic metamorphism, albeit on a very large scale. The foliations in the hanging wall and footwall of the San Tin Fault are presumed to be of the same age. As the youngest formation affected by the dynamic metamorphism along the San Tin Fault Zone is the Tai Mo Shan Formation, of middle or late Jurassic age, the metamorphism probably occurred during or after the late Jurassic.

Foliation associated with fault development is seen in zones near the base of the shallowly northward-dipping Tiu Tang Lung Fault in the centre of the district. Mylonitic schists are also developed near the base of the hanging wall of the fault, within Upper Jurassic rocks of the Tai Mo Shan Formation. Foliation also occurs in zones, particularly within fine-grained sedimentary lithologies, subparallel to the Shuen Wan Hoi Fault and the Chek Mun Fault Zone, both in the southeast of the district.

Regional Metamorphism

Allen & Stephens (1971) considered that regional metamorphism was of greater significance in the Territory than had been previously suspected. They considered that the Carboniferous Lok Ma Chau Formation had been regionally metamorphosed during the Mesozoic, but prior to granitoid emplacement. Bennett (1984b) interpreted the regional metamorphism of the Lok Ma Chau Formation as greenschist facies and also suggested the possibility that the formation could have been metamorphosed at an earlier date, before it was tectonically emplaced during the Jurassic. However, within the district all the observed metamorphic effects are attributed to dynamic metamorphism.

Regional metamorphism is a more appropriate interpretation of the low grade metamorphism evident in the Bluff Head Formation sedimentary rocks in the southeast of the district. The development of preferred metamorphic fabrics is generally restricted to finer-grained lithologies, including siltstones and mudstones. The age of the metamorphism is uncertain but is considered to be of Triassic age (Indosinian), as comparable mineralogical changes are not seen in Lower Jurassic sedimentary rocks of the Tolo Channel Formation in the same area.

Hydrothermal Alteration

Hydrothermal alteration including silicification, carbonatization, the development of quartz veins, and recrystallization is evident locally, in relation to faults, shear zones, volcanic centres and proximity to intrusions. However, it is not generally widespread, nor is it intensely developed. The only significant hydrothermal alteration recognised in the district is seen in and around areas of lead-zinc mineralization centred on the Lin Ma Hang Mine in the northwest of the district. Quartz veins, trending mainly northwest-southeast, and to a lesser extent northeast-southwest, are

sporadically developed. These two trends are parallel to the main fault trends in the district, and evidence of fluid migration causing silicification and greisenization within and near to faults and shear zones is common. Hydrothermal alteration would inevitably have been associated with the dominant dynamic metamorphism in the northwest of the district, but its effects are virtually impossible to differentiate.

Thermal (Contact) Metamorphism

Thermal (contact) metamorphism related to emplacement of granodiorite intrusions and rhyolitic dykes is locally developed, but is rarely sufficiently extensive to be shown on the published maps of the district. There are, however, zones of thermal metamorphism, west and south-southeast of Fung Yuen Lo Tsuen in the extreme southwest of the district, related to emplacement of a granodiorite intrusion in the south of the district. The hornfelsing and recrystallization have affected block-bearing tuff and tuffite of the Shing Mun Formation.

Chapter 9
Superficial Geology

Introduction

Superficial deposits are those sediments that have not generally been lithified. The onshore and offshore superficial deposits of the district are described separately. For the purposes of this memoir, the boundary between onshore and offshore deposits is taken, regardless of their mode of occurrence, at the pre-reclamation or natural coast, low water line. Beaches, estuarine deposits and mud flats of the intertidal region are treated as onshore deposits. Relationships between the various types of superficial deposits are shown in Figure 22, all of which are believed to have formed during the Quaternary period. The most important onshore superficial deposits in the district are alluvial and slope deposits, the latter being generalised as debris flow deposits on the published 1:20 000 scale geological map sheets 3 and 4. These sediment types also occur offshore, usually beneath marine deposits.

This chapter also includes an account of the weathering products of both the common rock types and superficial deposits.

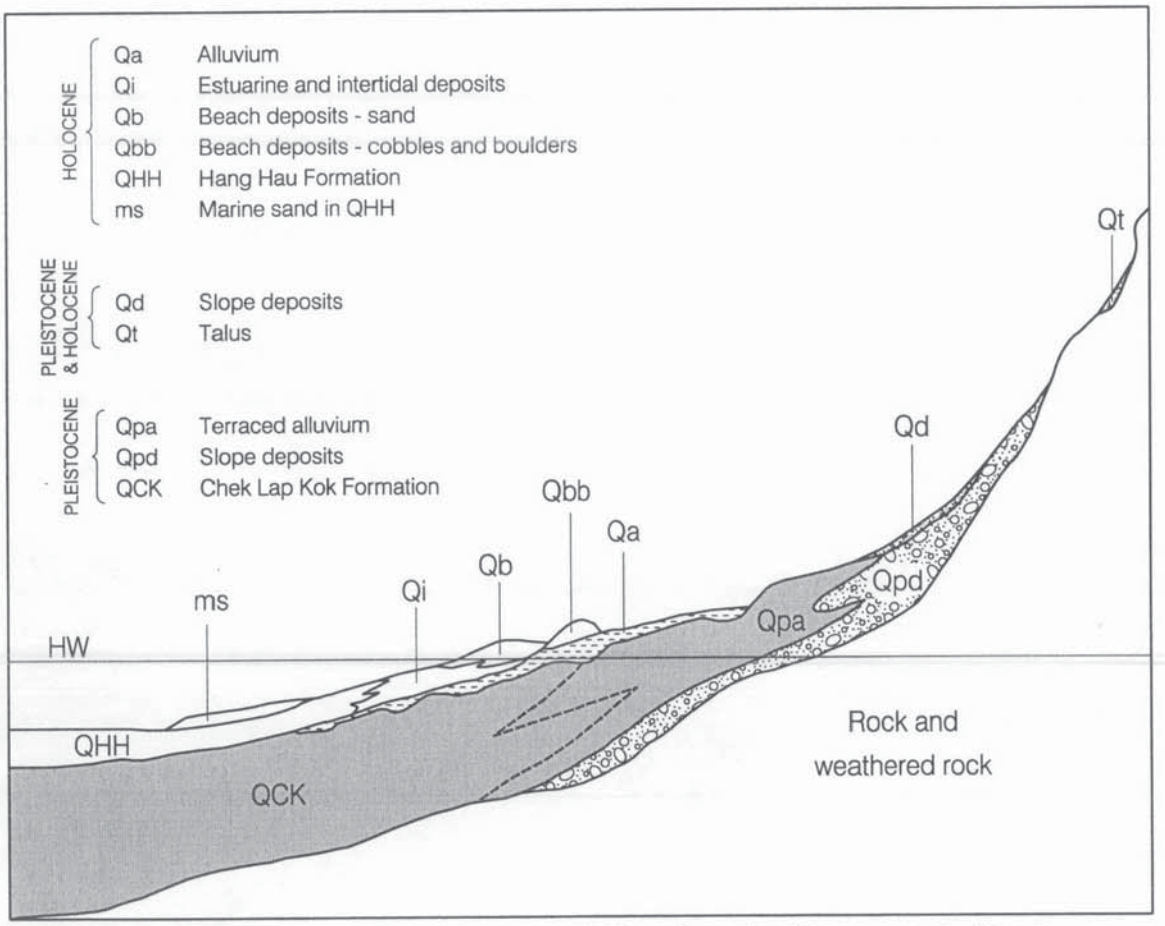


Figure 22 - Schematic Section Relating Onshore to Offshore Superficial Deposits in the District

Onshore Superficial Deposits

Classification and Distribution

The onshore superficial deposits of the district comprise mainly alluvial, slope (including debris flow), estuarine, and intertidal deposits of Pleistocene and Holocene age. Alluvium is widespread along the Sham Chun and Ng Tung Ho (River Indus) river valleys in the west and northwest of the district, forming extensive floodplains. Debris flow and other slope deposits, commonly occur topographically above the alluvium on valley sides, and in isolated upland areas. Both the alluvial and debris flow deposits are composed of clay, silt, sand and gravel in varying proportions, but the debris flow deposits usually contain, in addition, subangular to angular cobbles and boulders. Talus or rockfall deposits, dominantly composed of angular blocks, have a very limited distribution, occurring only below freefaces on the steep slope south of Ping Fung Shan. The thickest Quaternary superficial deposits occur along the Ng Tung Ho (River Indus) valley, on the Fanling and Sheung Shui plains (Figure 23).

Beach deposits, usually comprising sand with gravel, have accumulated in sheltered embayments of the deeply indented and rocky coastlines in the east of the district. Storms have created elevated beaches of sand and gravel, and even boulders, up to a height of 10 mPD.

Small areas of reclamation on the Sheung Shui and Fanling plains, and at Sha Tau Kok and Shuen Wan, and onshore fill deposits are shown on the published geological maps (sheets 3 and 4).

Alluvium

Alluvium is widespread along the Sham Chun and Ng Tung Ho (River Indus) valleys and particularly on the Sheung Shui and Fanling plains. It is rarely exposed in section, but has been widely observed in investigation boreholes and construction caissons. The deposits consist mainly of well-sorted to semi-sorted clay, silt, sand and gravel, and are variably grey to reddish brown, depending on the nature and proximity of the bedrock source.

Alluvial deposits of two ages have been recognised: Pleistocene deposits form several extensive fluvial terraces that can be subdivided, primarily on relative age criteria supported by several radiocarbon and Optically Stimulated Luminescence (OSL) dates, into lower and upper units while Holocene alluvium occurs mainly along the narrow courses of recent steams incised into the terraced surface.

The lower unit of the fluvial terrace deposits is typically mottled red and brown and supports boulders and cobbles with a weathered surface rind. These deposits are largely restricted to elevated fluvial terraces. The surface elevation of these deposits ranges from 33.7 mPD inland to -2 mPD towards the coast. The lower unit is from early late to middle Pleistocene in age (OSL age 84 700 to 157 000 years BP, Table 6). They are always overlain by late Pleistocene alluvium and, or debris flow and other slope deposits, and have been classified as Pleistocene alluvium on the 1:20 000 scale published geological maps (sheets 3 and 4).

Lithofacies of the late Pleistocene fluvial terrace deposits vary across the district. Near the bases of slopes and in upper valley sections, these deposits may pass imperceptibly into late Pleistocene debris flow deposits. The upper unit of the terrace deposits consist mainly of semi-sorted, yellowish to orangish brown, gravelly silty sand containing pebbles and cobbles (Plate 39), intercalated with layers of dark grey organic mud that may represent lacustrine or marsh sediments. On distal plains, fluvial terrace deposits are characterized by well-sorted clayey sandy

