The Quaternary Geology of Hong Kong

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Foreword

This publication describes the Quaternary geology of Hong Kong and includes accounts of the superficial deposits, weathering and geomorphology. Pre-Quaternary geology is described in a related publication (Sewell *et al.*, 2000). This account is the culmination of over ten years of mapping and analyses, largely carried out by the Hong Kong Geological Survey (HKGS) of the Geotechnical Engineering Office (GEO). The report is accompanied by six maps at a scale of 1:100 000 showing: topography; place names; fill and borrow areas; onshore and coastal Quaternary deposits; the base of the offshore Quaternary formations; the Late Pleistocene–Early Holocene erosion surface offshore; and seabed sediments. The main body of the account, including most offshore interpretation, was prepared by Mr Fyfe and Dr Shaw. Dr Shaw also largely prepared the chapters on weathering and erosion, geomorphology and resources. Additional contributions were made by Dr Campbell (particularly onshore weathering), Mr Lai (onshore superficial deposits), and Mr Kirk (Tung Chung Formation). Final compilation was by Dr Campbell and Dr Shaw. Dr C.J.N. Fletcher led the HKGS during preparation of this publication, critically reviewed its various drafts, proposed many improvements and greatly contributed to its final form.

Knowledge of the onshore superficial deposits and weathering profiles has been derived from surface mapping and observation, and increasingly in recent years from boreholes and large excavations. As the scale and extent of development have increased with time in Hong Kong, so too has knowledge of the superficial deposits and weathering profiles. Offshore site investigation began in the 1950s. Since then, reclamation and coastal engineering projects have provided extensive nearshore borehole data. In the 1980s, the search for marine sand for reclamation fill allowed the drilling of longer boreholes further offshore, and other boreholes were drilled to resolve the Quaternary stratigraphy. Offshore geophysical exploration was begun in the 1970s, mainly by Electronic and Geophysical Services Ltd (EGS). Their cooperation, and that of many other contractors and consultants, is gratefully acknowledged.

The HKGS began onshore mapping in 1983 and offshore mapping in 1984. Quaternary superficial deposits are shown on all 15 maps published at 1:20 000-scale. The onshore mapping was mainly carried out by Dr R. Addison (1983-1984), Mr K.W. Lai (1984-1990), Mr R.S. Arthurton (1985-1986), Mr P.J. Strange (1985-1989), Dr R.L. Langford (1985-1992) and Mr P.A. Kirk (1991-1992). The offshore mapping was carried out by Mr R.J. Purser (1983-1984), Mr R.S. Arthurton (1985-1986), Mr J.W.C. James (1989-1991), Mr J.A. Fyfe (1991-1993), and Dr R. Shaw (1985-1993). Dr I.C Selby (GEO) and Dr C.D.R. Evans (British Geological Survey) also made significant contributions to the interpretation of the offshore geology.

Extensive Quaternary geological research has been carried out in tertiary institutions in Hong Kong, notably by Dr W.W.S. Yim (University of Hong Kong), Dr R.J. Neller (formerly - Chinese University of Hong Kong), Dr R.B. Owen (Baptist College University), and Dr P. Tanner (Hong Kong City University). Research in the adjacent Pearl River Delta and South China Sea has also been conducted by various institutions in Guangdong Province.

The maps accompanying this report were compiled from various sources, including the HKGS published 1:20 000-scale geological maps and unpublished archive maps and other published and unpublished records of the GEO. Site investigation data lodged in the Geotechnical Information Unit of the Civil Engineering Department were extensively used. In particular, interpretative reports by EGS were invaluable for refining several contour maps, and most of the geophysical figures were produced from their survey records. The seabed topography was compiled from published navigational charts and from unpublished hydrographic data collected by the Civil Engineering Office of the Civil Engineering Department.

This account has also benefited from comments made by Mr Y.C. Chan, Mr C.S. Covil, Mr N.C. Evans, Mr Matthew W.C. Lai, Mr W. Meacham, Mr S. Parry, Mr W.N. Ridley Thomas and Mr P.G.D. Whiteside.



R.K.S. Chan
Head of the Geotechnical Engineering Office



Frontispiece - Offshore sediments exposed on the floor of the High Island reservoir (萬宜水塘) following construction of the dams and draining of the area (Photograph by David Eastaff)

Summary

The Hong Kong SAR (香港特別行政區) is situated on the southern coast of China, to the east of the Pearl River Estuary (珠江口). The region has an extensive Quaternary sedimentary record, both onshore and offshore. Quaternary superficial deposits vary from thin and patchy veneers to laterally extensive sequences up to several tens of metres in thickness. The thickest sequences are developed in the northwestern New Territories (新界) and in offshore areas. Quaternary sediments provide a record of deposition throughout the Middle and Upper Pleistocene and Holocene, spanning 200 000 years or more, interspersed with periods of non-deposition and erosion. The sediments generally overlie terrain that has a weathered mantle of highly variable thickness. While typically a few metres to several tens of metres in thickness, weathered profiles are locally up to 170 m thick, suggesting a very prolonged period of weathering probably commenced far back into the Tertiary.

The distribution of Quaternary sediments and their facies variations reflect the influence of a weathered and actively eroding topography, not dissimilar to that of the Hong Kong SAR today. Volcanic rocks of Jurassic and Cretaceous age have formed steep sided massifs with sharp peaks and ridgelines, whereas the more subdued, rounded topography typical of the lower lying areas, is underlain mainly by granitic and sedimentary rocks, ranging in age from Devonian to Tertiary. The presence and substantial influence throughout the Quaternary of a large river system, located in much the same position as the Pearl River (珠江) today, can be identified. This was fed by a network of tributaries that occupied many of the same valleys that contain rivers at present.

Weathering processes in Hong Kong are particularly effective, due to the seasonally hot and humid climate and periodically extreme rainfall. These conditions promote chemical weathering by oxidation, hydrolysis and solution, and give rise to physical weathering processes, including the development of stress relief jointing and exfoliation. The latter in particular is responsible for generating the corestone-bearing weathering profiles that characterise some of coarser volcanic lithologies and granitic lithologies in general. However, weathering profiles in Hong Kong exhibit extreme variations in both the thickness and character, even on a very local scale. The principal controls of weathering profile development, and geomorphology in general, are mineralogy, texture and structure of the rock, especially relict joints and faults, topography, the rate of erosion, the groundwater regime and the microclimate. A significant feature of many weathering profiles is an abrupt interface between highly to completely decomposed material and moderately to slightly decomposed and fresh material. This interface, termed the weathering front, may be a preferred location for kaolin accumulation during weathering, an important hydrogeological influence, and, where dipping directly out of a cut slope, may adversely affect the stability of the slope.

In onshore areas, processes of mass wasting and fluvial erosion, and associated transport and deposition, are mainly responsible for moulding the landscape. During the Quaternary these processes were probably similar to those at present, although they did not necessarily occur at the same scale, intensity or frequency. The most pronounced effects of water erosion are likely to have been sheet erosion and gullying. The latter is most profound on weathering profiles in granitic terrain. Within slopes, eluviation and piping have probably been the most important processes. With respect to mass transport, a wide range of phenomena have been identified in Hong Kong, the commonest of which are debris slides, debris avalanches and debris flows. These generate the broad class of deposits that are generally referred to as colluvium. This material is fed either directly or indirectly into the drainage system and is ultimately redistributed and redeposited by a variety of fluvial, coastal and offshore processes.

Coastal morphology is primarily controlled by the orientation or aspect of the coastal sections and the characteristics of the rocks. Eastern areas of Hong Kong are generally more exposed to prevailing southeasterly onshore winds resulting in a rugged cliffed coast. In contrast, western areas are generally more sheltered and are subject to the effects of sediment-laden discharges from the Pearl River. These influences have generated a more subdued, depositional appearance to the coast.

Generally, the seabed falls in elevation gently to the southeast. Seabed morphology in the western part of Hong Kong is controlled to a large degree by the location of tidal channels. Narrow straits between the islands and the mainland constrict the tidal currents and increase their velocity. Similar, but more localized funnelling occurs between islands in the east, scouring the seabed and preventing deposition of sediments.

Onshore superficial deposits include locally thick colluvium and widespread alluvium. In offshore areas, the stratigraphy is more varied. In addition to substantial older fluvial and alluvial deposits, estuarine and marine deposits also occur. The nature and distribution of the estuarine and marine deposits have been strongly influenced by the rises and falls of sea level associated with the glaciations of the Pleistocene period, the oceanic current patterns in the South China Sea (南中國海), and the water and sediment discharges of the Pearl River. During the cooler glacial periods, world sea level fell by up to 150 m below its present level and the sea retreated approximately 120 km to the south of Hong Kong. This exposed the continental shelf to subaerial processes, resulting in areas of non-deposition and periods of erosion. In addition, the distributary system of the Pearl

River extended southwards and large tracts of fluvial and alluvial sediments were deposited over the former seabed.

Currently, sea level is close to the highest level that it has reached during the Quaternary. As a consequence, a blanket of marine mud, representing deposition throughout the Holocene and continuing at present, occurs in most offshore areas of Hong Kong. However, the majority of the sedimentary deposits of Pleistocene age that underlie the Holocene muds, are alluvial and fluvial. In onshore areas, the sequences are more discontinuous. Marine deposits are virtually absent and instead, both the Pleistocene and Holocene deposits include substantial colluvium as well as fluvial and alluvial sediments.

This memoir proposes major modifications to the existing Quaternary stratigraphy of Hong Kong. Much of the revision stems from the linking of Quaternary sequences that are currently offshore, with those that crop out onshore. Earlier mapping and description treated the onshore and offshore sequences as discrete entities. Indeed, there is good reason to do so with respect to the Holocene marine stratigraphy and its onshore subaerial equivalent. However, with the ready availability of data on superficial deposits in offshore areas, it is now clear that there is no reason to adopt the same approach for Pleistocene stratigraphy, in relation to which the location of the present shoreline has no relevance.

Extensive engineering activities in Hong Kong have generated a large amount of investigation data, especially borehole and trial pit logs, records of cut slopes, and in addition in offshore areas, seismic survey records and seabed test results. Much of the offshore data have come from reclamation projects and the associated exploration for offshore sand sources for reclamation fill. A seismic stratigraphy of the offshore Quaternary succession has been established from an interpretation of the dense network of high resolution seismic profiles correlated with borehole logs. This stratigraphy comprises five formations that are characterised by two principal seismic styles.

The ***Tung Chung Formation*** is the oldest Quaternary Formation in Hong Kong. The formation, which has a restricted occurrence, was identified initially on seismic reflection profiles, and has recently been confirmed in boreholes at Tung Chung (東涌) and north of Lantau Island (大嶼山), to the east of the Brothers islands (大小磨刀). The formation comprises poorly sorted sandy silts with cobbles and boulders. These sediments occur in steep-sided basins that are typically hundreds of metres across. These appear to be infillings of sinkholes or channels within a karstic environment. The age of the formation has yet to be determined with confidence, but it contains pollen possibly of Middle Pleistocene age.

The ***Chek Lap Kok Formation*** is the lowest part of the Quaternary succession in most parts of Hong Kong, and is considered to be Middle to Late Pleistocene in age. Originally the formation was only recognized in what are currently offshore areas of Hong Kong. However, the formation is broadened in scope in this memoir to include equivalent deposits in onshore areas of Hong Kong. These deposits mainly comprise colluvium and alluvium but also include lacustrine sediments. Colluvium is widespread on the flanks of the mountain massifs but is generally thickest in the major drainage lines and towards the bases of slopes. These colluvial deposits comprise silt with sand, gravel cobbles and boulders. They were generated by a variety of gravitationally driven slope processes largely associated with mass transport, and landsliding in particular. Colluvial deposits interdigitate, mainly near the bases of major slopes, with fluvial and alluvial deposits. The latter two increase in relative thickness and lateral extent onto the flattish plains at the foot of the mountains. Substantial deposits of alluvium, forming laterally extensive terraces, occur in the northwest of the New Territories. These deposits comprise sediments of widely ranging grain size, including clay, silt, sand, gravel with cobbles and boulders.

Two members have been defined in onshore areas. The ***Wong Kong Shan Member*** comprises fluvial and alluvial terrace deposits that consist of cobbles and boulders in a clayey sandy silt matrix. The age of the member is between c. 158 000 and 126 000 years BP (Middle Pleistocene) and it is currently known only from the northern New Territories. The ***Shan Ha Tsuen Member*** comprises widespead alluvial and fluvial terraces in the northwestern New Territories. Proximally, these deposits interdigitate in upper valleys with colluvium and distally with lacustrine deposits on plains. The sediments range from gravelly silty sand to well-sorted clayey sand, silt, sand and organic-rich silty clay The member ranges in age between 79 000 and 16 000 years BP (Upper Pleistocene).

In offshore areas, the Chek Lap Kok Formation is seismically complex, comprising discontinuous reflections, packets of laterally continuous parallel reflections and major and minor channel forms. A complex seismic style and the absence of laterally continuous reflections preclude a subdivision of the formation or regional seismic correlation. Sediments comprise sand and mud of dominantly terrestrial origin that unconformably overlie deeply weathered bedrock. Some of the channels contain inclined reflections that correlate with accumulations of quartz and lithic sand. These are inferred to be cross-bedded fluvial sediments that accumulated by lateral accretion within the channels. Channel forms also commonly occur within distinctive seismic units that are characterised by sub-parallel reflections and are composed of very fine sand, silt and clay. In most areas these units are clearly fine-grained floodplain sequences that contain lenses of sandy fluvial channel sediments. However, in a few localities shell fragments have been recovered from the sediments suggesting that they accumulated in an intertidal, estuarine or marine environment.

The upper part of the succession is characterised by four major laterally continuous seismic reflections: two are interpreted as fluvial entrenchment surfaces and two as ravinement (marine planation) surfaces. In western and eastern waters the lowermost fluvial entrenchment surface (FE1) represents a phase of lowstand fluvial incision, responsible for the creation of a series of channels that were subsequently filled with estuarine and marine sediments of the ***Sham Wat Formation***. Sediments of this formation are dominantly clayey silt and silty clay, generally grey in colour, but with yellowish oxidation spots and bands. The distribution of shell fragments and foraminifera in the sediments indicates that the formation represents a transgressive systems tract deposited during a high sea-level stand, possibly during the Eemian (c. 120 000 years BP) in eastern waters, although it may be younger in the west.

In southeastern waters, this fluvial entrenchment surface is truncated by a southerly dipping, planar ravinement surface (R1) created during a marine transgression. This surface is overlain by the ***Waglan Formation***, which comprises two distinct seismic units. The lower unit, which is characterised by a brighter, chaotic reflection pattern, consists of a shelly sand deposit that probably accumulated by the reworking of shoreface sands adjacent to the northward-retreating coastline. Low-amplitude parallel reflections characterise the upper unit, which is composed of clayey silt sediments that were deposited in shallow marine conditions. The formation is considered to be of late Weichselian age (c. 80 000 years BP), deposited during an interstadial when global sea level was relatively high.

The youngest part of the Quaternary succession is represented by two formations: the ***Fanling Formation*** in onshore areas, and the ***Hang Hau Formation*** offshore. Sea level began to rise at the end of the Late Pleistocene (c. 18 000 years BP) and fully marine conditions were established in the area around Hong Kong at the beginning of the Holocene Period (c. 10 000 years BP). Subaerial environments persisted throughout the Holocene in most of the present onshore areas.

The Fanling Formation, whose deposition commenced during the Holocene Period and continues at the present time, comprises colluvial, fluvial and alluvial deposits. Compared with the deposits of the preceding Chek Lap Kok Formation, the formation is generally more restricted in distribution and generally occurs along presently active drainage lines. These are commonly incised into older and more indurated colluvium and terraced alluvium of the Chek Lap Kok Formation.

Offshore, the basal deposits of the Hang Hau Formation occur above a second fluvial entrenchment surface (FE2) that appears on seismic records as a series of channels. This surface reaches its lowest elevation in southeastern Hong Kong waters and north of Lamma Island where the channels contain sediments of the ***Tung Lung Member*** of the Hang Hau Formation. Inclined seismic reflections characterise the member, which is inferred to be a lateral accretion deposit composed of very fine silty sands. The sediments are believed to have accumulated as fluvial channel fills during the final phase of terrestrial sedimentation prior to the late Weichselian to Holocene marine transgression (c. 13 000 years BP). A second, younger series of channels are less well developed, but occur over the whole of Hong Kong waters. The channels contain clayey silt sediments of the ***Pok Liu Member*** of the Hang Hau Formation, an intertidal deposit that probably accumulated on tidal flats during the early phase of the Holocene marine transgression (c. 9 000 years BP).

The main phase of the Holocene transgression is represented by a second ravinement surface (R2), recognized on seismic profiles as a southeasterly dipping, planar surface that truncates lower reflections. In the southeast, this surface is overlain by the ***Kwo Chau Member*** of the Hang Hau Formation, a unit interpreted as reworked shoreface sands related to the northward-retreating coastline. An overlying mud blanket, the ***Tseung Kwan O Member*** of the Hang Hau Formation, underlies virtually all of Hong Kong waters. On seismic profiles it appears as a series of parallel and sub-parallel reflections, and is mainly composed of clayey silt that is sandy in places. The marine sediments accumulated during the maximum flooding event of the Holocene (c. 7 000 to 6 000 years BP), in a depositional environment similar to that prevailing on the shelf today.

The suspended sediment levels in the modern offshore environment are largely controlled by the Pearl River, which has a highly seasonal water discharge of about 370 000 million m^3 each year and carries over 100 million tonnes of sediment. Strong ebb and flow tidal channels and wet season sediment pulses from the Pearl River are directed southeastwards along the tidal pathways through Hong Kong. Very little of the fine suspended sediment discharge remains in Hong Kong, the majority is deflected southwestwards along the South China coast by the prevailing oceanic currents.

Various resources have been identified within the Quaternary superficial deposits, and in addition, some resources have been generated as a result of weathering processes. Most are of modest importance (e.g. kaolin, tungsten, quartz sand etc.). However, sand deposits that occur offshore are of major economic importance and have been extracted on a large scale, mainly for use in reclamations. The refinement of geological models to guide the search for suitable sand deposits has been the principal focus of offshore geological surveying in recent years. In addition to the extensive dredging of sand deposits, seabed development has also included areas of reclamation to expand the urban areas of Hong Kong and to provide platforms for major infrastructure developments such as Chek Lap Kok airport. Suitable seabed sites for the disposal of mud, including contaminated mud, have also been utilized.

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2 Place Names, Fill and Borrow Areas
3 Onshore and Coastal Quaternary Deposits
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5 Late Pleistocene-Early Holocene Erosion Surface Offshore
6 Seabed Sediments

1. Introduction

This publication describes the geomorphology, weathering characteristics and Quaternary (Holocene and Pleistocene) geology of Hong Kong (香港) (in this publication, the area of the Hong Kong Special Administrative Region (HKSAR) (香港特別行政區)). It is accompanied by six 1:100 000-scale maps of the region (Maps 1 to 6). These maps show, 1. Topography and Bathymetry, 2. Places Names, Fill and Borrow Areas, 3. Onshore and Coastal Quaternary Deposits, 4. Base of the Offshore Quaternary Deposits, 5. Late Pleistocene–Early Holocene Erosion Surface Offshore, and 6. Seabed Sediments. The offshore maps include only survey data obtained prior to 1997. Therefore, the limit of the survey shown was the administrative boundary of Hong Kong at that time, and is not that of the Hong Kong SAR now.

Hong Kong lies on the northern margin of the South China Sea (南中國海), at the mouth of the Pearl River (珠江) (Figure 1.1). The region comprises the peninsula of Kowloon (九龍) and the New Territories (新界), with a coastline 354 km long, and a total of 232 outlying islands, of which the largest is Lantau Island (大嶼山), and the second largest Hong Kong Island (香港島). The landscape is rugged, with several high peaks, which include Tai Mo Shan (大帽山) (957 m), Lantau Peak (鳳凰山) (933 m) and Sunset Peak (大東山) (869 m). There



Figure 1.1 - Location of Hong Kong on the northern margin of the South China Sea (南中國海)

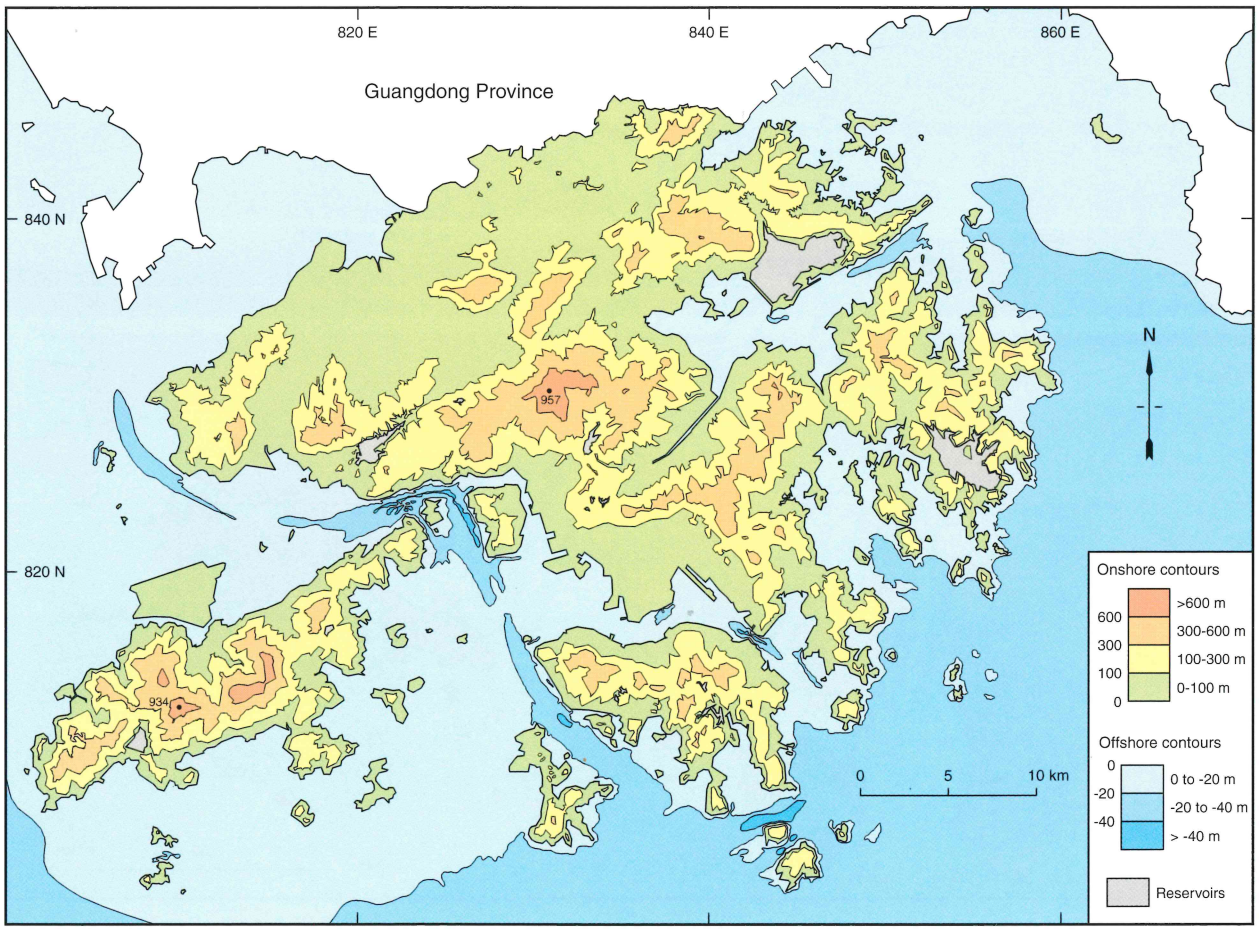


Figure 1.2 - Map of Hong Kong showing onshore and offshore topography

are only comparatively limited areas of flat land.

The total area of the region is 2 904 km². This comprises 1 076 km² of land area, which represents about 40% of the total area, while the remaining 1 828 km², some 60% of the total area, is covered by sea.

Almost 5% of the land area is reclaimed land. The earliest reclamation dates back to the mid-1800s. About 14% of the onshore area is covered by Quaternary deposits greater than 2 m thick (Map 3). These deposits are up to 50 m thick, but generally they form thin veneers, and are referred to as 'superficial deposits' on the fifteen 1:20 000-scale geological maps and in the six memoirs (see Chapter 2) produced by the Hong Kong Geological Survey (HKGS). The deposits are unlithified and were formed by a variety of processes in a wide range of environments.

The Quaternary superficial deposits commonly occur in flat valley bottoms and across plains where they form fertile land that was extensively cultivated in the past. More recently, under the pressures of a rapidly expanding population, these flatter areas have been increasingly developed for housing and infrastructure and now, only about 7% (79 km²) of Hong Kong's land surface is agricultural land. As a result of the development, however, the volume of available geological data on superficial deposits has greatly increased. Many of the drainage lines on steeper slopes also contain concentrations of Quaternary superficial deposits accumulated largely by mass movement processes. Therefore, they are of particular significance as a guide to where landslides have occurred in the past, and could do so again in the future, and so have become the focus of detailed investigations in recent years (e.g. Evans *et al.*, 1997; Evans & King, 1998). In general, on steeper slopes in Hong Kong, landslide morphologies and landslide deposits are typical.

The geomorphology of Hong Kong is described in Chapter 2. Volcanic rocks give rise to rugged scenery and form the highest peaks, while granitic and sedimentary rocks generally form lower relief (Map 1, Figure 1.2). The coastline is commonly cliffed and deeply indented, with isolated sandy coves (Plate 1.1), especially in the east of Hong Kong.

Under the influence of a subtropical monsoonal climate, Hong Kong's landscape experiences relatively rapid and intense weathering. Weathering profiles, described in Chapter 3, are up to 200 m thick in extreme cases beneath flatter areas, including those now offshore. More typically, however, the profiles are metres to a few 10s of metres thick. The weathering profiles in Hong Kong are of uncertain age, but are suspected to date back

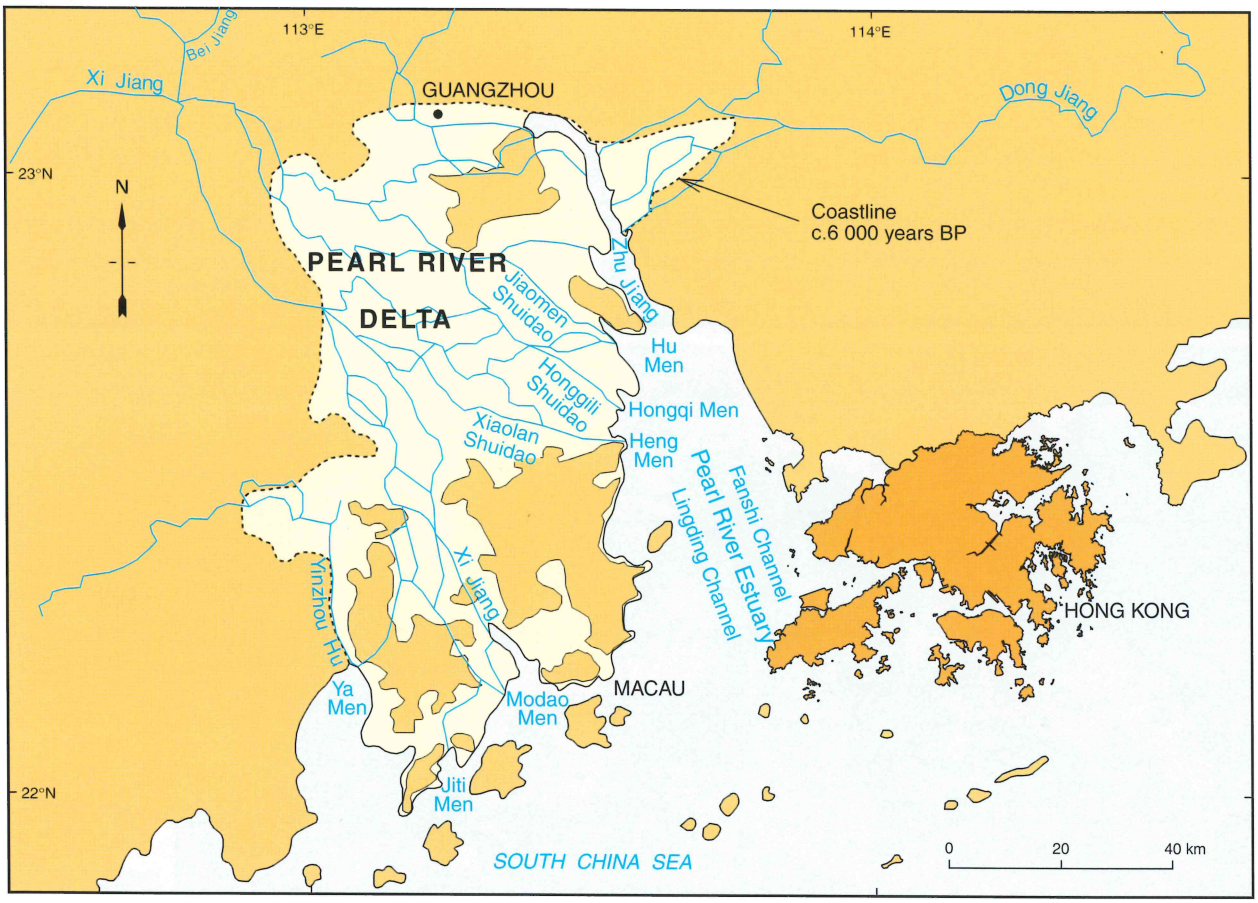


Figure 1.3 - Location of Hong Kong in relation to the Pearl River Estuary (珠江口)

to the Tertiary. Some economic resources result from weathering processes. The main resources of this type, as well as offshore sand deposits which are of major economic importance, are described in Chapter 12.

The sea area, which comprises 1 828 km², has had an important influence on the prosperity of Hong Kong. The growth in offshore development, including reclamation, offshore fill extraction and mud disposal, is described in Chapter 13. With the increase in engineering activity offshore has come the acquisition of much valuable new data.

The first comprehensive geological survey of the region was published at 1:50 000 scale (Allen & Stephens, 1971), but the survey did not extend offshore. Systematic surveying of Hong Kong's offshore area was begun in 1982, as part of the regional 1:20 000-scale geological mapping programme by the HKGS.

The seabed (see Chapter 2) has a low relief, slopes gently to the south (Figure 1.2, Map 1) and largely comprises soft clayey silt with some sand bodies and local areas of rock (Map 6). The Pearl River (珠江) (Figure 1.3) deposits coarser sediment as sand banks in the estuary northwest of Hong Kong, while silt and clay are carried out to the shelf south of Hong Kong (Plate 1.2) (Figure 1.4).

Quaternary deposits are subdivided on the basis of environment of deposition (e.g. onshore or offshore), mode of formation and age. Onshore and offshore deposits interdigitate as a result of shifts in the coastline caused by Quaternary fluctuations of sea level.



Plate 1.1 - Oblique aerial photograph of eastern Hong Kong illustrating the indented coastline

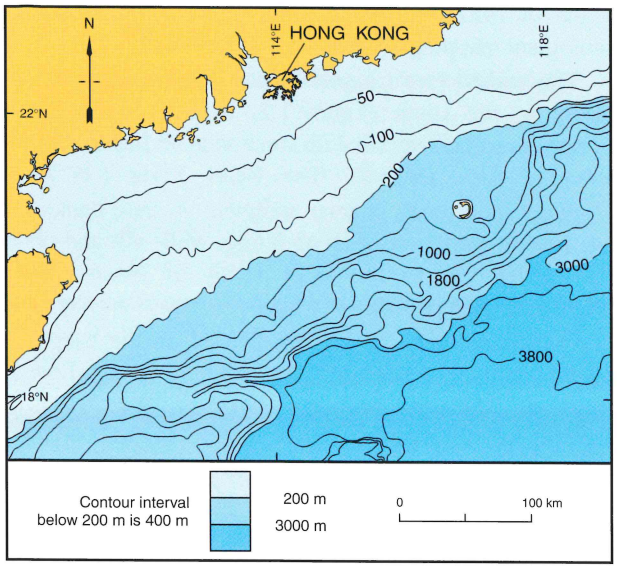


Figure 1.4 - The topography of the continental shelf, south of Hong Kong

The broad principles of Quaternary stratigraphy are described in Chapter 5. A formal lithostratigraphy has already been established for the offshore Quaternary deposits in Hong Kong, but no attempt has been made previously to extend this onshore, mainly because of the difficulties in correlating between discontinuous onshore deposits. Instead, onshore deposits have, until now, been classified mainly in relation to their mode of deposition, such as alluvium, or their environment of deposition, as in the case of beach deposits. On the 1:20 000-scale maps, mass movement deposits have been classified both in terms of depositional processes (debris flow deposits), and depositional environments (slope debris and slope deposits). However, in other publications (e.g. Allen & Stephens, 1971) they have been classified more generally as colluvium, and that term is preferred here for broad descriptive purposes.

In this account, a lithostratigraphy is proposed that encompasses all superficial deposits, regardless of whether they occur onshore or offshore. Wherever possible, the terminology used previously for offshore



Plate 1.2 - Satellite image of Hong Kong

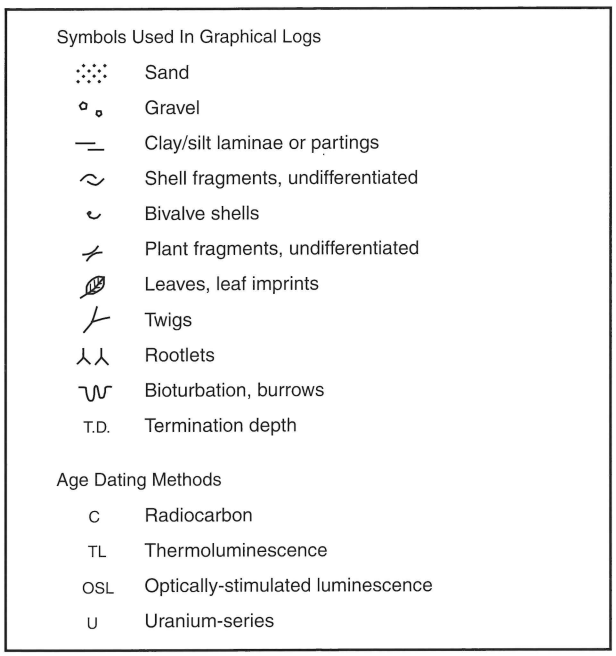


Figure 1.5 - Standard key to symbols used on borehole logs throughout this publication

superficial deposits has been adapted to include onshore equivalents. Thus, the Pleistocene Chek Lap Kok Formation, described in Chapter 7, is extended onshore to embrace both alluvium and colluvium of Pleistocene age. Two new members, the Wong Kong Shan Member and the Shan Ha Tsuen Member, are also described. A new formation, the Fanling Formation (Chapter 11), includes all Holocene alluvium and colluvium. Holocene beach, intertidal and estuarine deposits, however, are included within the Hang Hau Formation (Chapter 10).

Geological study of the offshore area of Hong Kong has relied on several survey methods and interpretative techniques (Chapter 4). Probably the most valuable of these has been the interpretation of shallow seismic data. Over 5 000 km of seismic traverses have been run in Hong Kong waters. The seismic data have been supplemented by boreholes, several of which were drilled specifically to study the Quaternary geology of the region.

The Quaternary sediments beneath the seabed are thickest, at around 100 m, in the southern part of the region. Five formations have been recognized. They include the recently proposed Tung Chung Formation, the Chek Lap Kok Formation, the Sham Wat Formation, the Waglan Formation described for the first time here, and the Hang Hau Formation. These formations are described individually in Chapters 6 to 10 and the Hang Hau Formation is divided into a number of new members (Chapter 10).

All depths given in this publication are in metres below Principal Datum (mPD). Reference to other sources may give depths in metres downhole. These can be converted by reference to the surface datum. A key to the symbols used on the borehole logs throughout the publication is given in Figure 1.5.

Explanations of some of the expressions used in this publication are given in the glossary of terms. The glossary is not exhaustive, but explains many of the more specialised terms. Preferably, it should be used in conjunction with the index. Place names are given both in English, or their anglicized form, and in Chinese characters. A glossary of English and Chinese place names is also included, and this supplements the locations illustrated on Map 2.

2. Geomorphology

There have been few comprehensive accounts of the geomorphology of southern China and Hong Kong. However, many authors have dealt with specific aspects, particularly the deep weathering developed in the area, and the evidence for and against the existence of raised beaches.

The first regional description of the geomorphology of Hong Kong was compiled by Tregear (1958) as part of a wider study of land use. Berry and Ruxton (1960) carried out a detailed study of the evolution of the Victoria Harbour (維多利亞港) area. Erosion surfaces in Hong Kong were first discussed by Berry (1961), who suggested levels at around +130 mPD and +230 mPD, with concordant summit levels at about +480 mPD. Other regional summaries have been compiled by Hansen (1984) and So (1986). The agricultural soils of Hong Kong have been mapped and described by Grant (1962, 1986), who also discussed soil development in the context of the geomorphology of the area.

Hong Kong is situated on the south coast of China, and the local geology and geomorphology broadly comprise the same elements as those developed on the adjacent mainland. The landscape of Hong Kong is founded on a geological basement that comprises sedimentary country rocks of Devonian, Carboniferous, Permian and Early–Middle Jurassic age. Middle Jurassic to Early Cretaceous volcanic rocks then formed from tuffs and lavas erupted, and at the same time, granitoid magmas were intruded. These igneous rocks constitute the main rock types at surface in Hong Kong, cropping out over about 76% of its area. Early Cretaceous to Early Tertiary sedimentary rocks form an unconformable cover. The weathered mantle is variable in thickness and covers most of the area. Weathering depths are greater over the granitic and coarse-grained volcanic lithologies. Late Pleistocene and Holocene transported superficial deposits form a discontinuous cover onshore and an almost continuous cover offshore.

The area of Hong Kong is located within the Lianhuashan (蓮花山) Fault Zone (BGMRGP, 1988), a northeast-trending belt, 30 kilometres wide, comprising subparallel strike-slip faults that are continuous for several hundreds of kilometres along the coastal provinces of the mainland. These faults control the major topographical grain of the area, largely determining the orientation of the major valleys and ridges. Orthogonal northwest-trending faults, and east-northeast- to east-trending faults, also form distinctive features in the landscape. Weathering and erosion have picked out these discontinuities.

The overall form of the landscape of Hong Kong, and the wider region, was probably largely sculpted during the Tertiary Period. It is considered that weathering and erosion during the Quaternary Period have resulted only in relatively minor changes to the geomorphology, adding details and facets to the pre-existing relief.

As is typical of subtropical mountainous areas, the geomorphological processes are dominated by mass movements and intermittent, large scale erosional events. These are superimposed on a regional landscape that has undergone protracted and aggressive deep weathering, and has a mature and integrated drainage network. The relative contributions of these processes are evident in the different aspects of the Hong Kong landscape. Slope failure scars, catchment erosion, deep weathering profiles and stream valleys characterise different elements of the land surface. Weathering tends to produce a smooth, rounded topography with thick regoliths on the ridge tops and side slopes, incised by fluvial valleys of a slowly evolving drainage system. Catchment erosion and slope failures add an irregular and angular overprint of scars, rock-free faces, and angular rocky ridgelines.

Mass movements have displaced the unconsolidated cover on hillslopes forming large debris sheets and lobes on the steeper slopes and in the steep tributary valleys, and extensive creep deposits on the shallower slopes. Fluvial processes, such as rilling, gullying and stream flow, have generally played a subordinate role, primarily serving to winnow the matrix from weathered profiles and to remove mass movement debris.

Coastal processes shape the outline of Hong Kong, control the base level of streams and determine the fate of fluvial sediments (Plate 2.1). Coastal processes are largely driven by tides, winds and waves. A dynamic geomorphological zone exists in the exposed eastern areas of Hong Kong. This has created a rugged, highly indented and cliffed coastline with an intricate pattern of headlands, bays and many small islands. In these areas, where coastal erosion predominates, there is a continuous supply of sediment whose distribution is controlled mainly by the tides and waves. In contrast, less dynamic conditions in western waters have produced a more subdued, depositional coastline of beaches and muddy tidal inlets.

The boundary between the coastal and seabed zones is necessarily loosely defined. In the east, the rocks that make up the shoreline extend beneath the sea. In these areas, and along cliffed coasts, the boundary is clearly determined. However, in Deep Bay (后海灣), Starling Inlet (沙頭角海), and similar bays, the fringing mudflats are intertidal and there is a gradual transition from the coastal to the offshore environment.

The sea generally deepens towards the south and southeast (Map 1) (Figure 1.2). Seabed processes are less dynamic than those near the coast, although the seabed is being continually modified by tidal currents and storms, particularly during typhoons. However, any changes are only minor and probably transient as the available evidence suggests that a hydrodynamic equilibrium has

been reached over most of the offshore area. For example, Chalmers (1984) concluded that there had been very little net sedimentation in Victoria Harbour during the previous 80 years, except where the seabed had been modified by man. In contrast, Deep Bay (后海灣), in the northeast New Territories (新界) is an area of net sedimentation (Li & Lee, 1996).

Data sources

Interpretation and characterisation of the geomorphology of Hong Kong largely depends on direct observation in the field, and on aerial photographs, and is greatly assisted by comprehensive topographical and geological map coverage. In addition to natural exposures, abundant data are available from cut slopes and boreholes. These data sources, discussed further below, are also relevant to interpretations of weathering profiles (see Chapter 3).

Aerial photographs

Hong Kong has an extensive archive of high quality aerial photographs (both black and white and colour) being available for a wide range of scales. In addition, some oblique aerial photographs, taken at very high flying heights are also available. Further information on aerial photographs is presented below in relation to Onshore Quaternary superficial deposits.

Topographical maps

The ready availability in Hong Kong of high quality topographical maps on a wide range of scales, including complete coverage at 1:1 000 scale (>3200 sheets), is invaluable in identifying and recording geomorphological features. These, and other maps are also now available in digital format, enabling the construction of digital terrain models as a further adjunct to geomorphological interpretation.

Geological maps

Geological map coverage is available for the whole of Hong Kong at 1:20 000 scale (15 sheets). In addition, for selected areas, there is more detailed coverage at 1:5 000 scale. Hence, the geomorphology is interpretable in relation to lithological and structural controls.



Plate 2.1 – An alluvium-filled valley with a lagoon developed behind a beach bar and an elongate sandy beach in a sheltered bay, Double Island (往灣洲)

Cut slopes and boreholes

Weathering profiles in Hong Kong are most readily defined using data from cut slopes and boreholes. Some cut slopes in the urban areas, especially those developed behind major platforms developed for housing or other infrastructure, extend for several tens of metres vertically, and hundreds of metres laterally. Therefore, weathering mantles can be proven across large areas and in three-dimensions.

As a result of intense urban development in Hong Kong, a vast number of boreholes have been drilled. These provide data on the nature and extent of weathering, and enable the three-dimensional form of interfaces between zones of different weathering characteristics to be established across large areas (e.g. Shaw, 1997; see Chapter 3).

Landscape controls

Six major factors control the evolution of the landscape. These are: the lithology of the underlying rocks; the geological structure; the climate and related weathering patterns; the types of geomorphological process operating in the area; the stage of development of the landscape; and the time over which these processes have been operating.

Lithology

Lithology, or rock type, exerts a fundamental control over the development of the landscape. The relative resistance to weathering and erosion of the different rock types in Hong Kong is clearly reflected in the modern landscape.

Three main rock types make up the geology of Hong Kong. These are, in order of importance, volcanic rocks, granitic rocks and sedimentary rocks (Figure 2.1).

Volcanic rocks are exposed over about 48% of the land area of Hong Kong. They occur mostly in the New Territories (新界), and form the scenery of most of the country parks. They generally form the higher, more angular and rugged uplands.

Granitic rocks are exposed over about 28% of Hong Kong. Granite forms the lower rounded hills and is characterised by a more subdued topography than that developed on the volcanic rocks. Deep gullies are commonly developed in some areas of granitic terrain. Most of the main urban areas of Hong Kong are built on granitic rocks, especially the urbanized Kowloon peninsula (九龍半島), and the new towns of Tsuen Wan (荃灣) and Sha Tin (沙田). Granodiorite underlies Tai Po (大埔).

Sedimentary rocks are only exposed over about 5% of the onshore area of Hong Kong. They mostly occur in the northern and northeastern New Territories, where they

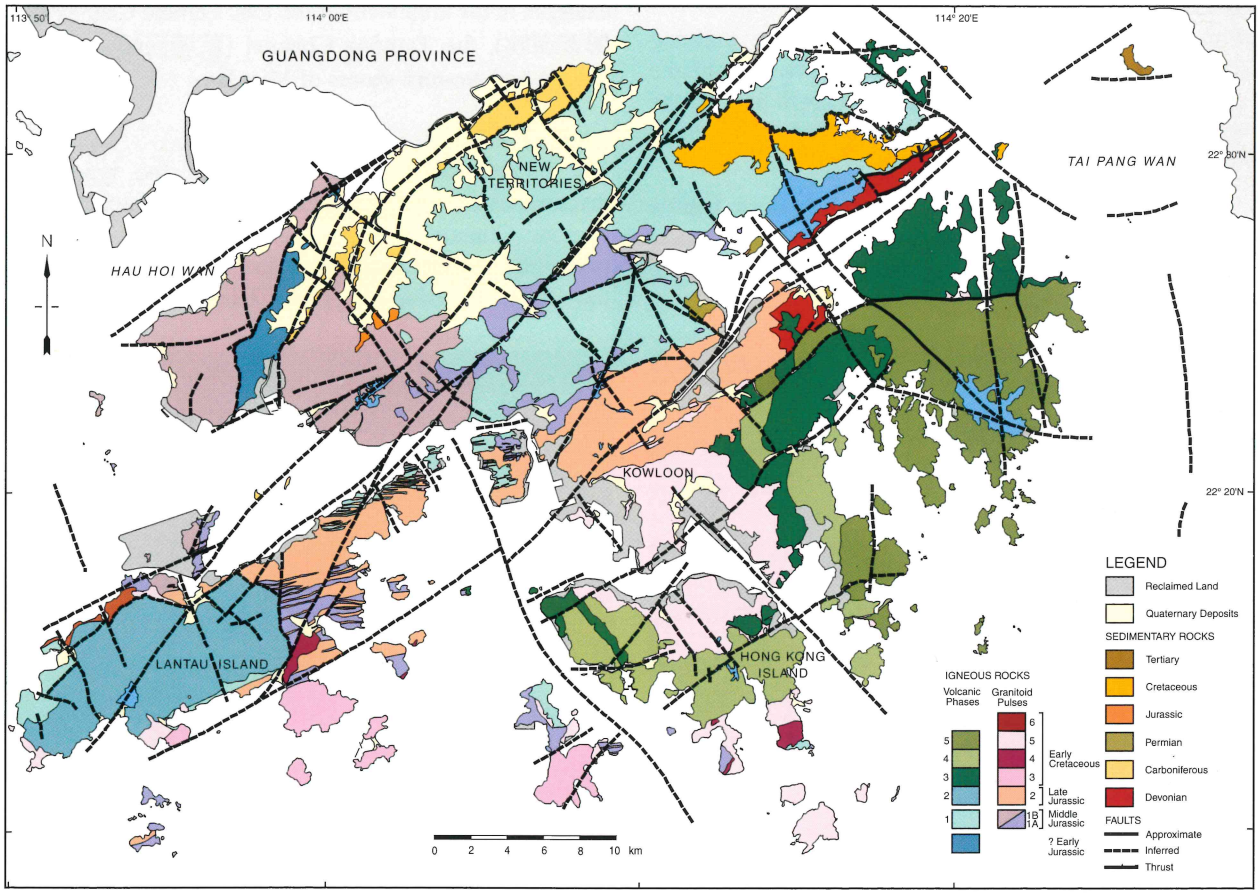


Figure 2.1 - Geological map of Hong Kong, compiled from maps of the Hong Kong Geological Survey



Plate 2.2 - Subvertical joints within granite, showing incipient toppling failure, south Po Toi Island (蒲台島)

form the intricate and varied scenery of the outlying islands. Marble occurs as a subcrop below part of the Yuen Long (元朗) plain, and locally beneath parts of the Ma On Shan (馬鞍山) new town area and Tung Chung (東涌) New Town.

Quaternary deposits greater than 2 m thick mantle about 11% of the land surface, while reclamations make up about 5% of the land area, and reservoirs constitute about 3%.

Structure

Geological structures are discontinuities of various origins that occur within the solid rocks of an area. The structures are typically lines of weakness that influence the effects of geomorphological processes on the different rock types. Thus, otherwise resistant lithologies can be easily weathered if they contain discontinuities.

Structures occur on a wide range of scales. They can be distinguished at the regional, local and outcrop level, and include faults, joints (Plate 2.2), and bedding planes. Exploitation of geological structures by weathering and erosion produces a distinctive grain or fabric to both the regional and local topography (Plate 2.3) and to individual bedrock exposures. This structurally derived grain is reflected in the outline of the coastline and the form of the hills, which can be seen on topographical maps. Differential weathering of rock exposures commonly emphasises the rock structure, producing geometrical weathering patterns (Plate 2.4).

The dominant structural trend in southern China is northeastwards (Figure 2.1) (Plate 1.2). This trend controls the general orientation of the coast and the shapes of many of the headlands and bays. In Hong Kong, it defines the alignment of such features as the Tolo Channel (赤門), the north coast of Lantau Island (大嶼山), and the north coast of Mirs Bay (大鵬灣). An orthogonal, northwestward trend is also present, for example in the alignment of the East Lamma Channel (東博寮海峽), the Tathong Channel (藍塘海峽), and the eastern and western shores of Mirs Bay.

Climate

The climate of a region determines the types and magnitudes of weathering and erosional processes that operate. Climate in this context encompasses both the prevailing weather conditions and those experienced in the recent geological past. Clearly, the climatic



Plate 2.3 - Inclined sedimentary strata (Port Island Formation), east side of Port Island (赤洲)



Plate 2.4 - Differential weathering along joints within volcanic rock (High Island Formation), Yim Tin Tsai (鹽田仔)

fluctuations of the Quaternary Period have had a major influence on the modern landscape of Hong Kong. Of direct influence are the range, magnitude, duration and combination of meteorological conditions that affect the land surface.

Individual elements of the climate of the south China region are a function of the monsoonal system. This determines the temperature and rainfall characteristics of the region and its relief. The prevailing subtropical morphogenetic regime in Hong Kong is characterised by a hot, humid, rainy summer, and a warm, dry, generally rain-free winter.

The monsoon circulation system is controlled by the seasonal heating and cooling of the Chinese mainland. This creates a sharp contrast in temperature between land and ocean, causing seasonal changes in wind direction. Two main monsoon seasons occur, with transitional seasons intervening.

The winter monsoon, or dry season, usually extends from November to February. During this period, continental cooling creates an anticyclone that generates cold, dry northerly winds. The mean January temperature is 15.6° C. Frosts only occur infrequently on the highest summits. March to April is a transitional season, during which the continental anticyclone weakens. This is a period of changeable weather. Summer, between May and September, is the wet season that receives about 80% of the annual rainfall of about 2 000 mm. July has a mean temperature 28.6° C. The prevailing southerly monsoon brings warm, damp air to Hong Kong and typhoons cause exceptionally heavy rains several times each year during this period. Individual rainstorms may generate 100s of millimetres of rain within a 24-hour period and peak hourly rainfall of more than 100 mm. Tropical monsoons also develop between August and September. Between September and November is the autumn transitional period when the wind direction shifts to easterly. Surges of cooler air arrive from the north, tropical cyclone activity wanes, and rainfall amounts decline.

Process

The subtropical climatic in Hong Kong favours deep chemical weathering of the rocks, markedly seasonal stream flow, and mass movements of the thick regolith.

Mass movements and periodic large scale erosional events, usually associated with strong monsoon or typhoon rains, are the principal geomorphological processes in mountain areas. These ephemeral erosional mechanisms are imprinted on a background of continuous deep weathering and the slowly evolving drainage network. For a very long period, perhaps as much as the last 60 million years, subtropical conditions have been weathering the rocks of Hong Kong and have produced a thick layer of weathered rock over much of the landscape. The seasonal monsoonal rainfall results in a high runoff, but the river system of Hong Kong is not well developed. There are no large streams and the majority of the smaller streams are seasonal. Erosion, mainly by running water, and mass movements, remove and redistribute the soft weathered rocks to expose new rocks to weathering and shapes the landscape. Mass movements have formed large debris sheets and debris lobes on the steeper slopes, and extensive creep deposits on the shallower slopes.

Stage

Stage is a measure of the status of development of a landscape. Young, high mountains at an early stage of landscape development are characterised by steep slopes, angular topography and energetic erosion. Extensive, levelled plains reflect a late stage of landscape development, characterised by little or no relief, gentle gradients, and low energy processes.

The majority of onshore Hong Kong is typified by rugged, steep-sided topography, and immature natural drainage, suggesting a comparatively early stage in landscape development. More mature characteristics are shown by the flat plains in the northwest New Territories (新界), and by the subdued seabed topography typical of most offshore areas, especially Mirs Bay (大鵬灣). Currently active geomorphological processes, especially those concentrated around the shoreline, reflect comparatively recent adjustments to the rise in sea level during the Holocene, and to the unusually high sea level at present.

Time

It is important with respect to current geomorphological processes to establish the time over which they have operated, largely uninterrupted by climatic, tectonic or other changes. In Hong Kong, Quaternary sediments reflect substantial variation in the environment during the last 200 000 years. This can be attributed mainly to fluctuations in global sea level in response to glacial maxima and minima. Changes, especially in rainfall and in relation to advance and retreat of the shoreline, have had major influences on the geomorphological processes. However, physical evidence of these variations is harder to detect in the landscape. Coastal cliffs at some distance from the present shoreline in the northwest New Territories (新界) (Figure 2.2) record erosion associated with the furthest advance of the sea, probably about 6 000 years ago. Similar features are seen in Kowloon (九龍) also. Evidence suggesting a broader continuity of geomorphological processes prior to 200 000 years ago, is provided by the nature and extent of the weathered mantle. In offshore areas, this mantle underlies Quaternary superficial deposits and locally, is up to 200 m thick. Such deep-seated weathering profiles must have developed over a considerable timespan. Their preservation also points to prolonged periods without substantial erosion in some areas. The gap in the sedimentary record in Hong Kong extends from the Middle Pleistocene back to the early Tertiary. At that time, important regional changes in local and regional tectonics, and climate, would have occurred due to the rapid evolution of the Himalayan Massif, following

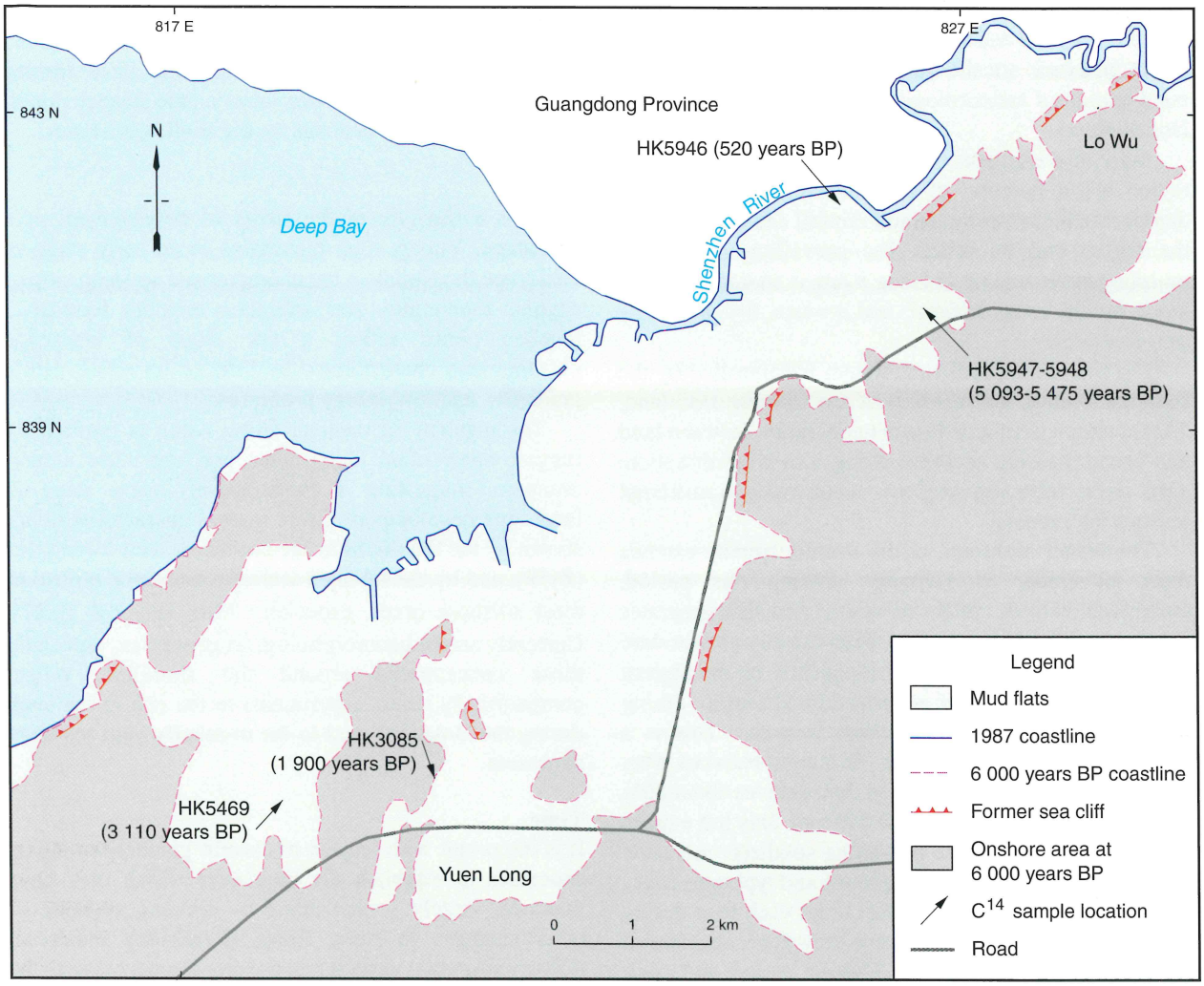


Figure 2.2 - Coastline changes in the Yuen Long (元朗) to Lo Wu (羅湖) area during the last 6 000 years

collision of the Indian subcontinent with Asia. Indeed, the onset of the monsoonal system in southeast China can probably be dated back to this event. Hence, broad continuity of the climate might have been maintained in the region since the early Tertiary.

Landscape development

Landscapes are not static phenomena, but evolve slowly through time as the crustal plates migrate, tectonic forces raise and depress the land, the climate changes, and the sea level rises and falls. Contained in the rocks of Hong Kong is a record of the environmental evolution of the region over the period from about 400 million years ago to the present day (Sewell *et al.*, 2000).

Tertiary and Quaternary environments

The details of the present landscape of Hong Kong are presumed to have formed mainly during the Quaternary Period (1.4 million years ago to the present). However, subtropical deep weathering of the rocks of the region probably began during the Tertiary Period, about 60 million years ago under relatively stable, warm, humid climatic conditions (Ruxton & Berry, 1957). This gradually produced a thick layer of soft weathered rock over the exposed rocks of the Early Tertiary land surface. Abundant evidence of the results of this weathering can be seen over the modern land surface. Selective erosion of this weathered mantle occurred as stream patterns and hill slopes developed, producing the fundamental outline of the modern scenery. Weathering continued at the same time as landform development, preferentially exploiting joints and faults in the mainly granitic and volcanic rocks. Erosion exploited these weakened zones, which became the master valleys. Thicker weathering profiles were generally preserved on the ridges and interfluves, and also below the floors of some of the major valleys. Areas of more resistant rocks, most commonly the finer-grained volcanic lithologies, were left upstanding, forming the hills.

This pattern was interrupted during the Quaternary Period when the climate became unstable. Cyclical climatic changes occurred, during which the earth experienced a general climatic cooling and widespread, multiple glaciations affected higher latitudes. These glacial-interglacial cycles resulted in major fluctuations

of world sea level and shifts in world climatic zones that had important consequences for the region, particularly the offshore area. The affects of the most recent of these changes in the Pearl River Delta (珠江三角洲) region were described by Feng *et al.* (1988). About 120 000 years BP interglacial conditions prevailed. The local climate was warmer than at present, and the sea level was about +4 m to +6 m higher than today. Climate subsequently began to cool. Around 75 000 years BP a glacial maximum had been reached and sea level had fallen to about 77 m lower than at present. Later climatic amelioration was accompanied by a gradual rise in sea level. This rise culminated about 28 000 years BP with marine transgression across the Pearl River Delta.

The last glaciation commenced about 25 000 years ago, reaching a maximum about 17 000 years BP to 18 000 years BP. Sea level was at its lowest at this time, falling to around -120 mPD or -130 mPD. This extreme sea level fall resulted in the south China coastline receding to a position about 120 kilometres to the south of Hong Kong. The Pearl River system and streams in Hong Kong responded to the sea level fall by extending southwards out over the former sea floor, expanding the anastomosing system that characterises the Pearl River Delta today (Plate 1.2) (Figure 12.5). These extended channels would probably have eroded and reworked most of the existing soft marine sediments, and any surviving fluvial sediments from large areas of the newly exposed shelf. Associated fluvial deposition formed the complex sequence of subaerial deposits that characterise much of the Chek Lap Kok Formation today. Sediments accumulated in channels of the extended stream network contemporaneously with deposition of the Chek Lap Kok Formation alluvial deposits in the valleys and the colluvial sheets and lobes in the upland areas. The lowering of mean annual temperatures in this region also affected the composition of the local flora. Variations in floristic composition can be determined from the pollen record, which provides a valuable technique for the characterisation and relative dating of sediments (Chapter 8) (Figure 8.3).

Initial climatic amelioration began following the final glacial maximum, but deglaciation accelarated around 12 000 to 11 000 years BP. Postglacial climatic amelioration resulted in a sea level rise. However, the sea level rise was not constant. A postglacial sea level high, possibly reaching +1 m to +3 m above its present level, was attained at about 7 000 to 6 000 years BP. A minor regression occurred about 4 000 years BP, and there is evidence of a further minor transgression at about 2 000 years BP. As the postglacial climate slowly warmed and the rose, a thick layer of Holocene marine mud, the Hang Hau Formation, gradually encroached over the alluviated valleys and progressively buried the floodplains and channels of the receding fluvial system. A new coastline was established, with beach sand accumulating in sheltered locations and cliffs developing in the steeper and more exposed eastern areas.

Onshore, weathering and erosion continued throughout the Quaternary Period, although subject to the cyclical changes experienced offshore. The drainage system would have had to readjust constantly to the shifting base levels that resulted from the cyclical rise and fall in sea level. Climatic changes caused variations in both the temperature and rainfall, affecting weathering rates and fluvial discharges. Valleys were eroded and overdeepened during periods of low sea level, whereas deposition prevailed during sea level highstands and sediments accumulated in the river valleys. Mass movements dominated the erosion of mountain slopes, building up a veneer of colluvial deposits on hillslopes and lobes in mountain tributary valleys. In many areas, these colluvial deposits extend onto the valley floors and interdigitate with the alluvial sediments. In present onshore environments, the Pleistocene sediments comprise the alluvial and colluvial deposits of the Chek Lap Kok Formation (Chapter 7) and the younger sediments make up the Holocene Fanling Formation (Chapter 11). Slowly, the shape of the modern landscape and its mantle of superficial deposits have evolved, and surviving superficial deposits are the visible result of Quaternary geomorphological processes.

Onshore morphology

Topography

The topography of Hong Kong (Map 1) is characterised by rugged uplands and steep slopes. However, although flat land is limited in area, about 53% of the land surface of Hong Kong has an elevation of less than 100 m above Principal Datum, and only about 12% is higher than 300 m in elevation (GCO, 1989). Within this higher region, 23 peaks are higher than +500 mPD, and a further seven have summits between +480 and +500 mPD. The highest peaks include Tai Mo Shan (大帽山) (957 m), Lantau Peak (鳳凰山) (933 m) and Sunset Peak (大東山) (869 m) (Figure 1.2) (Map 2).

The topography of Hong Kong shows a marked contrast from west to east. Landforms in the west are generally lower lying and more subdued, with larger areas of open plains, whereas steep hillsides, narrow valleys, and a cliffed coastline are characteristic of the natural terrain in the east. The only extensive areas of flat land occur in the northern and northwestern parts of the New Territories (新界). Level ground is otherwise restricted to small areas on valley floors and along the narrow coastal fringes. The largest extent of lowland is the area comprising the Yuen Long (元朗) and Fanling (粉嶺) plains in the northwest. This is an extensive, continuous plain with abrupt boundaries in the south, where it abuts against the Tai Lam Chung (大欖涌) massif, and the east, where it is bounded by Tai Mo Shan, Kai Kung Leng (雞公嶺) (572 m) and Tai To Yan (大刀屻) (565 m). The highest areas of continuous relief are the northeasterly trending ridge from Tai To Yan (565 m) to Pak Tai To

Yan (北大刀岬) (480 m), and the Hung Fa Leng (紅花嶺) ridge (Robin's Nest) (492 m).

Structural controls

Hong Kong lies within the northeast-trending Lianhuashan (蓮花山) Fault Zone (BGMRGP, 1988) and displays the same dominant structural trend (Figure 2.1) that typifies coastal provinces of southeast China. This defines the linear nature of the coastline and the elongate nature of the upland ridges. Most of the bays along the mainland coast are very rectilinear, controlled by this and a subsidiary northwest trend. These structural trends have also largely controlled the geometry of the present river valleys, ridges and uplands, as well as the morphometry of the coastal estuaries, channels, bays and headlands. The overall outline of Hong Kong is bounded by two large rectilinear embossments, the Pearl River Estuary (珠江口) to the west and Mirs Bay (大鵬灣) to the east.

The alignments of the main valleys and ridges of Hong Kong show the same broadly rectilinear pattern, reflecting the effects of weathering and erosion along the main structural trends (Figure 2.3). Topographical maps (Map 1) clearly show the elongate shape of the uplands, which form pronounced ridgelines that are predominantly oriented northeast to southwest. The subordinate northwest to southeast trend is apparent in certain areas, and it becomes dominant in eastern and southeastern parts of Hong Kong. Several small intermontane basins also occur on these alignments, in which Quaternary alluvial and colluvial sediments have accumulated.

Drainage patterns

The drainage network in Hong Kong is compact and simple (Plate 2.5). Drainage lengths are typically short and there are few large master streams (Map 3) (Figure 2.4). Catchments are rarely greater than fourth order. Streams on the steep hillslopes are usually closely spaced, and most upper stream courses tend to be linear. Fluvial gullying and associated soil erosion have affected many upland areas in Hong Kong, particularly around the headwaters of streams in granite areas (Plate 2.6), e.g. west of Castle Peak (青山) in northwest Hong Kong. The characteristics and effects of this commonly major and extensive fluvial process have been the subject of many descriptions and studies (Skertchly, 1893; Berry, 1955a, 1955b; Tregear, 1958; Grant, 1968; Lam, 1977, 1978; Hansen & Nash, 1985; Shaw, 1993).

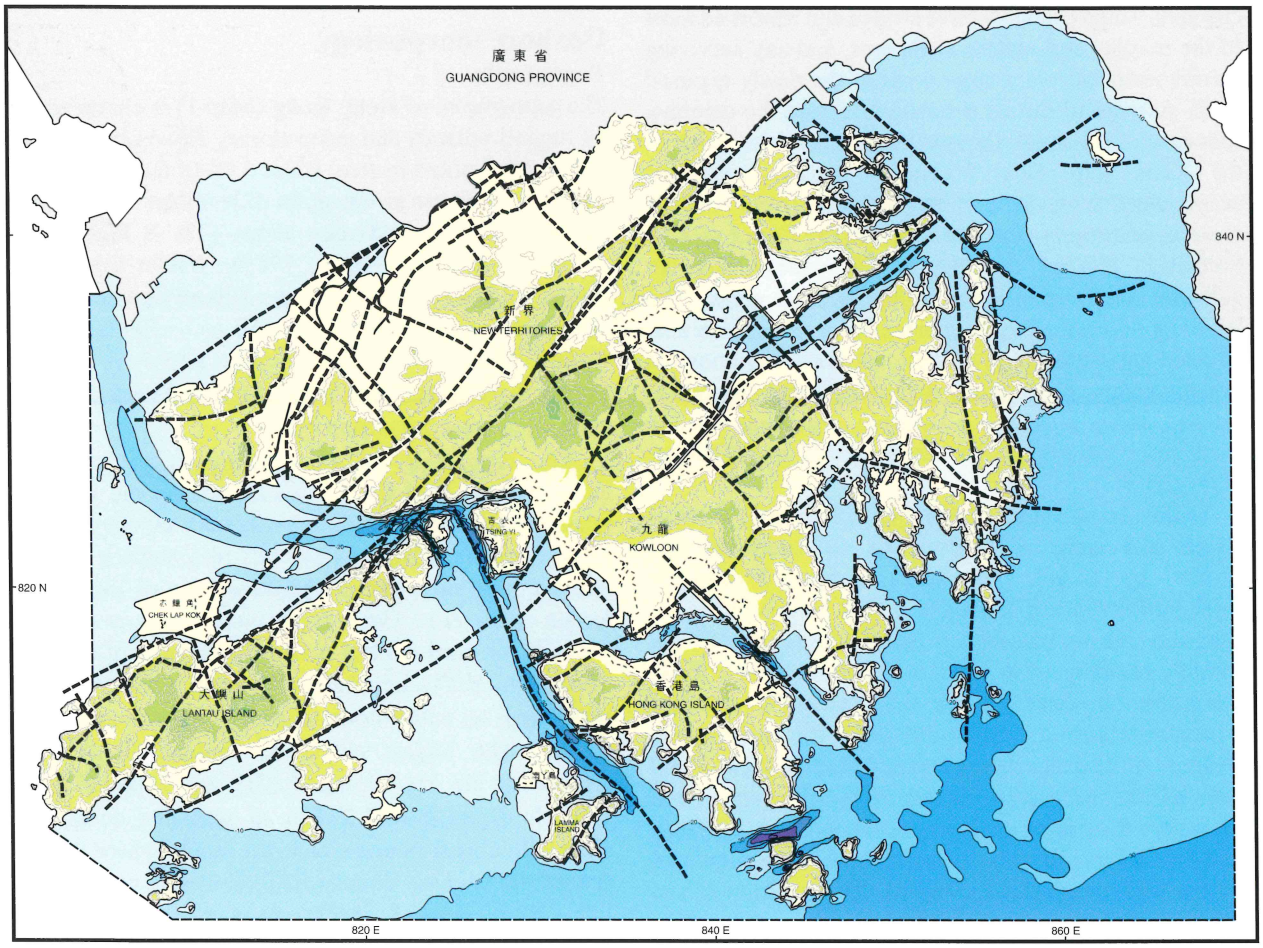


Figure 2.3 - Onshore topography and seabed morphology of Hong Kong (key as for Map 1) superimposed with the framework of faults (black broken lines)



Plate 2.5 – Looking southwest towards High Island Reservoir (萬宜水庫) (top left) along a fault-controlled valley passing through mainly volcanic rocks of the High Island Formation, northeast New Territories (新界); significant colluvium and alluvium (Fanling Formation, see Chapter 11) have accumulated only in the valley bottom in the right foreground



Plate 2.6 - Gully erosion near the summits and along ridges producing badlands topography in the area underlain by medium-grained granite to the west of Castle Peak (青山). Relatively few corestones are present along the ridge crests, most of which are formed of saprolite.

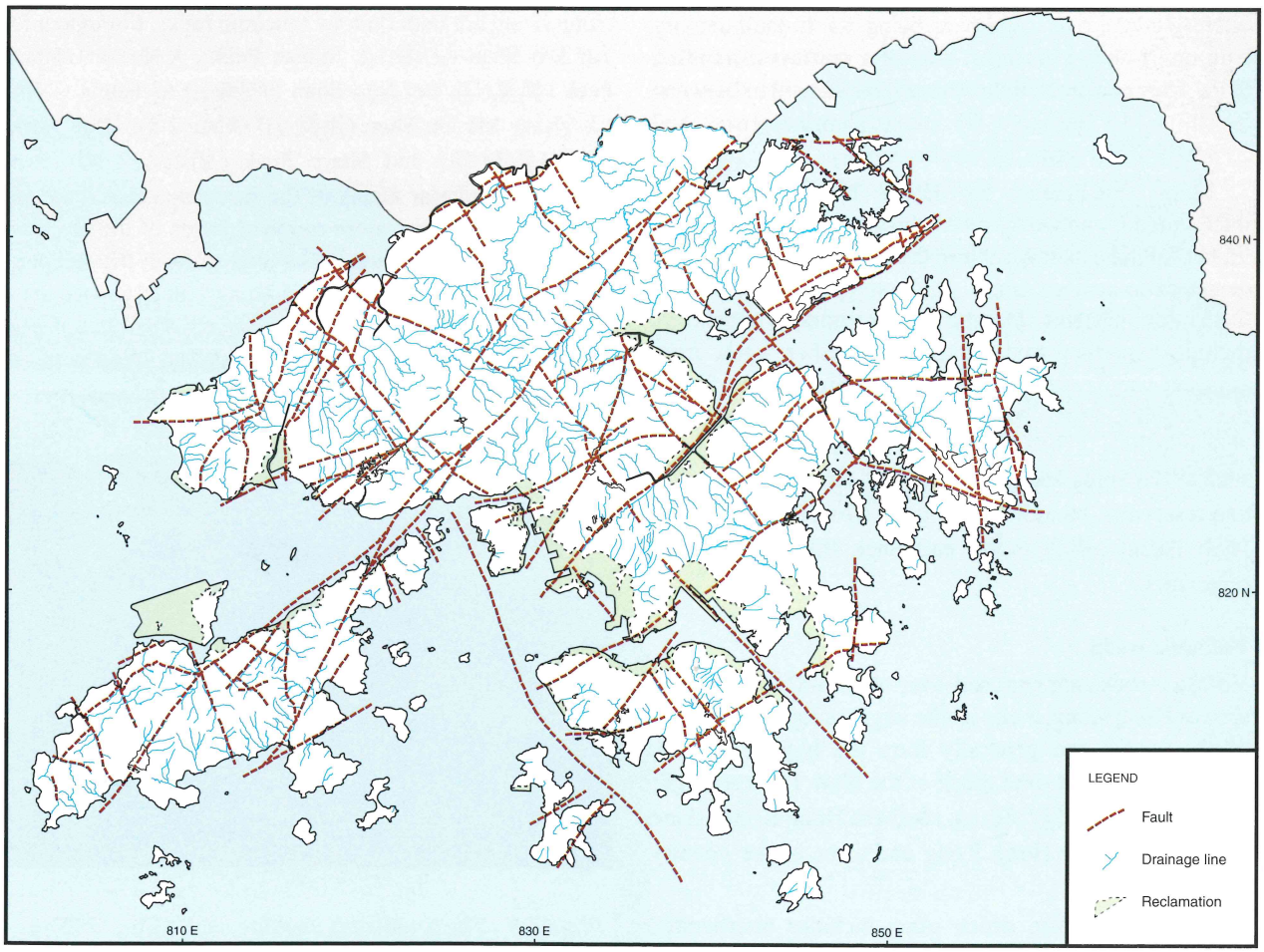


Figure 2.4 - Drainage network of Hong Kong superimposed with the framework of faults

Several small examples of stream diversion, probably caused by landslide deposits, occur around Hong Kong. However, the course of the Lam Tsuen Valley (林村河谷) shows the best evidence of large-scale river capture (Allen & Stephens, 1971; Lai & Langford 1991; Ding & Lai 1997). The river rises on the slopes of Tai Mo Shan (大帽山) and, upon reaching the floor of the main Lam Tsuen Valley, flows northeastwards for a little over 2 km. Near Hong Lok Yuen (康樂園) the elbow of capture can be seen. At this point the river turns sharply through a discontinuous rock-cored ridge, to flow southeastwards towards Tai Po (大埔). Prior to capture, the river flowed northwards through the Kau Lung Hang (九龍坑) Valley to Fanling (粉嶺) (Figure 7.3). Following capture, the Lam Tsuen River (林村河) incised a new channel into the contemporary floodplain forming a narrow, inset floodplain. Currently the river runs in a confined channel about 5 m below the old alluvial deposits that now form an abandoned terrace. The river cliffs provide a clear section through the fining-upwards alluvial sequence, which has a coarse cobble bed at its base (see Chapter 7). A flat alluvial plain, with a misfit stream, extends through the Kau Lung Hang Valley at the same level as the Lam Tsuen Valley terraces. Ding and Lai (1997) have interpreted the river capture as being due to fault activity with uplift on the northeast side of a northwest-trending fault. They constrained the inferred movement to between 84 700 ± 16 300 years BP (thermoluminescence) and 23 950 ± 5 300 years BP (radiocarbon).

Many catchments in Hong Kong have been intercepted by networks of catchwaters. These concrete-lined channels, mainly built in the 1920s and 1930s, were designed to collect runoff and convey it to reservoirs. Collection systems for the larger modern reservoirs include tunnelling and pumping to gather water from adjacent catchments. Reservoirs constitute about 3% of the onshore area. Altogether, Hong Kong contains approximately 2 500 hectares of channelized estuaries, such as the Shing Mun River (城門河) in Sha Tin (沙田), and reservoirs, including the Plover Cove (船灣淡水湖), High Island (萬宜水庫) and Shek Pik (石壁水塘) reservoirs.

Volcanic rocks

Volcanic rocks are exposed over about 48% of the land area of Hong Kong, make up the largest single component of the terrain and generally form the highest ground. These rocks occur over much of the New Territories (新界), Lantau Island (大嶼山), southern Hong Kong Island (香港島), eastern Hong Kong and most of the country parks.

Volcanic terrain, which often includes interbedded sedimentary units, is typically angular, characterised by moderate to steep slopes, gently concave sideslopes and



Plate 2.7 - Ridgelines in an area of volcanic and sedimentary strata, Cheung Sheung (嶂上)

narrow convex ridges. Bedrock exposures are a feature of ridgelines (Plate 2.7), and free faces occur on spur ends and steeper slopes. Large boulders are common, littering the slopes below these exposures. Generally, a thin veneer of bouldery colluvium mantles the slopes, above a thin, stoney, clayey soil. The highest peaks and ridges of Hong Kong are underlain by volcanic rocks. For example Tai Mo Shan (大帽山), Sunset Peak (大東山), Lantau Peak (鳳凰山), Fei Ngo Shan (飛鵝山) to Tate's Cairn (大老山), Ma On Shan (馬鞍山) (Plate 2.8), High Junk Peak (釣魚翁) and Sharp Peak (蚺蛇尖) all form prominent, angular facets of the landscape that stand in sharp contrast to the more rounded forms of the granitic hills. Similarly, volcanic rocks tend to form the steeper, cliffed coastlines that surround Hong Kong, particularly in the east.

The massive, coarse ash tuff lithologies weather in an analogous way to the granitic rocks, with moderately



Plate 2.8 - The prominent angular peak of Ma On Shan (馬鞍山), capped by volcanic rock (Shing Mun Formation)



Plate 2.9 - Corestones cropping out along a ridge underlain by lapilli-bearing coarse ash crystal tuff (Tai Mo Shan Formation), on the flank of Tai Mo Shan (大帽山)



Plate 2.10 – Well-stratified sedimentary rocks (Pat Sin Leng Formation, along the crest of the southerly-facing Pat Sin Leng (八仙嶺) escarpment, unconformably overlying relatively massive volcanic rocks (Tai Mo Shan Formation)



Plate 2.11 - The Pat Sin Leng (八仙嶺) escarpment, as in Figure 2.10, showing contrasting topography and drainage of the scarp and dip slope

thick weathering profiles, corestones (Plate 2.9) and uplands with generally smoothed outlines. However, the fine ash tuffs and eutaxites have locally pronounced bedding structures or bedding parallel foliation. They weather less deeply, do not tend to form corestones, and produce shallow, clayey soils on very angular uplands. The eutaxitic rocks display a pronounced layered structure and tend to form escarpments and distinctive topographical features. Therefore, the topography of these lithologies, which have more combinations of weaker and more resistant strata in the succession, is analogous to the thickly bedded sedimentary rocks (Plate 2.10). These lithologies form distinctive escarpments. The most prominent and extensive escarpment is the Pat Sin Leng (八仙嶺) Range (Plate 2.11). Other notable examples occur around Three Fathoms Cove (企嶺下海) and Fei Ngo Shan, and on the western flanks of High West (西高山), the northern flanks of Lantau Peak, the slopes skirting Shek Pik Reservoir (石壁水塘), and above Tai O (大澳). These resistant, feature-forming bands also act as local base levels to erosion, and give rise to impressive waterfalls such as at Bride's Pool (新娘潭) and Three Fathoms Cove (企嶺下海). On the northern flanks of Tai Mo Shan (大帽山), a series of waterfalls and plunge pools has developed over a sequence of resistant bands.

Evidence of mass movements, both recent and relict, is common in the shallow, clayey weathering residues of the volcanic rocks. Erosion gullies are rarely developed to any extent, in contrast to the deeply weathered granitic rocks. Colluvial deposits, derived from the shallow weathering profiles, are thinner than over the more deeply weathered granitic rocks.

Granitic rocks

Granitic rocks are exposed over about 28% of Hong Kong. Granite forms the lower, more rounded hills and is generally characterised by a more subdued topography than that developed on the volcanic rocks (Plate 2.12), as it is less resistant to weathering. Most of the main urban areas of Hong Kong are built on granitic rocks, especially the heavily urbanized Kowloon Peninsula (九龍半島), and the new towns of Tsuen Wan (荃灣)and Sha Tin (沙田) and granodiorite underlies most of Tai Po (大埔). Granite bedrock forms areas of moderate relief, with amplitudes of generally less than 70 m. Weathering mantles and soils are generally thicker than on the volcanic lithologies, there is commonly less evidence of mass movements, although gully erosion is more common. The distinctive scenery of granitic rocks makes up the landscapes in the western New Territories (新界),



Plate 2.12 - Typical rounded topography and prominent sheeting joints in granitic terrain, Po Toi Island (蒲台島)



Plate 2.13 - The granitic terrain of north Kowloon (九龍) and the Lion Rock (獅子山) Ridge



Plate 2.14 - Granite tor in Kowloon (九龍)

the central New Territories (新界) from Tsuen Wan (荃灣) to Sha Tin, the Kowloon peninsula (九龍半島) and Lion Rock (獅子山) ridge (Plate 2.13), the northern and central parts of Hong Kong Island (香港島) from Happy Valley (快活谷) to Shau Kei Wan (筲箕灣), and on southern Lamma Island (南丫島) and southern Lantau Island (大嶼山). Granite is believed to underlie most of the offshore area in central and western Hong Kong.

The granitic rocks in Hong Kong are high level granites that were originally emplaced perhaps to within 1 km of the surface. They were probably unroofed by the earliest Cretaceous Period and have been weathering since then. Humid subtropical deep weathering throughout most of the Tertiary Period has created the thick weathered profiles. Granite landscapes are therefore characterised by rounded summits with long convex upper slopes. Many ridgecrests and side slopes from which the vegetation has been cleared, are gullied by erosion of the granular weathered material. Exposures of relatively unweathered bedrock are common, forming tors in the landscape (Plate 2.14). Tors occur in a variety of topographical situations, such as ridge crest, spur end and valley side features. Rounded granite boulders commonly litter the landscape (Plate 2.15). They usually originate as exhumed corestones, following removal of the finer weathered matrix by erosion, or by freefall from free faces and tors. Boulders are common on ridgelines and open slopes, but characteristically choke valley lines forming boulder trains down slopes.

Mass movements are less common than on the more clayey, less freely drained volcanic rocks. However, colluvial deposits are generally thicker over the granites. This suggests that there must have been a greater degree of past mass movement associated with the deeply weathered granitic terrain.

Several interesting landscape features are developed on the intrusive igneous rocks that occur around Hong Kong. For example, large-scale sheet jointing parallel to the smooth hill slopes can be seen on the eastern side of the Cape D'Aguilar Peninsula (鶴咀半島) above Shek O



Plate 2.15 - Abundant corestone boulders in granitic terrain, Po Toi Island (蒲台島)



Plate 2.16 - Sheeting joints in granitic terrain, Southwest Po Toi Island (蒲台島)

(石澳), on coastal slopes of Po Toi Island (蒲台島) and Chi Ma Wan Peninsula (芝麻灣半島) (Plate 2.16), and Mount Butler (畢拿山) on Hong Kong Island. Exposed quarry faces at Mount Butler clearly reveal a decrease in the separation of joints towards the summit. Master joints in granite have been eroded out around many sections of coastline to produce slot caves. Feldsparphyric dykes in the northeast of Lantau Island have weathered differentially to produce a distinctive lineated topography, characterised by prominent ribs, ridges and ledges that are oriented in an east-northeast direction. The centres of the dykes have resisted weathering, in contrast to their chilled margins and to their host granite lithologies, so that the central sections of the dykes form ridges. These ridges comprise coarse, joint-bounded blocks that topple and collapse to feed debris streams and sheets on the flanking slopes. The rectilinear grain, which can be clearly seen on aerial photographs, has given rise to a trellised drainage pattern that contrasts markedly with the radial patterns on the adjacent granitic hills.

Sedimentary rocks

Sedimentary rocks are only exposed over about 5% of the onshore area of Hong Kong. They mostly occur in the northern and northeastern New Territories (新界), where they form the intricate and varied scenery of the outlying islands (Plate 2.17).

Marble occurs as a subcrop below part of the Yuen Long (元朗) plain, Ma On Shan (馬鞍山) new town, and Tung Chung New Town (東涌新市鎮). The carbonate rocks are a continuation of extensive limestone and marble outcrops across southern China (Sweeting, 1986, BGMRGP, 1988), and which crop out to the west and north of Hong Kong, around Zhaoqing (肇慶) Yunfu (雲浮), Yangchun (暘春) and Shenzhen (深圳).

Bedding in the rocks give a clear grain to the topography, forming pronounced and continuous ridges and a trellised drainage pattern. Vertically dipping rocks, as at Bluff Head (沙塘口山), form a distinctive ridgeline along the northern shore of the Tolo Channel (赤門).

Superficial Deposit

Quaternary deposits mantle about 11% of the land surface, while reclamations make up about 5% of the onshore area of Hong Kong. Colluvium blankets most slopes, but in many areas it is too thin to be mappable. Mapped deposits, greater than 2 m thick are thickest on the footslopes. They form extensive deposits over the base of Lion Rock (獅子山) ridge (Plate 2.12), and also in Mid-Levels (半山區), on the slopes of Fei Ngo Shan (飛鵝山), and other large hill masses in the New Territories (新界), such as below Castle Peak (青山), Tai Mo Shan (大帽山) and on Lantau Island (大嶼山).

Colluvium is thickest over the granites, derived from thicker and deeper weathering profiles, but is thinner over the less deeply weathered volcanic rocks.

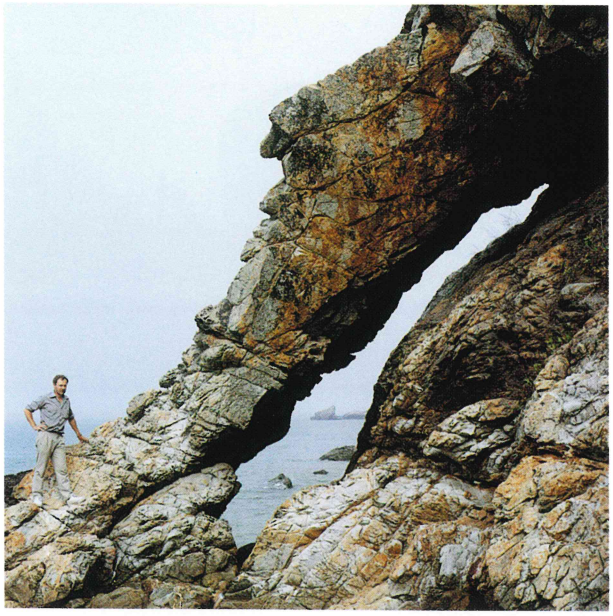


Plate 2.17 - Arch formed in quartz sandstone, (Tai O Formation) Tai O (大澳)

Alluvium fills the stream and river valleys in Hong Kong, forming distinctive dendritic patterns on the geological maps.

Coastal morphology

The morphology of the Hong Kong coastline is broadly controlled by the orientation, or aspect, of the coastal section and the characteristics of the onshore geology, described above. Aspect determines the relative exposure to the dominant or prevailing wave direction. Wave action on exposed shores tends to be destructive, in contrast to sheltered shores that experience a more constructive environment. Weathering patterns, and the alignment of many valleys, bays, channels and coasts, are controlled by the well-defined structural trends. These comprise the main northeast and secondary northwest trends. The extensive alluvial lowlands in the northwest New Territories (新界) form the low-lying, muddy, mangrove-fringed shores of Deep Bay (后海灣) (Plate 2.18). Sedimentary rocks give rise to the intricate headlands, bays and sandy shores in the northeast, around Mirs Bay (大鵬灣) and along the Tolo Channel (赤門). To the south, erosion of the granitic and volcanic rocks has resulted in the development of steep cliffs that are commonly fronted by rocky wave cut platforms and boulder-strewn beaches.

The distinctive morphology of the coastal regions is largely determined by their position relative to the main fluvial influences, in particular those from the Pearl River (珠江), and the main oceanic regimes. Hence, in the northwest the muddy shores and sheltered mudflats have been created by sediments from the Sham Chun (深圳) and other local rivers, that introduce a colder, brackish, low salinity influx. The rocky shores in the southwest are

similarly influenced by the Pearl River. This region is characterised by long, gently sloping coasts and several tombolos between islands. In the northeast, in Mirs Bay and Tolo Harbour (吐露港), the coasts are depositional and predominantly sandy. They are affected by the highly seasonal discharges from local rivers, but the major influence is the warm, silt-free, highly saline oceanic waters that predominate in the winter dry season. In the southeast, the rocky coast is fully exposed to the prevailing wave action that maintains the steep cliffs by active erosion.