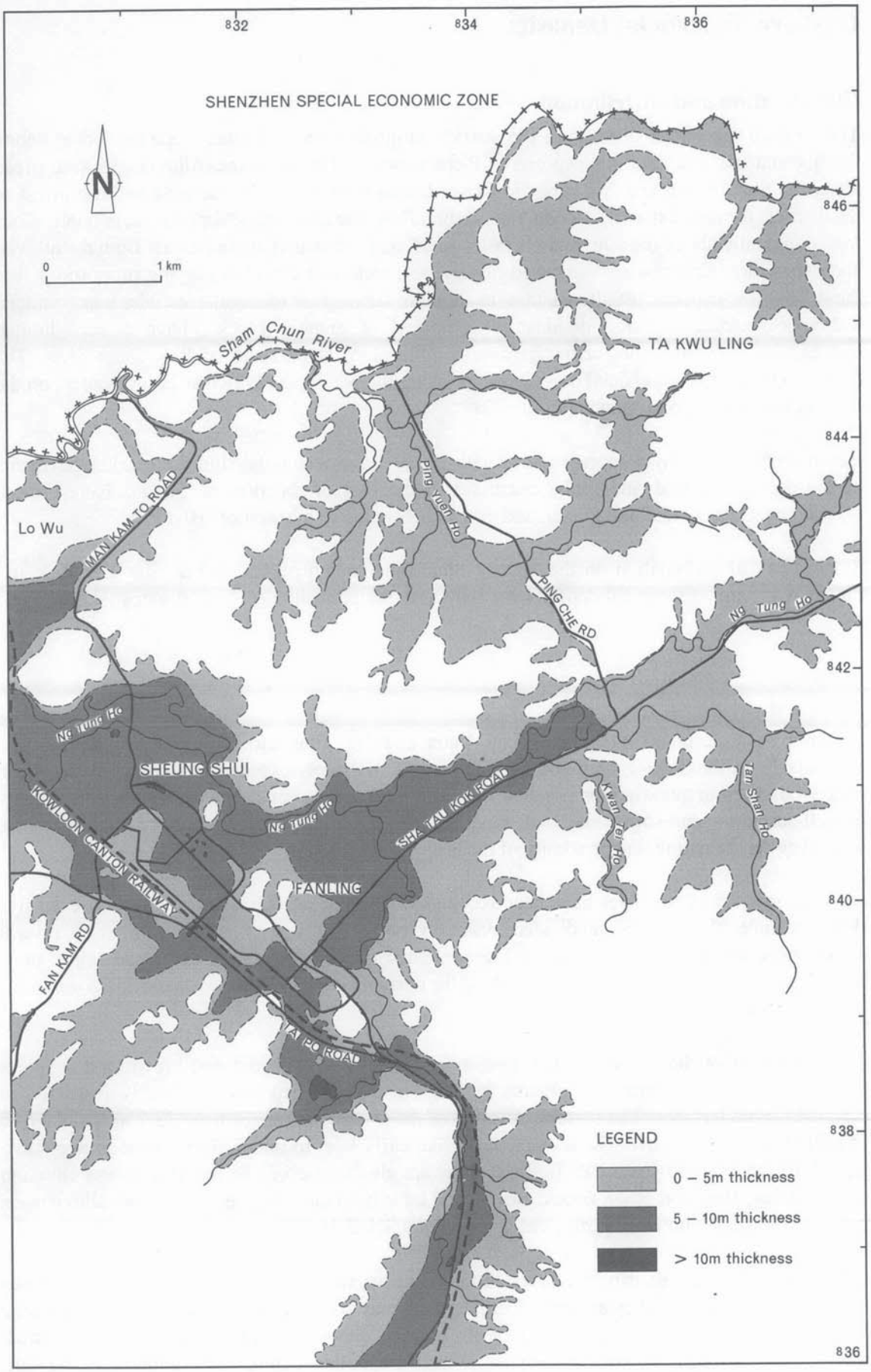


Figure 23 - Thickness of Quaternary Superficial Deposits between Lo Wu and Fanling

silt with some sand layers. The deposits are commonly from 3 m to 6 m thick. Radiocarbon dating of organic mud from Wong Kong Shan (3270 3890) and Lin Wo Hui (3266 3968) on the Fanling plain has given ages of between 10 160 ± 340 to 23 950 ± 530 years BP, indicating a late Pleistocene age (Table 6). A typical profile of this sediment occurs 150 m west of Wong Kong Shan near Fanling (see below).

Most of the areas of Holocene alluvium (610 ± 50 to 2 250 ± 90 years BP; Table 6) are relatively low-lying, being between 5 and 10 mPD, and most are also narrow, incised by between 0.5 m and 3 m, into the surrounding Pleistocene terraced alluvium. The deposits comprise semi-sorted subrounded boulders and gravelly sand in upper stream courses, and yellowish brown, well-sorted silty sand or clayey silt in lower courses. In places along the coast in the east of the district streams are dammed by sand bars or spits, behind which lagoon or back shore deposits have formed.

Table 6 - Radiocarbon and Optically Stimulated Luminescence Dates from Quaternary Deposits in the Northeastern New Territories

Samples Number	Location	Grid Reference	Landform	Sample Type	Depth m	Elevation mPD	C^{14} age years BP	OSL age years BP
HK 11980	Fanling Center	3273 2898	Alluvial terrace	Silty sand with cobbles	5.5	10.29	-	157,500±36,300
HK 11979	Fanling Center	3273 2898	Alluvial terrace	Silty sand with cobbles	4.8	10.99	-	>50,000±14,000
HK 11978	Fanling Center	3273 2898	Alluvial terrace	Silty sand with cobbles	4.3	11.49	-	84,700±16,300
HK 3744	Wong Kong Shan, Fanling	3269 3863	Alluvial plain	Organic mud	2.1	11.3	23,950±530	-
HK 3734	Wong Kong Shan, Fanling	3270 3890	Alluvial plain	Organic mud	2.35	11.05	22,780±530	-
HK 3748	Lin Wo Market, Fanling	3263 3972	Alluvial plain	Organic mud	2	9	10,160±340	-
HK 3703	Po Leng, Fanling	3130 3880	Alluvial plain	Organic mud	3.5	15	2,250±90	-
HK 3735	Wong Kong Shan, Fanling	3270 3890	Alluvial plain	Organic mud	1.9	11.5	2,100±90	-
HK 9379	Chim Uk, Tai Po	3943 3608	Mud flat	Marine mud	1.55	-0.5	610±50	-
HK 9380	Chim Uk, Tai Po	3943 3608	Mud flat	Shell fragment	1.55	-0.5	610±50	-

Note : Radiocarbon (C^{14}) samples analysed by the Guangdong Institute of Geological Sciences, Guangzhou, China
Optically Stimulated Luminescence (OSL) dating by Institute of Earth Studies, University of Wales, U.K.

Details

Ng Tung Ho (River Indus). At San Wai (3310 4084), the river is fed by two tributaries. One rises on Pat Sin Leng and Hung Fa Leng (Robin's Nest), the other in the Lam Tsuen Valley. The Lam Tsuen River was diverted southeastwards from the Lam Tsuen Valley to Tai Po Hoi (Tolo Harbour) by river capture, leaving a river terrace up to 800 m wide, formed of Pleistocene alluvium. Entrenched within the older terrace is a recent stream course, 5 m wide, that forms a restricted Holocene alluvial deposit. Two sedimentary units have been recognised in the Pleistocene river terrace. The upper unit is composed of pale grey, fine to medium sand and clay, and the lower unit comprises dark yellowish brown coarse sand, gravel and boulders. Variations in the character of the alluvial deposits of the Ng Tung Ho downstream from Hong Lok Yuen to Lo Wu are as follows:

--Tai Po Road (3338 3595) near Hong Lok Yuen: mainly the lower alluvial unit, 2 to 5 m thick, is present, comprising dense mottled red, yellowish brown and grey sandy, clayey silt with subrounded gravel, cobbles and boulders, some between 300 to 500 mm across. The clasts include completely decomposed aplite, highly to completely decomposed granodiorite and moderately to slightly decomposed tuff. A weathered rind of up to 30 mm thick is present on many of the boulders. Thermoluminescence dating of two samples from these sediments has given ages of 40 800 ± 3 300 years BP and 76 300 ± 6 200 years BP.

-- Tai Hang to Kiu Tau: the alluvium is 5.5 to 7.5 m thick. In Borehole RDH6/GIU3385 (3387 3771) the upper unit is a silty clay, 2.4 m thick, and the lower unit a reddish brown gravel and cobble bed, 5.6 m thick.

-- Wong Kong Shan near Fanling Centre (3274 3898): boreholes, caissons, and trial pits reveal that the Pleistocene alluvium is 7 m to 9.8 m thick, and is overlain by 1 m to 3 m of fill. The upper unit contains 2.3 to 4 m of dark grey to black organic mud that has given radiocarbon dates of 22 780 ± 530 years BP and 23 950 ± 530 years BP, and 1-2 m of medium dense, reddish brown, clayey, silty, fine to coarse sand with gravel and cobbles; the lower unit comprises 1-2 m of cobbles and boulders, ranging from 20 to 600 mm in diameter. The matrix is silty and sandy. OSL dates from the lower unit range from 84 700 ± 16 300 to 157 500 ± 36 300 years BP.

-- Lung Yeuk Tau: In boreholes F4105A (3330 4005) and F4108/GIU3067 (3325 3993) the alluvium varies from 5.5 to 5.8 m thick. The upper unit comprises 2.5 m of loose, grey, silty, medium to fine sand , overlain by an intermittent layer, up to 2.2 m thick, of dense, yellowish brown, sandy silt. The lower unit comprises 1.1 to 2.9 m of gravel, cobbles and pebbles in a silty coarse sand matrix.

-- Luen Wo Hui, Fanling: In borehole F4111/GIU3067 (3265 3954) the alluvium is 7 m thick. The upper unit comprises a 1.5 m thick, black organic mud and 3.5 m of brown to grey clayey silt with some coarse sand. The lower unit comprises 2 m of gravel, cobbles and pebbles in a silty sand matrix. An organic mud sample (HK3748, 3263 3972), from 150 m to the northeast of Borehole F4111 at 2 m below ground level, gave a radiocarbon date of 10 160 ± 34 years BP (Plate 39).

-- Shek Wu Hui: In borehole BH3/GIU11799 (3154 4028) the alluvial deposit is 7.7 m thick. The upper unit comprises 2.7 m of firm, dark brown silty clay and 2.6 m of medium dense, grey to light yellowish brown silty fine sand. The 2.4 m-thick lower unit contains gravel and cobbles within a silty sand matrix.

-- Tin Ping Shan: In borehole B/BH3/GIU11688 (3203 4092) the thickness ranges up to 9.3 m, including 7.5 m of medium dense, light yellowish brown, silty fine to coarse sand, which overlies 0.46 m of subrounded gravel and of quartz cobbles in silty sand matrix and 1.3 m of medium dense, light yellowish brown, silty fine to coarse sand.

-- Sheung Shui Sewerage Treatment Works: In Borehole FL30/11/GIU8276 (3026 4100) at Shek Sheung River shows that the deposit is 11 m thick, including 3.0 m of pond deposits, overlying dark grey silty fine sand with decayed plants, 4.0 m of loose greyish white silty sand and 4.0 m of dense greyish brown silty sand with quartz gravel. In borehole SWH4/4/GIU6670 (3059 4097), at the same site, the alluvium is 7.5 m thick, comprising 2 m of silty medium sand, overlying 5 m of silty sand with gravel and 0.6 m of cobbles.

-- Man Shek Tong to Sheung Shui: The alluvium is 9 m thick in Borehole B4/GIU6883 (3106 4154). The upper unit comprises 4 m of loose, yellowish brown clayey silt with some fine sand, overlying 5 m of medium dense, yellowish brown silty sand with gravel and cobbles.

-- Sheung Shui Wah Shan: Borehole C/BH7/GIU11701 (3138 4188) reveals a sequence comprising:

4. CLAY, silty, soft, light greyish to yellowish brown, with organic mud	4.0 m
3. SAND, fine to coarse, silty, with gravel, medium dense, dark grey	4.0 m
2. COBBLES and GRAVEL, subrounded quartz, with silty sand	0.5 m
1. CLAY, silty, soft, light yellowish brown	1.5 m

San Wai to Loi Tung (northeastern tributary of the Ng Tung Ho (River Indus).

-- Tai Tong Wu: In Borehole BH1/GIU59779 (3619 4227) the deposit is 2.5 m thick and composed of yellowish brown sandy silt with gravel and cobbles.

-- Hung Leng: In Borehole B2/N53/GIU 6382 (3518 4148) the thickness of the alluvium varies from 1 to 6 m. It consists of 3 m of yellowish brown, silty, medium to coarse sand with gravel and cobbles overlying 3 m of dense yellowish brown clayey sandy silt.

-- Kwan Tei: In Borehole BH1/GIU11083 (3469 4123) the deposit is 5 m thick. The upper unit consists of loose, yellowish brown, silty, fine to medium sand. The lower unit is a medium dense, light yellowish brown gravel with silty sand. Nearby, in Borehole BH1/GIU11700 (3421 4113), the deposit is 5 m thick and includes 4.5 m of silty, fine to coarse sand overlying 0.4 m of gravel cobbles.

-- Shek Chung Au: In Borehole STK-H4/GIU10993 (8395 8439) the deposit is 6.9 m thick. It comprises silty, fine to coarse sand with two 0.5 m layers of gravel and cobbles.

Sham Chun River. In borehole BGS45/GIU13020 (8334 8453) at Chuk Yuen, the deposit is 4.55 m thick. The upper unit is a yellowish brown, fine to medium sand with quartz gravel, and the lower unit is a layer of pale grey, yellow and pink, subangular to subround gravel and cobbles. Borehole BH4/GIU14170 at Tong Fong (3350 4421), on a branch of the Sham Chun River, shows that the deposit consists of 2 m of loose, yellowish brown to light grey, silty, fine sand with gravel overlying a 0.5 m thick basal quartz gravel.

Pat Sin Leng to Wang Leng. Alluvium is confined to stream courses and local deltas. It is thicker on the south side of Pat Sin Leng and Wang Leng than on the north side. Alluvium in the streams and deltas on the south side of the ridge and along the coast of Shuen Wan Hoi (Plover Cove) at Po Sam Pai, Ting Kok, Chung Mei and Kam Chuk Pai varies from 3 to 8 m thick. Borehole TK2/18/GIU 7143 (4189 3696) reveals that the alluvium at Ting Kok delta comprises 5 m of yellowish brown sandy silt overlying 3 m of cobbles and boulders in a silty sandy matrix. Along streams on the north side of the ridge, the alluvium is up to 2 m thick. The courses of the streams at Luk Keng Chan Uk (4050 4180), Ha Tsat Muk Kiu (4010 4100) and 300 m south of Nam Chung Lo Uk (3940 4170) are largely eroded.

Slope (Debris Flow) Deposits

Slope deposits, are accumulations of material transported by gravitational processes, commonly water-mobilized. These include debris flow deposits, and have been referred to as such on the 1:20 000 scale published geological map sheets (3 and 4) for the district. They are also usually referred to as colluvium in Hong Kong. The deposits are diverse in composition and also commonly poorly sorted. Most commonly they consist of boulders and cobbles embedded in a gravelly sandy silt matrix. However, grain size can vary between predominantly silt, sand, gravel, cobbles or boulders, depending on the original topography, parent rock type and distance travelled. Generally, the fine debris occurs on gentle slopes or the upper parts of hillslopes, whereas the boulder deposits lie at the foot of steep slopes or fill the heads of valleys.

The largest expanses of slope (debris flow) deposits occur on the southern slopes of Pat Sin Leng (415 200) and Wong Leng (390 387), with the thickest accumulations at the base of the steep slopes. Other substantial deposits occur around the higher hills in the district, such as in the Sha Lo Tung Valley (370 378) and below Pak Tai To Yan (320 378). More restricted deposits, forming dendritic valley fills, have been mapped on the northern slopes of Wong Leng (395 392), to the north of Tiu Tang Lung (445 420) and on the flanks of Hung Fa Chai (385 445). These deposits occur in narrow, confined areas, rarely more than one kilometre long, and generally only tens of metres wide.

Slope (debris flow) deposits were recognised and studied in the Territory by Berry & Ruxton (1960) and Grant (1960). Allen & Stephens (1971) noted their widespread occurrences on Tsing Shan and at Shek Kong. They were classified Territory-wide by Lai (1982) as belonging to three ages: middle to early Pleistocene, late Pleistocene, and Holocene. The criteria for this classification include particle composition, colour, weathering grade, thickness of weathering rind on boulders, soil texture, strength properties, geomorphological setting and stratigraphical relationships.

Two types of Pleistocene debris flow deposits are present in the district, but are not differentiated on the published geological maps. The older are stiff to very stiff, mottled, red to brick red, brown and white, or with reticulated streaks, and comprise a matrix of clayey sandy silt, containing highly to completely decomposed cobbles and boulders. The deposits are up to 5 m thick. Larger boulders may be moderately to highly decomposed and often have a weathered rind more than 20 mm thick. White streaks, consisting mainly of kaolin, infill relict joints within the decomposed boulders. These deposits are believed to be of middle Pleistocene age and are always overlain by late Pleistocene deposits. The younger type of slope deposits is considered to be of late Pleistocene age. They consist of firm to stiff, reddish brown or dark yellowish brown to orangish red, slightly clayey sandy silt, with some subangular, slightly to moderately decomposed boulders (Plate 40). These deposits can be up to 9 m thick and they can grade into late Pleistocene alluvial deposits that offshore are in turn overlain by Holocene marine deposits.

By contrast, Holocene slope deposits are soft to firm, light yellowish brown, slightly clayey sandy silt to gravelly silty sand. The clasts are of slightly to moderately decomposed, subangular to angular cobbles and boulders with weathered rinds on the larger boulders never more than a few millimetres thick. These deposits, which vary from 1 to 3 m thick, overlie late Pleistocene alluvial and offshore may overlie or be intercalataed with Holocene marine deposits.

Details

Sha Ling to Lo Shu Leng. Debris flow deposits flanking the low hill in metasedimentary rocks vary from 0 to 1 m, but are widespread at the foot of the hill. Borehole BH9/11701 (3088 4204) at Cheung Po Tau shows the deposit is 9 m thick, comprising medium dense, light yellowish brown, mottled red and brown very silty fine sand with scattered gravel fragments of tuff.

Wong Mau Hang Shan to Sha Tau Kok. The deposit is a 1 m thick, yellowish brown sandy silt with some subangular cobbles. In Borehole STK-H8/GIU10993 (3985 4415) at Wu Shek Kok shows the deposit is 3.85 m thick, comprising yellowish brown, silty, fine to coarse sand with slightly to highly decomposed gravel, cobbles and boulders.

At Wong Mau Hang Shan, the slope deposit on the low hill varies from 0.5 to 3.5 m thick. It consists of dense, yellowish brown clayey silt with highly to moderately decomposed subangular gravel containing rootlets.

Pak Tai To Yan. The thickness varies from 0.5 to 5 m, thinnest on the hill top, and thickening at the foot of the hill. Borehole DH19A/GIU5947 (3177 3759) shows the deposit is 7 m thick, and composed of reddish brown silty gravel with cobbles and boulders.

Kau Lung Hang Shan (Cloudy Hill). Along the Tai Po Road, on the western slope of Kau Lung Hang Shan, the deposit is generally 2 to 3 m thick.

Nam Shan to Lai Pek Shan. Below Nam Shan (3830 3890) and Shan Liu (4040 3770) the deposits form colluvial fans composed of yellowish brown silty sand with more than 50 % of cobbles and large boulders of tuff, conglomerate and siltstone. Some conglomerate boulders are up to 30 m^3 and their horizontal transported distance from bedrock source is up to 1 200 m.

Pat Sin Leng. Generally the deposit on the southern slope is thicker than on the northern slope of Tung Tsz, the thickness varying from 0.5 to 6.0 m. From Tung Tsz to Ha Hang, along the southern slope of Pat Sin Leng, the deposit varies from 1 to 3 m thick and is composed of yellowish brown silty sand with gravel and cobbles.

Along the coast between Shuen Wan and Tai Mei Tuk, slope deposits vary from 1 to 3 m thick and may reach 10 m at the foot of the hill. They comprise medium dense to dense, mottled red, yellow and white, sandy silt with cobbles and boulders.

Chek Ma Tau, Wang Leng and Kwun Yam Tung. Colluvial deposits also occur at the foot of the southern hillslope. Some boulders, 1 to 4 m across, of sandstone, conglomerate and tuff, are widespread along the reservoir beach. The boulders have been transported up to 600 m from their source.

Plate 39 - Black Organic Mud, Upper Unit of Late Pleistocene Alluvial Terrace Deposits Overlying Yellowish Brown Silty Sand with Subrounded Cobbles, Lower Unit, Luen Wo Hui (3263 3972), Fanling

Plate 40 - Pleistocene Slope (Debris Flow) Deposit (4480 3858), Wang Leng Tau

Plate 41 - Escarpment Formed by Sandstone, Siltstone and Conglomerate of the Lower Cretaceous Pat Sin Leng Formation, Unconformably Overlying Tuff of the Jurassic Tai Mo Shan Formation, Wang Leng (454 394)

Plate 42 - Natural Rock Arch (4568 4593) in Undercut Cliffs in Conglomerate and Tuffaceous Breccia within the Kat O Formation, Northern Tip of Ap Chau

Chek Mun Hoi Hap (Tolo Channel). Most of the hills on both sides of Chek Mun Hoi Hap are deeply eroded. The deposits are thin, varying up to 3 m thick. Borehole W9/GIU 2621 (5307 3736), north of Tai Leng Tun (Goliath Hill), shows the deposits are 5.5 m thick and composed of loose to medium dense silty coarse sand with gravel and cobbles.

Tai Pang Wan (Mirs Bay). Most of the islands in Tai Pan Wan (Mirs Bay) are deeply eroded. The slope deposits are generally thin, varying from 0.5 to 2 m thick. Deposits below the steeper slopes are thicker, such as that north of Mau Ping Shan, Tap Mun Chau (Grass Island) which is greater than 5 m thick.

Talus (Rockfall Deposits)

Talus comprises angular cobbles and boulders with a limited matrix of sand and silt. Talus is formed by the accumulation of gravity-transported rockfall debris at the base of a cliff or very steep rocky slope. These deposits occur at only a few localities in the district, commonly overlying Pleistocene debris flow deposits. They are still accumulating and are entirely of Holocene age.

Details

Ping Fung Shan. Talus mainly occurs on the southern flanks of Ping Fung Shan (380 390). It occurs as two blocky fans at the base of a steep cliff on the flanks of the conglomerate ridge.

Ngau Kwo Lo. Talus deposits are exposed 500 m east of Ngau Kwo Lo (5180 3630). They comprise large angular boulders and cobbles of fresh coarse ash tuff that form a small fan below a steep rocky slope.

Estuarine and Intertidal Deposits

Estuarine deposits are of mixed alluvial and marine origin. They generally consist of grey, clayey silty sand with plant remains, and dark grey, organic silty clay with shell fragments. These deposits mainly occur along tidal rivers and at river mouths. At high tide, water of the Shum Chun River can rise to the foot of Lo Shu Leng. These deposits are regarded as Holocene in age.

Details

Sham Chun River. At Man Kam To (3120 4430), the estuarine deposits are up to 6.0 m thick. The sequence consists of dark grey, organic estuarine mud, up to 2.5 m thick, overlying 2.5 to 3 m of loose silty sand to clayey silt and a 0.3 to 1 m layer of alluvial gravel and boulders.

Shuen Wan Hoi (Plover Cover) and Tolo Channel. Along the coast, the thickness of the intertidal deposits varies from 1 to 6 m thick. In Borehole TK1/P6H/GIU5911 (3946 3617) it comprises 3 m of grey to yellowish brown, silty, medium to coarse sand with some shell fragments overlying 3.0 m of soft, dark grey, silty organic mud with some quartz gravel and shell fragments. Radiocarbon dating of shell fragments and organic mud gave an age of 610 ± 50 years BP.

Beach Deposits

Beach deposits are unconsolidated sediments accumulated by marine action, extending from the low-tide mark to the uppermost limit of wave action. They are usually composed of well-sorted gravelly, silty sand with shell fragments and form a narrow fringe around the natural coastline. Along the rocky shoreline of islands in Tai Pang Wan (Mirs Bay), these deposits ocur in sheltered bays and comprise gravel to boulders.

Back shore deposits occur behind the contemporary sand beach, especially in the sheltered bays around some islands. They are composed of gravelly coarse sand with scattered pebbles and examples occur at Kat O Chau, Ap Chau, Ping Chau and Wong Wan Chau (Double Island).

Storm beach deposits can be recognised on several islands in Tai Pang Wan (Mirs Bay). At Kang Lau Shek, pebbles and boulders have been deposited high on the shore by storm action. Large boulders of chert and siltstone, from 1 to 2.6 m^3, were moved 150 m from the sea bed to the top of a promontory (6346 4435) over 10 mPD.

Beach rock occurs in small localised pockets, 600 m south of Pak Kok Shan on the north shore of Tolo Channel (5095 3933). The deposit consists of boulders, cobbles, gravel and sand, with a ferruginous cement.

Details

Sha Tau Kok Hoi (Starling Inlet). Boreholes (BH21/GIU 5881 (4087 4491) and STK11/GIU 6597 (4103 4518) to STK17 in the northwest tidal beach reveal that the deposit comprises up to 1 m of soft silty mud and 4 to 5 m of loose, yellowish brown, silty, medium to coarse sand with shell fragments overlying 1.5 to 6.0 m of alluvium comprising medium dense to dense, yellowish brown sandy silt with gravel and cobbles.