In Deep Bay, the coastal area comprises low-lying mudflats and brackish back-swamps (Plate 2.18). Mangroves fringe the shoreline and the mudflats are a refuge for a wide variety of crustaceans and other fauna. This is the most important mangrove habitat in Hong Kong (Pitman & Peck, 1979). Accretion of sediment around the roots of the mangroves has led to a seaward extension of the mudflats and, consequently, of the coastline. To the south and around the southern coast of the western New Territories (新界), the granite of the Castle Peak (青山) area forms a shoreline of low relief. The island of Sha Chau (沙洲) is a tombolo, comprising two islets of granite connected by a sand spit. The sand forming this feature has largely been excavated as a source of fill.

The northern coast of Lantau Island (大嶼山) comprises natural cliffs of volcanic and sedimentary rocks with a few small beaches developed in bays. Stretches of this coast have been reclaimed for the new airport at Chek Lap Kok (赤鱲角) and related infrastructure. On the southern coast of Lantau Island, the shoreline is less steep and beaches are more common. The most extensive beach, at Cheung Sha (長沙), is one of the longest in Hong Kong. The morphology of this beach is characteristic of many in Hong Kong, exhibiting a single berm with a mature high level beach deposit inland (Pitman & Peck, 1979).

Between Lantau Island and Hong Kong Island (香港島), there are a number of small rocky islands, mainly composed of granite intruded by rhyolite dykes. The islands are surrounded by steep cliffs and generally have rounded tops. In some cases the coastlines are characterised by large boulders that have toppled off the



Plate 2.18 - Mudflats with mangroves, and tidal channels, Deep Bay (后海灣)

steep sides of the islands. The island of Cheung Chau (長洲), which comprises two granite hills connected by a sand spit, is the best example of a tombolo in Hong Kong (Plate 2.19).

Hong Kong Island has a similar coastline to that of Lantau Island. Much of the northern shore is now reclaimed. The beaches in Deep Water Bay (深水灣), Repulse Bay (淺水灣) and Big Wave Bay (大浪灣) are the most significant depositional features. Like most of the beaches around Hong Kong, these are formed on coasts with a southerly aspect that face the prevailing wind and waves. By 1991, the beaches in Repulse Bay, Middle Bay (赤洲口) and South Bay (南灣) had deteriorated due to sand loss in storms and typhoons. Consequently, a beach replenishment programme was begun (Davies *et al.*, 1996), using seabed sand from the south of Tsing Yi (青衣). In the south, the peninsulas of Stanley (赤柱) and Cape D'Aguilar (鶴咀) have a rounded topography surrounded by steep clifflines, often fringed with accumulations of fallen boulders. Similar beaches of angular boulders are found on gently inclined shorelines such as at Boulder Point (北角) on the northern coast of Lamma Island (南丫島), and around the Fan Lau peninsula (分流) on Lantau Island (Plate 2.20).

The coastlines in eastern waters are formed in almost vertically jointed ash-flow tuffs. This characteristic jointing leads to the development of high cliffs with natural arches and caves. The tallest cliffs in Hong Kong occur around Bluff Island (黃麻角), where they exceed 140 m in height. Arches and caves occur both above and below sea level. Several shallow underwater caves exist off the coast and on islands from Basalt Island (火石洲) northwards to Tai Long Wan (大浪灣). An underwater cavern runs east-west through the entire width of the island of Tai Chau (大洲) in Tai Long Wan.

To the north, rocky wave cut platforms are developed (Plate 2.21) on the northeastern coast of the New Territories (新界) and around Crooked Island (吉澳洲), Crescent Island (娥眉洲) and Double Island (往灣洲). Owen (1995) described two types of platform: sub-tidal



Plate 2.19 - Inter-island tombolo, Cheung Chau (長洲)



Plate 2.20 - Coastline strewn with fallen granite boulders, Fan Lau (分流) peninsula, Lantau Island (大嶼山)

and supra-tidal, both of which generally slope gently seawards and are backed by steep clifflines.

Sub-tidal platforms are present around Ping Chau (平洲) in the eastern part of Mirs Bay and also to the south at Hok Tsui (鶴咀), both of which are open to direct wave action from the South China Sea (南中國海). High energy wave action has eroded a platform and redistributed the eroded material locally. Large blocks of chert from the sub-tidal platform on Ping Chau are found further shoreward on the platform, a process that would only be possible in typhoons or due to tsunamis.

Supra-tidal platforms are found in more sheltered areas such as around the shores of Double Haven (印洲塘). Here salt weathering and capillary action, occurring in the splash zone, have affected the volcanic rocks. The platforms are characterised by a narrow bench sloping seawards and a wave cut notch at the base of the cliff.

Evidence of sea level change

The landscape of Hong Kong has the distinct appearance of a recently drowned mountain range. This is particularly noticeable in the southeast where the hillslopes plunge directly into the sea with no coastal plains or wave cut benches to suggest that prolonged coastal erosion has occurred. The limited erosion that has been accomplished has only succeeded in over-steepening the hillslopes to form steep fringing cliffs. Similarly, most of the drainage lines in the area appear to be truncated. Extensive deposition in the drowned coastal extremities of the streams has formed large areas of alluvial flats around the coastline.

Onshore and coastal evidence for changing sea levels in Hong Kong was first discussed by Kingsmill (1865). Sea level change has subsequently been discussed by many authors in the context of archaeology (Heanley & Shellshear, 1932; Schofield, 1940), raised beaches (Brock & Schofield, 1926; Heim, 1929; Williams *et al.*,1945), or in relation to East Asia (Schofield, 1943). Schofield described an Asian regional sea level at about +1 mPD, discussing evidence for this in Tolo Harbour. Allen and Stephens (1971) described widespread occurrences of turf-covered alluvium around the coastline of Hong Kong. These features, at between 1 to



Plate 2.21 - Rock platform, Ping Chau (平洲), Mirs Bay (大鵬灣)

2 m above High Water Mark, and from 1 to 10 m wide, were found to be best developed on the southern shore of Starling Inlet (沙頭角海) and at several localities in the east around Mirs Bay.

Schofield (1943) discussed raised beaches at between +5 to +6 mPD and also at about +15 mPD in Southeast Asia, and Berry (1961) cited evidence for raised beaches at these levels in Hong Kong. Schofield (1943) noted a marine bench at +20 mPD, comparing it with similar platforms in Singapore and river terraces along the lower Yangtse (長江) River. Berry (1961) later wrote of a marine bench at +20 mPD, and others at +40 mPD and +71 mPD.

Several additional lines of evidence support the concept of drowning of the topography due to a rise in sea level. The most convincing evidence, which was first pointed out by Berry (1961) from borehole evidence in the harbour area, is that subaerial weathering of the granite has taken place prior to submergence. Extensive offshore seismic surveys have confirmed the widespread existence of this weathered mantle (Strange & Shaw, 1986; Fyfe *et al.*, 1997a). Deep weathering must, therefore, have occurred over a very long time span and would also have required a considerable period of emergence.

Other authors have pointed to evidence of subaerial emergence, although this could be accounted for by exposure during the Pleistocene sea level lowstands. For example, Berry (1961) remarked upon a buried platform at between -11 to -13 mPD, Williams *et al.*, recorded peat in boreholes at -30 mPD, and Berry (1961) discussed stream action at -60 mPD.

Recent work around Yuen Long (元朗) (Frost, 1992) has shown that the buried marble bedrock surface descends to a maximum of -80 mPD beneath the Yuen Long Plain. Below this, the marble is weathered and dissolved with widened joints and solution cavities extending to depths of 60 m below the epikarst surface. This indicates prolonged subaerial exposure, at a relative sea level at least 100 m, and perhaps even up to 140 m, below that at present. Dating of the base of the thick, overlying superficial deposits suggests that doline formation ceased about 50 000 years BP.

Seabed morphology

The seabed topography of the offshore area of Hong Kong is shown on Map 1, and is generalized in Figure 1.2 (Chapter 1).

Seabed morphology in the western part of Hong Kong waters is largely controlled by the location of the tidal channels. Narrow straits between the islands and the mainland cause constriction of the tidal currents with a consequent increase in their velocity. Similar funnelling also occurs between islands in the east, scouring the sediments, but these features are more localized.

Deep Bay (后海灣) to Kap Shui Mun (汲水門)

The English name, Deep Bay (后海灣) is a misnomer, as the water depth nowhere exceeds 5 m. The bay is a sheltered inlet on the eastern margin of the Pearl River Estuary (珠江口) with a relatively large catchment. Intertidal channels occur along the eastern margin of the bay, where the Sham Chun (深圳) and Shan Pui (山背) rivers discharge fresh water into the bay. Both the northern and southern shores of Deep Bay comprise mudflats with mangroves. Prior to reclamation and the creation of ponds in the last century, the mudflats were more extensive and tidal influences extended further inland. The Kam Tin River (錦田河) was navigable as far as Kam Tin Village (錦田村). In the north, to the east of the Shekou Peninsula (蛇口半島), a small delta marks the mouth of the Tai Sha River (大沙河).

Southwest of Deep Bay, the major topographical feature is the Urmston Road Channel (龍鼓水道). This feature is the southern extension of the Fanshi Channel (矾石水道) of the Pearl River Estuary (珠江口) that passes over a topographical high into the Brothers Channel (大小磨刀海峽) to the east. In the central part of Urmston Road Channel, off Black Point (爛角咀) and Tap Shek Kok (踏石角), the water depth reaches over 20 m where the tidal current is strongest.

Between the Urmston Road Channel and the northern coast of Lantau Island (大嶼山), the stretch of shallow water represents the submarine interfluve between the Urmston Road and Lantau channels. A number of islands occur in this area. West of Lung Kwu Chau (龍鼓洲), a bathymetric hollow descending to below -10 mPD marks local erosion of the seabed near the island. A similar deep runs between Sha Chau (沙洲) and Tree Island (白洲).

Over most of the area to the south, the water depth is around 5 m, which reflects both the sheltered position of the region and the high sediment input at the mouth of the Pearl River Estuary. Development of the new airport has reclaimed much of the sea area west of Chek Lap Kok (赤鱲角).

To the west, the floor of the northern extension of the Brothers Channel (大小磨刀海峽) reaches a depth of -20 mPD off Brother Point (大欖角). North of Ma Wan (馬灣), the water depth in the middle of the channel exceeds 40 m. North of Tsing Yi (青衣), in the Tsing Yi Channel (青衣海峽), the water reaches a depth of 15 m. The effects of flood and ebb channels through this gap have been discussed by Evans (1986). Strong tidal flow continues eastwards and passes through the Rambler Channel (藍巴勒海峽), the floor of which is scoured down to rock.

Kap Shui Mun (汲水門) to the West Lamma Channel (西博寮海峽)

The most significant features in this area are Kap Shui Mun (汲水門) and the Ma Wan Channel (馬灣海峽). The floors of both channels are scoured to bedrock, to a level of below -40 mPD. Strong tides sweep through these channels, both in flood and ebb. Southwards they merge to form the wide trough that divides to form the East Lamma (東博寮) and West Lamma channels (西博寮海峽).

The seabed to the east and south of Lantau Island (大嶼山) is generally featureless, sloping gently to the south. South of Cheung Chau (長洲), the seabed is disturbed and subject to continual modification as the gazetted mud disposal ground is extended. The Lantau Channel (大嶼海峽) to the west is a continuation of the Lingding Channel (伶仃洋) of the Pearl River Estuary (珠江口). A moderate submarine slope extends seawards from below the steep cliffs of Lantau Island's west coast towards the channel. Currents on the south coast of Lantau Island have created a deep to the south of Kau Ling Chung (狗嶺涌).

The gentle southerly slope of the seabed south of Lantau Island is interrupted by the Soko Islands (索罟群島). Water movements around the islands are influenced by tidal currents and the southeasterly monsoon. Strong currents have prevented deposition down to over -20 mPD. A low rise occurs in the strait between Siu A Chau (小鴉洲) and Lantau Island. The area between this and the Lantau Channel is shallow due to siltation in the sheltered area northwest of the Soko Islands. Prior to dredging, an elongate bank of fine sand extended westwards from Siu A Chau (小鴉洲).

A similar northeast-trending channel occurs between the island of Shek Kwu Chau (石鼓洲) and the Chi Ma Wan Peninsula (芝麻半島). Several bathymetric lows occur between Lantau Island and the outlying islands of Peng Chau (平洲) and Hei Ling Chau (喜靈洲), in areas where constriction of the tidal flow has maintained shallow channels. The remainder of the seabed in this area is largely featureless, following the regional southerly slope.

The East Lamma and West Lamma channels are important tidal conduits. The West Lamma Channel has been scoured to a depth of over 30 m. Water depth in the East Lamma Channel reaches a maximum of 40 m, and current velocities of up to 0.5 m s^{-1} are attained. Near the centre of the channel, to the southwest of Ap Lei Chau (鴨

刪洲), the Hang Hau Formation has been eroded to reveal a window of Chek Lap Kok Formation sediments.

Victoria Harbour (維多利亞港) to Waglan Island (橫瀾島)

The western entrance to Victoria Harbour (維多利亞港) is marked by a natural deep water channel that runs northwestwards from the East Lamma Channel (東博寮海峽) towards the Rambler Channel (藍巴勒海峽), east of Tsing Yi (青衣島). Kellet Bank (奇力灘), to the northwest of Hong Kong Island (香港島), is a seabed high between this channel and a southeasterly directed branch through Victoria Harbour (Chalmers, 1984). The summit of the bank shallows to -5 mPD. In contrast, the Sulphur Channel (琉磺海峽) between Hong Kong Island (香港島) and Green Island (青洲) is over 20 m deep.

The former seabed below the sites of the West Kowloon Reclamation (西九龍填海) and Container Terminal 8 was less than -10 mPD. This area was sheltered from the effects of the southeasterly monsoon and tidal streams. Within Victoria Harbour the water depth is generally around 15 m. However, between Hung Hom (紅磡) and Causeway Bay (銅鑼灣) the channel reaches a depth of over 20 m and an inlier of the Chek Lap Kok Formation is exposed at the seabed. This is also the site of early marine sand dredging for the Kai Tak Airport extension (啓德機場擴建) (Henry *et al.*, 1961).

Kowloon Bay (九龍灣), to the north of Victoria Harbour, is sheltered and the water depth is less than 10 m. In the Lei Yue Mun (鯉魚門海峽) channel, at the eastern entrance to Victoria Harbour, the water is over 40 m deep and the seabed sediments are scoured to reveal a window of bedrock. On the eastern side of Hong Kong Island (香港島) the steep coastal cliffs descend to the seabed at about -10 mPD. From this level the seabed shelves steeply to round -15 mPD, and a gentle slope declines to the floor of the Tathong Channel (藍塘海峽) at about -20 mPD.

Sheung Sze Mun (雙四門), north of the Po Toi Islands (蒲台島), and the Beaufort Channel (螺洲門), between Po Toi Island and Beaufort Island (螺洲), are bathymetric deeps descending to below -60 mPD. The Beaufort Channel is the deepest point of the shelf in the waters around Hong Kong. Tidal streams in these channels reach velocities of 0.5 m s^{-1} and have deeply scoured the sediments of the Hang Hau and Chek Lap Kok formations. In the centre of Sheung Sze Mun, superficial sediments are absent and bedrock of unknown lithology floors the channel.

Port Shelter (牛尾海) and Eastern Waters

The eastern coastline of the New Territories (新界) is fringed by rocky cliffs that plunge down to a generally flat seabed at around -20 mPD. At Long Ke Wan (浪茄灣) and Tai Long Wan (大浪灣), the coastal zone slopes gently from wide beaches to a seabed at around -20 mPD. North of High Island (糧船灣), the seabed maintains an almost constant elevation northwestwards to the dam that blocks the former inlet.

Along the north of this area, Nam She Wan (蚺蛇灣) and Long Harbour (大灘海) similarly shelve gently. The bays off the Tolo Channel (赤門) are generally shallower than those in the east, which have a more open aspect. Three Fathoms Cove (企嶺下海) is mostly less than 10 m deep, except between the mainland and the islands of Bun Sha Pai (磞沙排) and Che Lei Pai (扯犂排) where there is a deep of below -20 mPD that is maintained by currents passing through the constriction.

In the southwest, around Inner Port Shelter (西貢海), the cliffs plunge down to -10 mPD near the coast and then gently shelve away out into the bay. The greater part of this area lies at between -20 mPD and -30 mPD, indicating a depositional surface that is in hydrodynamic equilibrium in a slightly more sheltered area than that to the south.

Around the islands in this area, the steeper coastline occurs on the east. Along the sheltered northwestern shores of these islands, the submarine slope is more gentle than on the exposed southeastern coast. This is attributed to preferential deposition in the quieter waters to the lee of the islands.

A number of submarine highs occur in eastern waters. The most significant feature is Victor Rock (七星排), which has very steep sides that plunge to the surrounding seabed at between -25 and -30 mPD within a few hundred metres of the rock.

Tolo Harbour(吐露港) to Mirs Bay (大鵬灣)

Tolo Harbour (吐露港) has a water depth of between 5 and 15 m. The seabed slopes from around -5 mPD just off the coast to -15 mPD in the centre, deepening along the Tolo Channel (赤門). South of Harbour Island (白沙頭洲), which is now incorporated into the southern wall of Plover Cove Reservoir (船灣淡水湖), there is a small channel with a floor at -25 mPD and an exposure of Chek Lap Kok Formation sediments in the deeper part.

Along the coast to the north and off Grass Island (塔門洲) and Port Island (赤洲), the coastal cliffs drop steeply down to around -10 mPD. Off Double Island (往灣洲), Crescent Island (蛾眉洲) and Kat O Chau (吉澳洲), there is an extensive shelf at around -5 mPD. The bays that make up the western sides of Double Haven (印塘洲) and Crooked Harbour (吉澳海) are all less than 10 m deep. They are clearly sheltered from waves and currents, allowing the accumulation of thick sediments.

There are deeps between some of the islands, which are kept open by currents. In particular the floor of the strait between Crescent Island and Kat O Chau (吉澳洲) is below -20 mPD. Grass Island and Port Island (赤洲) both exhibit depositional tails to the east. This contrasts with the features seen to the south, where the dominant

current direction is from the southeast, associated with the Tolo Channel.

Starling Inlet (沙頭角海) is a sheltered inlet with a relatively small catchment. The seabed shelves gently from the coast into water less than 10 m deep. The drainage pattern in the New Territories (新界) is very asymmetrical. Streams that originate in Starling Inlet flow west towards Deep Bay (后海灣).

There is a localized deep, at -10 mPD, between the mainland and Sai Ap Chau (細鴨洲), caused by currents in the restricted passage. Few features of interest interrupt the monotonous regularity of the seabed in the extreme east. Young Hebe Shoal (澳北淺灘) is the exception, the shallowest point of which is -5.5 mPD. This compares with the surrounding seabed which has a depth of around -14 mPD.

The main bathymetric features of interest are around the islands of Ping Chau (平洲) in the north and Shek Ngau Chau (石牛洲) in the south. Breaker Reef (浪花排) in the south dries to +1.5 mPD. The flanks of these islands slope steeply down into the soft sediment, to a surrounding seabed that is generally flat. The rock platform around Ping Chau extends to a depth about -15 mPD.

3. Weathering and erosion

Hong Kong is situated in the subtropical zone, close to the Tropic of Cancer, between latitudes 22° 09' N and 22° 37' N (Figure 1.1). The area experiences a subtropical monsoonal climate (Chin, 1986), which is hot and humid with a markedly seasonal rainfall. These climatic conditions result in large fluctuations in runoff and periodic saturation of the regolith that covers the solid rocks. There is extreme variability in the rates and extent of weathering and erosion, and consequently, the thickness of the regolith in Hong Kong. To formulate geological models that adequately represent these variations, and so ensure effective engineering in Hong Kong, a thorough understanding of the genesis and preservation potential of weathering profiles is essential.

The main causes of variation in regolith thickness are rock type, structure, prevailing slope angle, hydrogeology and the nature and extent of erosion. The weathered mantle is generated by differential breakdown of the minerals that constitute the bedrock. Some minerals, most notably quartz, survive weathering with little or no modification, whereas others, such as feldspar and the ferromagnesian minerals biotite and hornblende, are usually completely transformed, mainly to clay minerals.

Erosion comprises the processes of detachment of *in situ* materials by a variety of processes at and near the land surface, and includes their removal and eventual deposition elsewhere. The main agencies of detachment are those associated with physical and chemical weathering. Biological factors, such as root penetration are also important. Processes of removal are commonly associated with down-slope movement of surface and groundwater. In Hong Kong, the most active agencies of detachment and down-slope transport are mass transport and mass wasting. Although mass movement in general is often excluded from definitions of erosion (e.g. Gary *et al.*, 1972), some authors (e.g. Holmes, 1978, Selby, 1993) regard it as a component of erosion and this approach is preferred here.

Weathering processes

Weathering processes initially attack all rock faces exposed at the surface of the earth, gradually penetrating downwards, preferentially along joints, faults and other discontinuities that allow easy ingress to rainwater, and passage of groundwater. Weathering causes physical and chemical changes in the rock material that steadily progress inwards from joint faces to affect the mineralogy of the entire rock mass.

The seasonally hot and humid environment of Hong Kong promotes active chemical weathering of the rocks by oxidation, hydrolysis, and solution of the constituent minerals. Related physical weathering processes include volume changes of the mineral crystals as they are chemically weathered, repeated wetting and drying of the rock and stress relief jointing, or exfoliation, as a consequence of the removal of the overlying load by weathering and erosion. Exfoliation also occurs at the outcrop scale, creating subconcentric shells around corestones and boulders (Plate 3.1). Essentially, therefore, the corestones are less decomposed remnants of the rock mass, supported by a matrix of generally highly to completely decomposed material. The matrix, except where residual soil, contains relict joint structure and may also contain relict corestones, usually identifiable by concentric colour banding. At the rock mass scale, exfoliation is manifested by the phenomenon known variously as stress relief jointing, sheet jointing, unloading joints, and topographical jointing (Plate 2.16) (Twidale, 1982). The lattermost term derives from the characteristics of rock masses to develop extensive joint surfaces that are sub-parallel to the topography, and that increase in their spacing with depth into the rock mass. In Hong Kong, these joints are most evident in igneous rock masses. Weathering profiles can vary considerably in their characteristics, generally as a function of rock mineralogy, rock texture, rock structure, topography, the rate of erosion, the groundwater regime, and characteristics of the microclimate. Hydrothermal alteration, which occurred particularly during the emplacement of the volcanic and granitic rocks, is an additional factor affecting the results of later weathering in many areas, although its distinction from the effects of more general weathering in Hong Kong is often difficult.

Rock weathering classification

Rock weathering has important geotechnical implications in Hong Kong. Several authors have examined the mineralogy of weathered rocks (Brock, 1943; Ruxton,



Plate 3.1 - Well-developed corestones in quartz monzonite, Tai Miu Wan (大廟灣)

1968; Parham, 1969; Lumb & Lee, 1975), while others have focused their attention on the specific geotechnical properties of weathered rock materials (Lumb, 1962, 1965; Irfan & Powell, 1985; Irfan, 1996). Two main methods are used to classify the weathering of rocks in Hong Kong. The first grades the material in terms of its relative decomposition whereas the second assesses the weathering of rock masses.

Material decomposition

Weathered rock material is usually classified in terms similar to those first used in the descriptive scheme of Moye (1955). A six-fold scheme for classifying the weathered granitic material encountered in Hong Kong in terms of rock material decomposition grades (I to VI), was presented by the GCO (1979) in a geotechnical guidance document. This scheme, which was later extended to include volcanic and sedimentary lithologies (GCO, 1988) (Table 3.1), adopted the term decomposition in preference to weathering. This is because of the relative dominance of chemical decomposition in Hong Kong rocks.

Beggs and Tonks (1985) compiled a four-fold scheme to classify weathered sedimentary and metamorphic rocks encountered in the Yuen Long (元朗) area. Following the discovery of buried marble below Yuen Long, Shaw (1990b) proposed a four-fold scheme for classifying this soluble lithology for logging purposes.

Rock mass weathering

Ruxton & Berry (1957) devised a broad four-fold zonal scheme to describe and classify granitic weathering profiles in Hong Kong (Table 3.1). The model (Figure 3.1a) was based on the concept of a gradually increasing percentage of corestones down the profile. This was adopted as a basis for engineering classification in Hong Kong (GCO, 1979, 1984). The model has been revised and modified as larger and more numerous exposures, higher cutslopes and deeper excavations were formed in Hong Kong. For example, Gamon and Finn (1984) (Figure 3.1b) published a model that described the largely corestone-free granite exposures revealed during a major excavation project for an urban development at Kornhill (康怡花園), on Hong Kong Island (香港島). Similar profiles also occur in fine ash tuffs, including the Ap Lei Chau and Che Kwu Shan formations on Hong

GCO (1988) Rock Material Description	GCO (1988) Rock Material Grades	GCO (1988) General Characteristics	Ruxton & Berry, (1957) Zone	Ruxton & Berry, (1957) Pedological Horizon	GCO (1988) Rock Mass Weathering Zones	
Residual Soil	VI	Original rock texture completely destroyed Can be crumbled by hand and finger pressure into constituent grains	I	Residual Debris	Residual Soil	RS
Completely Decomposed	V	Original rock texture preserved Can be crumbled by hand and finger pressure into constituent grains Easily intended by point of geological pick Slakes when immersed in water Completely discoloured compared with fresh rock	IIA	Residual	Partially Weathered Rock	PW 0/30 (<30% Rock)
Highly Decomposed	IV	Can be broken by hand into smaller pieces Makes a dull sound when struck by geological hammer Not easily indented by point of geological pick Does not slake when immersed in water Completely discoloured compared with fresh rock	IIB	Debris with Corestones (0-50% rock)		PW 30/50
Moderately Decomposed	III	Cannot usually be broken by hand; easily broken by geological hammer Makes a dull or slight ringing sound when struck by geological hammer Completely stained throughout	III	Corestones with Residual Soil (50-90% rock)		PW 50/90
Slightly Decomposed	II	Not broken easily by geological hammer Makes a ringing sound when struck by geological hammer Fresh rock colours generally retained but stained near joint surfaces	IV	Partially Weathered Rock		PW 90/100
Fresh	I	Not broken easily by geological hammer Makes a ringing sound when struck by geological hammer No visible signs of decomposition (i.e. no discolouration)		Bedrock	Unweathered Rock	UW

Table 3.1 - Comparison of engineering and geological schemes for classifying rock material decomposition grades and rock mass weathering zones. Precise correlations not intended

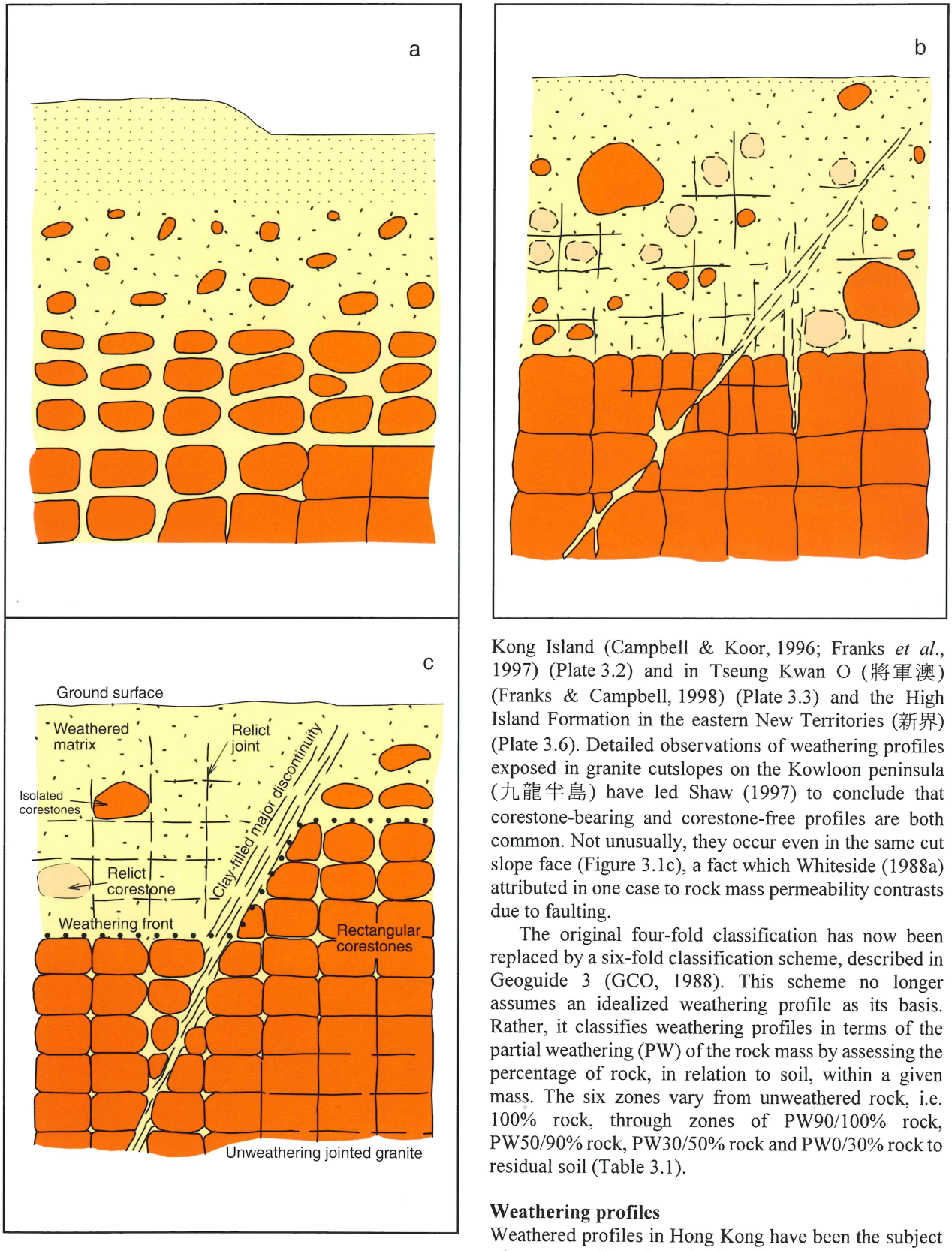


Figure 3.1 - Models of weathering profiles developed in Hong Kong, based on granitic rocks: a. after Ruxton & Berry (1957) b. after Gamon & Finn (1984) c. after Shaw (1997)

Kong Island (Campbell & Koor, 1996; Franks *et al.*, 1997) (Plate 3.2) and in Tseung Kwan O (將軍澳) (Franks & Campbell, 1998) (Plate 3.3) and the High Island Formation in the eastern New Territories (新界) (Plate 3.6). Detailed observations of weathering profiles exposed in granite cutslopes on the Kowloon peninsula (九龍半島) have led Shaw (1997) to conclude that corestone-bearing and corestone-free profiles are both common. Not unusually, they occur even in the same cut slope face (Figure 3.1c), a fact which Whiteside (1988a) attributed in one case to rock mass permeability contrasts due to faulting.

The original four-fold classification has now been replaced by a six-fold classification scheme, described in Geoguide 3 (GCO, 1988). This scheme no longer assumes an idealized weathering profile as its basis. Rather, it classifies weathering profiles in terms of the partial weathering (PW) of the rock mass by assessing the percentage of rock, in relation to soil, within a given mass. The six zones vary from unweathered rock, i.e. 100% rock, through zones of PW90/100% rock, PW50/90% rock, PW30/50% rock and PW0/30% rock to residual soil (Table 3.1).

Weathering profiles

Weathered profiles in Hong Kong have been the subject of many studies, from both geological (Berry, 1957; Ruxton & Berry, 1957; Berry & Ruxton, 1959) and engineering (Hencher & Martin, 1982; Gamon, 1983; Gamon & Finn, 1984; Martin & Hencher, 1984) perspectives. Particular attention has been paid, for

example, to zonation of weathering profiles, assessment of the proportions of rock, including corestones, and soil, i.e. matrix, and to the difficulties of identification of the base of weathering profiles.

Much of the earlier work on weathering profiles in Hong Kong concentrated on the relatively deep weathering profiles developed within granitic rocks. This was largely because of the predominance of granite in the urban areas of Kowloon (九龍) and northern Hong Kong Island. More recently, however, greater attention has



Plate 3.2 - Weathering profile in fine ash tuff (Che Kwu Shan Formation), looking west at Slope 11SE-D/C188 during its development in 1987 at Siu Sai Wan (小西灣), showing: an abrupt transition in the profile, marked by a colour change at the weathering front from grey below to orangish brown above; a major step in the weathering front towards the left, which appears to be related to a fault above which there is a drainage line on the surface; and coreslabs preserved at higher levels in the weathering profile. Kaolin occurs as infillings within sheeting joints, particularly along the weathering front, and along the upper surfaces of coreslabs, and as infillings in subvertical relict joints in the mainly completely decomposed material above the weathering front, but it is virtually absent below the weathering front



Plate 3.3 - Weathering front in volcanic rock (Che Kwu Shan Formation), Tseung Kwan O (將軍澳), showing an abrupt transition in the weathering profile. Shallowly inclined sheeting joints at the interface are infilled with white and buff kaolin (after Franks & Campbell, 1998)



Plate 3.4 - Weathering front in volcanic rock (Che Kwu Shan Formation), Siu Sai Wan (小西灣), showing an abrupt relatively planar interface with possible white kaolin infill of relict joints near base of soil profile and apparent contortion of the infills consistent with down-slope movement (after GCO, 1988)

been paid to the weathering profiles developed in volcanic rocks. This has been due partly to the expansion of Hong Kong into previously undeveloped areas on steeper slopes that are commonly underlain by volcanic rocks. In addition, further interest was generated as a result of two major landslides that occurred in fine ash tuff on Hong Kong Island in 1995 (GEO 1996a and b).

The weathering front

Definition of the base of the weathering profile is controversial and different definitions are used depending on the context in which they are applied (e.g. tunnel engineering, foundation engineering or slope engineering). For example, if it is important to identify whether or not weathering has caused any opening of joints, a strict definition of the base of weathering, i.e. separating fresh rock (decomposition grade I) from decomposed rock (decomposition grades II–VI) might be appropriate. However, extending this definition towards surface, the base of weathering will extend on either side of individual joints, sometimes for several metres, and will include the interfaces of individual corestones. Alternatively, greater emphasis may be placed on the

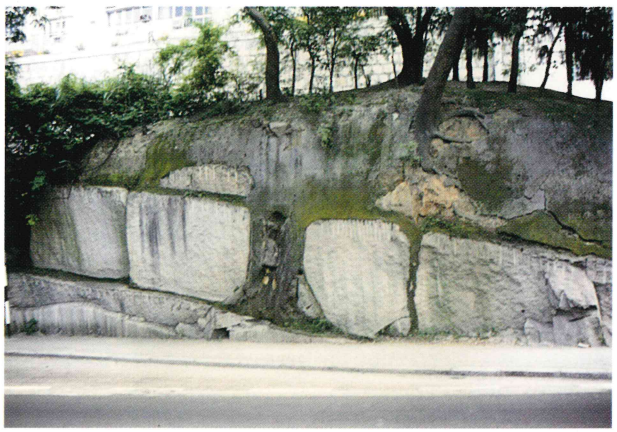


Plate 3.5 - Planar weathering front in medium-grained granite, Stubbs Road (司徒拔道), showing incipient development of coreslabs



Plate 3.6 - Fine ash tuff (High Island Formation), columnar jointed, with relatively thin weathering profile, Kwo Chau Kwan To (果洲群島)

depth in the weathering profile at which material of grade III or II becomes largely uninterrupted. This change in material decomposition grade commonly occurs at a planar interface (Figure 3.1), that often coincides with abrupt changes in rock mass weathering characteristics (e.g. from PW90/100% or PW90/50% rock, to PW50/30% or PW0/30% rock) and colour. This interface, or horizon, has been variously termed the basal platform (Linton, 1955), basal surface (Ruxton & Berry, 1961), or weathering front (Mabbutt, 1961a), the descriptive term preferred here. The horizon is also commonly described as the soil–rock interface, or rockhead. Where a more gradual transition in material decomposition grade occurs, these terms are less readily applied and interpreting the base of the weathering profile is more subjective.

The weathering profile is therefore considered to comprise *in situ* material of PW0/30% or PW30/50% rock, and mainly composed of completely to highly decomposed material (grades V and IV respectively) but with some residual soil (grade VI). This overlies the main rock mass (PW 90/100% or PW50/90% rock), mainly comprised of moderately to slightly decomposed (grades III and II respectively) and fresh (grade I) material.

Below most slopes, the base of the weathered mantle, i.e. the weathering front, is subparallel to the topography. The weathering front tends to rise nearer the ground surface below hills, which usually occur in less well-jointed rocks, and to lie deeper below fault controlled valleys, in which the weathered mantle is thicker. In many areas this surface is stepped, a phenomenon that is dependent on the geometry and infilling of the rock and relict jointing pattern. This determines the local hydrogeology, and hence the intensity of weathering and eluviation. The soil–rock interface in weathered volcanic rock profiles has been shown to be a potential site for kaolin accumulation (Plates 3.2 to 3.4).

In some fine-grained tuffaceous and sedimentary lithologies, the base of the weathered profile may grade imperceptibly into unweathered rock. However, in more massive igneous rocks, including granite and coarse ash tuffs, and in some fine ash tuffs also, a relatively abrupt contact commonly exists between completely and highly decomposed material on the one hand, and moderately to slightly decomposed on the other (Plate 3.5). Below this relatively planar interface, the weathered joints may extend for several tens of metres.

Steps in the weathering front commonly coincide with subvertical or steeply inclined faults or major joints. The change in vertical elevation of the weathering front may be 20 m or more, as described by Campbell and Koor (1996) in fine ash tuff in eastern Hong Kong Island (香港島) (Plate 3.2). Where the step is associated with a steeply inclined planar discontinuity, the hanging wall is usually the more deeply weathered (Whiteside, 1988a).

Field studies in the Kowloon peninsula (九龍半島) by Shaw (1997) showed the weathering front in medium-grained granite to be very irregular, and steps were well documented (Figure 3.1c). There is also a strong correlation between the topography of the weathering front and the main structural trends in the area (Figure 3.2). This shows that the linear, discontinuity-controlled zones of deep weathering are preferentially eroded out to create valleys and the intervening areas form the high ground.

The most irregular and abrupt weathering fronts in Hong Kong occur on buried marble in the Yuen Long (元朗) area (Figure 3.3), in the northwest New Territories

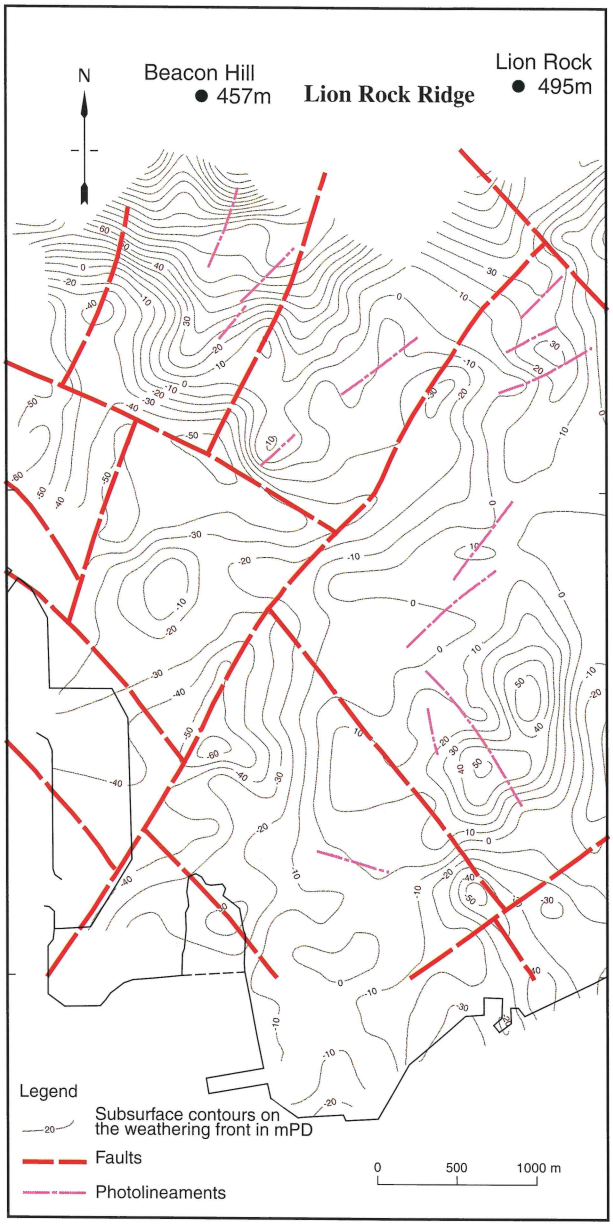


Figure 3.2 - Contours on the granite weathering front beneath the Kowloon peninsula (九龍半島), constructed from available borehole data, with the major faults and photolineaments superimposed (after Shaw, 1997)

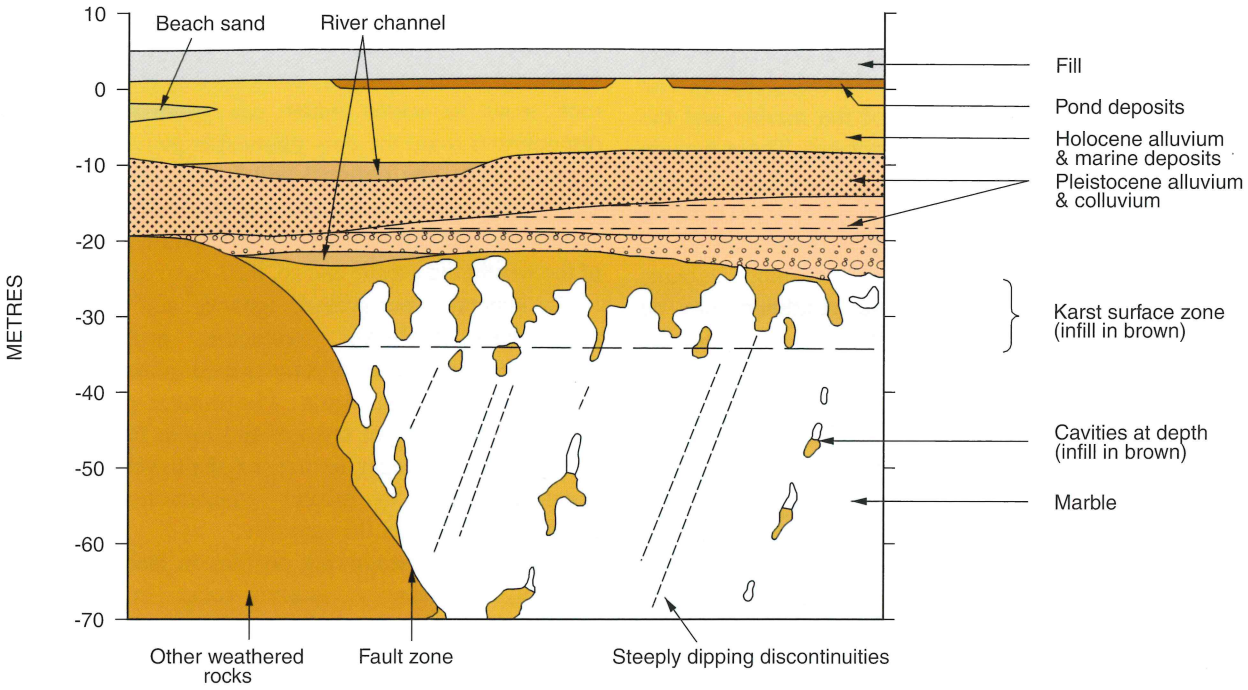


Figure 3.3 - Schematic profile through superficial deposits and weathered rock including marble, in Yuen Long (元朗) (after Langford, 1990)

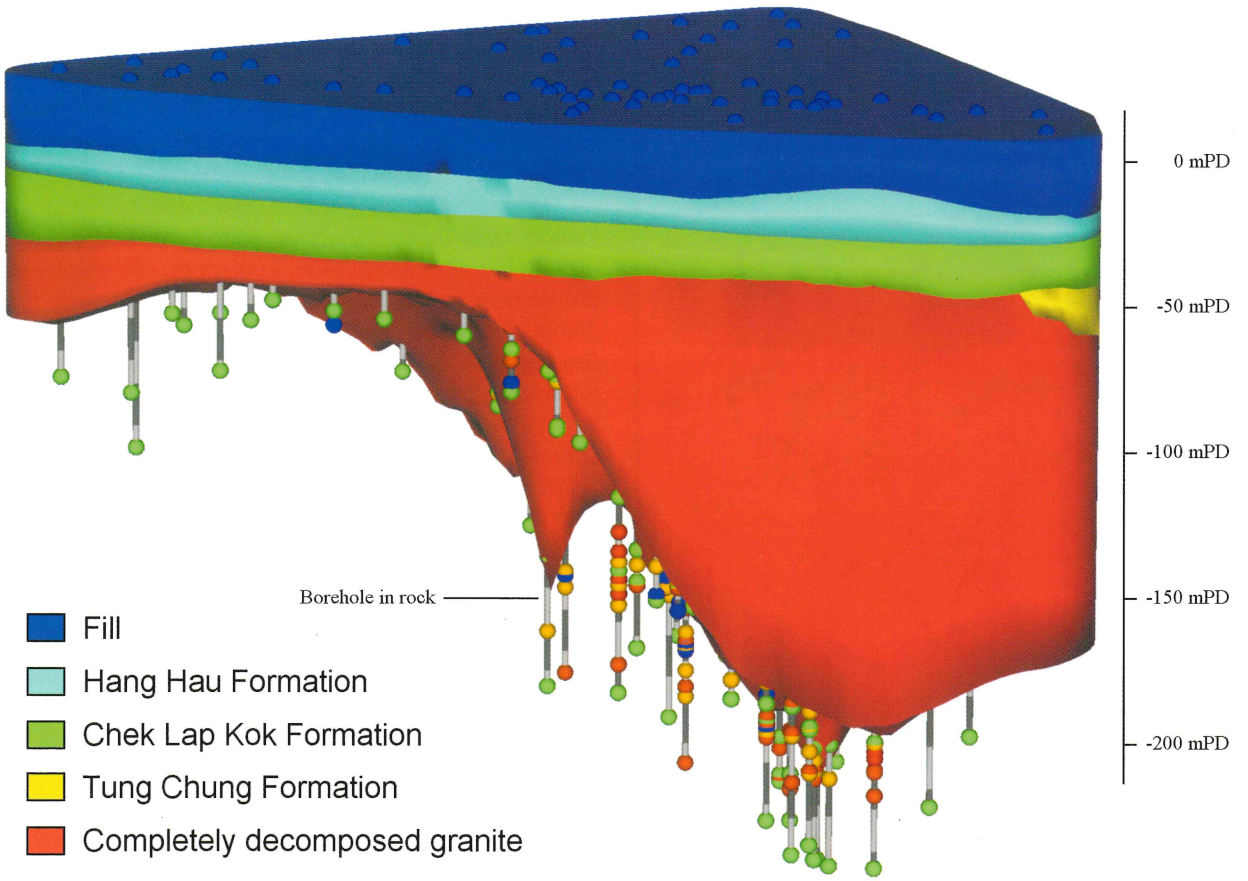


Figure 3.4 - Visualization of geology at 'Site 3', Tung Chung (東涌) Reclamation, looking north, showing the extremely deep weathering profile in mainly granitoid rocks

(新界), beneath Ma On Shan (馬鞍山), in the northeast New Territories, and in the Tung Chung (東涌) area, and locally offshore, of northern Lantau Island (大嶼山). The irregularity reflects the solution of the marble and the development of complex karstic surfaces. These include some deep-seated cavities that interconnect through complex arrays of discontinuities (Figure 3.3). There are thin *in situ* soils overlying the marble in these areas, as the marble weathers by solution, leaving only minor amounts of residual material. Much of the residuum may be transported down into the marble where it may gradually infill cavities (Figure 3.3).

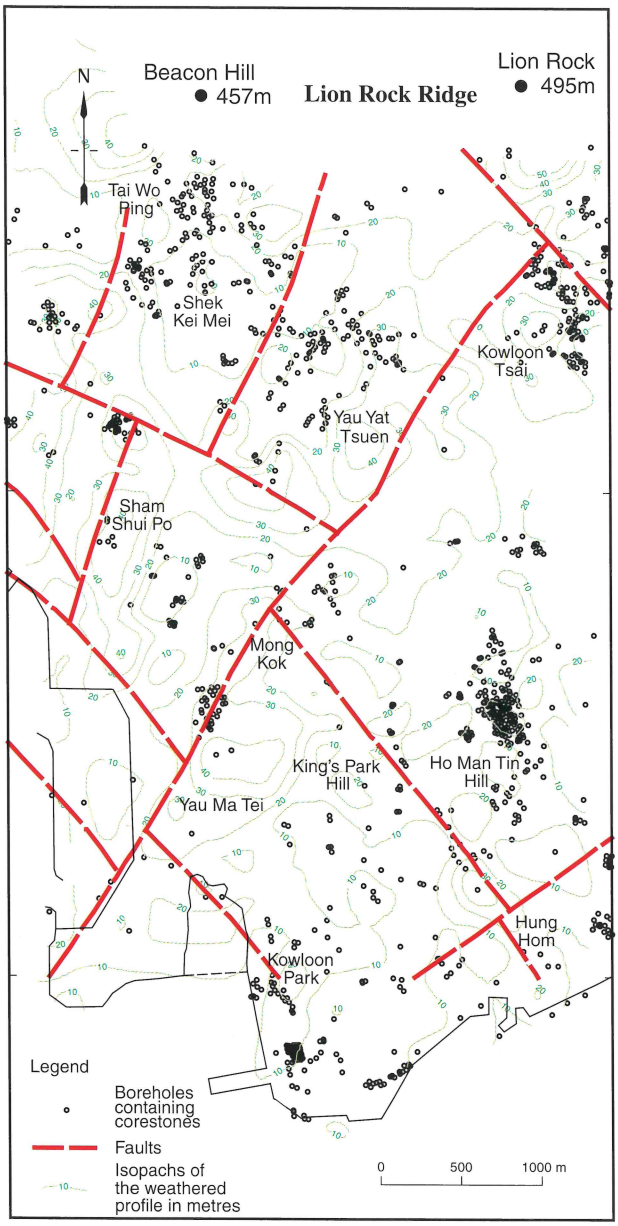


Figure 3.5 - Weathering profile thickness in granite, corestone occurrences in boreholes, and the main structural trends in the Kowloon peninsula(九龍半島) (after Shaw, 1997)

Weathering depths

The base of weathering, and hence the thickness of the weathered profile, is largely controlled by the depth in the rock mass to which water can penetrate. Because discontinuities are the only permeable pathways in most igneous rocks, the regional and local patterns, spacing and openness of discontinuities in the rock mass largely control the groundwater regime and in turn, the character of the weathered profile and so, the topographical setting.

In general, finer-grained igneous and sedimentary rocks have shallower weathering profiles, fewer corestones, and more closely-spaced joints than their coarser-grained equivalents. The thinner profiles may reflect higher rates of erosion and more frequent mass movements on steeper terrain, or shallower weathering penetration due to greater concentrations of low permeability clays in the saprolite.

The thickest weathering profiles in Hong Kong are generally developed in granitic rocks. In exceptional circumstances, as beneath the reclamation at Tung Chung New Town (東涌新市鎮), completely decomposed granite has been proved at depths of -200 mPD, indicating a weathering profile greater than 170 m thick (Kirk, in press) (Figure 3.4). This phenomenon is associated with large xenoliths of Palaeozoic metasedimentary rock within the granite intrusions.

Typically, weathering profiles in granitoid rocks are a few tens of metres thick or less. Shaw (1997) has contoured the base of the weathering profile, and generated isopachs of the thickness of the profile in the Kowloon (九龍) area, which is underlain mostly by the medium-grained Kowloon granite (Figure 3.5).

Deep weathering profiles also occur within the metavolcanic rocks of the Tuen Mun Formation that crop out in the northwest New Territories. A weathering profile near Yuen Long has been proved to be more than 203 m thick in a borehole terminating at -198.9 mPD (borehole VB4-B6). Weathering profiles up to c.50 m thick have been identified around Tuen Mun, where the base of weathering extends to more than -70 mPD locally (Owen & Shaw, in press) (Figure 3.6).

Zones of deep weathering are commonly associated with faults, which are typically zones of more closely spaced discontinuities than their surrounds. Hence, they are zones of deeper groundwater penetration and so deeper weathering. Faults in Hong Kong are often inferred on the basis of linear zones of deep weathering.

At the other extreme, some rocks, such as fine-grained tuff and rhyolite, or sedimentary rocks in general, are often overlain by comparatively thin weathering profiles, no more than a few metres thick. Good examples of these profiles can be seen within fine ash tuff of the High Island Formation in the northeast New Territories (Plate 3.6).

Weathering also affects transported material, including colluvium and alluvium. The degree of weathering increases with the age of the deposit. In this regard, weathering penetration in clasts within colluvium

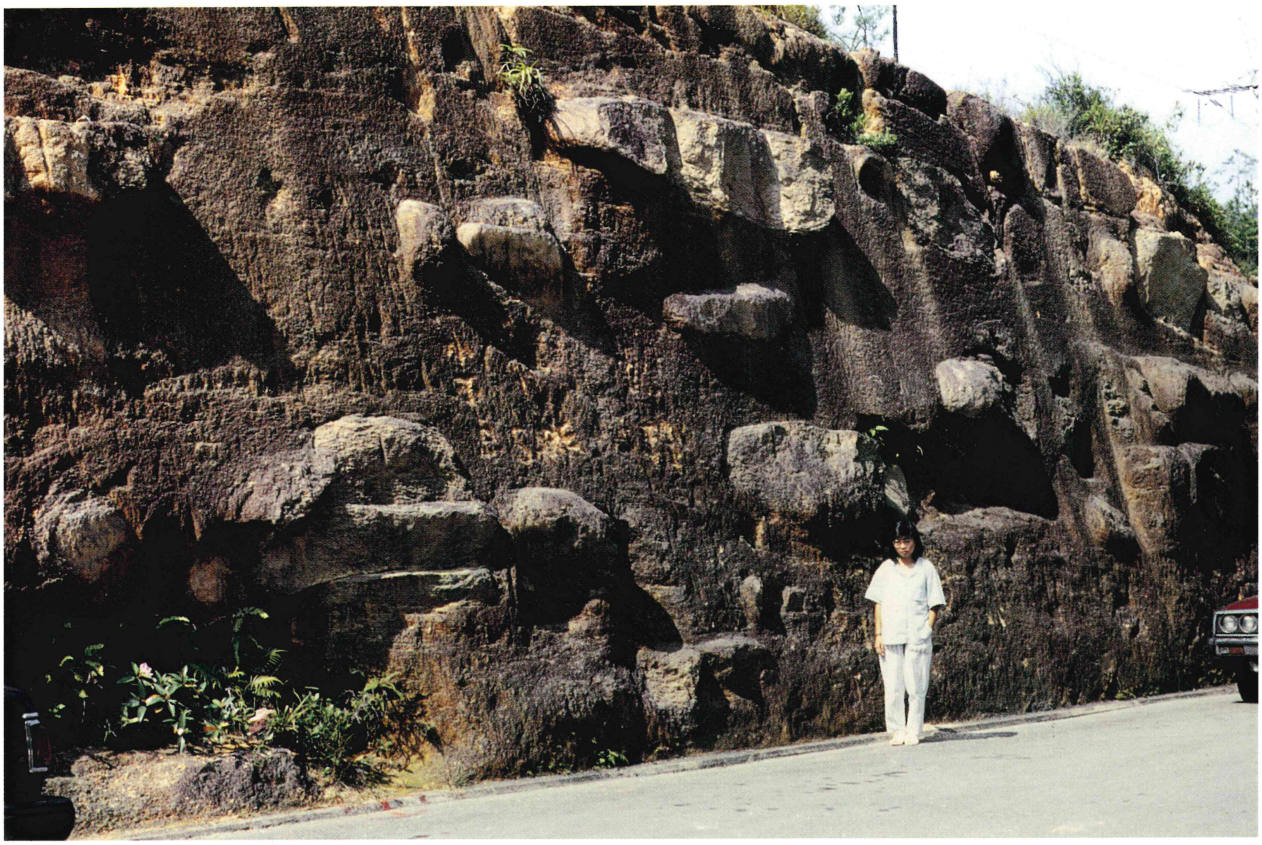


Plate 3.7 – Corestone-bearing weathering profile in fine- to medium-grained granite, Tai Tam Road (大潭道)



Plate 3.8 - Corestone complexes, joint-bounded, in the weathering profile in fine- to medium-grained granite, Tai Tam Road (大潭道)

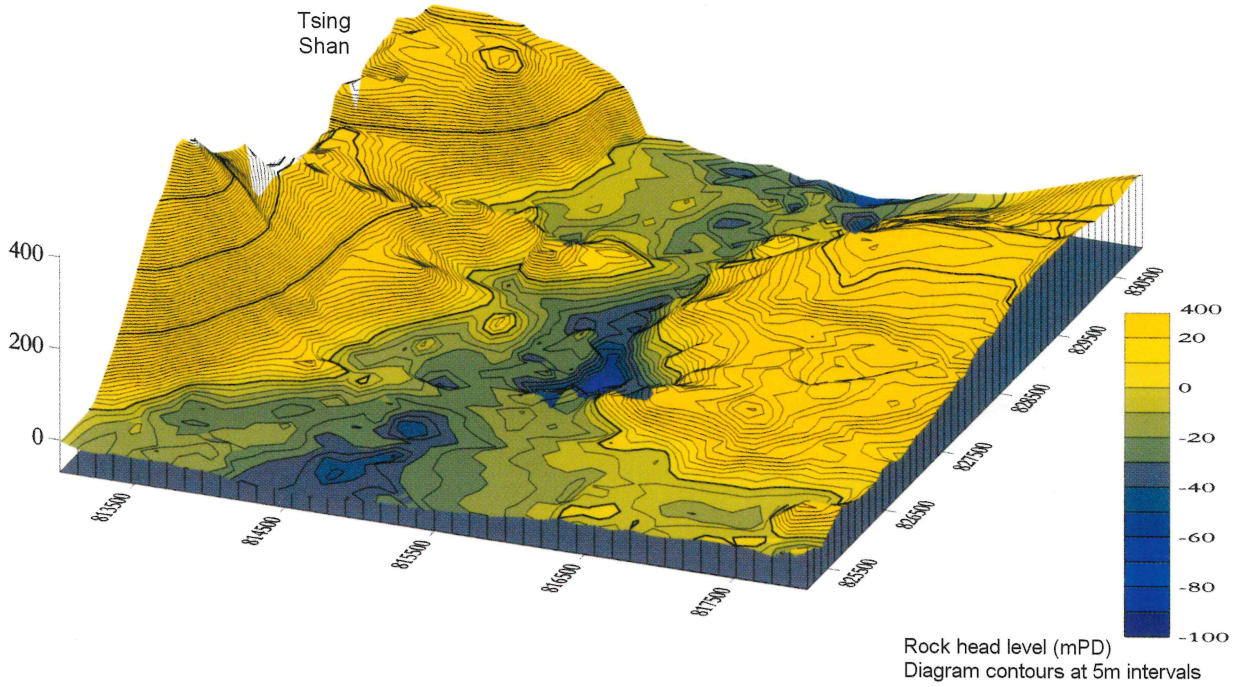


Figure 3.6 - Isometric projection of weathering front variation (rockhead) in the Tuen Mun (屯門) area, northwestern New Territories (新界) (after Owen and Shaw, in press)

is of great assistance in determining the relative age of the deposit (Lai & Taylor, 1984).

Subdivisions of the weathering profile

The weathering profile can be subdivided into several broad zones. The term saprolite is usually applied to the lower, sedentary part of the weathering profile, a zone that has not undergone marked volume changes and preserves original structures, such as joints and quartz veins, directly inherited from the parent rock. Above the saprolite zone, towards the ground surface, there is usually a mobile zone of slightly transported material that shows evidence of disturbance by such processes as gravitational creep, settling, and bioturbation. The mobile zone is commonly subject to leaching of soluble components and eluviation of the fines, mostly in colloidal suspension. This material may be precipitated or deposited lower in the profile, downslope, or completely removed. Features such as loss of rock texture, disturbance of structures such as relict joints, stone lines and outcrop curvature characterise this portion of the profile. In most weathered profiles in Hong Kong, the mobile zone is only a few metres thick. Commonly at the top of the profile is a layer of entirely transported material – the ubiquitous blanket of colluvium of variable thickness derived from higher up the slope.

Corestone development

The formation and distribution of corestones contained in weathered profiles is determined primarily by the bedrock lithology, and secondarily by the local joint patterns and their characteristics. Corestones are optimally developed in granitic lithologies (Plate 3.7), and to a lesser extent in the well-jointed, coarse-grained volcanic lithologies. Clusters of corestones may also occur (Plate 3.8), especially where influenced by a dominant joint set, or sets. However, corestones are not a ubiquitous component of all weathered profiles developed in these lithologies.

Individual corestones tend to be less common in the finer-grained volcanic lithologies, such as fine ash tuffs and rhyolites, because of the close jointing, or in the sedimentary rocks. A notable exception is the area of fine ash volcanic rocks on Ap Lei Chau, southwest of Hong Kong Island, where corestones are relatively common. Otherwise, weathering profiles in fine ash tuffs, and to some extent fine-grained granite also, are often characterised by larger tabular blocks of slightly to moderately decomposed material within predominantly highly to completely decomposed material. These bodies are referred to here as coreslabs. They have maximum longitudinal dimensions of several metres and sometimes of more than 10 metres. They generally have a low aspect ratio with subhorizontal width usually an order of magnitude greater than the vertical thickness. They are joint-bounded, with the main upper and lower joint surfaces forming part of the topographical, or sheeted joint set. Good examples of coreslabs have been described at Tseung Kwan O (將軍澳) (Franks & Campbell, 1998) (Plate 3.3).

Based on studies of weathered granite profiles in Kowloon (九龍), Shaw (1997) has interpreted corestone



Plate 3.9 - Closely-spaced kaolin-infilled joints illustrating early stages of corestone development

development, and their preservation at high levels in the profile, as a function of hydraulic compartmentalisation of the weathered mantle. Generally, as fresh granitic rocks weather, clay minerals are produced. The clays migrate by slow eluviation through the matrix of joint-bounded, weathered blocks, to reach the circumscribing joint planes. Suspended clays then migrate relatively rapidly along widened joints to accumulate at lower levels in the weathering profile. The clay minerals infill discontinuities and form continuous bands or sheets depending on the local topography and hydraulic gradient (Plate 3.9). These clay bands create hydrological cells or compartments within the profile. Each compartment appears to weather, and be exhumed, at different rates depending on the hydraulic connectivity (Plate 3.10). As a result, corestones develop either individually or in groups within a particular compartment, which is isolated laterally and vertically from adjacent weathering compartments (Plate 3.11). They are usually separated by an abrupt planar discontinuity such as a fault or joint. The presence or absence of corestone-bearing profiles is dependent on topographical position (Shaw, 1997) (Figure 3.5), as well as the spacing of discontinuities and lithology. In particular, corestone-free profiles were found to be most common in low-lying, deeply weathered zones. Corestone-bearing profiles were most commonly encountered below ridges and hills (Plate 3.12), the locations and morphologies of which are controlled by regional joint spacing and orientation.



Plate 3.10 - Formation of hydrological cells and exfoliation illustrating the intermediate stage of corestone development, and subsequent exhumation



Plate 3.11 - Advanced stage of corestone development, and its subsequent exhumation

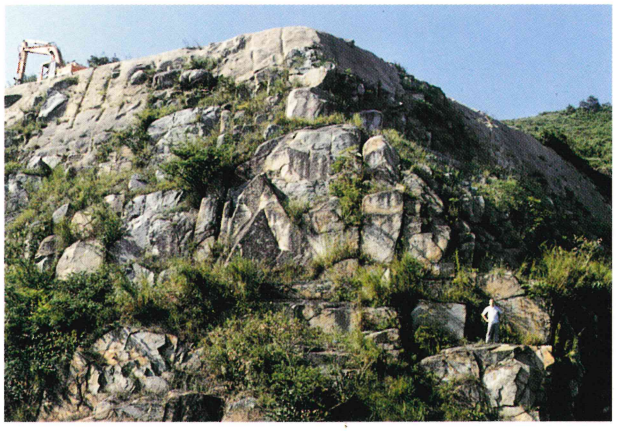


Plate 3.12 - Corestone development in fine- to medium-grained granite, Mount Butler (畢拿山), Hong Kong

Kaolin occurrences

A comprehensive review of described occurrences and the mineralogy of kaolin in Hong Kong has been compiled by Parry (1999a).

Kaolin is a major mineralogical component of partially weathered rock masses in Hong Kong. Most kaolin is observed in weathering profiles within rhyolitic tuffs and granitoid rocks. The kaolin may be broadly distributed in partially weathered rocks, either replacing specific minerals, especially feldspars and ferromagnesian minerals, or disseminated evenly throughout, especially in completely decomposed material and residual soil. Alternatively, the kaolin may be locally concentrated in lenses or seams, commonly infilling discontinuities.

Kaolin can be generated either as a product of hydrothermal alteration or at lower temperatures as a product of weathering. Early work (e.g. Ruxton & Berry, 1957) suggested that most kaolin in Hong Kong was generated by weathering. Subsequently, however, a hydrothermal origin was argued for by some (e.g. Strange & Shaw, 1986, Irfan 1994a, 1996). Recently, interpretations have again broadly favoured a weathering origin for many kaolin concentrations that occur as infillings of discontinuities in partially weathered rock (e.g. Campbell & Koor, 1996). The most persuasive evidence for this lies in the typical distribution of kaolin within the weathering profile. Significant concentrations are mainly reported in material of weathering grades V and IV. By contrast, only minor concentrations of kaolin are usually seen in material of weathering grades I to III. This distribution strongly suggests that the source of the kaolin must lie near the present land surface. If the kaolin was generated hydrothermally, its present distribution would bear little or no relationship to the present weathering profile and it would be equally abundant in both fresh and completely decomposed material. However, although available evidence suggests that much, if not most kaolin in partially weathered rocks in Hong Kong, has been generated by weathering, a hydrothermal origin remains likely at least locally.



Plate 3.13 - White kaolin and black manganiferous infill of subvertical discontinuities in fine ash tuff (Ap Lei Chau Formation), Shum Wan Road (深灣路) Landslide site (1995)



Plate 3.14 - White and buff kaolin and black manganiferous infill of subvertical and subhorizontal discontinuities in fine ash tuff (Ap Lei Chau Formation), showing multiple infill of, and displacement along, discontinuities

Often, the kaolin remains at its site of genesis. For example, individual mineral species such as feldspar may be completely replaced by kaolin although the relict crystal form remains preserved. Similarly, concentric bands of kaolin surrounding corestones are also likely to have been generated and preserved *in situ.* However, eluviation and transport by groundwater are also important. The kaolin can be transported either in solution or in colloidal suspension (Kirk *et al.*, 1997; Campbell *et al.*, 1998). Sites of deposition are commonly relict discontinuities (Plate 3.13) and multiple infillings of discontinuities have been identified (Plate 3.14). Complex histories of kaolin infillings have been inferred to have resulted from the physical and chemical redistribution of clay minerals. Repeated opening of the discontinuities in relation to down-slope movements has

been suggested at some localities. (Kirk *et al.*,1997; Campbell *et al.*, 1998).

Numerous analyses of kaolin in Hong Kong have been undertaken (e.g. Irfan, 1990, 1994b and 1996; Merriman & Kemp, 1995; Merriman *et al.*, 1996; see also Parry, 1999a and b). These have shown that the kaolin largely comprises kaolinite and halloysite which vary widely in relative amounts, even on a very local basis. Commonly, where both minerals occur together, the tubular halloysite does so as an overgrowth on the kaolinite. Additional components within the kaolin may include minor amounts of muscovite, illite, quartz and smectite.

Lenses, or seams, of kaolin infilling discontinuities in weathered volcanic rock have been identified as significant factors contributing to two very large, deep-seated slope failures in Hong Kong (Kirk *et al.*, 1997) (Plates 3.15 and 3.16). Important discontinuities included bedding-parallel shears in a shallowly-dipping tuff and closely-spaced joints in zones of syn-volcanic folding and shearing (GEO 1996a and b). In both cases, kaolin was found to have accumulated along relict discontinuities in the weathering profile (Figure 3.7). Many other examples of laterally extensive kaolin-infilled discontinuities have recently been documented, for example in fine ash tuffs in southwest Hong Kong Island (Irfan 1990, 1994a; Franks *et al.*, 1997), eastern Hong Kong Island (香港島) (Campbell & Koor, 1996; Campbell *et al.*, 1998), and Tseung Kwan O (將軍澳) (Franks & Campbell, 1998).



Plate 3.15 - Views northwest towards cut slope at Fei Tsui Road (翡翠道), above in 1977, below in 1995 after failure. The dark band in mid-slope in 1977 is the kaolinitic clay-rich layer that influenced failure in 1995; in 1977, chunam covered soil, but rock (fine ash tuff of the Che Kwu Shan Formation) was unprotected (after Kirk et al., 1997)



Plate 3.16 - Block sample from Shum Wan Road (深灣道) Landslide site (1995) showing a white and buff kaolin seam on an inclined interface between in situ material and landslide debris. The host rock is fine ash tuff (eutaxite) of the Ap Lei Chau Formation

Studies in deeply weathered granitic terrain have also identified accumulations of clay minerals along relict discontinuities, most commonly on joint surfaces, in weathering profiles (Irfan, 1996; Shaw, 1997).

Local preferred concentrations of kaolin along the interface between rock mass weathering zones PW90/100% and PW0/30% rock have been emphasized by several studies (e.g. Campbell & Koor, 1996; Kirk *et al.*, 1997; Franks & Campbell, 1998) (Plates 3.3 and 3.4).

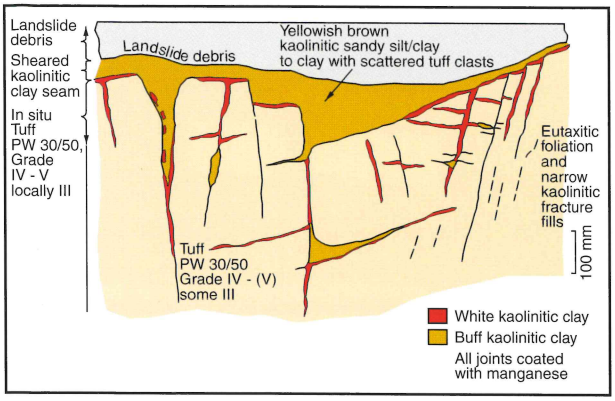


Figure 3.7 - Schematic representation of kaolin-infilled discontinuities in weathered tuff (Ap Lei Chau Formation) which influenced development of the Shum Wan Road (深灣道) Landslide in 1995 (after Kirk et al., 1997)

This has important implications for slope engineering where the interface dips out of slopes at moderate angles (>20°), the kaolin is laterally continuous, irrespective of thickness, and there is significant seepage at the interface.

Hydrogeology

The rate of weathering is controlled by the hydrogeological regime that is established below the ground surface, particularly in the weathering profile.

Groundwater conditions are largely a function of the local topography and geology. Discontinuities, such as faults and joints, provide important conduits for the movement and storage of groundwater. This is readily demonstrated in cut slopes in Hong Kong where seepage is generally concentrated at individual discontinuities, most notably, low-angle discontinuities dipping out of slopes and subvertical discontinuities striking directly out of slopes.

In general, the volcanic and plutonic rocks have a low porosity that may be increased by fracturing and the opening up of joint sets. Groundwater movement and storage is then a function of the spacing and aperture of the joints. However, to date, there has been no systematic regional study of the groundwater characteristics of the commonly occurring lithologies in Hong Kong, although several detailed area studies have been carried out for specific projects. For example the hydrogeology of the Yuen Long Plain (元朗平原) was monitored as part of



Plate 3.17 - Typical mass movement features (debris avalanches and debris flows) along scarp below Ngong Ping (昂平), Lantau Island (大嶼山)

the examination of buried marble in the area (Gale & Cook, 1990; Frost, 1992).

Erosion

Erosion encompasses the many chemical and physical processes that together result in loosening, abrasion and removal of rock and soil at, and close to, the earth's surface. Detached materials are removed from their site of formation and are transported down slope. Typically, individual particles are transported either under the direct influence of gravity, for example by rolling, or are transported by water, or within a mixture of water and other types of material. In Hong Kong, mass movement phenomena are particularly important in this regard (Plate 3.17) and are included below as the dominant component of slope erosional processes. It should be stated, however, that some authors (e.g. Gary *et al.* 1972) regard mass movement as being distinct from erosion. Erosional processes in Hong Kong are divided below into slope, river, coastal, and offshore processes.

Slope processes

Two main categories of erosional slope process are dominant in Hong Kong, water erosion and mass movement phenomena.

Water erosion

Water erosion is a continuum of processes that include rainsplash, sheet erosion, gully erosion, and stream bank erosion at the ground surface. Berry (1955) reviewed erosional processes in general in Hong Kong. More recently, Shaw (1993) reviewed erosion in relation to granitic terrain, although some of his observations relate also to terrain underlain by volcanic and sedimentary lithologies. Processes of erosion also result from surface infiltration of water and include eluviation and erosion related to piping within the soil layer and weathered mantle. Nash and Dale (1984) have considered these processes specifically in relation to piping.

Rainsplash

During intense rainstorms, the physical impact of raindrops causes the dislodgement of soil particles that then tend to migrate down slope. The process of washing away of the mainly fine material is elutriation. This phenomenon is especially prominent in Hong Kong within completely decomposed, coarse-grained granite.

Sheet erosion

On smooth, or well vegetated slopes, surface water flows as a moving layer of uniform depth. This erodes the slope evenly by a process referred to as sheet erosion. The relative significance of sheet erosion in Hong Kong is hard to quantify. However, although its effects are less obvious than those of gully erosion, it may account for a significant part of the total erosion that occurs.

Gully erosion

Surface flow may concentrate into discrete flowlines as a result of various factors including topography, rainfall duration rainfall intensity, soil infiltration capacity, soil friability, vegetation density and vegetation type (Shaw, 1993). When this occurs, the erosion that results is also focussed along these flowlines. On a small scale, shallow channels called rills are cut. As the process is enhanced and the scale of cutting increases, gullies are formed.

As defined by Brice (1966, in Selby, 1993), gullies are recently extended drainage channels that transmit ephemeral flow, are typically steep sided, with a steeply sloping or vertical head scarp, and have a width greater than 0.3 m and a depth greater than 0.6 m.

Gullies tend to originate on the lower or middle sections of slopes, on mechanically weak materials, where there is a break in slope or disruption of the vegetation cover, and where accumulated discharges are sufficient to erode the surface. Once initiated, they develop rapidly by headward sapping and lateral undercutting accompanied by slumping (Hansen & Nash, 1985).

Gullies coalesce to form dendritic systems. Slopes on which the vegetation has been disturbed or removed are particularly susceptible to gully erosion. Conversely, the increase in vegetation on many slopes in Hong Kong in recent years has reduced the tendency for gully erosion.

All rock types in Hong Kong exhibit gullying. However, severe gullying, resulting in badlands-type landscapes, is restricted to areas underlain by granite. Prior to the urban development of Kowloon (九龍) there was widespread gully erosion on many hills in the area, as is evident on older aerial photographs. Many of these areas of gullying have now been removed.

Gully erosion is also less evident in many areas than previously due to tree planting schemes for erosion control. However, gully erosion remains extensive in the Kowloon foothills, on the eastern side of Kowloon Bay (九龍灣), in areas on the western side of the Sha Tin Valley (沙田谷), west of the Kowloon Reservoirs (九龍水塘), on Cheung Chau (長洲) and in parts of northeast Lantau Island (大嶼山). The most intensely developed gully erosion in Hong Kong occurs around Castle Peak (青山) (Plate 3.18) and in the Tai Lam Country Park (大欖郊野公園).

Lam (1977) provided estimates of rates of erosion in the badlands terrain of Tai Lam Chung (大欖涌). The data are very variable, but mean ground retreat was estimated as being nearly 22 mm over a 15 month period. However, revegetation in this area has reduced the scale of erosion in recent years.

Stream bank erosion

The two principal agencies of stream bank erosion in Hong Kong are entrainment, especially on the outer bends of meanders, and mass transport, which is also



Plate 3.18 - Gully erosion below ridges west of Castle Peak (青山)

prevalent, but not exclusive to, the outer bends of meanders. Associated deposition on the inner bends of meanders results in the progressive accumulation of point bar deposits (see also River processes).

Eluviation

Eluviation, the removal by groundwater of material, either in suspension or solution, occurs mainly within the soil profile. The material is transported either to a lower horizon or out of the profile. The importance of eluviation relative to other erosional processes in Hong Kong is largely unknown. However, eluviation has been invoked in many instances as the process responsible for liberating kaolin, and so enabling it to migrate to favourable depositional sites within discontinuities (see below).

Piping

Soil piping, or natural tunnel erosion, is widespread in Hong Kong, and has been reviewed by Nash and Dale (1984), and Hansen and Nash (1985). A comprehensive model for soil piping in Hong Kong has been developed by Nash and Dale (1984) (Figures 3.8 and 3.9). Soil pipes are essentially preferential flow paths for groundwater (Figure 3.8). They evolve progressively due to eluviation leading to interconnection of voids and further erosion and expansion of the pipe (Figure 3.9). Most reported examples in Hong Kong are less than 100 mm in diameter and within 1 m of the surface. They mainly occur within superficial deposits, most notably residual soils and colluvium. However, Whiteside (1996) described a pipe network at the base of saprolite more than 10 m thick, and infilled pipes were identified at greater depth in granite saprolite in northeast Kowloon (九龍) (GEO, 1998).

Initiation of pipes at surface can be attributed to various factors, including hollows formed by decayed tree roots, and shallow surface depressions and cracks, particularly in clay and organic-rich soils. Excavations, landsliding and removal of vegetation promote soil pipe development. Piping often occurs at textural or permeability boundaries such as between different types of colluvium, and between residual soil and other *in situ* soil types (Figure 3.8).

Shallow pipes are most commonly developed in granite, granodiorite, coarse ash tuff, corestone-bearing profiles in general, and other highly permeable soils, including gravel and cobble-rich colluvium. They may coalesce and feed into deeper-seated, more substantial pipes in completely to highly decomposed *in situ* rock. These are influenced in their development by relict joints, especially in the coarser-grained lithologies, such as the

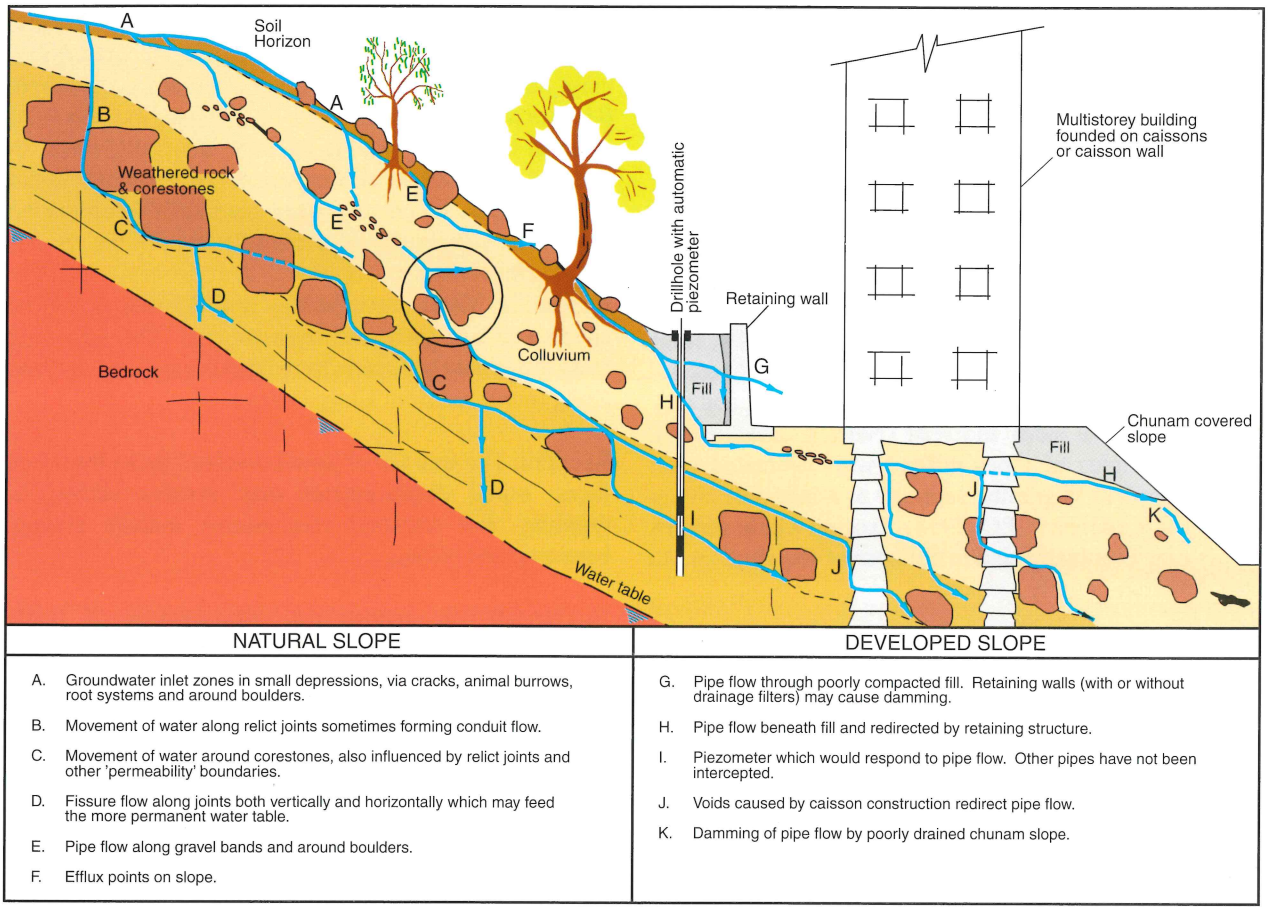


Figure 3.8 - Soil pipe development and its effects on groundwater regimes (after Nash & Dale, 1984)

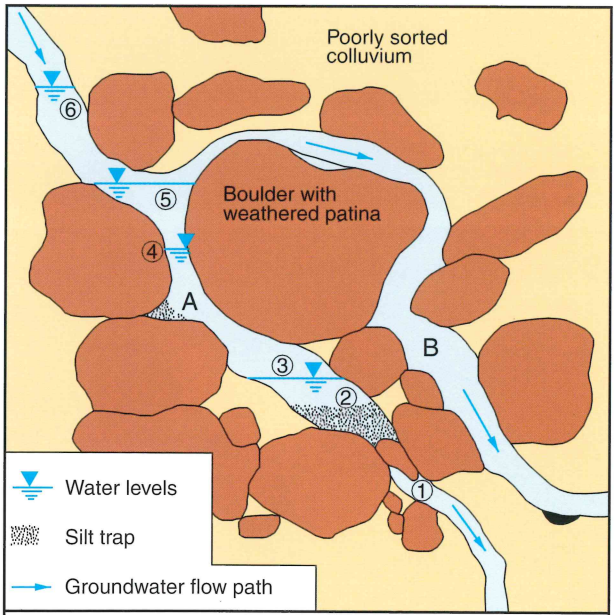


Figure 3.9 - Schematic representation of redirection of pipe flow in a blocked system (after Nash & Dale, 1984)



Plate 3.19 - Large soil pipe, Lai Ping Road (麗坪路) Landslide site, near colluvium/in situ soil interface, east of Sha Tin (沙田) (after Koor & Campbell, 1998)

Tai Po Granodiorite and coarse-grained granite (Nash & Dale, 1984). Deeper-seated pipes, seen in cut slopes and in landslide mainscarps, may be up to c.1 m in diameter (Plate 3.19). Where open-ended and free draining, the soil pipes provide efficient drainage within the slope. However, soil pipes may be closed, have become blocked, or had their capacity exceeded, during a period of extreme rainfall. In such circumstances, they have been interpreted at several locations in Hong Kong as having caused high water pressures to develop, so adversely influencing slope stability (e.g. Nash & Dale, 1984; Koor & Campbell, 1998; GEO, 1998; Whiteside, 1996, etc.).

Sediment is often seen on the floors of pipes, and clay may encrust the sides and roof (Nash & Dale, 1984). Many examples of pipes infilled with laminated sand were identified in granitic saprolite at a landslide site in northeast Kowloon (GEO, 1998). Erosion within shallow pipes may eventually lead to collapse of the pipes and to the initiation of gully erosion.

Mass movement

Mass movement phenomena have been classified according to a wide range of geological, geomorphological and engineering criteria depending upon the purpose of the scheme (e.g. Sharpe, 1938; Varnes, 1958; Hutchinson, 1988; Cruden & Varnes, 1996). Mass movements can be usefully separated into mass transport and mass wasting processes for example (Gary *et al.*, 1972). The former involves the movement of material in or on a moving medium, generally water. In contrast, the latter involve movement of material, but not within, under, or on any other medium of contrasting properties. Despite the different objectives of the various classification schemes, however, their general principles are similar. Hence, terminology and definitions can be adapted to suit particular environments. The following mass movement processes have been recognized in Hong Kong (modified from King, 1997).

Rockfall: The free fall of joint-bounded blocks from free faces. Initial displacements may involve sliding or toppling, and transport mechanisms include sliding, bouncing and rolling.

Boulderfall: The gravitational displacement of single blocks from weathered profiles or colluvial deposits, usually as a result of erosion of channel banks and steep hillsides.

Debris slide: A landslide in which an intact displaced



Plate 3.20 - Small open slope debris avalanche, south Lantau Island (大嶼山)



Plate 3.21 - The large volume Tsing Shan debris flow, 1990, east of Castle Peak (青山)



Plate 3.22 - Debris avalanches with sources close to ridge crest, northeast New Territories (新界)

mass moves by the dominant mechanism of sliding. These often occur on steep hillsides where they typically form an elongate scar.

Debris avalanche: A landslide comprising a rapid to extremely rapid, shallow movement of partially or fully saturated, mainly granular debris on steep slopes, with minimal water mixed into the displaced material after failure. Movement is by sliding and/or liquefaction and/or rolling and/or bouncing and/or saturated or inertial granular flow (Varnes, 1978) (Plates 3.20 and 3.22).

Debris flow: A landslide in which landslide debris moves by the dominant mechanism of slurry flow. The presence of remoulded landslide debris is a good indication that slurry flow has occurred. Debris flows may be separated into either confined or unconfined hillslope debris flows that form an elongate scar on a relatively planar hillslope, or channelized debris flows that form a channelized elongate scar (Plate 3.21).

Debris flood: The transport of a significant load of sediment by the dominant mechanism of stream flow or hyperconcentrated stream flow. The load can range in grain size from clay to boulders. A debris flood may originate from outwash of landslide debris or gully erosion.

A recent study of large landslides (>20 m wide mainscarp) in Hong Kong (GEO, unpublished data) identified 1,976 recent and relict features on low-level aerial photographs. Mass movements are also very



Plate 3.23 - Undercutting of the coast by wave erosion, resulting in mass movement, northwest Lamma Island (南丫島). The host lithology is mainly fine-grained granite



Plate 3.24 - The Yuen Long Plain (元朗平原), from Tin Shui Wai (天水圍)

prominent around the coastline where cliffs are undercut by waves (Plate 3.23).

Debris refers predominantly to coarse soil. In Hong Kong such material is usually the weathered profile and/or colluvium (see below). Displaced material that has disintegrated is commonly called "debris". To retain conformity with international practice, the term landslide debris is used for displaced material.

Colluvium is the general term, preferred here, for heterogeneous, and incoherent masses of soil and rock fragments deposited on, and at the base of, slopes principally by mass movement processes. Colluvial deposits are shown on Hong Kong Geological Survey maps (1:20 000 scale) as debris flow and slope deposits.

Transient elevation of pore pressure, during and immediately after heavy rainfall, is the essential cause of slope failure in Hong Kong, and hence the genesis of mass movements. Three main hydrogeological factors are consistently identified as contributing to slope failures: direct water infiltration; development of transient perched water tables at interfaces with materials of low permeability, e.g. clay seams (GCO, 1996a); and rapid and extreme elevation of the groundwater table and increase in water pressure (e.g. Sun & Campbell, 1998), due to infiltration of subsurface zones of higher permeability. Consequently, piezometer monitoring of water table levels in engineered slopes is common practice, and recent investigations of major slope failures have attempted to map the hydrogeological flow paths (e.g. Koor & Campbell, 1998). In addition, there are abundant observational data on seepage in Hong Kong, mainly in relation to cut slopes.

River processes

Despite the high rainfall of the region and the resulting intense runoff, precipitation is markedly seasonal and the river system of Hong Kong is not well developed. With the exception of the Sham Chun River (深圳河), there are no large master streams and the majority of the first order streams are ephemeral. The paucity of large streams in Hong Kong means that fluvial loads are generally small. With the exception of the Yuen Long Plain (元朗平原) (Plate 3.24), extensive floodplains are uncommon.

Most streams in Hong Kong have short, steep courses, flowing directly down hillsides to the sea (Plate 3.25). Few streams are larger than second or third order, feeding into now submerged trunk valleys such as Deep Bay (后海灣), Starling Inlet (沙頭角海), the Tolo Channel (赤門), and Port Shelter (牛尾海) (Figure 4.5). The location and alignment of many valleys show a strong structural control. The major valleys trend northeastwards and there is a secondary northwestward trend.