Further from the coast, in Borehole STK14/GIU65979 (4102 4478) the deposit is 6.5 m thick. It is composed of loose, dark grey, fine to medium sand with shell fragments. The underlying alluvium is a yellowish brown and grey, sandy silt with silty gravel up to 9 m thick.

Along Luk Keng Road, the beach deposit varies from 4 to 9.7 m thick and is composed of dark grey marine mud and silty sand with shell fragments.

Shuen Wan Hoi (Plover Cove). The deposit comprises loose yellowish brown silty sand or clayey silt with pebbles and some shell fragments. In Borehole TK2/21/GIU 7143 it is 6 m thick.

Kat O Hoi (Crooked Harbour), Yan Tong Hoi (Double Haven) and Tai Pang Wan (Mirs Bay). Most beaches in the sheltered bays are sandy with pebbles. The bays on the eastern side of Ping Chau are composed of mixed, pale yellowish brown quartz and white coral sand. Beach deposits below the steep slopes, cliffs and the eroded rocky coasts, are pebbly or bouldery, such as at Tai Shek Ha (5084 4150) and Wong Wan Chau (Double Island), and some beaches (5230 4050, 5000 3870, 5030 3700 and 5100 3740) on both sides of Chek Mun Hoi Hap (Tolo Channel) and in the east of Chek Chau (Port Island) and Tap Mun Chau (Grass Island).

Offshore Superficial Deposits

Classification and Distribution

The offshore superficial deposits of Hong Kong comprise three distinct lithostratigraphical formations, the Pleistocene Chek Lap Kok Formation, the Upper Pleistocene Sham Wat Formation and the largely Holocene Hang Hau Formation.

The oldest, the Chek Lap Kok Formation (Strange & Shaw, 1986), consists of clay, silt, sand and gravel, largely of alluvial or terrestrial origin. Weathering, oxidation, and consolidation are distinctive characteristics of these deposits, as well as the marked changes and rapid variations of sediment type. The formation is of almost universal occurrence in the district, and is thickest, at a little over 20 m in the east in Tai Pang Wan (Mirs Bay), although it thins markedly shorewards. Below it, separated by a major erosional break, is bedrock weathered to variable depth and degree. Commonly, the different lithologies have characteristic weathering patterns that can each be identified on seismic profiles by their distinctive geometry.

The Sham Wat Formation (Fyfe & James, 1995) has not been definitively identified in the district, being largely restricted to the thicker marine sequences occurring in the deeper waters of the western and southwestern parts of the Territory.

The youngest formation, the Hang Hau Formation (Strange & Shaw, 1986), is of marine origin. This formation is characteristically a clayey silt, with minor fine sand, thin bands of shell fragments and scattered intact bivalves. It is generally very sandy at the base, with concentrations of broken shells, and becomes sandy in areas of stronger current activity, such as in the Tap Mun Hau (South Channel) and at the heads of bays, such as Pak Sha O (Jones Cove). Very few site investigation boreholes have been drilled in the district, due to its relative remoteness, but three vibrocores and one continuously sampled Borehole (D1/4) were sunk as part of the Seamat Study, a project designed to locate offshore sources of granular fill (Cheung & Shaw, 1993).

Chek Lap Kok Formation

The Pleistocene Chek Lap Kok Formation (Strange & Shaw, 1986) is named after the type section of the formation in continuously sampled Borehole B13/B13A (10292 18701), located near the former island of Chek Lap Kok (Shaw, 1985; Shaw *et al.*, 1986). The formation is characterized by complex stratigraphy, variable lithology and generally chaotic seismic signature. On seismic records intricate patterns of erosive channelling and channel fills with lateral accretion foresets are usually distinguishable within the intricate pattern of reflector styles and variations in seismic tones (Figure 24).

Lithologically the formation comprises a wide range of grain sizes, from clay and silt, to sand and gravel, which typically exhibit marked vertical and lateral variations. The clay and silt are stiffer, and the sand denser, than in the overlying marine formations. Weathered layers displaying oxidation and mottling have been identified at several levels throughout the formation. Sedimentary features in continuously-sampled boreholes and vibrocore samples include upward fining sequences, upward coarsening sequences and firm silt with fine sand laminae and interbedded organic debris. Correlations between seismic reflector patterns and lithologies in boreholes are usually good in the upper levels of the formation, down to about 30 m below seabed, below which resolution is generally poor and the main sequence bounding reflectors are less clearly identifiable. Concave channel forms, laterally-accreting channel fills and well-laminated sequences near the top of the formation can all be clearly identified on seismic records and correlate well with sedimentary units identified in borehole samples. The range of sedimentary features are consistent with deposition on extensive fluvial palaeo-plains.

Accurately locating the base of the formation commonly poses a problem, due largely to the loss of acoustic energy at depths of about 30 m or more in the sedimentary column. In addition, in areas of deeply weathered granitic and volcanic rocks, there is usually a low acoustic impedance contrast between the generally sandy basal Quaternary sediments and the sandy and unstructured weathered mantle. Therefore weak definition, or even the complete absence, of reflectors in the rock compound the difficulty of precisely locating the base of the Quaternary sequence. However, in the north and east of the district the well-bedded sedimentary rocks occur at shallow depth and possess only a thin to non-existent weathered layer. Thus the bedding is clearly displayed on seismic records and it has been possible to calculate confidently the apparent dip of the strata along the seismic track lines. In these areas the bedrock surface comprises a series of sub-parallel, miniature escarpments such as can be seen exposed on the coastal rock platforms around Ping Chau and other islands in the district.

Details

Shau Tau Kok Hoi (Starling Inlet). Seismic surveys were not carried out in this inlet and details of the formation are therefore scarce. However, seismic records confirm that the formation is between 10 to 15 m thick to the north of Ap Chau at the entrance to the inlet. The large catchment of a stream feeding into the channel, in association with the intensely alluviated and debris-filled dendritic valleys on the north and south flanking hills, suggest that the formation is probably extensively and thickly developed throughout the inlet.

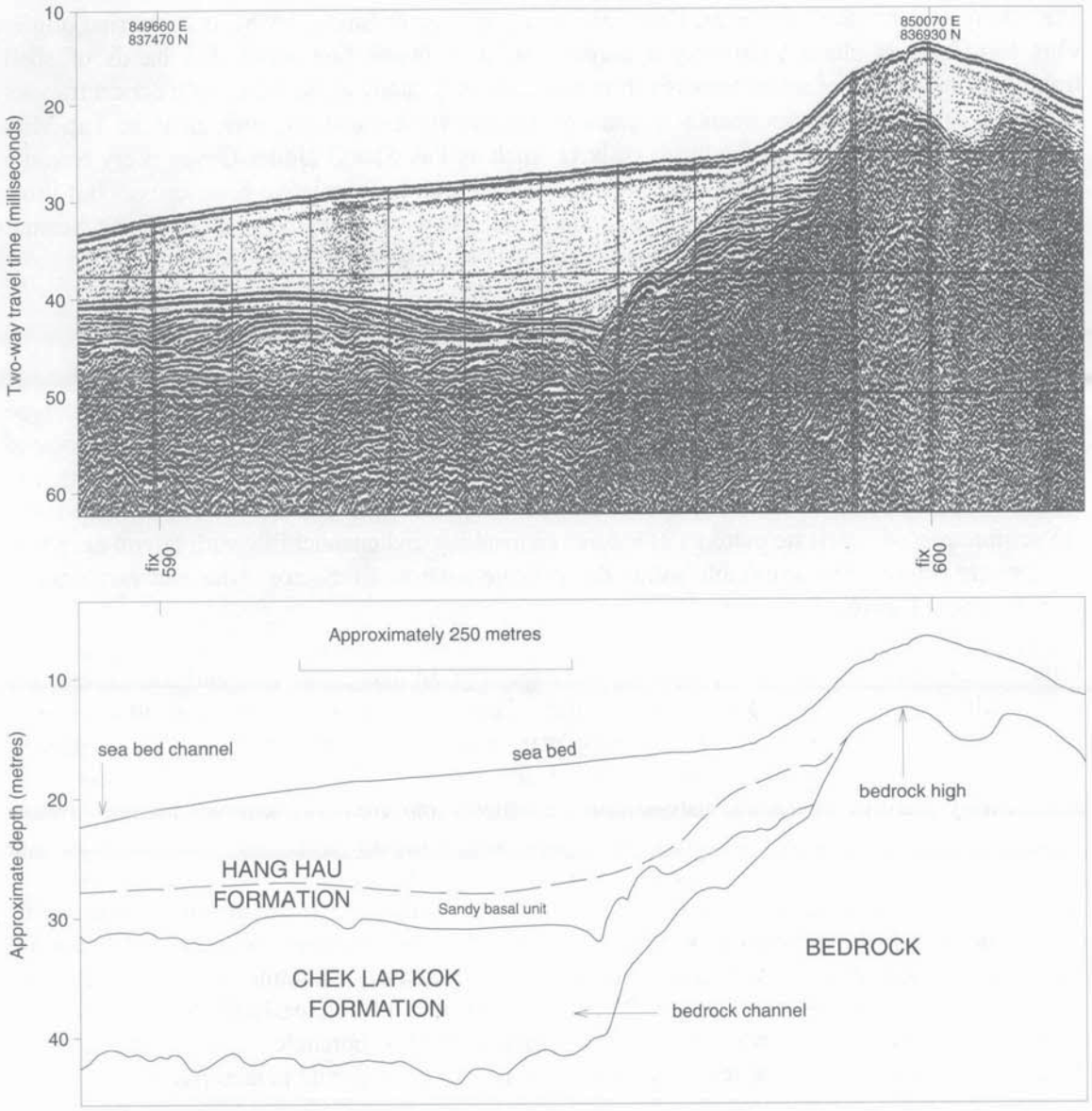


Figure 24 - Boomer Seismic Record Showing the Buried Bedrock Channel, Tolo Channel, Seismic Line D15

Plover Cove Reservoir. The absence of seismic survey information for this former inlet precludes a detailed description of the formation, but the restricted catchment, steep surrounding slopes and paucity of alluviated feeder streams suggest that the formation is probably only sporadically developed and thin in this area.

Chek Mun Hoi Hap (Tolo Channel). The formation is consistently about 15 m thick along the axis of Chek Mun Hoi Hap (Tolo Channel). It has a relatively horizontal upper surface, upon which a series of longitudinal channels, up to 5 m deep, were eroded. These channels follow the general valley line, indicating an earlier drainage network on the valley floor. Marginal thinning of the formation results from the rise of the rock floor towards the cliff-lined coastal slopes, rather than distal thinning of the deposit. The formation maintains a remarkably uniform thickness down the centre of the bedrock valley towards the margin of Tai Pang Wan (Mirs Bay).

Kat O Hoi-Yan Chau Tong (Crooked Harbour-Double Haven). The formation fills a well-defined bedrock channel that is initially aligned northwards from Tsing Chau Lek, changing to a northeast orientation around the northern end of Kat O Chau. Sediments of the formation are about 5 m thick near Tsing Chau, thickening northwards to about 15 m in the deepest part of the channel. The lack of seismic data and other evidence from the many bays and inter-island areas does not allow the thickness of the formation to be measured, but it is probably at least 5 m thick quite close to the coasts. In Yan Chau Tong (Double Haven) the formation fills a channel that runs

northeastwards across the area. Sediments attain a thickness of 5 to 10 m near the centre of the channel, but thin and are cut-out through Wang Mun Hoi (Deep Pass).

Tai Pang Wan (Mirs Bay). In this area the formation achieves its maximum development in a broad channel that runs northwest to southeast across the bay. The floor of the channel lies at about -50 mPD to the east of Chek Chau (Port Island), where it is filled with about 15 to 20 m of Chek Lap Kok Formation sediments. The deposit thins towards the coastline, being about 5 m thick close to the shore, and pinches out rapidly against the steeply-rising bedrock floor and the bounding coastal cliffs.

To the east of the buried channel the formation is about 10 to 15 m thick. A rapid thinning is recorded towards the rocky shelf that surrounds Ping Chau. The formation is cut out entirely about 500 m from the west coast of the island.

Age and Sedimentary Environment

Detailed analyses of continuously-sampled boreholes and correlation with seismic records in other districts have confirmed the complexity of the formation and the range of environments represented (e.g. Langford *et al.*, 1996). Generally, it has been demonstrated that microfossils, including diatoms, foraminifera, dinoflagellates, ostracods and sponge spicules are absent or scarce, and where they do occur, they are of very low diversity. Pollen analyses indicate a range of terrestrial organic material and palynofloral associations that include mixed forest, floodplain and backswamp environments. These environments are confirmed by sedimentary features such as vertically accreting channel-fills and migrating channels with lateral accretion foresets displayed on the seismic records.

The exact age of the formation is still a matter of conjecture, but by comparison with adjoining districts (Strange & Shaw, 1986; Langford *et al.*, 1996) is considered to be middle to late Pleistocene.

Hang Hau Formation

The designated type section for the formation was described from Borehole JBS1/1A (4500 1800) in Tseung Kwan O (Junk Bay) (Strange & Shaw, 1986), where the sediments of the formation are a characteristic soft to very soft, olive grey, clayey silt with scattered bivalves and bands of broken shells.

Except for a submerged rock platform, from 600 to 900 m wide, around Ping Chau and isolated rock shoals such as Shau Kei Pai (481 425) and Sha Pai (569 377), the formation makes up the sea bed in the entire district. Outside the extensive areas of littoral sands, the restricted occurrence of inter-island channel sands and the inter-island and coastal rock outcrops, it consists of a homogeneous cover of mud that unconformably overlies the Chek Lap Kok Formation. In some areas, particularly near coasts or bedrock highs, the formation rests directly on bedrock.

Lithologically, the formation consists of very soft to soft, olive grey, clayey silt (Figure 25) that contains articulated and disarticulated bivalves scattered throughout. The muds usually become firm where the thickness exceeds about 15 m. Silt commonly constitutes up to 80 % of the mud, with clay and fine sand forming the remaining 20 %. The mud is characteristically massive, with no visible structures such as bedding or lamination, although bands of comminuted shell debris do occur and thin, fine sand lenses have been noted. Near the base, the sediments are usually coarser with sand and shell debris dominating the lowest levels, a unit interpreted as a basal sand deposit that accumulated during the erosive and winnowing phase of the Holocene marine transgression.

On seismic records the formation characteristically displays laterally extensive, continuous, horizontal to sub-horizontal, parallel to sub-parallel, low to moderate amplitude reflectors (Figure 26). The reflectors commonly develop an onlapping pattern towards the steep coasts or

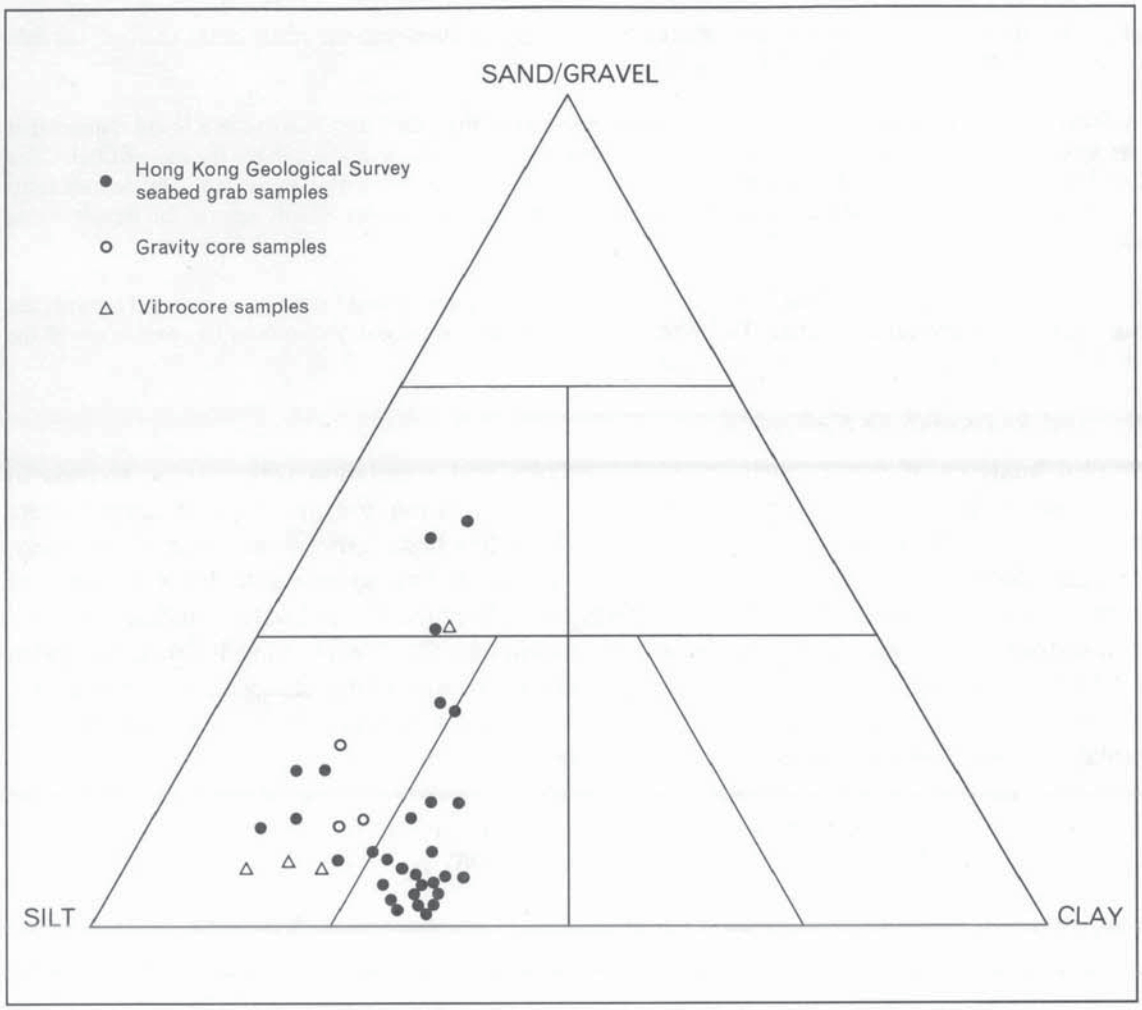


Figure 25 - The Relative Proportions (%) of Sand/Gravel, Silt and Clay in Seabed Grab Samples

bedrock highs, such as in Yan Chau Tong (430 475). Concave channel forms are developed throughout the district, for example in Chek Mun Hoi Hap (Tolo Channel). A well-developed, high amplitude reflector normally defines the base of the formation, which commonly cuts across the interfluves of the channelled surface of the underlying Chek Lap Kok Formation, suggesting a phase of marine planation following an earlier channel-filling phase. In some areas a clearly-defined intra-formational reflector occurs within the generally transparent formation (i.e. lacking strong reflectors). This may correspond to a change in current regime, or perhaps to a minor shallowing event identified in the microfossil record (Owen *et al.*, 1995).

Although the formation thins slightly towards the coasts and inter-island gaps, the steeply-inclined rock surface near the coast ensures that the formation remains up to 5 or 10 m thick very close to the shore. Away from the coast it rapidly thickens to 15 m and then thickens only gradually to its maximum of a little over 20 m in the centre of Tai Pang Wan (Mirs Bay).

Details

Shau Tau Kok Hoi (Starling Inlet). This inlet is bordered by extensive, mangrove-covered muddy intertidal flats up to 800 m wide. The mud flats are channelled and rippled. Minor sand splays emanating from the lateral tributary streams cross the flats, thus flaser-bedded sequences are common. Seismic surveys were not carried out in the area, so that the true thickness of the formation in this area is unknown. By analogy with other inlets in the district it is probably between 5 and 10 m thick near the centre of the channel. Three seabed grab samples from the inlet (Figure 25) demonstrate that the formation is an olive grey, slightly sandy silt with rare bivalves shell fragments.

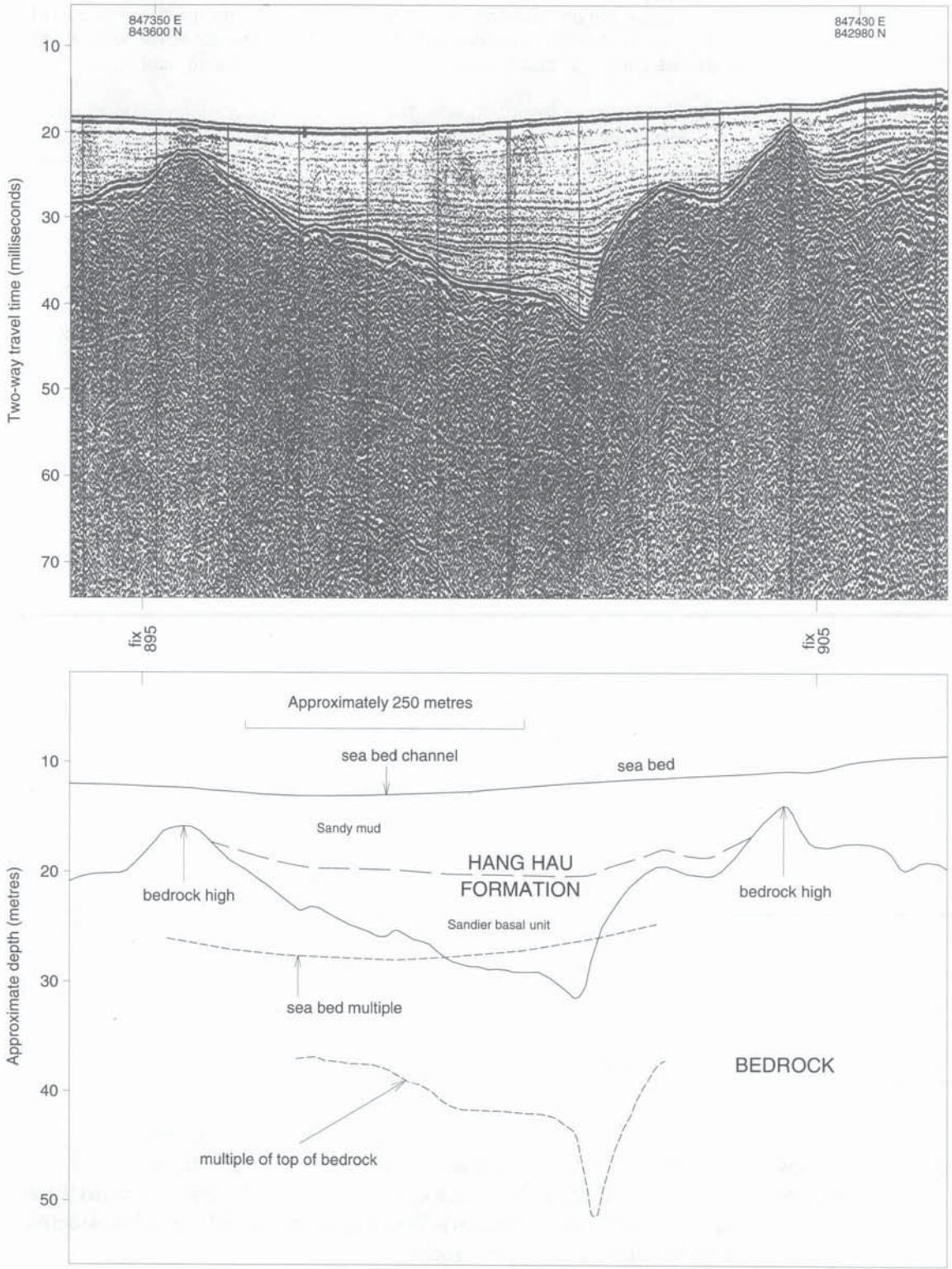


Figure 26 - Boomer Seismic Record Showing Bedrock High in Inter-island Gap, Tsing Tsau Lei, Seismic Line D22

Plover Cove Reservoir. Before the creation of the reservoir, this area was a brackish inlet surrounded by extensive intertidal mudflats fringed by mangroves. The formation is estimated to be up to about 5 m thick near the centre of the inlet, consisting of soft, olive grey, clayey silt which will probably be highly organic near the margins, with sandy splays and intercalations near the mouths of tributary streams. Near the main dam, the formation was determined to be 13 m thick in Borehole 101/GIU5349 (4411 3673).