The movement of river channels, particularly on floodplains, results from erosion, especially on the outer bends of meanders. Peart (1997) has illustrated some of the characteristic features of stream bank erosion in Hong Kong with reference to the Kam Tin River (錦田河). Meanders are typical of most of the rivers that cross the alluvial plains, many of which occur in the northern and northwestern New Territories(新界).



Plate 3.25 - *Stream gullies on Ma On Shan (馬鞍山)*



Plate 3.26 - Highly crenulated section of coastline, Town Island (仗頭墳洲), eastern New Territories (新界)

Coastal processes

Hong Kong has a highly crenulated coastline (Plate 3.26), about 354 kilometres long, with an intricate system of bays and intervening headlands (Map 1) (Figure 1.2). The offshore regime is designated as a mesotidal, low-energy environment with a normal tidal amplitude of 2.5 metres. Exceptional conditions prevail during typhoons, when waves may reach 8 m or more in height, and tidal levels are higher due to the intense low pressure at the centre of the disturbance. It is these extreme events that have the most profound effect upon the morphology of the local coastline. Landslides also cause major modifications of the coastline (Plate 3.27).

Coastlines are commonly classified on the basis of whether the dominant group of processes operating is erosional or depositional. In practice, combinations of processes occur, or the processes vary seasonally or during extreme events such as typhoons. Beaches, therefore, are either depositional and sandy (Plate 4.1), or erosional with cliffed coasts and residual lag boulder deposits (Plate 3.28). The eastern areas of Hong Kong are generally more exposed to the prevailing southeasterly onshore winds, whereas the western areas are more sheltered but subjected to the effects of the sediment laden discharges of the Pearl River (珠江). Consequently, the western regions of Hong Kong present a more subdued, depositional appearance than the rocky, cliffed and rugged eastern region. Thus, the most extensive beaches, sand spits, high level beaches and dunes are developed in the west, whereas the largest sea cliffs, sea caves (Plate 3.29), sea stacks (Plate 3.30), pedestals (Plate 3.31), natural arches (Plate 3.32) and wave cut platforms (Plate 3.33) are found in the east.

Offshore processes

The hydrology of Hong Kong waters is influenced by three major external factors: the oceanic and coastal current pattern in the South China Sea (南中國海), the fresh water discharge from the Pearl River Estuary (珠江口) to the northwest, and the tidal current regime. These factors vary considerably throughout the year; the South China Sea current pattern changes from summer to winter in response to the monsoonal wind circulation patterns and the discharge from the Pearl River (珠江) increases markedly during the wet (summer) season. The



Plate 3.27 - Talus deposit originating from a coastal landslide, northeast Lamma Island (南丫島)



Plate 3.28 - Residual lag boulder beach, Tung O Wan (東澳灣), on exposed section of coastline, east Lamma Island (南丫島)



Plate 3.29 - Sea cave, Crooked Island (吉澳洲)



Plate 3.30 - Sea stacks, Ping Chau (平洲)

interaction between these elements was given detailed consideration by Watts (1973), and Morton and Wu (1974).

The pattern of seabed sediment distribution in Hong Kong waters (Map 6) (Figure 10.15) is relatively simple, reflecting both the hydraulic conditions and the topography of the seabed. Around Hong Kong, the seabed comprises mostly soft clayey silt. Coarser sediments appear close to the coast, islands and submarine rock outcrops. This is a reflection both of increased wave action in shallow water and increased current strengths around shoals and headlands. Where current activity is greater, in several deep channels, sediment has either not been deposited or has been scoured completely exposing rock at the seabed.

Ocean current regime

For four to six months of each year, during the winter dry season, the prevailing northeast monsoon wind circulation pattern establishes and maintains a west-southwesterly flowing current. With the onset of the southwest monsoon a strong east-northeasterly current becomes established by June. This current persists until October, when it is gradually replaced by the west-southwesterly current. Typhoons commonly occur during this period. On average, five or six tropical cyclones threaten Hong Kong each year (Chin, 1986). These have a short but major influence on the wave climate, and usually cause considerable seabed disturbance.

During the winter months, two oceanic water masses affect Hong Kong (Morton & Wu, 1974) (Figure 3.10a).



Plate 3.31 - Pedestal and wave cut platform, Kat O Hoi (吉澳海)



Plate 3.32 - Sea arch (Kat O Formation), Ap Chau (鴨洲), northeast New Territories (新界)

The first of these is the Taiwan Current, which carries colder water (surface temperature 23°C) of relatively low salinity (31 to 33‰) southwest from the East China Sea. This mixes with the high salinity (34.4 to 35‰) waters of the Kuro Shio Current, which carries warm (surface temperature 29°C) water from the Pacific into the South China Sea via the Luzon Straits. In October and January the current has a surface strength of between 0.25 to 0.4 metres per second (m s^{-1}) and a constant direction for over half (50 to 75%) of the period. The current weakens by April to a surface strength of 0.1 to 0.25 m s^{-1} and a constancy of 25 to 50%.

During the summer months, the Hainan Current exerts a dominant influence (Figure 3.10b), carrying highly saline (34.4 to 34.6‰) warm water (surface temperature 29°C) up the northeastern coast of the South China Sea. On average in July, it has a surface strength of between 0.35 and 0.50 m s^{-1} and constancy between 75 and 100%.

These markedly seasonal currents have a controlling effect on the climate. In winter, the Kuro Shio Current helps to maintain warm waters around the coast, though the lower-density Taiwan Current causes the upper 20 m of water to become quite cold. For most of the year the Taiwan Current is located inshore of the Dangan Island group (担杆群島). However, in summer, the ocean-derived summer monsoon brings wet weather to the South China coast. Consequently, during the summer months the increased discharge from the Pearl River (珠江) pushes the Hainan Current further offshore.

Influence of the Pearl River (珠江)

The Pearl River Estuary (珠江口) has a major influence on the hydrology of Hong Kong waters, although the extent of this influence varies spatially and seasonally. The Pearl River (珠江) system comprises three large rivers, the Xijiang (西江), Dongjiang (東江) and Beijiang (北江). These rivers converge at the Pearl River Delta (珠江三角洲) where they separate into eight



Plate 3.33 - Wave cut platform, Ping Chau (平洲)

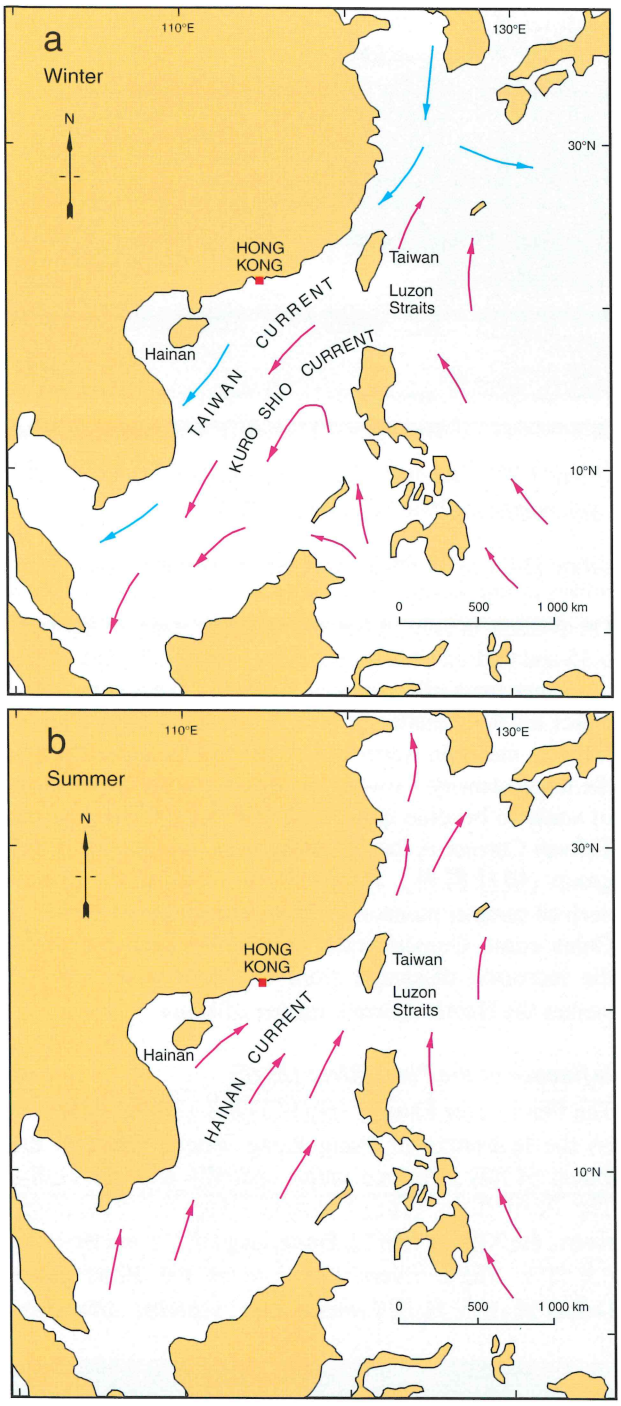


Figure 3.10 - Oceanic circulation affecting Hong Kong: a. in winter months b. in summer months

distributaries. Four distributaries enter the sea to the west of Macau (澳門), and the four largest enter the Pearl River Estuary. About 55% of the water discharge and 65% of the sediment discharge is directed through the estuary (Long & Huo, 1988).

A distinctive and controlling feature of the complex hydrodynamics of the estuary is that the majority of the discharges from the Pearl River are deflected down the western side of the estuary away from Hong Kong and towards Macau. Despite this deflection, the Pearl River

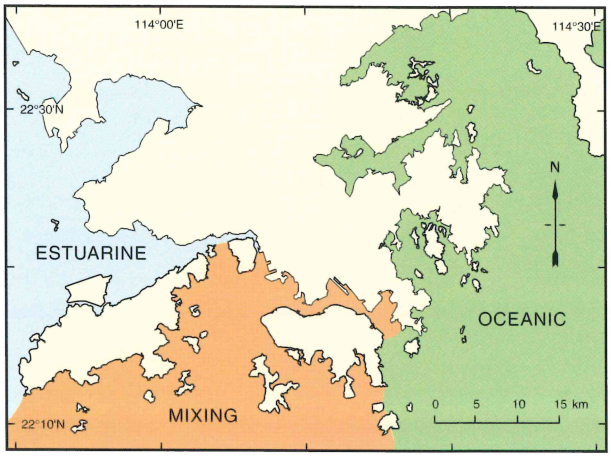


Figure 3.11 - Hydrographic regions of Hong Kong waters

still exerts an important influence on Hong Kong waters. This influence declines from west to east (Watts, 1973) (Figure 3.11). The western region, north of Lantau Island (大嶼山), is estuarine. The eastern region, which is least affected by the Pearl River, is predominantly oceanic, and between the two is a region of mixing.

The Pearl River Estuary is microtidal (characterised by a tidal range of less than 2 m) and is largely dominated by a highly seasonal, fresh-water discharge (Li & Wei, 1987). The tidal flow regime in the estuary is fundamentally diurnal, but exhibits a substantial semi-diurnal inequality, tidal range within the estuary ranging from 0.86 m at the mouth to 1.63 m at the head. Wave energy is weak because of the protection afforded by the islands of Hong Kong, in particular, Lantau Island. The main water discharge in the Pearl River Estuary is concentrated in the Fanshi (矾石) and Lingding (伶仃) channels (see Figure 1.3), while the currents issuing from the outlets on the western side of the estuary carry a higher load of suspended sediment (Weng & Dong, 1992). This differentiation may be a result of the Coriolis effect, which induces an anticlockwise rotation in the estuary (Ridley Thomas, 1985; Li & Wei, 1987).

In the wet season, the dominance of the Pearl River is more marked, especially in the western part of Hong Kong waters. The strong river discharge, weak tidal component and irregular semi-diurnal tides give rise to a pronounced multi-layered flow regime. During the summer, the increased rainfall is also a significant factor, causing dilution of the surface waters throughout the area. The direct influence of fresh water from rainfall leads to a marked salinity stratification of the water column. This stratification is particularly noticeable in the west, where fresh water discharge from the Pearl River forces the saline wedge south and creates an extensive fresh water lobe at the surface. The density imbalance created by this lobe is an important factor affecting the hydrology of Hong Kong waters (Ridley Thomas, 1985).

Tidal current regime

Reversing tidal flows dominate the hydrographic regime of Hong Kong, whose water movements are only minimally influenced by oceanic circulation. The boundary between the oceanic region and the inshore region, dominated by tidal flow, is transitional, and appears to shift seasonally. For example, it fluctuates between 1 and 3.3 km south of Lamma Island (南丫島).

Diurnal and seasonal differences in tidal ranges induce very high spring tides at the solstices in June and December, and low spring tides at the equinoxes in March and September. In addition, every two weeks during the spring and neap cycles, there is a transition from a semidiurnal tide (two tides a day) at the spring tide to a diurnal tide at the neap tide (Morton, 1979). Thus, the diurnal inequality creates a lower low tide in the morning from October to March, and a lower low tide in the evening from April to September. The strength and direction of the neap and spring ebb tides are constant, but the strength and direction of the neap and spring flood tides are more variable.

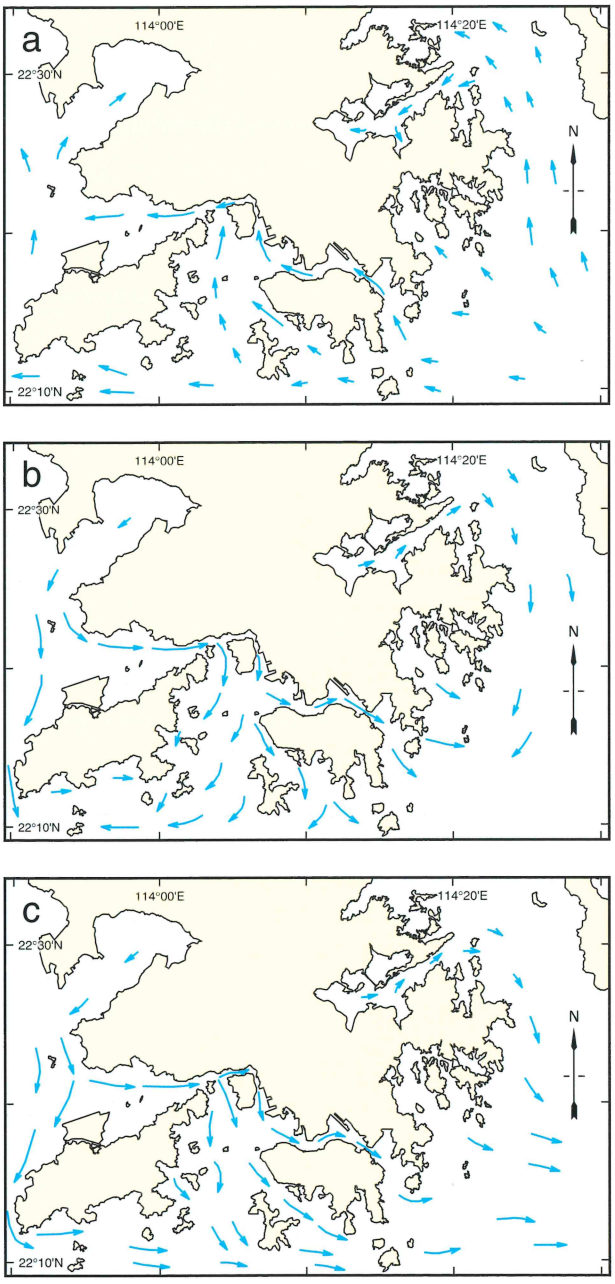


Figure 3.12 - Dominant tidal currents: a. flood tide b. ebb tide winter c. ebb tide summer

Figure 3.12 shows the dominant tidal current in Hong Kong at peak flood and ebb tides (Watts, 1973). In general, the tidal currents in Hong Kong waters are relatively weak (average velocity 0.1 to 2.2 m s^{-1}). The influence of the oceanic currents and wind patterns can be seen in the winter and summer ebb tides (Figures 3.12b and 3.12c). Several tidal channels are defined by these trends. The most significant of these are the East and West Lamma channels (東及西博寮海峽), Ma Wan Channel (馬灣海峽), Kap Shui Mun (汲水門) and the Brothers Channel (大小磨刀海峽) (see Figure 1.2). In addition, strong tides flow through Victoria Harbour (維多利亞港) (up to 0.5 m s^{-1}) and the Rambler Channel (藍巴勒海峽). The strongest flood and ebb tide circulation is recorded in the tidal pathway that runs through the Urmston Road (龍鼓水道) channel (0.6 m s^{-1}), the Ma Wan Channel (0.8 m s^{-1}) and the East Lamma Channel (0.5 m s^{-1}) to the waters south of Hong Kong. A subsidiary branch flows through Victoria Harbour and the Tathong Channel (藍塘海峽) (0.5 m s^{-1}). Tidal currents in Hong Kong waters have a westerly-directed residual component. During the wet season, however, freshwater discharges from the Pearl River (珠江) and water surface gradients induce easterly flows in the surface layers, although a strong westerly residual is maintained in the lower layers.

Tidal currents control erosion and sedimentation patterns, thereby determining the seabed morphology. Tidal currents and sedimentation in Victoria Harbour were discussed by Chalmers (1984), who concluded that the residual tidal flow in Victoria Harbour is negligible, as is deposition. Bathymetric charts show two tidal channels north of Tsing Yi (青衣), within the area marked as the Tsing Yi Channel. These features, which run parallel to the axis of the main channel, are considered to be flood and ebb tide channels (Evans, 1986). The southern channel carries the flood stream and the northern channel the ebb stream. Flood and ebb channel separation is not recognized elsewhere in Hong Kong.

Strong current movements through the tidal channels maintain their form, largely by preventing any significant deposition. The dominant sediment input is from the Pearl River Estuary (珠江口) to the west of Hong Kong. Topographical highs have developed on the seabed in the lee of some islands where the land provides protection from the dominant tidal streams and wave action. For example, prior to dredging, an elongate sand bank had developed to the west of Siu A Chau (小鴉洲) (Cheung & Shaw, 1993). Kellet Bank (奇力灘) is located between two tidal streams (Chalmers, 1984).

4. Data collection, analysis and interpretation

The methods used for data collection with respect to onshore and offshore Quaternary superficial deposits differ in many ways. Consequently, they are dealt with separately below.

Onshore Quaternary superficial deposits

Knowledge of the distribution and composition of onshore Quaternary superficial deposits has been derived from a variety of sources. These include aerial photograph interpretation and field surveying, which principally includes the description of natural exposures and temporary sections, and boreholes. However, the detailed correlation of Quaternary superficial deposits that has been achieved offshore, using borehole data in conjunction with seismic reflection data, has not yet proved possible for the onshore deposits.

Aerial photograph interpretation

Aerial photograph interpretation has been one of the principal sources of information for identifying the distribution of onshore Quaternary superficial deposits. Allen and Stephens (1971) used photogeological mapping to identify three classes of Quaternary superficial deposits across the whole of Hong Kong. Aerial photoreconnaissance studies at 1:20 000 scale formed the basis of a series of terrain classification maps that were compiled during the Geotechnical Area Studies Programme (GASP) (Burnett & Styles, 1982). Recently, extensive use has been made of aerial photographs in mapping onshore Quaternary superficial deposits by the Hong Kong Geological Survey during the 1:20 000-scale mapping of Hong Kong.

Hong Kong has an extensive archive of high quality aerial photographs taken at various flying heights. These date back to 1924, although prior to the 1960s, coverage for the whole of the territory in any one year was incomplete. Low-level aerial photographs taken in 1963 and 1964 are an especially useful resource and are of very high quality. They pre-date the extensive vegetation established on many slopes, much of which has been planted in recent years to control erosion in previously deforested areas. Furthermore, they pre-date much of the development that has taken place in the New Territories. Hence, they have been of particular value in identifying the limits of Quaternary deposits where these are now obscured. Most of the photograph collection is in black and white, but these have been augmented since 1982, by high-level aerial photograph coverage that is in full colour.

Field surveying

Field surveying has yielded considerable information on the nature of the Quaternary superficial deposits, but less so on their distribution. With respect to the latter, field surveying has proved more valuable in confirming interpretations previously made from aerial photographs. The principal limitation encountered in field surveying is the restriction of access caused by thick vegetation. This has become an increasing problem in recent years as vegetation has spread out of the valleys onto higher ground. Drainage lines are generally accessible, but even these can prove to be difficult to traverse in many instances.

Sections and boreholes

Descriptions of natural and temporary sections, (including trial pits, cut slopes, construction caissons, and deep excavations) have provided substantial information on material type and bedforms of Quaternary superficial deposits, and to a lesser extent on their lateral variability and stratigraphical variation. Most information derived from cut slopes has been obtained during their construction, or during their upgrading, as the general practice of sealing cut slopes with chunam and shotcrete largely prevents later field observations.

Boreholes are the main source of information on the thickness of Quaternary superficial deposits as many penetrate the full thickness of the deposits. In addition, they provide extensive information on the material type and variation. In some areas, most notably in the northwest New Territories (新界) and the New Town areas, there are sufficient boreholes to produce detailed isopach maps of the deposits (Frost, 1992; Owen & Shaw, in press; Kirk, in press).

Offshore Quaternary superficial deposits

Geophysical data

The information used to determine the geology of the offshore area is gathered from many sources. The primary technique is the interpretation of seismic reflection profiles. The profiling system essentially comprises a sound source and a receiving hydrophone that are towed behind a ship (Figure 4.1). The signal passes through the water and into the sediment beneath the seabed. Changes in density and acoustic velocity (acoustic impedance contrasts) between layers of sediment cause the sound wave to be reflected. The hydrophone receives the reflected signals and these are translated graphically to a continuous paper record. This is described more fully in Evans *et al.* (1995).

Three principal seismic sources have been used in Hong Kong waters, namely a sparker, a boomer and a pinger. Each source has its own characteristics and each varies in the acoustic penetration and resolution achieved (Figure 4.2). The sparker source emits a low frequency (range 50 to 1 000 Hz), high energy pulse with penetration of up to 150 m. Resolution, using a frequency of 50 Hz, was of the order of 3 to 4 m, improving at higher frequencies to 2 to 3 m. This source has been used

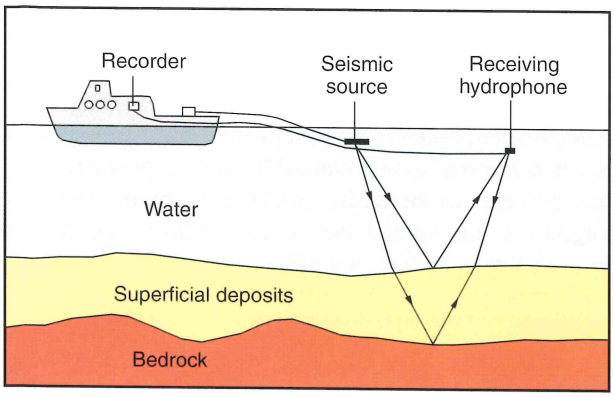


Figure 4.1 - Diagrammatic representation of continuous seismic profiling system

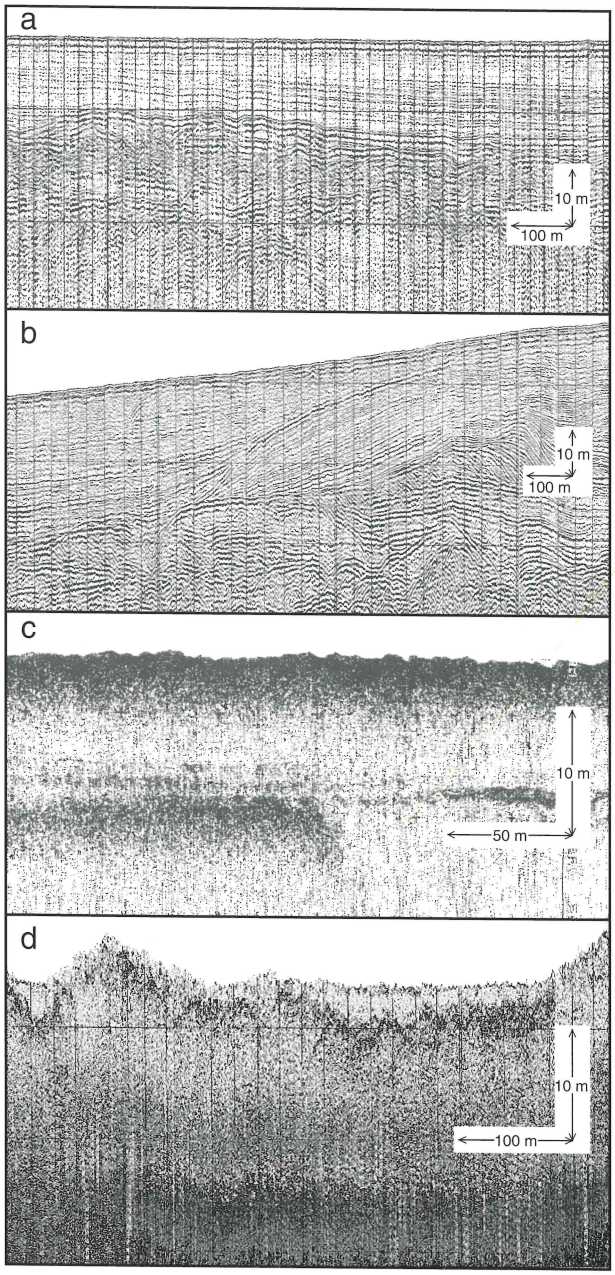


Figure 4.2 - Examples of profiles from different seismic sources: a. sparker b. boomer c. pinger d. chirp

to determine bedrock levels beneath thick Quaternary deposits, but is otherwise of limited value. The boomer, using an energy level of 100 joules, emits pulses in the frequency range of 250 to 2 000 Hz. A firing rate of 4 pulses per second was used. This achieved penetration, depending on the nature of the sediments, of around 80 to 100 m and a resolution of 0.5 to 1 m. This is the optimum combination of characteristics for interpretation of Quaternary stratigraphy in Hong Kong and is the most commonly used source.

The pinger uses a high frequency source (range 1 500 to 15 000 Hz) and yields resolution of less than 1 m, varying in exceptional circumstances to only 0.2 m, but penetration is only a few metres, even in soft mud. This restricts its use to specialized tasks such as trench and pipeline surveys.

In some cases, a chirp system has been used (Selby & Foley, 1995). This method uses a series of transducers with a range of frequencies and produces a very high-resolution profile for interpretation of near-surface features (Figure 4.2d).

Since 1985, over 5 000 line-kilometres of high-resolution boomer profiles have been acquired (Figure 4.3), together with a limited number of sparker, pinger and chirp lines. These provide a high-quality continuous record principally of the Quaternary sediments. In some places in Mirs Bay (大鵬灣), reflections representing bedding in underlying Tertiary rocks are also seen on boomer profiles (see Figure 4.4).

Although seismic data have been used, the bedrock geology and structural framework of the offshore area of Hong Kong have been interpreted largely from gravity and magnetic data. There is complete regional coverage of gravity data over Hong Kong (Busby *et al.*, 1992), with more detailed information in some areas. Magnetic surveys have been undertaken more locally, specifically north and southeast of Lantau Island (大嶼山), northwest, west and southwest of Hong Kong Island, and in Tolo Harbour (吐露港). These surveys were carried out by Electronic and Geophysical Services Ltd. (E.G.S., 1991, 1992, 1993a,b,c). [*Note added in proof – the offshore marine magnetic survey of Hong Kong is now complete*]

Seismic interpretation

A seismic profile comprises a series of seismic reflections. They are the representation of seismic reflectors, which are changes in acoustic impedance inferred, but not directly observed, within the sediments. The most prominent of these reflections is usually that of the seabed, which represents the interface between the sea water and the underlying sediments. In most surveys in Hong Kong waters, this reflection is commonly smoothed by a swell filter, which compensates for the sea swell and provides a regular trace on the record.

Below the seabed reflection on the profile are a number of major and minor reflections. The major reflections are normally of high amplitude, are laterally continuous and separate major seismic units. These are

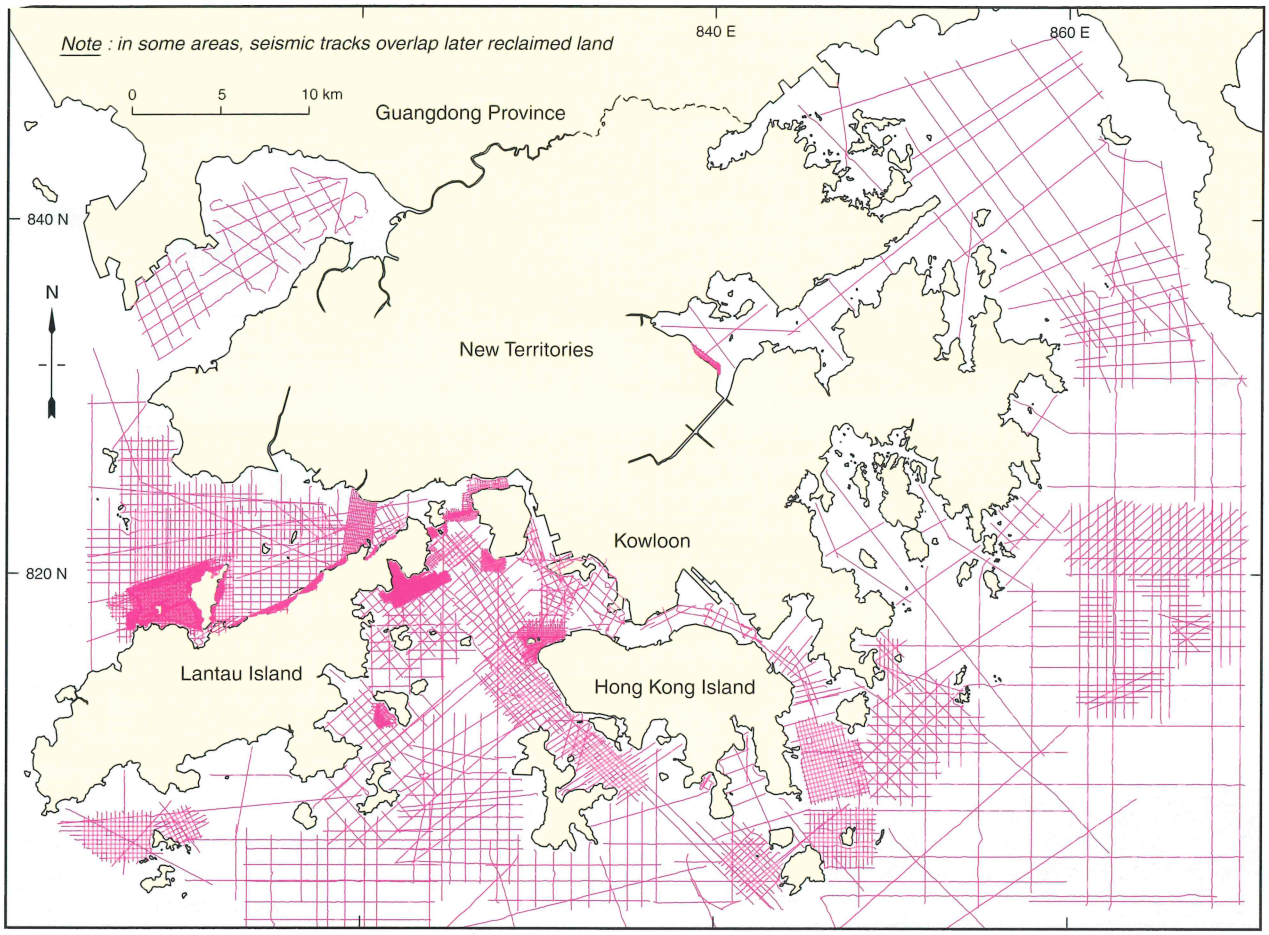


Figure 4.3 - Map of Hong Kong showing the tracks of seismic surveys

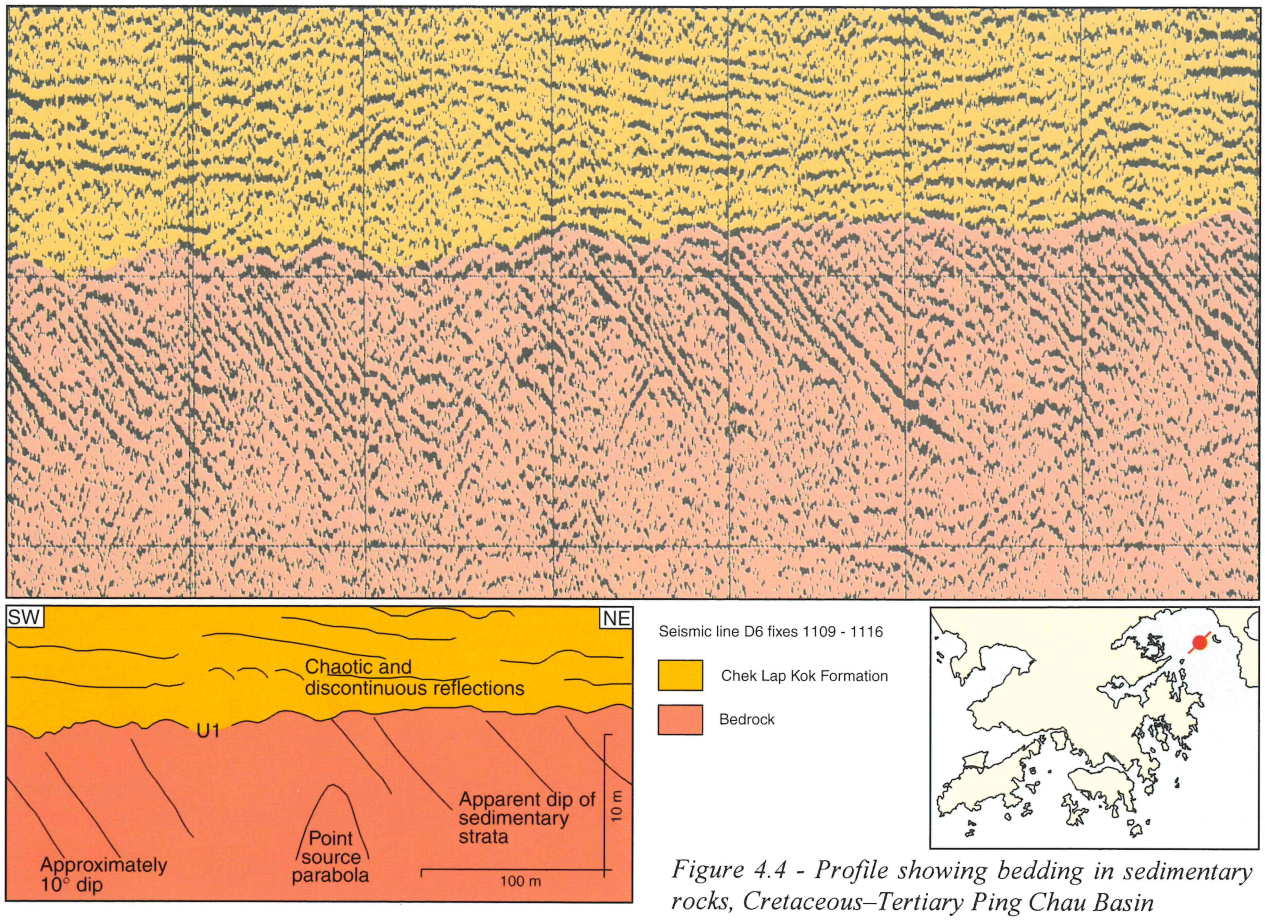


Figure 4.4 - Profile showing bedding in sedimentary rocks, Cretaceous–Tertiary Ping Chau Basin

often erosion surfaces and may be planar, indicating a period of transgression, or irregular, such as caused by an episode of channelling. Some major reflections have been traced across the whole of Hong Kong waters. These are the surfaces defined below using the technique of sequence stratigraphy.

The minor reflections occur within the major seismic units and are generally of low to medium amplitude. They represent minor changes in the character of the sediment and may be taken to demonstrate sedimentary bedding within the stratigraphical unit. These intra-formational reflections take a number of forms, applied to Quaternary deposits by Berryhill (1986) and summarised by Evans *et al.* (1995). They may be described in geometrical terms such as 'even', 'parallel', 'sub-parallel' and 'draped' (Figure 4.5). Where no pattern can be seen, they are often described as 'chaotic'. Alternatively, they are often described in terms of the bedding that they represent, such as 'onlapping' and 'conformable'. Channel-fill reflections may also be described after the styles identified by McKee (1957) (Figure 4.6). These represent various modes of sedimentation in the channel. An

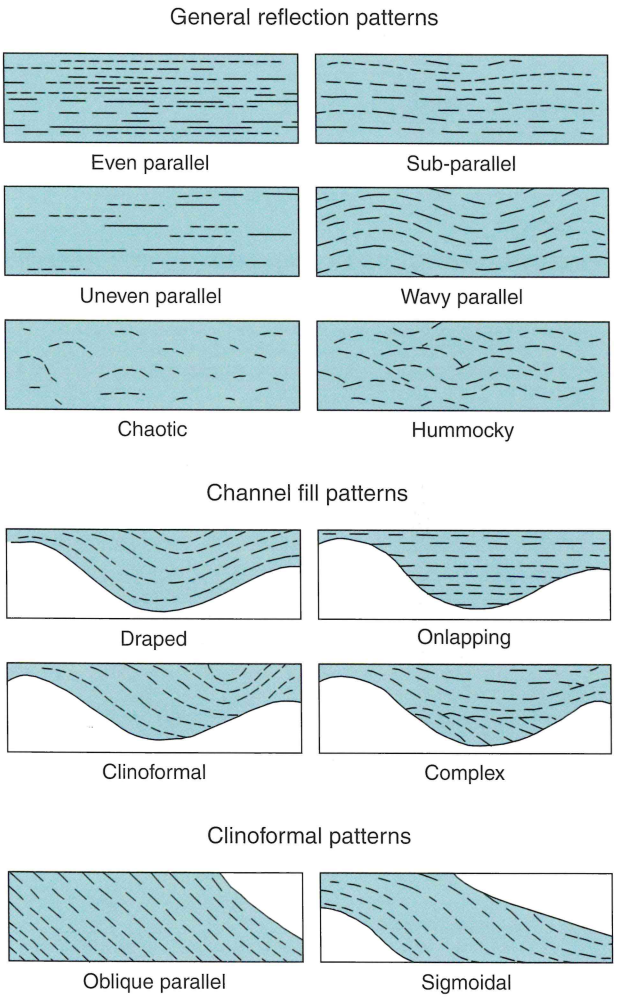


Figure 4.5 - Typical patterns seen in intraformational reflections

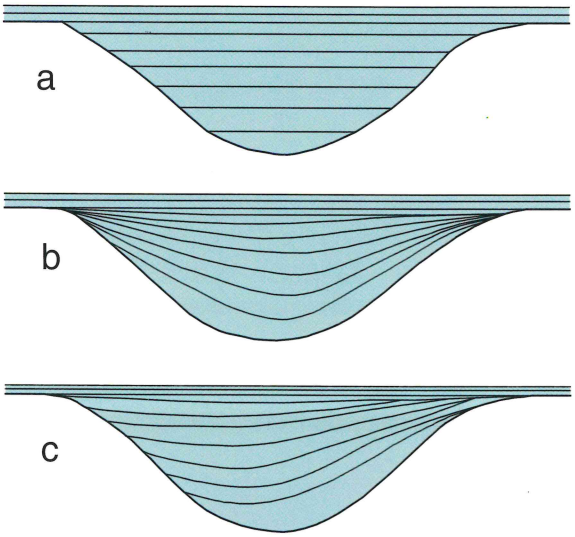


Figure 4.6 - Modes of channel fill: a. onlapping b. conformable c. symmetrical

onlapping bedding style may indicate shallow water, with sedimentation occurring during increasing depth of water. A conformable bedding style may be caused either by primary sedimentation in a channel-fill environment where sedimentation is constant over the whole width of the channel, or by post-depositional consolidation. Asymmetrical channel-fill may be the result of transverse currents in deep water over a channel feature, or as lateral channel fill in shallow water.

In some areas, reflection from within the Quaternary succession is masked by acoustic turbidity. This phenomenon is caused by the presence of occluded bubbles of gas in the sediments (Evans, 1988a; Premchitt *et al.*, 1992). In many cases, the morphology of the turbidity appears as a discrete 'plume' originating from a single channel (Figure 4.7). Elsewhere, the gas is manifest as broader 'pillars' or as an extensive blanket or 'plateau' over a much larger area (see Figures 10.8 and 10.9 for examples of seismic profiles and Figure 10.10 for distribution).

The gas has the effect of absorbing all the energy from the acoustic pulse. Although the morphology of the turbidity generally takes the forms already described, this

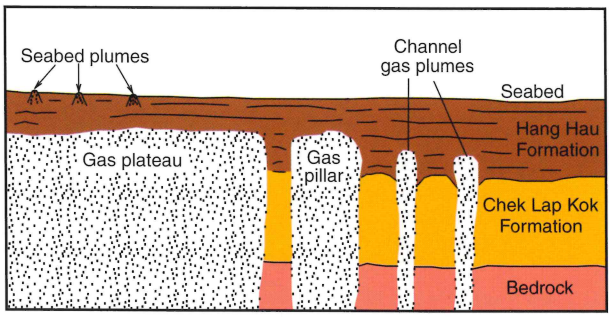


Figure 4.7 - Styles of acoustic turbidity seen on boomer profiles in Hong Kong (after Evans, 1988a)

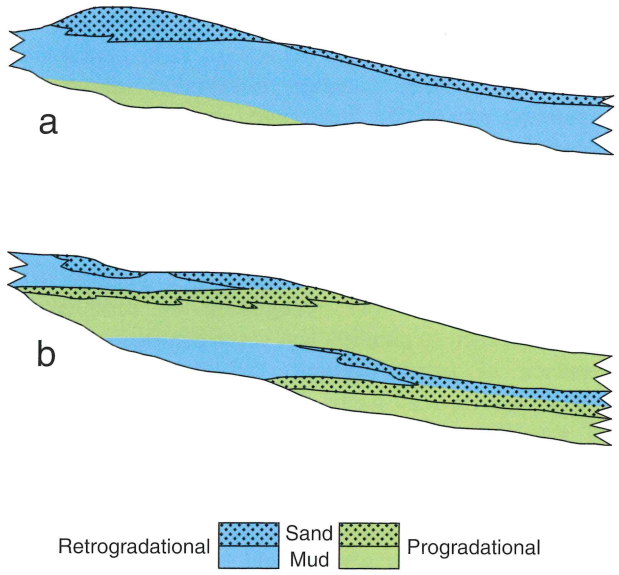


Figure 4.8 - Depositional regimes after Swift et al. (1991): a. supply-dominated regressive sequence b. accommodation-dominated transgressive sequence

does not imply that the gas is present throughout the Quaternary sedimentary pile; the loss of meaningful signal merely represents the gas front within the upper sediments.

Seismic and sequence stratigraphy

Seismic stratigraphy was originally used by Vail *et al.* (1977) for shelf-wide stratigraphical interpretations and the method has subsequently been refined and applied to Quaternary successions by workers such as Galloway (1989) and Swift *et al.* (1991). Sequence stratigraphy is based on the premise that depositional successions on continental margins develop due to the interaction of relative sea level change (transgressions and regressions), sediment supply (grain size and rate of transport), and sea floor subsidence (tectonics and compaction of sediments).

Combination of these factors results either in erosion (supply of sediment) or accommodation (space available for sedimentation) on the continental shelf and slope where deposition can occur. Surfaces of variable importance are thereby recognized, the most significant being lowstand erosion surfaces, ravinement surfaces, transgressive surfaces, and maximum flooding surfaces (Figure 4.8). These surfaces and their associated reflector geometry define the systems tracts that make up the sequences. Two major depositional regimes can be recognized on continental shelves: supply-dominated regressive sequences, and accommodation-dominated transgressive sequences (Swift *et al.*, 1991).

A lowstand erosion surface is a record of an erosional event during a period of lower sea level. Where this has involved fluvial erosion, such as channel-cutting, the process is known as fluvial entrenchment (Muto, 1993). The surface may have been subjected to subaerial weathering and a weathered profile or palaeosol developed on it. Some authors in Hong Kong (e.g. Yim & Tovey, 1995) have referred to these weathered horizons as a weathered or desiccated 'crust'.

A ravinement surface is produced by erosion of underlying sediments by landward migration of the shoreface during transgression (Suter *et al.*, 1987). A significant planar surface, dipping seaward at a low angle, may be developed in areas where wave energy is high. Elsewhere, such as in areas of low wave energy where little or no erosion has taken place, the process is recorded merely as a transgressive surface.

The major surfaces identified using the sequence stratigraphical approach thus record changes in sea level. These can be related to global sea level changes, such as those defined by the oxygen isotope stratigraphy of Shackleton (1987) (Figure 4.9). Oxygen isotope dating relies on the ratio of $^{18}O/^{16}O$ in contemporary sea water, recorded in calcium carbonate of microfossils such as foraminifera. The ratio changes in response to global climate. The heavier isotope, ^{18}O, is less volatile and is

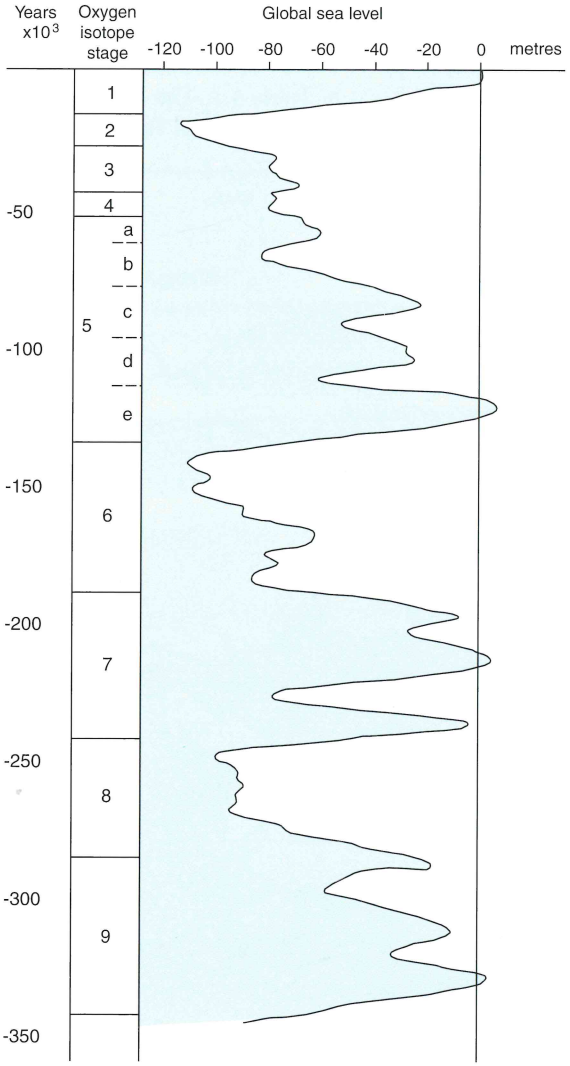


Figure 4.9 - Oxygen isotope stages related to global sea level changes

thus less common in meteoric water than in sea water. Expansion of the polar ice caps results in a reduction in volume of the world's oceans and a proportionate increase in concentration of ^{18}O. In the ice caps themselves, there is a corresponding increase in the concentration of ^{16}O, which is released into the oceans as the ice caps melt. The oxygen isotope record thus reflects changes in global sea level and a number of stages have been established (see Chapter 5, Figure 5.1). These permit sea level changes to be used as a method of relative dating.

Borehole and seabed test data

The offshore seismic data are complemented by a large number of boreholes and vibrocores. Many of these are nearshore and closely spaced, and were drilled for site investigation and reclamation projects. There have also been a number of boreholes drilled specifically for stratigraphical studies, typically to a depth of around 60 m. The description and interpretation of borehole cores provides an important step in understanding the nature and origin of offshore sediments. Several of those used for developing the offshore stratigraphy have been described in this publication; their locations are shown in Figure 4.10 and listed in Table 4.1. The details of many of these are held in the Geotechnical Information Unit (GIU) of the Geotechnical Engineering Office (GEO). Vibrocores are usually recovered in 12 m continuous tubes and provide valuable information about the uppermost part of the Quaternary sequence. However, vibration through the soft sediments can cause disturbance of bedding or any sedimentary structures.

Sedimentary units are identified in core samples according to their material characteristics and inferred depositional environments. Material composition and strength, together with recognition of sedimentary structures, such as parallel- and cross-lamination and the presence of other features, including bioturbation, discontinuities, shell bands and weathered horizons, are all valuable palaeoenvironmental indicators. Mineral assemblages are an important indication of the provenance of the sediments. Around Hong Kong, these comprise dominantly quartz, feldspar and lithic grains, usually consisting of granitic and volcanic rock clasts, together with fragments of biogenic origin, such as shells and plant material. The shape and roundness of grains are also a useful guide to the history of the sediment. Angular, freshly derived grains generally suggest an immature deposit from a local source, while rounded, well-sorted grains indicate prolonged transport and winnowing by water.

Boreholes and vibrocores have frequently been

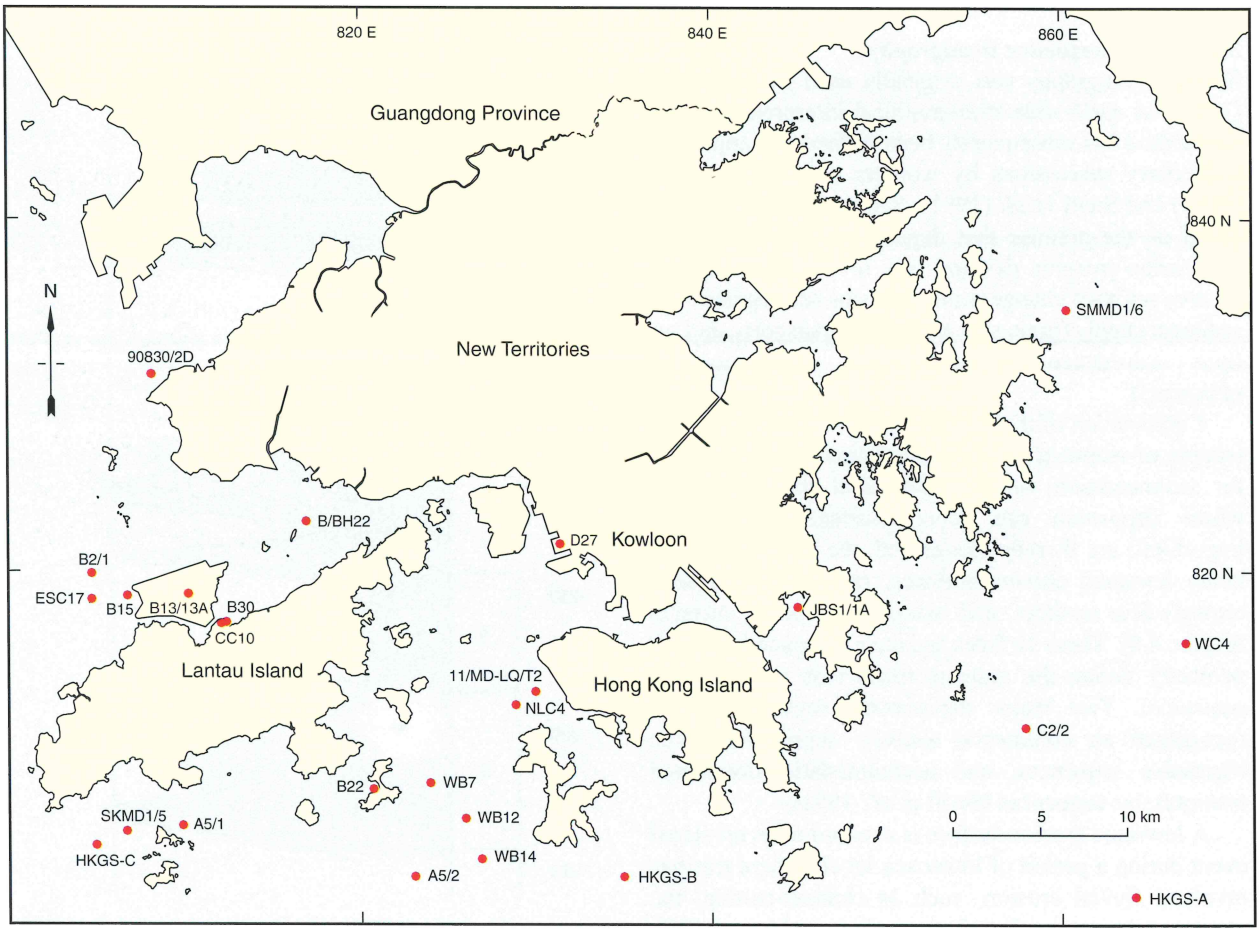


Figure 4.10 - Map of Hong Kong showing the position of boreholes described in this publication

Borehole Number	Easting	Northing	Elevation	GIU Report Number
A5/1	809 935	805 580	-10.0 m	12904
A5/2	823 109	802 705	-18.3 m	12904
B/BH22	816 970	822 826	-23.3 m	14258
B2/1	804 800	819 856	-6.7 m	12961
B13/13A	810 293	818 702	3.0 m	06380
B15	806 800	818 600	-6.1 m	14076
B22	820 757	807 666	-3.9 m	04220
B30	812447	817106	6.92	(TCTL4, C401)
C2/2	857 992	811 171	-30.4 m	12916
CC10	812147	817036	5.67	(TCTL3, C301)
D27	831 345	821 740	-7.8 m	-
ESC17	804 798	818 402	-5.3 m	15832
HKGS-A	864 290	801 594	-30.0 m	18110
HKGS-B	835 022	802 700	-22.8 m	18151
HKGS-C	804 990	804 450	-7.6 m	18553
JBS1/1A	845 000	818 000	-8.1 m	05890
NLC4	828 880	812 408	-11.5 m	18157
SKMD1/5	806 701	805 244	-5.0 m	16251
SMMD1/6	860 397	834 881	-21.7 m	17013
WB7	823 999	808 000	-10.2 m	16675
WB12	825 998	806 000	-13.6 m	16675
WB14	826 901	803 700	-19.2 m	16675
WC4	867 199	815 998	-27.1 m	18110
ZK3B	836 297	792 740	-31.5 m	-
90830/2D	808 235	831 170	-6.7 m	16442
11/MD-LQ/T2	830 048	813 320	-30.3 m	18325

Table 4.1 - Location details of offshore boreholes described in this volume (number in brackets – detailing contract reference report not yet lodged in GIU)

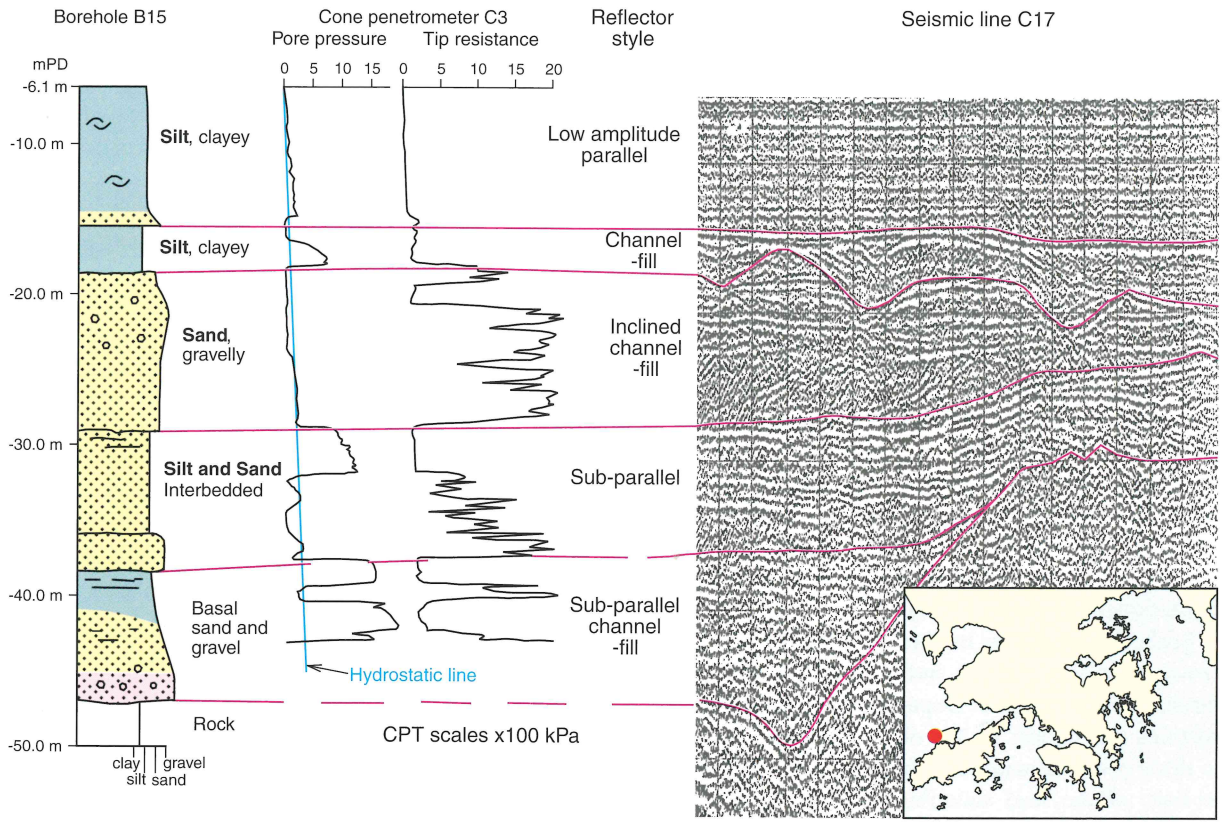


Figure 4.11 - Correlation between borehole log, cone penetrometer curves and seismic profile

supplemented by cone penetrometer tests (CPTs) and, in places, vane testing. Both are carried out principally in areas of planned reclamation where knowledge of the geotechnical properties of the sediments is required. The cone penetrometer consists of a cone-shaped probe that is forced into the sediment. The test results comprise cone resistance, cone friction and pore pressure measured on the shoulder of the cone. Of these, pore pressure and tip resistance are the most reliable parameters for correlation with sediment characteristics in Hong Kong (Endicott, 1992). The test results may also be correlated with lithostratigraphical divisions (Figure 4.11).

Seabed surface sediment samples have been taken mainly using grab samplers, though photographs and sidescan sonar images have been used to add further detail. Particle size analyses have been carried out on the seabed samples, and the results incorporated into the Geoscience Database maintained by the Geotechnical Engineering Office. This database also includes details of boreholes, vibrocores, CPTs and seismic track information.

Seabed sediments

The seabed sediments have been mapped using data gathered from a variety of sources; these are identified on Map 6. The Hong Kong Geological Survey has collected a large number of seabed samples across the region (Shaw, 1992), and the Environmental Protection Department (EPD) annually sample around 50 sites. The grab samplers used in these surveys take a disturbed bulk sample from the upper 0.2 m of sediment below the seabed. Particle size analyses of the samples are carried out to determine the percentages of the sand and mud fractions. Borehole data have not been used in the current investigation as these generally provide poor recovery of the surface sediments.

The Geotechnical Engineering Office has commissioned several seabed sediment investigations using a seabed profiling camera (Evans, 1994a; Valente *et al.*, 1996; Selby & Evans, 1997). This equipment penetrates the seabed and photographs a cross-section of the upper 0.1 to 0.15 m of the sediment. Minimum, maximum and modal particle sizes are later visually estimated using a photographic grain size comparator that allows particle size estimates down to medium–coarse silt size. Correlation of the results with sieve analyses has shown that the technique is most accurate in well-sorted sediments (Science Applications International Corporate, 1994).

Seabed materials are marked on navigational charts to provide mariners with an indication of 'quality of the bottom' (Hydrographic Department, 1984). Sediment notations that appear on the older charts were based on the description of material adhering to tallow applied to the base of the lead sounding weight. More recently, seabed grabs have been used. Descriptions of the quality of the bottom have been interpreted for this survey and Folk classes (Figure 4.12) assigned, allowing the

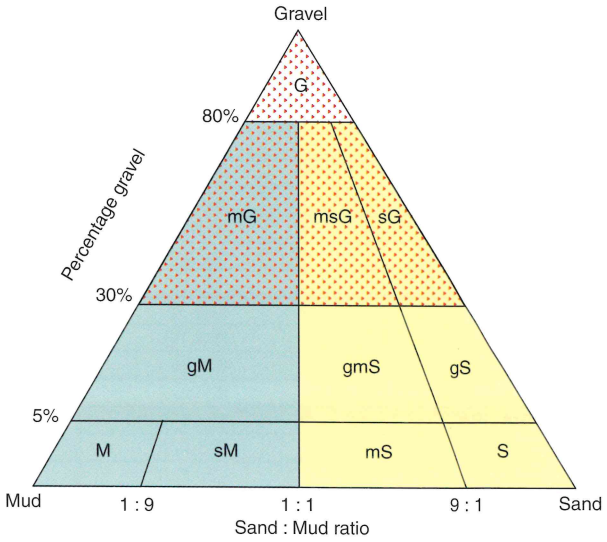


Figure 4.12 - Graphical representation of the sediment classification scheme modified from Folk (1954)

information to be incorporated into the database for the 1:100 000-scale seabed sediment map (Map 6).

Selected areas of the seabed around Hong Kong have been surveyed using sidescan sonar, which provides an acoustic image of the seabed. Features such as rock outcrops and areas of sand are distinguished by their different reflectivity, exhibiting darker tones and shades on the records. Morphological features, such as sand waves and ripples can also be identified. Recently, Electronic and Geophysical Services Ltd. deployed a Klein 595 sidescan that produced very high resolution records. Some examples are illustrated in Figures 10.20 to 10.22.

Seismic reflection profiling, using a surface-towed boomer, is primarily employed to determine the offshore stratigraphy. However, boomer records can also provide a useful guide to seabed sediment type. The seabed reflection from mud is weaker than that from sand. Mud generally exhibits a faint, or very weak, seismic signature, often with sub-parallel, laterally-continuous reflections. However, sand displays a stronger, higher contrast signature. As a result, a pronounced seabed multiple is commonly a characteristic indication of a sandy seabed.

Detailed descriptions of seabed conditions have also been taken from reports of scuba divers, both from those working on a variety of technical projects and those undertaking recreational dives. Although these descriptions cannot be used directly in determining the overall distribution of sediments, the observations give a valuable indication of local sediment types and the presence and nature of rock outcrops.

Analytical techniques

The analytical techniques used for the study of the Quaternary sediments are diverse. Seismic interpretation, restricted to offshore environments, is aided by sequence

stratigraphical methods, including correlation with oxygen isotope stratigraphy and its relation to global sea level change. Boreholes both onshore and offshore, have been studied using particle size analysis, geochemistry, radiocarbon dating and magnetic susceptibility. Micropalaeontological studies have also been undertaken on borehole material, mainly, but not exclusively, from offshore boreholes.

Particle size analysis

Environments of deposition can be inferred from the particle size of sediments, especially when used in conjunction with sedimentary structures, composition of the sediments and other parameters described during borehole logging. Particle size analyses are usually carried out by sieving and hygrometer methods.

Sediment grains can be divided into a number of size classes, generally based on a logarithmic function. The size classes used for description in this publication are those of the Wentworth (1922) scale (Figure 4.13). The Folk (1954) scale is used for the graphical logs. Particle size is indicative of the magnitude of the current that carries and deposits the grains. Clay and silt, which are generally carried in suspension, are deposited in low-energy environments, whereas sand and gravel are carried by increasingly higher energy currents. Grain size distribution statistics and particle size distribution curves are valuable techniques to assist with interpreting environments of deposition. The most useful statistic is sorting, which is a measure of the range of grain size classes present in a sediment. A well-sorted sediment comprises a small number of grain size classes. This characteristic produces a steep curve on a particle size distribution plot. Mature, well-sorted sediments in every major sedimentary environment are characterised by a distinctive modal grain size that determines the location of the curve on the plot (Figure 4.14).

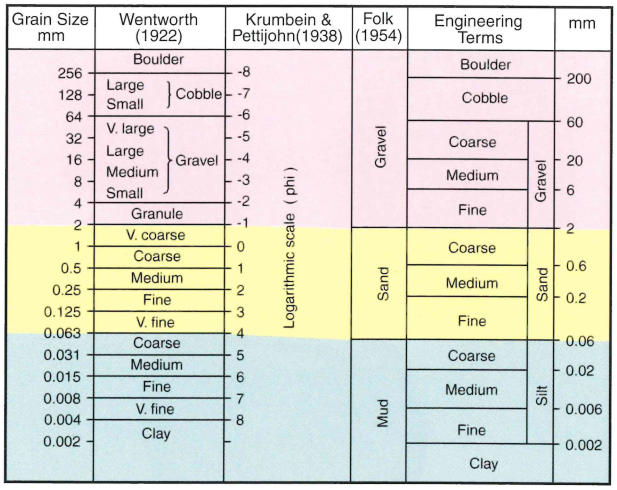


Figure 4.13 - Grain size classes of Wentworth (1922), Krumbein and Pettijohn (1938) and Folk (1954) compared with engineering terms (GCO, 1988)

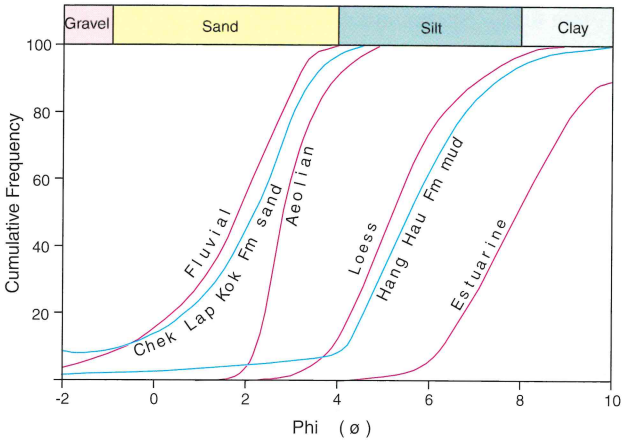


Figure 4.14 - Particle size distribution curves associated with different sedimentary environments

Micropalaeontology

Microfossils provide a reliable guide to salinity, temperature and other palaeoenvironmental conditions. Therefore, a range of different microfossils preserved in the offshore Quaternary sequence has been studied. These include calcareous microfauna such as foraminifera and ostracods, siliceous microflora such as diatoms, other organic microfossils including dinoflagellates, and terrestrial spores and pollen.

Foraminifera (Plate 4.1a) are marine protozoans that occur at all latitudes and in a wide variety of environments in all oceans. Their high species diversity makes them very useful in studying marine sediments, especially in marginal marine and estuarine areas. They occur both as planktonic and benthonic forms, the former being generally oceanic, while the latter live in all areas from intertidal to abyssal zones. On the continental shelf, they can usefully be divided into inner, middle and outer shelf species and the relative abundance of these forms is an effective palaeoenvironmental indicator.

Ostracods (Plate 4.1b) are arthropods that inhabit fresh, brackish and open marine waters, species diversity increasing with increasing salinity. They are mostly benthonic though, with limited locomotion, and are passively dispersed. Nevertheless, they are sensitive to salinity, water temperature and depth, which makes them very useful environmental indicators.

Diatoms (Plate 4.1c) are unicellular siliceous algae, adopting both planktonic and benthonic lifestyles. Relying on photosynthesis, they live only in the photic zone, though they tolerate a wide variety of environments from open tropical ocean to sea ice; they can even survive in water-logged soil. The assemblages are sensitive to temperature, salinity and availability of nutrients. They can be classified in terms of the relative proportions of marine and brackish species.

In addition to the planktonic and benthonic microfossils, palynology provides a useful tool in palaeoenvironmental analysis. Two main forms of terrestrial microflora exist: spores and pollen

(Plate 4.1d). Spores are derived from a number of plant species, the most common being ferns. Pollen originates from angiosperms such as shrubs and trees. Marine microflora, mainly dinoflagellates, are also used in Quaternary stratigraphy. Fluctuating sea level produces changing floral assemblages. In nearshore areas, the increase in mangrove assemblages such as *Sonneratia* and *Rhizophora* indicate predominantly intertidal conditions, whereas fern spores suggest a more terrestrial environment.

Microflora are also valuable palaeoclimatological indicators: a study of palynological assemblages (Yim & Yu, 1993) showed that the mangrove *Sonneratia alba* occurs only south of Hong Kong at the present day. The presence of this pollen thus indicates a warmer climate during deposition of sediments in which the species occurs. On the basis of more temperate pollen species, Yim and Yu (1993) inferred that marine sediments, of otherwise undetermined age, were pre-Holocene.

Geochemistry and mineralogy

Several studies have been undertaken using geochemical and mineralogical techniques (Tovey, 1986, 1991; Kemp, 1993; Tanner *et al.*, 1993; Owen *et al.*, 1995; Owen *et al.*, 1998). Several of these have concentrated on the clay mineralogy of marine sediments. The dominant clay minerals are illite, kaolinite and smectite. Smectite is present in higher concentrations in the Hang Hau Formation than in the Chek Lap Kok Formation.

Microfabric analyses have been carried out on sediments of the Hang Hau and Chek Lap Kok formations (Tovey, 1991). This technique is used to indicate the stress levels to which marine mud has been subjected. Increasing stress levels, caused, among other things, by consolidation, leads to increasing anisotropy in the orientation of the clay minerals but its usefulness in Hong

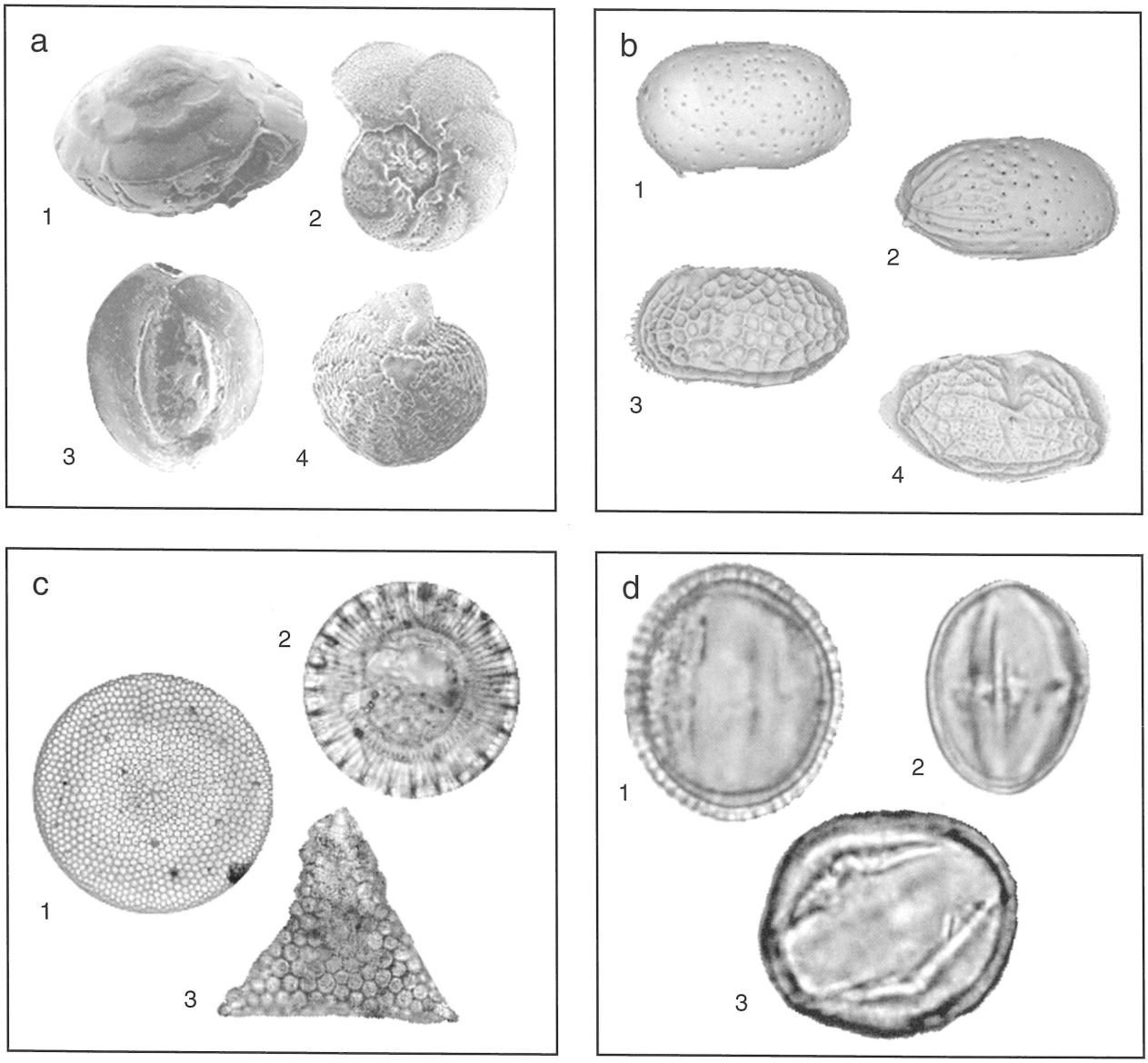


Plate 4.1 - Microfossils from the Quaternary of Hong Kong: foraminifera, ostracods, diatoms and microflora

Kong is limited by the high silt content of the sediments.

A number of geochemical parameters may be measured. The most important are pH level, organic carbon content and carbonate concentration. In a study of borehole A5/2, Owen *et al.* (1995) concluded that, in sediments deeper than around 25 m in the borehole, there was little correlation between these parameters and the original depositional environments inferred by other methods. This was attributed to diagenetic changes including compaction and dewatering. Yim (1992) included these parameters among a range of geochemical and other indicators that were considered to be diagnostic in distinguishing between marine and terrestrial deposits (see Table 7.1). The conclusions reached by Owen *et al.* (1995) for sediments shallower than 25 m in the borehole were in broad agreement with the trends noted by Yim (1992).

Dating of sediments

A number of different methods have been used to determine the age of the Quaternary sediments, including radiocarbon and uranium-series dating, thermoluminescence (TL) and optically-stimulated luminescence (OSL).

Radiocarbon dating is the most widely used method of establishing the age of Quaternary sediments as well as archaeological artefacts. Atoms of the radioisotope ^{14}C, which are produced in the atmosphere through the cosmic-ray neutron bombardment of ^{14}N, mix with other carbon isotopes in the atmosphere and hydrosphere, making up a steady-state concentration. The carbon is incorporated into plant and animal tissue and the ^{14}C subsequently decays. The isotope has a half-life of 5 730 years, which limits the technique to dating sediments younger than about 40 000 years BP.

The method depends upon the assumption that ^{14}C ratios in the atmosphere have been constant over the last 40 000 years. The dates yielded are measured as radiocarbon ages in years before an arbitrary date of 1950, known as years before present (BP). More detailed chronological work using tree rings has shown that the ratio has varied over the last 10 000 years. A correction factor, which depends upon geographical location, may be applied and the dates thus calculated are quoted in calendar years (AD or BC). A further correction (reservoir correction) can be made for samples that have been preserved in a marine environment. This level of refinement, which results in samples being a few hundred years older than the ages quoted, has not generally been applied to the Hong Kong data.

The principal geological materials used for radiocarbon dating are plant remains, such as wood and peat, and marine shells, including bivalves and gastropods. Microfauna such as foraminifera may also be selected by species and accurate dates can be obtained by atomic mass spectrometry even using very small samples.

The reliability of the radiocarbon method has been reviewed by Yim *et al.* (1990), who concluded that dates of Pleistocene age are subject to a young age bias. This has also been suggested by Owen *et al.* (1995), where a radiocarbon age of 35 000 ± 1 250 years BP has been correlated with OSL and TL dates of around 80 000 years. In many cases, finite dates that have been quoted are possibly spurious. Toscano and York (1992) have indicated that minimal amounts (0.1 to 5%) of modern carbon contamination are capable of producing significant errors in radiocarbon dates. Such contamination can come from circulating CO_2-rich groundwater during emergence at times of low sea level.

Despite the difficulties of applying radiocarbon dating to Late Pleistocene sediments, its use in dating Holocene sediments is less open to doubt. The Hang Hau Formation sediments have been continuously submerged since the rise in sea level during the early Holocene.

Thermoluminescence (TL) and optically-stimulated luminescence (OSL) have also been used as dating techniques for Hong Kong offshore sediments. These techniques rely on the capacity for mineral grains such as quartz and feldspar to trap electrons, which are the product of natural radiation in a rock (Dreimanis *et al.*, 1985). The electrons are activated when the grain is subsequently heated (TL) or stimulated by light (OSL) in a laboratory and the energy given out as light can be measured.

When a grain is heated, the electron traps are emptied. The time of this heating is known as the zero point, and the luminescence is therefore a measure of the time from the zero point until the present day. The zero point is well defined in dating pottery, where the firing of the artefact empties the traps. For this reason, TL has largely been developed from its application in the field of archaeology. The zero point for Quaternary sediments is not so easily defined, and in most cases, the exposure of the grain to sunlight, or bleaching, provides the mechanism for emptying the electron traps.

Luminescence techniques are, therefore, applicable to sediments that have been bleached by sunlight and subsequently buried and deprived of light. As such, they may be most useful in the dating of subaerial deposits, but are in more doubt for subaqueous deposits, such as the alluvial sediments of the Chek Lap Kok Formation, on which the technique has been principally applied. Thermoluminescence can successfully be applied to quartz grains of between 1 000 and 1 000 000 years old and feldspar grains of between 1 000 and 700 000 years old (Dreimanis *et al.*, 1985).

Uranium-series dating provides the opportunity to date even older sediments. This method is based on the measurement of the relative abundance of the short-lived radioactive products of ^{238}U and ^{235}U (Schwarcz & Blackwell, 1985). The method depends upon the tendency for the short-lived daughters of these radioisotopes to become separated from their parents during sedimentary processes. Where this separation accompanies the formation of natural materials, such as bone, shell or carbonate exoskeletons, measurement of

the relative abundance of the daughter radioisotopes provides an age for the sediment.

The radioactive products of ^{238}U and ^{235}U form two series of radioisotopes and the large range of half lives of these daughters means that the ages determined can range from a few days to around a million years. The method requires that the system does not remain open, i.e. that there has been no post-depositional mineral replacement. Also, assumptions must be made concerning the original relative abundance of the daughter isotopes in the material being dated.

Uranium-series dating has been used in Hong Kong on bivalve shells from the Chek Lap Kok Formation (Yim *et al.*, 1990; Owen *et al.*, 1998). Mollusc shells are considered to be poor material to date, as they act as an open system for several thousand years (Schwarcz & Blackwell, 1985). Coral, on the other hand, though a suitable material, is rarely found in the Quaternary fossil record in Hong Kong.

Magnetic susceptibility

Magnetic susceptibility measures the ability of materials to be magnetized. In the geological context, this depends upon the proportion of magnetic minerals in a rock or sediment. The principal magnetic minerals that occur in offshore sediments are magnetite, normally in very low concentrations, and goethite. These may either occur as sedimentary grains of primary origin or as a biogenic component.

Primary magnetite may occur where the sediment comprises the weathering products of basic igneous or other iron-rich rocks. Magnetic minerals may also record regionally significant events such as volcanic eruptions. These are of lesser importance in the Hong Kong Quaternary sediments; the principal component is probably the biogenic one. This relies on the production of minor amounts of biogenic magnetite by iron-reducing bacteria (Lovely *et al.*, 1987) and is most common in environments of low oxidising potential, such as estuaries.

The plotting of magnetic susceptibility curves may be used to correlate the sediments. The method has been used by Yim (1996) to identify broad stratigraphical zones. Work by Wright (1994) and James (1995), however, has indicated that apart from recording major lithological changes, magnetic susceptibility probably has only limited application in the detailed analysis of the offshore Quaternary sediments of Hong Kong.

Facies models

Although offshore sedimentary units are best mapped using seismic interpretation and sequence stratigraphy, these methods do not provide any information about the character of the sediments and their environments of deposition. Borehole logging, used in conjunction with other techniques, has provided the basic tool for developing an offshore sedimentological model in Hong Kong (Fyfe, 1992a).

The basic building block of this model is the sedimentary facies. This has been defined (Walker, 1992) as a body of material characterised by a particular combination of lithology, physical and biological structures that bestow an aspect different from the bodies of material above, below or laterally adjacent. Individual facies can be combined into facies associations. These are groups of related facies that together have some environmental significance (e.g. Collinson, 1969). Once facies associations have been identified, a facies model can be developed. The objective of facies modelling is to provide an integrated basis for a full geological interpretation (Walker, 1992). This approach has been adopted in Hong Kong for identifying units of related deposits that are sufficiently distinguishable and different in palaeoenvironmental terms to warrant being designated as a separate stratigraphic unit of formation. Sub-formation units are occasionally sufficiently distinctive to warrant singling out as representing significantly different though minor periods of deposition and these are termed members.

Much of the environmental interpretation comes from identification of primary structures within the sediments. The principal structures are described in terms of bedding and lamination. Although in surface sediment exposures, it may be possible to see bedding in sand layers, this is generally not possible in cores, as the collection, recovery and extrusion of the core lead to the destruction of any visible structures. In muddy sediments, however, lamination may be clearly seen. This is all the more evident when sand or coarse silt is interlaminated with finer sediment. Here, the coarser fraction can be seen in laminae, up to a maximum of a few millimetres thick, and lenses, often representing minor sand ripples. The lamination can be disturbed in a number of ways, including deformation while the sediment was still soft, and bioturbation, caused by burrowing of marine and other organisms. Laminae may also be distorted in the core sample tube during either collection, extrusion, or both.

5. Quaternary stratigraphy

The Quaternary is the shortest and most recent geological period in the Earth's history, spanning the period from about 1.61 Ma until the present day. It was first named by Morlot in 1854 (Harland *et al.*, 1982) and encompasses the Pleistocene and Holocene epochs. The age of the Pliocene–Pleistocene boundary at the base of the Quaternary is a matter of some debate. The original concept that the beginning of the Quaternary period was marked by the onset of the glacial deposition has been rejected with the recognition of Pliocene glaciations. Nevertheless, the guiding principle for stratigraphical subdivision of the Quaternary is the recognition of short-term global climatic fluctuations (Mitchell *et al.*, 1973) and the glacial–interglacial cycles that form the basis for this framework.

Quaternary chronostratigraphy

The nomenclature of the Quaternary stages varies worldwide, largely due to the geographical variation in response to global climatic changes. The British and Northwest European stages have been correlated with moderate success (Bowen, 1985) (Figure 5.1). Western and northern Chinese stage names (Derbyshire, 1987) are based principally on mountain glaciation and there are, therefore, a number of local nomenclatures. In some earlier work (e.g. Evans, 1990a), the British stages were applied to the Hong Kong offshore sediments and more recently to the Quaternary in Asia (Evans *et al.*, 1995). It is this stratigraphical nomenclature that is followed here. The terms 'Riss' and 'Wurm' have also been used for correlation in Asia (e.g. Huang & Chen, 1988; Long & Huo, 1988), but as they are part of the Alpine mountain glaciation classification, they are considered to be inappropriate for Hong Kong.

Accurate geochronology is difficult for the majority of the Quaternary, though radiocarbon dating may be used for the last 40 000 years (see Chapter 2). Magnetic polarity events may be confidently dated, but these are not conclusive for correlating sediments. Two magnetic epochs, the Matuyama Reversal and Brunhes Normal, encompass the Quaternary. Within these magnetic epochs occur a number of events that may be of value in relative dating. The Matuyama Reversal includes the Olduvai and Jaramillo normal events and the Brunhes Normal includes the Blake reversed event. However, this method is of limited use in Hong Kong as the vast majority of sediments were deposited during the Brunhes Epoch of the last 730 000 years.

The most valuable method of relative dating is oxygen isotope stratigraphy. This scheme, developed from analyses of deep ocean cores, reflects changes in global sea level. A number of oxygen isotope stages have been erected (Shackleton & Opdyke, 1976). These are essentially climatic, but can be correlated with the regional stratigraphical subdivisions (Figure 5.1).

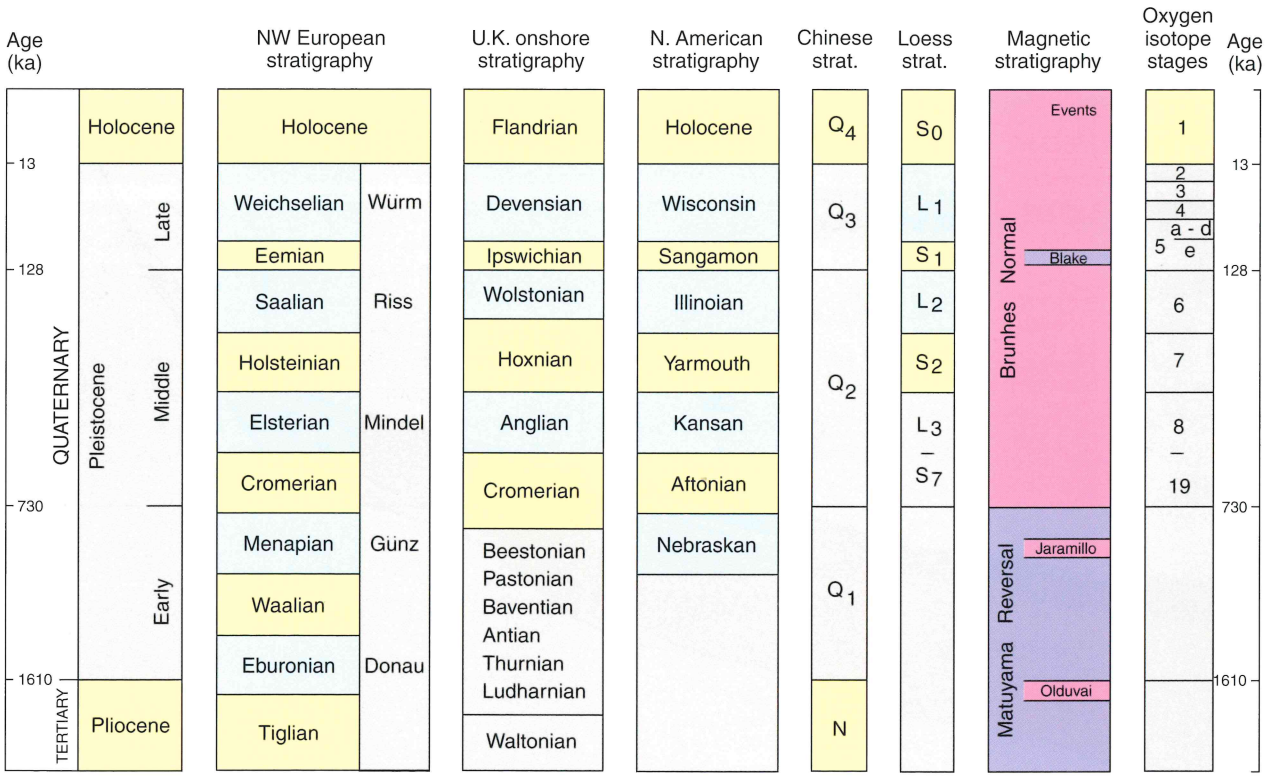


Figure 5.1 - Correlation of Quaternary stratigraphical schemes

Controversy still surrounds the definition of the Pliocene/Pleistocene boundary, although it is now generally taken to be at the top of the Olduvai Event, or 1.61 Ma (Bowen, 1985). The Pleistocene is subdivided into Early, Middle and Late units based on several criteria. The top of the Early Pleistocene is placed at the Brunhes/Matuyama boundary, whereas the boundary between the Middle and Late Pleistocene is marked by the base of oxygen isotope stage 5 at 128 000 years BP. The base of the Holocene is, again, a matter of some speculation, but Bowen (1985) defined it as the base of oxygen isotope stage 1, at 13 000 years BP.

In Chinese stratigraphy, the Lower, Middle and Upper Pleistocene and the Holocene are assigned the symbols Q_1, Q_2, Q_3 and Q_4 respectively. Yang and Liu (1994) discussed Quaternary stratigraphical correlation in China and adjacent areas. The primary Chinese subdivisions are based on loess stratigraphy from central China (Liu *et al.*, 1985). These have been correlated with the oxygen isotope stages (Figure 5.1) though, in some cases, several of the latter are grouped into one particular palaeosol (S) or loess (L) unit. Thus, the base of the Middle Pleistocene correlates with the base of palaeosol S_7, the base of the Upper Pleistocene with the base of S_1, and the base of the Holocene with the base of S_0.

Quaternary stratigraphy in Hong Kong

Onshore

Several regional studies have produced maps that depict the broad distribution of Quaternary superficial deposits in onshore areas of Hong Kong. Most notably, Allen and Stephens (1971) recognized, and mapped photogeologically, three classes of these deposits: alluvium, colluvium and, in littoral environments, marine sediments. Bennett (1984) carried out a review of published sources of information on the stratigraphy of the onshore superficial deposits. He concluded that they could be divided into two broad categories: fluvial deposits, which included alluvium and beach deposits, and mass wasting deposits (colluvium), which included debris flow and talus deposits. These two categories were adopted by the Hong Kong Geological Survey during the recent 1:20 000-scale geological mapping of the whole of Hong Kong.