Chek Mun Hoi Hap (Tolo Channel). The formation is about 15 m thick in the centre of the channel in the southwest, but thins to about 6 m near the margins of the channel and to about 10 m near the mouth of the channel. Several seabed grab samples (Figure 25) show the formation to be an olive grey clayey silt at the surface. One vibrocore off Fung Wong Wat showed a thin, 1 m muddy sequence overlying a 4.5 m thick sandy unit.

Kat O Hoi-Yan Chau Tong (Crooked Harbour-Double Haven). The formation attains a maximum thickness of a little over 15 m near the centre of Kat O Hoi (Crooked Harbour), thinning to 5 m close to the coasts. Three seabed grab samples (Figure 25) showed the sediments at the surface to be clayey silts. In Yan Chau Tong (Double Haven) the formation is 5 m thick near the coast, thickening to 15 m at the centre of the embayment, but thinning markedly into Wang Mun Hoi (496 437). Four grab samples in the area (Figure 25) were all muddy.

Tai Pang Wan (Mirs Bay). The formation attains a maximum thickness of almost 20 m in Tai Pang Wan (Mirs Bay) to the east of Chek Chau (Port Island), but thins northwards to about 10 m thick to the northeast of Pak Sha Chau (5210 4465). Marine muds thicken where the formation fills two southeast-trending, sub-parallel channels in the surface of the Chek Lap Kok Formation. These channels contain the maximum deposits of the formation. Around Ping Chau the formation thins rapidly and is absent on the rocky platform that surrounds the island. Seabed grab samples consistently showed that the surface of the formation is a very soft, clayey silt.

Age and Sedimentary Environment

Detailed analyses from continuously-sampled boreholes in other districts (Strange & Shaw, 1986; Langford *et al.*, 1996) have shown that the formation has an abundant and diverse microfauna comprising diatoms, foraminifera and ostracods (Owen *et al.*, 1995). At several sites, the microfauna indicate environmental changes associated with fluctuations in sea level or to variations in fresh and brackish water related to variations in the Pearl River discharge. Macrofauna are equally diverse, with articulated, disarticulated or broken bivalves, and also gastropods, scaphopods and echinoids.

The formation is marine and intertidal in origin. Seismic records suggest slow sedimentation from suspension, with onlapping horizontal reflectors against coasts and shoals. A uniformity of lithology is apparent, interrupted only by rare, thin sand bands or bands of broken shells that possibly represent typhoon events or perhaps changes in current strength or pattern. The latter fluctuations are supported by micropalaeontological evidence of fluctuating salinities.

Radiocarbon dates confirm the Holocene age of the formation. The oldest date of 9 310±80 years BP was obtained from the base of the formation in Borehole HKGS-B (35022 02700) at -34.3 mPD in the central southern waters of Hong Kong (Fyfe *et al.*, in press).

Weathered Rocks and Sediments

Volcanic and sedimentary rocks are the dominate rocks of the district with only a few very restricted outcrops of granodiorite in the southwest. The distinctive granite topography so characteristic of other parts of the Territory is therefore not seen here. Instead, the district has developed a distinctive suite of landforms, particularly resulting from the differential weathering and erosion of the bedded sedimentary and volcanic rocks.

The thickness of the weathered mantle varies considerably across the district, depending upon the lithology, structure and topographical location. Weathering profiles tend to be thicker on the volcanic tuffs than over the sedimentary rocks. In general, the average depth of weathering over

the tuffs is about 15 m, with a maximum of over 30 m. The thickest recorded weathering profiles in the district are developed in the Tai Mo Shan Formation volcanic tuffs on the Fanling plain. For example, Borehole BV11/GIU 12141 (3265 3913) on the southern outskirts of Fanling new town penetrated a weathering zone 47.06 m thick, and Borehole BH16/GIU11799 (3151 4021) at Shek Wu Hu near Sheung Shui penetrated 49.3 m of weathered rock. To the north, near the sewage treatment works (303 413), the weathered zone is about 38 m thick. Towards the border, borehole data from the low hill of Wong Mau Hang Shan (360 454) near Lin Ma Hang indicate a weathered profile of between 6 to 15 m thick with a maximum of 26.3 m. Boreholes in the coarse ash tuffs of the Long Harbour Formation to the north of Tai Leng Tun revealed a maximum weathering depth of 38 m in Borehole W20/GIU 2621 (5302 3716).

Over the metasandstones and metasiltstones of the Lok Ma Chau Formation the weathered zone averages about 10 m thick, reaching a maximum recorded depth of 28.5 m in Borehole SL3/GIU 6681 (3191 4310) at Kong Nga Po near Man Kam To. Weathering profiles over the sedimentary rocks of the hills and islands of the Tolo Channel and Mirs Bay are generally thin. They range from a few metres to about 15 m thick. Along fault zones or in areas of closely jointed rock the weathering is deeper.

The dominant feature of the district is the Pat Sing Leng escarpment (Plate 41), a major structural landform with a crest that extends for about 5 km, from Nam Shan (3736 3984) east-southeast to Hsien Ku Fung (4216 3837). It is approximately 500 m high with several minor summits reaching up to around 600 m. The escarpment is a composite feature. In the west along the Ping Fung Shan ridge the resistant sandstones and conglomerates of the Cretaceous Pat Sin Leng Formation form the northeast-dipping scarp slope, capping the coarse ash crystal tuffs of the Tai Mo Shan Formation. Along the Pat Sin Leng itself the layered strata of the Tai Mo Shan Formation are the capping layer, with weathering and erosion having removed the Pat Sin Leng Formation, that crops out on the dip slope about 1 km behind the crest. The resistant capping strata are clearly displayed at many localities, in particular at Ping Fung Shan (385 392). In the east, the resistant Pat Sin Leng Formation sandstones have created a prominent water fall at Bride's Pool (4265 4040), the underlying, softer conglomerates having been undercut to develop a marked overhang and plunge pool with deeply potholed outcrops on the lower valley floor. Northeastwards the escarpment crest declines in elevation, being only 200 m high at Wang Leng (454 394). Differential weathering of dipping strata also occurs on smaller scales. This feature is clearly displayed (530 400) on Chek Chau (Port Island) (Plate 18), where multiple scarps dominate the topography both onshore and offshore, around the coastal rock platforms of Ping Chau (Plate 7) and many other islands in the district. A similar phenomenon has been observed offshore at the base of the Quaternary sequence where distinctive scarps are well defined on the seismic records (Figure 27).

A range of minor landforms have been developed by weathering. For example, the coasts of many of the islands are characterized by wide rock platforms that cut across a range of gently dipping sedimentary and volcanic rocks (Owen, 1995). The origin of these is probably largely a result of salt weathering in the spray zone. Differential weathering has picked out the individual beds forming a stepped series of minor escarpments aligned parallel or oblique to the coastline (Plate 32). The surface of the beds, the dip slopes, are commonly pitted with weathering pits or pans up to 1 m in diameter (Plate 27). Many are coated with sodium chloride (sea salt) efflorescences occurring as thin white films or dense clusters of crystals. Differential weathering has also picked out primary and secondary structures in the sediment. These include more sandy bands in laminated muddy sediment, quartz clasts in conglomerate beds (Plate 3) and breccias (Plate 20), bedding in breccias (Plate 21) and mineral box works in quartz- and iron-filled joint and tension gash patterns. It has also emphasised sedimentary features such as cross-bedding (Plate 15), lateral channel accretion (Plate 18), folding (Plate 35), load structures, fault displacements (Plate 37), intraformational slumping (Plate 28), boudinage and gypsum pseudomorphs (Plate 30).

Vertical strata have been preferentially picked out by weathering to form slabs or columns, such as at Wong Chuk Kok Tsui (Bluff Head) (587 410) and Tai Leng (520 404). Other geological structures have been clearly delineated by weathering. These include faults that have weathered out as linear topographical depressions, such as at Fung Wong Wat (494 383), Wong Chuk Kok Tsui (Bluff Head) (524 413), Kai Kung Tau (507 456) and Ngo Mei Chau (510 431) (Plate 38). Smaller displacements are emphasised by differential weathering of the adjacent bedded strata. Well developed examples can be observed on the southeast coast of Ap Chau (4595 4560) in the Kat O Formation conglomerates, and on the western shore of Ping Chau (6179 4540) in Ping Chau Formation siltstones. Dykes are exposed as upstanding ridges adjacent to the less resistant sedimentary rocks. Erosion has emphasised the differential weathering of the coarse Kat O Formation sedimentary rocks to form wave-cut notches at the foot of the cliffs. At the northern end of Ap Chau, the process has undermined the promontory to form a natural arch (Plate 42).

The weathered mantle observed onshore also extends offshore beneath the Quaternary superficial deposits where it can be recognised on seismic reflection profiles. In general, the relatively unweathered bedrock is characterized by high amplitude reflectors, whereas the overlying weathered rock records moderate amplitude reflectors. Within the district the offshore buried bedrock surface commonly has a low amplitude topography with a thin or discontinuous weathered mantle.

Sediments of the predominantly alluvial Chek Lap Kok Formation are characteristically oxidized, and commonly mottled and streaked, indicating subaerial weathering. The weathering is believed to have occurred during, or soon after, deposition, and prior to deposition of the overlying grey, reduced marine muds of the Hang Hau Formation. In places, palaeosols up to 2 m thick can be recognised within the sequence, similar to those preserved in the onshore sedimentary rocks.

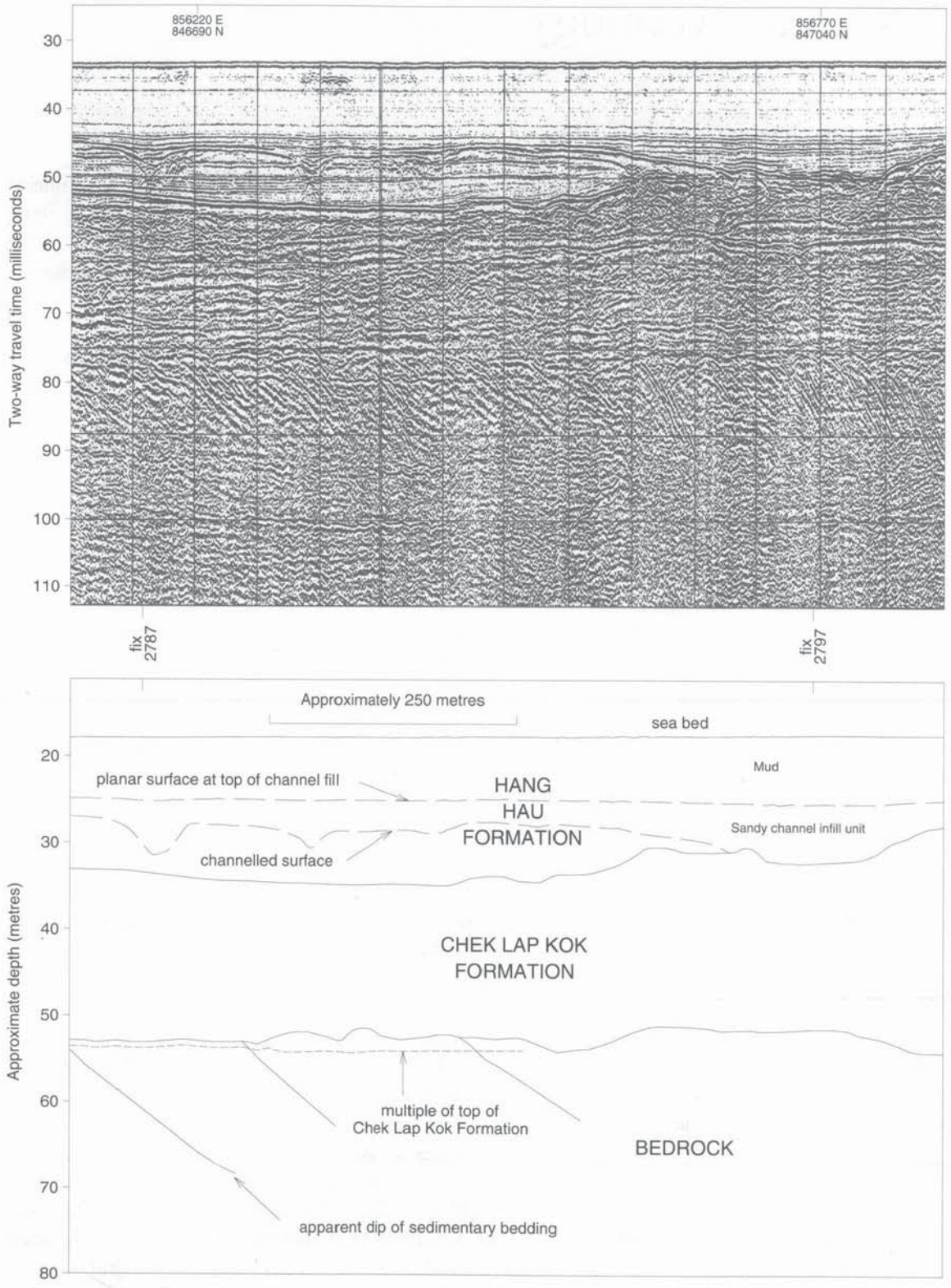


Figure 27 - Boomer Seismic Record Showing the Dipping Sedimentary Bedrock in Tai Pang Wan (Mirs Bay), Seismic Line D7

Chapter 10
Economic Geology

Introduction

The district is generally poorly endowed with economic minerals and there has been no mineral extraction since 1958. There was, however, an important metalliferous deposit at Lin Ma Hang Mine, close to the border with China, that used to be worked for its lead and silver content. There are also other occurrences of lead, and non-metalliferous mineral occurrences of kaolin, graphite and haematite.