Prior to the publication of this memoir, only a limited attempt had been made to erect a formal lithostratigraphy for the onshore Quaternary sequence in Hong Kong. The principal exception to this was the description of two Pleistocene alluvial formations, the Wong Kong Shan Formation and the Shan Ha Tsuen Formation, by Lai (1997, 1998) in the New Territories. With respect to

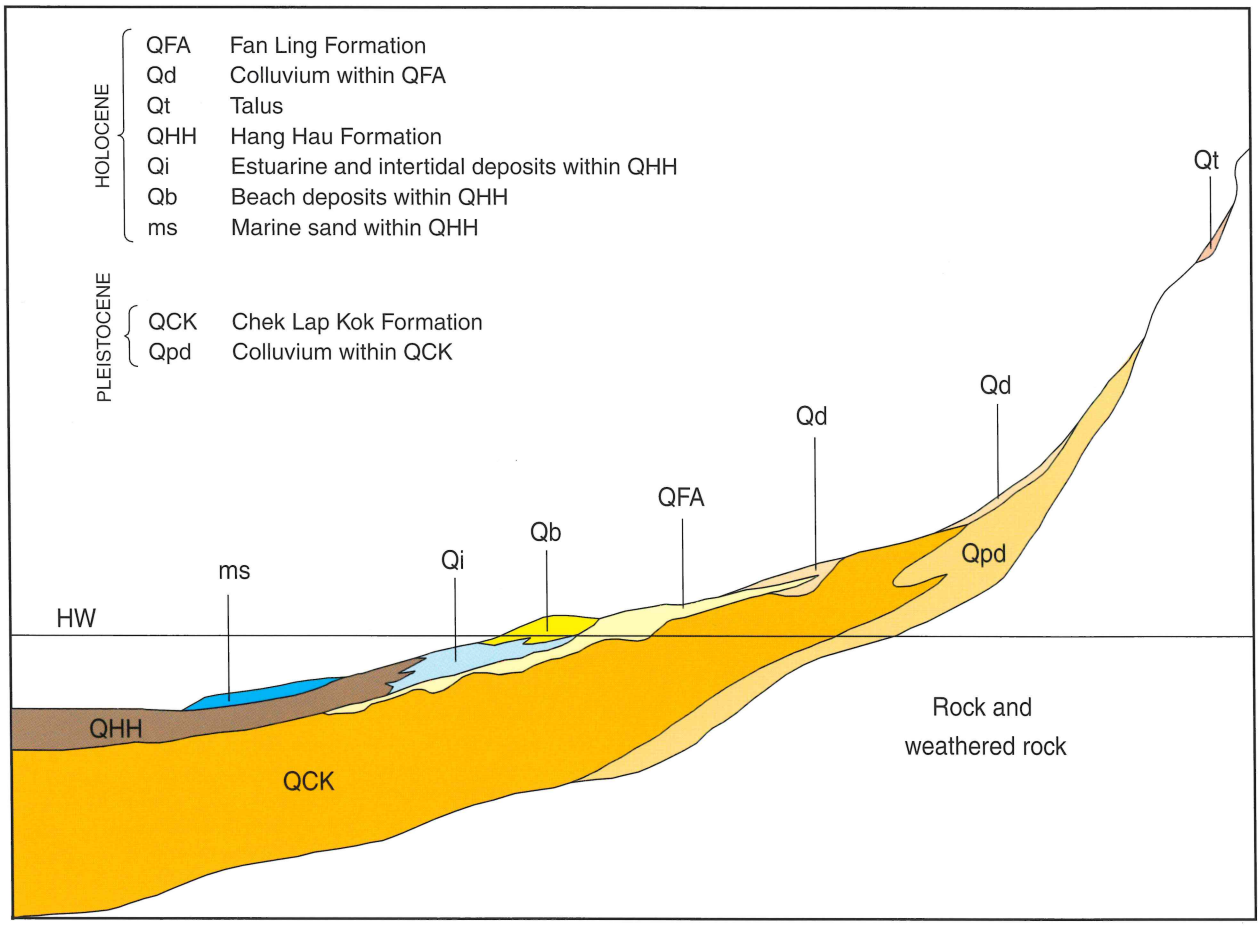


Figure 5.2 - Correlation and revision of Quaternary stratigraphy between onshore and offshore areas

chronostratigraphy, onshore Pleistocene deposits of various types have been differentiated from similar deposits of Holocene age on some, but not all, of the 1:20 000 geological maps of Hong Kong produced by the Hong Kong Geological Survey. Otherwise, the onshore Quaternary deposits have generally been described, and their distributions mapped, in terms of depositional processes and environments of deposition. This approach has been in contrast to that adopted for offshore Quaternary deposits, for which a robust lithostratigraphy has been developed, based on extensive seismic reflection and borehole data.

To redress the imbalance in treatment of the onshore and offshore Quaternary stratigraphy, this memoir presents a comprehensive lithostratigraphy that encompasses all Quaternary deposits. The proposed stratigraphy (Table 5.1, Figure 5.2) is essentially an extension of the existing offshore stratigraphy with the addition of one new formation, the Holocene Fanling Formation. In addition, the two alluvial 'formations' previously described by Lai (1997, 1998) are incorporated in the lithostratigraphy, but as members within the Chek Lap Kok Formation: the Wong Kong Shan Member and the Shan Ha Tsuen Member.

Correlation of the onshore Pleistocene alluvial deposits with the Chek Lap Kok Formation is relatively straightforward (Figure 5.2), but the stratigraphic treatment of the Pleistocene mass transport deposits (debris flow deposits, slope debris, etc.) is rather more problematic. They clearly interdigitate with the Pleistocene alluvial sequence onshore and have been reported within the predominantly alluvial and fluvial Chek Lap Kok Formation. As such, they can be regarded as members within the Chek Lap Kok Formation, although they do not necessarily have to be named individually. However, as these deposits are traced into more proximal environments, where they become the dominant component of the stratigraphy, it could be argued that they provide the basis for a separate, predominantly colluvial, formation. However, this solution has not been adopted here. This is mainly because the colluvial material is very heterogeneous and, more importantly, extremely laterally variable in thickness.

Offshore

Development of the offshore Quaternary stratigraphy of Hong Kong has recently been discussed by Fyfe (1992b), and Yim and Fyfe (1992). Initial attempts to subdivide the offshore succession were derived from the descriptions of sediments in boreholes. Offshore Quaternary deposits were divided into a basal 'alluvium' or 'colluvium', comprising interbedded gravel, sand and mud, and an overlying 'marine deposit' of silty clay with shell fragments (Binnie & Partners, 1974; Hong Kong Malayan Drillers & Engineers Ltd., 1974). This simple subdivision constituted a rudimentary stratigraphy that was used for many years, and still provides a general outline of the Quaternary sequence. Subsequently, more exacting work has refined this scheme using the results of detailed borehole analyses, interpretation of seismic records and, more recently, the application of sequence stratigraphy.

Alternative attempts at stratigraphical subdivision of the offshore Quaternary deposits were also made by Ma (1974), Tang (1974) and Yeung (1976) during work on the West and East dams of the High Island Reservoir (萬宜水庫) scheme. They developed a simple genetic classification that was later applied by RMP Encon Ltd. (1982) in the first study for the replacement airport at Chek Lap Kok (赤鱲角). Sediments at that site were divided into four depositional stages (Fung *et al.*, 1984).

Yim (1984a, 1984b) has extended this genetic classification to other sites across Hong Kong. Later Yim *et al.* (1988) expanded the scheme to include a Middle Terrestrial and a Middle Marine unit. These divisions were based primarily on micro-palaeontological analyses of samples from sixteen boreholes across Hong Kong. The complete succession of six units was reported as being seen in only one proximal borehole, H3 in Tai Tam Bay (大潭灣).

Subsequently, Yim (1992) revised his earlier classification and correlated the Middle Terrestrial with the Eemian interglacial, and the Lower Terrestrial with the Holsteinian interglacial. More recently, Yim (1994) has proposed a tenfold stratigraphy, postulating a series of marine and terrestrial units. Without the support of absolute dates, these units have been matched with the Chinese loess stratigraphy and assigned to the five known glacial–interglacial cycles. Distinction between marine and terrestrial units was based on a number of environmental indicators, as discussed in Chapter 4. Significantly, the full succession has not been identified in any single borehole and the units cannot be correlated with seismic data.

Most of the early work on the Quaternary stratigraphy of Hong Kong was carried out before the routine and widespread use of seismic profiling in the region and had to rely solely on borehole data. The current offshore stratigraphy is substantially based on an interpretation of regional seismic data.

The first formal offshore stratigraphy was published by Strange and Shaw (1986). This two-fold lithostratigraphy was based primarily on the detailed examination of several nearshore continuously sampled boreholes, correlated with an interpretation of the limited nearshore seismic data then available. They identified two main lithostratigraphical units, the Chek Lap Kok Formation and the Hang Hau Formation. The type sections for these two formations are boreholes B13/13A at Chek Lap Kok and JBS1/1A in Junk Bay (將軍澳) respectively.

Regional offshore seismic surveys began in 1986 with the commencement of the Seamat Study (Cheung & Shaw, 1993), a regional search for offshore sources of sand for use as reclamation fill. These surveys provided the framework for the development of a comprehensive seismic stratigraphy.

A third formation, the Sham Wat Formation (James, 1993) was subsequently identified on seismic records. Although not as widespread as the Chek Lap Kok and Hang Hau formations, it has been mapped over the western and southern parts of Hong Kong waters. The type section for this formation is borehole ESC17, north of Lantau Island (大嶼山).

In the southeast, the Waglan Formation has recently been recognized. The formation, which is formally defined here (Chapter 9), is restricted in its occurrence and has been identified only in deeper water areas of the continental shelf, where a more continuous succession exists. Its type section is borehole HKGS-A in southeastern waters.

A further formation, the Tung Chung Formation, has also been identified recently (Kirk, in press) and is defined here (Chapter 6). The formation is only known at present from local occurrences in the vicinity of Tung Chung (東涌), east of The Brothers (大小磨刀) islands, and along the north coast of Lantau Island. The formation is the oldest known Quaternary formation in Hong Kong. The type section of the formation is designated as being

Formation		Environment of Deposition and Typical Sediments	Age
FanLing Formation	Un-named colluvial members	Mass transport deposits on slopes, filling drainage lines, forming fans at slope base and interdigiting with alluvial deposits. Poorly sorted clayey sandy silt varying to gravelly silty sand with cobbles and boulders	TL date of 1 400 ± 200 and 22 200 ± 300 years BP
	Undifferentiated	Mainly alluvial deposits within present drainage lines, including incisions into older terraces on plains. Generally well sorted clays, silts, sands and gravels with occasional lacustrine silts and clays	Radiocarbon dates range from 520 ± 112 years BP to 6 760 ± 130 years BP
		Unconformity	
Chek Lap Kok Formation	Un-named colluvial members	Mass transport deposits on slopes, interdigiting with alluvial and fluvial deposits towards slope bases. Poorly sorted, slightly mottled, slightly clayey gravelly sandy silt with cobbles and boulders	OSL date of 196 100 ± 12 600 years BP
	Undifferentiated	Fluctuating sedimentary environments, predominantly alluvial but including lacustrine and mass transport deposits Sediments range from clays and silts, to sands, gravel, and also cobbles and boulders	-
	Shan Ha Tsuen Member	Alluvial and fluvial terrace deposits interdigiting in upper valleys with colluvium and on plains with lacustrine deposits. Sediments range from gravelly silty sand to well-sorted clayey sand, silt, sand and organic-rich silty clay	Radiocarbon dates range from 16 289 ± 831 years BP to 33 575 ± 3 186 years BP. TL dates from 23 800 ± 2 000 to 29 300 ± 2 300 years BP and possibly 79 000 ± 6 300 years BP. OSL date 30 400 ± 8 000 years BP
	Wong Kong Shan Member	Fluvial and alluvial terrace deposits. Cobbles and boulders in a clayey silty sand matrix	OSL dates from 126 100 ± 10 100 to 157 500 ± 36 300 years BP
		Unconformity	
	Bedrock	Granitic, volcanic and sedimentary rocks. A weathered mantle is developed over the bedrock. Generally the mantle is thickest over the granites, less over volcanic rocks, thinnest over sedimentary rocks	Mesozoic to Tertiary Weathering: Tertiary to Quaternary

Table 5.1 - Quaternary stratigraphy of Hong Kong – Onshore areas

Borehole CC10 at Tung Chung.

In addition, the Hang Hau Formation has now been divided into four members. These members can be identified on seismic profiles and are described fully in Chapter 10. They are mainly Holocene, but may be locally Late Pleistocene in age and represent various phases in the transgression. The Tung Lung Member is present in eastern waters and north of Lantau Island. The Pok Liu Member is represented in all areas of Hong Kong, though as a channel facies, is not present as a continuous deposit. The Kwo Chau Member has been identified only in the southeast of Hong Kong. In contrast, the Tseung Kwan O Member, representing the widespread deposition of marine mud, is present everywhere.

The complete lithostratigraphy for the offshore Quaternary of Hong Kong is given in Table 5.2. The upper three formations have clearly identifiable characteristics on seismic profiles. However, the Chek Lap Kok Formation is more complex, possibly covering several marine and terrestrial episodes. The formation can only be subdivided locally on seismic evidence. Seismic profiles show this sequence to be a series of cross-cutting major and minor channels, a complex seismic character that precludes extensive lateral correlation of the sediments.

Sequence stratigraphy

Recently, sequence stratigraphical concepts (see Chapter 2) have been applied to the Hong Kong Quaternary succession (Fyfe *et al.*, 1997a). This work is governed by the fact that, at the present day, Hong Kong lies at the coastal limit of the South China continental shelf. As a consequence, only major Quaternary highstands will have led to the complete marine inundation of the area. As the Hong Kong–Guangdong (廣東) area is part of a relatively tectonically stable region (Whittaker *et al.*, 1992), the observable erosional and depositional architecture is considered to have been produced only by relative sea level changes and sediment supply.

Fyfe *et al.* (1997a) have identified three major unconformities, labelled U1 to U3, in the Hong Kong Quaternary sequence. They broadly coincide with the previously defined formation boundaries. Application of the sequence stratigraphical approach has underlined the significance of these surfaces. In addition, the importance of the intra-Holocene ravinement surface was recognized.

The lowermost unconformity (U1) lies at the top of weathered bedrock and is assumed to form the base of the Quaternary succession. It is immediately overlain by the complex series of sediments that make up the Chek Lap Kok Formation. The sequence stratigraphy has been further refined (Fyfe *et al.*, 1997b) (Figure 5.3), with two unconformities being identified as fluvial entrenchment surfaces, FE1 and FE2 respectively. The intra-Holocene ravinement surface, R2, follows a Late Weichselian ravinement, R1, which is overlain by the newly named Waglan Formation.

The lowermost unit, the Chek Lap Kok Formation, is seismically complex and is interpreted as a series of laterally discontinuous sheets and major and minor channels. They represent dominantly terrestrial sedimentation throughout a series of highstands, and possible erosion during a series of lowstands. The erosion of the fluvial entrenchment surface FE1 was followed by deposition of the Sham Wat Formation, a back-stepping wedge of fine-grained sediment that was deposited during the following highstand when sea levels were much the same as at the present day. This most probably occurred during the Eemian interglacial.

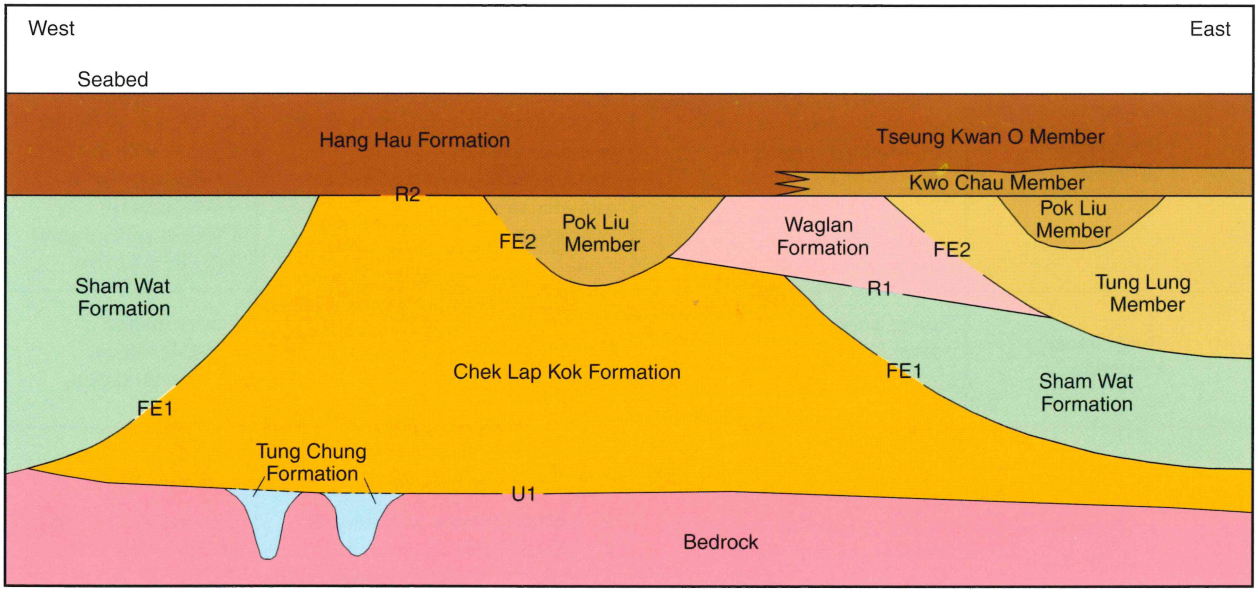


Figure 5.3 - Sequence stratigraphy model for Hong Kong correlated with existing lithostratigraphy

Formation		Seismic Character	Environment of Deposition and Typical Sediments	Age
Hang Hau Formation	Tseung Kwan O Member	Strong basal reflection Horizontal or sub-horizontal parallel layering, low amplitude, some low angle truncation and channel erosion features	Open marine conditions Very soft to soft, grey, structureless clayey silt, with common shells and lenses of fine sand	Oldest radiocarbon date of 7 990 ± 70 years BP
	Kwo Chau Member	Chaotic intraformational reflections	Transgressive marine conditions Muddy, shelly sand overlain by interbedded sand and clayey silt	Oldest OSL date of 11 342 ± 2 468 years BP
		Ravinement Surface R2		
	Pok Liu Member	Strong basal reflection Channel-fill structures, sub-horizontal bedding, asymmetrical channel fill and conformable bedding	Shallow, brackish waters Grey, sandy, shelly, clayey silt with organic debris and bands of fine sand	Radiocarbon dates 8 080 ± 130 to 9310 ± 80 years BP
	Tung Lung Member	Channel cut and fill structures, cross-cutting features and pro-grading channel-fill reflections Large scale asymmetric and clinoform reflections	Laterally accreting filling of meandering, fluvio-estuarine channels Sand with interbedded clayey silt, coarser sand with gravel at the base	Estimated 13 000 to 12 000 years BP
		Fluvial Entrenchment Surface FE2		
Waglan Formation		High amplitude planar basal reflection Chaotic package of lower reflections, overlain by sequence of parallel reflections	Shallow marine deposits Basal Shoreface Sand Unit of interbedded shelly sand and clayey silt (barrier beach?) Upper Marine Shelf Unit of firm, grey, shelly, clayey silt	Radiocarbon dates range from 29 100 ± 1 300 to 40 400 years BP. OSL dates from 23 175 ± 4 738 to 92 000 ± 8 000 years BP
		Ravinement Surface R1		
Sham Wat Formation		Strong undulating basal reflection Low to moderate amplitude reflections, continuous, sub-parallel, draped into channels	Fluctuating brackish and open marine conditions Soft to firm silty clays, grey with bands of yellowish mottling, patches of intense mottling with nodules, some thin sand bands, rare shells commonly corroded	Undetermined: Radiocarbon dates range from 19 580 ± 320 to > 43 860 years BP. OSL dates from 11 283 ± 1 567 to 94 000 ± 16 000 years BP
		Fluvial Entrenchment Surface FE1		
Chek Lap Kok Formation		Complex seismic character, generally chaotic, but containing strong parallel reflections, channel forms and cross-bedded channel fills	Fluctuating sedimentary environments, predominantly alluvial but including lacustrine, mass wasting, intertidal and possibly marine sequences Sediments range widely from clays and silts, to sands, gravels, and also cobbles and boulders	Undetermined: Radio-carbon dates range from 16 420 to >40 000 years BP. TL date of 78 000 ± 8 500, OSL date of 80 000 years BP ± 9 000 years BP Uranium series date of 248 000 ± 12 /16
Tung Chung Formation		Strong, subhorizontal reflections within steep-sided basins	Poorly sorted sandy silt with cobbles and boulders, infilling sinkholes or channels in a karstic environment	Undetermined: Possible Middle Pleistocene pollen
		Unconformity U1		
Bedrock		Parabolic reflections over granitic corestone-bearing weathering profiles, undulating surface over volcanic rocks, minor scarps developed on inclined bedding in sedimentary rocks	Granitic, volcanic and sedimentary rocks A weathered mantle is developed over the bedrock Generally the mantle is thickest over the granites, less over volcanic rocks, thinnest over sedimentary rocks	Mesozoic to Tertiary Weathering : Tertiary and Quaternary

Table 5.2 - Quaternary stratigraphy of Hong Kong – Offshore areas

A Late Weichselian ravinement surface has been identified and labelled as R1. The unit overlying R1 comprises chaotic reflections, interpreted as reworked shoreface sands, overlain by a back-stepping wedge of marine sediments, represented by the Waglan Formation. Fluvial entrenchment of surface FE2 typically erodes to a base level of around -50 mPD. The surface is overlain by two stages of infill: a lowstand prograding-wedge of fluvial sediments (Tung Lung Member) and a series of estuarine to marine deposits that infill the remaining channels (Pok Liu Member). These sediments are sandy and fine grained and are believed to have been deposited during the transgression.

The ravinement surface R2 is an extensive, seaward-dipping, planar unconformity at a depth of around -30 mPD and is overlain by a 2 to 3 m thick deposit of regressive shore-face sands. Deposition of the intertidal and shallow marine clayey silts, that lie unconformably on the ravinement surface, occurred during the final stages of the last transgression. These fine-grained sediments commonly form the majority of the Hang Hau Formation, which is a regressive depositional system.

Correlation between Hong Kong and southern China

The Quaternary sediments of Hong Kong form the prodelta and nearshore shelf succession of the Pearl River Delta (珠江三角洲). The location of Hong Kong on the northern margin of the South China Sea (南中國海), however, provides a complicated sedimentological regime and the stratigraphy developed for the Hong Kong Quaternary can therefore be correlated with the published stratigraphies of the Pearl River Delta and the South China Sea.

Long and Huo (1988, 1990) presented a stratigraphy for the Pearl River Delta (Table 5.3). This scheme had little absolute dating control but two formations, each divided into Lower, Middle and Upper members, were recognized. Shaw and Fyfe (1992) tentatively correlated the Hang Hau Formation with the Shunde Formation and the Sham Wat Formation with the Middle Member of the Zhongshan Formation. This latter correlation was based mainly on the descriptions given by Long and Huo (1988) of wavy reflections on seismic records from the Pearl River Delta. However, the fossil-rich nature of the Middle Member of the Zhongshan Formation conflicts with current knowledge of the Sham Wat Formation in Hong Kong and, as the seismic data have not been directly compared, this correlation must now be questioned.

On the basis of absolute ages, the Middle Member of the Zhongshan Formation may be correlated with the Waglan Formation. There is no lateral continuity, however, but as the former is interpreted as a submerged valley (Long & Huo, 1990) and the latter as regressive marine sediments, both represent a period of inundation by the sea. The Shunde Formation is reliably correlated with the Hang Hau Formation, the Lower Member with the Tung Lung Member, the Middle Member with the Pok Liu Member and the Upper Member with the Tseung Kwan O Member.

The Quaternary stratigraphy of the South China Sea has been discussed by Feng *et al.* (1988) and the Second Marine Geological Investigation Brigade (1993). The work by Feng *et al.* (1988) concentrated on a number of deep-sea boreholes at water depths of between 1000 and 3000 m. These dominantly comprise clayey silts with thin sandy beds and occasional tephra layers. Borehole V_6, drilled in 1597 m of water, has been correlated with the Hong Kong sequence (Figure 5.4).

Nearer shore, four boreholes (NZQ_1–NZQ_4) have been drilled in water depths of 75 to 125 m (Second Marine Geological Investigation Brigade, 1993). Four

Stratigraphy			Sediment Description	Environmental Interpretation
Holocene	Shunde Formation	Upper Member	Yellowish brown clay or sandy clay	Prograding delta
		Middle Member	Greenish grey silty clay or sandy clayey silt, rich in microfossils	Tidal estuary and bay-filled delta
		Lower Member	Dark brown, putrid, wood-bearing clay, medium coarse sand and gravel layers	Headward accumulation
Late Pleistocene	Zhongshan Formation	Upper Member	Variegated granophyric clay	Major sea regression
		Middle Member	Greenish grey silty clay and medium gravelly sand and gravel; fossil-rich	Transgressive submerged valley bay
		Lower Member	Greenish grey silty clay or sandy clayey silt	Passing river erosion

Table 5.3 - Lithostratigraphy of the Pearl River (珠江) Quaternary sediments

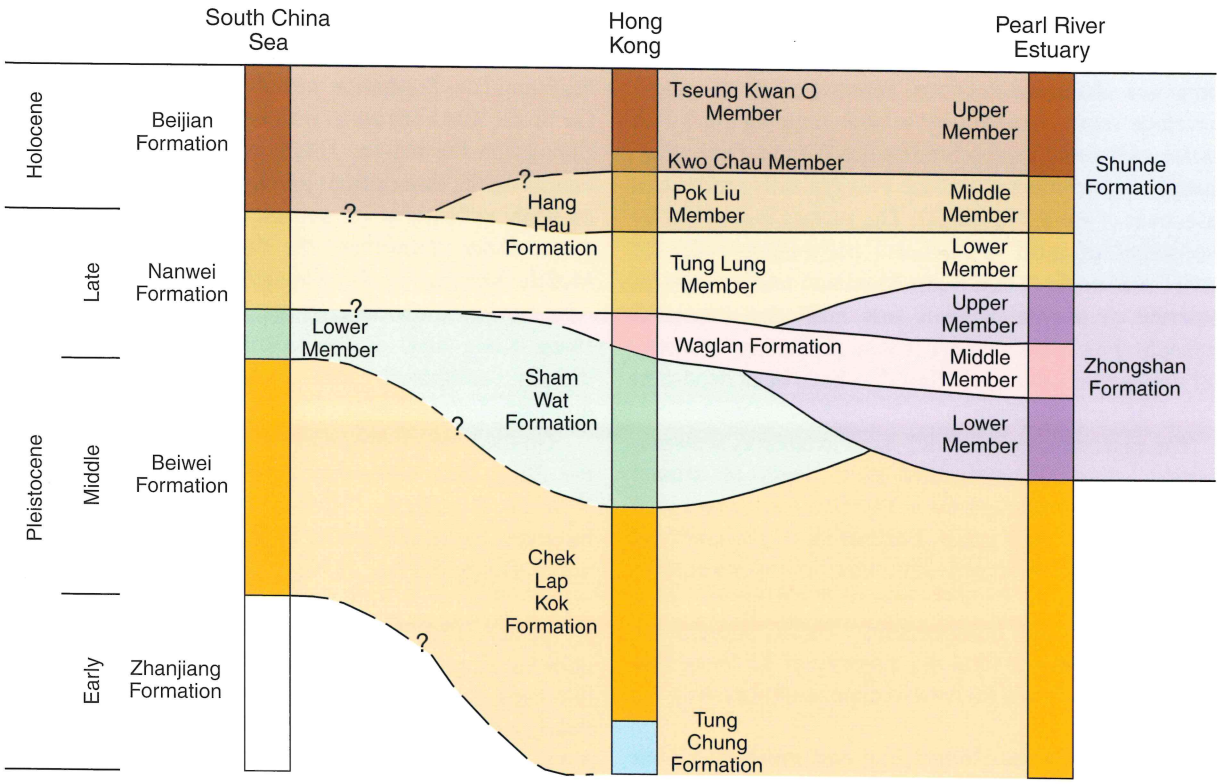


Figure 5.4 - Correlation of Hong Kong stratigraphy with those of the Pearl River (珠江) and South China Sea (南中國海)

main formations have been identified, corresponding with the chronostratigraphical division of the Quaternary. These are the Early Pleistocene Zhanjiang Formation, the Middle Pleistocene Beiwei Formation, the Late Pleistocene Nanwei Formation and the Holocene Beijian Formation. Borehole NZQ_1 has been correlated with the Hong Kong sequence (Figure 5.4). The Upper Member of the Beiwei Formation comprises fine sand with gravelly horizons, interpreted as fluvial sediments. The Lower Member of the Nanwei Formation comprises sands, silts, clays and occasional gravel, with shell fragments, interpreted as an intertidal to marine unit which possibly correlates with the Sham Wat Formation. The Beijian Formation is probably equivalent to the Hang Hau Formation. This general correlation is based mainly on age criteria, with little supporting lithological evidence. However, the sequences identified are geographically so far removed from each other that continuity of the facies would be unlikely.

6. Tung Chung Formation

The oldest laterally continuous sequence of sediments that can be identified in offshore boomer seismic records is the Chek Lap Kok Formation. However, isolated and restricted older sequences have been identified in several areas in western waters. These outliers (Figure 6.1) are here grouped together and have been formally established as the Tung Chung Formation (Kirk, in press).

Langford *et al.* (1995) described a small (c.300 by 500 m) basin off the north Lantau Island (大嶼山) coast to the east of The Brothers (大小磨刀) islands, which is recognizable on seismic records. The basin was infilled with older sediments and informally recognized as the "Pre-Chek Lap Kok Formation deposits". The interpretation was based both on the seismic character of the deposits, which is distinct from typical basal facies of the Chek Lap Kok Formation, and its position below an identifiable erosional base of the overlying Chek Lap Kok Formation. The unit was not considered to have more than local significance.

However, a recent review of ground investigation data for several north Lantau infrastructure projects has identified a wider distribution of "Pre-Chek Lap Kok Formation deposits". In particular, in the recent developments for the Tung Chung New Town (東涌新市鎮), more than 50 ground investigation boreholes penetrated a sequence of unlithified sediments with quite different lithological characteristics from the overlying Hang Hau and Chek Lap Kok formations (Gillespie *et al.*, 1998).

Kirk (in press) proposed the name Tung Chung Formation for these older (Pre-Chek Lap Kok) Quaternary sediments in north Lantau Island area. In all cases, sediments of the Tung Chung Formation unconformably overlie Mesozoic or older rocks, and are in turn overlain conformably by the Chek Lap Kok Formation. The Tung Chung Formation only occurs in subcrop, and its distribution has only been determined where detailed ground investigation has been carried out.

Type section

The type section of the Tung Chung Formation has been described from borehole CC10 at the Tung Chung (東涌)

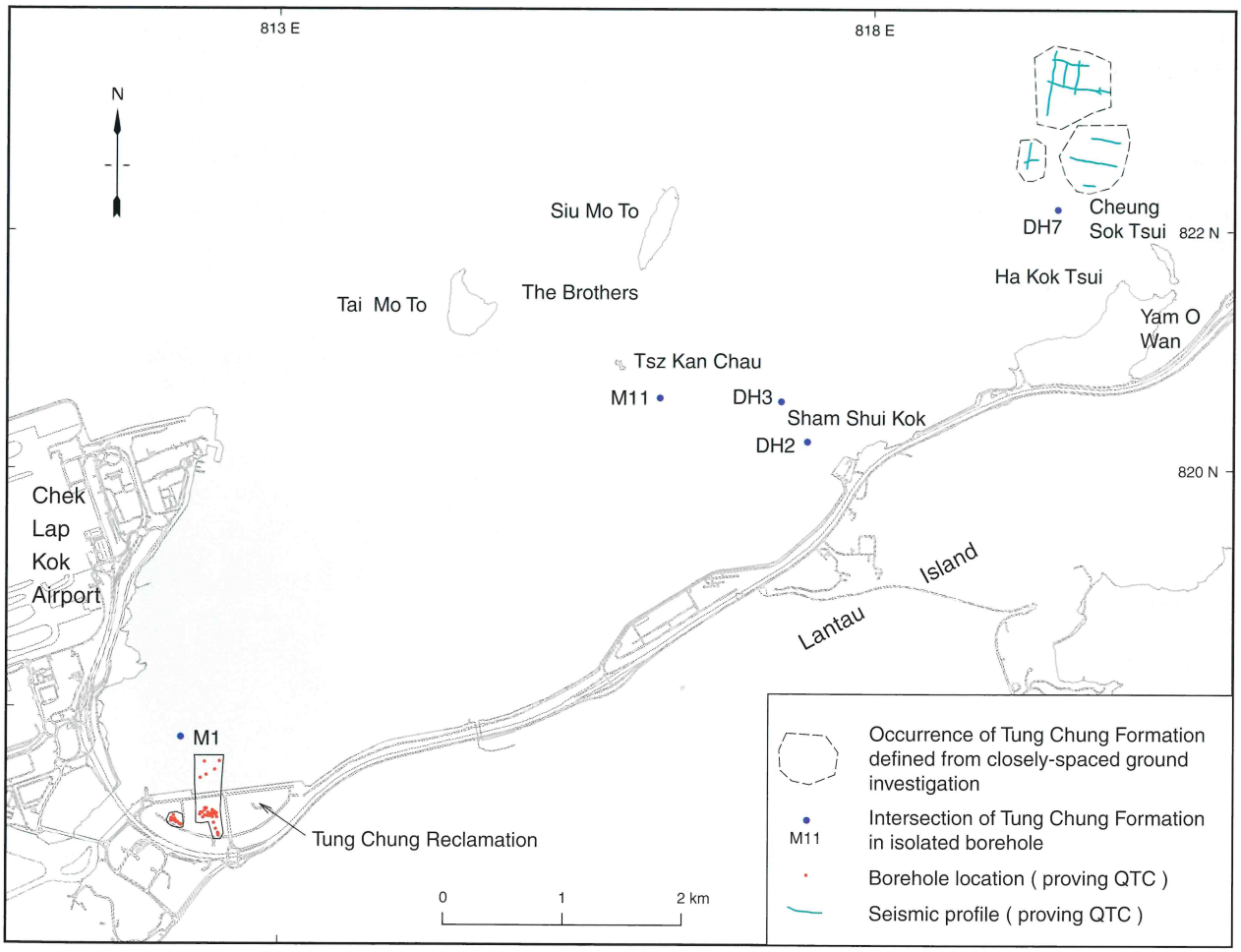


Figure 6.1- North Lantau Island (大嶼山) showing the known distribution of the Tung Chung Formation

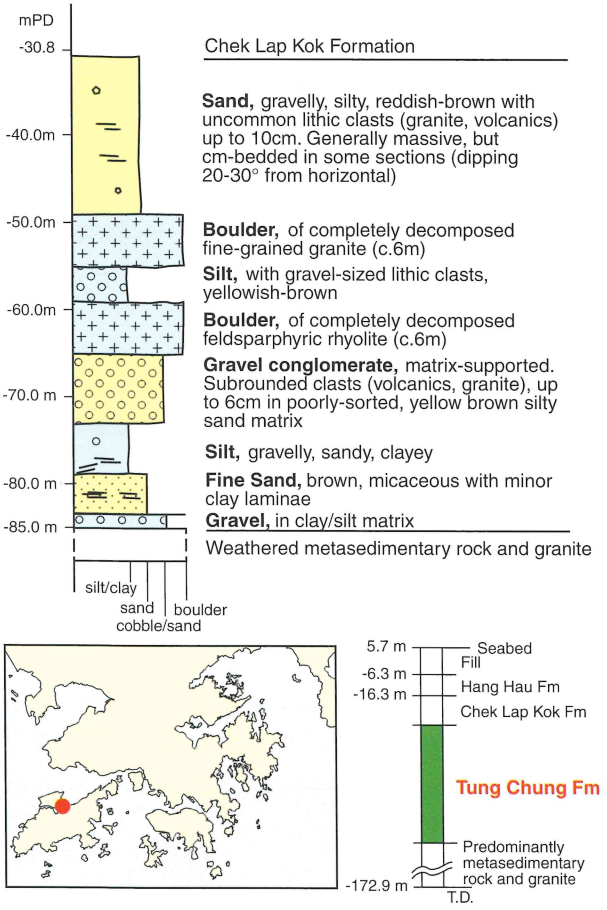


Figure 6.2 - Details of the Tung Chung Formation in the type borehole CC10

Reclamation in what is regarded as the type area of the formation. Borehole CC10 (Figure 6.2) is dominated by 'granite'-derived sediment, and comprises reddish-brown sandy silt with common matrix-supported, rounded to sub-rounded boulders, 0.5 to 3 m in diameter, of completely decomposed granite, feldsparphyric rhyolite and, rarely, tuff. The matrix is generally poorly sorted sandy silt, lacking any sedimentary structure. However some horizons, up to a few 100s of mm thick, are relatively well bedded (alternating silty clay with silty sand).

Seismic character

Numerous seismic profiles were made prior to reclamation in the type area of the formation at Tung Chung (東涌) Reclamation. However, the quality of this information on the Tung Chung Formation is poor, partly due to gas blanking, and partly due to the thick cover of younger sediments. The best quality seismic data for the formation remain those from the separate northeastern area of the formation, beneath the main channel north of Lantau Island (大嶼山), between Yam O Wan (陰澳灣) and Tai Lam Kok (大欖角).

The sequences display well developed, relatively strong seismic reflectors generally parallel to the base of the unit. The seismic character suggests that the lithologies are sands and gravels rather than fine-grained sediment (Langford *et al.*, 1995). A typical seismic profile through the unit is shown in Figure 6.3.

Stratigraphical and regional lithological variations

Langford *et al.* (1995) described a single basin, 300 m by 500 m in area, and up to 15 m thick in the northeastern area of the formation. However, re-interpretation suggests the formation occupies three separate, sub-circular basins with diameters of c.200 m, 300 m and 600 m (Figure 6.1). None of the four marine boreholes in the vicinity of these basins were deep enough to penetrate the formation. By contrast, more than 50 boreholes have penetrated the formation in its type area at Tung Chung (東涌) Reclamation. These demonstrate the formation's variability in lithology and geometry and three or four separate basins can be defined in this area. The two largest, at 'Site 3' and 'Site 4' (Figure 6.4) are 100 m by 60 m, and at least 200 m by 100 m respectively. Both are very deep and steep-sided. The thickest borehole intersections of the formation are 70.5 m (borehole CC9) and 96.5 m (borehole B19), and the formation reaches levels of below -100 mPD, or 70 m below the base of the Chek Lap Kok Formation.



Plate 6.1 - Mazier sample from borehole B30 (c. - 92.5 mPD), 'Site 4'

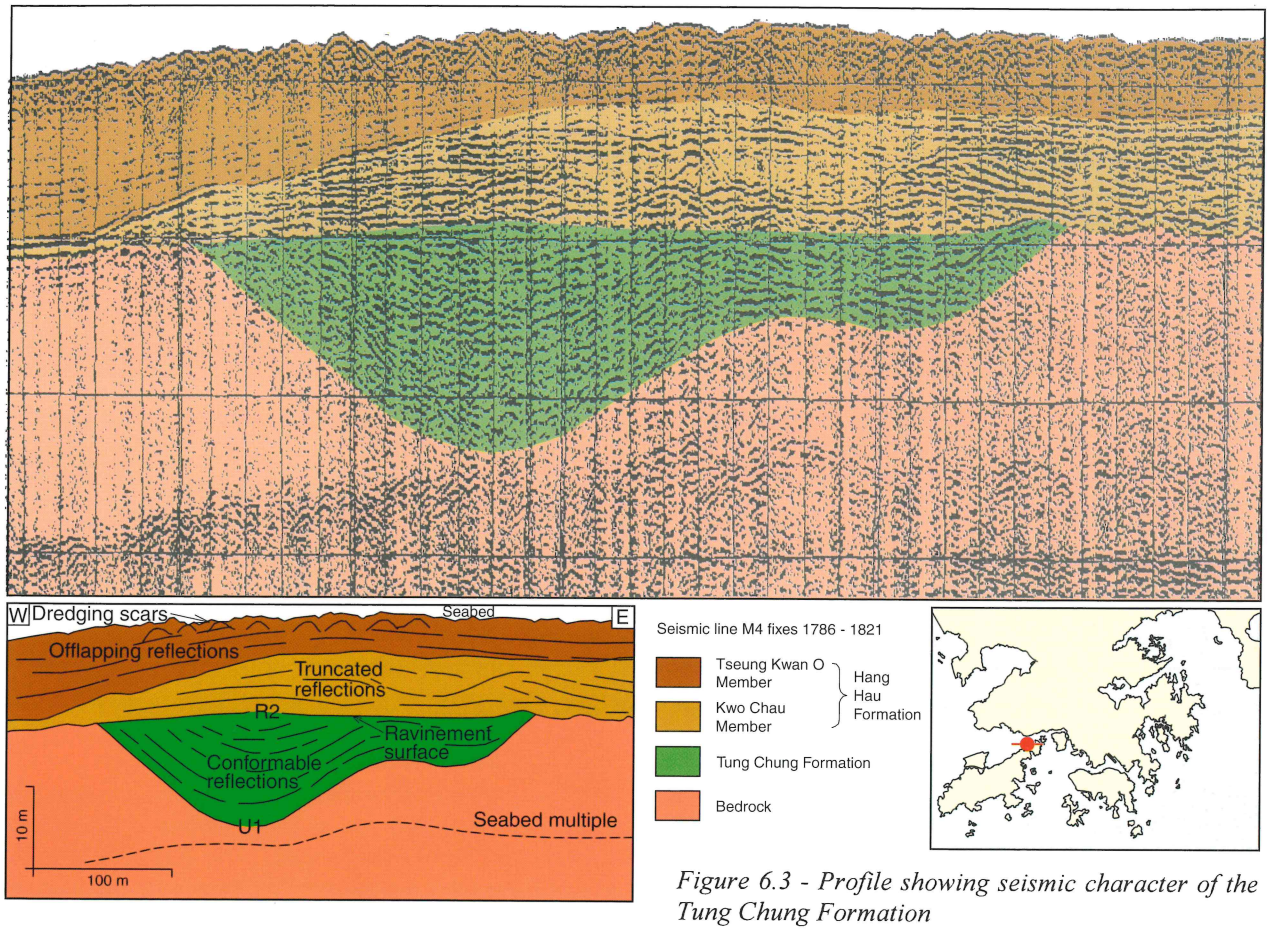


Figure 6.3 - Profile showing seismic character of the Tung Chung Formation

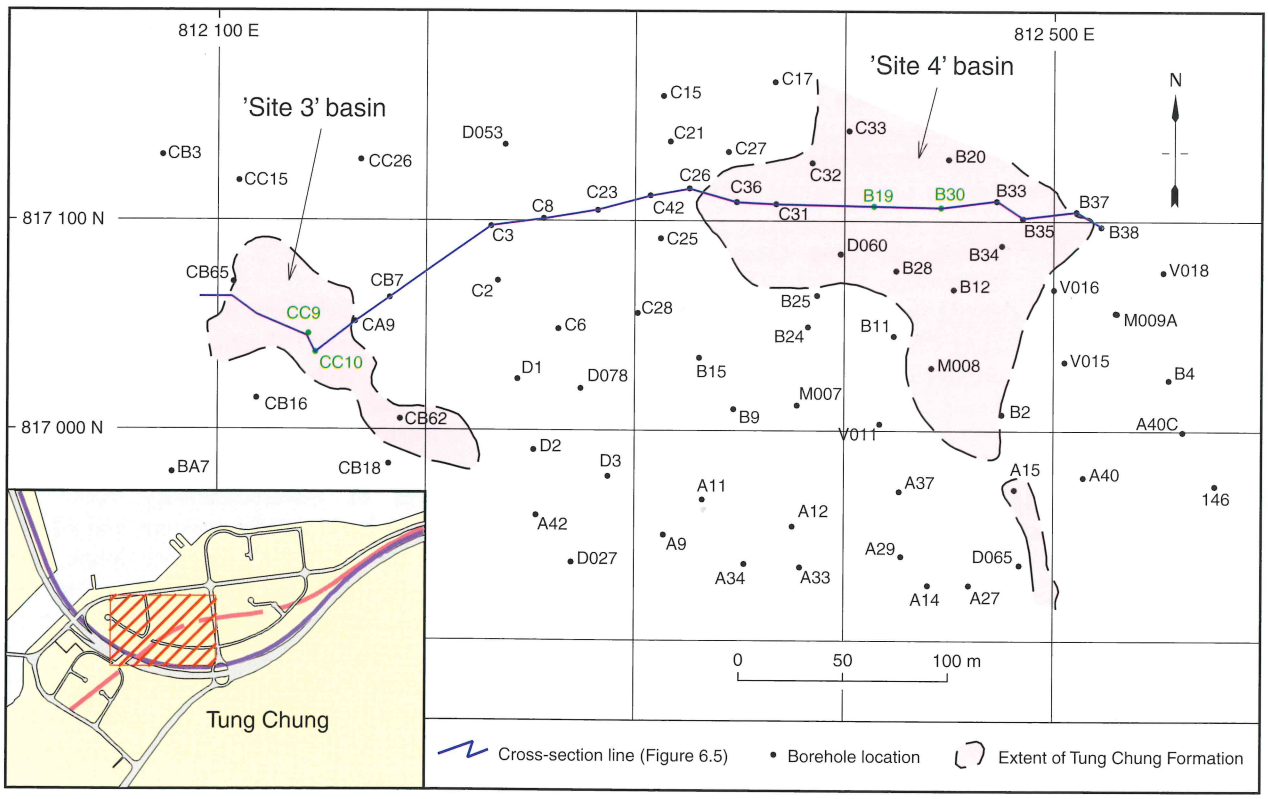


Figure 6.4 - Distribution of the Tung Chung Formation at Tung Chung (東涌) Reclamation

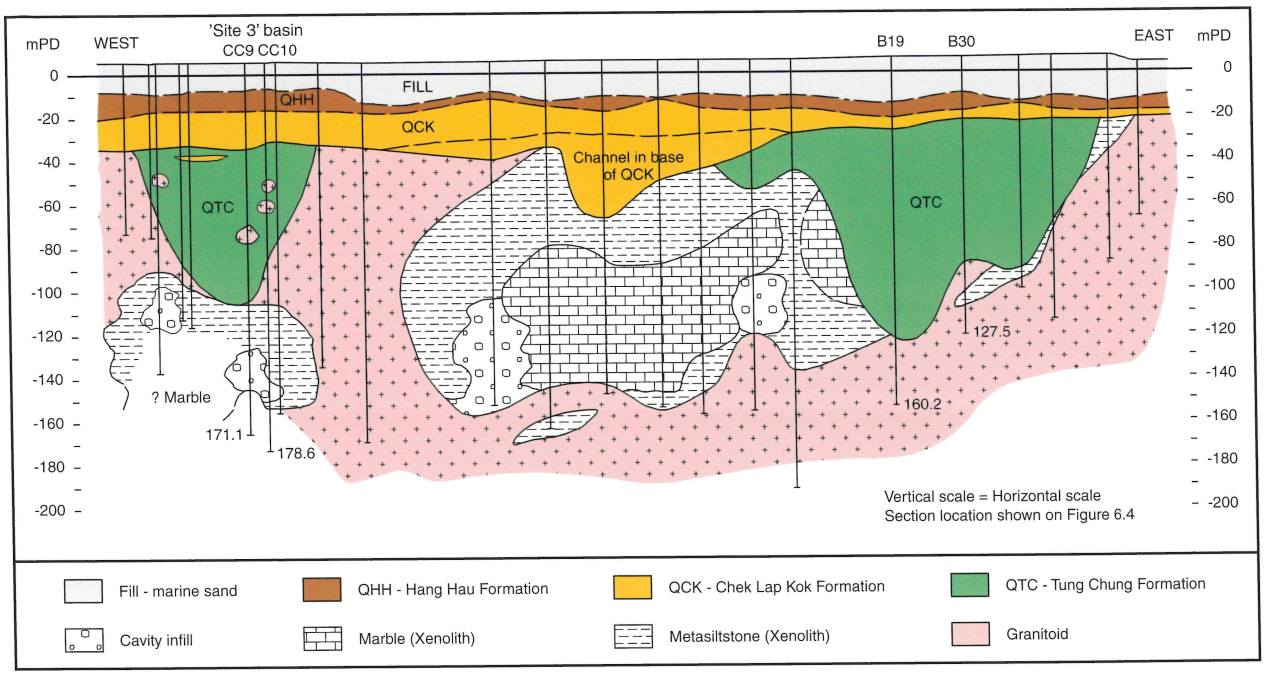


Figure 6.5 - Cross-section of the Tung Chung Formation at Tung Chung (東涌) Reclamation ('Sites 3 and 4')

The lithologies are boulder- and cobble-bearing, gravelly, sandy silts, but they vary in composition due to differing provenances of the sediment. The sediment in the type section (borehole CC10) in the 'Site 3' basin, is largely derived from a granite source. However, the 'Site 4' basin is dominated by clasts from a sedimentary source rock. Olive-green gravelly silt or silty gravel predominate. The lithic clasts are almost all derived from metasiltstone, giving rise to the characteristic olive colour. Boulder-sized clasts in certain horizons are also predominantly metasiltstone, although granite cobbles and boulders occur near the base of the unit (Plate 6.1).

The Tung Chung Formation is also known from isolated boreholes in northern Lantau Island (大嶼山) (Figure 6.1). These boreholes were undertaken for the "Study of Complex Geology at Tung Chung New Town" (Geotechnical Information Unit (GIU) 28034, 29998), "Preliminary Ground Investigations for Further Development between Tung Chung to Tai Ho" (not yet in GIU), and "North Shore Reclamations" (GIU 30023).

Age

Superposition by the (?)Early, Middle and Late Pleistocene Chek Lap Kok Formation gives an upper bound for the age of the Tung Chung Formation. The uppermost beds of the Tung Chung Formation in the 'Site 3' basin intercalate with basal Chek Lap Kok Formation deposits. According to Tang Linyu (Nanjing Institute of Geology & Palaeontology, personal communication), samples from borehole B19, in the 'Site 4' basin, have yielded several pollen genera. They include *Microlepia* sp., *Anaphales* (Compositae) sp. and *Pinus* sp., and indicate a Middle Pleistocene age.

Depositional environment

The Tung Chung Formation is interpreted as sediment that was deposited in a Late Tertiary to Middle Pleistocene karst environment. The karst developed where Palaeozoic marble occured at, or near, the palaeo-surface. The distribution of the Palaeozoic metasediments (including marble) reflects complex tectono-magmatic processes of Jurassic age (Kirk, in press). A number of occurrences of metasediment are known in the northeast-trending zone from west Lantau Island (大嶼山) to Tolo Harbour (吐露港). In north Lantau Island, the setting of marble varies from xenolithic blocks within granitoid intrusions at Tung Chung (東涌) Reclamation to more extensive fault-bounded bodies east of The Brothers (大小磨刀) islands (Figure 6.1).

At Tung Chung Reclamation, the formation occurs as doline-infilling sediment. The nature of each infill reflects the individual style of sinkhole development. For example, the 'Site 4' basin (at the east end of the cross-section in Figure 6.5) was formed by infilling of a solution doline, with material largely derived from adjacent exposures of metasedimentary rock. By contrast the 'Site 3' basin (at the western end of the cross-section in Figure 6.5), is a collapse-doline, and most of the infilling sediment was derived from the decomposed granitic cover rock. East of The Brothers islands, the sedimentary basins are less well known, but they appear to be more extensive and probably represent deposition in karst valley systems. These deposits are buried by sediments of the Chek Lap Kok Formation and younger Quaternary deposits.

7. Chek Lap Kok Formation

The oldest Quaternary sediments found offshore in most parts of Hong Kong are those of the Chek Lap Kok Formation. They are considered to be mainly Middle to Late Pleistocene, and in the case of its oldest colluvial members, possibly Early Pleistocene, in age.

The Chek Lap Kok Formation occurs over virtually all of Hong Kong's offshore area, reaching a maximum development in the south. Although the formation has only previously been mapped offshore, it is extended here to include its continuation onshore. The deposits onshore include considerably more colluvium than their mainly alluvial equivalents in offshore environments, but are otherwise broadly similar.

In both offshore and onshore environments, the Chek Lap Kok Formation overlies bedrock in various states of decomposition. In general, the thickest weathering profiles are developed on the granitic rocks and coarse ash crystal tuffs, whereas the thinner profiles occur over the fine ash vitric tuffs and bedded sedimentary rocks. The morphology of this bedrock surface offshore is shown in Map 4. Onshore, the present topography approximates, in broad terms, that of the bedrock surface. This reflects the fact that the Chek Lap Kok Formation, and the overlying Holocene Fanling Formation, essentially comprise a veneer of only modest thickness over the bedrock.

In onshore areas, Pleistocene superficial deposits have previously been mapped on 1:20 000-scale geological maps and described in Hong Kong Geological Survey memoirs as terraced alluvium and debris flow deposits or slope debris. In some areas, Pleistocene deposits were not differentiated from similar deposits (including terrace deposits and slide deposits) of Holocene age.

Offshore, the formation is considered to have been deposited in a variety of sedimentary environments. Although most of the sediments are believed to be of terrestrial origin (fluvial, alluvial plain and colluvial), intertidal, estuarine and possibly marine sediments are also present within the formation.

Onshore, the formation varies considerably in thickness and character. Where present, deposits are generally less than 10 m thick, but may be up to 50 m thick. On sloping ground, the deposits are generally unstratified and poorly sorted colluvium, comprising boulders and cobbles within variably clayey, gravelly, sandy silt matrices. On lower, flatter ground, extensive terraces of well-bedded alluvium predominate. These comprise gravel, sand, silt and clay. Towards the bases of slopes, and near the margins of plains, interdigitating sequences of colluvium and alluvium are typical.

In offshore environments, the formation varies from only a few metres thick in nearshore areas to over 70 m in the south and southeast, where the bedrock surface shelves towards the South China Sea (南中國海). The formation is absent over and around seabed rock outcrops and pinnacles and immediately adjacent to steep coastlines. In some coastal regions, the formation is represented by a thin veneer of locally derived lithic gravel and lithic quartz sand filling channels and hollows in the eroded bedrock surface.

Further offshore, where the Quaternary succession thickens, the formation becomes more lithologically variable. To the west, north of Lantau Island (大嶼山), up to 30 m of sand and mud lie on a deeply weathered and irregular bedrock surface. To the east, in Mirs Bay (大鵬灣), the formation reaches a similar thickness, though the topography of the inclined sedimentary bedrock is more subdued (Map 4).

The seismic character of the formation on boomer records is complex, including chaotic reflections, some showing indistinct channel forms, well-developed erosional channels and strong parallel reflections. The sediments are heterogeneous and comprise quartz and lithic gravel, coarse to fine quartz sand, and silt and clay. These range in colour from dark grey to bright reds and yellows, and in strength from soft to very stiff.

The relationship between the deposits onshore and those offshore can be represented in terms of a simple facies model for the formation as a whole (Figure 5.2). The formation is absent in many onshore areas, especially on steep slopes and hill summits. However, the high ground was the main source of weathered debris and slope failures that generated the colluvium. On higher ground and in the upper reaches of drainage systems, the formation comprises thin sequences of mainly coarse, poorly sorted and poorly bedded colluvium. Further downslope the colluvial deposits increase in thickness and lateral extent. Towards the bases of slopes, and around the margins of the plains developed on low-lying ground, they interdigitate with well-bedded alluvium, composed of sand and gravel. The thickest and most widespread sequences are present beneath the plains, and in most offsore areas. These are mainly composed of well-bedded and occasionally cross-bedded and channelized alluvial sand and clay (Plate 7.1), containing only occasional thin colluvial interbeds, if any at all.

Type section

The type section of the Chek Lap Kok Formation (Figure 7.1) was described in borehole B13/B13A (Strange & Shaw, 1986) which is now under the Chek Lap Kok (赤鱲角) airport platform, north of Lantau Island (大嶼山). The formation in the borehole comprises an 18.8 m interbedded sequence of sand, silt and clay. There, the sediments overlie weathered granite and underlie 2.9 m of soft clayey silt of the Hang Hau Formation and fill.

Four lithological units make up the type section. These comprise two units of mainly grey laminated mud and two units of bluish grey mottled clay (Shaw, 1985). The lower laminated mud unit is a broadly laminated silty clay that is sandy at the base of the formation where it sits directly on weathered granite. Black carbonaceous fragments are disseminated throughout the unit. The lower mottled clay unit is grey to buff in colour with red, ochre and yellow mottles, the most vivid colours occurring in the middle part of the unit. Fine to coarse sand and gravel bands within this unit include quartz clasts and rock fragments. The upper laminated mud is sandy at the base, and contains abundant organic fragments including twigs and rootlets higher up. The upper mottled clay unit has a similar mottling pattern to that of the lower unit and includes a 1 m-thick bed of fine to medium sand, which is gravelly at the base. The unit is capped by a thin palaeosol with a well-developed rootlet horizon, which indicates a former subaerial surface.



Plate 7.1 - Intercalated sand layers within alluvial clay, terrace deposits, Chek Lap Kok Formation, Leng Tsai, Fanling (粉嶺龍仔)

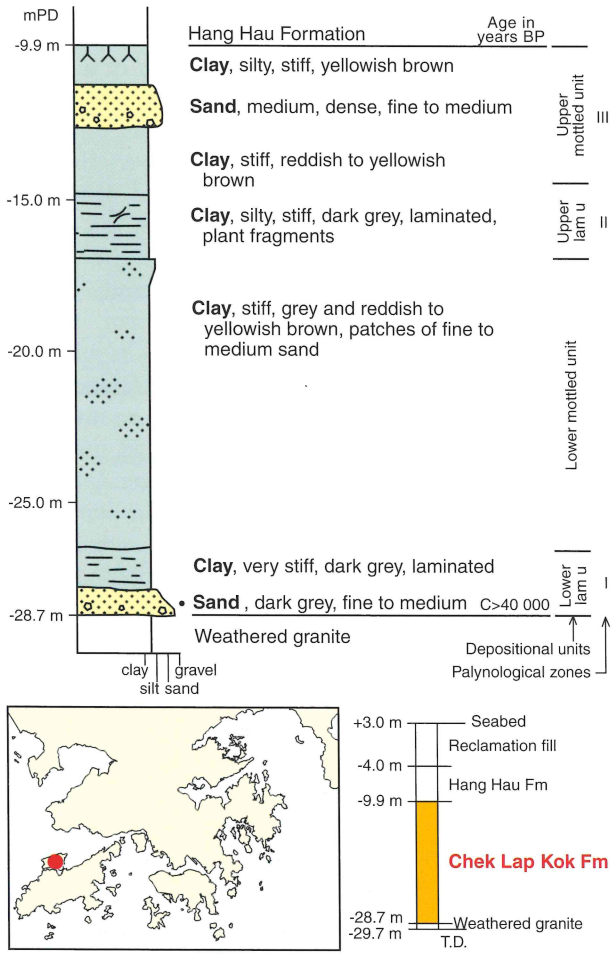


Figure 7.1 - Details of the Chek Lap Kok Formation in borehole B13/13A

The palynological associations in this borehole have been subdivided into a number of zones (Shaw *et al.*, 1986) (Figure 7.1). The lower mottled clay unit is devoid of palynomorphs, though the upper mottled clay unit contains several fern species. The lower laminated mud unit is dominated by *Castanopsis* pollen with numerous fern spores. *Castanopsis*, still common in the upper laminated mud unit, is accompanied by mangrove pollen, principally *Sonneratia*. This suggests that the lower laminated mud unit accumulated as a back-swamp deposit on an alluvial plain, while the upper laminated unit represents an intertidal sediment.

The type borehole was drilled on the Chek Lap Kok test embankment and, as a result, is not intersected by any modern seismic line. The track of a 1981 survey passes 100 m to the north of the borehole site but the record quality is poor. The units identified in the borehole cannot be traced laterally with any degree of certainty, though the formation as a whole comprises a series of parallel reflections cut by channel-like features.

The formation in the type section is interpreted as an alluvial plain and intertidal deposit. The fine to medium sand beds at the base and near the top of the section may be channel sediments, while the isolated bands of fine to coarse sand and gravel appear to be fluvial channel sands that were deposited on the alluvial plain during river flood stages. The concentration of vivid colours in the middle part of the mottled horizons suggests that oxidation was diagenetic and was controlled by the acidic waters in the carbonaceous laminated mud units above and below.

Seismic character

The seismic character of the Chek Lap Kok Formation varies in detail throughout Hong Kong waters. Chaotic reflection patterns are commonly seen associated with the formation, but other recognizable geometries include strong parallel reflections, indistinct channel forms, and well-developed erosional channels up to around 10 m deep and several hundreds of metres across. In some areas, particularly in channels, high-angle reflections represent large-scale cross bedding.

The base of the formation is commonly difficult to determine on seismic profiles as it usually overlies weathered rock of similar acoustic impedance. Further,

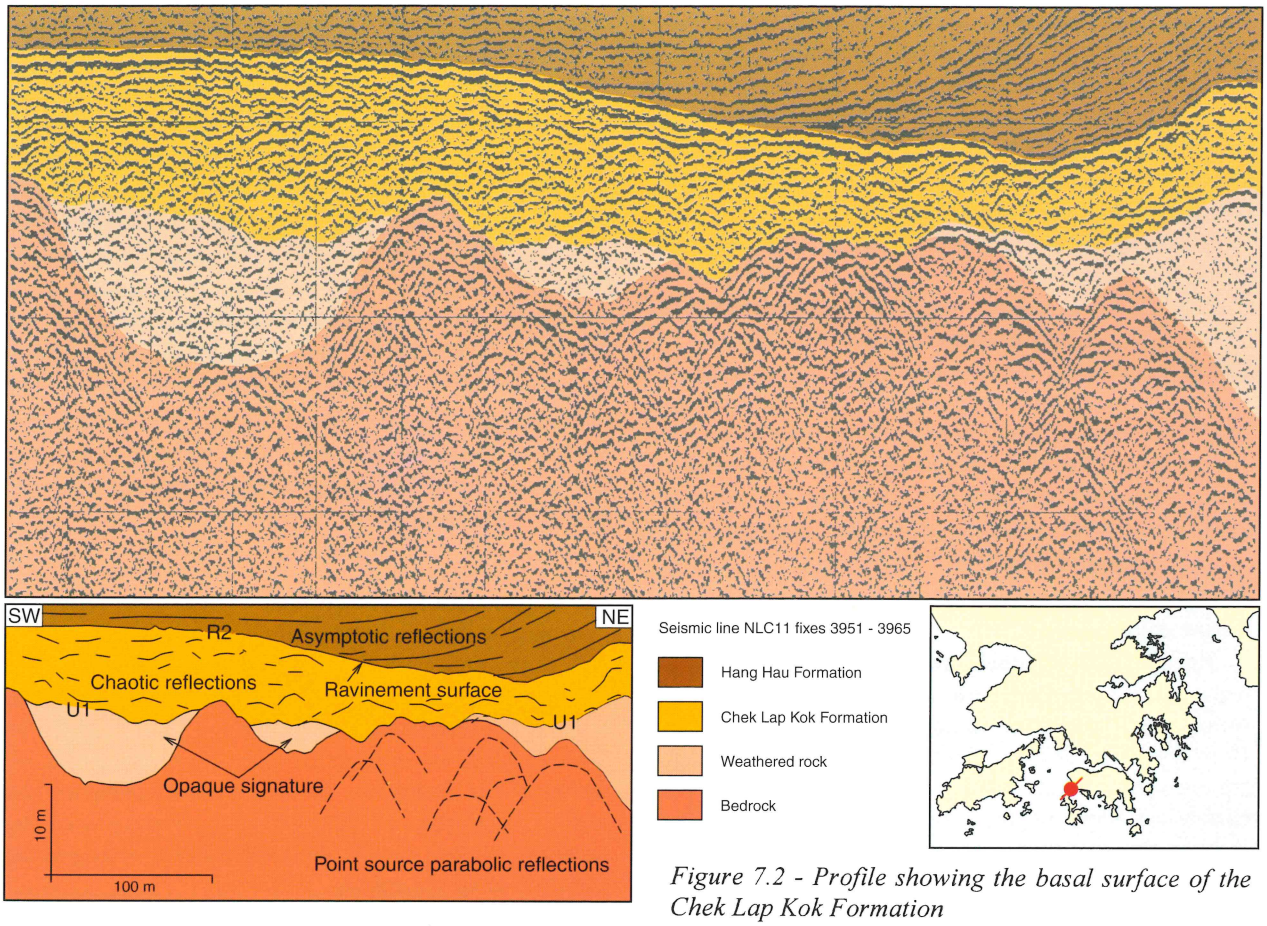


Figure 7.2 - Profile showing the basal surface of the Chek Lap Kok Formation

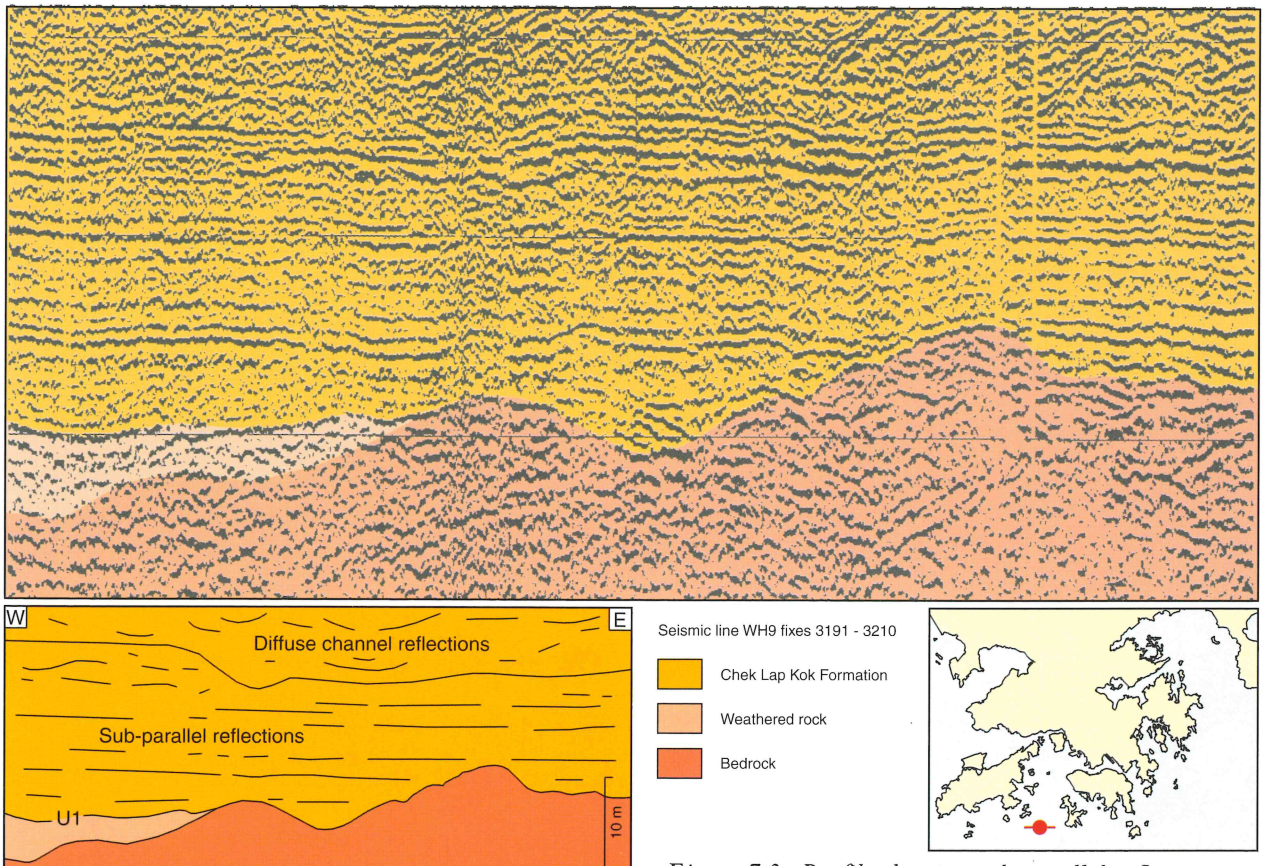


Figure 7.3 - Profile showing sub-parallel reflections at the base of the Chek Lap Kok Formation

the weathered mantle is normally devoid of laterally persistent internal reflections. Though parabolic reflections sometimes occur, these are presumed to indicate corestones. In areas where the Quaternary sequence is thin, or where the weathered rock mantle is absent, the base of the Chek Lap Kok Formation can be identified with more certainty (Figure 7.2).

Where the Chek Lap Kok Formation is thickest, such as in the south, the basal part of the formation is characterised on seismic profiles by high-amplitude, sub-parallel, laterally continuous reflections (Figure 7.3). These are overlain by a seismically structureless unit. This succession has not been drilled and the lithology and depositional environment have yet to be determined.

Similar sub-parallel reflections can be seen elsewhere in the formation and generally prove to indicate fine-grained sediments. This reflection style is therefore taken to be representative of widespread, low-energy deposition such as in a floodplain, lacustrine or shallow marine environment.

Recognizable channels take several forms. Some are wide, open features, a few hundred metres across, in which other channels are nested. Others are shallow, up to 10 m deep, and of more limited lateral extent. Channels are normally discrete features and no laterally persistent channelled horizons have been identified on seismic profiles. Bases of channels can be seen both to cut units of horizontal reflections and to occur in otherwise seismically structureless sequences.

Intrachannel reflection patterns comprise several different styles, though in many cases they are nebulous. Most channels show some degree of asymmetrical filling (Figure 7.4); this reflection geometry is believed to represent point bar sedimentation in a fluvial environment. Some of the wider channels are characterised by sets of inclined reflections, for example at the site of borehole A5/2 . The unit is interpreted as an eastwardly prograding, laterally accreting, sandy channel fill (Owen *et al.*, 1995). Similar tabular units of inclined reflections that are not directly associated with recognizable channel forms occur throughout the formation; these are believed to be prograding sediments that accumulated fills in less discrete, and substantially eroded, wide channels.

Stratigraphical variation

Two new members are described within the Chek Lap Kok Formation, both for the first time: the Wong Kong Shan Member and the Shan Ha Tsuen Member. In addition, colluvial deposits that have been mapped in onshore areas are considered to be un-named members within of the formation. In offshore environments, the seismic character of the formation, underpinned by borehole control, ideally demonstrates the stratigraphic variation of the formation.

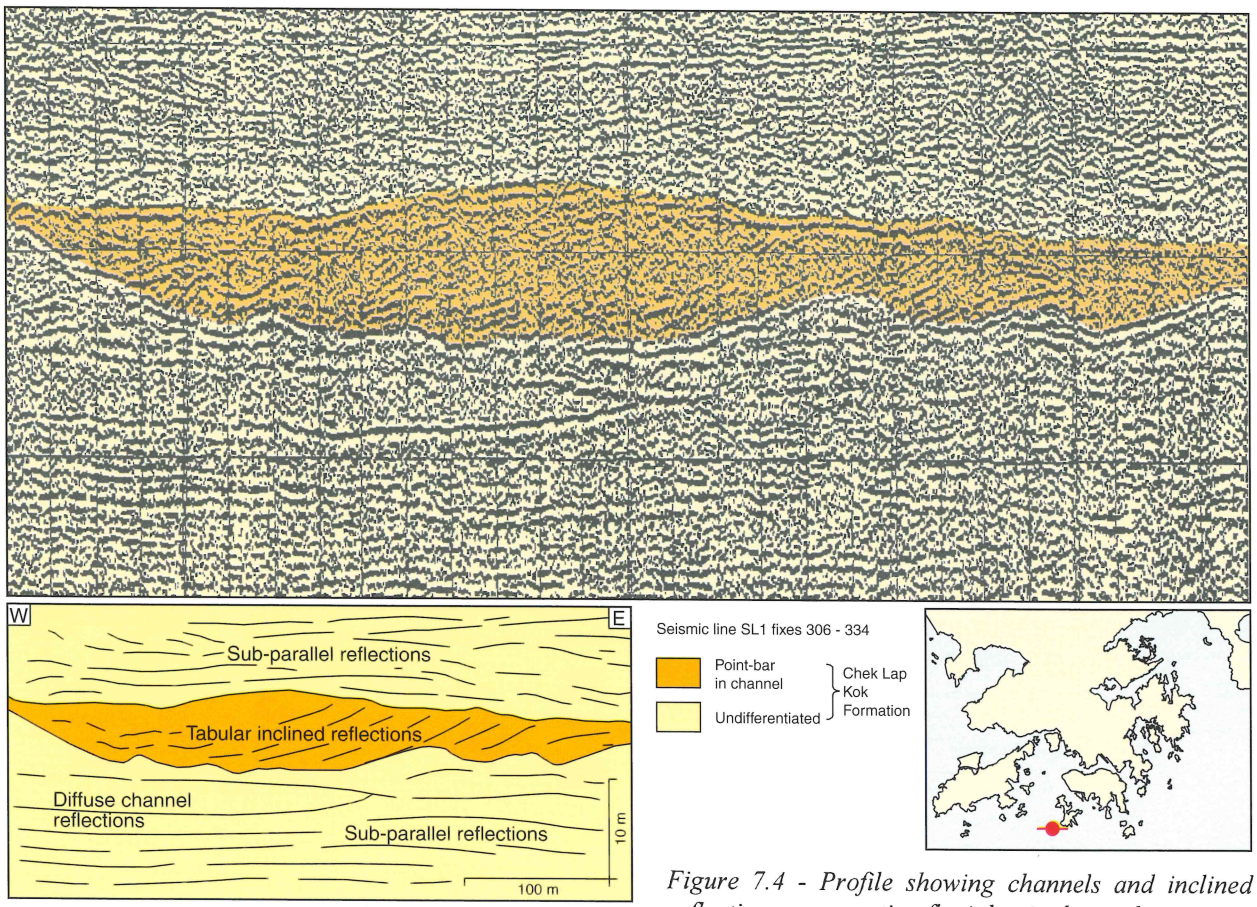


Figure 7.4 - Profile showing channels and inclined reflections representing fluvial point bar sedimentation

Wong Kong Shan Member

This member is formally described here for the first time, and the following description is based largely on that of the 'Wong Kong Shan Formation' by Lai (1998). The 'Lam Tsuen Formation', also described by Lai (1997), is essentially a synonym of the 'Wong Kong Shan Formation' and so is formally reclassified here also.

The type section of the Wong Kong Shan Member is located on the plain to the west of Wong Kong Shan (黃崗山) (3270 3890). Here the member mainly comprises yellowish grey to mottled red and yellow silty medium sand with subangular to subrounded gravel to boulders of moderately to completely decomposed tuff, granodiorite and fresh vein quartz. The member is up to 3.7 m thick. Another section through the member is exposed at Wai Tau Tsuen (圍頭村) (3333 3600), about 2 km northwest of Tai Po (大埔), near the junction of Lam Kam Road (林錦公路) with the Tai Po Road (Figure 7.5). The member is mainly exposed on the second alluvial terrace at elevations between +80 and +7.4 mPD (Addison, 1986). Typically, the member comprises subrounded cobbles and boulders, up to 0.8 m in diameter, set in a mottled red, yellow and brown, clayey silty sand matrix. Individual boulders display a weathered rind up to 5 mm thick.

In the area of the type section, the formation overlies completely decomposed granodiorite and is in turn overlain by debris flow deposits which are themselves part of the Chek Lap Kok Formation. Along the Lam Tsuen Valley (林村河谷), the member thins downstream to only 1 m thick at Wong Kong Shan .

Lai (1998) has reported several OSL dates from the Wong Kong Shan Member (Figure 7.6). These ages range between from 126 100 ± 10 100 years BP (State Seismological Bureau, China) up to 157 500 ± 36 300 years BP (University College of Wales) and indicate a Middle Pleistocene age. The member is always overlain either by deposits of the Shan Ha Tsuen Member, described below, or by colluvium of Late Pleistocene age.

Shan Ha Tsuen Member

The member is described here for the first time and the following description is based on that presented for the 'Shan Ha Tsuen Formation' by Lai (1997, 1998).

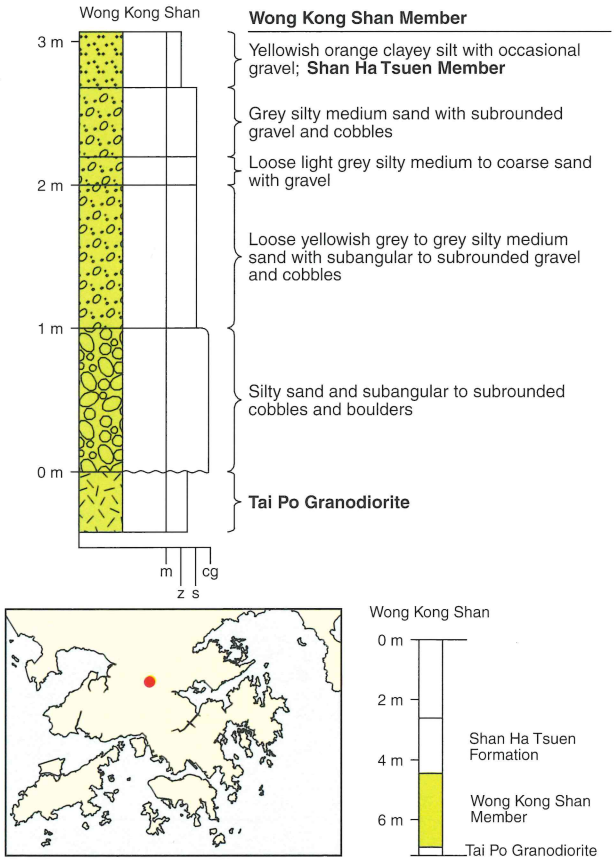


Figure 7.5 - Details of the type section of the Wong Kong and Shan Ha Tseun members, Chek Lap Kok Formation, Wong Kong Shan (黃崗山)



Plate 7.2 - Late Pleistocene alluvial terrace deposit (Shan Ha Tsuen Member, Chek Lap Kok Formation), Shan Ha Tsuen, Yuen Long (元朗山下村)

The type section of the Shan Ha Tsuen Member (Figure 7.7) is 600 m southwest of Shan Ha Tsuen (山下村) village (1920 3210), southwest of Yuen Long (元朗). Here, the member is 3 to 15 m thick. At Shan Ha Tsuen, the member (Plate 7.2) overlies Pleistocene slope wash and is overlain by a debris flow deposit of the Holocene Fanling Formation.

The lithology of the member varies with topography. Near the foot of hills, it comprises yellowish brown, gravelly silty sand, interbedded with dark grey, organic-rich silty clay layers. The clays are interpreted as lacustrine or marsh sediments. In upper valley sections, the member may pass laterally into coarser colluvial deposits. In more distal plains, fluvial terrace deposits are mottled red to brick red, yellow, brown and white, well sorted clayey sandy silt with sand layers (Figure 7.5).

Radiocarbon dating of organic-rich samples from the type section has yielded ages of 32 500 ± 490 years BP for the lowest exposed clay layer (+15.7 mPD) and 16 289 ± 831 years BP for the highest layer (+20.5 mPD). A clay sample from a locality 150 m northeast of the type section has yielded a radiocarbon age of 33 575 ± 3 186 years BP. These dates are supported by TL dates (Figure 7.3) that range from 23 800 ± 2 000 years BP to 29 300 ± 2 300 years BP (State Seismological Bureau, China), and an OSL date of 30 400 ± 8 000 years BP (University College of Wales). These dates indicate a Late Pleistocene age for the member as a whole, However, a further, significantly older OSL age of 81 000 ± 13 500 years BP (University College of Wales) has also been reported from near the base of the member (Lai, 1998).

Un-named colluvial members

Colluvial deposits of Pleistocene age are included within the Chek Lap Kok Formation. Most occur onshore and where greater than 2 m thick, are depicted on the 1:20 000-scale geological maps and described in accompanying Hong Kong Geological Survey memoirs as debris flow deposits, slope debris or slide deposits. On some of the maps in the 1:20 000-scale series, these deposits were not differentiated from similar deposits of Holocene age whereas on other maps in the series, they also include some talus deposits.

The colluvial deposits are generally poorly sorted and commonly comprise a reddish brown or dark yellowish

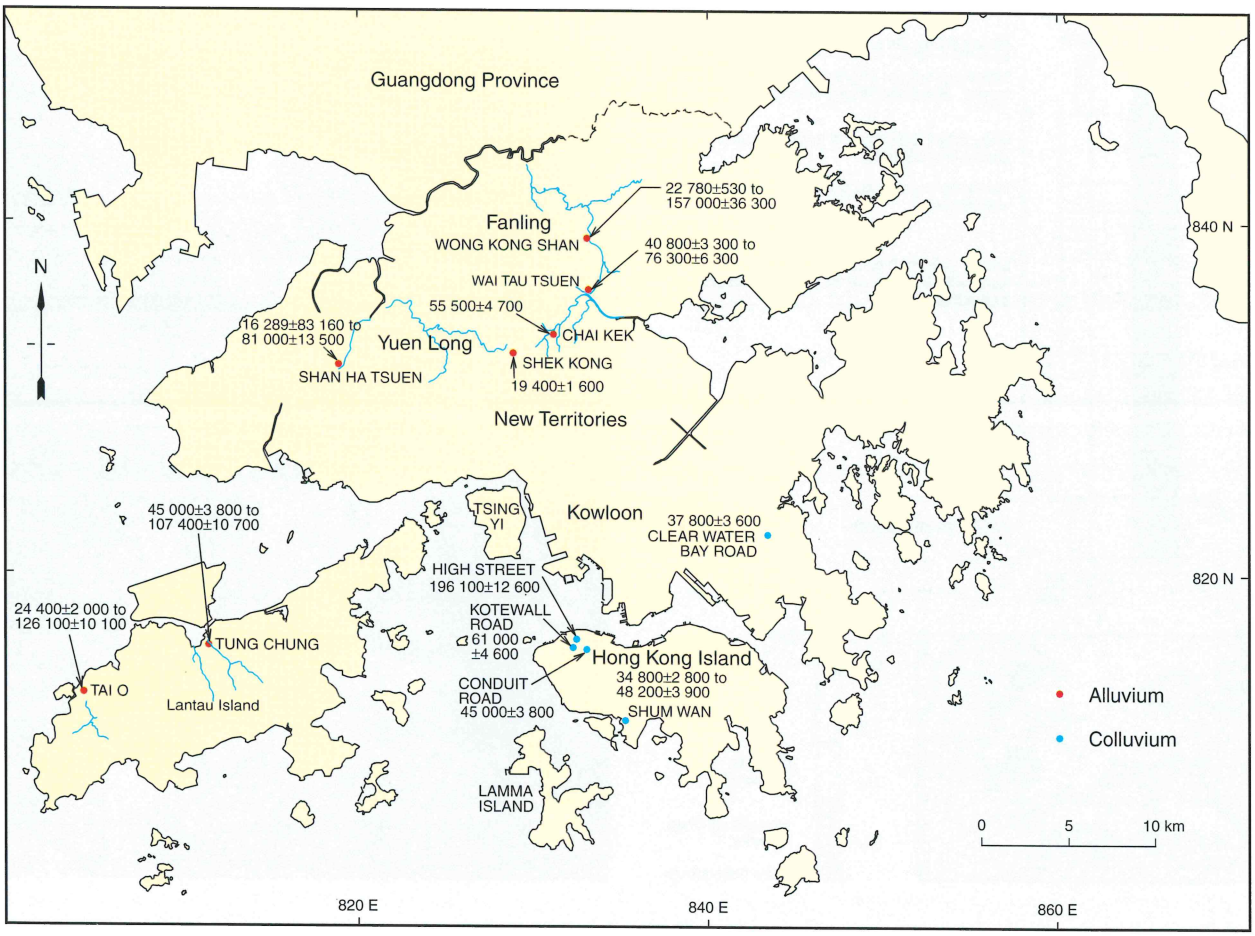


Figure 7.6 - Location map of Pleistocene alluvial and colluvial deposits for which luminescence age data are available

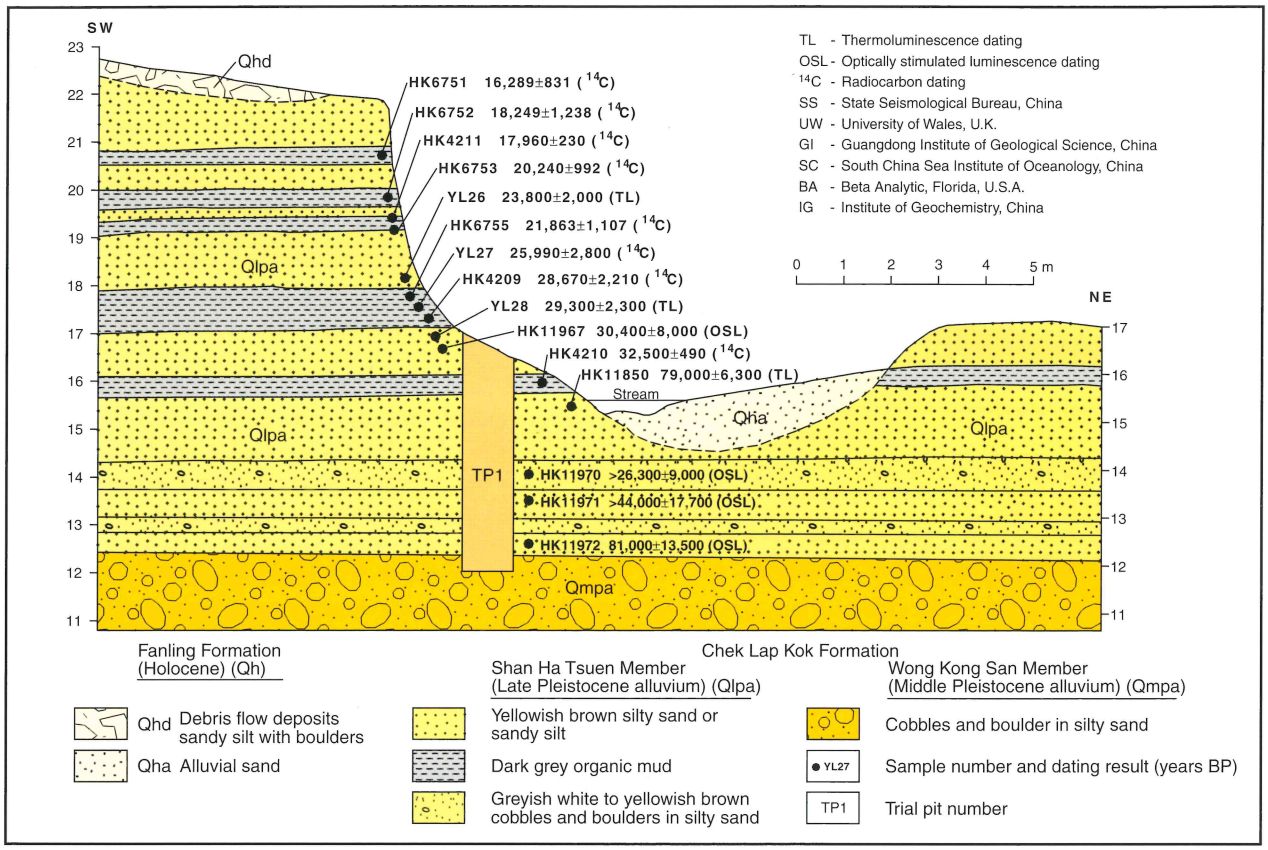


Figure 7.7 - Profile though the type section of the Shan Ha Tsuen Member (Late Pleistocene), Chek Lap Kok Formation, near Shan Ha Tsuen (山下村) village, southwest of Yuen Long (元朗), showing horizons from which radiocarbon and luminescence age data have been obtained

brown to orangish red, slightly mottled slightly clayey gravelly sandy silt matrix containing subangular, slightly to moderately decomposed boulders and cobbles. The grain size can vary between predominantly silt, sand, gravel, cobbles or boulders, depending on the original topography, parent rock type and distance travelled. Based on observations first made in the Mid-Levels (中半山) of Hong Kong Island (香港島) by Lai (1982), GCO (1982) and Lai and Taylor (1984), and then elsewhere in Hong Kong (e.g. Lai, 1997, 1998), deposits of this type have been interpreted as colluvial deposits of Late Pleistocene age (Plate 7.3). They have been differentiated from older colluvial deposits of Early to Middle Pleistocene age that comprise red to brick red, brown or white clayey sandy silt with highly to completely decomposed boulders and cobbles. For larger boulders, the extent of development of highly to completely decomposed material is restricted to a distinctive rind, commonly up to 20 mm thick (Lai & Taylor, 1984; Lai, 1997), but which can be up to 100 mm thick (Lai, 1998). Thin, white, kaolin infillings (Plate 7.4) are often observed within boulders in the older colluvial deposits in particular. The Early to Middle Pleistocene colluvium, also contrasts with Late Pleistocene equivalents in terms of its engineering strength, being stiff to very stiff as opposed to firm to stiff.

Lai (1997, 1998) has reported typical examples of Late Pleistocene colluvium, up to 10 m thick, from slopes below Lion Rock (獅子山) in north Kowloon (北九龍), and Mount Butler (畢拿山), on Hong Kong Island. In addition, he has described examples of colluvium of Early and Middle Pleistocene age, at elevations of between +150 and +100 mPD, below steep slopes such as at Fei Ngo Shan (飛鵝山), Castle Peak (青山), and Victoria Peak (扯旗山) where the thickness of deposits in



Plate 7.3 - Late Pleistocene colluvium (Chek Lap Kok Formation), slightly mottled with weathered rind around gravel and cobbles, Shum Wan (深灣)



Plate 7.4 - Middle Pleistocene colluvium (Chek Lap Kok Formation), very stiff, mottled, with white clayey veinlets along relict joints and clayey skin around surface of highly decomposed granite boulders, So Uk Tsuen (蘇屋村)

the Mid-Levels area is up to 16.7 m thick. All of these deposits are included here within the Chek Lap Kok Formation.

Whereas colluvium within the Fanling Formation (Chapter 11) of Holocene age characteristically infills drainage lines in the present topography, the equivalent deposits within the Chek Lap Kok Formation do not exhibit such a strong relationship and often occur within spurs in the present topography.

The colluvial deposits interdigitate with and, to varying extents, grade laterally and vertically into alluvial and fluvial deposits of the Chek Lap Kok Formation as a whole, and locally with the Wong Kong Shan and Shan Ha Tsuen members in particular.

Regional lithological variations – onshore

Onshore alluvial deposits of Pleistocene age, incorporated here within the Chek Lap Kok Formation, include extensive terraced alluvium in the western, northern and central parts of the New Territories (新界). In other onshore areas of Hong Kong, Pleistocene terraced alluvium is less widespread.

Considerable variation has been observed in the characteristics of the colluvium of Pleistocene age assigned here to the Chek Lap Kok Formation. To a large extent this reflects the lithology of the source of the deposit. In addition, variations in maximum grain size and of the ratio of coarse to fine material reflect changes in topography. Coarser debris is associated with steeper slopes and valleys (Plate 7.5).

New Territories (新界)

The most widespread alluvial deposits occur in the New Territories. They are particularly well developed along the Tuen Mun (屯門) and the Ngau Tam Mei (牛潭尾) Valley and on the Yuen Long (元朗), Kam Tin (錦田) and San Tin (沙田) plains in the northwestern New Territories, and in the central New Territories, along the Sham Chun (深圳), Ng Tung Ho (梧桐河) and Sheung Yue Ho (雙魚河) valleys, and particularly on the Sheung Shui (上水) and Fanling (粉嶺) plains. The largest areas of colluvium of Pleistocene age occur on the northwestern slopes of Tai Mo Shan (大帽山), below Castle Peak (青山) in the Tuen Mun Valley and around Tai To Yan (大刀屻), and Tai Shek Mo (大石磨). The thickest accumulations are at the bases of steep slopes, especially around the high hills comprising volcanic rocks.

In the Tuen Mun Valley, Late Pleistocene fluvial terrace deposits, locally interbedded with colluvium, underlie most of the low-lying land in the broad valley. The valley has a central watershed and extends 11 km from Tuen Mun in the south to Tin Shui Wai (天水圍) in the north. In the main Tuen Mun Valley, the deposits vary in thickness from 8 m in the south, to 1.2 m near the watershead, and thickening to 16 m in the north. Although generally poorly exposed, the deposits locally comprise yellowish brown and grey clayey silty sand with thin layers of gravelly coarse sand and boulders in the



Plate 7.5 - Pleistocene colluvium (Chek Lap Kok Formation), very large boulders of quartz monzonite with little matrix, Cape D'Aguilar (鶴咀)

beds of buried former channels.

Pleistocene colluvium occurs on the footslopes of Castle Peak, on the western side of the Tuen Mun Valley, and further north towards the coast. Here, it is preserved as terraces that form the interfluves between the present drainage lines and larger fan-shaped bodies. The deposits are typically 1 to 10 m thick, generally poorly-sorted and comprise moderately to completely decomposed boulders and cobbles and gravel of sandstone, siltstone, vein quartz and granite in a variably mottled red and ochre sandy clay matrix. Deposits on the lower slopes also include debris of tuff breccia and fine ash tuff derived from the Tuen Mun Formation. Several depositional mechanisms have been interpreted. These include debris flow, mud flow and alluvial torrent. The granite boulders are highly to completely decomposed. On the east side of the valley, the colluvium is also mainly of Pleistocene age.

The Yuen Long Plain is a broad alluvial valley surrounded by low hills, except towards the north where the plain passes into coastal mudflats. The valley is filled by Late Pleistocene fluvial terrace deposits overlain by Holocene alluvium (Plate 11.5). The elevation of the Pleistocene terraces varies from +23 mPD in the south, to -2.5 mPD in the north. They vary in thickness from 3 to 7 m near the margins of the plain to over 15 m in its central region with a maximum of 31.5 m in a buried channel. The deposits typically comprise firm to stiff, mottled red and yellow clay with some sand. Towards the base of the deposits they generally comprise gravelly sand with cobbles. Up to five layers of dark grey organic clay may be present. Deposits in the south and west, derived from granite and sandstone, have a high sand content whereas those in the east, derived from tuff, have high silt and clay and vary to a yellowish brown colour.

The Kam Tin (錦田) plain is a broad valley lined with widespread Late Pleistocene fluvial terrace deposits whose surface elevation varies from +27.6 mPD in the east to -3.9 mPD in the west. At the head of the valley, Pleistocene colluvium, interpreted as debris flow deposits (Langford *et al.*, 1989) are mostly derived from volcanic rocks. The deposits are up to 18 m thick and comprise moderately to highly decomposed boulders, up to 4 m diameter, and cobbles of coarse ash tuff or tuff breccia in a matrix of yellowish brown gravelly silty sand. The colluvium grades into, or underlies, Pleistocene fluvial terrace deposits in the upper part of the Kam Tin Valley. The fluvial deposits comprise yellowish brown gravelly sand, about 1 to 3 m thick, with thin layers of mottled red and brown silty clay. In the central part of the valley these deposits are up to 14 m thick, but are more typically 8 m thick. Here, the lower part of the deposit comprises silty sand with gravel, with a layer of gravelly sand with cobbles at the base. The upper part is mainly mottled red, brown and grey sandy silt or silty clay. At the western end of the valley, where it passes into mudflats, boreholes have proved the thickness of the Pleistocene alluvium to be up to 11.5 m. Three units have been identified: a lower

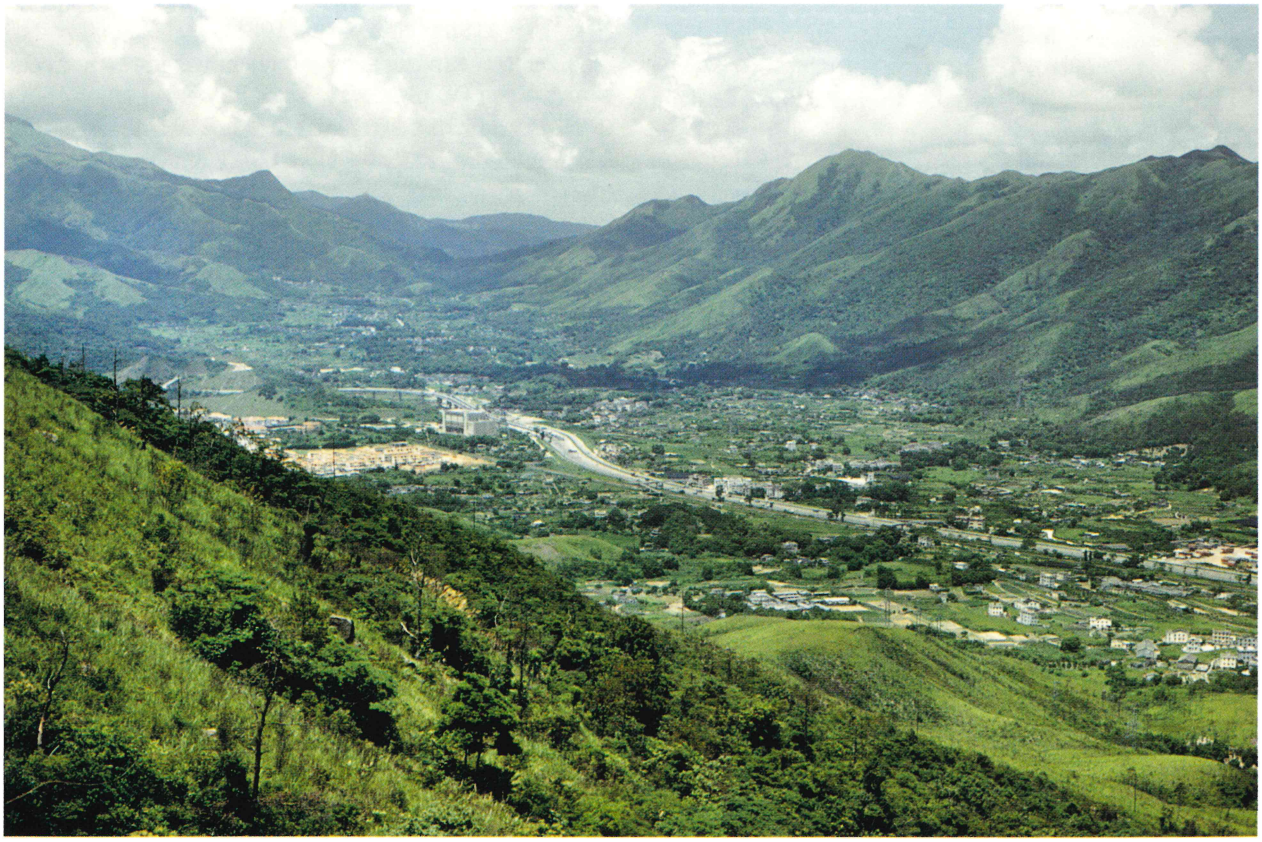


Plate 7.6 - Pleistocene alluvial deposit (Chek Lap Kok Formation), Lam Tsuen Valley (林村河谷)

layer up to 2.4 m thick of gravelly sand with cobbles; a middle layer of 5 to 7 m of yellowish brown silty sand; and an upper layer of 3 to 4 m of mottled red, yellow and grey silty clay (Langford *et al.*, 1989).

Ngau Tam Mei (牛潭尾) is a narrow valley with Pleistocene fluvial terraces. They vary from elevations of +26 mPD in the east to -1 mPD in the west. The deposits are 1 to 10 m thick and comprise silty coarse sand with some boulders in proximal environments and silty sand with thin layers of clay distally. Deposits of similar thickness occur in the Sheung Yue Ho (雙魚河) Valley.

The Ng Tung Ho (梧桐河) rises from a source on Pat Sin Leng (八仙嶺) and is fed by a major tributary from the Lam Tsuen Valley to the south and southeast. Colluvium, mainly of Pleistocene age, occurs on both sides of the alluvial plains and in the valley heads. It comprises highly decomposed cobbles in a gravelly clayey silt and is typically 1 to 4 m thick, but is locally up to 10 m thick. The Lam Tsuen Valley (Figure 7.8) contains an 800 m wide Pleistocene alluvial terrace containing two units (Plate 7.6). These units are also recognized further down river beneath the Fanling plain. The lower unit is 1 to 5 m thick and typically comprises dark yellowish brown, varying to mottled red and grey, sandy silt, coarse sand, gravel, cobbles and subrounded, highly to moderately decomposed boulders. The upper unit, which is 1.5 to 4.7 m thick, contains pale grey, fine to medium sand and clay, yellowish brown sandy silt and dark grey to black organic clay and silt. In the lower part of the Ng Tung Ho, the Pleistocene deposits are up to 12 m thick.

Late Pleistocene alluvium, up to 15 m thick, comprising mottled red and yellow clayey silt, is widespread beneath the San Tin (沙田) Plain. The plain incorporates the estuaries of the Shenzhen River (深圳河) and the Shan Pui River (山背河). The alluvial deposits underlie Holocene marine deposits of the Hang Hau Formation.

Colluvium of Pleistocene age commonly occurs as narrow deposits infilling the dendritic river systems in the northeastern New Territories. However, deposits are not generally widespread. They are commonly 1 to 3 m thick and are composed of yellowish brown silty sand with boulders, cobbles and gravel of tuff, conglomerate and siltstone, depending on the underlying geology.

A few Pleistocene fluvial terraces are present in the eastern New Territories. Their scarcity probably reflects the generally limited extent of alluvial tracts in this part of Hong Kong. In addition, intensive agricultural terracing may have obliterated some natural terrace features (Strange *et al.*, 1990), for example at Ho Chung (蠔涌).

Kowloon (九龍), Hong Kong Island (香港島) and neighbouring islands

The extent of Pleistocene alluvium in Kowloon is very limited although such deposits may have existed in East Kowloon and Junk Bay (將軍澳) prior to agricultural terracing and building developments. Some probable Pleistocene terraces were observed by Ruxton and Berry (1957) on aerial photographs taken prior to development in the So Uk (蘇屋), Lei Cheng Uk (李鄭屋) and Shek Kip Mei (石硤尾) areas of northwestern Kowloon. The terraces in this area are approximately 3 m above the level of the Holocene alluvium. A Han dynasty tomb was discovered within the terrace at Lei Cheng Uk (Strange & Shaw, 1986). Alluvial terraces thought to be of Pleistocene age also occur at Yung Shue Wan (榕樹灣) on Lamma Island. Pleistocene alluvium has not been recognized on Hong Kong Island or on the Po Toi Islands (蒲台群島) (Strange & Shaw, 1986).

Excellent exposures of colluvium were present in cut slopes along the old Clear Water Bay Road (清水灣道) (Plate 7.7 and 7.8), 300 m east of Choi Wan Estate (彩雲邨), but unfortunately the slopes have now been covered. The deposits, up to 10 m thick, were described (Strange & Shaw, 1986) as being poorly sorted and



Plate 7.7 - Middle Pleistocene colluvium (Chek Lap Kok Formation), very stiff, mottled, with granite boulder 4.5 m across, highly decomposed, gravel and cobbles being completely decomposed, Clear Water Bay Road (清水灣道)



Plate 7.8 - Middle Pleistocene colluvium (Chek Lap Kok Formation), with highly decomposed boulders and completely decomposed cobbles and gravel, Clear Water Bay Road (清水灣道)

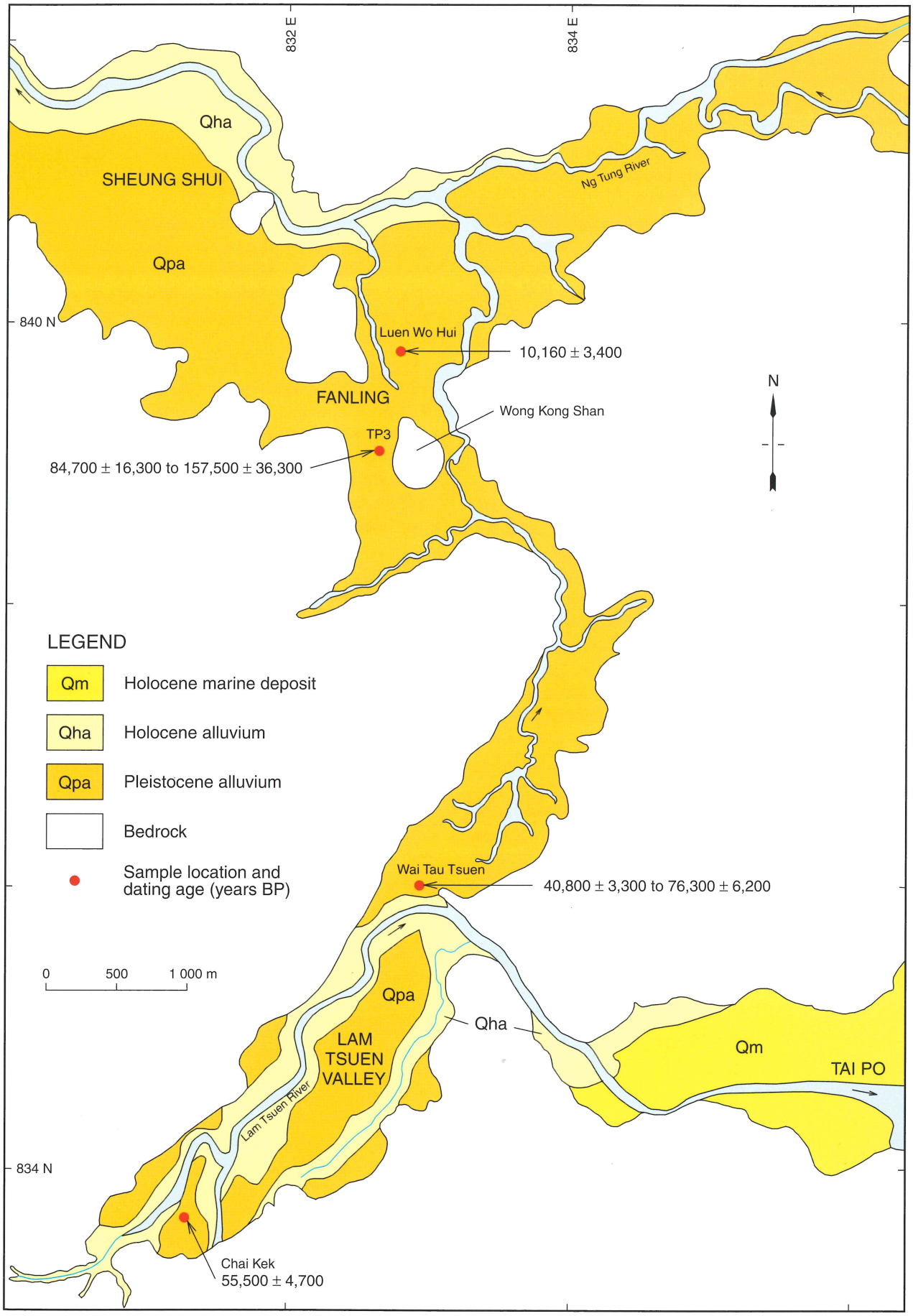


Figure 7.8 - Distribution of Quaternary superficial deposits in the Lam Tsuen Valley (林村河谷) and Fanling (粉嶺) areas, northern New Territories (新界)

comprising subangular to rounded volcanic boulders and cobbles, typically highly decomposed, in a well consolidated light orange-brown clay matrix. These deposits were interpreted as Early to Middle Pleistocene by Lai and Taylor (1984).

At several localities around northern Kowloon, for example on the slopes below Lion Rock (獅子山), the colluvium is up to 10 m thick. Temporary exposures here have revealed colluvium of presumed Pleistocene age, underlying more recent colluvium. Commonly, the Pleistocene colluvium occupies ridge spurs, in contrast to the more typical valley-fill morphologies of the recent colluvium. On the southern slopes of Piper's Hill (琵琶山), Whiteside (in Strange & Shaw, 1986) reported that just above weathered rock, the matrix at the base of the colluvium, was mostly a white clay (kaolinitic?) while above that, elongate white flecks, 20 to 40 mm long, interpreted as caused by iron reduction, and containing rootlets, occurred within the more typical brown matrix.

On Hong Kong Island, a widespread mantle of colluvium covers the northern slopes of Victoria Peak (扯旗山). During the Mid-Levels Study (GCO, 1982), this was examined in detail. At least three cycles of colluvium were identified of which the older two, described above as Late, and Early to Middle Pleistocene age deposits, are assigned here to the Chek Lap Kok Formation. The debris are almost entirely composed of volcanic rock derived from the source area around Victoria Peak (扯旗山). The colluvium, including deposits of Holocene age, is up to 33 m thick in this area. The deposits extend downslope to Sheung Wan (上環) reaching the former coastline (Howat, 1985b), and possibly beyond.

Lantau Island (大嶼山) and neighbouring islands

On Lantau Island (大嶼山), extensive elevated fluvial terraces of Late Pleistocene age are present. Similar lithofacies variations to those observed in the western, northern and central parts of the New Territories (新界) occur on Lantau Island. Near the foot of hills, deposits mainly comprise semi-sorted, yellowish brown to orange, gravelly silty sand that was probably derived from hillwash from the adjacent slopes. In upper valley sections the deposits grade into more bouldery colluvium whereas in the distal plains, the deposits are typically mottled red, yellow, brown and white, well-sorted clayey sandy silt with some sand layers.

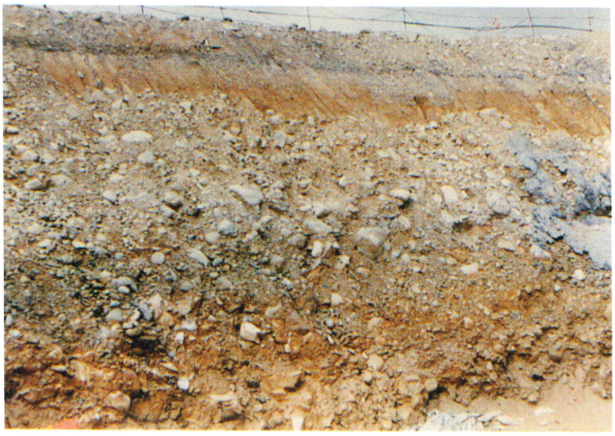


Plate 7.9 - Pleistocene alluvial deposit (Chek Lap Kok Formation), Tung Chung (東涌)

Alluvium of the Chek Lap Kok Formation infills the western Tung Chung Valley (東涌谷) (Plate 7.9) to form a raised terrace from 400 to 500 m wide. The deposit extends inland for about 2000 m and reaches an elevation of almost +20 mPD. The terraces grade up into coarse bouldery debris on the surrounding slopes. Although rarely exposed, the partially indurated deposit is coarse and comprises boulders and cobbles within a mottled red and yellow sandy silt with some sand lenses and layers. More isolated remnants of terraced alluvium occur in the eastern Tung Chung Valley and in the Sham Wat Valley (深屈谷).

Colluvium of the Chek Lap Kok Formation, i.e. of Pleistocene age, has not generally been distinguished on Lantau Island from colluvium of Holocene age. Typically the colluvium occurs in isolated upland valleys, and on lower slopes as more extensive accumulations that usually merge imperceptibly into the alluvium. Colluvium is mainly developed on the lavas and tuffs and is more restricted on the granites and feldsparphyric rhyolites. The thickest and most extensive deposits fill entire valley systems, extending from the coast to dendritic accumulations that reach ridge crests in the headwaters. Good examples include dendritic networks of deposits feeding down from Nei Lak Shan (彌勒山), Tung Chung Au (東涌坳) and Sunset Peak (大東山) towards Tung Chung. These deposits, comprising coarse boulders within a stiff mottled sandy silt matrix, grade downslope into the extensive, alluvial terrace deposits. Other laterally extensive deposits of colluvium blanket the western slopes of Sze Shan (獅山) above Tai O (大澳), and on the northwestern slopes of Por Kai Shan (婆髻山), crossing the coast near Lau Fau Shan (流浮山). Prior to construction of the airport, there was a large area of colluvium at Chek Lap Kok (赤鱲角), which was proved to be at least 4 m thick.

Regional lithological variations – offshore

Several boreholes have penetrated the Chek Lap Kok Formation in Hong Kong waters. The base of the formation is usually only reached nearshore, where the formation is thin, or in the longest offshore boreholes. Towards the southern limit of Hong Kong waters, the Quaternary sediments thicken, and the base of the formation is interpreted only from seismic profiles.

Deep Bay (后海灣) to Kap Shui Mun (汲水門)

In the area of Deep Bay (后海灣), the sedimentary character of the Chek Lap Kok Formation has been controlled by the outflow of the Shenzhen River (深圳

河), a tributary of what is now the Fanshi Channel (矾石水道) of the Pearl River Estuary (珠江口) (see Figure 1.3). Seismic data are of poor quality in this area, but a channel is eroded into bedrock (Map 4), running along the axis of Deep Bay. The valley floor falls from -28 mPD at Tsim Bei Tsui (尖鼻咀) to -40 mPD at the mouth of Deep Bay (Langford *et al.*, 1989). The Chek Lap Kok Formation here comprises a thick unit of sand and gravel, largely confined to the bedrock channel, overlain by mottled clayey silt. To the south, off Black Point (爛角咀) in borehole 90830/2D, a similar sequence of fine to coarse sand, overlain by mottled clayey and sandy silt, overlies weathered granite (Figure 7.9).

In the Urmston Road–Brothers Channel (龍鼓水道-大小磨刀海峽), the formation is thin, due to channelling of its upper surface (James, 1993). Around The Brothers (大小磨刀) islands the thickness of the formation varies considerably as a result of local thinning over bedrock highs and selective erosion of the top of the formation, but reaches a maximum of around 27 m (Sewell & James, 1995).

North of Lantau Island (大嶼山), the type section has been described in borehole B13/13A, on the site of the new airport platform (Figure 7.1). To the west, in borehole B15, a large-scale channel identified on seismic profiles can be correlated with a well-developed upward-fining sequence (James, 1993). The channel is characterised by subhorizontal intraformational reflections and is believed to represent a single phase of valley cutting. Higher in the borehole, a 10 m-thick sand horizon correlates with lateral accretion reflections on the seismic profile. Similar reflections are seen across the area but cannot be correlated regionally.

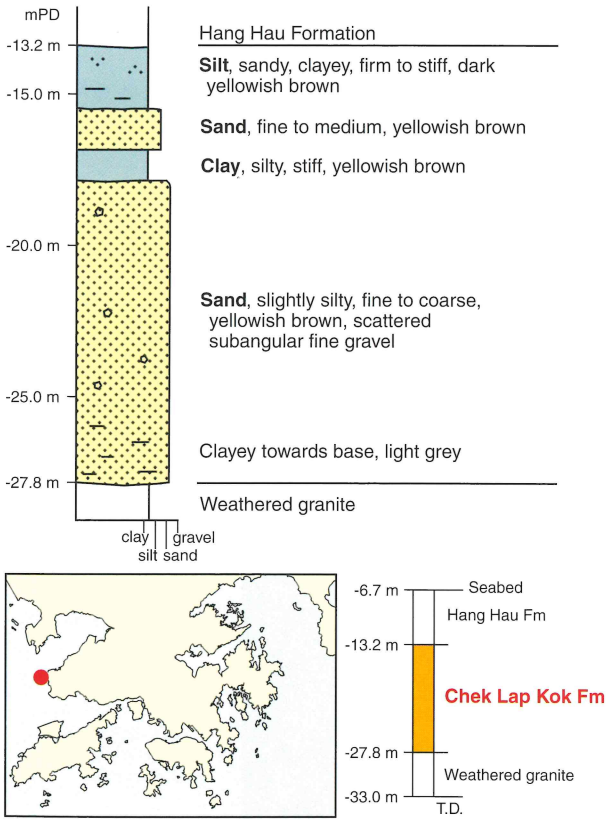


Figure 7.9 - Details of the Chek Lap Kok Formation in borehole 90830/2D

Channels of the type seen here form a deeply incised network draining the whole area to the north of Lantau Island and merging with the Lantau Channel (大嶼海峽) to the west (James, 1993). Detailed work around the airport site has revealed the existence of a palaeotributary entering the channel system from the Tung Chung Valley (東涌谷).

Channels are visible on the seismic profiles around the site of borehole ESC17, where they are associated with thick sand deposits. The mineralogy of these sands is dominated by quartz, kaolinite and mica, with subordinate smectite, siderite, calcite and feldspar (Kemp, 1993). The presence of minor amounts of rutile in one sample, just above the channel sand, is unusual. Hong Kong granites tend to be deficient in titanium (Sewell *et al.*, 1992), though in the east, the Devonian and Jurassic sedimentary rocks are known to be rutile-bearing. It is possible that this occurrence is associated with sedimentary rocks on the north coast of Lantau Island.

Around the Chek Lap Kok (赤鱲角) airport site, a number of units have previously been identified: a 'lower alluvium', a 'lower marine clay' and an 'upper alluvial crust' (Fung *et al.*, 1984; Yim, 1984a) These units can be correlated with horizons identified on seismic records from the new airport site at Chek Lap Kok (James, 1995), though not regionally throughout Hong Kong waters.

The Chek Lap Kok Formation thins to the east and is absent over the rock platform north of Kap Shui Mun (汲水門), except where possible remnants are preserved in isolated erosional bedrock hollows. North of Tsing Yi (青衣), the formation is again thin and is represented by poorly sorted, weathered, sandy silty clay and gravel (Sewell & Fyfe, 1995).

South of Lantau Island (大嶼山) to Hong Kong Island (香港島)

West of the Soko Islands (索罟羣島), the basal erosional surface of the Sham Wat Formation cuts out much of the Chek Lap Kok Formation. In borehole HKGS-C, the sediment comprises 4 m of sand, overlain by 11 m of silty clay. The sand ranges from poorly sorted fine to coarse sand at the base to well-sorted very fine to fine sand and is dominantly quartzose. From seismic evidence, the sand is close to the bedrock surface and thus is termed a basal sand. The silty clay is highly weathered, and at the base is interlaminated with silty very fine sand. Interlamination of this type (Plate 7.10a) is common south of Lantau Island (大嶼山) in the lower part of the succession. Abundant plant fragments, up to 15 mm across, are found throughout the upper part of the succession.

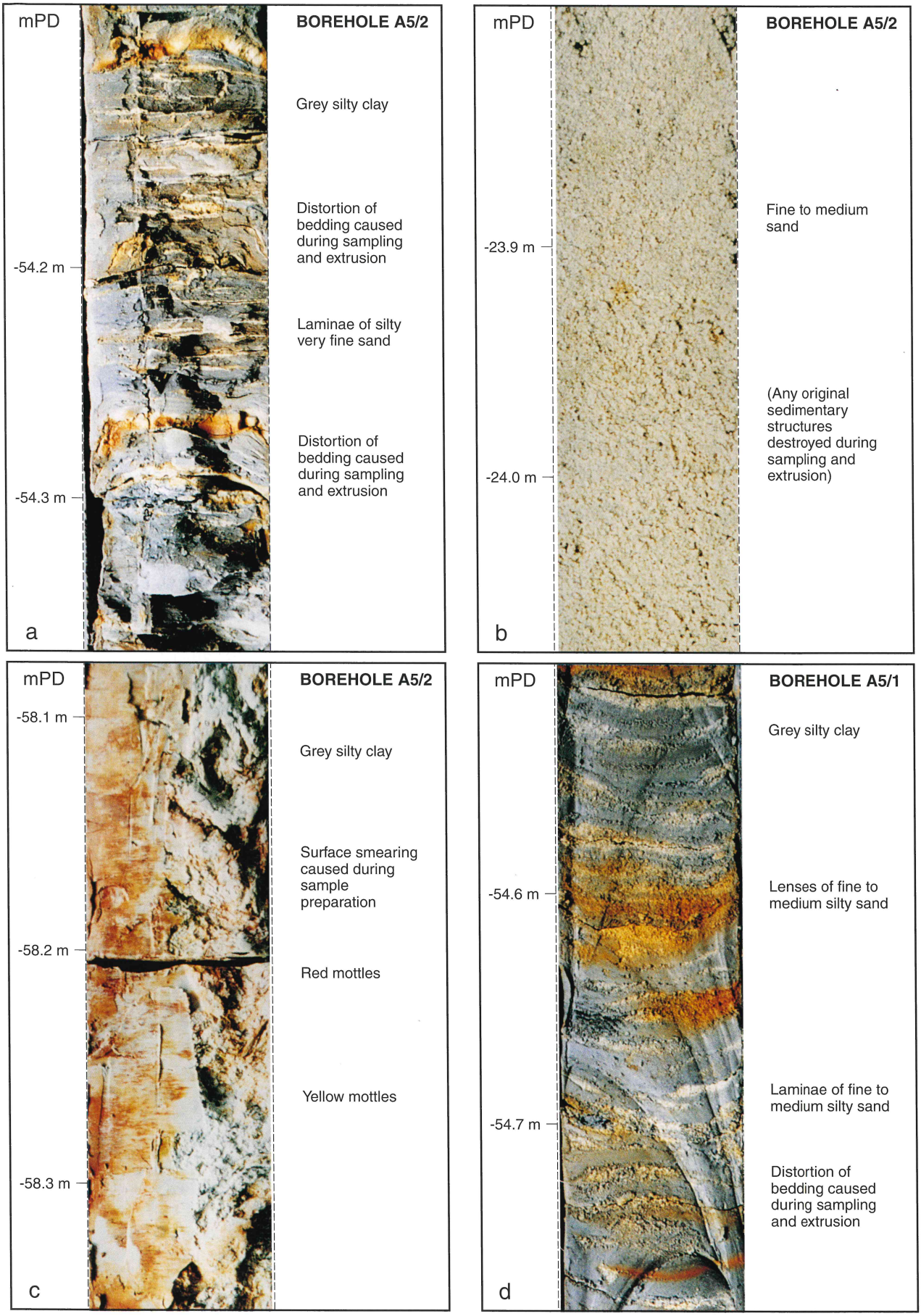


Plate 7.10 - Sediments from the Chek Lap Kok Formation

East of the Soko Islands, in borehole A5/1 the formation is a dominantly sandy sequence, 32.4 m thick. The main sedimentary units clearly correlate with the seismic units and contain laterally persistent reflections (James, 1993) that probably define the boundaries of large channels. The basal unit comprises silty clay, some of which is organic-rich, with laminae and lenses of fine sand. This is overlain by an upward-coarsening sand unit, dominantly quartzose with occasional silty clay laminae and lenses. An iron-rich palaeosol is developed in this sequence, the clay-rich part of which is highly weathered. This is overlain by a further unit of interlaminated silty clay and sand.

Samples from borehole B22, southeast of Cheung Chau (長洲), have been described by Yim and Yu (1993).

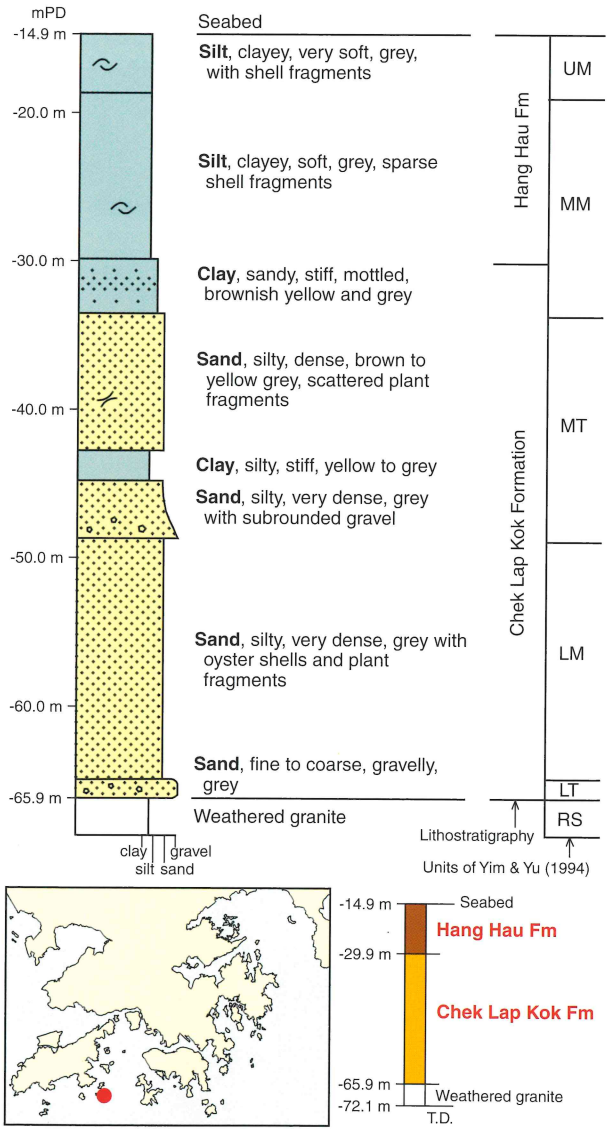


Figure 7.10 - Details of the Chek Lap Kok and Hang Hau formations in borehole B22, showing units described by Yim and Yu (1994) correlated with the established lithostratigraphy

Three marine horizons (UM, MM and LM – Upper, Middle and Lower Marine) were recognized. The borehole lies on seismic line P20 and thus may be correlated with the established seismic stratigraphy (Figure 7.10). The upper two marine units correspond to the Hang Hau Formation and are considered here to be of

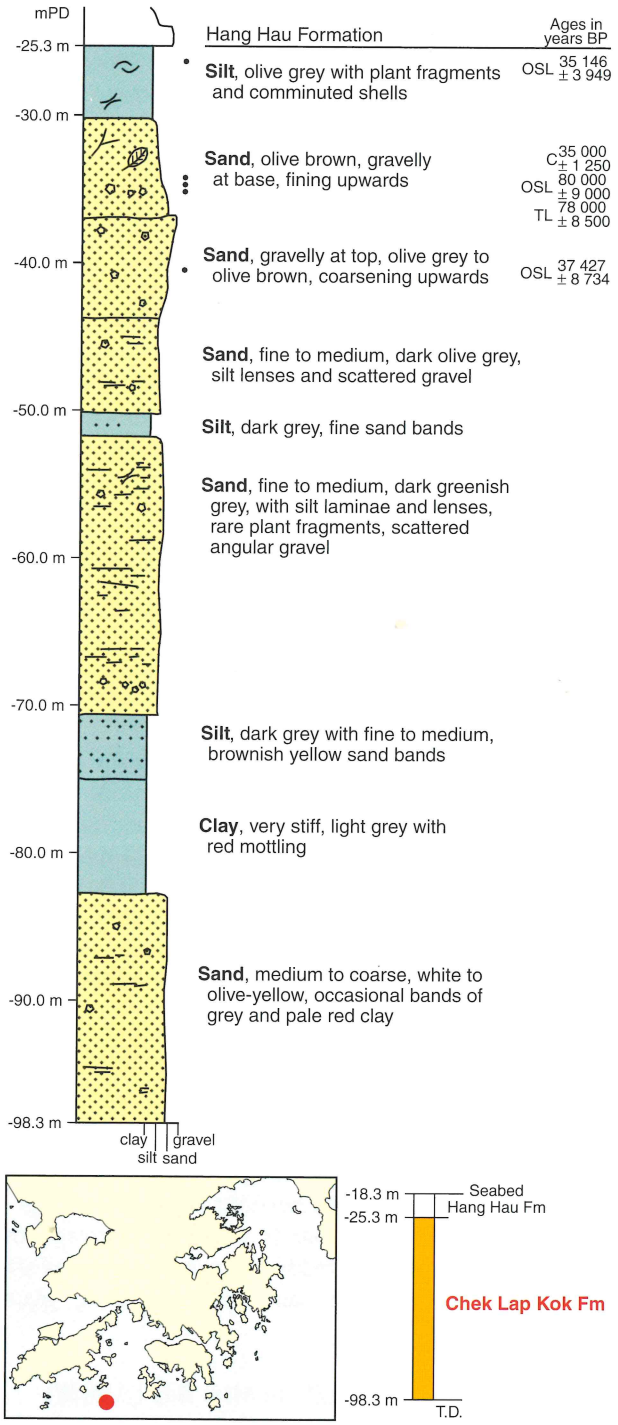


Figure 7.11 - Details of the Chek Lap Kok Formation in borehole A5/2

Holocene age. The LM horizon is interpreted as marine on the basis of the presence of oyster shells and microfossils, in particular marine and brackish-water diatoms. This correlates with a unit of diffuse, flat-lying reflections within the Chek Lap Kok Formation.

To the east, borehole A5/2 (Figure 7.11) was drilled to penetrate an interfluve between channels eroded on the top of the formation. The borehole sampled 73 m of Chek Lap Kok Formation but did not reach bedrock. Here, the formation has been divided into four main depositional units, the lower three of which are interpreted as terrestrial and the uppermost as shallow marine (Owen *et al.*, 1995). Based on the seismic character, Owen *et al.* (1998) interpreted the upper unit to be a lateral equivalent of the Waglan Formation in the southeast. The main sedimentary units (Plate 7.10) clearly correlate with seismic units.

In the Western Harbour (西區海港) area, acoustic turbidity caused by the presence of biogenic gas in the lower part of the Hang Hau Formation masks the Chek Lap Kok Formation on many seismic profiles. In the north of the area, the formation is generally thin (Sewell & James, 1995), but thickens southeast from Penny's Bay (竹篙灣). North of Lamma Island (南丫島), in borehole NLC4 (Figure 7.12), the Chek Lap Kok Formation comprises 16 m of weathered clayey silt overlain by 14 m of interbedded silt and sand. The clayey silt unit contains shell fragments, including corroded oyster shells at -55 mPD (Owen *et al.*, 1998).

A number of boreholes have been drilled in the West Lamma Channel (西博寮海峽). Three of these, WB7, WB12 and WB14, comprise interbedded clayey silt and sand, some in upward-coarsening beds with gravel (Figure 7.13). The finer-grained beds are normally organic-rich with plant fragments up to 15 mm long. Some beds are pale to medium grey in colour with occasional ochre, yellow and red mottling. These variations in colour result from variable weathering, and may take the form of streaks and pods, which could represent bioturbation (Plate 7.10c).

South of the East Lamma Channel (東博寮海峽), the Chek Lap Kok Formation in borehole HKGS–B comprises interbedded sand and clayey silt. The seismic reflections corresponding to the lower part of the borehole are chaotic, but suggest the presence of channels. In the upper part, however, a horizon of high-amplitude parallel reflections (Figure 7.14) corresponds with intensely weathered reddish brown, firm, clayey silt interlaminated with fine sand and containing plant remains throughout.

Hong Kong Island (香港島) to Mirs Bay (大鵬灣)

Around Hong Kong Island (香港島), where there are strong currents, the Chek Lap Kok Formation is generally thin. However, in sheltered areas the formation is more fully developed. For example in Tai Tam Bay (大潭灣) the formation is up to 30 m thick. The bulk of these sediments is probably derived from fluvial erosion and mass wasting of the surrounding coastline. Several debris flows from the Stanley peninsula (赤柱半島) were identified on seismic profiles and in borehole samples by Howat (1985a). A possible colluvial intercalation within the formation was recognized in a tunnel excavation off Western District (西區) (Howat, 1985b). The deposit, which is presumed to have originated from the slopes of the Mid-Levels (中半山) area, was dated by radiocarbon on oyster shells at 30 560 ± 580 years BP.

In the Causeway Bay (銅鑼灣) area, two palaeovalleys extend seawards beneath the reclamation (Willis & Shirlaw, 1984). Tunnelling through sediments contained in these palaeovalleys exposed several cross-

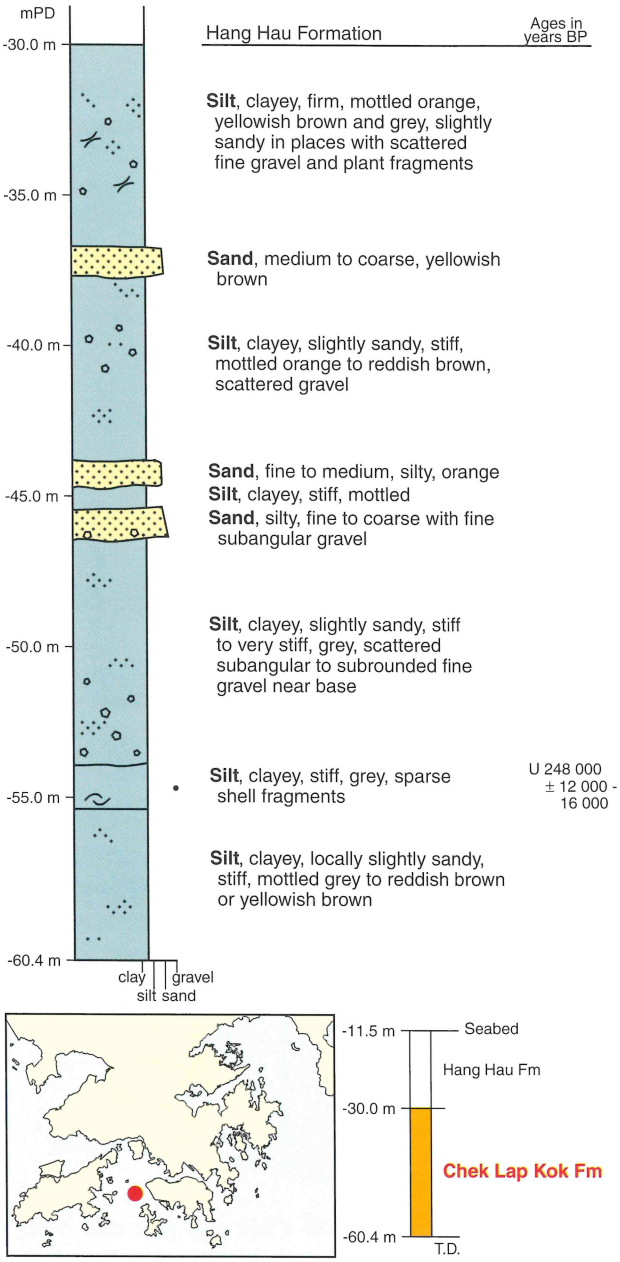


Figure 7.12 - Details of the Chek Lap Kok Formation in borehole NLC4, site of 248 000 year-old oyster shell

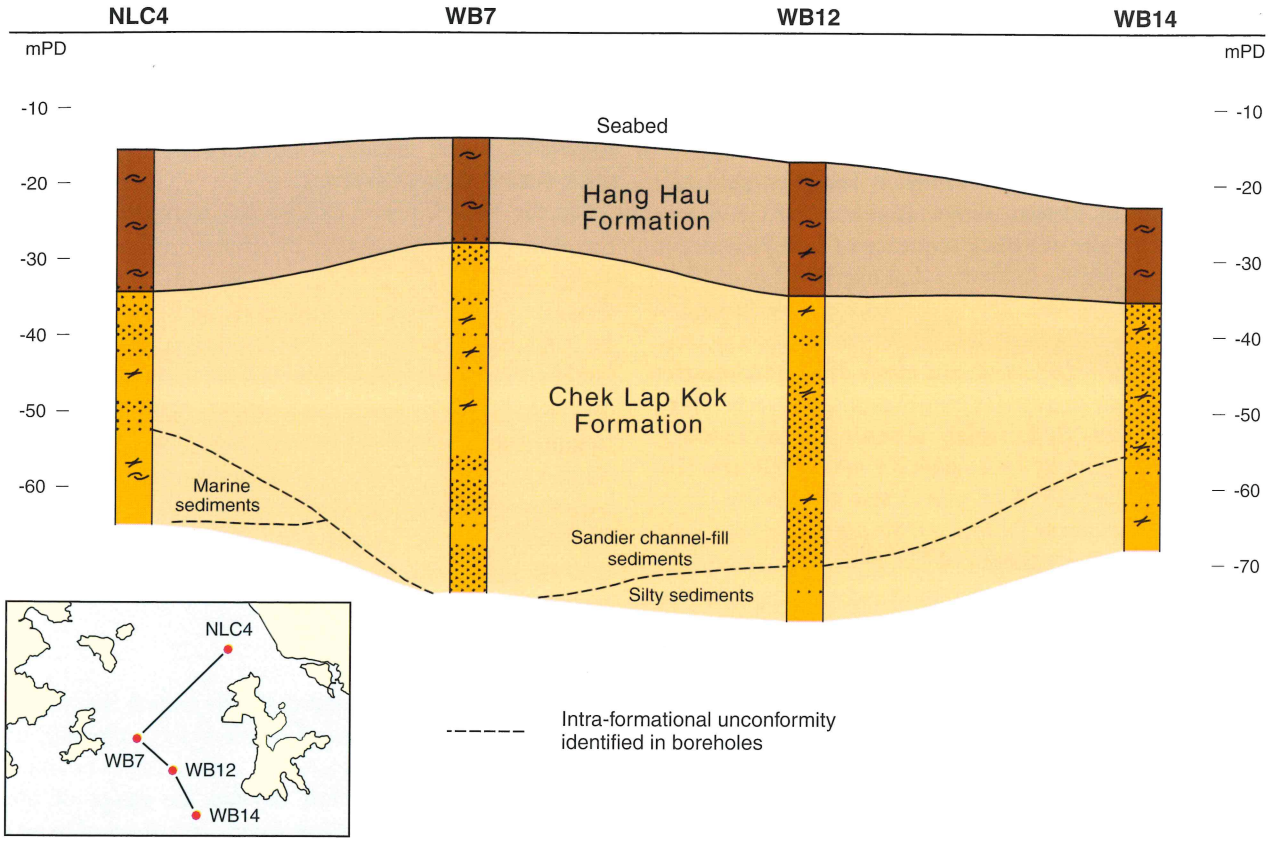


Figure 7.13 - Boreholes WB7, WB12 and WB14 from the West Lamma Channel (西博寮海峽) correlated with borehole NLC4 from north of Lamma Island (南丫島)

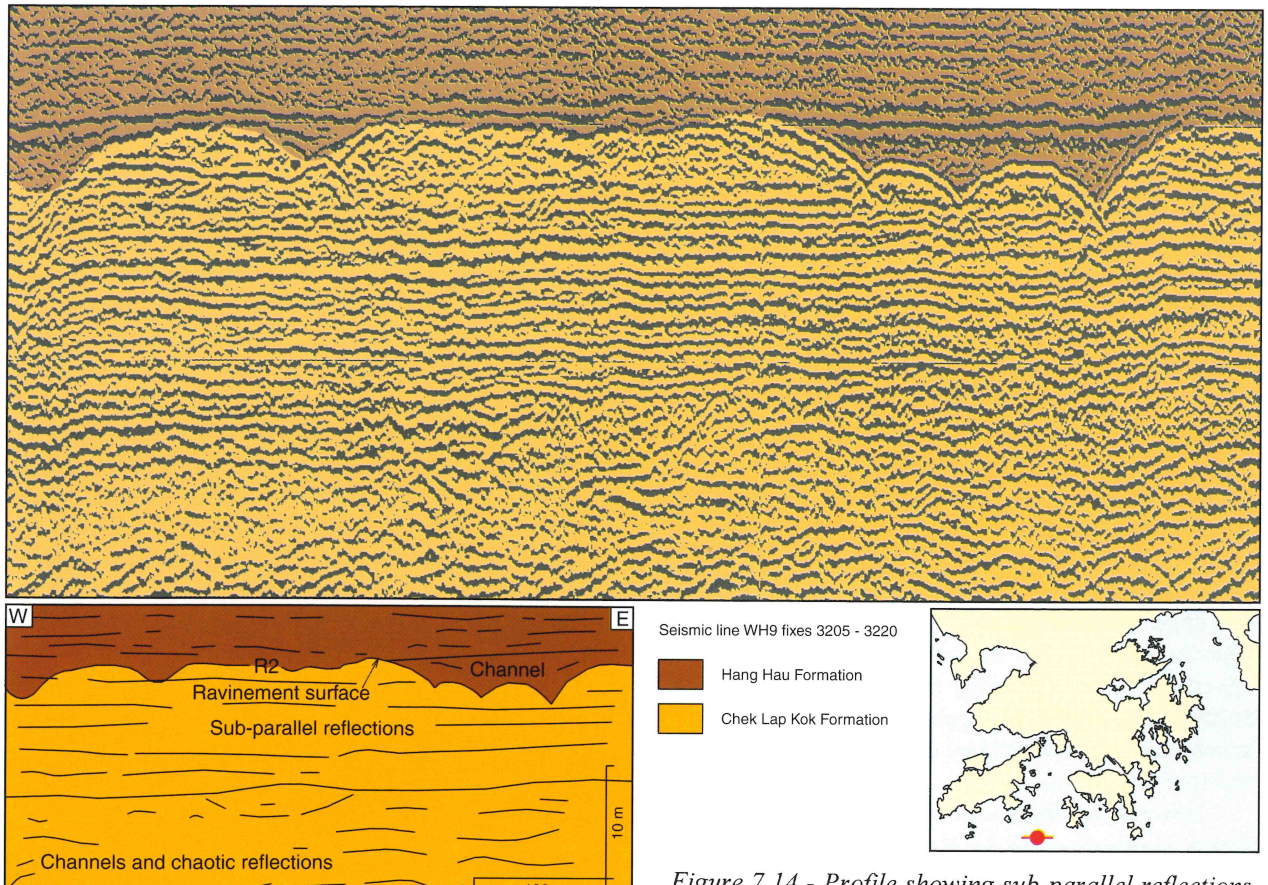


Figure 7.14 - Profile showing sub-parallel reflections at the top of the Chek Lap Kok Formation

sections through the Chek Lap Kok Formation revealing laterally discontinuous, interbedded sand and clayey silt. The palaeochannels are continuations of the steeply incised, thickly alluviated valleys on the flanks of Jardine's Lookout (渣甸山).

The Chek Lap Kok Formation becomes generally more sandy in eastern waters. Borehole HKGS-A was drilled on the site of a thick sequence of Late Pleistocene to Holocene marine sediments that overlie 20 m of Chek Lap Kok Formation. The lower part of the formation comprises silty clay, which is interbedded with laminated fine sand and contains scattered clasts of mud and coarser sand. This unit is overlain by a 7 m-thick, poorly sorted fine to coarse sand, which appears to be generally homogeneous except for a single 0.1 m bed of firm to stiff oxidized clayey silt. Fine gravel and mud clasts, up to 10 mm across, occur throughout the core.

To the north, southwest of The Ninepin islands (果洲群島), 53.5 m of interbedded sand and silty clay has been sampled in borehole C2/2, and ascribed to the Chek Lap Kok Formation (Strange *et al.*, 1990). The fine to medium sand is predominantly yellowish brown in colour and characteristically colour banded and mottled. Some coarse sand, gravel and rare plant fragments are present. The silty clay is dominantly grey in colour with bands, thin laminae and lenses of yellowish brown sand (Owen *et al.*, 1998). Sediments of this type often include mud clasts and pods, possibly representing bioturbation (Plate 7.10d). The formation here is thickest in two major bedrock channels (Map 4) that drain in a southerly direction from Mirs Bay (大鵬灣).

In Port Shelter (牛尾海) and Rocky Harbour (糧船灣海), the numerous seabed rock ridges influence the thickness of the Chek Lap Kok Formation. As seen around Hong Kong Island, the formation is generally very thin or absent near the coast, but is laterally continuous with onshore alluvium that extends seawards from the numerous valleys in the area.

Several sections through the Quaternary succession were exposed during excavation for the High Island Dam (萬宜水壩) (Frontispiece) (Kendall, 1975; Yim, 1984b). The West Dam site consisted of brown alluvial clay with lenses of silt, sand and sandy gravel, which included locally derived volcanic rock clasts. Organic debris included relatively well-preserved tree trunks, bark, leaves and nuts.

At the East Dam site, three sedimentary units were revealed beneath the Holocene marine sediments – lower and upper alluvial deposits separated by 'lower marine deposits'. The alluvial deposits are clast-dominated, the upper unit also containing fine sand and a limonitic horizon, interpreted as a palaeosol. The lower marine deposits are characterised by decomposed plant material and shell fragments.

The formation thins northwards towards Mirs Bay (大鵬灣). Northeast of the Sai Kung Peninsula (西貢半島), in borehole SMMD1/6, the Chek Lap Kok Formation consists of around 15 m of interbedded fine, medium and coarse sand, with soft, sandy silty clay. The crudely cross-stratified sandy units appear to be confined to a channel; both sandy and silty units contain shell fragments. These appear to be corroded fragments of thick-walled, ribbed bivalves.

In the Tolo Channel (赤門), the formation forms a linear body along the axis of the channel (Strange *et al.*, 1990). On seismic profiles, the formation displays a chaotic reflection pattern, with no recognizable channels. In Tolo Harbour (赤門), the formation has a similar pattern. The formation, sampled in over 130 large-diameter bored piles on the northern side of the inlet formerly known as Tide Cove (沙田海), comprises a thin white clay layer overlain by orange-brown sand, with a weathered hardpan palaeosol horizon in the upper metre (Whiteside, 1984). This is overlain by silty sand fining upward into sandy silt and silty clay, containing wood fragments up to 200 mm across.

Age

There are difficulties in dating the formation due to the general absence of calcareous fossils in the sediments. In addition, much of the formation is considered to be older than 40 000 years, and thus beyond the range of the radiocarbon dating technique. Dates have been obtained using thermoluminescence (TL) and optically stimulated luminescence (OSL) (Owen *et al.*, 1995). Uranium-series dating (Yim *et al.*, 1990; Owen *et al.*, 1998) has provided the oldest ages in the Chek Lap Kok Formation, but these dates are on isolated shells and therefore must also be treated with caution.

Radiocarbon ages

Several radiocarbon ages have been obtained from wood and peat in the formation. Radiocarbon dates obtained offshore have been reported from material from organic clay in the Shan Ha Tsuen Member at several localities in the northeast New Territories (Langford *et al.*, 1989; Lai, 1997, 1998; Lai *et al.*, 1996). These dates range in age from 16 289 ± 831 years BP to 33 575 ± 3 186 years BP (Beta Analytic; Guangdong Institute of Geological Sciences; South China Sea Institution of Oceanology). In addition, carbonaceous material within a colluvial deposit in a borehole (BGS 12, at 20.2 m depth) at Tin Shui Wai (天水圍) in the northeast New Territories, has yielded a radiocarbon age of 26 000 to 27 000 years BP (Frost, 1990).

At offshore localities, radiocarbon ages range from 16 420 years BP at Chek Lap Kok (RMP Encon Ltd., 1982) to >40 000 years BP (Kendall, 1975; Yim & Yu, 1993; Strange & Shaw, 1986).

All of the radiocarbon dates may be subject to a young-age bias due to the introduction of a few percent of modern carbon, through CO_2-rich groundwater having permeated the sediment during high sea level stands (Yim *et al.*, 1990; Toscano & York, 1992). The work by Yim *et*

al. (1990) shows that bivalves with radiocarbon ages of 39 460 ± 2 320 and 45 700 ± 2 088 years BP yielded ages of 142 000 ± 20 000 and 130 500 ± 5 300 years by the uranium-series method. This alone may cast sufficient doubt on the radiocarbon ages to make them all questionable. However, comparison of TL and OSL dates with radiocarbon dates from similar horizons within the Shan Ha Tsuen Member (Lai, 1998) has demonstrated good correlation, with overlapping uncertainty bands in all but one instance.

TL and OSL ages

TL and OSL ages have been reported by Lai (1998) from the Chek Lap Kok Formation in the northeastern New Territories (新界) (Figure 7.6). For the Shan Ha Tsuen Member, these ages range from TL dates of 23 800 ± 2 000 years BP (State Seismological Bureau, China) to 79 000 ± 6 300 years BP (Guangdong Institute of Geological Science). For the Wong Kong Shan Member, the dates range from 126 100 ± 10 100 years BP for a TL date (State Seismological Bureau, China) to an OSL date of 157 500 ± 36 300 years BP (University College of Wales).

Lai (1997, 1998) has reported a maximum age for colluvium thought to form part of the formation onshore, based on an OSL date of 196 100 ± 12 600 years BP (University College of Wales). The sample was obtained from a locality on the northern slopes of Victoria Peak (扯旗山) in northwest Hong Kong Island (香港島).

Offshore, an OSL date of 31 743 ± 4 456 (HKU Radioisotope Unit) was obtained from -44.55 mPD in borehole C2/2, at the top of the formation, immediately below the Waglan Formation. A number of Weichselian ages have been recorded from boreholes. The oldest of these are from borehole A5/2, where an OSL date of 80 000 ± 9 000 years BP was obtained from sandy silt at -32.23 mPD, and a TL date of 78 000 ± 8 500 years BP from similar sediments at -32.27 mPD (Owen *et al.*, 1998). These dates were obtained immediately below a horizon at -32.11 mPD, where a wood fragment had been radiocarbon dated at 35 000 ± 1 250 years BP (Beta Analytic).

Yim and Yu (1993) tentatively ascribed their lower marine deposits (LM) to oxygen isotope stage 7 (Holsteinian age). In borehole NLC4, 1 km north of Lamma Island (南丫島), Owen *et al.* (1998) recorded the presence of oyster shells, one of which has been uranium-series dated at 248 ± 12–16 kA (Guangzhou Institute of Geochemistry; P.C.T. Cheung, personal communication). This is an isolated date, but it indicates that part of the Chek Lap Kok Formation may be as old as pre-Holsteinian.

Depositional environment

The widespread distribution and variable lithology of the Chek Lap Kok Formation indicate prolonged deposition in several fluctuating sedimentary environments. In onshore areas the general geomorphology of the deposits provides valuable clues to their sedimentological interpretation. However, in offshore areas, interpretation depends on the identification of characteristic geometries using seismic reflection data, and of lithofacies in the few available boreholes.

In onshore areas, the formation is associated in large part with extensive floodplains, especially in the western and northern New Territories (新界). These reflect fluvial and alluvial deposition within and alongside meandering channels, of varying size. The fluvial deposits include point bar deposits of widely varying grain size. The overbank deposits of the channels, generated during times of flood, are characteristically finer-grained. These are intercalated with organic rich clays and silts that were deposited in ephemeral lakes on the floodplains and probably also in oxbow lakes created in abandoned channel meanders. The fluvial and alluvial deposits are also extensively intercalated with, and may pass imperceptibly into, colluvium, particularly on steeper slopes and in valley heads.

The colluvium is the product of mass wasting with the material transported by gravitational processes. In this regard, the matrix-supported, rather than clast-supported nature of the material is characteristic. Water-initiation is generally inferred. The colluvial deposits have often been interpreted as debris flow deposits (e.g. Strange & Shaw, 1986; Langford *et al.*, 1989 etc.). However, this represents only one of several transportational mechanisms that are likely to have been responsible for forming these deposits. Others include rock fall, rock slide, rock avalanche, debris slide, debris avalanche, earth flow, continuous creep and other compound and more complex mass wasting processes. The resulting deposits would be further dependent on the degree, or otherwise, of channelization of the debris, the degree of saturation of the debris, and the prevailing slope angle.

Seismic profiles show a large number of channel-fill features, some of which have been drilled and shown to contain upward-coarsening sequences. Elsewhere, the presence of flat-lying parallel reflection patterns suggests more regular deposition, such as floodplain, intertidal or possibly marine sedimentation. The paucity of fauna has hindered attempts to establish firmly the environments of deposition; this paucity may be either primary or a result of post-depositional decalcification during periods of subaerial exposure (Wang & Yim, 1985).

The formation lies on a comparatively subdued topography (Map 2) in which the broad pre-Quaternary drainage pattern can be distinguished. The oldest seismic unit is probably represented by the package of flat-lying basal reflections that are seen on some seismic profiles from the south. Seismic facies analysis provides limited information on sedimentary facies (Stoker *et al.*, 1992). Nevertheless, laterally persistent sub-parallel reflections are consistent with low-energy conditions, such as those in floodplain, intertidal or marine environments. Poorly defined, flat-lying reflections may be seen on seismic

profiles from the site of borehole A5/2. The sediments are interpreted as terrestrial sands overlying a thick sequence of lacustrine clays, derived from nearby granites, interbedded with alluvial plain sediments (Owen *et al.*, 1995).

The wide channels identified on seismic records can be explained by several facies models. Channels may be cut during periods of fluvial entrenchment, as with those of the Tung Lung Member of the Hang Hau Formation (see Chapter 10). These features must have formed as wide valleys in which fluvial sediments were deposited. Upward-coarsening sands are characteristic of nearshore sand-barrier and marine sand sheet sequences (Cant, 1992), though their occurrence in wide channels indicates that they probably formed as point bar sediments. Dominance of sand has been shown by Walker and Cant (1984) to indicate braided river systems with low-sinuosity channels (Figures 7.15 and 7.16).

In the area to the south of Lamma Island (南丫島), the sand unit from the upper part of borehole A5/2 is upward-coarsening, consistent with a prograding point bar deposit. Migration of the channel to the east is indicated by the eastward-dipping seismic reflections. However, given the complex nature of the Chek Lap Kok Formation, palaeocurrent directions are probably only of local significance.

Though slope processes may account for some of the Chek Lap Kok Formation sediments, such as those described at Tai Tam Wan (大潭灣) and Western District (西區) (Howat, 1985a, 1985b), they cannot account for the formation over the whole of Hong Kong waters. Nevertheless, alluviation of mass wasting deposits may be a significant mechanism in some areas.

Shells have been recovered in the Chek Lap Kok Formation from two boreholes in central waters, one to the north of Lamma Island and the other in the West Lamma Channel (西博寮海峽). In both cases, the shell-bearing horizon corresponds with a sequence of diffuse parallel seismic reflections. The southernmost of these is borehole B22 (Figure 7.10), described by Yim and Yu (1993). Their lower marine (LM) deposits contain not only oyster shells but marine microfossils, including the brackish-water diatoms *Cyclotella comta*, *C. striata*, *C. stylorum* and *Melosira (=Paralia) sulcata* and the marine forms *Cocinodiscus* sp. and *Nitzschia cocconeiformis*. To the north, in a similar sequence in borehole NLC4, Owen *et al.* (1998) recorded the presence of oyster shells. Shell fragments recovered from the formation in a third borehole, SMMD1/6 in Mirs Bay (大鵬灣), are from thick-walled, ribbed bivalves, typical of estuarine or high-energy shallow marine environments. Seismic records reveal that the sediments from this horizon occupy a broad channel, suggesting that they were deposited in a brackish to estuarine inlet or possibly a coastal swamp.

There has been considerable debate in Hong Kong over the presence or lack of pre-Holocene marine units. The debate centres around whether the finer-grained units in the Chek Lap Kok Formation are terrestrial or marine in origin. For example, Wang and Yim (1985), and Yim (1994) argued that decalcification has destroyed any faunal remains. Owen *et al.* (1995), in a detailed analysis of borehole A5/2 (Figure 7.11), pointed out that not only are calcareous microfauna, such as foraminifera, absent but also siliceous microflora, such as diatoms. They argued that an extreme range of fluctuating Eh and pH

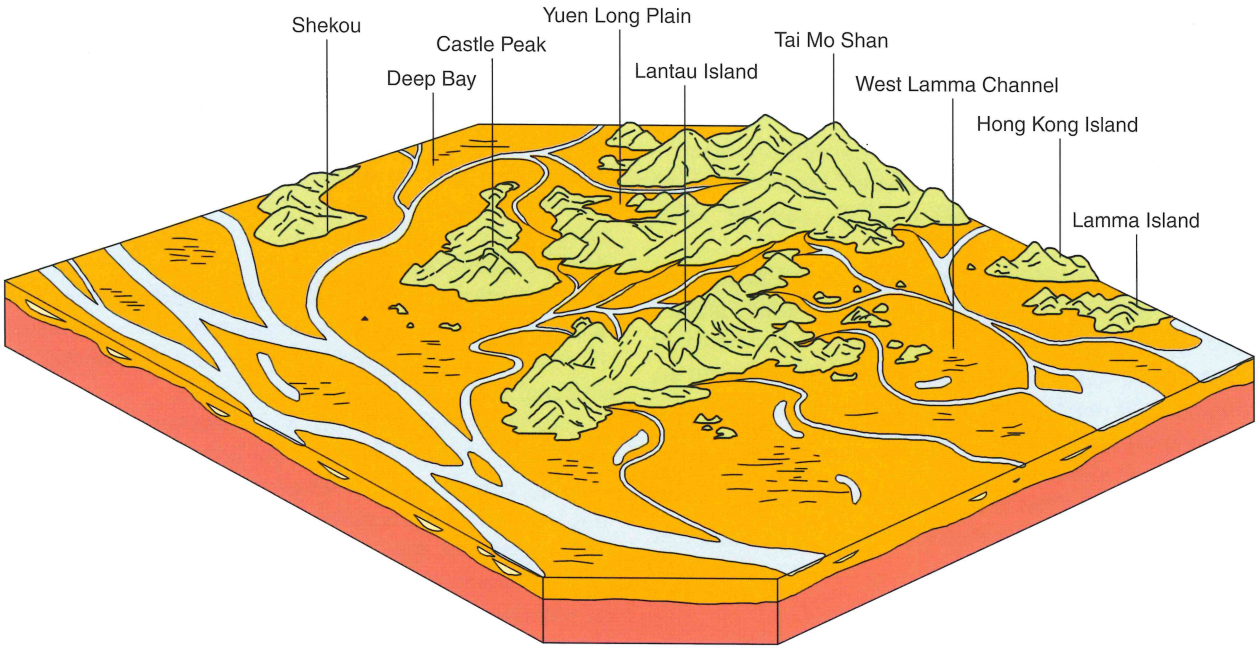


Figure 7.15 - Palaeogeographical reconstruction during deposition of the Chek Lap Kok Formation sediments in southwestern waters of Hong Kong during a low sea level stand

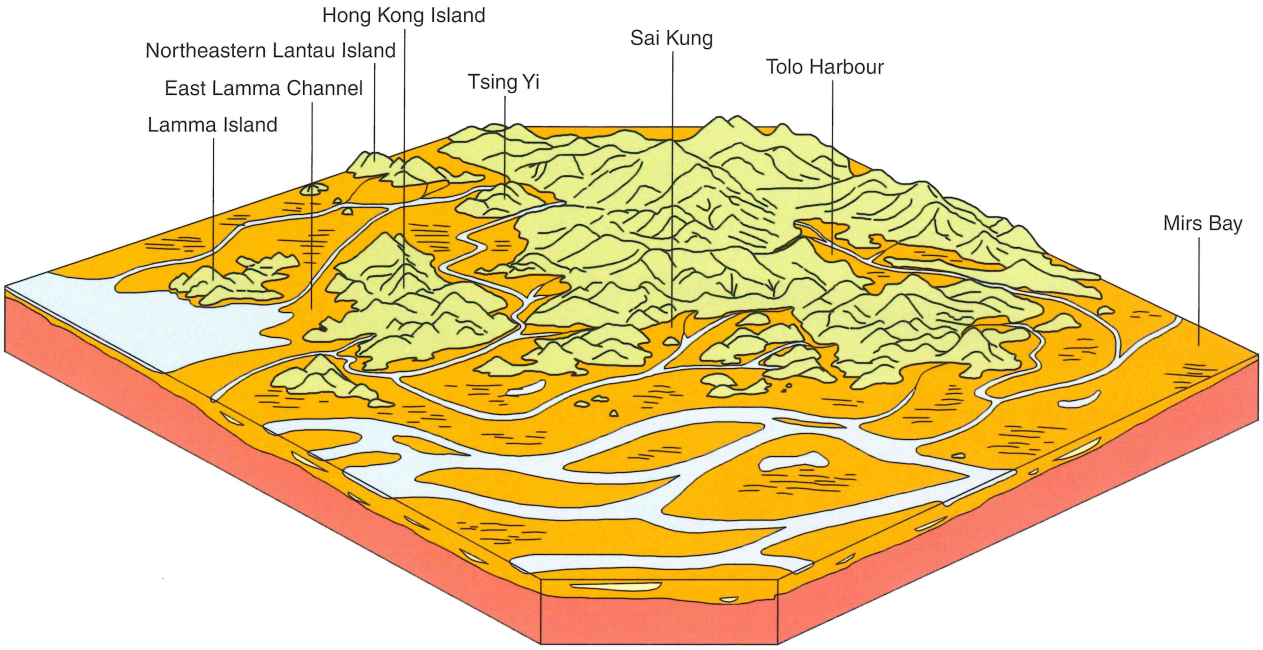


Figure 7.16 - Palaeogeographical reconstruction during deposition of the Chek Lap Kok Formation sediments in southeastern waters of Hong Kong during a low sea level stand

conditions must have prevailed to account for the observed absence. The degree of weathering in the Chek Lap Kok Formation does indicate that diagenetic changes have been intense and varied. It may be possible that both calcareous and siliceous microfossils have been destroyed.

Yim *et al.* (1990) presented a table of environmental indicators (Table 7.1) used to differentiate terrestrial and marine deposits. With the significant diagenesis suggested by Owen *et al.* (1995), it is questionable if many of these environmental indicators would survive.

Yim (1994) proposed a tenfold stratigraphy of five terrestrial units interbedded with five marine units (see Chapter 5). However, Owen *et al.* (1995) have shown that there is no evidence of marine sediments within the Chek Lap Kok Formation in the West Lamma Channel. Rather, they interpreted the formation as a single development of terrestrial sediments, with proximal alluvial sands overlain by a lacustrine unit and later floodplain deposits. This model has subsequently been extended across the whole of Hong Kong waters (Owen *et al.*, 1998).

In conclusion, the Chek Lap Kok Formation is clearly a complex unit. In broad terms, the onshore areas currently occupied by the formation were the sources of debris generated by mass wasting. The debris was fed into fluvial environments. These were essentially minor tributaries that in turn supplied sediment to the main fluvial channel systems, and onto the main floodplains that now lie in offshore areas of Hong Kong.

Extensive large-scale channelling is visible on the seismic records. Consequently, any older surviving marine units will not have remained laterally continuous. It is believed that the formation comprises a number of depositional phases which are not clearly ressolved on the seismic records. Resolution of the stratigraphy would require further seismic data specifically calibrated to give higher resolution in deeper levels of the Chek Lap Kok Formation. Interpretation would also benefit from the discovery of further macrofossils, similar to the oyster shells found in the East Lamma Channel (東博寮海峽) area.

Features		Marine	Terrestrial
Palaeontology	Marine fossils	Present (*)	Absent
Sedimentology	Colour	Darker	Paler
	Grain size	Finer	Coarser
	Sorting	Better	Poorer
	Rock fragments content	Lower	Higher
Mineralogy	Feldspar content	Lower	Higher
	Clay content	Higher	Lower
	Clay type	Illite/smectite	Kaolinite
	Glauconite	Possible	Absent
	Iron content	Lower	Higher
	Pyrite content	Higher	Lower
	Organic content	Higher	Lower
	Sodium chloride content	Higher	Lower
	Feldspar/quartz ratio	Lower	Higher
Chemistry	pH	Neutral	Acidic
	Eh	Reducing	Oxidising
Engineering	Density	Lower	Higher
	Compaction	Softer	Firmer
	SPT	Lower (<10)	Higher
	Water content	Higher	Lower
	Permeability	Lower	Higher
	Tip resistance	Lower	Higher
(*) Marine fossils may be absent due to dissolution			

Table 7.1 - Environmental indicators of Yim et al.(1990)

8. Sham Wat Formation

The Sham Wat Formation is present only in subcrop beneath the Hang Hau Formation in the west, or beneath the Waglan Formation in the southeast (Figure 5.2). Although the age remains uncertain, it is considered to be an Eemian deposit (Fyfe & James, 1995), but may be younger in western waters (Owen *et al*, 1998). The formation is of marginal distribution in the western and eastern parts of Hong Kong waters and is inferred to extend and thicken westwards into the Pearl River Estuary (珠江口) and to the south of Hong Kong waters (Figure 8.1).

On boomer profiles, the seismic character is very distinctive. Continuous undulating reflections drape down into the deeper channels cut into the surface of the Chek Lap Kok Formation and lie sub-parallel to the planated crest of the interfluves. Intraformational reflections are commonly truncated by the erosion surfaces that define the bases of the overlying formations. The sediments are dominantly silty clays that range in colour from dark to light grey with yellowish mottling and vary in strength from soft to firm. Subordinate silty, very fine sand is present at the base of, and sometimes in lenses and laminae throughout, the formation.

The thickness of the Sham Wat Formation in Hong Kong waters varies from only a few metres at the northern edges of the subcrop to over 40 m at its maximum development near the Soko Islands (索罟群島).

The formation was first identified on reconnaissance seismic surveys in western waters (Thorley *et al*., 1990) and was later described during mapping of the area north of Lantau Island (大嶼山) (James, 1993; Langford *et al*., 1995). A similar seismic unit identified in eastern waters of Hong Kong (Evans, 1993) is possibly a lateral equivalent of the Sham Wat Formation (Fyfe & James, 1995). The deeply eroded nature of the basal surface of the overlying Hang Hau Formation in eastern waters does not allow the unit to be mapped with any degree of certainty. Therefore, because continuous mapping is not possible between the two areas, there remains the possibility that this eastern unit may represent an older formation (Owen *et al*., 1998).

The Sham Wat Formation is wholly intertidal to marine in origin. Although the underlying Chek Lap Kok Formation contains some intertidal and possibly marine sediments, the Sham Wat Formation has yielded a fauna that unequivocally indicates a marginal marine to marine environment of deposition.

Type section

The type section of the formation is borehole ESC17 (James, 1993; Langford *et al*., 1995), near the island of Sha Cha (沙洲), north of the village of Sham Wat (深屈) on Lantau Island (大嶼山) (Figure 8.2). There the sequence comprises 17 m of sand, silt and clay. The formation overlies the Chek Lap Kok Formation and is itself overlain by 10.2 m of soft clayey silt of the Hang Hau Formation.

In the type section, the formation comprises dominantly soft to firm silty clay, medium grey in colour with pale yellowish grey oxidized bands, creamy patches

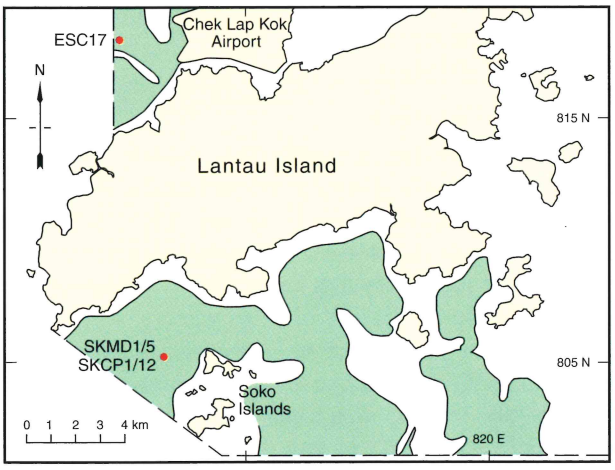


Figure 8.1 - Extent of the subcrop of the Sham Wat Formation in western waters of Hong Kong

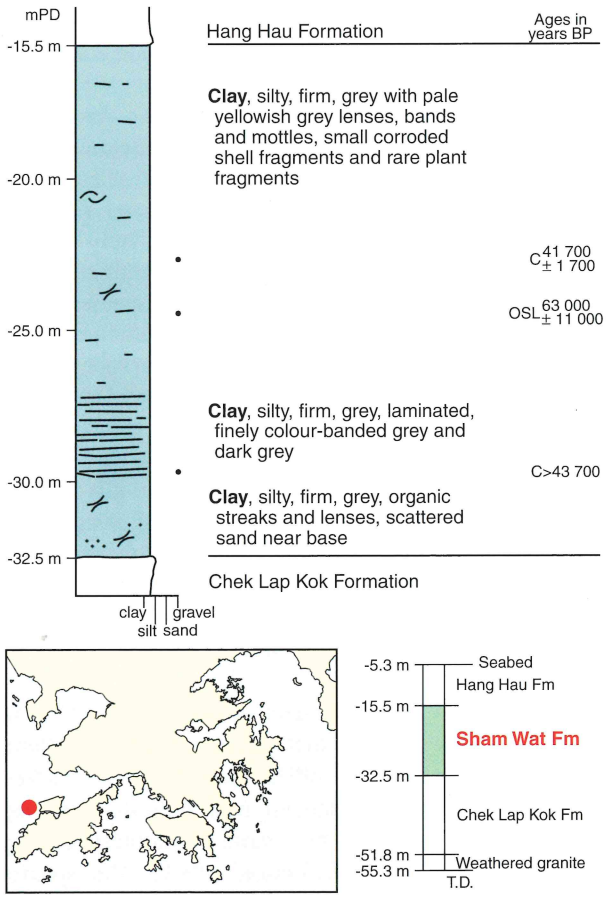


Figure 8.2 - Details of the Sham Wat Formation in borehole ESC17 (see Figure 5 for key to symbols)

and sparse mottles. Some of these bands contain hard nodules. Corroded shell fragments occur throughout the formation. These are commonly less than 2 mm across and usually soft and friable, so that species identification is difficult. Disarticulated bivalves, up to 6 mm across, are also preserved, as are sparse plant fragments. At the base of the formation, the sediment is dominantly very fine to fine sand, which grades upwards into interbedded silty clay and sand. Thin streaks of dark organic material are recorded near the base of the formation. Minor concentrations of black sulphides occur throughout the sequence.

X-ray diffraction studies have shown that the sediment mineralogy is dominated by kaolinite, smectite and mica (Kemp, 1993). Silt-grade quartz also occurs with traces of feldspar, calcite and pyrite. In places, authigenic pyrite replaces carbonaceous fragments (Merriman & Prior, 1993).

The spores in the Sham Wat Formation are generally dominated by fern species such as *Pteris* and *Alsophyla* types with broad-leaved evergreens such as *Castanopsis*, *Liquidamber* and *Quercus* (Jolley, 1992). The ferns and broad-leaved evergreen plants appear to occur in inverse proportions throughout deposition of the Sham Wat Formation (Figure 8.3). Mangrove pollen such as *Rhizophora* and *Acrostichum* are present in small quantities, though *Sonneratia* appears to be absent. It can be inferred that although subtropical forest pollen was washed into the area, the environment was not conducive to colonization by mangroves.

Foraminifera and ostracods are sporadic throughout the type section (Wilkinson, 1992, 1993). Below around -25 mPD the sediments are devoid of microfossils. Above that depth, the number of foraminifera and ostracod species increases (Figure 8.3). Immediately above -25.3 mPD, the foraminifera are dominated by *Quinqueloculina seminulum*, with several species of the genus *Elphidium*. *Ammonia beccarii* is common between -22.8 and -20.8 mPD, with sparse *Elphidium* species. The interval -19.8 to -17.8 mPD shows a marked increase in abundance and diversity, suggesting a change from shallow (<20 m) brackish waters to somewhat deeper marine waters. The foraminiferal test size in this interval is small, indicating that individuals matured quickly, and implying a near-optimal environment for foraminiferal development (Wilkinson, 1992). Above this depth, the *Ammonia beccarii–Elphidium* spp association again reasserts itself, suggesting a return to hyposaline shallow water conditions.

The fluctuating environment shown by the ostracod fauna is broadly similar to that shown by the foraminifera. Immediately above -25 mPD, however, a marked abundance of ostracod species may indicate changing environment leading to rapid colonization by opportunistic species (Wilkinson, 1993). The species diversity initially decreases before increasing slowly, achieving the *crispata/bisanensis* assemblage (Zhao *et al.*, 1985). Below -19.8 mPD, the fauna belongs to the

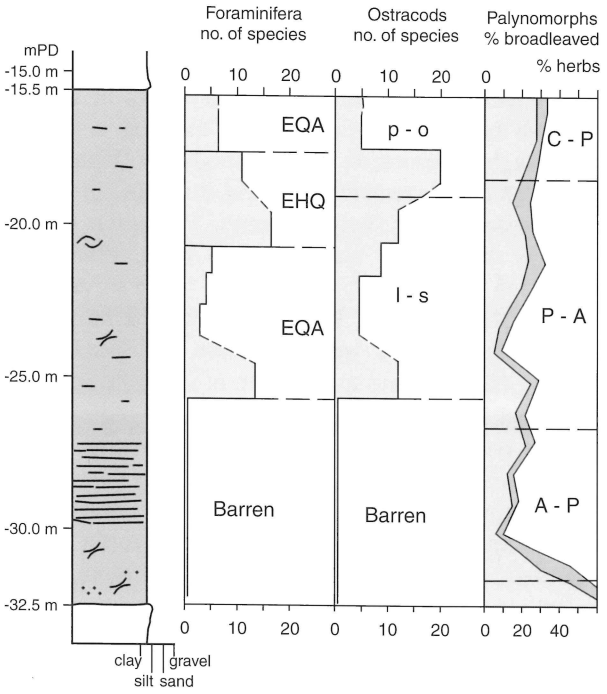


Figure 8.3 - Faunal and palynological assemblages in the Sham Wat Formation in borehole ESC17

Sinocytheridea latiovata/S. longa/Sinocythere spp sub-assemblage, implying brackish water of depths less than 20 m. At -17.8 mPD, a sudden increase in diversity places the fauna within the *Copytus postersulcus/Hemikrithe orientalis* sub-assemblage (Zhao *et al.*, 1985), implying fully marine conditions with a water depth of between 20 and 50 m. Species diversity declines rapidly above this level, indicating a return to brackish water.

The Sham Wat Formation in its type section appears, therefore, to have been deposited initially in an estuarine environment which became fully marine for a period before returning to estuarine conditions. The presence at -17.8 mPD in the borehole of foraminifera and ostracods favouring water deeper than 20 m suggests that at its maximum incursion, sea level would have been slightly higher than today.

Seismic character

The formation has a distinctive seismic character (Figure 8.4), which has facilitated its mapping in western waters and its identification in the east. The character is not unique, however, and elsewhere the Pok Liu Member of the Hang Hau Formation has a similar appearance on seismic profiles.

The base of the formation is represented by a strong reflection with a distinctive undulating form that in part defines the seismic character. This basal surface is commonly deeply incised into the underlying Chek Lap Kok Formation as a series of channels (Figure 8.4). The interfluves between the channels exhibit a distinctly planated crest, representing the remnants of an older

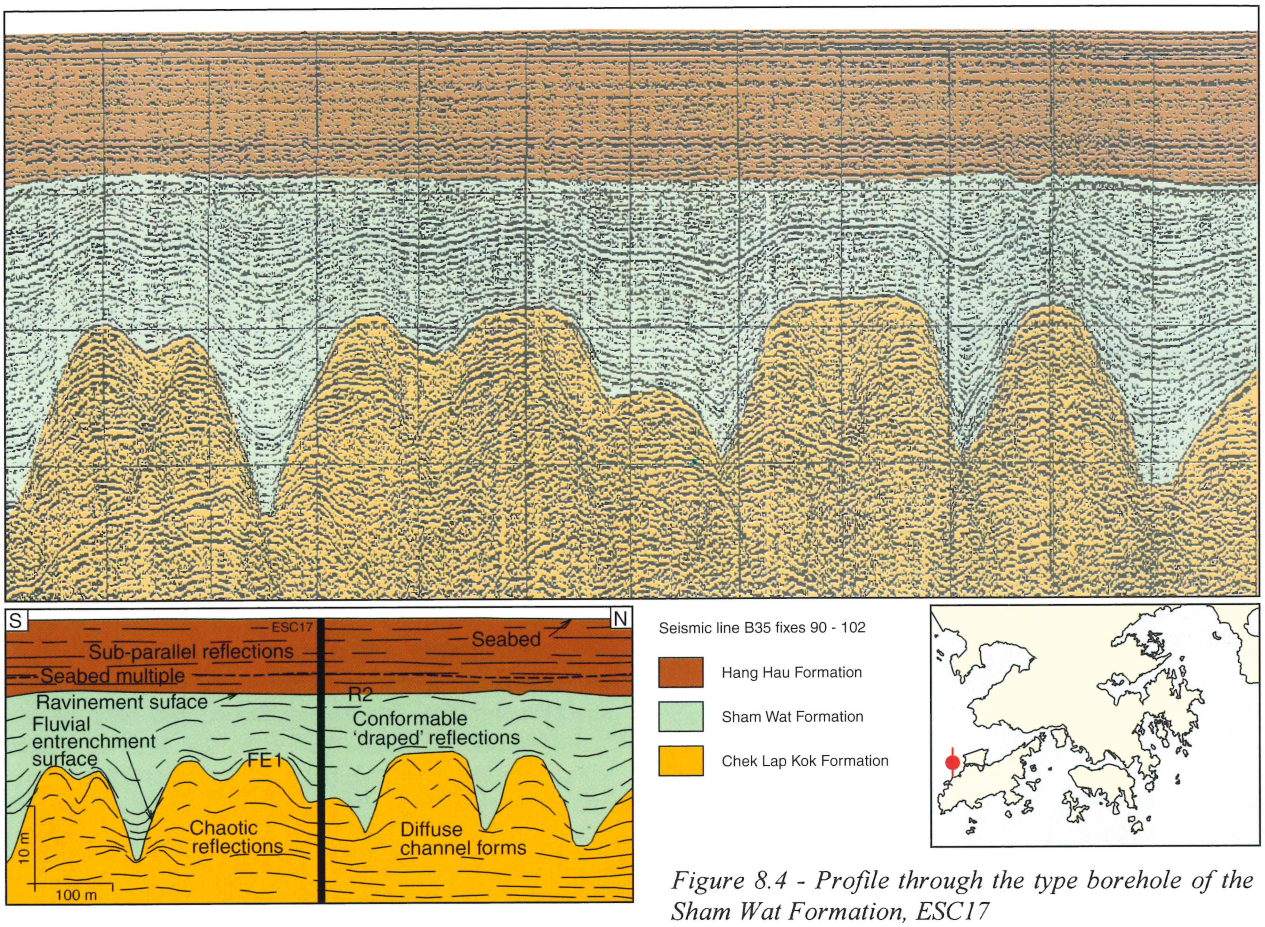


Figure 8.4 - Profile through the type borehole of the Sham Wat Formation, ESC17

erosion surface. This planar surface dips to the south and west. Individual channels are up to 100 m across, 12 m deep and are characterised by steep (15-20°) sides. They usually appear to have a symmetrical U- or V-shaped profile, although the true shape of the features with steeply dipping surfaces is distorted on seismic sections (Evans *et al.*, 1995).

The intra-formational reflections are of low to moderate amplitude and their geometry is controlled by the morphology of the channels. The reflections are continuous, sub-parallel to the planated crest of the interfluves and drape down into the deeper channels. In some areas, a stronger reflection with a geometry that mimics the basal surface occurs within the sequence. At the top of the sequence, the internal reflections are truncated by the reflection marking the erosional base of the overlying Waglan or Hang Hau formations.

Where the formation is thin, the intra-formational reflections may be poorly developed. In such cases, it is possible to confuse the Sham Wat Formation with the Pok Liu Member of the Hang Hau Formation, which also usually has an irregular channelled base. Resolution of this problem can be achieved by close examination of the stratigraphical relationships along the same profile. Moreover, in some areas the upper part of the Chek Lap Kok Formation may include channel features; these can usually be differentiated from Sham Wat Formation channels by the different intra-formational reflection style and the lower amplitude of the basal reflection.

The upper surface of the Sham Wat Formation is normally a low-angled unconformity overlain by the Waglan or Hang Hau formations, though in the deepest troughs, west of the Soko Islands (索罟群島), the succession may be disconformable. In the southwest, an intensely weathered layer occurs at the top of the formation. The presence of similar weathered horizons in other areas where pre-Hang Hau Formation erosion was minimal, cannot be discounted. A comparison of the intra-formational reflection over the interfluves and in the channels indicates that in places more than 10 m of sediment from the Sham Wat Formation has been eroded (James, 1993).

Stratigraphical and regional lithological variations

The Sham Wat Formation has been penetrated by several boreholes in western Hong Kong waters. North of Lantau Island (大嶼山), it has been drilled in many of the boreholes in the western part of the new airport site.