Small-scale quarries have been worked in the past but none are active. There are no borrow areas in the district but offshore studies have revealed potential sand resources.

Metalliferous Minerals

The only significant metalliferous deposit known in the district is located at the Lin Ma Hang Mine (centred around 3745 4595). The mine, which was abandoned in 1958, lies near the village of the same name, close to the border with China. The mine extracted argentiferous galena hosted in quartz veins. The earliest workings at the mine are reported (Davies & Snelgrove, 1956) to date back to the beginning of the 19th century. The mine operated intermittently between 1915 and 1936 under various operators, but by far its most active period of production followed the acquisition of the mine by Hong Kong Mines Limited in 1936. 13 990 tons of lead concentrates were declared between 1937 and 1941. The mine's infrastructure, however, was completely ruined during and immediately after the Japanese occupation (1941-45) and subsequent attempts by the owners to revive the mine had very limited success. An estimated 16 000 tonnes of lead metal and 360 000 ounces of silver have been extracted from the mine (Williams, 1991).

There were workings on 6 main levels numbered, unusually, in ascending order through the mine. There is some confusion as to the numbering system used, which appears to have changed with time. The levels were accessed from adits into the hillsides. Southeast- or south-trending crosscuts intersect the orebodies on levels 1 to 3. The configuration of the upper levels is less clear. The levels are still mostly accessible but locally dangerous.

The orebodies are hosted by coarse ash tuffs of the Tai Mo Shan Formation. Mineralization occurs in lensoid *en echelon* veins, up to several metres thick, that mainly comprise quartz and sericite. Generally the veins dip 15-30° to the northeast, locally steepening to vertical. These orebodies mainly trend at a high angle to the regional schistosity which trends northeast to southwest, typically dipping 35-55° to the northwest. In the upper levels of the mine, however, some orebodies dip shallowly to the northwest (15-20°, Davies & Snelgrove, 1956). These are reported to strike concordantly with the contacts presumed to be between foliated and unfoliated crystal ash tuff. Reverse faults offset these orebodies in the upper levels. The faults strike northwestwards (varying from 285° to 345°) and dip to the northeast (65-90°). Slickensides (plunging 45-55° to the northwest) suggest oblique dextral-reverse movements (cf. Davies & Snelgrove, 1956).

Davies and Snelgrove (1956) identified four phases of quartz veining, with the initial vein filling being a coarse, barren, milky quartz. The fine-grained metalliferous mineralization (rarely

>10 mm grains), comprising galena, pyrite, sphalerite and chalcopyrite, accompanied a second phase of fine-grained quartz. Peng (1978) also reported pyrrhotite. The galena carries 300-500 g/tonne of silver and concentrate assays contained 1.3 g/tonne of gold and 1.56 % copper. Wall rock alteration consists of sericite, with subordinate chlorite, pyrite and galena and other metallic minerals.

Non-metalliferous Minerals

Non-metalliferous minerals have only been extracted on a small scale in the district. Knowledge of their general distribution and potential is mainly limited to a few established occurrences of limestone, graphite, haematite and limonite, and the widespread occurrences of quartz veins.

There are records of kaolin occurring in the vicinity of Princess Hill (365 421) or Loi Tung (371 423) nearby, but the precise locations are uncertain.

Quartz veins are common within the Tai Mo Shan Formation, typically occurring subparallel to the dominantly northeast- or eastnortheast-striking regional foliation. In some instances they are associated with zones of schist. A few quartz veins strike, however, approximately at right angles to the strike of the foliation. Some also occur within other formations in the district. Most of these have been recorded within the Pat Sin Leng Formation, where the dominant vein trends are northwest, north-northwest and north-northeast.

Details

Cheung Pai Tai (Ledge Point). A small quarry (4442 4554), now disused and flooded, was the site of limestone extraction. The limestone occurs as blocks, up to 0.6 m in size, within a tuff, which also contains black mudstone, lava and other tuff blocks. The limestone is dark grey to light grey and pink , and is commonly cut by veins of calcite (Williams, 1943). The tuff is restricted to a fault zone, up to 15 m wide, that trends east-west and dips towards the north at 48°.

Cheung Po Tau. Graphitic schist bands have been recorded at several localities within the Mai Po Member of the Lok Ma Chau Formation in the northwest of the district (e.g. 3044 4230 , 3062 4221) 600 m west of near Cheung Po Tau, and at Kong Nga Po (3184 4288). The bands are concordant with other stratification in the succession.

Plover Cove Reservoir. Haematite is present in veins within sandstones of the Bluff Head Formation around the shores of Plover Cove Reservoir (Allen & Stephens, 1971). It occurs both as aggregates of thin scales, a few millimetres across, of steel-grey brilliant haematite, scattered in white milky quartz (Peng, 1978) and as more massive lensoid veins of haematite up to 0.5 m thick within the Bluff Head Formation near Fu Tau Sha (4715 3750) on the northwest side of Chek Mun Hoi Hap (Tolo Channel).

Ping Chau. A complex array of non-metalliferous minerals has been identified within the calcareous siltstones and mudstones of the Ping Chau Formation, exposed on Ping Chau, but none are thought to be of economic significance. They include calcite, apatite, aegirine, silicates and zeolites, including analcime and natrolite (Peng, 1978). The minerals occur on some bedding planes as authigenic pseudomorphs after an unknown lozenge-shaped mineral (possibly gypsum) up to 40 mm in size. Also, goethite forms pseudomorphs after pyrite.

Construction Materials

There have only been a few small-scale quarries in the district, mainly developed for building and roadmaking materials. None are active.

Sand resources were located offshore in the district during the Seamat Study (Cheung & Shaw, 1993) carried out by the Geotechnical Engineering Office (formerly Geotechnical Control Office). Extraction of these resources has been prevented by environmental and other considerations. The principal resources lie in Chek Mun Hoi Hap (Tolo Channel) and in north Tai Pang Wan (Mirs Bay), details of which are taken from Cheung & Shaw (1993).

Details

North Tai Pang Wan (Mirs Bay). In the northern part of Tai Pang Wan (Mirs Bay) to the east of Kat O Chau, a small resource was determined (Cheung & Shaw, 1993) that comprises sand averaging about 1.5 m thick that occurs above -20 mPD, and a further thickness of 5 m below -20 mPD. The area of the resource is 0.5 km^2. The estimated volumes of sand were 1 Mm^3 and 2 Mm^3 for the upper and lower deposits respectively. Neither are considered viable resources given present circumstances.

Chek Mun Hoi Hap (Tolo Channel). The Chek Mun Hoi Hap resource is overlain by mud. This cover is 10 m thick, and the sand, with an average thickness of 4 m, has a volume of 6 Mm^3 below -30 mPD. This resource occurs at a relatively shallow depth, and in a sheltered location close to possible future areas of reclamation, it could prove to be an economically viable deposit in the future.

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Appendix 1

Selected Whole-rock XRF Geochemical Analyses of Sedimentary, Volcanic and Intrusive Rocks from the District. Major Oxides in wt%, Trace Elements in ppm

Sample	HK7938	HK11573	HK7980	HK7436	HK10081	HK9478
SiO_2	93.63	54.17	65.11	68.24	66.57	76.52
TiO_2	0.17	2.24	0.55	0.50	0.55	0.16
Al_2O_3	4.04	15.12	13.73	13.80	11.91	12.63
Fe_2O_3*	0.31	11.46	4.45	3.90	13.87	1.10
MnO	0.02	0.15	0.08	0.10	0.02	0.02
MgO	0.09	3.35	1.59	1.55	0.39	0.17
CaO	0.06	5.34	3.56	1.20	0.04	0.18
Na_2O	-	4.37	3.79	4.10	0.09	2.00
K_2O	1.19	2.06	2.81	4.19	4.44	5.80
P_2O_5	-	0.81	0.13	0.13	0.04	0.02
Total	99.51	99.07	95.80	97.71	97.92	98.60
LOI	0.01	0.65	2.11	1.25	1.86	1.14
Cr	-	33	114	77	160	16
Ni	-	2	16	8	8	8
Co	-	-	9	8	4	3
V	-	-	30	36	43	6
Cu	-	-	49	30	8	1
Pb	-	4	38	20	21	36
Zn	-	-	53	30	16	42
Sn	-	-	3.3	4.6	2	8
W	-	-	4	4.0	4	7
S	-	47	-	-	-	-
As	-	7	-	-	-	-
K	9879	17101	-	34782	36858	48148
Rb	-	44	144	193	230	276
Ba	-	119	370	157	473	286
Sr	-	11	200	42	21	49
Ga	-	5	9	9	-	-
Nb	-	2	8	13	7	18
Zr	-	80	198	179	143	202
Ti	1019	13429	-	2998	3297	959
Y	-	15	39	35	26	61
Th	-	10	14.5	21.1	12	35
U	-	-	3.7	5.7	3	6
La	-	16	41	30	64	95
Ce	-	44	90	82	119	153

		Grid reference
HK7938	White quartzite, Bluff Head Formation, Ngor Kai Teng	4834 3871
HK11573	Quartzitic sandstone, Tolo Channel Formation, Fung Wong Wat	4979 3836
HK7980	Block-bearing fine ash tuff, Shing Mun Formation, Tung Tsz	3913 3702
HK7436	Lapilli ash lithic crystal tuff, Tai Mo Shan Formation, Shek Wu Hui, BH/B4	3324 3802
HK10081	Feldspar-bearing dacite lava, Sai Lau Kong Formation, Fun Chau	4660 4375
HK9478	Eutaxitic fine ash vitric crystal tuff, Ngo Mei Chau Formation, Ngo Mei Chau	5113 4390

Appendix 1 (continued)

Sample	HK8932	HK8879	HK7804	HK8045	HK7313B
SiO_2	64.83	71.09	82.50	85.25	72.90
TiO_2	0.68	0.35	0.19	0.14	0.09
Al_2O_3	14.37	13.64	9.66	8.57	12.90
Fe_2O_3*	4.19	3.00	1.86	1.49	1.26
MnO	0.04	0.07	0.02	0.04	0.04
MgO	1.39	0.69	0.41	0.22	0.21
CaO	3.35	2.18	0.07	0.12	1.66
Na_2O	0.10	3.00	0.09	0.03	8.53
K_2O	4.47	4.90	5.18	2.60	0.92
P_2O_5	0.02	0.11	0.04	0.05	0.00
Total	97.73	99.03	98.24	98.51	98.51
LOI	2.09	0.73	0.02	-	1.28
Cr	22	11	-	-	-
Ni	10	5	-	-	-
Co	2	6	-	-	-
V	-	22	-	-	-
Cu	1	4	-	-	-
Pb	16	22	-	-	-
Zn	5	33	-	-	-
Sn	-	5	-	-	-
W	4	2	-	-	-
S	184	-	-	-	-
As	17	-	-	-	-
K	36692	40676	29055	21583	7637
Rb	161	232	-	-	-
Ba	595	491	-	-	-
Sr	230	161	-	-	-
Ga	-	15	-	-	-
Nb	14	19	-	-	-
Zr	185	173	-	-	-
Ti	4077	1619	1139	1559	540
Y	41	54	-	-	-
Th	24	30	-	-	-
U	4	5	-	-	-
La	37	57	-	-	-
Ce	63	107	-	-	-

		Grid reference
HK8932	Granodiorite, medium-grained, Borrow Area Z, Tung Tsz	3925 3724
HK8879	Coarse ash crystal tuff, Long Harbour Formation, Tai Leng Tun	5283 3607
HK7804	White sandstone, Pat Sin Leng Formation, Lai Pek Shan	4007 3918
HK8045	Sandstone, Port Island Formation, Chek Chau (Port Island)	5520 3991
HK7313B	Chert, Ping Chau Formation, Lung Lok Shui, Ping Chau	6212 4460

* Total iron as Fe_2O_3
LOI Loss on ignition
\- Element not determined

Appendix 2

Fossil Plants from the Ping Chau Formation, Ping Chau

PTERIDOPHYTA

Equisetum ?sp.
Salvina ?sp.
Adiantopteris ?sp.