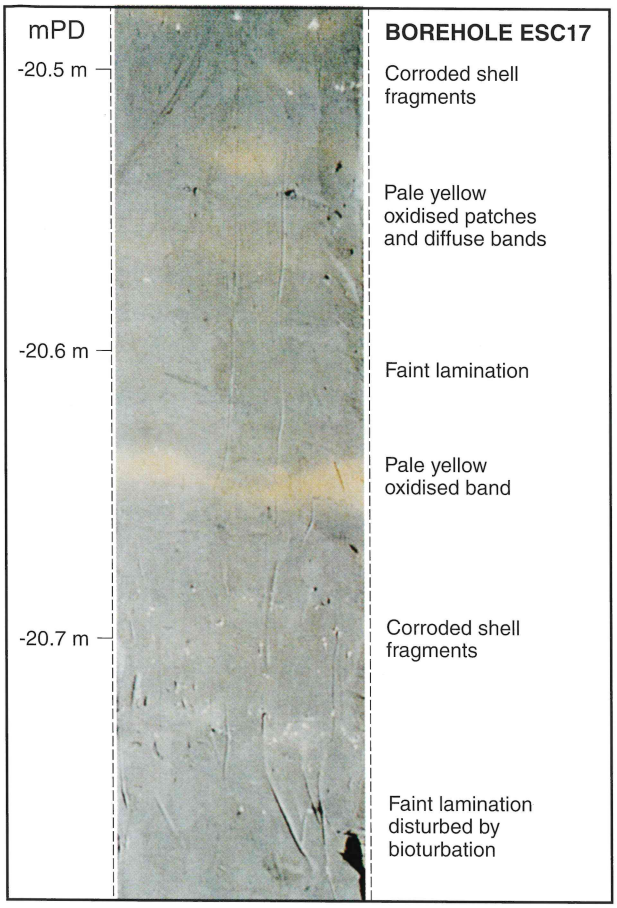


Plate 8.1 - Core from the Sham Wat Formation in borehole ESC17

South of Lantau Island, it occurs in several boreholes around the Soko Islands (索罟群島). The sediments are mainly soft to firm silty clays, grey in colour with bands of yellowish grey mottling (Plate 8.1). In some cases, the mottling is more intense and nodules occur at the centre; these are usually soft. Shells and shell fragments are rare and often corroded, having a chalky texture.

Around the Soko Islands, the formation has also been penetrated in cone penetrometer tests (CPTs). One such test, SKCP1/12, was carried out just 16 m south of the site of borehole SKMD1/5, which allows a correlation to be made (Figure 8.5). The Hang Hau Formation here contains sand bands that are reflected in the upper part of the CPT profile. The Sham Wat Formation is marked by a gradual increase in pore pressure with depth. At the base of the upper unit, the CPT profiles suggest the presence of thin sandy horizons.

The dramatic fall in pore pressure and increase in tip resistance at -40 mPD indicate a clean, well-sorted sand horizon, which is not recorded in the borehole. It may, however, correlate with a sandy unit at the base of the borehole. The seismic profiles in this area are masked by acoustic turbidity and the nature of the base of the formation is unknown. However, the lack of direct correlation by depth suggests that the sites of the borehole and CPT may be located on a channel wall that slopes at around 5° northwards (Figure 8.5 inset).

In addition to the type borehole, ESC17, the formation has been intersected in boreholes HKGS-C, B2/1 and A5/1 in the west, and HKGS-A in the east (Figure 8.6). In none of these boreholes, however, were the microfossils as abundant or diagnostic as in borehole ESC17.

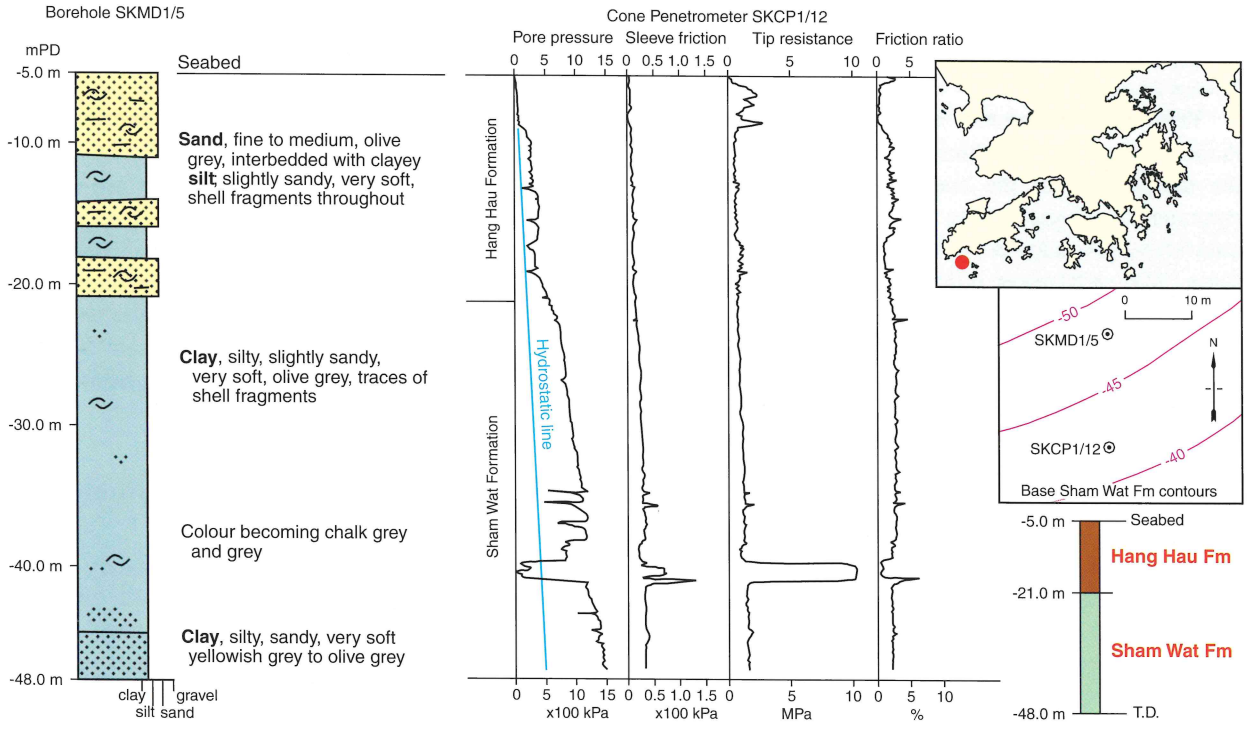


Figure 8.5 - The Sham Wat and Hang Hau formations in borehole SKMD1/5 and cone penetrometer test SKCP1/12

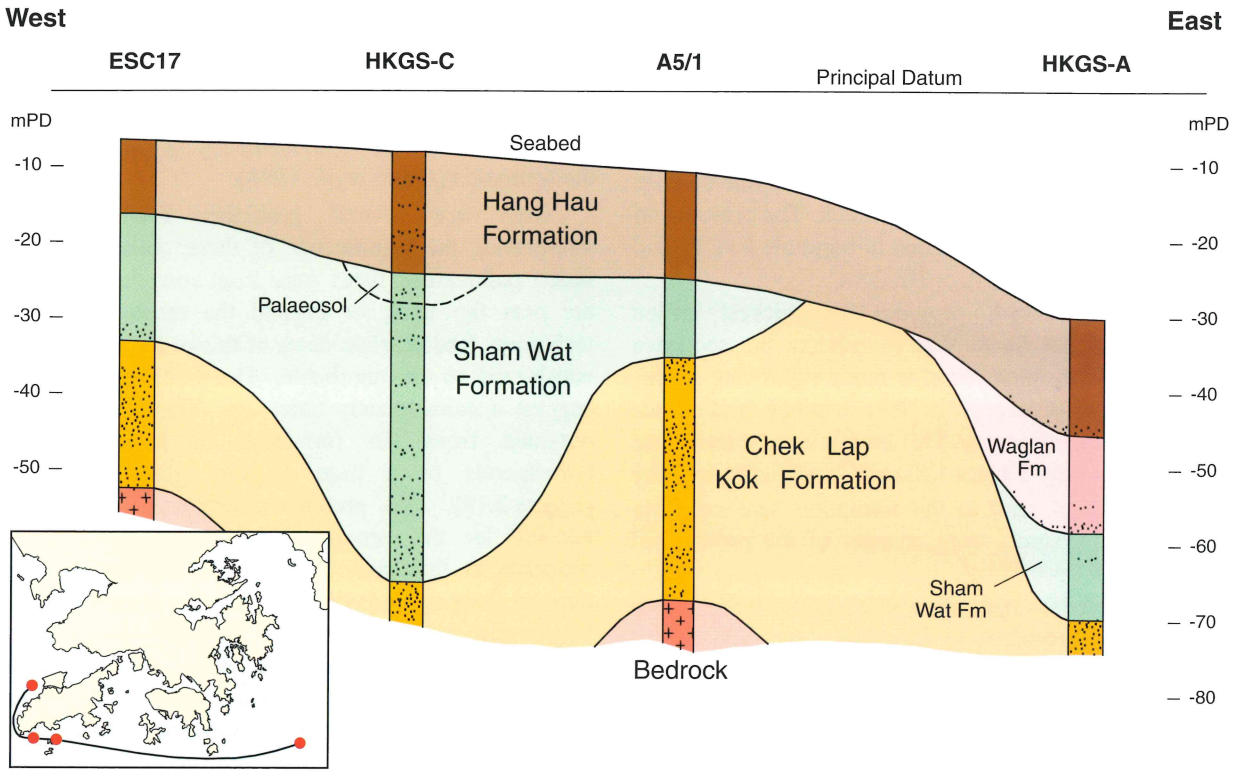


Figure 8.6 - Correlation of the successions in boreholes ESC17, HKGS-C, A5/1 and HKGS-A

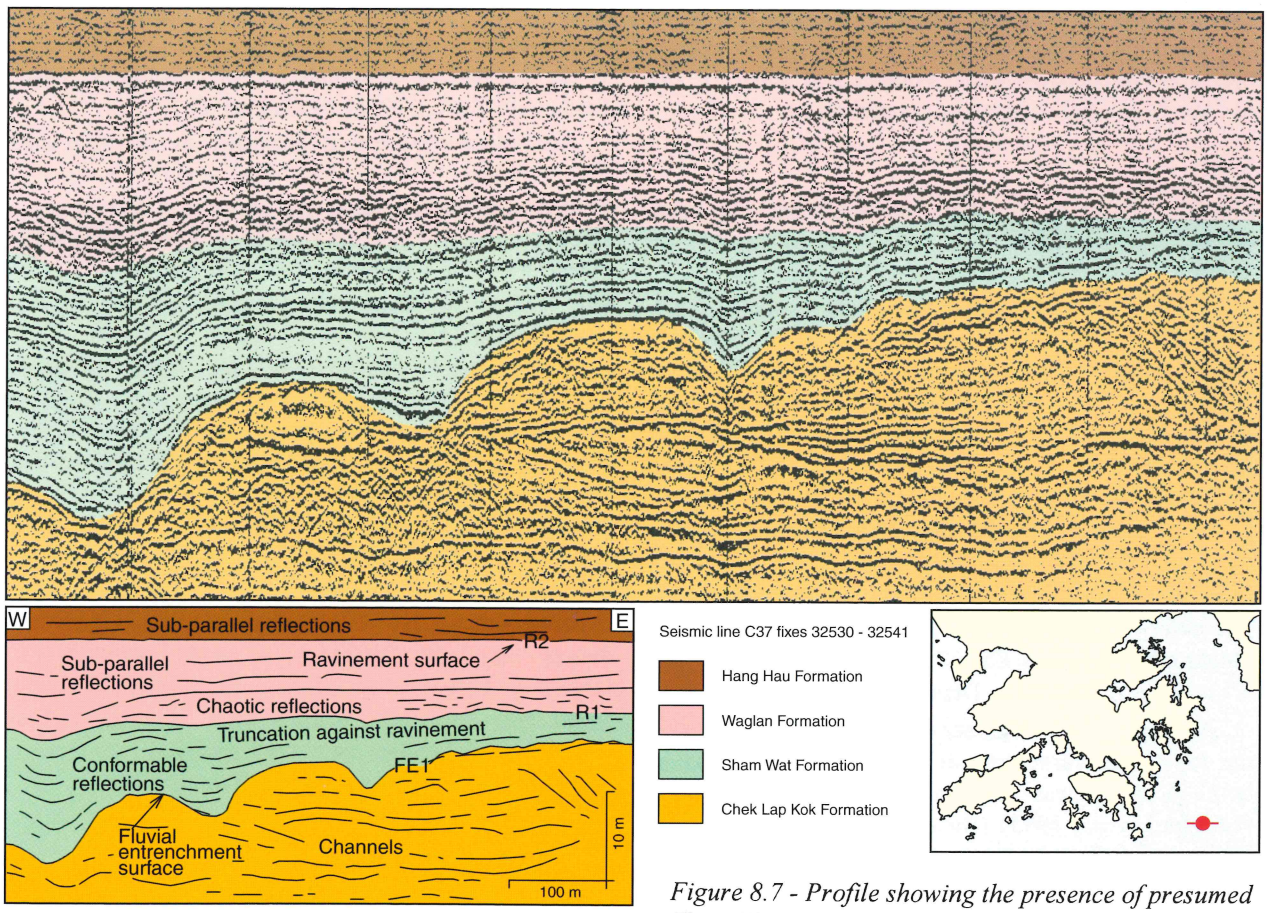


Figure 8.7 - Profile showing the presence of presumed Sham Wat Formation in eastern waters of Hong Kong

In borehole A5/1, located about 200 m southeast of the feather edge of the subcrop, the formation is 10.4 m thick. The basal part comprises clayey fine sand with organic remains; a 60 mm thick peat layer is present 0.5 m above the base. Other peaty horizons occur above this, often associated with the presence of fine sand in lenses and thin bands up to 4 mm thick. The presence of plant fragments is also recorded in borehole ESC17 and B2/1, but not in HKGS-A or HKGS-C.

Borehole HKGS-C provides the thickest drilled occurrence of the Sham Wat Formation, the sequence being over 40 m thick. Sand is more significant in this borehole, and it occurs in thin laminae and bands throughout the entire core. This borehole is located close to the present-day Lantau Channel (大嶼海峽) and the predominance of sand in the formation here probably reflects the proximity of a channel of the proto-Pearl River (珠江).

In borehole HKGS-C, the upper 4 m of the Sham Wat Formation is weathered to an ochrous red colour. The weathered horizon is dominantly a silty sand displaying crude horizontal colour banding in cream, ochre and red; scattered patches of intense weathering can be seen. The sediments include some lenses of reddish brown silty clay. In its upper part, the section is less sandy.

In borehole HKGS-A, in the east, the formation lies beneath Late Weichselian sediments of the Waglan Formation (Figure 8.7). The sediments comprise firm silty clay, and are grey with diffuse and banded yellowish grey mottling. Some mottled areas occur around buff to brown coloured concretions. Pockets and lenses of silt and very fine sand occur throughout the core.

Age

The age of the Sham Wat Formation has not been confidently established (see Table 5.2). A number of corroded shells and wood fragments have been age-dated using radiocarbon methods (Figure 8.2). A shell from a depth of -55.48 mPD in the formation in borehole HKGS-A has yielded a date of >43 860 years BP (Beta Analytic / Oxford Radiocarbon Laboratory) and luminescence dating of sediments from -70.01 mPD in the same borehole gave a date of 94 000 ± 16 000 years BP (Riso, Denmark). In borehole ESC17, shell samples occurring at levels of -24.8 mPD and -17.8 mPD yielded ages of >43 700 and 41 700 ± 1 700 years BP respectively (Langford *et al.*, 1995) (Oxford Radiocarbon Laboratory). Luminescence dating of sediments from -24.45 mPD borehole ESC17 yielded a date of 63 000 ± 11 000 years BP (Riso, Denmark).

A sample of wood, preserved in a peaty horizon near the top of the formation, at a level of -25.6 mPD in borehole A5/1, was dated at 19 580 ± 320 years BP (Langford *et al.*, 1995) (Beta Analytic). Luminescence dating of sediments from -24.65 mPD in the same borehole gave a date of 11 283 ± 1 567 years BP (HKU Radioisotope Unit), whereas sediments obtained from -32.20 mPD, also dated by luminescence, yielded an age of 60 000 ± 6 000 years BP (Riso, Denmark). In addition, in borehole B2/1, a date of 20 760 ± 480 years BP was obtained from a wood fragment at -24.2 mPD, immediately below the base of the formation (Owen *et al.*, 1998).

There are several problems associated with interpreting the significance of these dates. The three oldest radiocarbon dates were from corroded shells and are near the limit, or beyond the resolution, of the technique. Radiocarbon dates of this order are generally considered to be unreliable. The luminescence dates suggest a considerately older age. The youngest date, obtained from the formation in borehole A5/1, corresponds to a time of low global sea level (Figure 2.14). This presents a practical difficulty, to account for the deposition of a dominantly marine sequence at this time. However, if the fragment was derived from older sediments, then the formation could be younger than the contained fragment. Based on this reasoning, and the similarity of seismic character, Owen *et al.* (1998) proposed that the formation in western waters is younger than in the east and represents an earlier phase of the Pok Liu Member of the Hang Hau Formation. The date obtained from below the formation in borehole B2/1 also suggests that the formation was deposited within the last 20 000 years, representing a Late Pleistocene rapid aggradational phase (Shaw & Fyfe, 1992). Alternatively, all the dates could be erroneous if the dated materials have been contaminated by the introduction of modern carbon (Yim *et al.*, 1990; Toscano & York, 1992) (see Chapter 4).

Additional evidence is provided by the sequence stratigraphical relationships. The erosion preceding deposition of the formation has been interpreted as taking place at a time of fluctuating sea level. This fluctuation is characterised by a rising sea level interrupted by a rapid fall, leading to down-cutting associated with fluvial entrenchment.

Foraminiferal analysis in the type borehole (Wilkinson, 1992) suggests a maximum water depth of around 20 m. This represents a sea level slightly higher than that of the present day. James (1993) inferred that erosion of the upper part of the formation during the Holocene transgression has removed up to 10 m of sediment, based on this and the extent of weathering, and thus regarded the formation as a pre-Holocene deposit. Because global sea level curves did not reach this level during the Late Weichselian stadial periods (see Chapter 4, Figure 4.14), James (1993) inferred that the Sham Wat Formation is older than Weichselian and proposed an Eemian age, corresponding to oxygen isotope stage 5e (Chappell & Shackleton, 1986).

Depositional environment

The fine-grained nature of the Sham Wat Formation sediments, its lithological similarity to the Hang Hau

Formation, and the nature of the macro- and microfossils, indicate that the formation was deposited in a predominantly marine environment. Microfaunal analyses in borehole ESC17 (Wilkinson, 1992, 1993) suggest alternation of brackish and marine water, and the environment of deposition is interpreted as marginal marine, probably estuarine.

The age and mechanism of the erosion (surface FE1) at the top of the Chek Lap Kok Formation are matters of some debate. Two main phases of erosion have been recognized: the original planation of the gently dipping surface and the subsequent deep incision of channels into this surface. Planar erosion surfaces may be associated with rising sea level or stillstands (Posamentier & James, 1993), or, less likely, with falling sea level (Nummedal *et al.*, 1993). Rising sea level is known to produce shoreface erosion, in the form of a ravinement surface (Swift *et al.*, 1991). This mechanism is inferred for the planar surface north of Lantau Island, which dips to the west at 0.25°.

Conversely, incised channels are normally formed by rapid downcutting during a fall in sea level (Wood *et al.*, 1993) or during a period of fluvial entrenchment. Incision may also occur during sea level rise or stillstand where stream discharge increases or stream sediment load decreases significantly (Posamentier & James, 1993).

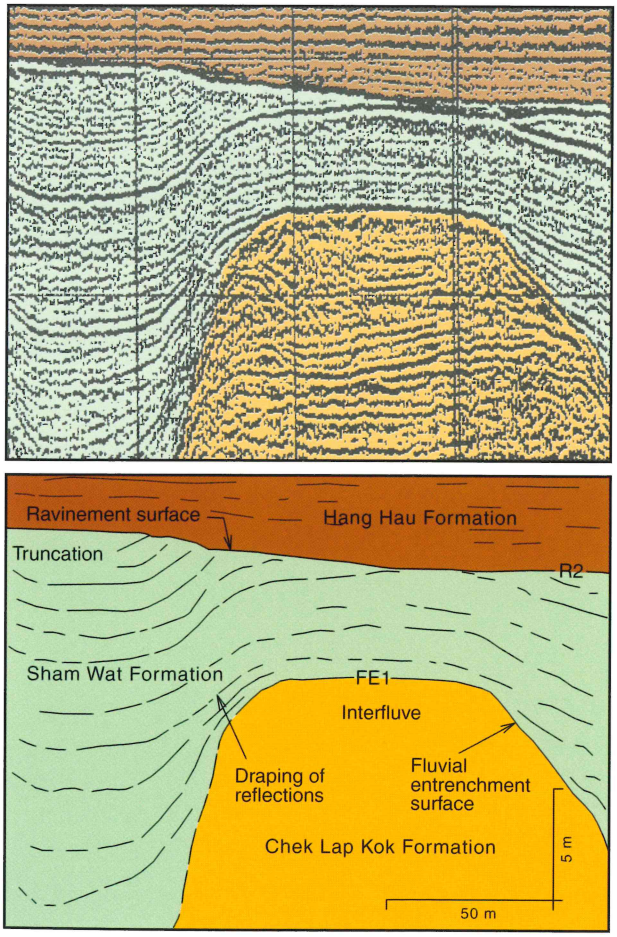


Figure 8.8 - Detail of thinning reflections and consolidation pattern in the Sham Wat Formation

The discharge and sediment load of the proto-Pearl River (珠江) during this period are unknown. In Hong Kong, the valley incision immediately followed the planation event and, therefore, rapid downcutting during a fall in sea level seems the most likely mechanism.

The evolution of the FE1 surface at the base of the Sham Wat Formation is therefore interpreted as having been caused by an initial rise in sea level, associated with planation and minimal marine sedimentation. This was followed by a fall in sea level during which channels were incised. These two phases of erosion were followed by a further rise in sea level allowing sedimentation of the brackish-water and marine sediments.

The draped intraformational reflection pattern of the Sham Wat Formation possibly indicates post-depositional consolidation. This mechanism is supported by the observed thinning of reflectors over channel margins (Figure 8.8) and a degree of consolidation present in these sediments. Compaction may not be the sole factor, however, and the reflection pattern may also represent a primary depositional structure.

The creation of draped reflectors as a primary structure can be related to a number of factors such as water depth, sediment load and sedimentation rate. McKee (1957) identified three modes of channel-fill, characterised by horizontal, conforming and asymmetrical layering (see Figure 2.11). The Sham Wat Formation corresponds to the second mode, which can be attributed to the filling of completely submerged channels. The Sham Wat Formation differs from McKee's model in that the layers above the level of the channel margins also conform with the channel. This latter effect can be attributed to compaction of the sediments. The reflection pattern is thus taken to represent a combination of post-depositional compaction and the response to rapid sedimentation in a submerged channel.

The presence of brackish-water microfossils in the lower and upper parts of the sequence in ESC17 suggests that the channel erosion was followed by an estuarine phase in this area. Rapid rise in sea level led to submergence of the channel system, followed by deposition of marine sediments. Estuarine conditions then re-established, possibly as a result of falling sea level, or in response to a prograding shoreline.

A continued fall in sea level resulted in emergence of the marine mud. The subaerial exposure allowed a weathered horizon at the surface and oxidation within the formation. Such profiles may develop over a relatively limited period of a few thousand years (Turner, 1980). Corrosion of carbonate shell fragments may have occurred during this period of emergence, or by partial dissolution at depth during later burial of the sediments. The formation therefore represents a period of rapidly rising and falling sea level, terminating in a prolonged fall with subaerial exposure of the sediments. Erosion by subsequent transgression has removed the upper part of the formation in the west and, elsewhere, the entire formation.

9. Waglan Formation

The Waglan Formation is mainly recognized in the deeper southeastern part of Hong Kong waters, where a thicker, more complete Late Pleistocene succession is developed. The formation is considered to be Weichselian in age, deposited during an interstadial rise in global sea level. Stratigraphically, the formation occurs above the Chek Lap Kok and Sham Wat formations and below the Hang Hau Formation. Originally, the formation was considered to be a transgressive facies of the Hang Hau Formation (Shaw, 1990a; Strange *et al.*, 1990). Additional seismic interpretation and analysis of borehole HKGS-A has suggested that the 'dense basal unit' and the 'upper transparent unit' should be assigned to a separate formation.

On seismic profiles, the formation appears as two distinct units. The lower unit is characterised by a high-amplitude basal reflection and a chaotic internal reflection pattern, and the upper unit by sub-parallel, low-amplitude reflections.

The formation has been penetrated by a number of boreholes, which confirm the presence of two lithological units. The lower unit comprises a layer of sand, generally 2 to 3 m thick, overlying a ravinement surface (R1). The upper unit comprises interbedded fine sand and silty clay, ranging in colour from medium grey to very dark grey. Shells and shell fragments are found throughout the sediments, though these are largely corroded.

The Waglan Formation sediments were deposited initially as shoreface sands that were subsequently reworked as an inner-shelf sand sheet in a sub-littoral to marine environment.

Type section

The Waglan Formation is formally defined here. The type section was recovered in borehole HKGS-A, near Waglan Island (Figure 9.1). The formation here consists of a 7 m sequence of interbedded sand and clayey silt overlain by 3 m of firm clayey silt. It overlies the Sham Wat Formation and is in turn overlain by 14.9 m of basal sand and clayey silt of the Hang Hau Formation.

The formation has an erosive base, ravinement surface R1, which is immediately overlain by a basal unit of interbedded shelly sand and clayey silt, comprising silty fine sand with pockets and lenses of clayey silt. These sediments, designated the 'basal sand', are succeeded by sand with minor clayey silt interbeds, the sand beds becoming thinner upwards through the section. Plant and shell fragment are common. This is overlain by firm grey clayey silt with lenses of coarse silt to very fine sand, and these sediments are designated as the 'marine mud'. Shell fragments are common, though largely corroded. Bioturbation, dominantly in the form of sub-vertical burrows, also occurs.

The majority of foraminifera in borehole HKGS-A are benthonic shelf species (Twiddy, 1994), with the

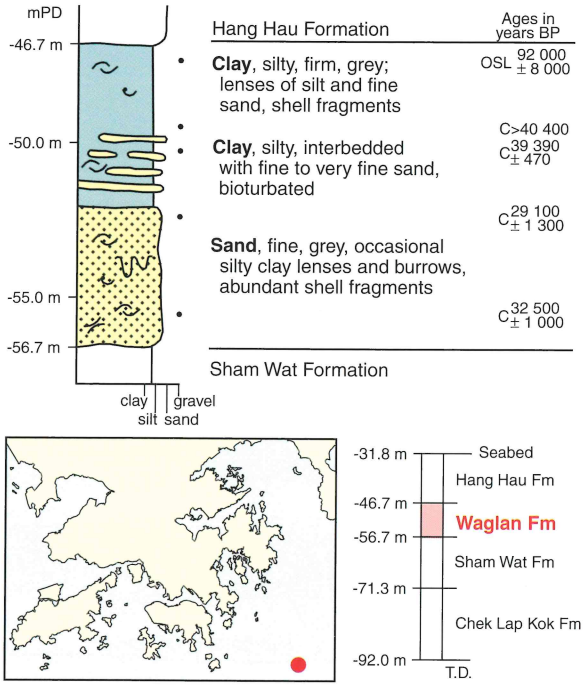


Figure 9.1 - Details of the Waglan Formation in borehole HKGS-A

exception of *Globigerina* spp, oceanic planktonic forms, which occur in the basal sand. The upper unit has yielded several shelf species, including *Quinqueloculina* spp and *Nonion* spp and inner shelf species such as *Elphidium* spp and *Ammonia becarii*. The shelf species generally decrease in dominance upwards through the core.

No diatoms have been recovered from the Waglan Formation sediments in this borehole (Wright, 1995). It is possible that their absence is a result of sub-aerial exposure causing dissolution of silica, but a corresponding absence of diatoms in the lower part of the overlying Hang Hau Formation suggests that the environment could be one of low productivity.

Radiocarbon dating of marine shells from the Waglan Formation in borehole HKGS-A has yielded two finite ages: 32 500 ± 1 000 years BP from a level of -55.7 mPD and 29 100 ± 1 300 years BP from a level of -52.4 mPD (Oxford University Radiocarbon Accelerator Unit). Minimum ages of >39 390 years BP and >40 400 years BP were obtained from -49.37 mPD and -50.15 mPD respectively (Beta Analytic).

Seismic character

The formation has a seismic character very similar to that of the overlying Hang Hau Formation (Figure 9.2). The base of the formation is normally represented by a high-amplitude planar reflection, succeeded by a chaotic reflection pattern. On some profiles, the basal reflection is absent and is replaced by a simple change in seismic character. The unit of chaotic reflections is succeeded

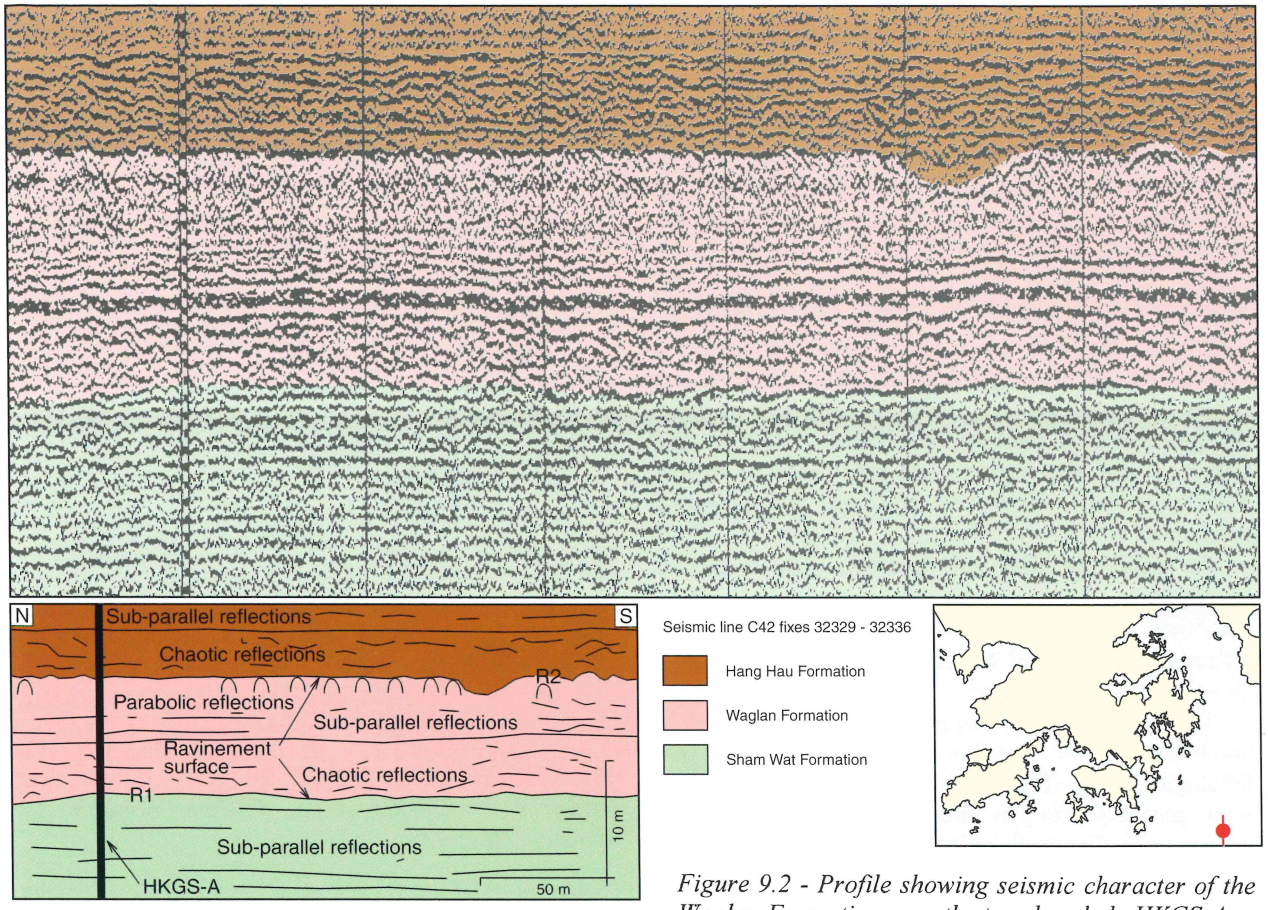


Figure 9.2 - Profile showing seismic character of the Waglan Formation near the type borehole HKGS-A

by one of parallel reflections. These two units represent the basal sand and marine mud respectively.

Reflections in the lower unit are of low to moderate amplitude, generally chaotic but containing packages of impersistent, sub-parallel reflections. The unit does not vary significantly in thickness over the area of subcrop, although the reflections tend to be more chaotic in the north. Intra-formational reflections in the upper unit are generally of low amplitude and are continuous, sub-parallel to the top of the underlying unit. In places, the pattern is complicated by many small parabolic reflections, suggesting point sources, perhaps from shell-rich gravel at the base of the Hang Hau Formation.

The basal ravinement surface, R1, is planar, dips very gently to the southeast, and is around -50 mPD at its deepest in Hong Kong waters. The upper surface of the formation is normally a further low-angled ravinement surface (R2) and is directly overlain by the Hang Hau Formation. Locally, the upper surface of the Waglan Formation is channelled by the erosional events that preceded deposition of the Hang Hau Formation.

Stratigraphical and regional lithological variations

The formation is restricted to the area beneath the deeper southeastern waters. The basal surface dips to the south and east and the thickness of the formation increases in the same direction (Figure 9.3). The basal sand is variable in thickness and does not occur over the whole area, whereas the overlying marine mud is present over most of the area. However, to the north and west the formation is progressively truncated by the lower erosional surface of the Hang Hau Formation (ravinement surface R2).

The formation has been sampled in other boreholes drilled in the eastern waters of Hong Kong, where the basal sand is variably an olive to dark olive grey, fine to coarse, subangular sand with subangular to subrounded fine gravel and shell fragments. The sand characteristically contains pockets of dark greyish silty clayey sand. The marine mud is generally dark to very dark grey, slightly sandy, silty clay, soft in the upper part and becoming firmer downwards. In some boreholes, the silty clay is interbedded with bands of fine sand and pockets of medium to coarse sand. Occasional shell fragments occur throughout the unit; some peat and wood fragments have also been recorded. As these boreholes are at the northern extremity of the subcrop where the upper mud unit is thin, it is commonly difficult to distinguish seismically the top of the sandy lower unit beneath the sandy basal unit of the overlying Hang Hau Formation. Similarly, in the north, where the basal sand is absent, it is often difficult to distinguish the top of the upper mud unit below the base of the overlying muddy formations (Figure 9.4).

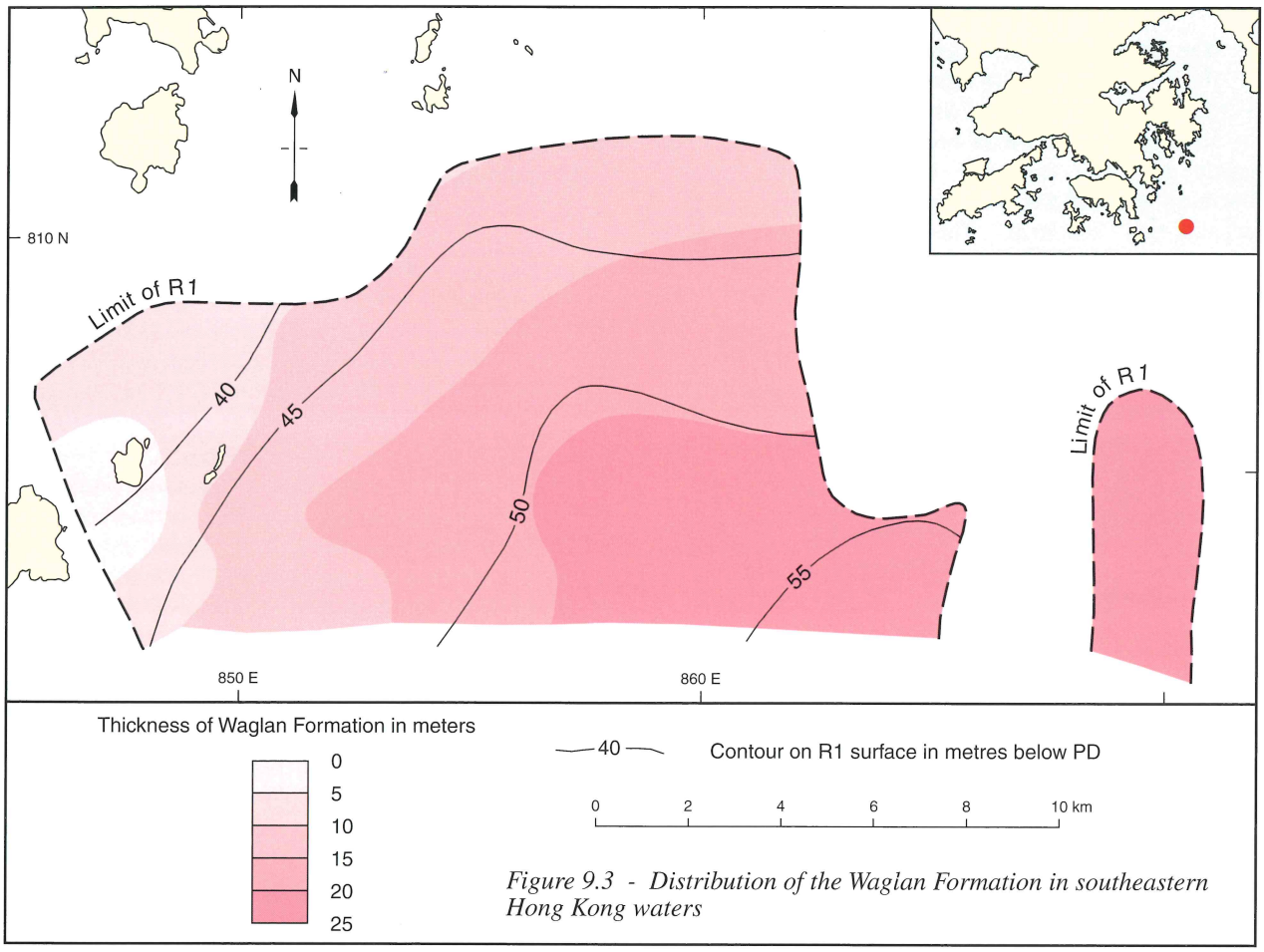


Figure 9.3 - Distribution of the Waglan Formation in southeastern Hong Kong waters

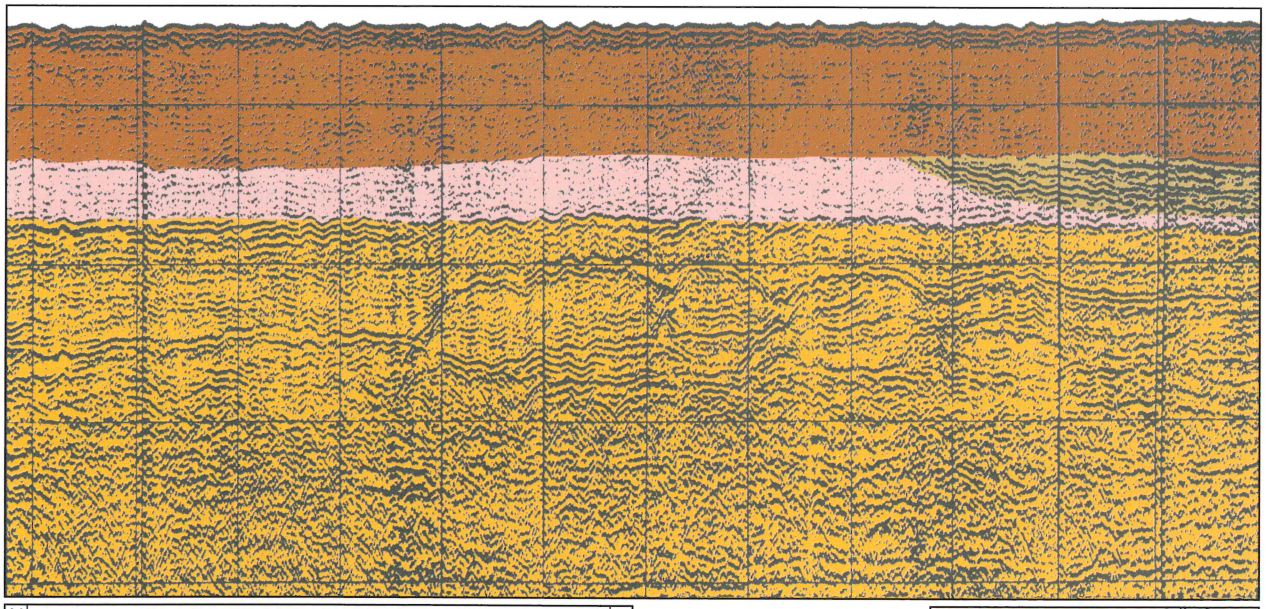


Figure 9.4 - Profile showing seismic character of the Waglan Formation in the north of the subcrop area

The formation is present in borehole C2/2 (Figure 9.5), beneath the basal sand of the Hang Hau Formation. The sediments comprise a 3.5 m-thick bed of olive grey to yellowish brown finely laminated fine sandy silt with corroded shell fragments, mottled horizons and nodules, and occasional pockets of black, organic-rich sediment. This overlies an intensely weathered sand that lacks any shell fragments. Therefore it is thought to be the upper part of the Chek Lap Kok Formation.

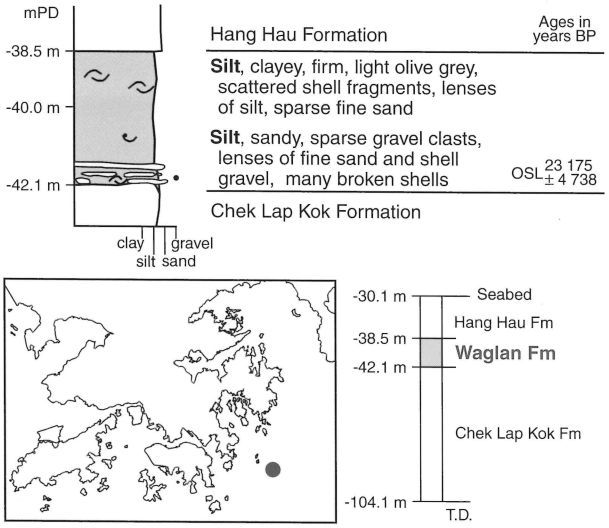


Figure 9.5 - Details of the Waglan Formation in borehole C2/2

Age

The marine character of the formation indicates that sedimentation took place during a high sea level stand. As the sediments overlie the Sham Wat Formation in the southeast, which has been inferred to be Eemian in age (see Chapter 8), the formation may be either a later phase of the Sham Wat Formation or have been deposited during one of the Late Weichselian interstadials.

A Holocene age is ruled out because of the strong erosive event marked by ravinement Surface R2 at the base of the overlying Hang Hau Formation. The radiocarbon dates of 32 500 ± 1 000 and 29 100 ± 1 300 years BP (Oxford Radiocarbon Laboratory) from -53.75 mPD and -50.60 mPD in the type HKGS-A borehole suggest that sedimentation may have been during the last Weichselian interstadial, before the glacial maximum. Alternatively, the dates may have been subject to young age bias (see Chapter 4), as suggested by the minimum radiocarbon ages of >39 300 years BP and >40 400 years BP (Oxford Radiocarbon Laboratory) from -48.35 mPD and -47.57 mPD in the formation in the same borehole. A luminescence date of 92 000 ± 8 000 years BP (Riso, Denmark) from -47.37 mPD in the borehole similarly points to an older age. However, luminescence dating of the sand from the formation at -41.90 mPD in borehole C2/2 gave a much younger date of 23 175 ± 4 738 years BP (HKU Radioisotope Unit) (See Table of dates).

Global sea level curves provide the most compelling evidence for the age of the formation. A maximum sea level of -75 mPD at the 30 000 years interstadial (Chappell, 1994) is inconsistent with a maximum depth of -50 mPD for the base of the formation. It is likely, therefore, that the dates of c. 30 000 years BP do indeed reflect contamination by more recent carbon and that the Waglan Formation was laid down in an earlier interstadial. The high sea level stand at around 80 000 years (see Figure 2.14) is the most likely possibility as sea level was then only 30 m below that of the present day.

Depositional environment

The lithological similarity of the Waglan Formation to the Hang Hau Formation in this area (see Chapter 10) and the macro- and micro-fossil assemblages indicate that the formation was deposited in a marine environment.

The planar nature of the basal surface of the formation and its unconformable relationship with the underlying formations indicate a period of relatively strong erosion. In sequence stratigraphical terms, the surface is a ravinement (R1), formed during transgression (Suter *et al.*, 1987). The immediately overlying unit, with its chaotic internal reflections, is taken to represent marine sands associated with shoreface migration and reworking during this transgression. The poor to moderate sorting of these sands and the presence of shell fragments suggest that they could have been deposited initially as beach or offshore barrier sands.

10. Hang Hau Formation

The youngest sediments found offshore are those of the Hang Hau Formation, which is mainly Holocene in age, but may include latest Pleistocene southwest of Hong Kong. The formation has been subdivided into four members: the early channel-filling Tung Lung and Pok Liu members, the locally restricted Kwo Chau Member and the more widespread Tseung Kwan O Member (Table5.2) (Figure 5.2).

The seismic character of the early phases of channel fill is distinguished by a variety of cross-cutting reflection patterns. These are generally truncated and succeeded by a sequence of more monotonous low-amplitude sub-parallel reflections, representing marine shelf deposition. The sediments of the Tung Lung Member comprise mainly very fine to fine sand, while those of the Pok Liu and Tseung Kwan O Members are dominated by clayey silt, ranging in colour from medium olive grey to very dark grey. Shells and shell fragments are found throughout these latter sediments. The Kwo Chau Member comprises muddy, medium to coarse, shelly sand.

The thickness of the formation varies markedly over Hong Kong waters, reaching a maximum of 60 m in the southeast. There, the channels filled by the Tung Lung Member are eroded deeply into the underlying formations (see Map 5) and the Holocene marine transgression is marked by a layer of sand, up to 3 m thick, associated with ravinement surface R2. In areas where the Pok Liu Member channel fill sediments have their maximum development, decomposition of organic debris in the sediment has led to the generation of methane gas. This has resulted in areas of acoustic blanking that mask the reflections on seismic profiles (see Figure 10.10).

The beaches and intertidal, or estuarine, deposits are formed in the coastal and intertidal zones by the marine reworking of fluvially-derived sediments. These features were mapped on the Hong Kong Geological Survey 1:20 000-scale maps using a combination of aerial photograph interpretation and field identification. They were classified as lithological units and distinguished by their mode of formation. In this account, they are interpreted as un-named members within the formation.

The formation as a whole is interpreted as having been laid down during the last post-glacial rise in global sea level, which commenced in the Late Weichselian at around 18 000 years BP. Fluvial entrenchment gave way to deposition of fluvial sediments, particularly in the east. This phase was succeeded by marine inundation of the area, firstly creating mudflats with intertidal channels, then a shallow shelf sea. The nature of this inundation varied in its timing and character across the area.

Type section

The type section of the formation is the continuously sampled borehole JBS1/1A (Strange & Shaw, 1986) (Figure 10.1), drilled close to the village of Hang Hau (坑口), in Tseung Kwan O (將軍澳). There, the formation unconformably overlies the Chek Lap Kok Formation. Interpretation of seismic profiles from the area show that, apart from the basal few metres, the section belongs to the Tseung Kwan O Member.

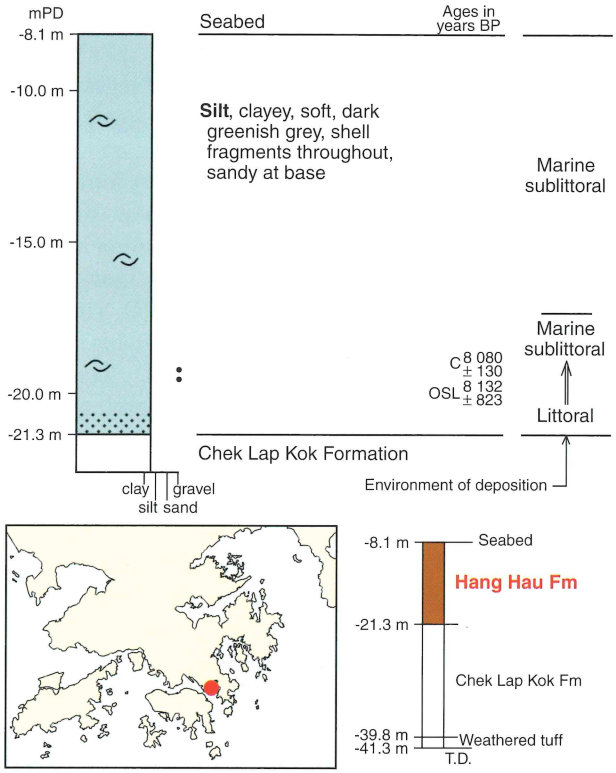


Figure 10.1 Details of the Hang Hau Formation in borehole JBS1/1A

Borehole JBS1/1A penetrates 13 m of dominantly very soft to soft clayey silt, which is dark bluish to olive grey in colour. The type section has a basal sandy unit and the mud is shelly throughout, though shell-rich and shell-free layers up to 1 m thick have been distinguished. The fauna comprises bivalves, gastropods and sparse echinoid fragments.

Palynological analyses from the type section have established the presence of *Lycopodium* and other fern spores in the basal 4 m of the formation (Palaeoservices China Ltd., 1986). There is a notable absence of littoral or marine palynomorphs from this part of the section. The upper 9 m of the sequence is dominated by pollen of *Castonopsis* and *Quercus*, together with conifers and ferns.

The foraminiferal assemblages reveal a dominance of the inner shelf benthonic species *Elphidium hispidulum*, *E. crispum*, *E. advenum* and *Ammonia becarii*. Outer shelf benthonic species are generally rare, though specimens of *Quinqueloculina seminumlina* are fairly common in samples from -19.35 to -14.25 mPD and *Bulimina marginata* from -14.25 mPD and -12.25 mPD. *Quinqueloculina seminumlina* is common in the seabed

sample at -8.25 mPD. Planktonic forms are represented only by rare *Globigerina bulloides* at -12.25 mPD.

Radiocarbon dating of marine shells between -19.50 and -19.88 mPD in borehole JBS1/1A yielded a date of 8 080 ± 130 years BP (CSIRO Australia) (Strange & Shaw, 1986). This date is supported by an OSL date of 8 132 ± 823 years BP (HKU – Radioisotope Unit, 1993). These samples, taken from the intertidal sediments, suggest that sea level was approximately 20 m below that of today at around 8 000 years BP.

Palynological and foraminiferal assemblages in the type section (Strange & Shaw, 1986) suggest minor fluctuations of sea level during deposition of the succession. The basal 3 m were dominated by fern spores and littoral foraminifera, with a diverse ostracod assemblage at -18.25 mPD indicating deposition in fairly well oxygenated inner sublittoral conditions. The succeeding 4 m, from -13.25 to -17.25 mPD, yielded a shallow marine fauna, indicating a high but stable relative sea level. The next 2 m of sediment contained microfossils indicating falling relative sea level, whereas the upper part of the section indicated a return to stable sea level, though at a lower elevation than suggested from -13.25 to -17.25 mPD.

The Hang Hau Formation sediments in the type section therefore appear to have been deposited initially in an intertidal environment, which became increasingly marine as sea level rose during the Holocene. At that time, Tseung Kwan O would probably have lain within the upper reaches of an intertidal channel system leading out through Tathong Channel (藍塘海峽). Changes in micro-flora and -fauna may be a consequence of the opening of the Lei Yue Mun (鯉魚門) channel, leading to circulation of marine water, as well as an increasing influence of the Pearl River (珠江).

Seismic character

The formation has a variable, but highly distinctive, seismic character. Intraformational reflections are generally of low amplitude, suggesting only subtle differences in acoustic impedance that distinguish the sedimentary structures within the formation. The formation has been subdivided into four members. The oldest Tung Lung Member is characterised by channel cut and fill structures, in particular cross-cutting features and prograding channel-fill reflection patterns. The Pok Liu Member exhibits a variety of channel-fill features. These include sub-horizontal bedding, asymmetrical channel fill and conformable bedding. A ravinement surface (R2) truncates the top of these two lower members. The Kwo Chau Member is distinguished on seismic profiles as a unit of chaotic intraformational reflections. The Tseung Kwan O Member generally displays horizontal or sub-horizontal parallel layering, though in some places, well-defined erosional features are evident. In the southeast, the formation is represented by a chaotic layer overlain by a unit of sub-parallel, low-amplitude reflections.

The Tung Lung Member is developed as two discrete channels, one north of Lantau Island (大嶼山), in the west of Hong Kong, and the other in Mirs Bay (大鵬灣), to the east. Both are wide features, though they differ in their basal topography (Map 5). The lower bounding surface of the member is represented on seismic profiles by a strong reflection that marks the base of a major transgressive systems tract. In the west, the member is represented by the 'channel and transgressive deposits' of James (1993). These were identified as filling a proto-channel of the Pearl River (珠江) running through the Urmston Road Channel (龍鼓水道), north of The Brothers (大小磨刀) islands to Kap Shui Mun (汲水門). The Mirs Bay Channel, which is aligned southeastwards on the western side of the bay, was identified by Strange *et al.* (1990), and later described by Cheung & Shaw (1993) and by Evans (1993). Both major channels comprise large-scale, asymmetrical, clinoform reflections.

The Pok Liu Member is characterised on seismic profiles by a strong basal reflection. Where the Tung Lung Member is absent, the base of the Pok Liu Member coincides with the FE2 fluvial entrenchment surface (Figure 5.3). The Pok Liu channels are incised into any of the underlying formations (Map 5). In many cases, the interfluves between the channels are truncated by the strong reflection at the base of the younger unit. The channels are characterised by moderately steep (5–10°) walls and normally display an open U-shaped profile on seismic profiles. Depth of incision of the channelling is minor compared with that observed at the base of the Tung Lung Member.

The intraformational reflections in the channels are generally of low amplitude and exhibit a variety of styles. The most common reflection style is sub-horizontal, onlapping the channel margins (Figure 10.2). In some cases, the basal reflections show a degree of asymmetrical filling (Figure 10.3). Conformable reflection patterns also occur (see Figure 10.8), but they are less characteristic of this formation than of the underlying Sham Wat Formation.

In several areas the channels are associated with acoustic turbidity, a phenomenon that results from the presence of occluded gas bubbles in the sediments (Premchitt *et al.*, 1992) (see Chapter 4). Methane gas is believed to be derived from decaying vegetation, buried either in the channels or on the adjacent intertidal mudflats. Single gas pillars originating from discrete channels are most commonly seen north of Lantau Island (see Figure 10.9), whereas in the West Lamma Channel (西博寮海峽) the gas occurs as a continuous 'plateau' that extends over a much larger area.

In western waters, the base of the Tseung Kwan O Member is normally represented by a strong reflection that truncates the interfluves of the Pok Liu Member as

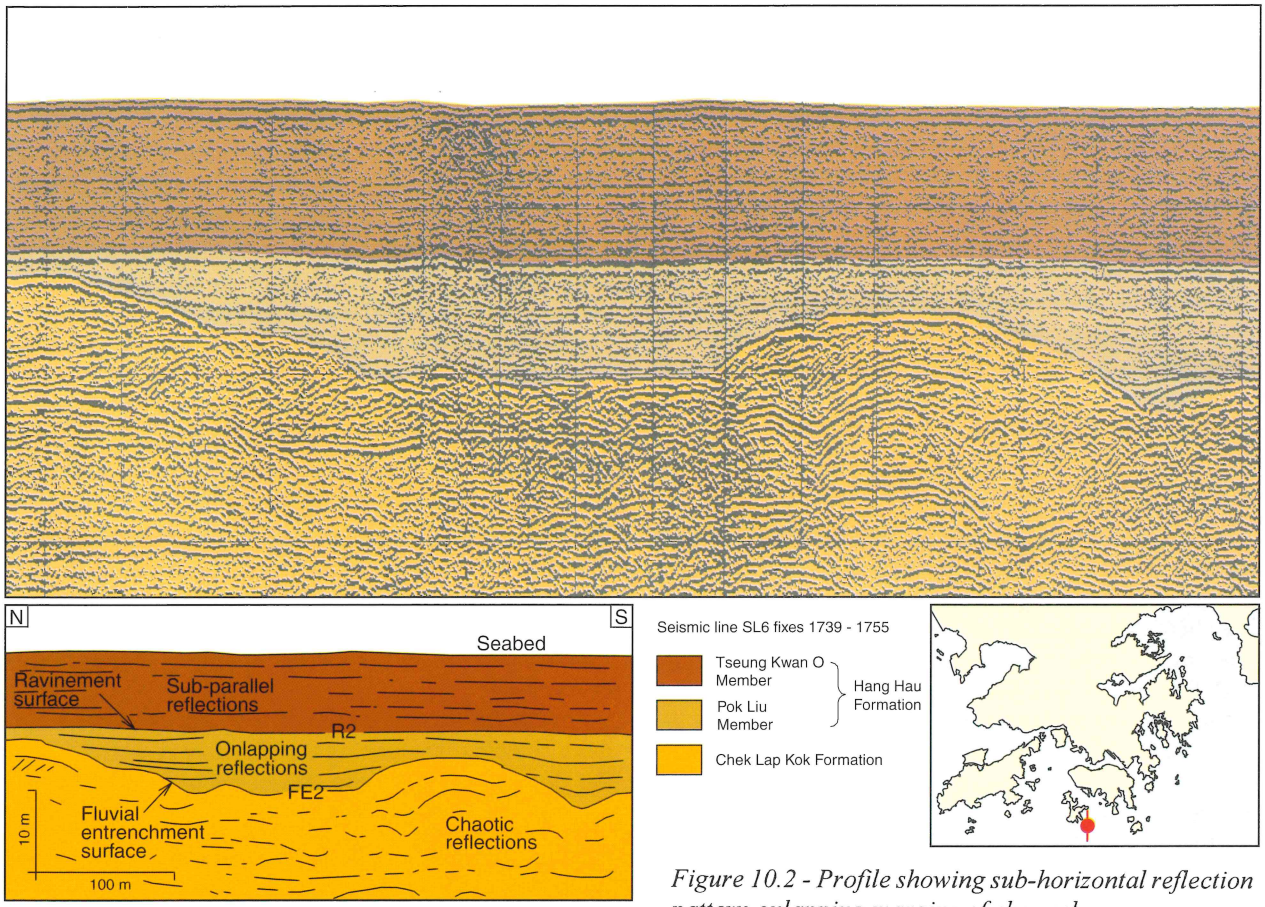


Figure 10.2 - Profile showing sub-horizontal reflection pattern onlapping margins of channel

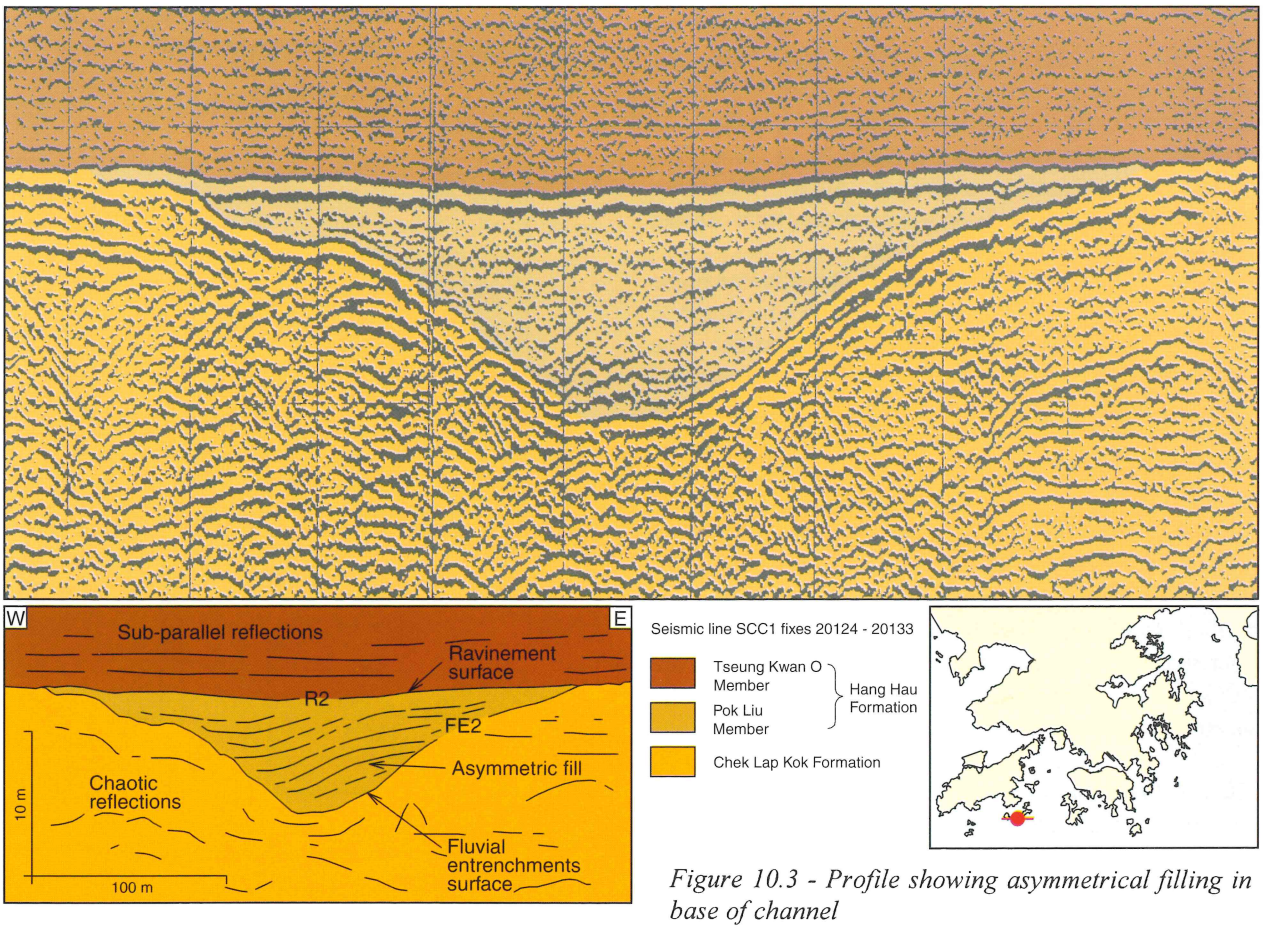


Figure 10.3 - Profile showing asymmetrical filling in base of channel

well as the Chek Lap Kok, Sham Wat and Waglan formations. This major bounding surface is interpreted as a ravinement surface and is labelled R2 (see Chapter 5). In eastern waters, the reflection is immediately succeeded by a horizon of chaotic reflections, interpreted as sand of the Kwo Chau Member. The R2 ravinement surface can be traced as a diachronous planation surface (Fyfe *et al.*, 1999).

The intraformational reflections are generally horizontal to sub-horizontal and of low amplitude. Low-angle truncation surfaces are common, indicating changing hydraulic conditions, probably representing variations in the current regime that occurred during the Holocene sea level rise.

Stratigraphical variation

The Hang Hau Formation comprises four named members that are developed exclusively offshore: the Tung Lung, Pok Liu, Kwo Chau and Tseung Kwan O members. Identification of the four named members, as well as an understanding of stratigraphical variations within them, was carried out using seismic interpretation combined with borehole control. The four members are described here for the first time, and were not previously distinguished on the Hong Kong Geological Survey 1:20 000-scale maps.

Strong tidal currents prevail in several areas of Hong Kong waters and have formed channels. In these generally linear zones, the seabed sediments are sandy. Current velocities have either prevented the deposition of finer, muddy sediments, or have preferentially winnowed the fines from the underlying Chek Lap Kok Formation alluvial sediments leaving a sand or gravel lag. These actively accumulating deposits have previously been depicted as marine sand on the Hong Kong Geological Survey 1:20 000-scale geological maps. They are designated stratigraphically here as un-named tidal channel members of the Hang Hau Formation.

In addition, beaches and estuarine deposits that occur in the coastal and intertidal zones, are here considered to be un-named members within the formation. The distribution and character of these two un-named members were mapped by the Hong Kong Geological Survey using a combination of aerial photograph interpretation and field mapping. The deposits were classified by their genesis, and subdivided on the basis of variations in lithology and age. By virtue of their accessibility during field mapping, they were previously considered, and described in the Hong Kong Geological Survey memoirs, along with the onshore superficial deposits. In this account they are instead assigned to the offshore Hang Hau Formation primarily because of the dominance of tidal reworking in their origin.

Tung Lung Member

The Tung Lung Member is the oldest of the four members developed in Hong Kong waters. Sediments of the member fill several major channels in the fluvially channelled surface of the Chek Lap Kok Formation. The Tung Lung Member only occurs in subcrop.

The Urmston Road–Brothers (龍鼓水道–大小磨刀) proto-channel varies in width, reaching a maximum of around 2 km near The Brothers (大小磨刀) islands. Within the channel, the intraformational reflections are characterised by planar sets with well-developed foreset beds dipping down the channel to the east and are considered to be lateral accretion features (James, 1993). The planar sets have a high degree of continuity along the channel.

Boreholes in the area show that the Tung Lung Member is predominantly sandy, though clayey silt and gravel are important components. These sediments normally occur as interbedded units, as in borehole B/BH22 (Figure 10.4), which is taken as a typical development of the unit in the west. The unit here is 10.45 m thick and comprises 3.55 m of dense, yellowish brown fine to coarse sand and gravel that fills a basal channel, overlain by loose to dense, brownish grey fine to coarse sand.

In eastern waters, the unit is both more extensive and more complex, comprising a main channel with a broad, flat floor and steep flanks. Minor tributaries enter from the northeast. The width of the main channel varies from 1.5 km in the north to almost 3 km in the south. The intraformational reflections consist of a sequence of cross-cutting features, indicating lateral accretion in a

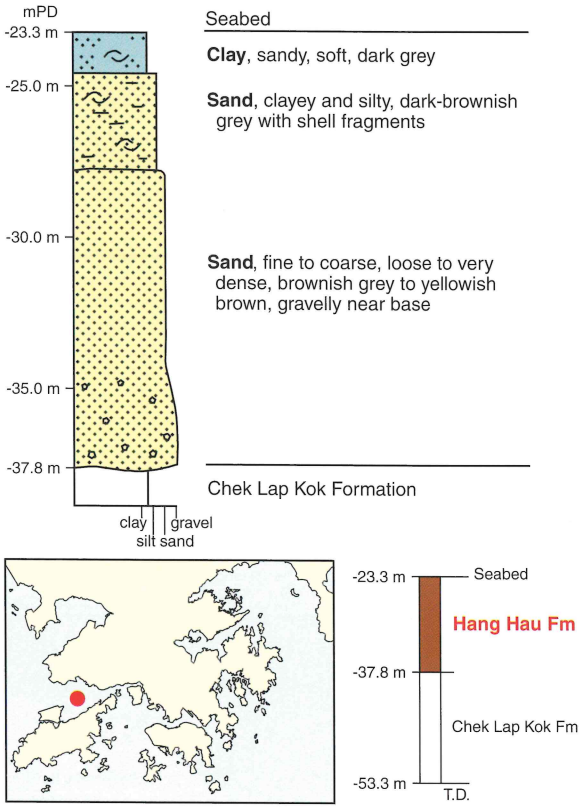


Figure 10.4 - Details of the Hang Hau Formation in borehole B/BH22

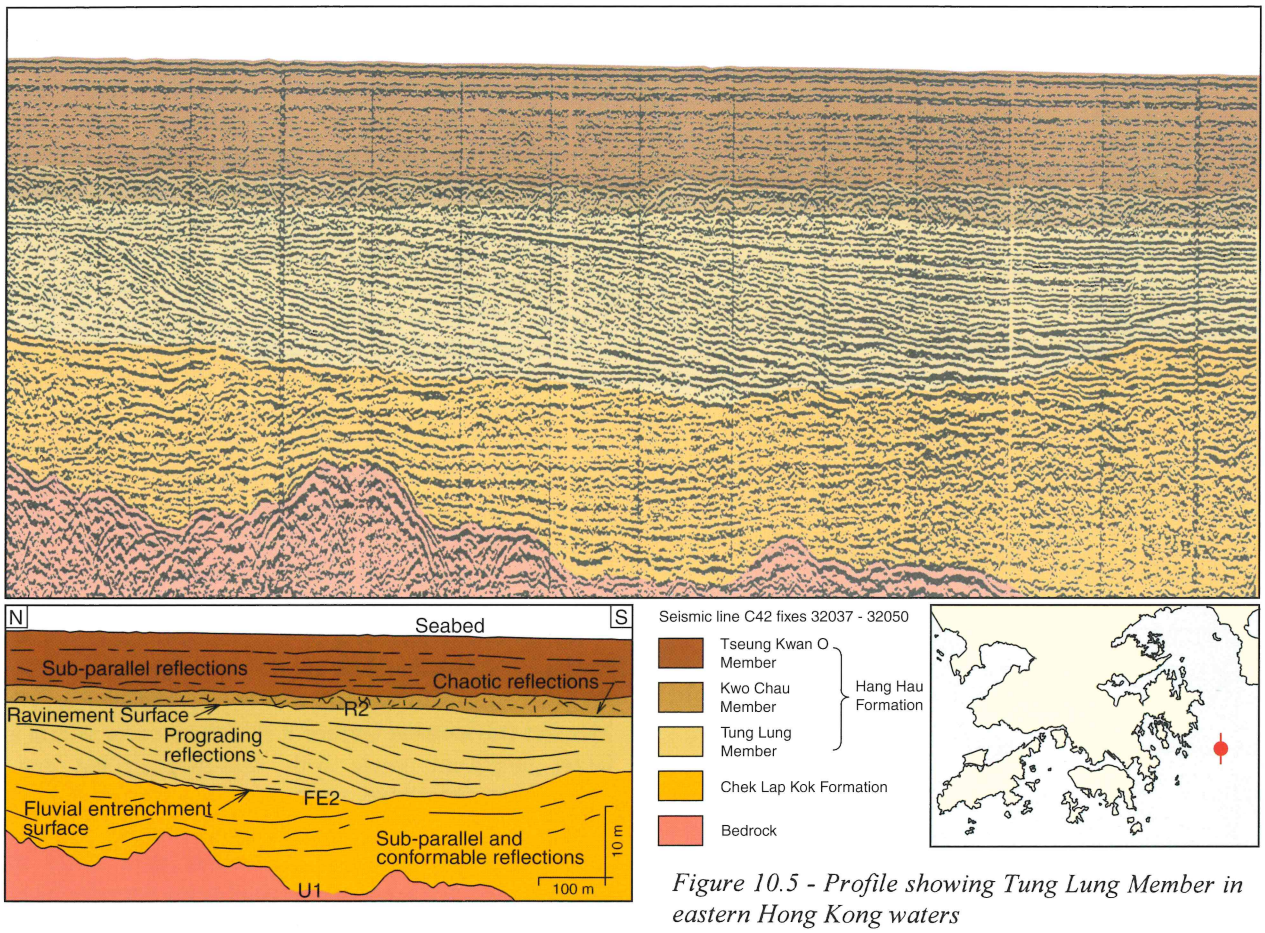


Figure 10.5 - Profile showing Tung Lung Member in eastern Hong Kong waters

series of channels (Figure 10.5). Dominant accretion was from the east, suggesting channel migration to the west.

As in the west, boreholes have proved the eastern Tung Lung Member to be predominantly sandy (Selby *et al.*, 1995), though the sand is generally restricted to the prograding units. The sand comprises yellowish brown, fine to medium, moderately to well sorted quartz grains with rare lithic fragments. Borehole WC4 contains silty fine sand with interbeds of medium to coarse sand, becoming clayey at the base of the Hang Hau Formation (Figure 10.6).

Pok Liu Member

The Pok Liu Member is developed over a wider area than the Tung Lung Member, filling complex patterns of minor channels on the pre-Hang Hau Formation erosion surface. The member only occurs as a subcrop.

The Pok Liu Member is best developed north of Lantau Island (大嶼山), in Victoria Harbour (維多利亞港) and in the southern part of the West Lamma (西博寮) and East Lamma channels (東博寮海峽). The majority of channels exhibit a sub-horizontal reflection style, with reflections that commonly onlap the margins of the channel (Figure 10.2).

In the West Lamma Channel, a number of boreholes have been drilled. Three of these near the centre, WB7, WB12 and WB14, have been logged and samples have been analyzed. WB7 has also been described by Yim (1994), who identified two marine units, a lower unit of grey clayey silt with organic debris and an upper more shelly unit. The lower of these may be assigned to the Pok Liu Member. However, microfossils are rare in these boreholes and there is a paucity of diatoms towards the top of the formation. Oyster shells were recovered from the base of the formation in borehole WB7. The fossil fauna and flora are likely to reflect the influence of the tidal channels in the area.

To the south, near the southern limit of Hong Kong waters, the Hang Hau Formation is thinner. In borehole A5/2, the basal 1.2 m comprises shelly sand and gravel, which represents a transgressive facies (Owen *et al.*, 1995; Owen *et al.*, 1998). The borehole was drilled on an interfluve between adjacent channels and these sediments may therefore not be entirely representative of the sedimentary facies in the area.

In some cases, the basal reflections show a degree of asymmetrical filling (Figure 10.3). Conformable reflection patterns are less common in the Hang Hau Formation than in the Sham Wat Formation. They do occur, however (Figure 10.7), and in some areas are difficult to distinguish (compare Figures 8.4 and 10.7). This has led Owen *et al.* (1998) to suggest that the Pok Liu Member and the western occurrence of the Sham Wat Formation are the same depositional event, with the intervening erosion surface representing a brief fall in relative sea level.

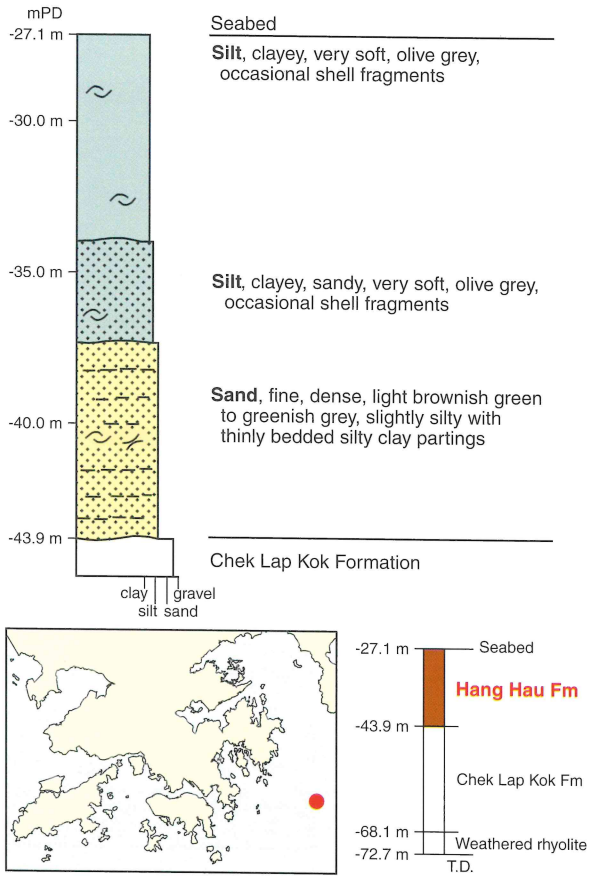


Figure 10.6 - Details of the Hang Hau Formation in borehole WC4

The best example of this phenomenon occurs to the south of Lamma Island (南丫島), at the site of borehole HKGS-B (Figure 10.8). Here, radiocarbon dating has proved the unit to be of Holocene age. The intraformational reflections are conformable with the channel perimeter and are truncated by the erosional surface (R2) at the base of the upper unit of the Hang Hau Formation. These sediments are soft, sandy, clayey silts, grey in colour, with very fine to fine sand occurring as lenses, laminae and bands.

The basal 2.4 m is dominantly sandy with abundant wood fragments, especially in the lower part. Cream coloured patches and poorly developed concretions are also present. They are very similar to those seen in the type borehole of the Sham Wat Formation. The overlying silty clay is sandy in parts with shell fragments and complete shells, some of which are articulated. The sequence becomes sandier and more shelly, and is capped with a 100 mm thick shelly sand band.

Many of the channels of this member appear to be isolated and discrete, their interfluves being truncated by the basal erosion surface of the overlying Tseung Kwan O Member (ravinement surface R2). Others occur within a larger amplitude swale with well-rounded but non-concordant interfluve crests (Figure 10.2), which occasionally overlap in a nested configuration. This suggests that the surface was subject to a series of channel-erosion phases, one channel being partially filled before incision of the neighbouring channel began.

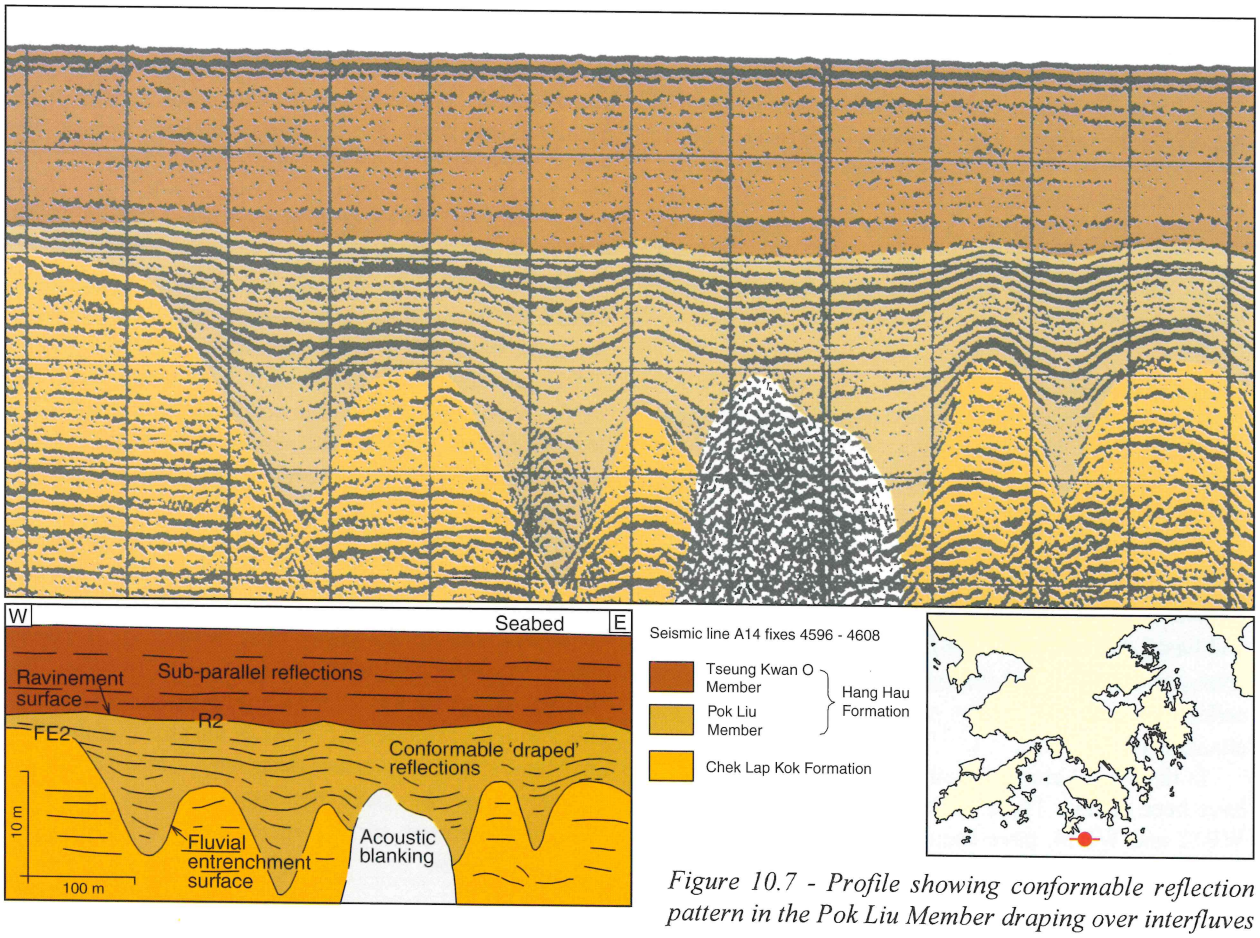


Figure 10.7 - Profile showing conformable reflection pattern in the Pok Liu Member draping over interfluves

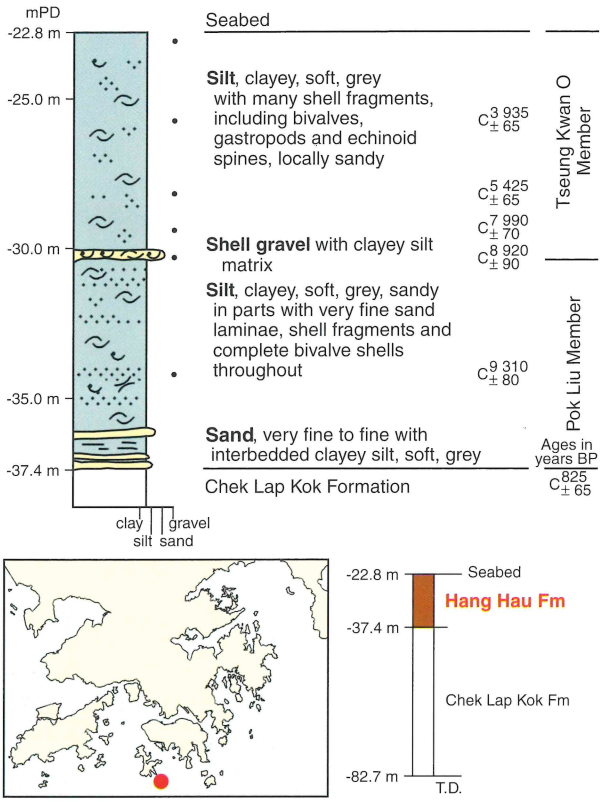


Figure 10.8 - Details of the Hang Hau Formation in borehole HKGS-B

North of Lantau Island and in the Victoria Harbour (維多利亞港) area, some of the channels are emphasized by the presence of biogenic gas in the sediments. This relationship is illustrated in Figure 10.9, where pillar-like acoustic turbidity obscures the underlying reflections. Although in this case the turbidity is seen as a plume, where the gas occurs in a solitary channel, gas may be more laterally extensive.

The distribution of acoustic turbidity identifiable on seismic profiles is shown in Figure 10.10. Acoustic turbidity occurs most extensively to the north of Lantau Island, around the Soko Islands (索罟群島) and between Lantau and Lamma islands. The occurrence of gas is largely coincident with the subcrop of the Pok Liu Member, which corresponds with the major intertidal areas that existed at the onset of the Holocene transgression. Gas also occurs in similar present-day settings, such as in Deep Bay (后海灣) and over much of the Pearl River Estuary (珠江口). Virtually no acoustic turbidity has been observed on profiles from eastern waters.

Kwo Chau Member

The Kwo Chau Member is a transgressive sandy facies, largely restricted to southeastern and southern waters, thinning out to the west and north. The member only occurs as a subcrop.

In the southeast, the Holocene transgression is

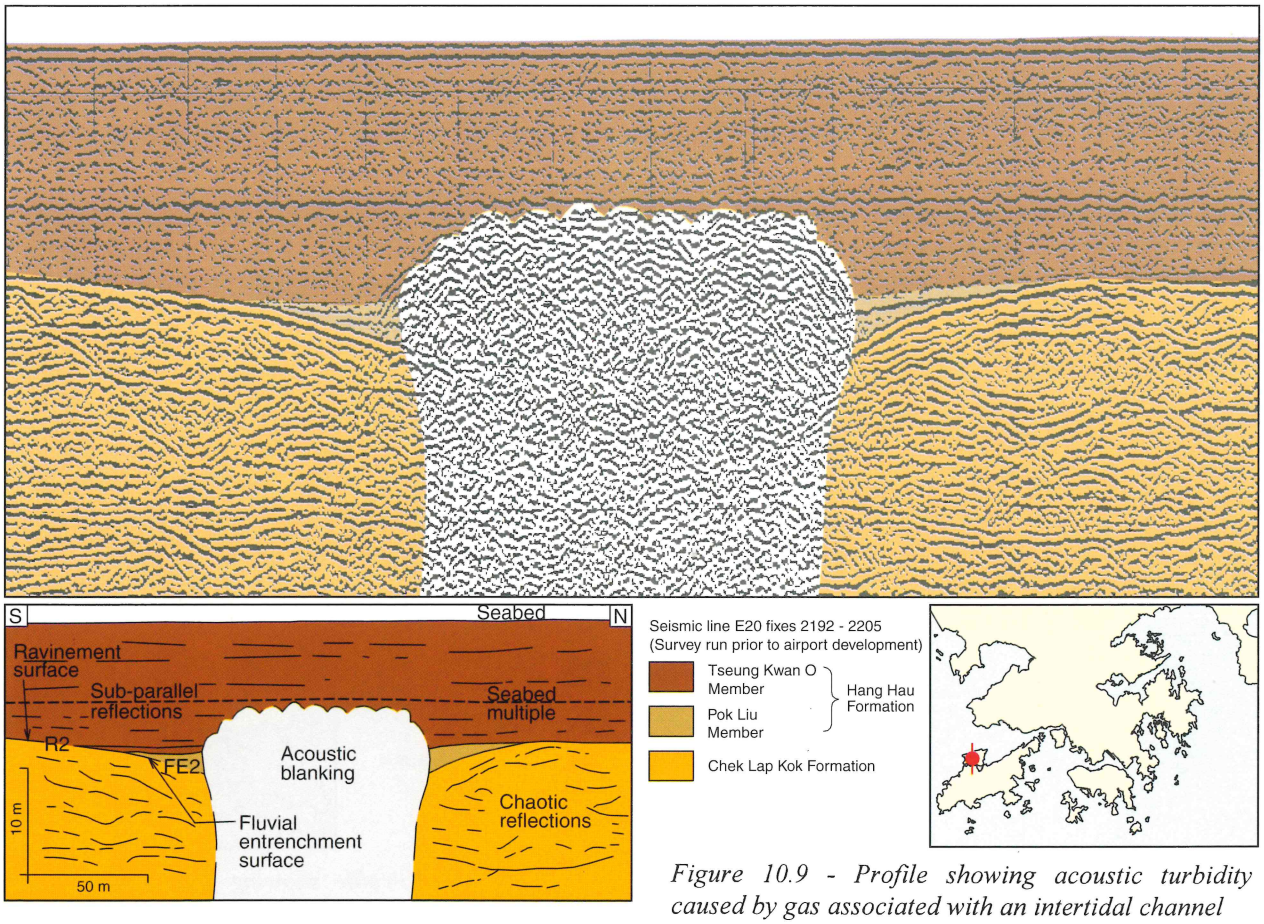


Figure 10.9 - Profile showing acoustic turbidity caused by gas associated with an intertidal channel

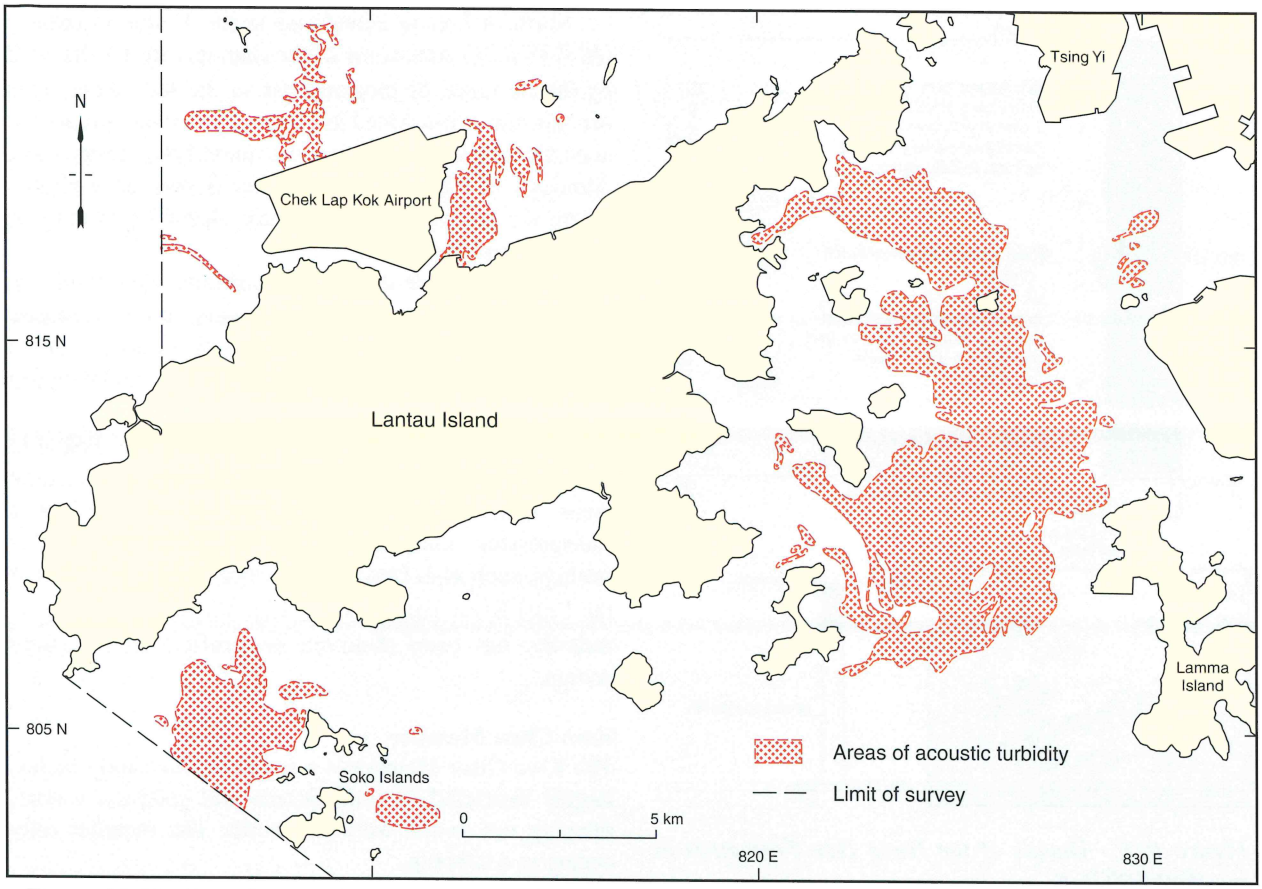


Figure 10.10 - Distribution of acoustic turbidity in Hong Kong waters

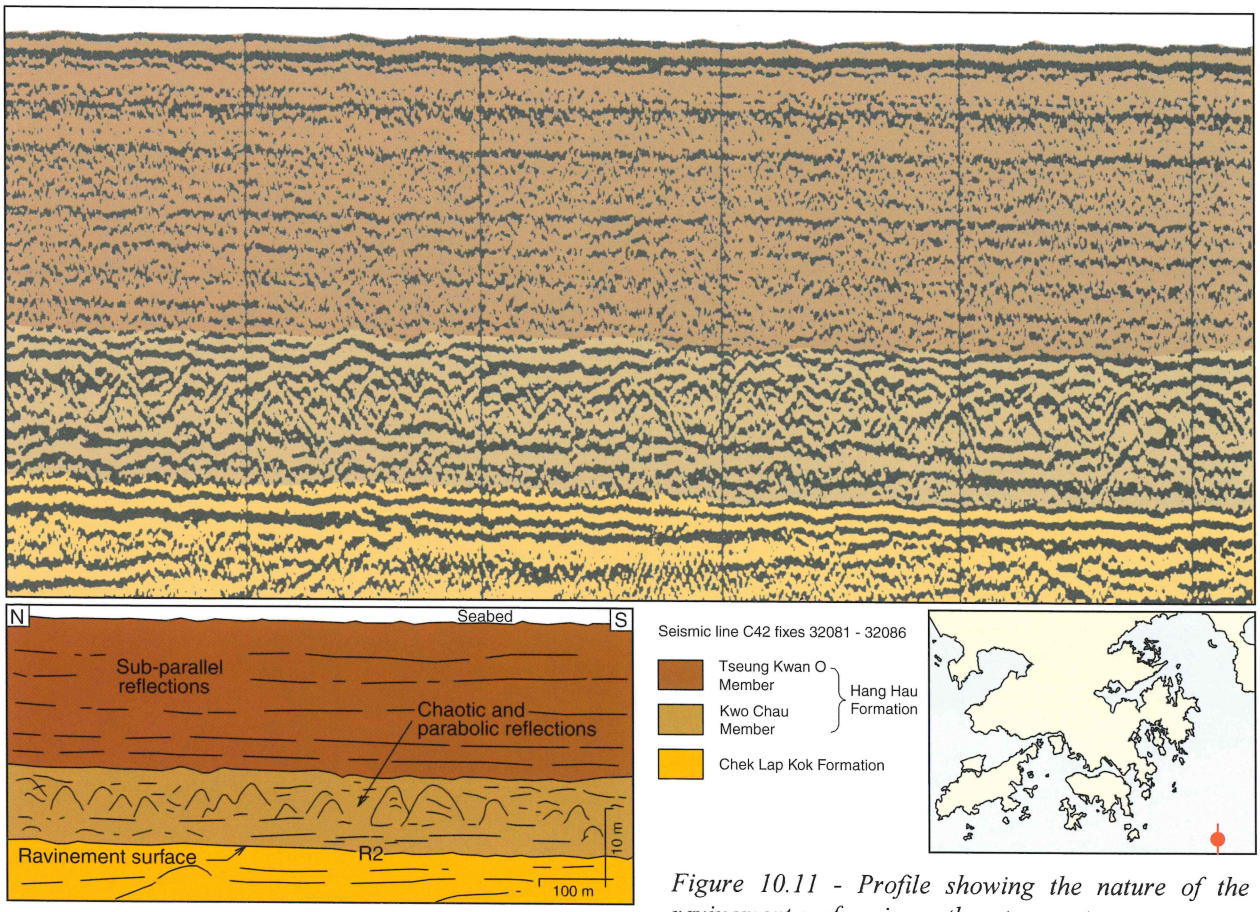


Figure 10.11 - Profile showing the nature of the ravinement surface in southeastern waters

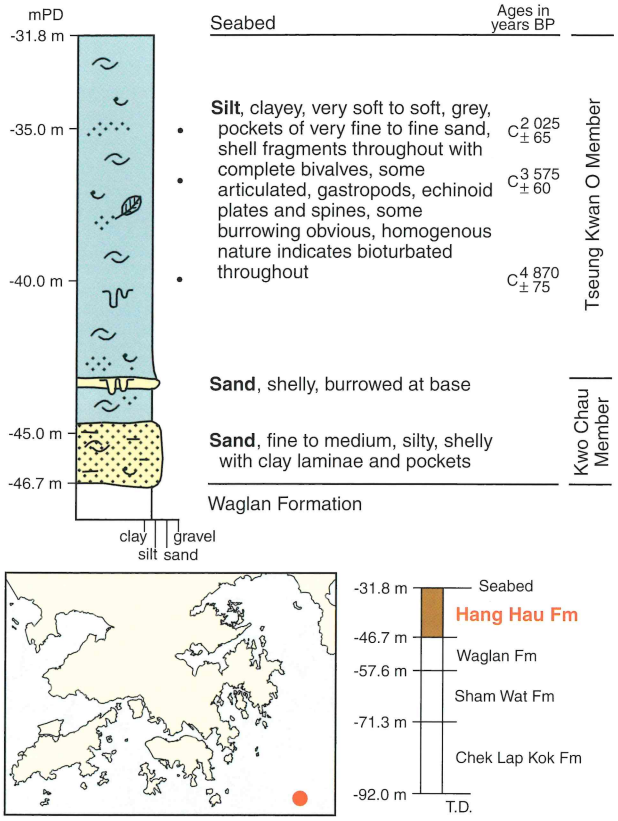


Figure 10.12 - Details of the Hang Hau Formation in borehole HKGS-A

represented by a ravinement surface (R2). The surface is overlain by a sand layer up to 2 m thick, identified on seismic profiles as an interval of chaotic intraformational reflections (Figure 10.11). This interval is thickest in the southeast, thinning to the west and north, where the Tseung Kwan O Member rests on the ravinement surface.