GYMNOSPERMAE

Otozamites sp. (*?nov.* sp.); *O.* ?sp. (*?nov.* sp.,); *O.* ?sp; *O.* sp.
Dictyozamites ?sp.
Brachyphyllum sp. (*nov.*sp.); *B.* sp.; *B.* ?sp.
Glyptostrobus cf. *europaeus* (Brongn.) Heer; *G.* ?sp.
Sphenolepis ?densifolis Cao
S. cf. *kurrians* (Dunker) Schenk
Schizolepis sp.
Pityolepis sp.; *P.* ?sp.

ANGIOSPERMAE

Cinnamomum sp.,
Nectandra quangxiensis Guo
Ocotea cf. *sinensis* Guo
Cercis ?sp.
Trapa ?sp.
Leguminosites ?sp.
Juglandaceae
Dicotylophyllum spp.; *D.* ?sp.
Sabalites sp.
Cyperacites sp.; *C.* ?spp.
Monocotylophyllum spp.; *M.*?sp.
Antholithes ?sp.; *A.*?sp.
Carpites spp.; *Carpites* ?sp.; *C.*?sp.

Collected by the Fossil Specialized Research Group. (Lee *et al.*, 1990a); Identified by Wu S Q

APPENDIX 3 - Sporo-pollen of Ping Chau, Mirs Bay

Sporo-pollen	HK 9497A	HK 9498A	HK 9499A	HK 9500A	HK 9661A	HK 8336	HK 9106	HK 9110
PTERIDOPHYTA	*							
	*				*			
Pterisisporites sp.	*	*	*	*	*	*	*	*
P. undulatus Sung & Zheng	*	*	*	*	*			
P. granulatus Sung & Zheng	*	*	*	*	*			
P. trizonatus Sung *et al.*	*	*	*	*				
P. bellus Sung *et al.*								
P. tuberus Sung *et al.*		*			*			
P. cretacius Sung *et al.*	*	*	*					
P. fatangularis Liu		*		*	*			
Verrutetraspora elegans Sung & Zheng	*	*			*			
V. verrucosa Ke & Shi	*							
V. sp.			*		*	*	*	*
Zlivisporis sp.		*	*	*				
Z. novamexicanum (Anderson)	*			*				
Leffingwell	*							
Echinatisporis sp.	*							
Klukisporities sp.	*							
Multinodisporities sp.	*		*	*				
Cicatricosisporites sp.								
Deltoidospora sp.		*	*					
D. regularis (Pflug) Sung & Zheng	*			*	*			
D. microlepioides (kretzsch) Wang		*	*	*				
D. apheles Huger				*				
Lygodiumsporites sp.						*		
Lygodioisporites sp.		*				*		
Lophotriletes cf. obscurus Bolch.		*						
Rouseisporites reticulatus Bolch.		*						
Schizaeoisporites palaeocenious		*						
(Selling) Potonie					*			
S. sp.			*					
S. minor Wan & Li			*		*			
Leptolepidities Verrucatus Couper			*	*	*			
L. sp.,				*	*			
Toroisporis sp.			*	*		*	*	
T. (T) lusaticu Krutzsch				*	*			
T. (D) brevidivisus Sung *et al.*				*				
Osmundacidites micanicus (verb.) Zheng			*					
Angiopteris sp.			*		*			
Divisisporites sp.					*			
Sphagnumsporites sp.					*			
Polypodiaceoisporites								
volubilispo Sung & Zheng								
Undulatisporites sp.						*		
GYMNOSPERMAE								
Classopollis annulatus (Ver.) Li								
C. sp.,	*		*	*	*			
Ephedripites sp.				*		*		
E. (E) viesensis Krutzsh	*	*		*		*	*	
E. (D) cf. scabratus Sung & Zheng	*				*			*
E. (D) fusiformis Krutzsch								
Pinuspollenites sp.		*			*			
P. labdacus f. maximus Potonie	*		*		*	*	*	*
P. banksianaeformis (Zakl.) Ke & Shi					*			
P. minutus (Zaki) Sung et Zheng								
Araucariacites sp.		*		*				
Inaperturopollenites sp.		*		*	*			
Sciadopityspollenites sp.		*	*	*	*	*		
Parcisporites parvisaccus			*					
Sung & Zheng					*			
Podocarpidites nageiaformis								
(Zaki) Krutzsch					*			
P. sp.								
Keteleeria ? sp.						*		*
Rugubivesiculites sp.					*	*		
Taxodiaceaepollenites sp.						*	*	*
Abietineaepollenites sp.						*	*	
Exesipollenites sp.							*	*
								*

APPENDIX 3 (Continued)

Sporo-pollen	HK 9497A	HK 9498A	HK 9499A	HK 9500A	HK 9661A	HK 8336	HK 9106	HK 9110
ANGIOSPERMAE								
Retitricolporites sp.	*		*	*				
R. oblongatus Sung *et al.*	*							
Tricolporopollenites sp.	*		*					
T. satzveyensis Thomas & Pflug			*					
Pentapollenites minor Sung *et al.*	*		*	*				
P. pentangulus Krutzsch	*			*	*			
P. laevigatus Krutzsch	*		*	*				
P. dungtaiensis Zhou	*		*		*			
Jiangsupollis striatus Sung	*							
J. striatus medius Sung			*					
J. ? sp.					*			
Symplocospollenites sp.	*							
Plicapollis granulatus Sung & Lee	*	*	*	*	*	*		
Subtriporopollenites granulatus Sung & Lee	*	*	*	*				
S. sp.						*		*
Ulmipollenites minor J. Groot & R. Groot	*	*	*		*			
U. sp.		*		*		*	*	
U. scabratus Sung *et al.*	*	*	*					
U. granulatus Stone		*						
Ulmoideipites granulatus Sung *et al.*	*	*	*	*	*			
U. Krempii Anderson					*			
U. sp.						*		
Myrtaceidites cajupitiformis (Zaki) Zhou	*							
Nuxpollenites bellatus Sung *et al.*	*							
N. corrugis Sung *et al.*	*							
Chenopodipollis multiporatus (Pflug & Thomson) Zhou	*	*	*	*				
Lonicerapollis sp.		*			*			
L. simplex Sung & Zheng		*						
Quercoidites sp.			*	*		*		
Q. hanrici (Pot.) Pot., Thoms. & Thier				*				
Extratriporopollenites perlucidus Skavby			*		*			
Cupuliferoipollenites pusillus (Pot.) Potonie				*				
C. pusullus Krutzsch			*		*			
Gothanipollis rutungensis Liu			*	*				
Caprifoliipites microratus Sung & Lee			*					
Sporopollis singularis Zaklinskaja			*		*			
Paranyssapollenites striatus Sung *et al.*	*		*					
Beaupreaidites proteaformis Sung *et al.*			*					
Proteacidites adenathoides Gouper			*					
Celtispollenites sp.				*	*			
Triporopollenites sp.				*		*		
Magnolipollis grandus Sung & Zheng				*				
Triorites sublveoatus Couper					*			
Tiliaepollenites indubitolilis R. Potonie					*			
Peltandripites davisii Wodehouse					*			
Sapotaceoidaepollenites granulatus Sung *et al.*					*			
Engelhardtioidites quietus Potonie					*			
E. punctatus Potonic					*			
E. sp.						*		
Tricolpites sanshuiensis Sung *et al.*				*				
Rhoipites sp.						*		
Jianghanpollis sp.							*	
Exesipollenites sp.								*
Callistopollenites sp.			*				*	
C. radiatus Zhou			*					

Note:
1. Samples HK9497A, HK9498A, HK9499A, HK9500A & HK9661A were identified by the Guangdong Institute of Geological Sciences.
2. Samples HK8336, HK9106 & HK9110 were identified by the Nanjing Institute of Geology and Palaeontology, Academia Sinica.
3. Sample locations : HK9497A, Kan Lau Shek (6342 4450); HK9498A, Kan Lau Shek (6348 4452); HK9499A, Chau Mei (6236 4583) HK9500A, Chau Mei (6237 4591); HK9661A, Cham Keng Chau (6179 4540); HK8336, Nan Kwo Shui (6336 4445); HK9106, Cham Keng Chau (6183 4548) & HK9110, Chau Mei (6234 4576).

APPENDIX 4. Palynological Comparison of the Ping Chau Formation with Strata of the Buxin Group of the Sanshui Basin, Guangdong Province

Sporo-pollen	Ping Chau	Sanshui Basin			
	Palaeogene *1	Upper Cretaceous *2	Palaeogene Buxin Group *2		
	Ping Chau Formation	Dalang Shan Formation	Final Formation	Second Formation	Third Formation
PTERIDOPHYTA					
Pterisisporites	29.1	2.4 - 26.0	0 - 1	4 - 50	4 - 7
Verrutetraspora	7.3	0 - 3.5	0 - +	0 - 12	0 - 2
Lygodiumsporites	1.5	0 - 1.6	0 - +	0 - 2	0 - 3
Schizaeoisporites	-	0.8 - 14.0	0 - +	-	0 - +
Gabonisporis	-	0 - 5.78	-	-	0 - +
GYMNOSPERMAE					
Inaperturopollenites	4.5	-	3 - 11	1 - 20	2 - 9
Iaxodiaceaepollenites	5.3	0 - 1.6	-	-	0 - 2
Ephedripites	4.0	0 - 1.6	0 - +	0 - 2	0 - 3
Classopollis	2.1	0 - 52.6	0 - +	-	-
Exesipollenites	4.5	4.3 - 52.9	0 - 5	-	-
Rugubivesicultes	4.5	1.4 - 13.2	-	-	-
ANGIOSPERMAE					
Ulmipollenites	6.8	0 - 8.2	17 - 19	6 - 17	0 - 11
Ulmoideipites	2.1	-	17 - 19	6 - 17	0 - 11
Subtriporopollenites	4.5	0 - 2.5	1 - 20	0 - 4	0 - 2
Plicapollis	1.5	1.65 - 4.35	16 - 26	5 - 16	0 - 4
Triporopollenites	0.7	0 - 1.4	1 - 2	1 - 11	0 - 6
Engelhardtioidites	0.7	-	-	0 - +	0 - +
Quercoidites	0.7	0 - +	+ - 3	1 - 12	2 - 38
Symplocospollenites	+	-	0 - +	-	0 - 1
Retitricolporites	+	-	0 - 6	0 - 7	0 - 17
Tricolporopollenites	+	-	-	1 - 14	0 - 14
Sporopollis	-	4.9 - 8.84	-	-	-

Note : + sparse

*1 sample HK 8336

*2 from Song Z.C. *et al.* (1986), Cretaceous and Early Tertiary Sporo-pollen assemblages from the Sanshui Basin, Guangdong Province

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