The sand associated with the ravinement surface is best illustrated in borehole HKGS-A, to the south (Figure 10.12). Here, a sand layer, 2 m thick, is overlain by interbedded sand and clayey silt. The sand is muddy and shelly, comprising fragments of bivalves, gastropods, scaphopods and echinoids. Occasional lenses of silty clay and rare plant fragments also occur throughout the core. The sand is overlain by 11 m of clayey silt of the Tseung Kwan O Member.

Tseung Kwan O Member

The Tseung Kwan O Member is widely developed offshore and forms the seabed beneath most Hong Kong waters. The intraformational reflections are generally sub-horizontal and of low amplitude. Low-angle truncation surfaces are also common (Figure 10.13). This member is present in virtually all boreholes throughout the offshore area and, in common with the type borehole, the sediments are dominantly very soft to soft, structureless clayey silt, olive grey in colour with common to abundant shells and shell fragments throughout the sequence.

In the west, north of Lantau Island (大嶼山) (borehole ESC17), the formation is about 10 m thick and comprises a clayey silt to silty clay with regularly occurring lenses and discrete laminae of silt to fine sand. Shells and shell fragments occur throughout, both as comminuted shell debris and as large broken valves. South of Lantau Island, boreholes HKGS-C and A5/1 provide thicker sections through the formation, where the succession is 15.8 m and 14.6 m thick respectively. Sand is more common in this area, occurring as thin laminae and lenses throughout the unit and in bands up to 1 m thick. The sand is fine to coarse and comprises dominantly quartz and lithic fragments. Shells are common throughout the sequence. These boreholes are located close to the present-day Lantau Channel (大嶼山海峽) and the predominance of sand in the formation here probably reflects the proximity of a proto-channel of the Pearl River (珠江).

Seismic profiles from the East Lamma Channel (東博寮海峽) clearly display two distinct phases of deposition, separated by a steeply inclined erosion surface (Figure 10.14). These two units were designated the Telegraph Bay and East Lamma members by Strange and Shaw (1986). However, these units have subsequently been shown to be of limited areal extent and unrelated to major phases of deposition and erosion elsewhere in Hong Kong waters. Thus they are not now considered to be distinct lithostratigraphical units.

The Tseung Kwan O Member thins to the east and south. Sediments in borehole A5/2 comprise clayey silt with occasional fine sand laminae and comminuted shell debris as well as shell fragments and complete shells throughout (Owen *et al.*, 1995). In nearby borehole HKGS-B, the Tseung Kwan O Member sediments comprise clayey silt, which is locally sandy with complete shells and fragments of gastropods, bivalves and scaphopods. Echinoid fragments and spines are also found. In some cases, articulated bivalves occur in their living position at the base of sand-filled burrows.

In the southeast, the Tseung Kwan O Member overlies the Kwo Chau Member. In borehole HKGS-A, the sand of the lower formation is overlain by 11 m of clayey silt with silty lenses and laminae, and bivalve and gastropod fragments occur throughout. The sequence overlying the ravinement surface (R2) comprises a unit of sub-horizontal low-amplitude reflections. This thins into Mirs Bay (大鵬灣) to the north. The pattern of persistent parallel reflections onlap the lower sand unit which dips gently to the south.

Un-named beach members

Beaches are laterally extensive, usually narrow, deposits of loose sand and gravel that accumulate in embayments, extending landwards from the low water mark to the inland limit of wave influence. This limit may be a cliffline, rising hill slope or back beach deposit. The upper limit of wave action under prevailing conditions is

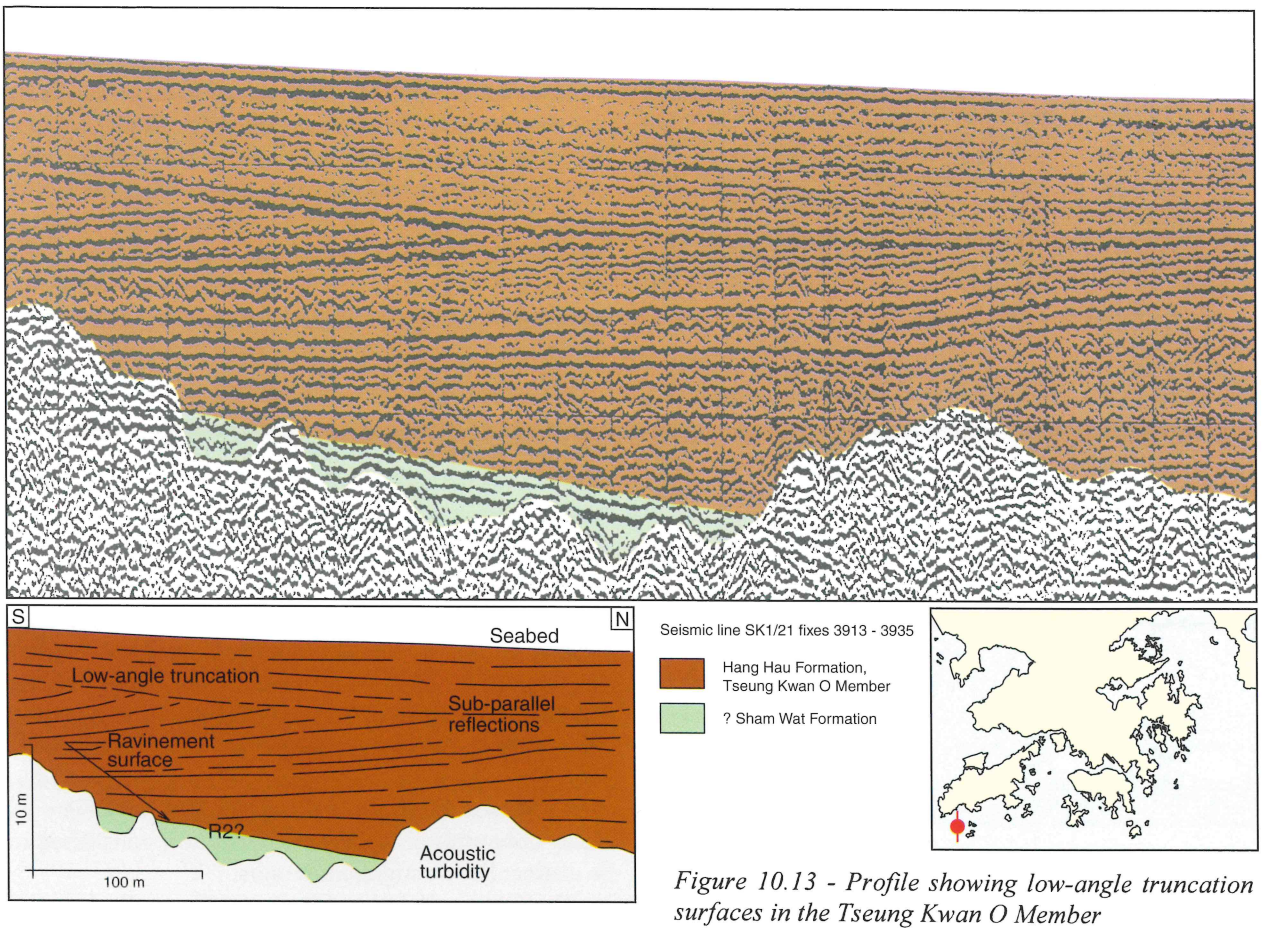


Figure 10.13 - Profile showing low-angle truncation surfaces in the Tseung Kwan O Member

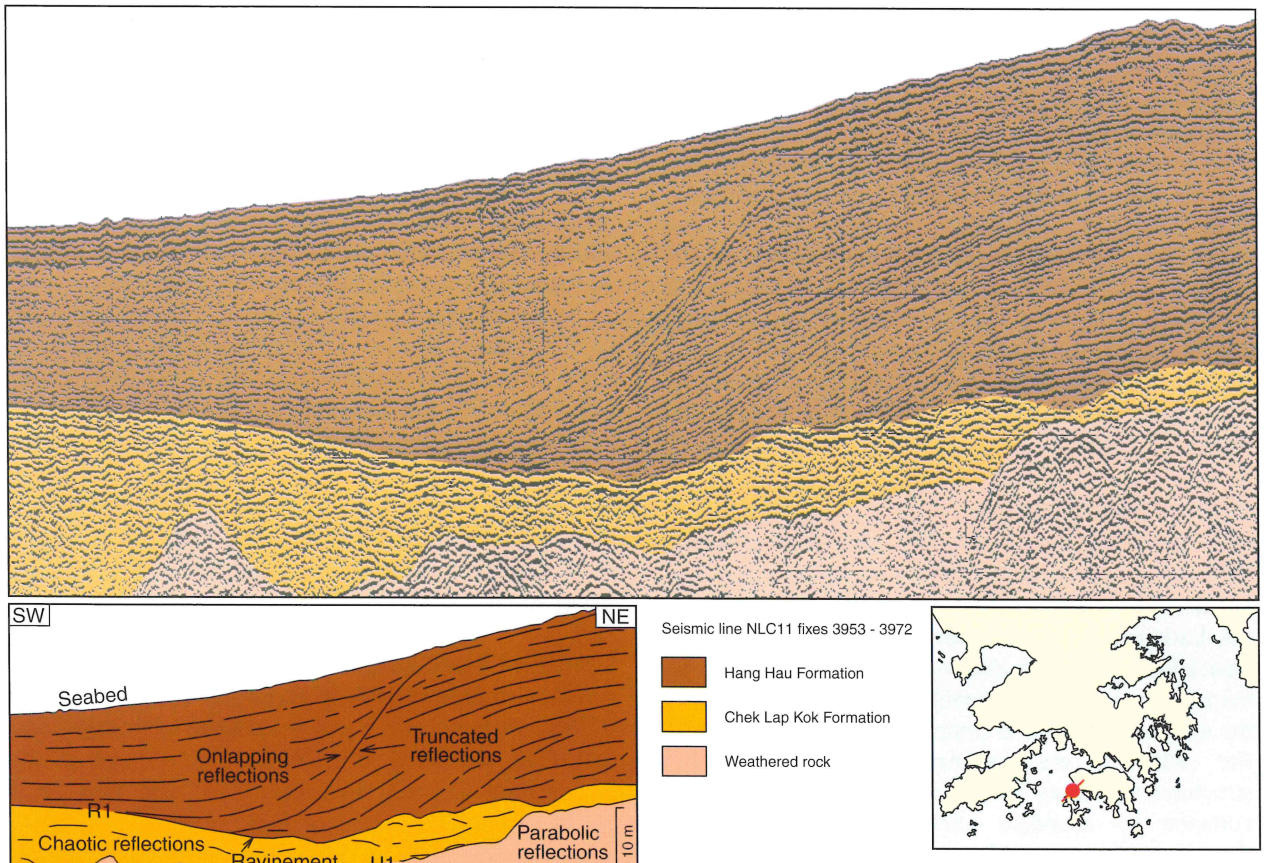


Figure 10.14 - Profile showing steeply dipping erosion surface in the Tseung Kwan O Member

usually up to about +3 mPD. Most beaches occur in relatively sheltered locations, in environments characterised by low energy, constructive wave activity. Sandy beaches have developed along most of the mainland coastline of Hong Kong, and around the majority of islands.

Beach deposits characteristically consist of clean, pale yellow sand, with occasional gravel and shell fragments. Seawards, these sands are usually laterally continuous with the littoral and sublittoral sands and muds of the Hang Hau Formation.

Beach deposits in the more exposed sections of coast, particularly southeasterly facing bays along southern coasts, may include pebbles and cobbles, and even boulders (Plate 3.28). Steep, cliffed shorelines are common along these high energy sections of the coastline. Cliffed coasts usually have only narrow boulder beaches fringing the bases of the cliffs. This material accumulates as aprons of coarse rockfall debris derived from the wave eroded cliffs, or from coastal exposures of colluvium. Strong wave action winnows out the fines leaving a lag of coarse debris.

In some areas, most commonly along exposed coasts with a southeasterly aspect, the upper limit of the beach may extend up to about +6 mPD. These deposits commonly comprise gravelly coarse sand with scattered pebbles, characteristics that suggest they formed in a high energy environment. Although several of these features have been mapped as raised beaches on 1:20 000-scale maps, they are probably storm beaches formed by strong wave surges associated with typhoon conditions. This interpretation is supported by the generally coarser grain size of the higher level beach deposits. Strictly, therefore, they should be regarded as storm beaches. True raised beaches, resulting from deposition during a period of higher sea level or from tectonic uplift, have not been unequivocally identified in Hong Kong.

Mostly inactive, high level storm beaches exist behind the active beaches. Diurnal tidal variations and seasonal wave activity rarely impinges upon them, except during typhoon storms. In some localities, such as at Pui O Wan (貝澳灣) on Lantau Island (大嶼山), storm beach ridges form barriers across the mouths of rivers (Plate 4.1). Freshwater lagoons have developed behind the barriers and extensive alluviated tracts extend inland along the river courses.

Rock platforms (Plate 4.21), extending out from the bases of coastal cliffs or surrounding rocky islands, are a common feature of coastlines in the eastern part of Hong Kong. They usually have only a thin veneer of sediment and are characterised by scattered boulders, numerous rock pools, and occasionally small stacks or rock residuals. In these areas there is usually a distinctive boundary between the exposed rock platform and the offshore sand or mud deposits. The irregular rock surface, covered with a diversity of intertidal flora and fauna, usually appears as a darker and mottled phototone that ends abruptly at the boundary with the smoother, more homogeneous marine mud or sublittoral sand sheet at the low water mark.

The most extensive beaches occur at Tai Long Wan (大浪灣), Long Kei Wan (浪茄灣) and Clear Water Bay (清水灣) in the Sai Kung (西貢) district, Deepwater Bay (深水灣) and Big Wave Bay (大浪灣) on Hong Kong Island (香港島), Cheung Sha (長沙), Pui O Wan (貝澳灣) and Silver Mine Bay (銀鑛灣), on Lantau Island (大嶼山), and Butterfly Beach (蝴蝶灣) and the Cafeteria beaches (咖啡灣) in the western New Territories (新界). Several of the largest beaches in Hong Kong have been gazetted for recreational uses and some, notably Repulse Bay, have been artificially replenished for this purpose, following recent erosion of the features.

Un-named intertidal members

Estuarine intertidal deposits are of mixed alluvial and marine origin. The deposits form a wide transitional zone in lowland areas where wide, shallow gradient river valleys meet the sea along sheltered sections of the coastline. Fine-grained fluvial sediments accumulate in deep coastal re-entrants or wide, sheltered embayments forming extensive mudflats. Intertidal flats extend between the high and low water marks.

Branching and anastomosing distributaries are commonly developed across these flats, with patterns of deeper base-flow master channels, and shallower high tide channels separated by wide, flat and very low interfluves (Plate 4.18). Current ripple patterns are usually developed on the muddy surface of the interfluves, created by the waters of the diurnal tidal inundations. The floors of the master channels are usually sandy. Sand splays and sand ribbons cross the flats, spreading out from the channels during times of increased fluvial discharge. Mangroves, and associated halophytes, are a common feature of the saline mudflats and channel margins.

Intertidal deposits usually consist of grey clayey silt over the mudflats. Grey silty sand characterises the channel floors, with the mud adjacent to the channels being sandy in places or containing sandy intercalations. Flaser bedding is a common sedimentary feature. Plant remains, dark grey, organic clayey silt lenses and shell fragments are common throughout the deposits.

Intertidal deposits are well developed around the coast in many parts of Hong Kong. The most extensive occurrences are around the shores of Deep Bay (后海灣) (Plate 4.18) and Starling Inlet (沙頭角海) in the New Territories (新界). Around the coast of Lantau Island (大嶼山), intertidal deposits occur at Tai O (大澳) and adjacent Yi O (二澳), at Sham Wat (深屈), and at Shui Hau Wan (水口灣). Many small coastal streams in the eastern New Territories have muddy, mangrove-fringed, tidal lower courses.

Intertidal muds are difficult to identify unequivocally in borehole samples, appearing similar to sandy organic coastal muds. However, it is suspected that mangrove-

clad intertidal mudflats were probably widely developed under the sites of many of the present New Town reclamations. Prior to development, they probably occurred at Tuen Mun (屯門), Tin Shui Wai (天水圍), Tai Po (大埔), and fringing the Sha Tin (沙田) Valley. Intertidal mudflats were also more extensive around the shores of what is now the Plover Cove Reservoir (船灣淡水湖), before the freshwater level of the artificial lake was raised, and under the site of Tung Chung New Town (東涌新市鎮) on Lantau Island.

Un-named tidal channel members

A network of tidal channels runs through Hong Kong waters. Strong tidal currents have created, and kept open, these channels. The currents have prevented the deposition of marine mud, moving it in suspension to areas of lower current velocity that are conducive to settling. In some channels the underlying Chek Lap Kok Formation, or even bedrock, is exposed at the seabed. During periods of lower sea level these channels were the courses of some of the main distributary channels of the extended Pearl River (珠江) system. Hence, the underlying Chek Lap Kok Formation usually consists of sandy fluvial channel sediments. As a consequence, these areas have proved to be important resource targets during the search for seabed sources of sand for reclamation fill (Cheung & Shaw, 1993) (Chapter 12). Marine channel sand at the seabed could either be directly dredged for fill, or the underlying sandy Chek Lap Kok Formation fluvial channel sediments were easily accessible because the marine mud cover was missing or thin.

Tidal channels extend southwards from the Pearl River Estuary (珠江口) through the western and central waters. In addition, the southwesterly-directed South China (南中國海) coastal currents have created channels in the south. The main tidal pathways on the eastern side of the Pearl River run past the western end of Deep Bay (后海灣). One branch has cut a deep channel, the Lantau Channel (大嶼山海峽), around the western coast of Lantau Island (大嶼山). The other branch runs southeastwards along the Urmston Road Channel (龍鼓水道) and then diverges to form Kap Shui Mun (汲水門) and the Ma Wan (馬灣) channels. These continue southwards in to the East Lamma Channel (東博寮海峽), and to a lesser extent, the West Lamma Channel (東博寮海峽). A weaker tidal stream runs to the north of Tsing Yi (青衣) and down the Rambler

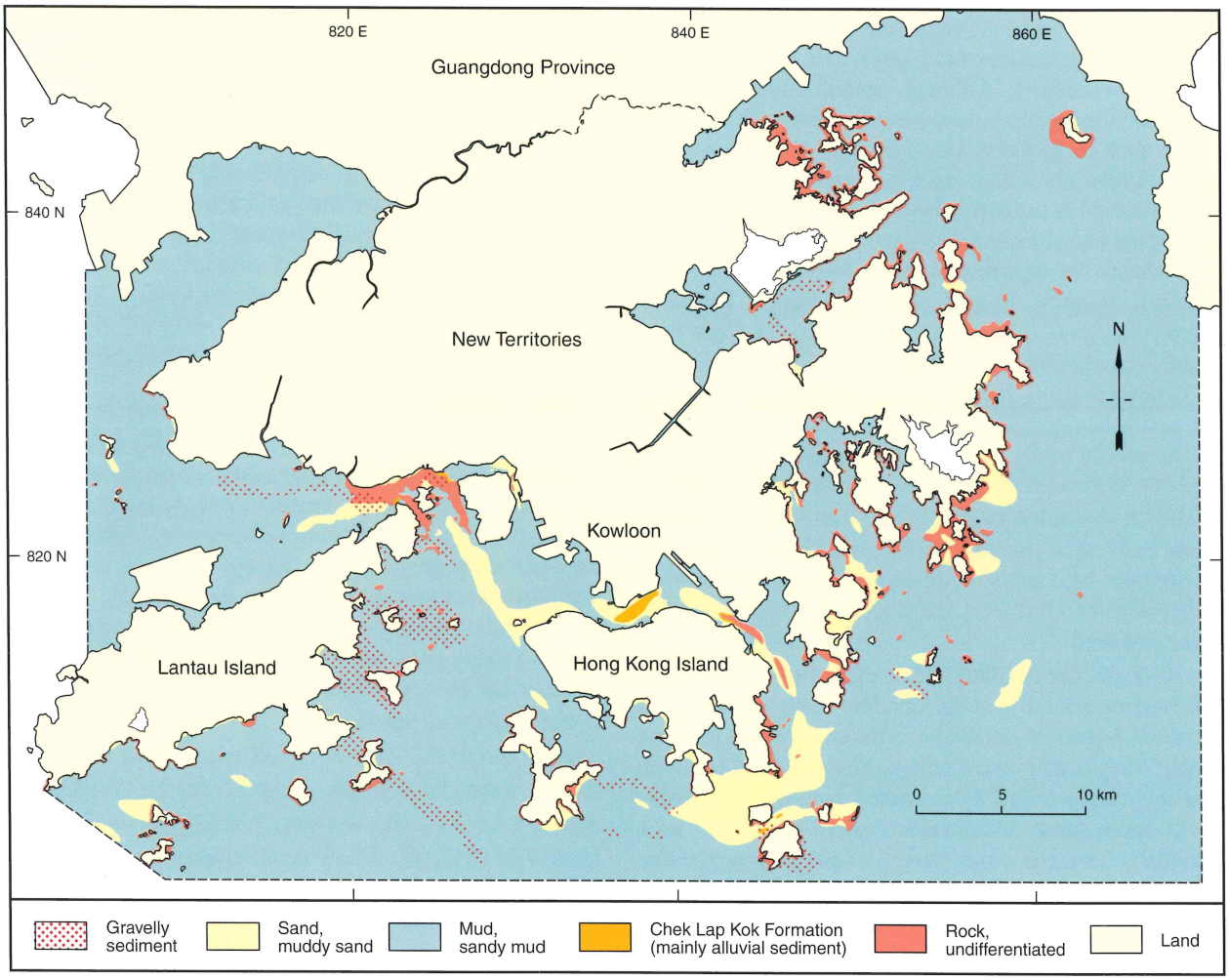


Figure 10.15 - Distribution of seabed sediments in Hong Kong waters

Channel (藍巴勒海峽). South of Tsing Yi a strong current flows through Victoria Harbour (維多利亞港) and the Lei Yue Mun (鯉魚門) gap to Tathong Channel (藍塘海峽). Coastal currents have created channels between several islands. The Sheung Sze Mun (雙四門海峽) channel lies between Cape D'Aguilar (鶴咀) peninsula and Beaufort Island (螺洲), and the Lo Chau Mun (螺洲門) channel between Beaufort Island and Po Toi Islands (蒲台島).

Sandy seabed sediments occurring in these channels are designated here as un-named channel members of the Hang Hau Formation (Map 6) (Figure 10.15). The character of the sediments along these channels varies. Thus, the floor of the Urmston Road Channel is only slightly sandy in the west, but becomes sandy towards The Brothers (大少磨刀) islands. Nearer Ma Wan (馬灣) island the channel has bedrock exposed on the floor. The only fully developed sand bank in Hong Kong waters had formed on the southern flanks of this channel (Figure 10.19). This feature has now been dredged. Rock, with a thin sand or gravel lag, is exposed on the floors of the Kap Shui Mun and Ma Wan channels. To the south of the Ma Wan Channel, a linear deposit of seabed sand had accumulated in the wide channel, although much of this has now been dredged for fill. Seabed sand, with an inlier of Chek Lap Kok Formation sediments exposed, occurs in the southern part of the East Lamma Channel.

Sandy seabed sediments occur in the central part of Victoria Harbour, south of the Kowloon (九龍) peninsula, where a large, elongate inlier of the Chek Lap Kok Formation occurs. Bedrock is exposed on the deepest section of the Lei Yue Mun channel. Sandy channel sediments are developed adjacent to the western and eastern mouths of this channel. Extensive deposits continue down the Tathong Channel and splay out near the Po Toi Islands. Sandy channel sediments occur along the floor of the Sheung Sze Mun channel, with Chek Lap Kok Formation sediments and bedrock exposed as inliers in the deepest central parts. Lo Chau Mun is a shorter sandy floored channel, with two inliers of Chek Lap Kok Formation sediments exposed. Prior to dredging, sandy sediments floored the un-named channels between the Soko Islands (索罟灣), and also formed a leeward sandbank to the west of Siu A Chau (小鴉洲).

Seabed sediment characteristics

The sedimentary character of the Hang Hau Formation varies according to tidal current regime, proximity to the Pearl River Estuary, coasts, islands and seabed outcrops.

The understanding of the thickness and vertical variation of the Hang Hau Formation has been obtained mainly from seismic reflection data and borehole correlation. Seabed surface sediments are important with respect to the ecology, utilisation of the seabed, and as a source of seabed sand.

The seabed sediments have been sampled in a variety of ways including grab sampling (Shaw, 1987), vibrocores (Cheung & Shaw, 1993), sidescan sonar, and from direct observations by divers.

Map 6 shows the distribution of seabed sediments around Hong Kong. This distribution is generalized in Figure 10.15. Mud is widespread throughout the area. The seabed becomes increasingly sandy in areas that experience strong current or wave activity. Gravel is generally found only near seabed rock outcrops, where cobbles and boulders may also be present as erosional lag deposits.

Mud

Mud describes a mixture of clay (<2 μm) and silt (2–63 μm) sized particles, together with water and an admixture of other grain sizes. Folk (1954) defined mud as a sediment that comprises less than 30% gravel and contains more silt and clay than sand (see Figure 10.16). In Hong Kong waters, seabed mud usually includes a coarser fraction that is dominantly shelly. In places, lithic sand and gravel are also present as minor constituents.

Analyses of the silt:clay ratio and sand percentage in samples from Hong Kong waters (Shaw, 1992) have shown that the majority of seabed sediments are silts and sandy silts, with a clay content of between 10% and 30% (Figure 10.16). The silt:clay ratio appears to be fairly constant over the whole offshore area.

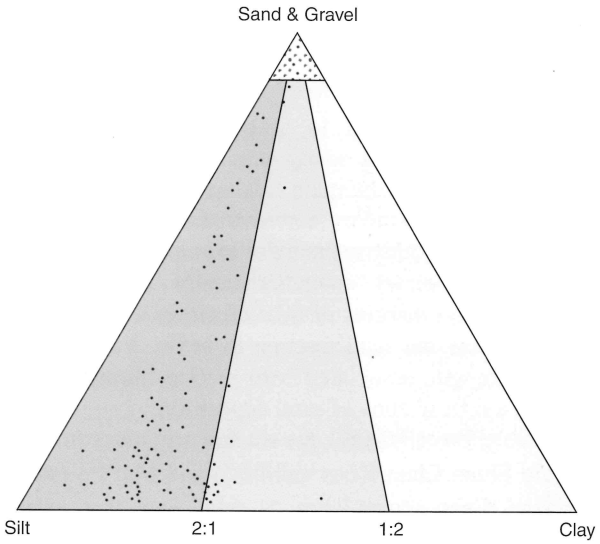


Figure 10.16 - Triangular diagram showing the ratio of sand, silt and mud in seabed sediments around Hong Kong

Scuba divers in Hong Kong have described a widespread layer of suspended mud, up to 0.75 m thick, above the firmer seabed (Shaw, 1992). This layer is commonly thicker in natural and man-made depressions in the seabed. It can be identified as a first return on some high frequency echo sounder records and, more clearly, on chirp records (Figure 10.17). The characteristics of this mud layer may fluctuate in response to factors such as

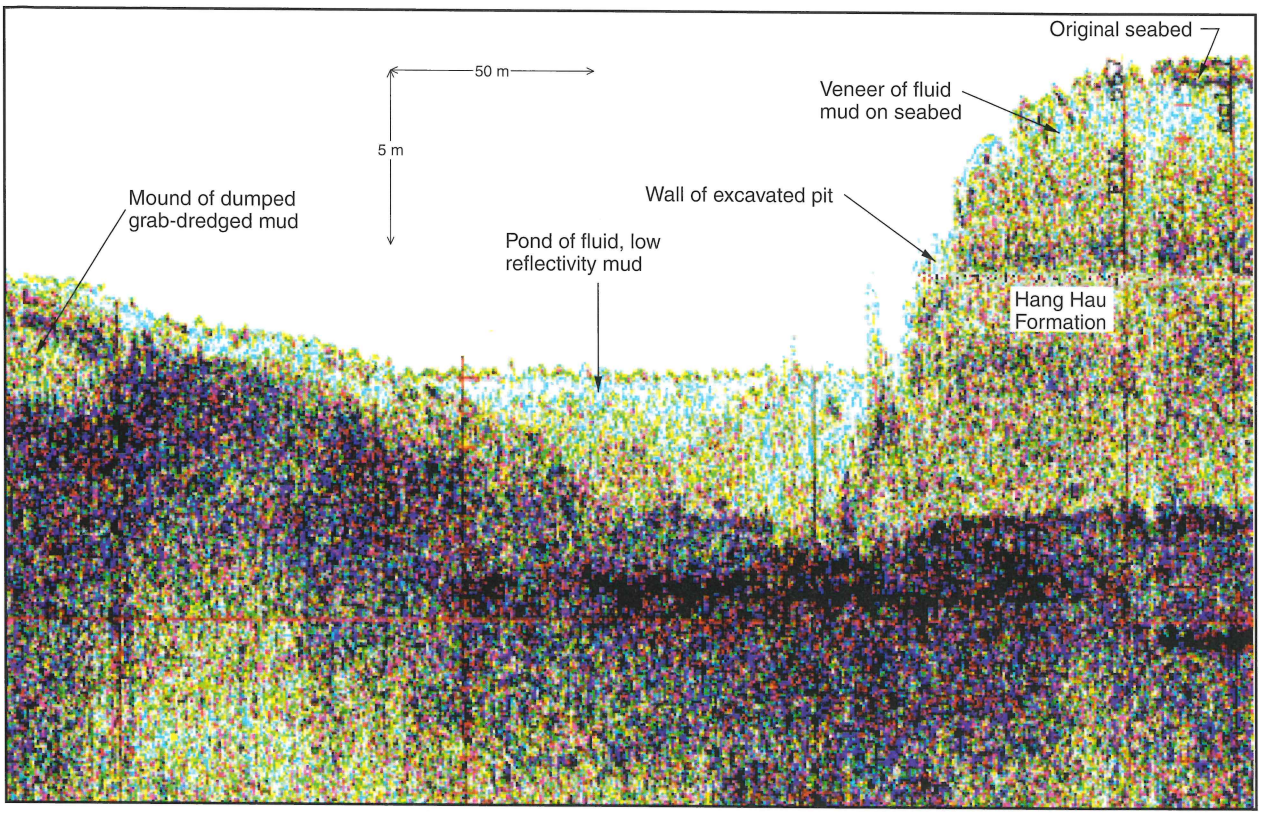


Figure 10.17 - Chirp record from an excavated pit near Sha Chau (沙洲), showing a layer of suspended mud

seasonal variations in the discharge from the Pearl River (珠江) or the disturbing effect of typhoons.

In areas peripheral to seabed sand deposits the sediment is usually a sandy mud. Decreasing current strength away from the main tidal stream is reflected in the gradational boundary between seabed sand and the more common muddy seabed. For example, residual sand sheets (see below) characteristically occur at the extremities and margins of tidal channels where waning currents allow the sand fraction to settle. Variations in current strength, associated with mixing during storms, result in a diffuse zone of sand deposition.

In Deep Bay (后海灣), the silt that originates from the languid Shum Chun River (深圳河) and Mai Po (米埔) drainage areas accumulates as tidal flats that extend underwater into the bay. Sandy silt adjacent to the northern coast of Deep Bay is derived from the Tai Sha River (大沙河) in Shenzhen (深圳). In the southern part of the bay and along the coast, patches of sand identified in recent analyses are probably related to sand spilled from dredgers during operations associated with reclamation at Tin Shui Wai (天水圍). North of Lantau Island (大嶼山), the seabed is dominantly silty in the west, due to the predominant influence of the Pearl River. Around Chek Lap Kok (赤鱲角) and off the northern shore of Lantau Island (大嶼山), the occurrence of gravelly silt indicates the influence of the nearshore shelly sediments.

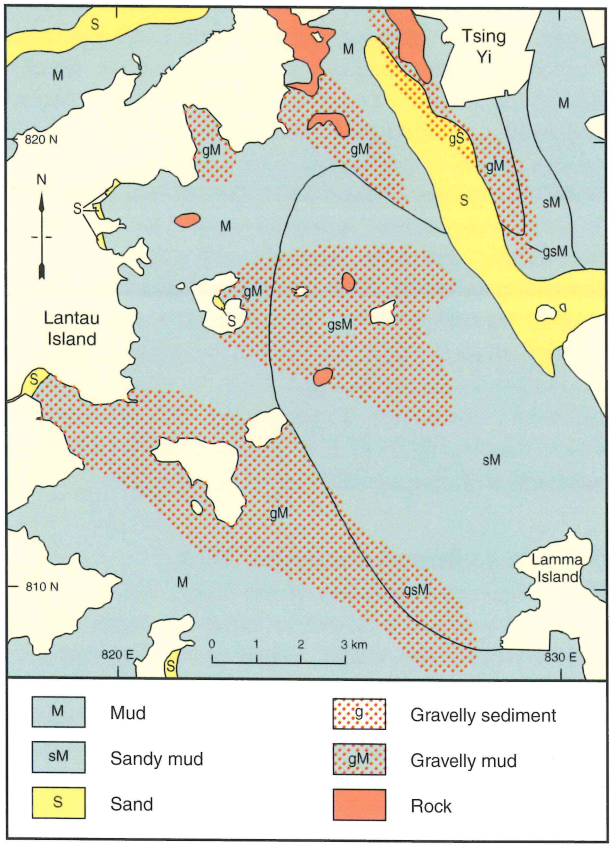


Figure 10.18 - Distribution of gravelly and sandy/muddy sediments west of Kellet Bank (奇力灘)

South of Kap Shui Mun (汲水門) and the Ma Wan Channel (馬灣海峽), a tongue of marine channel sand is flanked by deposits of sandy silt. These occur as a narrow band to the northeast but, to the southwest, fine sand has been reworked by tides and storms and forms a 2 km wide swathe into the West Lamma Channel (西博寮海峽). An area of sandy silt also occurs around the Soko Islands (索罟群島), possibly associated with the residual sand sheet that occurs near these islands. Gravel is associated with the area of bays and islands south and west of Lantau Island. The distribution of these two sediment associations west of Kellet Bank (奇力灘) is shown in Figure 10.18.

Sediments in southeastern waters of Hong Kong are generally sandier than in the west, a result of the reduced influx of silt from the Pearl River. In contrast, the sediments tend to contain less shell gravel, except in areas close to islands such as The Ninepin Islands (果洲羣島). Although the rocky inlets that make up Port Shelter (牛尾海) and Rocky Harbour (糧船灣海) are in places fringed with sand, clayey silt occurs in the deepest water.

In Tolo Harbour (吐露港) and the Tolo Channel (赤門) the mud is generally gravelly, the gravel fraction comprising dominantly shell fragments. Further out into Mirs Bay (大鵬灣) the coarse fraction component decreases and the seabed comprises a soft mud. The mud is more sandy in the central part of the bay. Some samples from the north of Mirs Bay have a higher clay content than elsewhere in Hong Kong. This probably reflects the lack of significant terrestrial influx in this area.

Sand

Sand, as a component, comprises those sediment particles that are between 63 μm and 2 mm. Folk (1954) defined sand as a sediment with less than 30% gravel and having more sand than mud (see Figure 2.8). This definition can only be applied rigorously where particle size analyses have been carried out. Therefore, in most cases, and especially where sediment descriptions are taken from navigational charts, the description is only an approximation.

Shaw (1988) identified four main facies of seabed sand in Hong Kong: sand banks, sand sheets, sublittoral sand, and river channel sand. The majority of sand banks have now been dredged and examples are only seen on historical seismic records held in the archives of the Hong Kong Geological Survey (Figure 10.19). The sand banks were developed in areas of strong tidal activity, such as in narrow straits between islands. Evans (1988b) described the occurrence of sand banks in the western waters of Hong Kong. Many of the sand banks that were identified were either wholly or partially buried beneath surrounding marine mud, suggesting that they were formed during the early, transgressive phase of the Hang Hau Formation, before deepening water and decreasing current strength favoured deposition of muddy sediment.

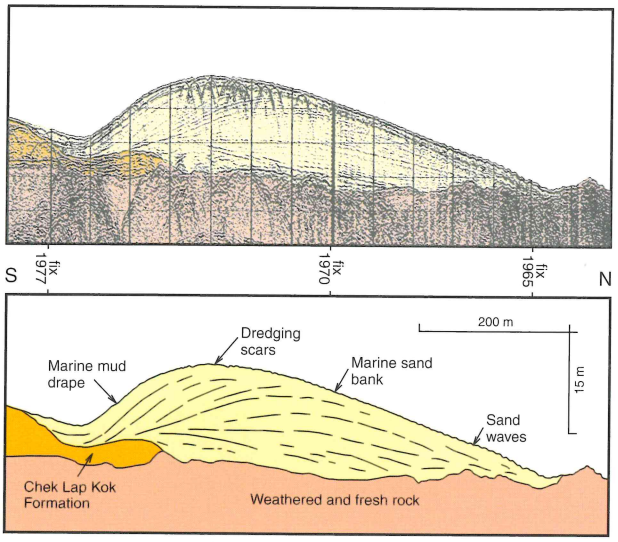


Figure 10.19 - Profile showing a moribund sand bank north of Lantau Island (大嶼山)

Sand waves were not widely developed on the exposed surface of sand banks, indicating that the banks were moribund. An exception was a sand bank to the north of Lantau Island (大嶼山) that had sand waves evident on the less steep northern flank (Figure 10.19). Elsewhere, sand waves may develop on the irregular surface left after sand dredging has been completed. However, Evans (1988b) concluded that prevailing hydraulic conditions are not conducive to the regeneration of sand banks that have been removed by dredging.

In areas of high tidal currents, especially in hollows in scoured bedrock, patches of sandy sediment occur. These are frequently covered with sand waves, indicating that they are part of the active current regime.

In addition to the raised sand banks, planar sand sheets have accumulated in several localities. Sand sheets tend to be optimally developed at the margins of the tidal channels described above. They form where strong currents within the channels begin to dissipate, allowing the sand fraction of the suspended load to be deposited. The common occurrence of sand waves on the surface of the sand sheets suggests that they are active features.

Nearer to the coast, sublittoral shoreface sand forms a seaward continuation of the littoral sand that comprises the beaches of Hong Kong. Most beaches occur at the heads of small arcuate bays, although in some areas extensive linear beaches are a distinctive feature of the coastline. A notable example is Cheung Sha (長沙) on the southern coast of Lantau Island. Linear beaches appear to have very little offshore extension, but in many small bays, sublittoral sand is found for some distance out from the shore. Sublittoral shoreface sand is more extensive in bays and inlets in the east (Strange *et al.*, 1990). In some cases, ripple marks, sand waves and mega-ripples indicating oscillating wave action can be seen on sidescan

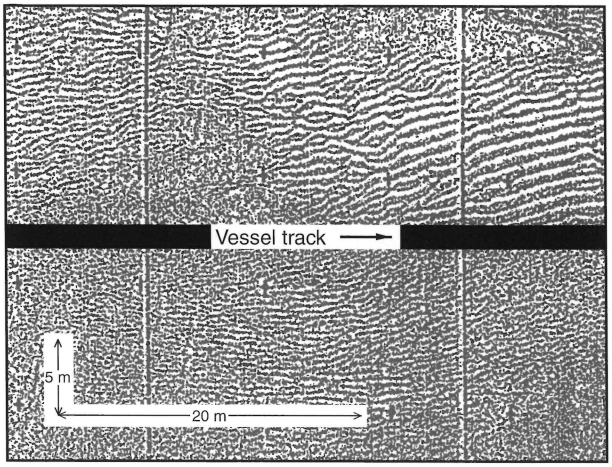


Figure 10.20 - Sidescan sonar record showing sand waves from north of Lantau Island (大嶼山)

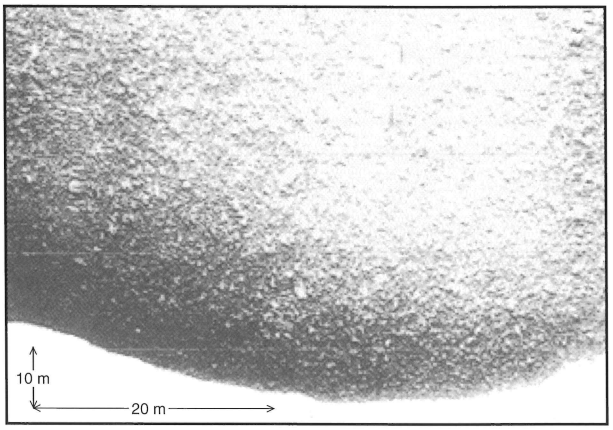


Figure 10.21 - Sidescan sonar record showing gravel lag on rock surface north of Kap Shui Mun (汲水門)

sonar records. For example, Shaw (1988) reported the presence of sand waves in Tung O Wan Bay (東澳灣), at the southeast of Lamma Island (南丫島) (Figure 10.20).

Sand has accumulated in small deltas near the mouths of several of the minor rivers of Hong Kong. The majority of these occur around the natural coastlines of Lantau Island (Langford *et al.*, 1995) and the eastern New Territories (新界) (Strange *et al.*, 1990). In some cases, such as at the mouth of the Tai Sha River (大沙河) in Deep Bay (后海灣), the offshore sand forms a submarine deltaic fan that is clearly visible on aerial photographs. The majority of rivers in Hong Kong have restricted catchments and the sediment is generally immature.

Many of the seabed sand features described above originated earlier in the Holocene, when sea level was lower than today. Sand banks in the present Pearl River Estuary (珠江口) occur north of the island of Neilingding (內伶仃) (Evans, 1988b), in the delta front zone. However, during periods of lower sea level the southern limit of tidal sand bodies would have been situated to the south of Hong Kong; today their locations coincide with the earlier tidal pathways.

During the Holocene sea level rise, the limit of sand deposition migrated northwards. In the channels between islands, tidal scouring and winnowing of the fluvial sand from the Chek Lap Kok Formation provided a further source of sand. This was redeposited as sand sheets near the limits of the channels. In many areas, the early Holocene sand bodies were completely buried by mud derived from the Pearl River Estuary. In a few places, residual sand and moribund sand banks remained at the seabed, surrounded by onlapping mud.

Sublittoral and deltaic sands have a more local provenance than the sand banks and sheets found in deeper water. Sublittoral shoreface sand deposits are primarily shelly, in common with the beach sediments of which they form the seaward extension. During the Holocene sea level rise, barrier islands and beaches would have retreated landward, depositing littoral sand at the heads of coves. In eastern waters, which are remote from the influence of the silt-laden discharge of the Pearl River (珠江) and are subject to greater wave action, the original sublittoral sand was locally not covered with marine mud.

Gravel

Gravel, as a component, describes sediment particles that range between 2 to 60 mm. Folk (1954) defined gravel as sediment with more than 30% gravel-sized particles (see Figure 2.8), including biogenic and lithic clasts. Biogenic gravel comprises shells, either broken or whole, and coral. Lithic gravel normally consists of quartz and rock fragments, which are usually subangular to subround.

Gravel is relatively scarce in seabed sediments around Hong Kong. Most of the gravel that has been mapped occurs as lag deposits adjacent to submarine rock outcrops or on bare rock surfaces between islands (Map 6). Strong currents in these areas either winnow and remove the mud and sand fractions or prevent their deposition. Examples of these deposits are clearly seen on sidescan sonar records north and south of the rocky floor of Kap Shui Mun (汲水門) (Figure 10.21).

South of Kap Shui Mun, gravel is recorded as a fraction of the mud and sand. The gravelly sediments have accumulated as a series of northwest-trending bands (Figure 10.18), related to the pattern of beaches and islands. These sediments, however, are not dominantly gravelly, though they do indicate that a source of gravel exists in adjacent bays and from islands in this area.

Around the islands in the east, patches of shelly gravel make up the sea floor. Divers have noted that these shell lags occur around rocks and coral reefs. In many cases, the shells appear to be weathered and decayed, suggesting that the gravel is probably reworked from older mud or sand deposits.

The seabed environment

Rates of sedimentation

In general, present day sedimentation rates in Hong Kong waters are low, though they were undoubtedly greater

earlier in the Holocene when sea level was rising rapidly. The sediment load of the local rivers is small, so there is very little locally-derived sediment. This situation contrasts starkly with the silt-laden waters of the Pearl River (珠江). Satellite photographs clearly show the sediment plume (Plate 1.2), which is deflected southwestwards by the prevailing oceanic currents. Suspended sediment concentrations measured in Hong Kong waters during the wet season spring and neap tides are several orders of magnitude less than those reported from the Pearl River Estuary (珠江口) (Hydraulics Research Asia Ltd., 1990).

The deep water port of Hong Kong is naturally maintained by the flushing action of strong tidal streams that have a strong westerly residual. Consequently, the limited amount of sediment that does enter from the east is carried through Hong Kong waters. The offshore area therefore has a limited requirement for maintenance dredging, compared to Macau (澳門) and Zhuhai (珠海), which face considerable problems sustaining their deepwater port facilities.

Without tidal flushing, the sediment entering Victoria Harbour (維多利亞港) from the Pearl River, sewage solids and losses from dredging and reclamation might be expected to raise the seabed level by 40 mm per year. However, comparison of hydrographic charts of Victoria Harbour from 1903 to 1980 revealed no conclusive evidence of net sedimentation, implying that the seabed is in a state of dynamic equilibrium (Chalmers, 1984). Assuming that sedimentation in Hong Kong waters began about 8 000 years ago, deposition of the 10 to 20 m of marine mud must have occurred at an average sedimentation rate of between 1.25 and 2.5 mm per year. Available evidence (Owen *et al.*, 1998) indicates that the rate of Holocene sedimentation has not been steady. Radiocarbon dating suggests that the majority of sedimentation has taken place over the past 4 000 to 5 000 years (Fyfe *et al.*, 1999).

Quasi-fluid mud layers and thin beds of recently deposited sediment, identified using a seabed camera (Valente *et al.*, 1996), indicate that the seabed is subject to scour and redeposition during typhoons and tropical storms. These can occur at any time between May and October, raising surface wave height up to 15 m and producing transient bottom currents. They have an important effect on seabed conditions in the shallow coastal waters around Hong Kong, creating considerable disturbance, resuspending large quantities of sediment and causing widespread death of marine organisms.

Seabed stability

Over most of Hong Kong waters the seabed is flat and monotonous, with a regional gradient to the south. Steeper submarine slopes occur adjacent to tidal channels and exposed coasts.

Marine mud of the Hang Hau Formation was deposited relatively slowly, hence it is generally normally consolidated. In addition, modern net sedimentation rates are low, erosion is minimal, and the area has low seismicity. There is no evidence from boomer profiles to show that faults have affected the deposition of the Hang Hau Formation (Evans, 1990b). Consequently, natural seabed slopes in Hong Kong are considered to be generally stable and in a state of dynamic equilibrium with the prevailing hydraulic and seismic conditions (Evans, 1994b).

The magnitude of reclamation and marine engineering projects in Hong Kong has expanded in recent years, extending further offshore and into deeper and more exposed waters than previously. There has been an associated increase in the number and size of dredged slopes being formed, and in the amount of dredged spoil disposed of in the designated grounds (see Figure 12.7). Generally there is very little indication of slope failures on the flanks of seabed disposal mounds. However, Evans (1994b) reported the occurrence of a translational slide on the southern margin of The Ninepins (果洲群島) islands uncontaminated mud disposal ground (Figure 10.22). The failure originated from a large depression about 5 m deep and appeared to have a runout distance of over 1.5 km on a gradient of about 1 in 800.

Modern offshore engineering activities in Hong Kong

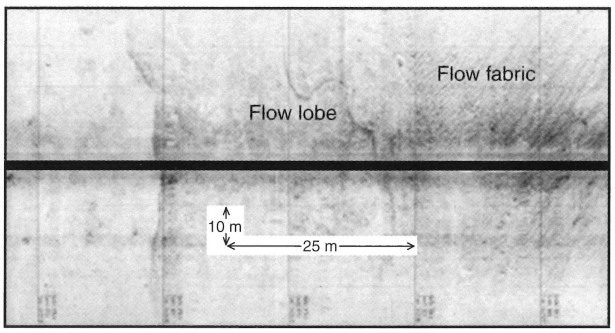


Figure 10.22 - Sidescan sonar record showing mud flow patterns near Kwo Chau Kwan To (果洲群島)

create major structures that modify both the natural topography and the hydrodynamic regime. These activities present an increased risk of instability on the seabed, particularly during extreme natural events such as typhoons. Consequently, Evans (1994b) proposed adding a fourth type of generic failure to the three categories itemized by Moore (1978), that of failures triggered by engineering works. These would include projects such as excavation, dumping, or any alteration of the hydraulic regime that would result in scour or increased deposition.

Natural conditions to the west of Hong Kong and within the influence of the Pearl River (珠江) contrast markedly with those elsewhere in Hong Kong. The hydraulic and sedimentation regimes are highly dynamic, with a strongly seasonal discharge, high suspended sediment concentrations and rapid velocity fluctuations caused by the diurnal inequality of the tides.

Consequently, weak, rapidly-deposited, under-consolidated, metastable sediments accumulate. For example, in the Lingding Channel (伶仃洋) at least 59 million cubic metres (Mm^3) of mud has been deposited over the last 20 years, and a further 8 Mm^3 has probably been dredged over the period to combat the constant problem of shoaling and to maintain navigation (Zhong *et al.*, 1990). Overall, the bed of the Pearl River Estuary (珠江口) is considered to be potentially less stable than the seabed around Hong Kong.

Marine ecology

Hong Kong is at the northern limit of temperature tolerance for many tropical marine organisms. Local waters support over 150 species of fish. The distribution of less mobile subtidal biological communities is controlled by several factors, chiefly the location of the site in relation to the Pearl River Estuary (珠江口), proximity to sources of pollution, water depth, exposure to oceanic swell and substrate availability (Binnie Consultants Limited, 1995). Dive surveys have determined that biological diversity is low close to the Pearl River Estuary, with most of the exposed rock surfaces devoid of life and the only common organisms being estuarine species tolerant of wide salinity variations. Areas close to sources of organic or industrial pollution are commonly sites of silt accumulation. They are characterised by the lowest species diversity, although one or more species may be abundant, and by a low representation of sessile (immobile) species. Ambient wave conditions affect shallow marine communities more than deep water assemblages. Wave agitation may damage fragile forms, although conversely it may cause beneficial mixing of polluted water with clean, and of saline with fresh. Freshwater discharge from the Pearl River (珠江) primarily affects the surface layers, so communities at depth are largely isolated from the associated low salinity zone. Light penetration declines rapidly with depth, especially in the highly turbid waters of western Hong Kong, and thus limits the range of light-dependent forms.

Surveys have revealed that infaunal benthic communities in eastern and southeastern waters are dominated by polychaete worms (46% of the total species), with subordinate crustaceans (25%), molluscs (15%) and echinoderms (4%) (Shin, 1989). Polychaetes appear to thrive with an increase in trawling activity, but with an accompanying decrease in crustacean and molluscan populations.

Corals are an important marine community, providing protection, food and a breeding area for thousands of other species. Hard corals are a sensitive indicator of a deterioration in water quality. Light-dependent hard corals occur in the East Lamma Channel (東博寮海峽), around The Ninepins (果洲群島) islands and in Mirs Bay (大鵬灣), where they occur down to -15 mPD. Coral reef development is prevented by extreme wave action at exposed sites, although wave movement is required to prevent sediment accumulation and to promote currents that distribute nutrients. In contrast, hard corals are rare in the highly turbid waters of the Pearl River Estuary to the west where light does not penetrate below about -5 mPD. Nevertheless, thriving communities have been observed below -10 mPD in the waters of the saline wedge. The presence of blocks of skeletal coral on the beaches around Lantau Island (大嶼山) suggests that these waters may not always have been as turbid as they are at the present day. Light-independent soft and ahermatypic corals may flourish in the deeper water.

Age

Radiocarbon dating from the Pearl River Delta (珠江三角洲) (Huang *et al.*, 1982) suggests that a number of sedimentary cycles mark the evolution of the delta. Within the Holocene, two transgressive phases were identified, from 8 050 to 4 445 years BP and from 2 350 to 1 260 years BP. In the Hong Kong area, there is no evidence of this later transgression (Yim & Nau, 1984), though high-resolution stratigraphy in Hong Kong waters is complicated both by its location on the delta (Kidson, 1982) and by the occurrence of infrequent high-magnitude typhoon storms (Yim, 1986).

Radiocarbon dating of the Hang Hau Formation has been carried out over much of Hong Kong (Yim, 1986). Dates from the earlier work were obtained from both shell and plant material. More recently, many additional dates have been obtained, mainly from shells, but also from foraminifera. Wood fragments tend to be preserved in the shallower parts of the section. All the dates show a reasonable correlation with the regional sea level curve (after Tushingham & Peltier, 1992) (Figure 10.23).

The age of the Tung Lung Member has not been precisely determined. The sediments are interpreted as river sand deposited in channels on a fluvially entrenched topography during the early stages of the Late Weichselian–Holocene transgression. An age of

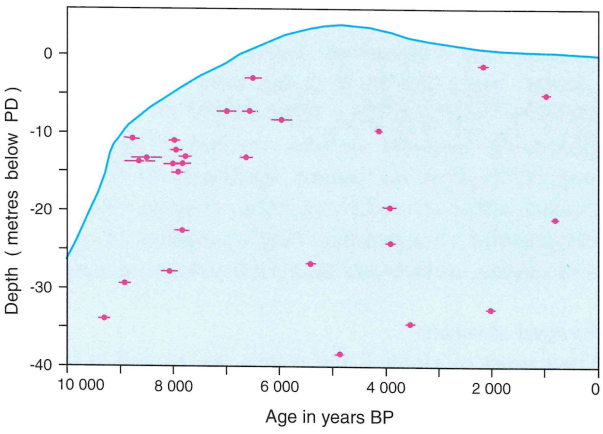


Figure 10.23 - Radiocarbon dates from Hong Kong waters plotted against the regional sea-level curve derived from Tushingham and Peltier (1992)

approximately 12 000 to 13 000 years BP is anticipated for this part of the formation.

Radiocarbon ages obtained from borehole HKGS-B (see Figure 10.7), that penetrated the Pok Liu Member, indicate an age of between 8 920 ± 90 and 9 310 ± 80 years BP (Beta Analytic) at -30.10 mPD and -34.15 mPD respectively. These are the oldest Holocene dates yet yielded by the Hang Hau Formation. Radiocarbon and OSL ages of 8 080 and 8 230 years BP from -19.70 mPD and -20.00 mPD respectively from the type section (borehole JBS1/1A) constrain sediments from the base of the succession, interpreted as the Pok Liu Member. As sea level rose, deposition of tidal channel sediments would have occurred diachronously and the member

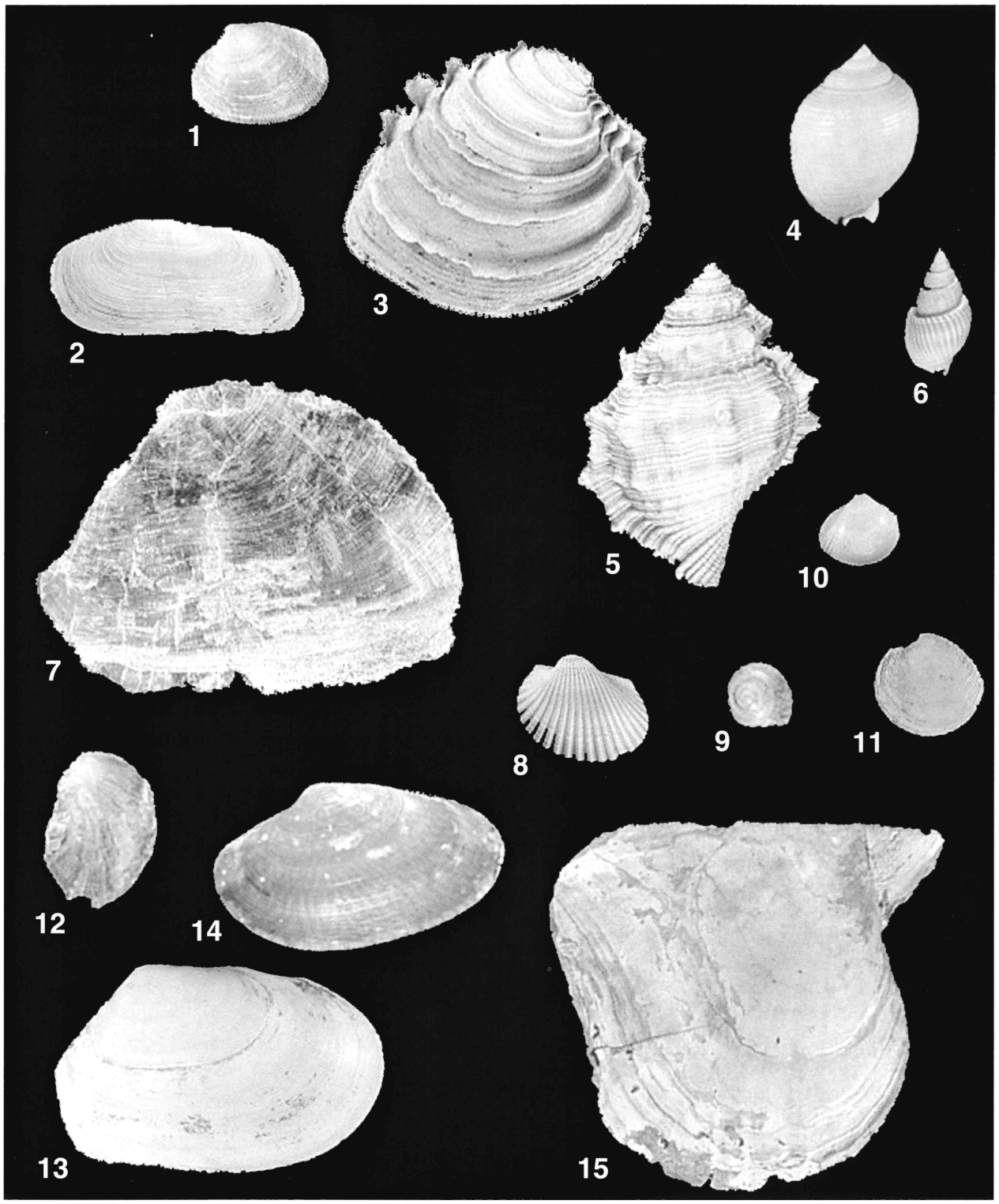


Plate 10.1 - Bivalves and gastropods from the Hang Hau Formation

would therefore be expected to young northwards.

The base of the overlying Tseung Kwan O Member in borehole HKGS-B truncates the reflections of the Pok Liu Member with angular unconformity. The draped reflections of the underlying member suggest that, prior to the erosive episode, a degree of compaction may have taken place, possibly related to a brief period of subaerial exposure. This may correlate with a short interruption in the rise of sea level that occurred at around 8 200 years BP (Huang *et al.*, 1986). This event may have global significance, as a sea level hiatus at around this time has been noted by other Quaternary workers (Blunier *et al.*, 1995; Sowers & Bender, 1995). Available radiocarbon dates confirm that the erosion surface represented by the seismic discontinuity, developed at about this time, probably represents the minor global sea level fall.

Like the Pok Liu Member, deposition of the Kwo Chau Member is considered to have been diachronous. The ravinement surface (R2) in southeastern waters is a time-transgressive plain. Ages from shells in sands at the base of this member in HKGS-A are in doubt and introduction of seabed sediments during drilling may account for the discrepancy. The oldest date in this borehole, at -40.0 mPD in the overlying Tseung Kwan O Member, is 4 870 ± 75 years BP. Three other dates obtained from the Kwo Chan Member range between 6 624 ± 956 years BP in borehole A5/2 (Owen et *al.*, 1998) and 11 342 ± 2 468 years BP (HKU Radioisotope Unit) in borehole B15.

Older dates in the Tseung Kwan O Member are 7 990 ± 70 years BP from -29.4 mPD in borehole HKGS-B and 7 960 ± 85 years BP from -15.1 mPD in borehole ESC17. It is suggested that at around 8 000 years BP, the sea was less than 10 m deep. At that time, the mouth of the Pearl River Estuary (珠江口) would have been farther to the north, close to Guangzhou (廣洲) (Figure 1.3). Western Hong Kong would then have been situated in the shelf zone, rather than the pro-delta zone as at the present day. Other dates for the Tseung Kwan O Member are given in Table 5.2.

The older dates on the graph (Figure 10.23) are broadly grouped with a general trend suggesting that, during the sea level rise, deposition was on the leading edge of the transgression. At this stage, there would have been no accommodation behind the transgressive front. More recent dates are scattered, representing living organisms on all parts of the shelf.

Depositional environment

The seismic character of the Hang Hau Formation, the overall upward-fining of the sediments and the macro- and micro-fossil content indicate that the formation was deposited during successively deepening phases in a transgressive, marginal marine environment. A selection of commonly occurring marine macrofossils is illustrated in Plate 10.1. The Tung Lung Member is dominantly sandy and is considered to have been laid down during the Late Weichselian–Holocene rise in sea level. Microfaunal analyses suggest that the Pok Liu Member was deposited in shallow, brackish water, with deeper, more open marine conditions prevailing during the deposition of the later, more widespread mud blanket of the Tseung Kwan O Member.

Erosion of the basal surface of both the Tung Lung and Pok Liu members is considered to have been initiated by fluvial entrenchment towards the end of the last glacial (Fyfe *et al.*, 1999). Major channels north of Lantau Island (北大嶼山) and in Mirs Bay (大鵬灣) were cut and subsequently infilled in a meandering fluvial to estuarine depositional environment constrained by bedrock highs (Evans, 1993). The channels are believed to have developed by the entrenchment of a Late Weichselian lowstand river system. Inclined reflection patterns indicate lateral accretion in a channel that migrated to the southwest, eroding its western bank and building up a succession of point bars on the eastern bank. The scale of the foreset architecture shows that the channel was at least 18 m deep. The form of the foresets and their flattening-out immediately below the overlying ravinement surface (R2) indicate moderately rapid deposition with a water surface at least at this level throughout their deposition.

During the initial stages of the final transgression, tidal conditions would have developed within this flooded valley. Low rock islands deflected and constrained the tidal currents along pre-existing fluvial channels. With the continuing sea level rise, the rocky islands would have become submerged and the area passed below wave base. Consequent changes in the tidal patterns and the associated depositional regime would have occurred. This model satisfactorily accounts for the presence of these large channels in an area with no significant fluvial systems in the hinterland. As no major rivers discharge into Mirs Bay, channels in this area must have been small and the sands have accumulated during lateral migration rather than by filling an open valley (Evans, 1993).

Elsewhere also, the fluvial channels became the sites of tidal channel development and, with rising sea level, were filled by muddy intertidal sediments. Three main styles of intraformational channel-fill reflection patterns are observed: onlapping, conformable and asymmetrical (Figure 10.24).

The onlapping pattern can be attributed to deposition in a partly filled channel (McKee, 1957), although similar channel-fill styles may also occur with rapid deposition (Reineck & Singh, 1980). However, the former interpretation is favoured as both the seismic and sedimentological evidence suggests that these channels were originally of fluvial origin, tidally reworked and filled during the early stages of the Holocene rise in sea level.

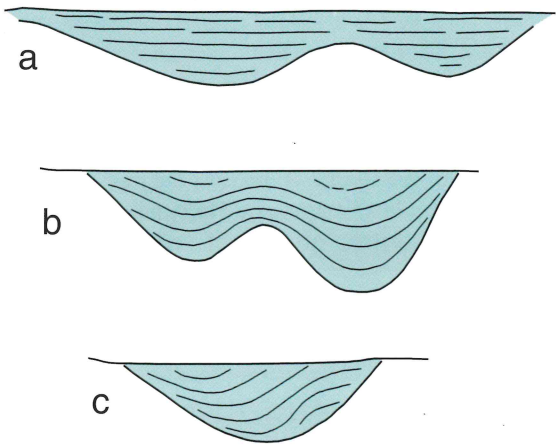


Figure 10.24 - Channel-fill styles from the Pok Liu Member of the Hang Hau Formation: a. onlapping b. conformable c. asymmetrical

Patterns of asymmetrical filling on the beds of some channels may represent remnants of late-stage fluvial point bar sedimentation. This style of fill may also be produced by diagonally passing currents, such as occur on submerged tidal flats where the direction of water flow is not confined within a channel (McKee, 1957). Point bar sedimentation is considered to be more likely during the early stage of channel filling.

The conformable reflection style suggests an entirely different mode of cut and fill. A draped reflection pattern may be the result of post-depositional compaction but may also represent a primary feature, such as filling in a submerged channel. It is believed that these channels were probably formed late in the intertidal phase, being cut by strong currents, perhaps catastrophically. Alternatively, they may have been formed earlier, but have been the loci of strong currents that prevented deposition in the channel. The channels were subsequently filled rapidly, perhaps in response to a change in current regime.

Generation of gas by bacterial decay of organic material within the sediments is an important environmental indicator. The most extensive occurrences of gas are to the north of Lantau Island and in the West Lamma Channel (西博寮海峽). These areas were probably the main intertidal areas at the onset of the Holocene transgression (Figure 10.25). Peat, woody plant remains, and mangrove and fern pollen found in the sediments is evidence that the tidal channels were fringed by halophytic vegetation, similar to the vegetation associations that occur in Mirs Bay and Deep Bay (后海灣) today. Detailed investigations have confirmed that the gas exists only in very minor amounts, manifest as discrete, occluded bubbles of methane, nitrogen and carbon dioxide (Premchitt *et al.*, 1992).

The transgression is represented by a ravinement surface (R2) in the east, where it is associated with a basal sand layer. Attempts to date this layer have been unsuccessful. The ravinement surface maintains a gentle regional dip of 0.2° to the south. Therefore, assuming a sea level rise of 10 m per 500 years, this low gradient plain would have resulted in a rapid coastal recession of around 4 to 5 m per year. Sand deposition is believed to have occurred as a series of retreating barrier bars, as modelled by Suter *et al.* (1987) (Figure 10.26). Similar ravinement surfaces associated with the Holocene transgression have been recorded from around the world,

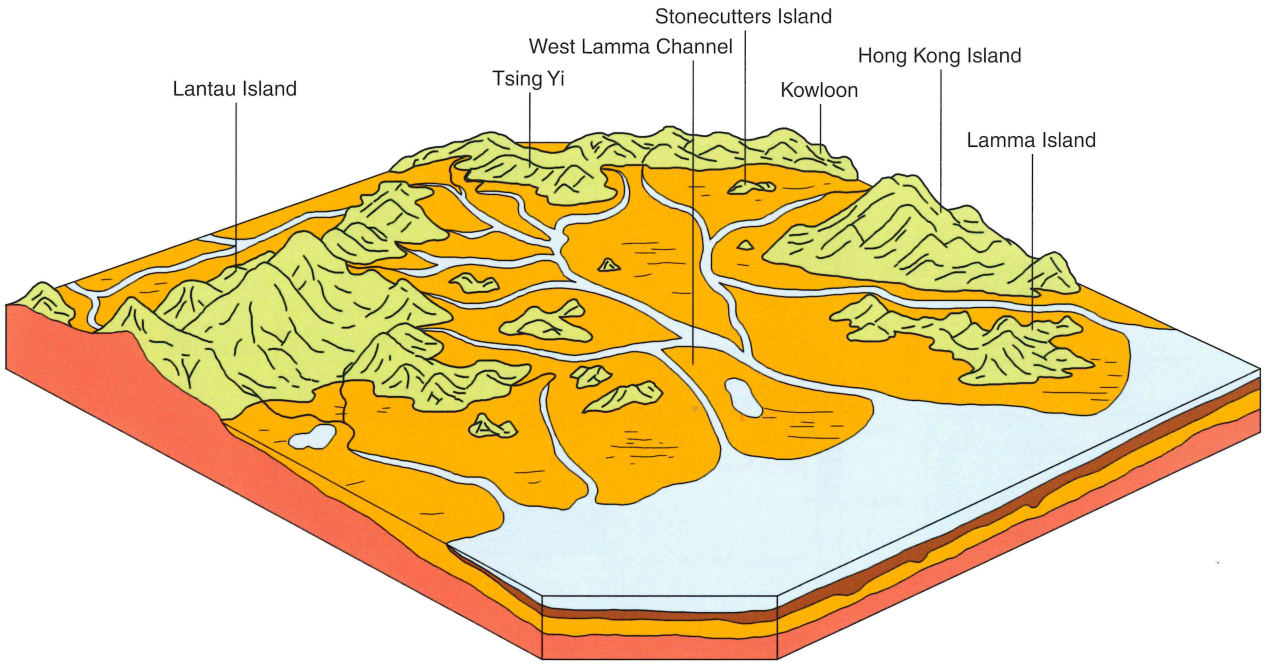


Figure 10.25 - Palaeogeographical reconstruction during deposition of Hang Hau Formation sediments in the West Lamma Channel (西博寮海峽)

including the eastern seaboard of America where they have been intensively studied (Toscano & York, 1992).

Several lines of evidence indicate that the marine transgression was not regular. For example, shells are unevenly distributed throughout the Tseung Kwan O Member. Subtle changes in the colour or firmness of the muddy sediments may indicate minor fluctuations in sea level or changing rates of sediment supply. Diatoms from borehole D27 at Kwai Chung (葵涌) show an overall progression from brackish-fresh assemblages that occur near the base to near-fully marine assemblages at the top (Figure 10.27), though there is also evidence for two minor regressions. The persistence of brackish indicators near the top of the formation reflects the coastal location of the borehole. In this area, the Holocene transgression flooded a network of fluvial channels directed

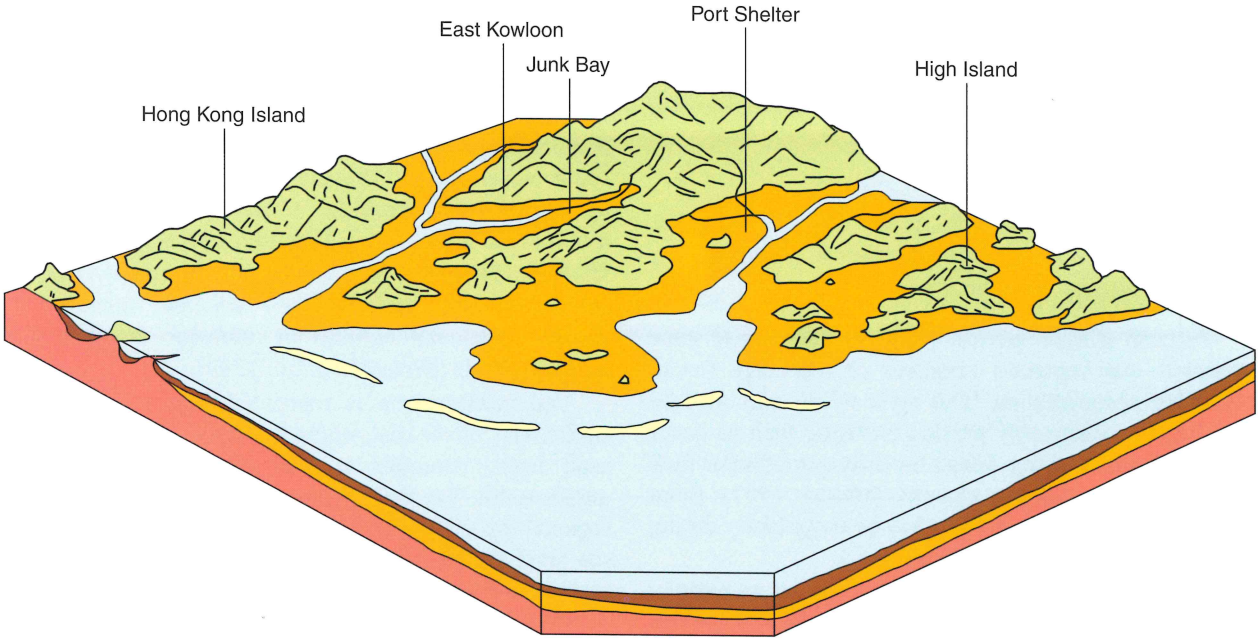


Figure 10.26 - Palaeogeographical reconstruction during deposition of Hang Hau Formation sediments in southeastern waters

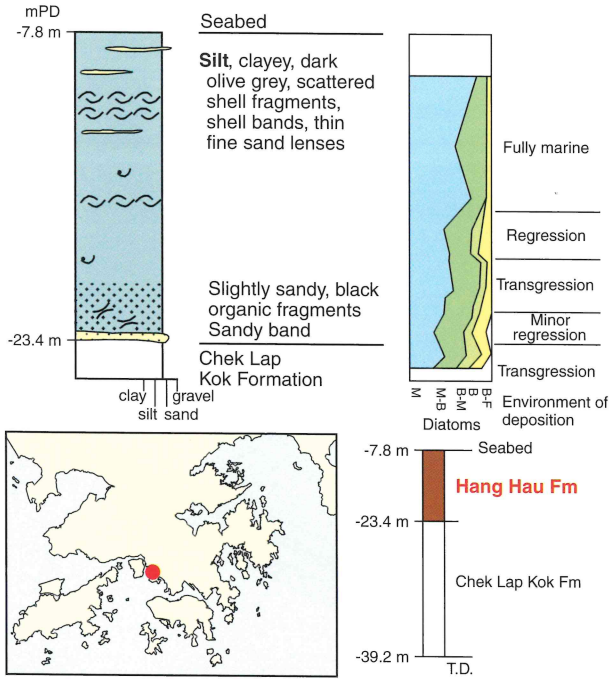


Figure 10.27 - Borehole D27 and distribution of marine, brackish and freshwater diatoms

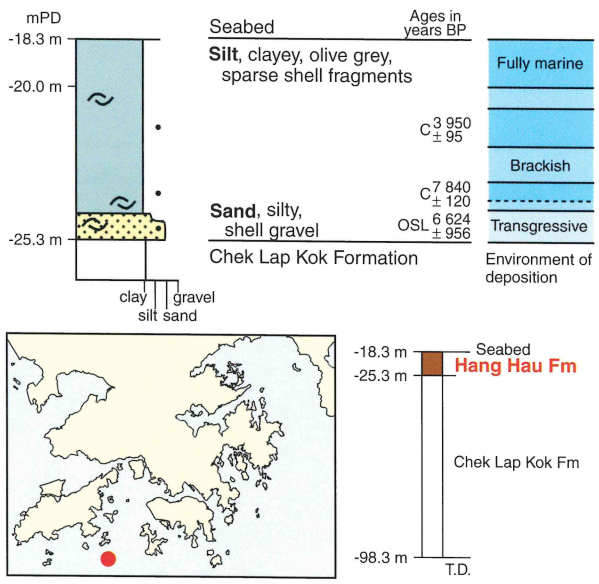


Figure 10.28 - Borehole A5/2 and distribution of marine, brackish and freshwater diatoms

southwestwards from the hills of West Kowloon (Strange & Shaw, 1986).

Similarly, diatom analyses in borehole A5/2 (Owen *et al.*, 1995) have clearly differentiated depositional regimes within the formation (Figure 10.28). Five zones have been recognized, based on the presence of the diatoms *Synedra spp.* and the total abundance of diatoms. These results confirm that salinity has fluctuated throughout the Holocene during deposition of the Hang Hau Formation.

In several areas, seismic profiles of the Hang Hau Formation reveal low- and high-angle intra-formational truncation surfaces. These erosional hiatuses are a feature of the evolution of the hydraulic regime in Hong Kong waters and are probably closely related to evolving or fluctuating hydraulic conditions in the Pearl River Estuary (珠江口) (Fyfe & Shaw, 1995). Progressive flooding of the early tidal channels during the marine incursion would have led to changes in regional and local current patterns, resulting in distinct phases of deposition and erosion.

In the case of the steep truncation in the East Lamma Channel (東博寮海峽) (Figure 10.14), the first depositional phase represents marine sedimentation after the early Holocene rise in sea level. The subsequent erosive event may have been associated with the breaching of the channel between northeastern Lantau Island and the mainland (Evans, 1988b) or to a fluctuation of sea level causing a change in current velocity. Any intertidal mud that originally filled the channel would have been removed relatively rapidly (over maybe tens of years) as a tidal pathway was established by erosional breaching in the narrows of Kap Shui Mun (汲水門) and the Ma Wan Channel (馬灣海峽).

The erosion surface is overlain by sediments deposited during the second phase, possibly in response to continued changes in the tidal regime. This may have been associated with the creation of the channel through Lei Yue Mun (鯉魚門) (Evans, 1988b).

The establishment of an additional tidal pathway in the east would have resulted in a change in tidal conditions that reduced current strength in the East Lamma Channel and establishing new depositional centres. An alternative hypothesis involves the breaching of the Rambler Channel (藍巴勒海峽). Either or both of these mechanisms would result in a greater flow through Victoria Harbour (維多利亞港) and a change to the depositional regime in the East Lamma Channel.

11. Fanling Formation

The Fanling Formation is a mixed alluvial and colluvial formation of Holocene age that is formally defined here. The formation occurs almost exclusively in onshore areas of Hong Kong where its main areas of development are in the northern New Territories (新界) on the Fanling (粉嶺) and Yuen Long (元朗) plains. The formation is also present in many other areas of Hong Kong. Alluvial components of the formation mainly occur in low-lying areas whereas colluvium is largely distributed on more steeply sloping ground. However, the alluvium and colluvium merge laterally and interdigitate, especially at the bases of slopes adjacent to floodplains.

Sediments of the formation are terrestrial in origin, and were deposited following the Holocene marine transgression. They are contemporaneous with the marine facies of the Hang Hau Formation defined offshore (Figure 5.2), and locally, especially in inshore areas, they may underlie, and interdigitate with, Hang Hau Formation sediments.

The formation has been mapped in detail (Map 3) on most, but not all, of the 1:20 000-scale geological maps produced by the Hong Kong Geological Survey and is described in accompanying memoirs. Depending on their origin, these onshore deposits have been variously mapped and described as Holocene alluvium, debris flow deposits, talus (rockfall) deposits, mixed debris flow and talus deposits, slide deposits, and slope debris. Deposits of the Fanling Formation often overlie sediments of the Chek Lap Kok Formation, although in some areas they may directly overlie bedrock in various states of decomposition. However, on some of the 1:20 000-scale geological maps, alluvial deposits of Holocene age, i.e. the Fanling Formation have not been differentiated from their Pleistocene equivalents, now included within the Chek Lap Kok Formation (Chapter 7).

Alluvial deposits of the formation typically consist of well-sorted to semi-sorted clay, silt, sand and gravel. Consistency is generally soft to firm, with many coarser deposits being loose and unstable in vertical sections. The colour usually ranges from light grey in areas of higher water table, indicating mild reducing conditions, to yellowish brown, indicating oxidising conditions above the permanent water table. Mottled sediments are rarely found, this being a more diagnostic characteristic of the older, more indurated sediments of the Pleistocene Chek Lap Kok Formation.

The Fanling Formation is absent in many onshore areas (Map 3) such as on the steepest slopes and hill summits. Where present onshore, the alluvial deposits of the formation may be up to 10 m thick in the lower courses of the rivers, but they are generally less than 5 m thick.

Near the bases of slopes, colluvial deposits interdigitate with, and to varying extents grade laterally and vertically into, alluvial deposits of the Fanling Formation. Consequently, they are an integral part of the formation, with the status of un-named members. Colluvium characteristically occurs as sheets on open hillsides or infills drainage lines, such as those concentrated in steep tributary valleys in the present topography.

The colluvial deposits of the Fanling Formation have not been systematically mapped. Only where they are more than 2 m thick, have the deposits been depicted on the 1:20 000-scale geological maps. They are shown on the maps and described in the accompanying memoirs variously as debris flow deposits, slope debris and slide deposits. In some areas they have been differentiated from similar deposits of Pleistocene age that form part of the Chek Lap Kok Formation. On some maps in the 1:20 000-scale series, the Holocene colluvial deposits include talus deposits, but elsewhere, talus is mapped separately. Some of the colluvial deposits overlie colluvial and, or alluvial deposits, of the Pleistocene Chek Lap Kok Formation. Locally, they overlie, or interdigitate with, Holocene marine deposits of the Hang Hau Formation.

The Holocene colluvial deposits are generally poorly sorted and commonly comprise a light yellowish brown, slightly clayey sandy silt to gravelly silty sand matrix containing subangular to angular slightly decomposed boulders with thin weathering rinds a few millimetres thick. The grain size typically varies with the topography, parent rock type and distance transported from source. Strange and Shaw (1986) described colluvial deposits containing boulders averaging 0.3 m to 0.8 m in diameter, with individual boulders of up to 10 m diameter.

Few figures are available for the maximum thickness of Holocene colluvial deposits that have accumulated over the undeveloped upland areas of Hong Kong. However, colluvial deposits that are 5 to 10 m thick are frequently encountered in boreholes. More substantial deposits, ranging up to 15 m in thickness, occur, for example on the slopes at Castle Peak(青山), Tsz Wan Shan (慈雲山) and Ap Lei Chau (鴨脷洲).

Type section

The Fanling Formation is formally defined here, with the type section occurring on the low ground below Wong Kong Shan (黃崗山), at the site of the Fanling Centre (粉嶺中心) development in Fanling (粉嶺) in the northern New Territories (新界). The formation here consists of 0.8 m of fill overlying a 1.55 m sequence of fine-grained, organic alluvial deposits, which in turn overlie an older mottled reddish brown clayey silt alluvium of the Chek Lap Kok Formation. In adjacent sections, the formation is up to 3 m thick.

The formation has an erosive base, which is immediately overlain by unmottled sandy, clayey silt sediments of the lower part of the formation. Sediments

are generally grey in colour, with white sand and dark organic lenses and inclusions.

Radiocarbon dating of a sample of dark grey organic mud at 1.9 m below ground surface (i.e. 1.1 m below the top of the formation) has yielded a date of 2 100 ± 90 years BP (Guangdong Institute of Geological Science, Sample No. 934).

Stratigraphical variation

No members are formally described within the formation, although there are many discrete colluvial deposits that have the status of un-named members. However, they have not yet been systematically mapped in all parts of Hong Kong enable them to be distinguished from colluvial deposits of Pleistocene age.

Regional lithological variation

New Territories (新界)

In the New Territories, alluvium of the Fanling Formation occurs mainly as narrow deposits adjacent to the recent

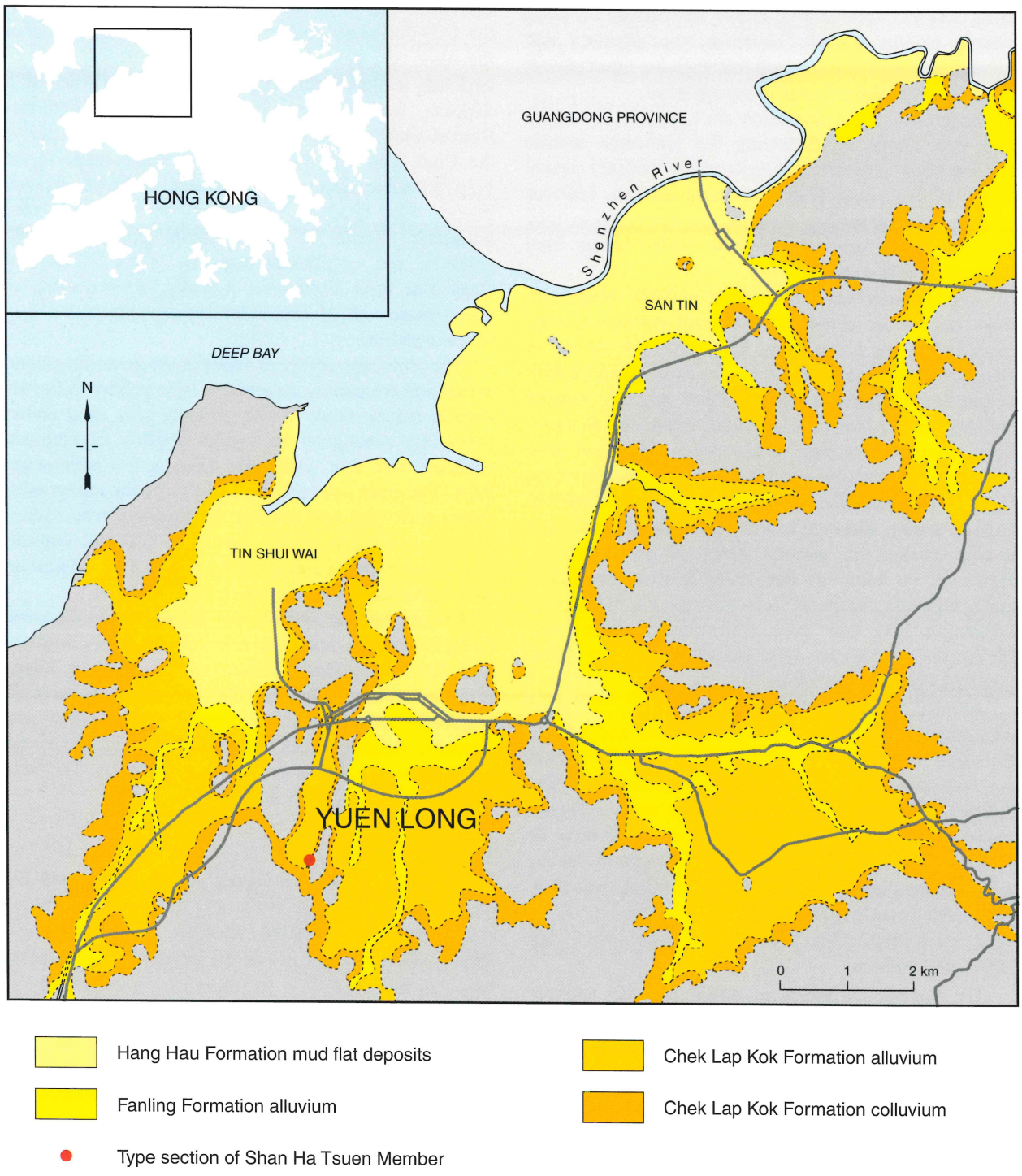


Figure 11.1 - Quaternary deposits in the northwest New Territories (新界)



Plate 11.1 - Holocene alluvium (Fanling Formation), Fanling Plain (粉嶺平原)



Plate 11.3 - Holocene colluvium (Fanling Formation) with loose matrix and angular gravel and cobbles, Ma Wan (馬灣)

stream courses. These channels are incised some 1 to 7 m into the broad Pleistocene alluvial terraces on the Yuen Long (元朗), Kam Tin (錦田) and San Tin (新田) plains (Figure 11.1) along the Tuen Mun (屯門) and Ngau Tam Mei (牛潭尾) valleys in the northwest New Territories. They also occur on the Sheung Shui (上水) and Fanling (粉嶺) (Plate 11.1) plains, and along the Sham Chun (深圳) and Ng Tung Ho (梧桐河) valleys in the northern New Territories. Alluvium up to 10 m thick occurs in the Ho Chung (蠔涌) Valley in the eastern New Territories.

Deposits comprise semi-sorted subrounded boulders and gravelly sand in upper stream courses, and yellowish brown, well-sorted clayey sand or silt in lower courses.

Most areas of alluvium of the Fanling Formation are low-lying, the surfaces being typically at less than +10 mPD. However, some small patches of hill alluvium are present, for example on areas of granitic outcrop, between Tsing Shan (青山) and Lin Fa Shan (蓮花山) in the northwestern New Territories, and in several parts of the eastern New Territories. This alluvium occurs in narrow, confined areas near the headwaters, especially where valley constrictions caused by geological factors



Plate 11.2 - Alluvial and estuarine deposits (Fanling Formation), Kuk Po (谷埔)

have acted as barriers across the stream courses. These alluvial deposits are generally only 50 to 100 m wide and usually extend for no more than a few hundred metres.

In places along the coast, streams are dammed by sand bars or spits, behind which freshwater or brackish lagoons have developed and lagoonal or back shore deposits have accumulated (Plate 11.2).

The colluvial deposits are light yellowish brown, slightly clayey sandy silt to gravelly silty sand. The clasts are slightly to moderately decomposed, subangular to angular boulders and cobbles (Plate 11.3) with weathered rinds on the larger boulders never more than a few millimetres thick. Deposits commonly vary from 1 to 3 m thick, but are up to 15 m thick, for example on the slopes of Castle Peak (青山), and typically overlie Late Pleistocene alluvial deposits. Offshore, they may be intercalated with, or overlie, Holocene marine deposits of the Hang Hau Formation.

Kowloon (九龍), Hong Kong Island (香港島) and neighbouring islands

Widespread deposits of Fanling Formation alluvium, up to 10 m thick, border Kowloon Bay (九龍灣) and occupy river valleys at Shek Kip Mei (石峽尾) and Kowloon Tong (九龍塘) in Kowloon, and at Happy Valley (快活谷) and Wong Chuk Hang (黃竹坑) on Hong Kong Island. These flat or gently sloping areas have mostly been obscured by buildings and other developments. Therefore, details about the distribution of alluvium have been mostly derived from aerial photograph interpretation and borehole records. Where undeveloped, the alluvial plain is either a major recreational asset, as at Happy Valley on Hong Kong Island, or is used for intensive agriculture, as in the Ho Chung Valley (蠔涌谷). The present alluvial surface generally lies 3 to 7 m below that of the Pleistocene alluvial terraces.

The alluvium typically comprises well sorted to semi-sorted grey to yellowish brown clay, silt, sand and gravel. Sand-size quartz grains are abundant where



Plate 11.4 - Holocene colluvium (Fanling Formation) of volcanic rock source, Mount Nicholson (聶高信山)



Plate 11.5 - Middle Pleistocene to Holocene alluvial deposits (Chek Lap Kok and Fanling formations), Po Chue Tam, Tai O (大澳寶珠潭)

mainly derived from a granitic source area, as in Kowloon.

Small patches of alluvium are common in upland valleys. Some valleys along the coast are dammed either by sand bars, as at Shek O (石澳) on Hong Kong Island, or by beach boulder barriers, as on the eastern side of Lamma Island (南丫島). As a result, lagoons have formed within which organic, silty lacustrine sediments have accumulated.

The colluvium is widespread in the area but has only been differentiated locally from Pleistocene colluvium. Most of the colluvium has been interpreted as debris flow deposits (Strange & Shaw, 1986). The deposits are described as poorly sorted and comprise boulders and cobbles in a gravelly clay matrix (Plate 11.4). The boulders are up to 10 m in diameter but generally less than 1 m in size. Granitic boulders, which are corestones exhumed from deep weathering profiles, are commonly subrounded whereas volcanic boulders and cobbles are typically more angular.

The colluvium usually infills valleys in the present landscape, in contrast to the Pleistocene colluvium that commonly occurs in spurs. On the northern slopes of Victoria Peak (扯旗山), the colluvium comprises soft to firm, uniform, pale brown clayey sandy silt with angular to subrounded, slightly to moderately decomposed cobbles and boulders. The deposits extend to the former coastline and possibly beyond where occasional boreholes indicate that the colluvium interdigitates with marine deposits of the Hang Hau Formation. For example, at Sheung Wan (上環) a tunnelling excavation revealed a colluvial lobe within the marine mud (Howat, 1985b).

Lantau Island (大嶼山) and neighbouring islands

Because of the generally steep and rugged topography on Lantau Island, alluvium of the Fanling Formation is only developed locally. It occurs in recent stream courses incised into Pleistocene fluvial terraces (Plate 11.5). The valleys are short, steep sided and mostly choked with bouldery colluvium. The alluvium comprises gravelly sand with some subrounded boulders in upper stream courses and yellowish-brown well sorted clayey sand or silt in lower stream courses.

With the exception of the Tung Chung Valley (東涌谷) and the Shek Pik Valley (石壁谷), alluvium is largely confined to the low-lying seaward ends of valleys. The surfaces of the deposits rarely exceed +10 mPD. The deposits therefore occur either as short linear valley fills, or as wide fans along the coastal zone. At several localities along the coast, such as at Pui O (貝澳), sand spits have dammed the streams and lagoonal deposits have accumulated behind the barriers.

In the Tung Chung Valley, alluvium forms a series of narrow strips, less than 100 m wide, adjacent to the present stream channels incised into the older terrace by up to 3 m. At Shek Pik (石壁) an extensive alluvial deposit fills the valley now occupied by the Shek Pik Reservoir (石壁水塘). A series of coalescing lacustrine fans mantle its eastern slopes.

Age

Radiocarbon ages have been reported from the formation at several localities, mainly in the New Territories (新界). The ages have been obtained from a variety of materials including rootlets, wood fragments, organic mud and a shell fragment. Ages range between 520 ± 112 years BP (South China Sea Institute of Oceanology) from the mud flat at San Tin to 6 760 ± 130 years BP (Guangdong Institution of Geological Sciences) from the mud flat at Yuen Long (元朗).

At Sheung Wan (上環), Howat (1985) identified marine mud of the Hang Hau Formation, underlying a possible colluvial lobe of the Fanling Formation The marine mud contained a fragment of wood that yielded a radiocarbon age of 8 600 ± 270 years BP.

Recently, King (1998) has reported two luminescence dates for material obtained from within a very large colluvial lobe at Sham Wat (深屈) in northwest Lantau

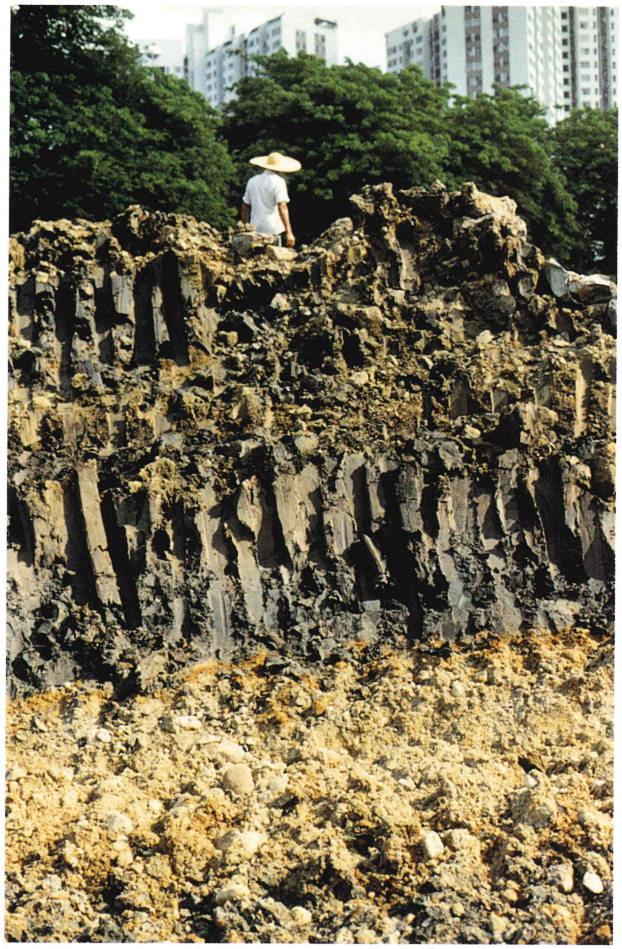


Plate 11.6 - Holocene alluvial black mud (Fanling Formation) overlying cobble-bearing silty sand of Late Pleistocene (Chek Lap Kok Formation), Luen Wo Hui (聯和墟)

Island (大嶼山). The dates, which were quoted as 'best estimates', are 1 400 ± 200 years BP and 2 200 ± 300 years BP (Nordic Laboratory, Denmark).

Depositional environment

The Fanling Formation is an actively accumulating formation. Older depositional environments associated with the formation are thought to have been broadly similar to those at present. However, changes in the fluvial discharge during the Late Pleistocene climatic amelioration and the Holocene climatic optimum at c.5 500 years BP would have probably caused variations in sediment load volumes and grain sizes.

The colluvium comprises accumulations of material transported by a broad spectrum of gravitational processes, many of which are water mobilized. They therefore include primary landslide deposits, accumulations related to the secondary mobilization of landslide deposits, and other mass movement processes. Most of the the colluvium probably originated from sources on slopes with gradients of between 30 and 40 degrees, similar to recent natural terrain landslides in Hong Kong (Evans & King, 1997). Some colluvial debris has probably been derived directly from the failure of *in situ* rock (of weathering grade III or better), generating rock fall, rock slide or rock flow deposits. However, most colluvium is probably derived from the failure of slopes comprising mainly soil and, or, colluvium. Analogy with recent natural terrain landslides in Hong Kong (Evans & King, 1997) suggests that the dominant mechanisms of failure and transport are likely to have been debris slides, debris avalanches and debris flows, with some compound and other more complex mechanisms. Certain rock types appear more susceptible to slope failure than others. In a comprehensive review of the distribution of recent and relict landslides observed on high level aerial photography and incorporated within the Natural Terrain Landslide Inventory, Evans and King (1997) concluded that certain lithologies, such as those of the Lai Chi Chong Formation, have higher susceptibility to landslides than others. Consequently, it can be inferred that these same lithologies have also been more susceptible to generating colluvium during the evolution of the Fanling Formation.

Some colluvium is concentrated within pre-existing stream channels, where there was an increased likelihood of the debris mixing with water, enhancing its mobility and so generating debris avalanches or debris flows, further expanding the distribution of the material.

Downslope, the colluvium generally grades downslope into, and interdigitates with, fluvial and alluvial deposits. In the headwaters of the streams, these are typically high energy deposits laid down within the narrow channels of ephemeral streams during flash floods. Further down stream, as the gradient decreases, the channels broaden and begin to meander. Seasonal fluctuations in discharge, coupled with the more extreme short-term variations during typhoons and tropical depressions, have resulted in extreme variations in depositional environment and hence in the grain size and bedforms of the deposits. The importance of alluvial floodplain deposition, compared with fluvial deposition within the main distributary channels, increases downstream. Floodplain deposits reach their maximum development in the northwestern New Territories (新界). Temporary seasonal lakes, some developed as a result of the abandonment of channels while others have developed on the floodplains, have resulted in the accumulation of organic-rich clays (Plate 11.6). Similarly, lacustrine deposits have also accumulated in lagoons developed near the coastline inland from sand bars and spits.

12. Resources

Hong Kong contains a diverse range of geological materials that have been, or still are, resources of economic importance. These broadly comprise three main categories: firstly, metallic vein minerals (formed mainly by Mesozoic igneous activity) and non-metallic industrial minerals; secondly, quarried rock and building stone; and thirdly, offshore sand deposits. This account deals with placer deposits derived from the first category, occurring in both the *in situ* weathered rocks and in the transported superficial deposits, and with the third category.

Archaeological evidence indicates that localized mining of the more easily obtained minerals, such as clay for pottery and iron for smelting, has been carried out since at least the Late Neolithic. Larger scale mining, organized on a more commercial level, began in the late 19th century. However, all mining records prior to 1945 were destroyed during the war. Post-war mining records and plans, gathered by the former Mines Division of the Labour Department, are now held by the Geotechnical Engineering Office.

Onshore resources

A range of metallic and non-metallic minerals have been produced in Hong Kong from both the *in situ* weathered rocks and the transported superficial deposits (Figure 12.1). Over much of the area, the thick weathered mantle severely hindered prospecting by masking the solid geology. However, in some areas the weathered material itself was a source of economic minerals, and in particular of clays. Weathering may also release metallic minerals from the host rock. These may then be eluviated or transported to sites were they are concentrated, accumulating as placer deposits.

Prospecting and mining have always played a subordinate role to other interests competing for the limited land area in Hong Kong. Furthermore, shortage of suitable waste disposal sites, stabilisation of spoil on steep slopes and in heavy rain, wet season erosion of mining areas and dry season water shortages affecting wet mineral dressing, are further problems that have restricted mining activity.

The first Prospecting and Mining Ordinance of 1906

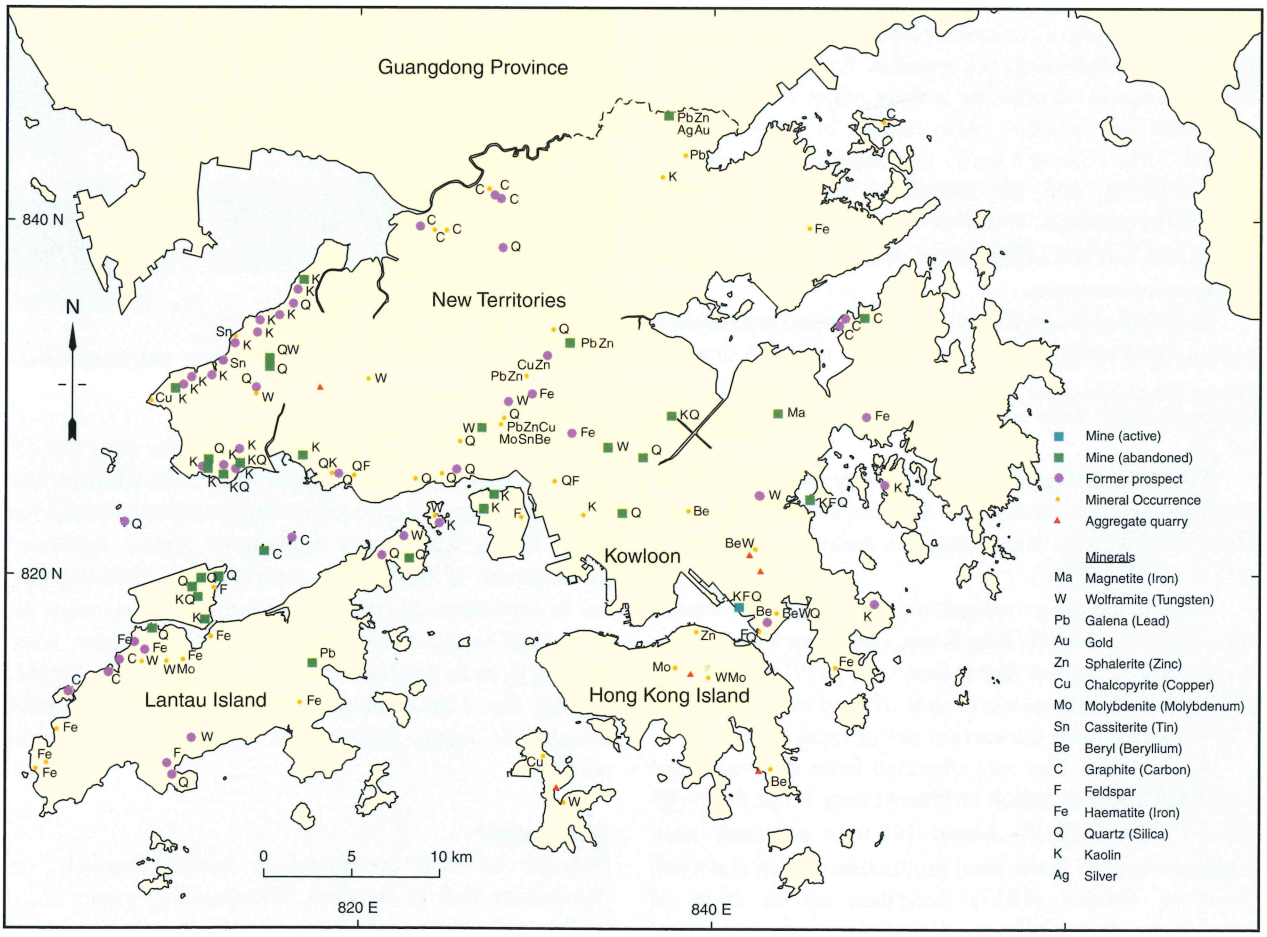


Figure 12.1 - Location of economic mineral occurrences in Hong Kong

allowed the Hong Kong Government to grant prospecting licences and mining leases, but only for areas in the New Territories (新界). A Mines Department was established in 1951. Comprehensive legislation was enacted in 1954, following concern over extensive damage to the landscape that resulted from a boom in illegal mining. No prospecting licences or mining leases are currently issued.

Despite its limited scope, mining, and particularly prospecting, have had a significant effect on the appearance of the landscape in several areas of Hong Kong. Degraded prospecting pits, trenches and shallow adits are scattered throughout the New Territories. Some of these are large scale features and clearly man made, but many smaller trenches may be confused with natural erosion scars or war-time fortifications.

Non-metallic minerals

Historically, the clays and non-metallic minerals have been the most economically important mineral resources in Hong Kong. Precious metals, although present, occur only in minor amounts.

Clays

Clay minerals are mainly the products of rock weathering. The sub-tropical climate of Hong Kong has favoured intensive and deep chemical weathering, so that clays are common in weathered rock mantles. Economic deposits of clay minerals accumulate in three major ways.

Eluvial, or residual, clays remain in the weathered mantle. They achieve a purity that depends on the degree of weathering and the extent of removal of other weathering products. Residual clays from Brick Hill (南朗山) and San Hui (新墟) were used to make a range of bricks, tiles and pipes.

Colluvial clays, or eluvial clays deposited near to their source, have traditionally been used by villagers to make sun-dried bricks, roofing tiles and coarse porcelain ware, although some were used commercially to manufacture bricks.

Alluvial, or river transported, clays usually occur as stratified beds on floodplains near the coast and on tidal flats. Workings existed at San Hui, making hollow ware, and at Lo Wu (羅湖).

Archaeological investigations have revealed twenty-nine kiln sites around Hong Kong, dating back to the Late Neolithic and Bronze Age (Meacham, 1979). Most of the kilns and their fittings were made of fired clay (Cameron, 1979a), confirming the earliest use of local deposits.

A fine white clay was obtained from the weathered Lok Ma Chau Formation sediments near Pillar Point (望后石) (Davis, 1952). About 100 tons a month were washed and used in the local production of face and tooth powders. Ruxton (1957) described up to 20 m of weathering on low hills in silicic volcanic rocks west of San Hui that contained large reserves of good clay similar to that used extensively for bricks, tiles, pipes and ornamental ceramic ware. Raw clay from stratified clay deposits, about 5 m thick, in between the hills were being used to make ordinary bricks, and the washed clay for hollow bricks. Other brick works were located at Tsing Yi (青衣), southwest of San Tin (新田), around Sheung Shui (上水), and near Au Ha (凹下) (Starling Inlet).

Kaolin

Kaolin mining has long been a feature of the economic activity of Hong Kong. During the 1950s, kaolin for local consumption was obtained from several small workings throughout the New Territories (新界) (Knapp, 1964), particularly from Tai Lam Chung (大欖涌) and northwest of Castle Peak (青山) (Ruxton, 1957), and from Chek Lap Kok (赤鱲角) (Plate 12.1). Total kaolin production in 1960 was 6 663 tons. One kaolin prospecting licence was issued in 1960, but no economically important discovery was made.

The largest kaolin working was a quarry at Cha Kwo Ling (茶果嶺) that produced good quality kaolin for export. The kaolin occurred mainly within a 50 m wide

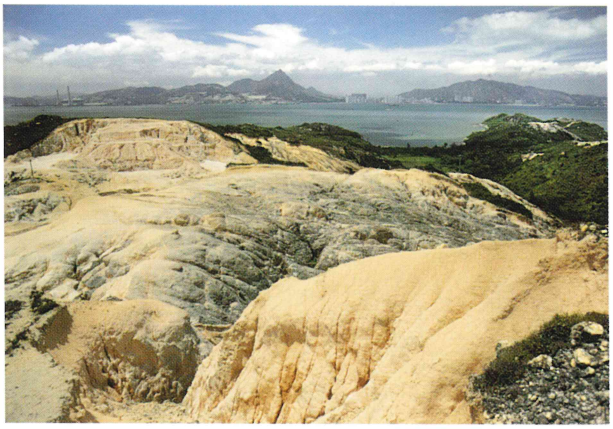


Plate 12.1 – Kaolin mine on the former island of Chek Lap Kok (赤鱲角)

east–west trending weathered quartz syenite dyke (GCO, 1986) in medium-grained granite. The dyke contains less quartz and more alkali feldspar than comparable dykes in Hong Kong, which may explain its almost exclusive development of kaolin when weathered. Variable quality led to separation of nine kaolin grades, which were air dried and stored prior to blending. Some clays were washed in tanks to reduce the silica and feldspar content. During the 1960s, about 5 000 tons were exported annually to Japan. Mining was active from 1939 until recently.

Quartz sand

Deposits of sand are found in stream channels, on floodplains and in beaches. Composition varies from well-sorted, pure, colourless quartz to poorly sorted deposits containing iron oxides, mica and feldspar. High quality sand suitable for glassmaking occurred in the

beach at Lau Fau Shan (流浮山), and the beaches around The Brothers (大小磨刀) islands contained quartz sand with a silica content of 90% to 95% (Davis, 1952).

Prior to the use of granite quarry crushing fines and imported river sand, local river sands and beach sand were used as aggregates in concrete (Ruxton, 1957).

Metallic minerals

A wide range of metallic minerals have been identified in the rocks of Hong Kong. However, very few occur in sufficient quantities to have been economically mined, and even fewer were incorporated in Quaternary superficial deposits.

Limonite

Davis (1952) described limonite deposits as being widespread throughout Hong Kong. Residual deposits, of ferric hydroxide mixed with clay and other impurities, were ascribed to tropical weathering and intense leaching of the iron-rich igneous rocks forming illuvial chemical precipitates. Various limonite deposits were worked in the 1950s. Up to 75 tons were used locally every month. Termed ochres, the red and brown ochres were milled and the powder was used to manufacture anti-corrosion paints, as a filler in red rubber, and as a pigment for red cement and floor tiles.

Several occurrences of residual limonite have been documented (Davis, 1952). An extensive deposit of red, nodular illuvial limonite was discovered at Kei Lun Wai (麒麟圍) near Castle Peak (青山). This resulted from oxidation weathering and intense leaching of the Lok Ma Chau Formation schists. The deposit formed an iron-pan about 60 centimetres below the surface of cultivated fields in the area. Surfaces covered with limonite nodules are a characteristic feature of deeply weathered granite terrain in the New Territories. In particular, small hills of decomposed granite along the Castle Peak Road were found to contain high percentages of limonite.

Tungsten

Tungsten, occurring as wolframite and scheelite (tungstates of iron, manganese and calcium), was largely produced by underground mining. However, alluvial or placer deposits, resulting from weathering and erosion of the wolfram veins, have been found along streams. The largest wolfram placer was in the Shing Mun River (城門河) below the Shing Mun Mine (城門鑛). This was discovered in 1935 while excavating sediments during construction of the Jubilee Reservoir (城門水塘) (Hui, 1978). Following the increase in the price of wolfram between 1949 and 1951, an estimated 5 000 freelance miners searched for wolframite in the Needle Hill (針山) area, including panning and sluicing the alluvial deposits in the Shing Mun River.

Residual wolframite, from weathered granite and greisen, on northeastern Lantau Island (大嶼山) was worked by sluicing and panning (Davis, 1964). The former technique stripped the land surface and produced an unvegetated, highly eroded badland topography.

Tin

Ormsby (1898) commented that deposits of silver and alluvial tin had been reported by the local population. According to Davis (1952), there is no record of tin mining in Hong Kong, although he described placer tin deposits around Kam Tin (錦田), and eluvial tin placers in the residual soils near Sheung Tong (上塘).

Commercial placer deposits of cassiterite were proved southwards from the Kam Tin plain, derived from the pneumatolytic veins on the southwestern slopes of Tai Mo Shan (大帽山). Both fluviatile and eluvial placers were located. Fluviatile placers occur as lag deposits on valley sides and in stream bed depressions following the erosional removal of the weathered host rock. Eluvial placers formed by accumulation of the resistant tin in the clayey residual soils.

Gold

Gold in minute quantities has been discovered in placer deposits in several alluvial areas (Davis, 1952). Pyrite and gold, from weathered quartz veins, have been noted at Sheung Tong (上塘), and found associated with tin deposits below Tai Mo Shan (大帽山).

Offshore resources

The offshore area of Hong Kong occupies about 60 percent of the total area of the Special Administrative Region. However, until recently, this important potential resource had remained largely unexplored and undeveloped.

Early settlements in Hong Kong were confined to coastal locations (Schofield, 1975) and coastal and nearshore mining have been an integral component of the local economy since prehistoric times. This mining was small-scale, localized and specialized. For example, coral and shells were extracted for lime and fertiliser, and marine mud was used locally for brickmaking.

Seabed sand was first used on a large scale for major engineering projects in the 1950s. The offshore granular material was dredged as both fill and aggregate. The consumption of seabed sand increased markedly in the 1980s and 1990s as the scale of reclamation increased.

Offshore sand deposits

The demand for aggregate sand and reclamation fill in Hong Kong has grown as the rate of urban development has increased. Fine aggregate sand was extensively extracted from beaches around Hong Kong in the 1920s and 1930s. Over-exploitation led to the enactment of the Sand Ordinance in 1935, which was designed to regulate removal of natural sand. It was in the 1950s, that the first major engineering projects began to use seabed sand. Offshore granular material was dredged as both fill and aggregate.

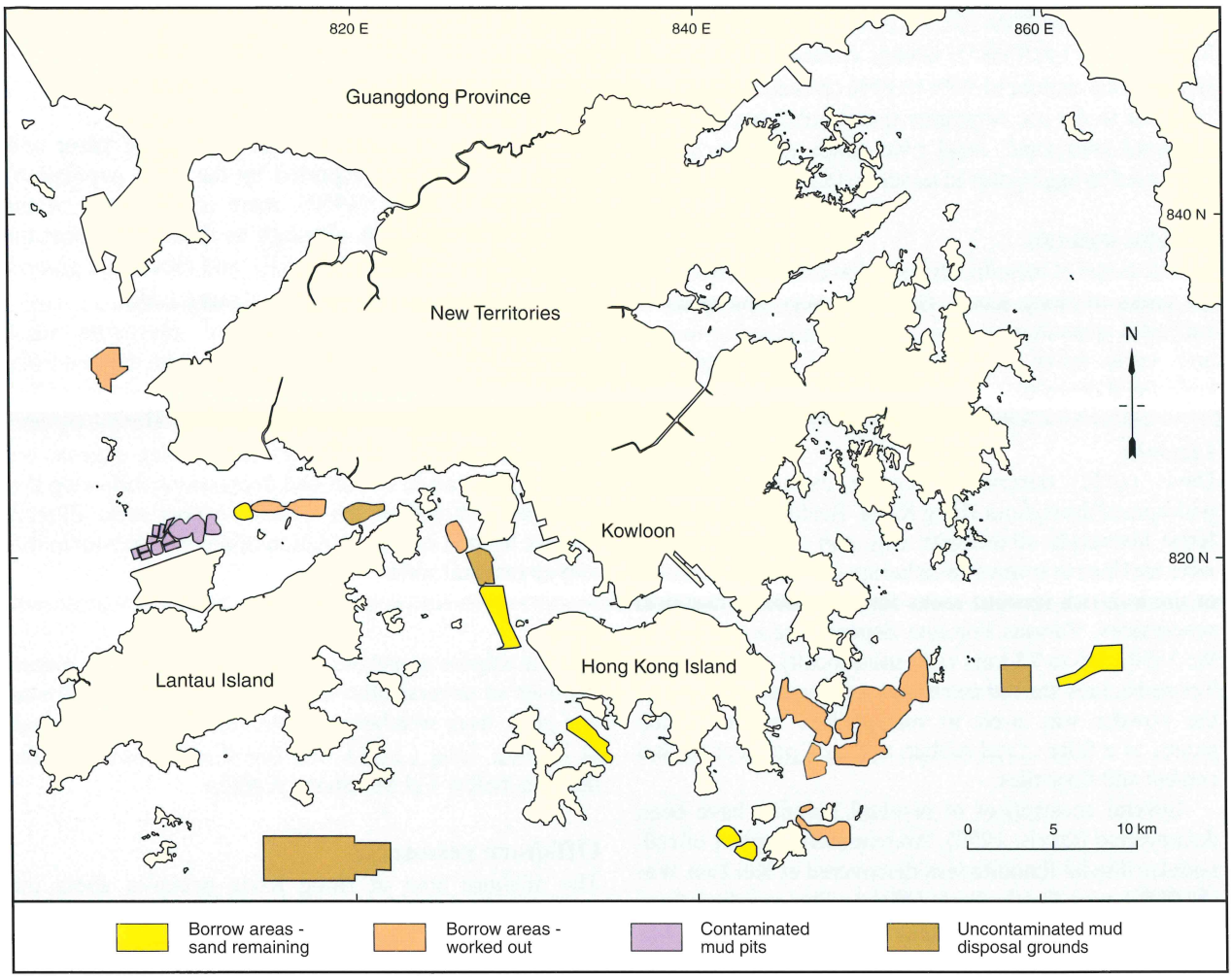


Figure 12.2 - Seamat resources, borrow areas and disposal grounds

During the 1960s, the then Public Works Department of the Hong Kong Government carried out a sand survey and compiled an inventory of some 30 Mm^3 of marine sand that was considered to be suitable for a variety of uses, including seawall foundations, construction aggregate and filter beds. However, by the 1980s, the scale of reclamation increased and most known sources were either depleted or concealed by reclamations.

Detailed offshore geological surveys and mapping began in 1982 to provide a geological framework to support marine geotechnology applications and offshore infrastructure projects (Premchitt & Shaw, 1991; Martin *et al.*, 1997) and to assist the exploration for offshore sand resources (Shaw & Cheung, 1995; Whiteside & Cheung, 1996).

In anticipation of the large quantities of fill required by planned major reclamation projects, the Geotechnical Control Office (now Geotechnical Engineering Office) began the Marine Sources of Fill Study in January 1987 (Choot, 1988). This prospecting survey was designed to locate 100 Mm^3 of granular fill in western and central waters. Following this preliminary survey, the Seamat (**Sea**bed **mat**erials) Study was begun in July 1988. This was a phased regional survey designed to locate and investigate all major offshore deposits of sand and gravel that could be used as fill material or building aggregate (Thorley *et al.*, 1990; Cheung & Shaw, 1993).

Prospecting investigations for the sand surveys were based on the prevailing understanding of the offshore Quaternary stratigraphy (Strange & Shaw, 1986) and palaeogeography of Hong Kong (Shaw & Arthurton, 1988), from which it was predicted that sand deposits were to be found in several discrete geological environments (Shaw, 1988).

The Seamat Study located fourteen major sand bodies that contained a total volume of 588 Mm^3 of identified resources (Figure 12.2). The Fill Management Study (FMS) (Whiteside, 1991) assessed these potential sand sources in greater detail, and determined their economic viability. Initially the more accessible sand deposits at or near the seabed were investigated and extracted. As these were worked out, the more inaccessible deposits were then considered. Several of the sand sources proved not to be economic reserves. For example, the muddy overburden at the target in the Tolo Channel (赤門) was found to be too polluted. In addition, the potential

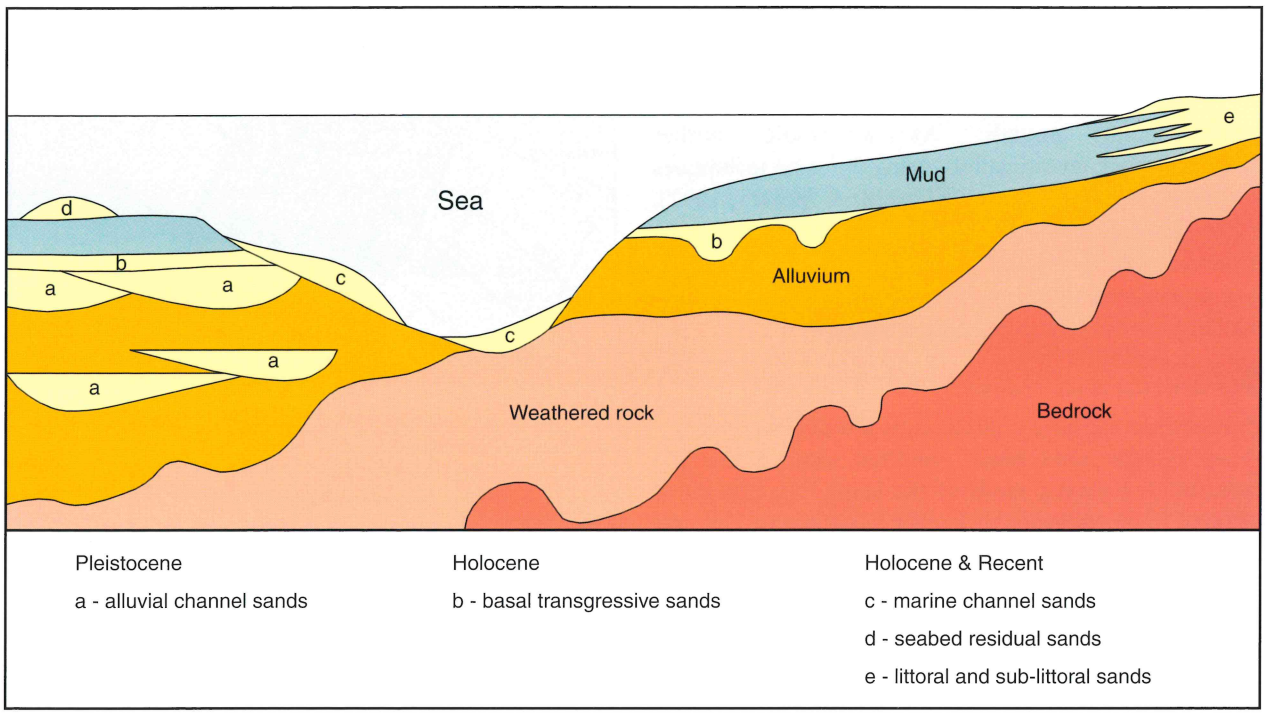


Figure 12.3 - Schematic representation of the modes of offshore sand occurrence (after Shaw, 1988)

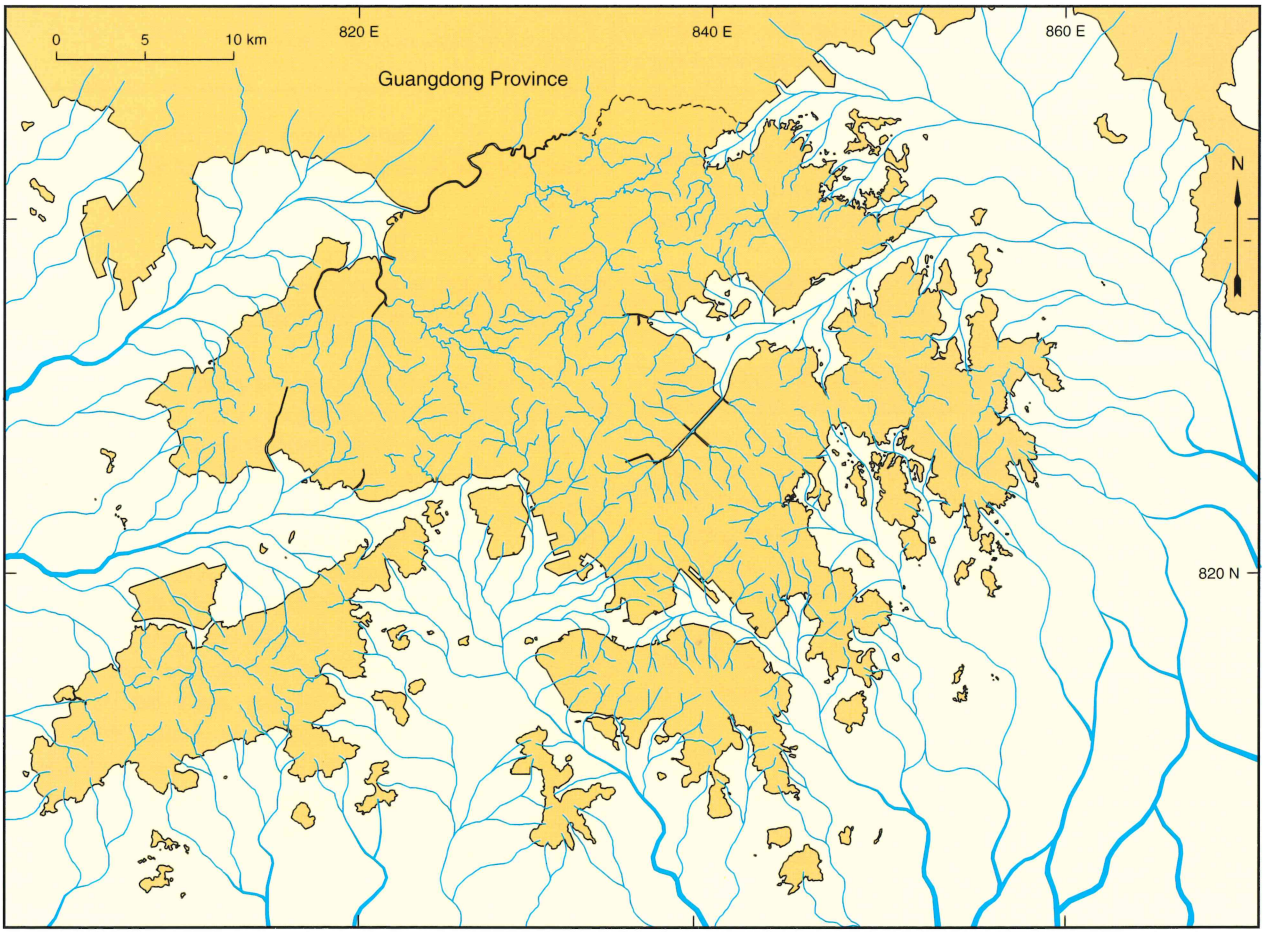


Figure 12.4 - Schematic reconstruction of the Late Pleistocene drainage pattern

resources offshore of Tai Long Wan (大浪灣), in the south of Mirs Bay (大鵬灣) and at High Island (糧船灣洲) and Basalt Island (火石洲) were left undredged on environmental grounds. As a result, further reconnaissance investigations, using the same techniques as before, were carried out (Whiteside & Massey, 1992), some in waters outside Hong Kong. Further economic reserves were identified. The current combined reserves are considered sufficient for Hong Kong's needs for reclamation fill well into the next century.

Depositional environments

Some of the offshore sand deposits are of Holocene age. They include sand banks, residual sand sheets and sublittoral shoreface sands of the Hang Hau Formation (Figure 12.3) (Chapter 10). The distribution of the granular seabed deposits is principally controlled by the location of the contemporary tidal channels and associated strong tidal currents. Transgressive sands, of variable thickness, occur at the base of the Hang Hau Formation.

Buried beneath the Hang Hau Formation marine deposits are the older, and commercially more important, Pleistocene river channel sands of the Chek Lap Kok Formation. Locating these deposits demands a knowledge of the patterns of the former Pleistocene drainage lines (see Chapter 7). During the sea level lowstands of the Pleistocene period, distributaries of the proto-Pearl River (珠江) extended southwards and large, braided sandy rivers deposited complex patterns of river channel sands over the exposed continental shelf. These channels had little direct influence upon Hong Kong, but constituted the regional base level to which the extended local streams were graded (Figure 12.4).

During the early stages of the Holocene marine transgression, large tidal channel systems developed in western and southeastern waters (Chapter 10). These were filled with sandy sediments of the Tung Lung Member of the Hang Hau Formation. When the area was finally inundated, towards the maximum of the Holocene transgression, the regional ravinement surface (R2) (Chapter 10) was formed. The underlying sediments were initially winnowed to produce a sandy basal transgressive sand, the Kwo Chau Member, which may be up to 2 m thick. Subsequently, a thick blanket of silty marine mud, the Tseung Kwan O Member, was laid down over most of Hong Kong waters. However, current flows in and adjacent to the main tidal channels prevented the accumulation of the finer-grained muds.

Thus the floors of the main channels were either left uncovered, or coarser-grained sandy sediments were deposited (Figure 12.3). Strong currents in some of the deeper channels have swept the seabed clean, exposing the bedrock surface.

The Marine Sources of Fill Study (Choot, 1988) and the Seamat Study (Cheung & Shaw, 1993) focused attention on these several modes of offshore sand occurrence. Reconnaissance seismic survey grids were aligned with the long axis of the channels and bays, to correspond with the anticipated orientation of the elongate granular bodies (Figure 12.5).

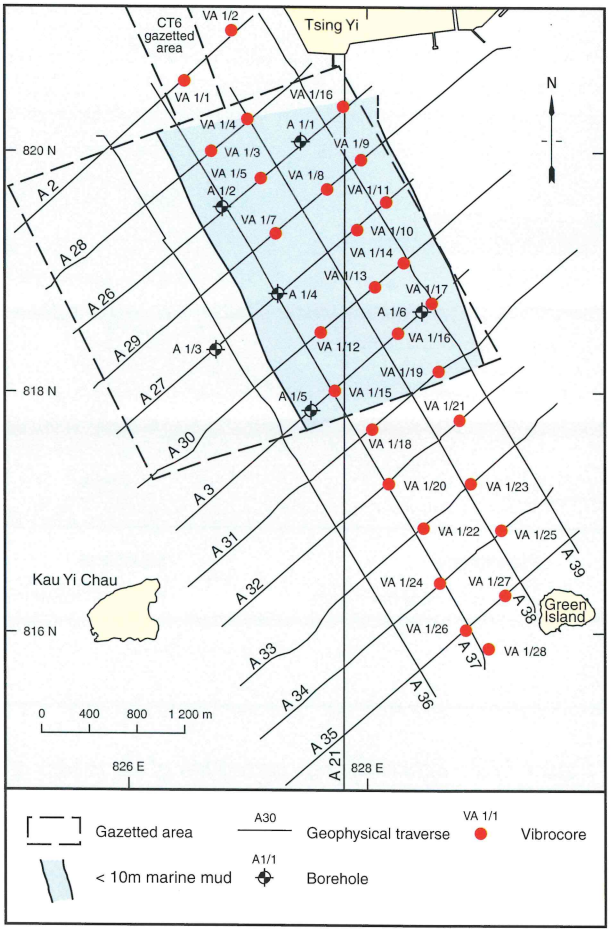


Figure 12.5 - Seismic survey lines and investigation holes over the Seamat sand resource at South Tsing Yi (青衣)

Detailed resource evaluations (Addison *et al.*, 1988) of these targets and dredging case histories, while substantiating the initial model (Shaw, 1988), have provided a more complete understanding of the various modes of offshore sand occurrence (Whiteside & Cheung, 1996). For example, these investigations confirmed that the most economic deposits were located where the Holocene tidal channels, with their thin mud cover, coincided with Pleistocene river channels (Whiteside, 1991). Investigations also confirmed that the geological characteristics of the sand bodies varied depending on the environment in which they were deposited. For example, the seabed residual sand sheets were found to be generally well sorted, fine and muddy, whilst littoral and channel deposits are coarser and more variable in geometry and lithology. The transgression appears to have introduced only minor amounts of new granular material offshore, some sediment probably being derived by removal of proximal and mass movement deposits from the reactivated coastline. An

important process during the Early Holocene was reworking of the Pleistocene channel sands deposited along the palaeo-drainage lines. This reworking produced a distinctive layer of sub-rounded quartz grains containing comminuted shell fragments. These basal transgressive sands (Figure 12.3) remain exposed at the seabed in areas where strong currents have prevented mud deposition. An economically important example occurred to the south of Tsing Yi (青衣) (Figure 12.5) (Whiteside, 1988b). In other areas, tidal reworking during the Early Holocene built up low, migrating, asymmetrical sand banks, such as that to the north of Lantau Island (大嶼山) (Evans, 1988b) (Figure 10.19). This feature became moribund as the sea level continued to rise and ultimately was partially buried by marine mud. In areas of strong currents, such as the Tathong Channel (藍塘海峽), residual sand sheets occur at the seabed (Shaw, 1988). The surface of these sands is commonly characterised by patterns of migrating sand waves that are clearly revealed on side scan sonar records (Figure 10.20). In the deeper tidal channels, such as Kap Shui Mun (汲水門) and Lei Yue Mun (鯉魚門), sand bodies have accumulated on the channel floors or against the channel walls.

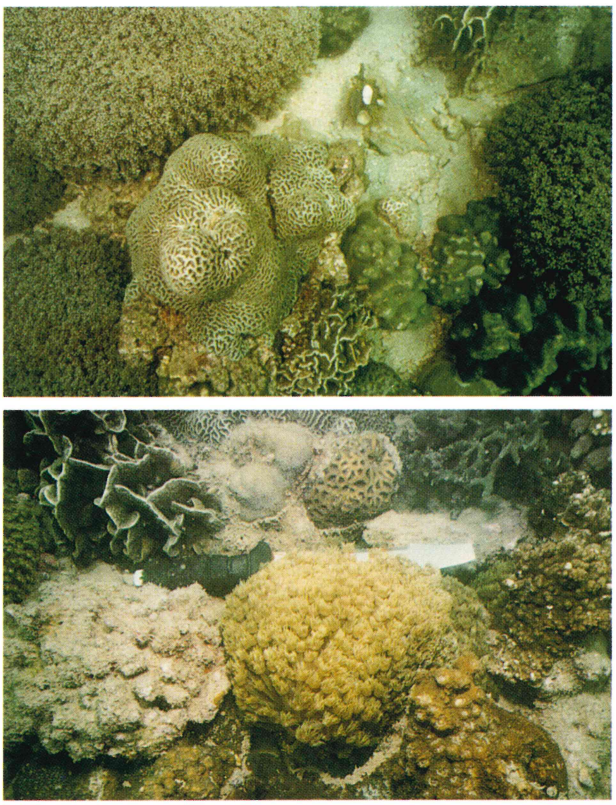


Plate 12.2 - Coral communities from near Ping Chau (平洲)

Coral and shells

The absence of limestone in coastal areas of Guangdong (廣東) Province led to the development, between 300 and 900 AD and again during the 19th and 20th centuries, of a local lime industry, using shells and coral (Plate 12.2), (Cameron, 1979b). Twenty-nine early kiln sites, located near coral beds, have been recorded in Hong Kong (Meacham, 1979) (Plate 12.3), mainly in the southwest around Lantau (大嶼山) and Lamma islands (南丫島). Later kilns were concentrated in the New Territories (新界) where, according to the Government Gazette of 1901 (Anonymous, 1979), the lime industry was the largest at the time. The slaked lime was used widely in building (Cameron, 1979b), as a fertiliser, and for desalination of reclaimed intertidal muds. Lime kilns continued to operate until 1948.



Plate 12.3 - Exhumed lime kilns at Fu Tei Wan (虎地灣) on the former island of Chek Lap Kok (赤鱲角)

13. Seabed development

The offshore area of Hong Kong occupies about 60 percent of the total area of the Special Administrative Region. During this century, attention has been directed to the seabed as a solution to various problems faced by Hong Kong. Since 1945, the population of Hong Kong has grown rapidly with a consequent increase in the demand for housing and related industrial and commercial development. Plans for urban expansion were constantly hindered by the limited areas of suitable flat land. Consequently, attention has increasingly been focused on the potential resources at and below the seabed, and especially on the development of urban reclamations (Figure 13.1). In addition, the seabed has been used for the disposal of various materials, the most important of which in recent years, has been marine mud dredged elsewhere. The various uses of the seabed, described below, are shown on Map 2, and the main areas where seabed sediments have been significantly affected by man's activities are shown on Map 6.

Reclamation

The earliest reclamations were on tidal flats in the New Territories (新界), in particular at Sha Tau Kok (沙頭角), Nam Chung (南涌), Luk Keng (鹿頸), Shuen Wan (船灣) and Yuen Long (元朗) (Guilford, 1997). These were carried out primarily to create new agricultural land, using fences of bamboo pickets behind which marine mud bunds were built up. Freshwater was periodically introduced through sluices to leach and desalinate the muds. Reclaimed intertidal areas were considered suitable for agriculture after seven years. Following several years of ploughing and planting the reclaimed mud, the top plough layer was removed and used as a clay for brickmaking. Many traditional New Territories (新界) houses adjacent to the mudflats were constructed of bricks made from desalinated marine muds.

Following the land auctions of 1841, small urban reclamation began around Victoria Harbour (維多利亞

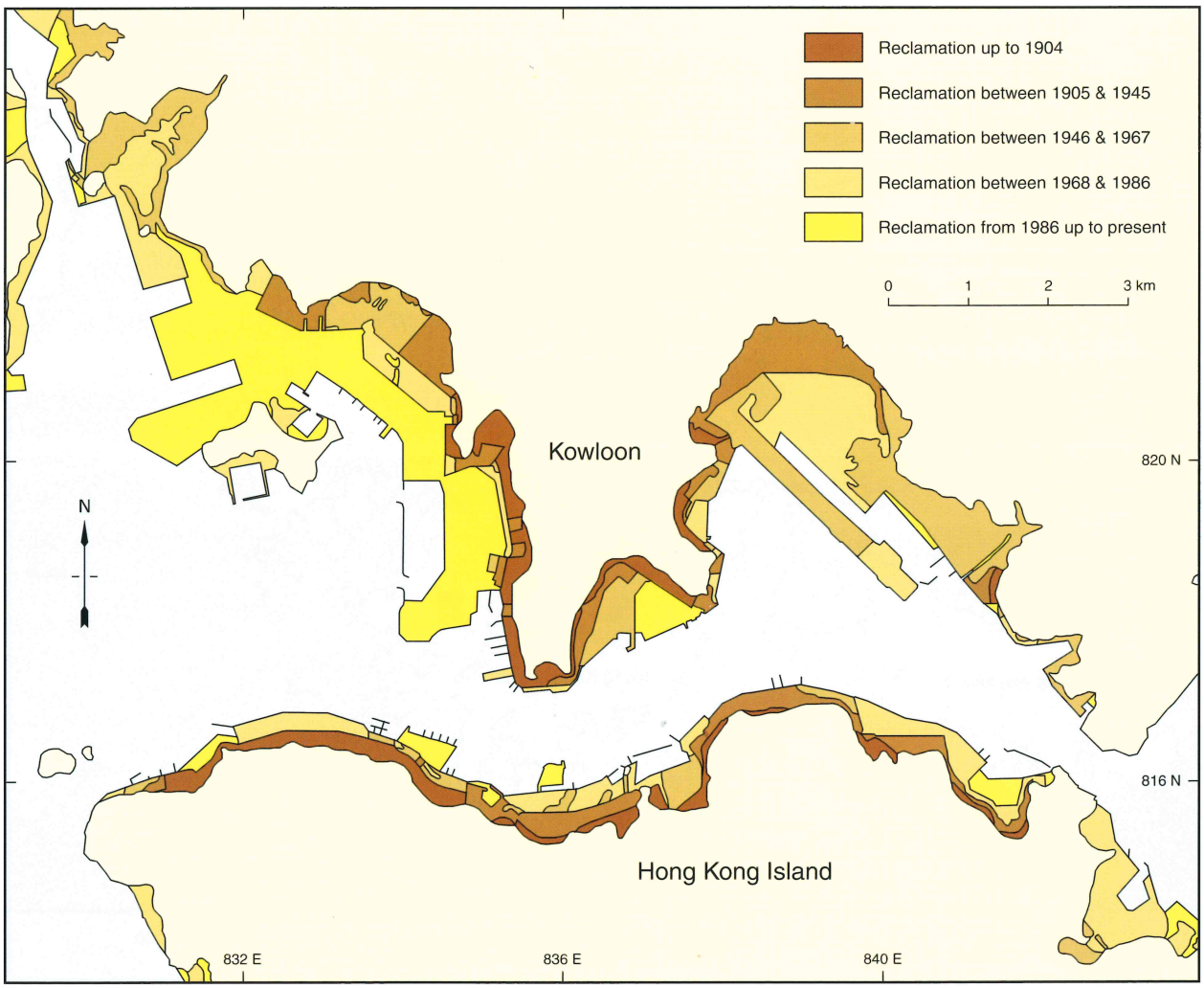


Figure 13.1 - The development of reclamation in Hong Kong

港) and formal waterfront reclamation commenced in 1851. By 1886, an 8 km long strip had been formed between Kennedy Town (堅尼地城) and North Point (北角) and areas of the West Kowloon (西九龍) waterfront had been extended. Further phases of reclamation occurred in the 1890s, the early 1900s, the 1920s and the 1950s (Guilford, 1988). By 1967, a total area of 1050 hectares had been reclaimed (Figure 13.1).

Early reclamations were, in general, confined to relatively narrow coastal strips in shallow water. More extensive reclamation into deeper water began in the 1970s. By 1991 a further 3 050 hectares had been completed, most of which was in deeper water. Between 1991 and 1995, large reclamations were constructed in connection with the new airport and related infrastructure projects. Up to 1995 a total of 6 000 hectares of land had been reclaimed (Figure 13.1 and 13.2). This new land, which represents about 2% of the onshore area, has provided land for housing about 20% of the population.

Initially the small, localized reclamations were completed using urban waste and spoil from nearby excavations. As urban development expanded on to the Kowloon peninsula (九龍半島) during the 1900s, extensive hillside cutting was carried out to create building platforms. This produced a supply of fill material, mainly of residual weathered granitic rocks, that was used to reclaim onshore valleys and extend coastal sites. This material was also used for stabilisation work (Henry & Grace, 1948a, 1948b), construction of earth dams (Ruxton, 1957), and for mortar and aggregate (Redmond, 1936). Early reclamations were formed mainly by end-tipping directly onto the underlying marine deposits. In some instances, this practice led to displacements of the soft sediments and to the creation of mud-waves beneath the fill. Early reclamation also adopted balanced cutting and filling, creating additional development platforms on the borrow areas (Guilford, 1997). As Kowloon (九龍) became more urbanized, fill had to be sought from farther afield, and land sources, usually in the New Territories (新界), were identified.

Granular fill material from the seabed was first used to develop Kai Tak airfield (啓德機場). Kai Tak opened in 1924, but was extended in 1929 and 1931 partly using hydraulic fill from Victoria Harbour (維多利亞港)

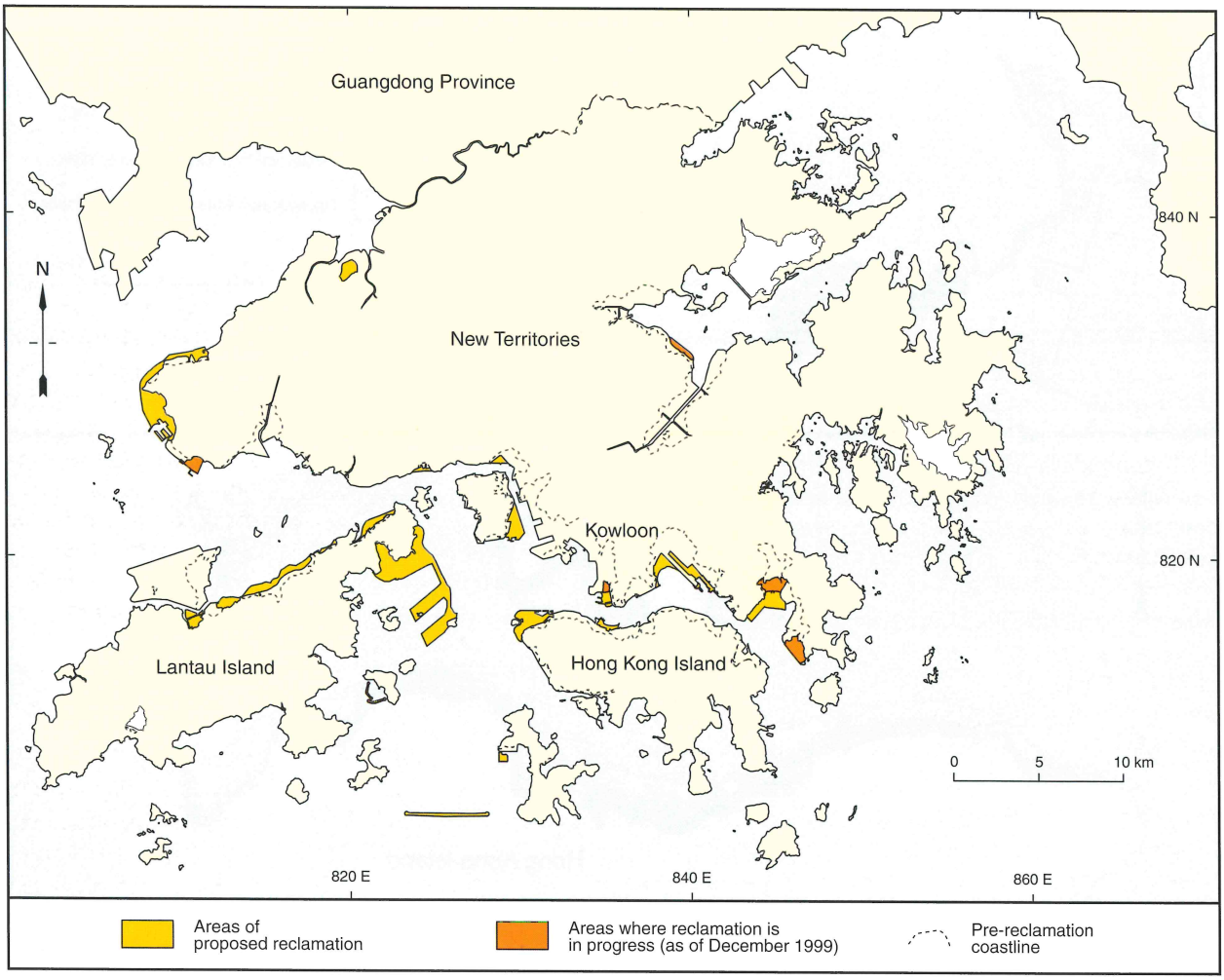


Figure 13.2 - Areas of existing and proposed reclamation in Hong Kong

Reclamation	Sand Volume Mm^3	Main borrow areas	Project Dates
Kai Tak Runway Extension	7.5	Hung Hom, South Tsing Yi, Fa Peng, Joss House Bay	1956 - 1959
Plover Cove Main Dam	2.0	Tai Shui Hang, Ting Kok, Chung Pui, Three Fathoms Cove	1960 - 1968
Tuen Mun New Town	3.5	Tung Chung, Sha Chau, Chek Lap Kok, Lung Kwu Chau, So Kwun Tan	1968 - 1973
Container Terminal No. 6	8.6	Kap Shui Mun	1986 - 1989
Container Terminal No. 7	16.4	South Tsing Yi	1986 - 1989
Tin Shui Wai	24.0	Outer Deep Bay	1986 - 1988
West Kowloon Reclamation South	33.0	Tathong Channel, East Tung Lung Chau & West Po Toi	12/90 - 05/95
West Kowloon Reclamation North	33.6	East Tung Lung Chau & East Po Toi	11/91 - 06/94
Tseung Kwan O	17.4	Tathong Channel & East Tung Lung Chau	01/91 - 07/96
Container Terminal No. 8	25.5	South Tsing Yi	03/92 - 01/95
Chek Lap Kok Airport	72.0	East Sha Chau, South Tsing Yi, West Po Toi & Brothers	11/92 - 01/96
Tung Chung New Town - Phase I	9.3	West Sokos	08/92 - 12/93
SENT Landfill	3.32	Tathong Channel	10/92 - 04/94
North Lantau Expressway	18.5	Tathong Channel, Kap Shui Mun & North of Lantau	11/92 - 01/95
Central and Wanchai Reclamation	3.6	Tathong Channel & East Po Toi	09/93 - 09/96
Stonecutters Island	1.0	South Tsing Yi	06/96 - 09/96

Table 13.1 - Examples of some major reclamations using offshore fill

(Guilford, 1997). In the 1940s, the Causeway Bay Typhoon Shelter (銅鑼灣避風塘) and Victoria Park (維多利亞公園) reclamations were both constructed using sand from Victoria Harbour off Hung Hom Bay (紅磡灣) (Guilford, 1988).

Offshore fill was used in increasing quantities during the 1950s (Table 13.1). Between 1956 and 1959, Kai Tak runway was realigned and extended seawards using 0.5 million cubic metres (Mm^3) of granular seabed material, mostly obtained from Victoria Harbour (Henry *et al.*, 1961). Subsequent major projects using marine sources of fill included the construction of the Plover Cove Reservoir (船灣淡水湖) main dam, and Tuen Mun New Town (屯門新市鎮).

With the restricted availability of onshore fill sources, the expanding scale and capital cost of proposed reclamations, and the new generation of ocean-going trailing suction hopper dredgers (Plate 13.1a), offshore sources of sand became increasingly attractive for both economic and environmental reasons. Two major reclamation projects, the construction of Container Terminal 6 (六號貨櫃碼頭) and the Tin Shui Wai New Town (天水圍新市鎮), were turning points in the history of seabed sand use in Hong Kong. Container Terminal 6 at Kwai Chung (葵涌) was completed using about 8.6 Mm^3 of seabed sand dredged from the area to the southwest of Tsing Yi (青衣) (Wragge-Morley, 1988). Tin Shui Wai (天水圍), a 400 hectare new town development site, was created using 24 Mm^3 of reclamation fill obtained from off Black Point (爛角咀) (Dutton, 1987). Since then, all major reclamations in Hong Kong have used suction-dredged offshore sand (Table 13.1). The largest reclamations are the Chek Lap Kok airport (赤鱲角機場) platform, north of Lantau Island (大嶼山), and the West Kowloon Reclamation (西九龍填海) (Plate 13.1f). Other important developments include Tung Chung New Town (東涌新市鎮), Chek Lap Kok Airport (赤鱲角機場) and related infrastructure, Central and Wan Chai (灣仔), Hung Hom Bay (紅磡灣), and Tseung Kwan O (將軍澳). Several other extensive reclamations are planned, including the Lantau Port (大嶼山港口) and Green Island (青洲). Offshore fill, from the several gazetted areas in Hong Kong, or possibly outside SAR waters, is an integral component of all these projects.

Beach Replenishment

Offshore sources of sand have been used to reinstate several popular bathing beaches that were eroding (Davies *et al.*, 1996). All of the 43 gazetted beaches in Hong Kong have been eroded to some degree. However, some deteriorated to an unacceptable level and required remedial action. Artificial nourishment was selected as a preferable alternative to a hard solution such as a sea wall or revetment, particularly as it provides an increased beach area for leisure activities and does not transfer the problem of erosion to adjacent (downdrift) beaches.

Several factors are taken into account in selecting replenishment sand, namely stability, comfort and aesthetics (colour). Coarse sand is the most stable, the least susceptible to turbidity and requires less fill volume. In contrast, comfort dictates a finer sand with a rounded particle shape.

Major replenishment projects were carried out in 1990 at Repulse Bay (淺水灣) and South Bay (南灣), using approximately 0.2 Mm^3 of sand obtained from the South Tsing Yi (青衣) borrow area. Rounded and well-sorted sand was selectively dredged from the reworked basal sands on the Holocene ravinement surface. Trials demonstrated that this material produced a uniform and non-abrasive beach. Private beaches at Discovery Bay (愉景灣), Sea Ranch (澄碧村) and Golden Beach (黃金泳灘) have also been artificially extended. Future beach

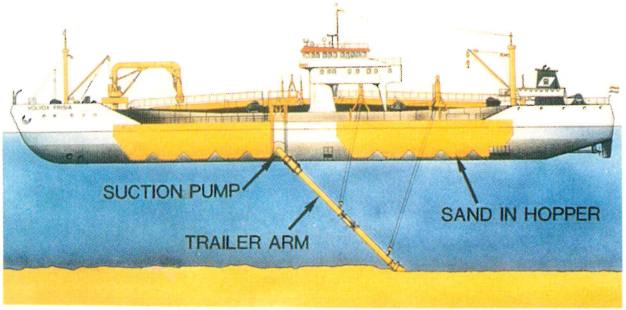












Plate 13.1 - Offshore sand dredging and reclamation operations: a. schematic view of a trailing suction hopper dredger b. sand dredging c. overflowing d. rainbowing e. sand pumping f. completed West Kowloon Reclamation (西九龍填海)

replenishment projects, such as at Stanley Main Beach (赤柱正灘), are being planned.

Effects of reclamation

During and after construction, reclamations, and dredged pits, affect the seabed. Mud is removed from the larger sites, the seabed is buried under reclamation fill, and the form of the coastline and the adjacent seabed are modified. An important consequence of this is to alter the local current flow patterns, a factor that is considered in the planning and design of reclamations. Detailed studies of the effects of reclamation on the hydrodynamics of Hong Kong waters have been carried out using a two-dimensional, two-layer model of tidal and oceanic flows to simulate the seasonally stratified waters around Hong Kong (Lai *et al.*, 1991; Stokoe & Lai, 1992).

Offshore fill extraction

Fill management

Management of fill resources in Hong Kong has, since 1989, been the responsibility of the Fill Management Committee (FMC) (Whiteside, 1991). Functions of the FMC include locating and assessing available fill resources and managing their efficient use for both Government and major private projects (Brand & Whiteside, 1990). The FMC also commission Environmental Impact Assessments (EIAs) to determine the implications of working each deposit (Brand *et al.*, 1994).

From the mid-1960s until 1991, when work on the major new airport-related reclamation projects began, Hong Kong was using about 15 Mm^3 of fill material a year. From then until the mid-1990s, offshore dredging in Hong Kong waters has generally recovered between 60 Mm^3 and 70 Mm^3 of granular fill each year from several designated borrow areas (Figure 12.2). Between 1989 and the end of 1994 the FMC reserved, or allocated, 270 Mm^3 of marine fill. Forecast fill requirements up to the year 2016 are for a further 340 Mm^3, from both marine and land sources.

Dredging

The majority of the offshore sand dredged in Hong Kong has been extracted from the Chek Lap Kok Formation. To expose these alluvial sands, most sand dredging projects have involved the removal of an overburden of Holocene marine mud and its transport to a disposal site. However, in some areas, the muddy marine deposits are sandy, especially in the basal layers. Overflowing during the suction dredging process (Plate 13.1c) can reduce the silt and clay content and yield additional suitable granular fill materials (Wragge-Morley, 1988). Throughout the dredging operation, the steepest sides possible are maintained in the dredged pit to minimize unproductive disposal journeys.

The most economically viable sand deposits are those with a low overburden ratio. Therefore, the optimum sand deposits occur where the Holocene mud is thin, which is primarily along the Holocene tidal channels where the prevailing currents have precluded, or restricted, mud deposition (Arthurton, 1985). Although several sand bodies have been located below the West Lamma Channel (西博寮海峽), and more extensive deposits are believed to exist (Cheung & Shaw, 1993), an overburden thickness of around 20 m has discouraged further exploration as the resources would be uneconomical.

As the dredging of marine sand increased, concern grew over its environmental impacts (Holmes, 1988). Hence, Environmental Impact Assessments (EIAs) became an integral component of borrow area studies (Sterritt, 1991), commencing with the West Kowloon Reclamation (西九龍填海) and Chek Lap Kok Airport (赤鱲角機場) projects in the early 1990s. Later EIAs have been more comprehensive and detailed, and some have led to the decision not to extract certain sand deposits.

The major environmental concern is the generation and dispersion of suspended sediment plumes produced by trailer suction hopper dredgers. During sand dredging (Plate 13.1b), the sand and water mixture that is sucked from the seabed is allowed to overflow. This process retains most of the sand but discharges the water, which contains the suspended silt and clay. All the granular bodies contain a component of finer particles. The alluvial sands have the lowest fines content, usually less than 15% and often below 5%, and the marine sands commonly contain between 20% and 50% fines. Computer modelling (Whiteside & Rodger, 1996), field measurements (Whiteside *et al.*, 1995) and remote sensing studies (Evans, 1994a) of suspended sediment plumes have confirmed that they have very little influence outside the immediate vicinity of the dredging area.

Concerns about possible effects of these disturbed sediments on the muddy benthic communities were addressed by using a specialized seabed camera (Rhoads & Germano, 1982) (Plate 13.2a). This produces photographs of a vertical profile through the upper 200 mm of the seabed, which can be used to assess the benthic fauna, pollution (Valente *et al.*, 1996) and sedimentary structures (Plate 13.2b & 13.2c). Of further interest are features produced by remobilisation and deposition of sediments during severe storms, and mud clasts produced by trawling (Selby & Evans, 1997).

Following extraction, the sand is transported to the reclamation site, where in the first stages it is bottom-dumped. Subsequently, as the water depth over the site decreases, sand is pumped over the site. This is achieved either directly from the dredger by rainbowing (Plate 13.1d) or along a moveable pipeline (Plate 13.1e). Pumping is commonly over a few hundreds of metres but occasionally, as at Tin Shui Wai (天水圍), may be considerably greater distances.



Plate 13.2 - The REMOTS system and photographs: a. REMOTS seabed camera b. a muddy seabed c. the abandoned disposal ground in Mirs Bay (大鵬灣)

Geological Factors Affecting Dredging

Several geological factors determine the suitability of a granular deposit for hydraulic filling (Ford, 1988; Reilly, 1991) and affect the economic viability of dredging the deposit (Verkerke & Volbeda, 1991). In particular, the ease of extracting the deposit, its grain size distribution, and the angularity of the component sand grains are important considerations in any borrow area investigation.

Many of the largest offshore sand deposits in Hong Kong are close to the urban development areas (Figure 12.2), thereby reducing the transport distance. However, these geologically proximal deposits generally comprise coarser, immature and angular alluvial quartz and lithic sands with a low fines content. Therefore, although they require minimal overflowing (Plate 13.1c), they are abrasive to the dredging equipment. With increasing distance from the coast, the deposits become more distal in character, and the sand is more mature, finer grained and has a higher fines content. These characteristics make overflowing more necessary, but also more difficult as there is little hydraulic distinction between the similar grain sizes. Furthermore, because most of the overflowed sediment descends directly to the seabed as a density current, there is a tendency for the borrow pits to become silted up. This is a particular concern in deposits with a high fines content, which includes the fine sand fraction as well as the less than 63 μm fraction. Thus, in order to extract all the sand, additional dredging is required to remove the redeposited fines and transport them to a disposal site. Clearly, overflowing is less important for borrow areas close to the reclamation site, as the deposits contain less fines and travel distances are short. Overflowing becomes more crucial as this distance increases, because the more distal deposits contain a higher fines content and travel time becomes significant.

The rate and amount of wear and tear on the pipes and pumps can significantly influence the overall cost of a dredging project. Excessive abrasion is of concern both for the dredger and for the distribution system used to pump sand around the reclamation area, a process that commonly uses a stationary dredger. Most of the sand in Hong Kong is quartz, although certain areas have a significant component of lithic clasts and some of the Holocene deposits, especially the early Holocene moribund sandbanks (Evans, 1988b), contain a high proportion of comminuted shell fragments. The angularity and size of the quartz grains is critical and in this respect there is a greater cost associated with dredging and rehandling the clean, immature Pleistocene river sands than with extracting the more distal finer-grained deposits. In contrast, the comminuted shell sands such as were used for much of Container Terminal 6 (六號貨櫃碼頭) (Wragge-Morley, 1988) cause very little wear, although the low density of the calcite shell increases the loss overboard and hence the overflowing time.

Although the basal Holocene ravinement surface is relatively planar (Chapter 10), it slopes gently southwards towards the shelf edge. Therefore, the targeted Chek Lap Kok Formation alluvial sediments that underlie it occur at progressively deeper levels away from the coastline. Because the efficiency of a dredger's suction pump reduces as the dredging depth increases, these more geologically distal deposits are less economic to work.

Generally, the older Pleistocene Chek Lap Kok Formation deposits are denser than the overlying Hang Hau Formation deposits. This enables steeper sideslopes to be formed and maintained in the working pits, increasing the production of mineral for each cubic metre of overburden that is dredged.

Mud disposal

Management of the disposal of marine mud has been an extremely important activity in recent years, demanding a

large capital outlay. Large quantities of mud have been dredged from the seabed at reclamation sites, and also removed, as overburden, from seabed borrow areas.

Most marine mud that is dredged in Hong Kong occurs either as a compressible layer covering a reclamation site, or as an overburden concealing a targeted sand deposit. To optimize dredging operations and to minimize the volume of mud disposal, borrow areas are commonly worked as a series of pits, the overburden from the newly opened pit being placed in an adjacent empty pit.

The optimum pit layout at any locality is usually dependent on geological conditions at the site. For example, areas with thick interburden or poorer sand are commonly selected as the locations for the unworked, dividing bunds between pits.

Marine disposal of dredged mud has several effects on the morphology and sedimentology of the seabed, both at the site and for some distance around. For example, during bottom dumping from barges or dredgers, prevailing currents disperse freshly deposited sediment beyond the dumping point to some degree (Nash & Yip, 1988).

Two gazetted disposal grounds, near The Ninepins Group (果洲群島) and south of Cheung Chau (長洲), are currently used for dumping uncontaminated mud (Figure 13.1). Specially excavated pits at East Sha Chau (東沙洲) have been used for the contained disposal of contaminated mud. Three are full and are capped and sealed by a layer of uncontaminated mud. Pit IV has been designated for further disposal (Figure 12.2).

Submarine spoil mounds possess distinctive characteristics. Individual mounds comprise a core of denser material with a covering of slurried spoil, much of which migrates laterally from the dumping impact point for a distance that depends largely upon the bulk strength of the material. The local seabed gradient increases as the spoil mound grows. During dumping, less than 5%, and often less than 1%, of discrete, fine-grained particles are lost as a suspension plume. This disperses and subsequently settles as a function of water depth, flocculating characteristics of the sediments, and local current characteristics.

The stability of dumped spoil materials is also a factor in their dispersal and persistence. Dispersal is largely a function of wave destabilisation and mass movement. Mud spoil has a low strength, is commonly underconsolidated and has excess pore pressures. On the generally flat and featureless seabed of Hong Kong, the raised spoil mounds are out of equilibrium with the local erosional and depositional regime. Consequently they are also subject to scour, with associated redistribution of the materials. Mud clasts, commonly larger than 50 mm across, have been observed at mud disposal sites overlying unbioturbated, dredged sediment (Selby & Evans, 1997). They are typically associated with mud suspensions and are attributed to the reworking of dredged sediments by mass flows and density currents at the disposal site, although in other cases they can be formed by trawling of the seabed.

Reinstatement of the seabed

Since 1993, uncontaminated marine mud has been used to reinstate the seabed by backfilling pits from which the underlying sand deposits have been removed. The pits are filled with mud until the seabed is restored to its original level. Six sites have been allocated for backfilling. At the time of writing, two of these had been completely filled, three were in operation and one remained open awaiting filling (Figure 12.2).

Subsequent monitoring of the reinstated seabed has confirmed that benthic communities re-establish very quickly on the newly formed substrate. Studies have also shown that in areas not backfilled, the sandy substrate left after fill extraction is also suitable for re-establishment of the benthos, although at a slower rate.

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Glossary of terms

Acoustic impedance: characteristic of a sediment or rock based on the velocity of sound through the medium and its density; the product of seismic velocity and density.

Acoustic pulse: sound signal electromechanically generated and of known characteristics, which is reflected back from discontinuities (**seismic reflectors**) within superficial deposits and rocks beneath the seabed. The return signal is received by hydrophones and recorded on a **seismic profile** on a continuous paper strip.

Acoustic turbidity: acoustic response that is created when gas within sediments causes the absorption and/or scattering of the **acoustic pulse**. This phenomenon appears on **seismic profiles** as zones of chaotic **seismic reflections** that obliterate any other reflections within or beneath these zones.

Alluvium: general term for unconsolidated detrital rock material deposited by a stream, or other body of running water, as a sorted or semi-sorted sediment; occurs in the bed of a stream, on a floodplain or delta, or as a cone or fan below gullies at the base of a mountain slope (after: Gary *et al.*, 1972).

Alluvial placers: deposits of economic minerals in and adjacent to stream channels. They accumulate both in the narrow, steeper upper reaches of drainage systems and in floodplains on the wider and flatter lower reaches. Floodplains comprise laterally extensive beds of gravel and other sediments in which the active channels are contained. Some deposits are related to the present drainage systems, while others are remnants of former drainage patterns (*cf.* **fluvial placers**) (after: Macdonald, 1983).

Assemblage: group of organisms or fossils that occur together in the same habitat and share the same localised geographical extent.

Bar: ridgelike accumulation of sediment, usually sand or muddy sand, formed in an area of strong fluid motion, such as in a river channel, estuary or shallow coastal waters.

Bathymetric: pertaining to measurement of the depth of the sea or ocean; commonly applied to maps portraying seabed **morphology**.

Benthonic: living on the (deep) seabed.

Bioturbation: reworking of sediment and soil by organisms and animals. The process may partially or completely destroy any primary sedimentary structure such as bedding or lamination.

Boomer acoustic source: source generating, by electromechanical means, pulses of high-frequency sound (**acoustic pulse**). The device is towed in the water by a survey vessel and fired repeatedly to provide a relatively high-resolution **seismic profile** of the sediments up to 100 m below the seabed (see **Pinger acoustic source** and **Sparker acoustic source**).

Chronostratigraphy: grouping and classification of rocks or sediments into units based on the time of their deposition.

Colluvial placers: economic mineral deposits contained in generally poorly sorted **colluvium** on slopes; resulting from the mass movement of rock waste (after: Macdonald, 1983).

Colluvium: a general term applied to loose, heterogeneous, and incoherent accumulations of soil material or rock fragments; deposited chiefly by mass wasting processes. Usually occurs as sheets on, or at the base of, a steep slope or cliff (after: Gary *et al.*, 1972). A wide range of transport mechanisms are involved, from rain splash and continuous creep, to sliding and flowing (after: Macdonald, 1983). The chief characteristic of colluvial deposits is the absence of sorting, with grain size varying from the finest particles to huge boulders (after: Raeburn & Milner, 1927).

Corestone: block of relatively unweathered rock within a mass of weathered rock.

Cross bedding: arrangement of strata that are inclined at an angle to the main (sub-horizontal) stratification.

Decalcification: process of leaching or removal by percolating waters of calcium carbonate from a sediment. Shell fragments are the main source of calcium carbonate in offshore sediments.

Diagenesis: chemical, physical and biological changes undergone by a sediment after its initial deposition, and during and after burial under

other deposits. This excludes pedological changes.

Diatom: solitary or colonial micro-organism that secretes a siliceous bivalve test or frustule.

Dinoflagellate: microscopic organism, single-celled, chiefly of marine habit and usually solitary.

Dissolution: taking-up of a substance by a liquid, such as calcium carbonate, by percolating ground water.

Diurnal tides: occurring approximately once every day.

Echo sounder: device for measuring water depth below a ship's hull, based on the return time of a high-frequency **acoustic pulse**.

Ecology: study of the relationship between organisms and their environment.

Elutriation: the washing away of light weight or fine particles in a soil by the splashing of raindrops (Gary *et al.*, 1972).

Eluvial placers: economic mineral deposits contained in residual materials derived from weathered rock zones in which the parent materials have undergone chemical, mechanical and biological changes resulting in the loss of some of their non-valuable constituents by **eluviation, leaching** and **elutriation** (*cf.* **residual placers**) (after: Macdonald, 1983).

Eluviation: the removal of suspended material (particularly colloids) and soluble material (*leaching*), either to a lower horizon or out of the profile, by groundwater percolation (after: Gary *et al.*, 1972).

Eluvium: a residual accumulation of weathered debris, produced by the *in situ* decomposition or disintegration of rock, from which the fine material (particularly the colloids) has been removed in suspension (**eluviation**) and the soluble material removed in solution (**leaching**) by percolating groundwater (after: Gary *et al.*, 1972); a weathering product or residue. In some accounts, eluvium includes material slumped or washed down the hill for a short distance (slightly transported **colluvium** or creep debris), but has not been transported by a stream (e.g. Wells, 1969).

Estuarine: pertaining to, or formed in, an estuary. An estuary is the mouth of a river where fresh water comes into contact with saline water and is characterised by distinctive hydrodynamic conditions relating to fluvial discharge, tidal currents and mixing.

Eustatic change: global change in sea level. During the Quaternary, this resulted dominantly from variation in the relative volumes of water in oceans and the polar ice-caps.

Facies: body of rock characterised by a particular combination of **lithology**, [and] physical and biological structures that bestow an aspect different from the bodies of rock above, below or laterally adjacent (Walker, 1992).

Facies association: group of **facies** genetically related to one another and which have some environmental significance (Collinson, 1969).

Facies model: general summary of a particular depositional system based on **facies associations** identified in the rock or sediment.

Fill (material): granular sediment and rock used for engineering purpose such as land reclamation.

Floodplain: low-lying area on either side of a fluvial channel that is periodically occupied by floodwaters that cannot be contained within the channel (see **overbank deposits**).

Fluvial erosion: removal of rock or an already-deposited sediment by fluvial/alluvial processes, including channelling.

Foraminifera: (*singular* foraminifer) marine- or brackish-water micro-organisms that secrete a calcareous shell.

Foresets: sediments deposited on a steep advancing slope. **Cross bedding** is commonly formed in association.

Formation: lithostratigraphical unit; body of rock or sediment identified by its lithological character and stratigraphical position and that is mappable as an **outcrop** or below the surface.

High amplitude: description given to a **seismic reflection** that appears as a dark trace on a **seismic profile**.

Highstand: interval of time during periods of sea level change when sea level is above the shelf edge, usually occurring during interglacial periods.

Holocene: period of geological time from around 10 000 years BP to the present day.

Hydraulic: describing the movement of water (and other fluids).

Illuviation: accumulation in a lower soil horizon of suspended material (by **eluviation**) and soluble material (by **leaching**) transported from an upper horizon by percolating groundwater (after Gary *et al.*, 1972).

Illuvium: deposit resulting from **illuviation** in a lower soil horizon of suspended material (particularly colloidal) and material in solution, both materials being derived by **eluviation** of an upper soil horizon.

Inlier: area of rock or superficial deposits that is surrounded by younger rock or superficial deposits.

Interfluve: positive topographical feature, linear or sinuous in plan form, that separates two fluvial channels.

Intra-: within; as in **intrachannel**, occurring within a channel.

Isopach: line on a map drawn through points of equal thickness of a particular deposit, **formation** or unit.

Isotopes: forms of an element (e.g. oxygen, carbon) differing from each other in atomic weight.

Lacustrine: relating to a lake or inland body of water.

Leaching: separation, selective removal, or dissolving out of soluble constituents from a rock or soil by the natural action of percolating water (after: Gary *et al.*, 1972).

Lithology: physical characteristics of sediments and rocks based on grain size, mineral content and colour.

Lithostratigraphy: grouping and classification of rocks or sediments into **units** based on their **lithology**.

Low amplitude: description given to a **seismic reflection** that appears as a faint traces on a **seismic profile**.

Lowstand: interval of time during periods of sea level change when sea level is below the shelf edge, usually occurring during periods of maximum glaciation.

Luminescence: emission of light; used as a general term referring to **thermoluminescence** and **optically-stimulated luminescence** dating techniques.

Marine regression: retreat or contraction of the sea from land areas, due to relative sea level fall during glaciation, or uplift of the land due to tectonism.

Marine transgression: advance or expansion of the sea over land areas, due to relative sea level rise during glaciation, or subsidence of the land due to tectonism.

Mass movement: the carrying of material in a moving medium such as water, air, or ice (after Gary *et al.*, 1972).

Mass transport: a general term for the dislodgement and downslope transport of soil and rock material under the influence of gravity and not within, on , or under another medium. The mass properties of the material being transported depend on the interaction of the soil and rock particles and on the moisture content. Mass wasting includes slow displacements, such as creep, and rapid earth movements such as rockfalls, rockslides and debris flows (modified after Gary *et al.*, 1972).

Member: lithostratigraphical unit subordinate to, and making up part of, a formation.

Morphology: the general shape, form and arrangement of superficial deposits and rocks. The term is also used to describe the shape of the land surface, or topography.

Optically-stimulated luminescence (OSL): the emission of light by a crystal of quartz or feldspar when exposed to radiation in the visible waveband; the basis of a Quaternary age-dating technique.

Ostracod: aquatic arthropod (crustacean), usually microscopic, characterised by a calcareous bivalve carapace (of the subclass Ostracoda).

Outcrop: that part of a body of rock or superficial deposit that appears at the surface of the earth or at the seabed; *verb* to **crop out** (see also **subcrop**).

Overflowing: a process designed to maximize the hopper load in a trailing suction hopper dredger whereby water taken in to the hopper during sand dredging is returned to the sea via a central pipe or side weirs. Ideally, the bulk of the entrained sediment settles and remains in the hopper, although some finer particles unavoidably overflow with the water.

Oxidation: chemical reaction involving the loss of electrons from an atom or, more specifically, the addition of oxygen to a molecule. Most well-drained sediments are oxidized (see **reduction**).

Palaeo-: ancient; as in **palaeochannel**, an ancient channel, no longer active due to burial or abandonment by a change in **hydraulic** regime.

Palaeontology: study of life from past geological times based on the preserved remains of animals and plants (fossils).

Palaeosol: remains of an ancient soil buried by later sediments. Palaeosols usually occur on former subaerial surfaces.

Palynology: study of living or fossil plant remains such as pollen and spores. Used in geology to determine the environment of deposition of a sediment.

Palynomorph: a microscopic organic body with resistant walls, found in palynological maceration residues; an object of palynological study.

Pinger acoustic source: electromechanical source of high frequency sound (**acoustic pulse**). The device is towed in the water behind a survey vessel, and fired repeatedly to provide a high-resolution **seismic profile** of the upper part of the seabed sediments (see **Boomer acoustic source** and **Sparker acoustic source**).

Planation: process of erosion whereby an elevated and undulating part of the earth's surface is reduced to an even or level surface, usually by marine or fluvial action.

Prograding: outward-building or lateral advance of a unit of sediments; associated with **foreset**s.

Proto-: initial; denoting the first appearance of, as in **protochannel**, a newly-formed channel.

Radioisotope: radioactive isotope of an element. Carbon radioisotopes ^{13}C and ^{14}C are commonly referred to as **radiocarbon**.

Rainbowing: a rapid method of discharging the hopper load from a dredger to a point on shore. An arcuate train of airborne material, extending up to 50 m ahead of the vessel, is pumped through a pipe that protrudes over the ship's bow.

Ravinement: surface identified on a **seismic profile** representing a period of planar marine erosion associated with a **transgression**.

Reclamation: extension of land seawards by the addition of fill material.

Reduction: any process in which an electron is added to an atom or, more specifically, the removal of oxygen from a molecule. Common in waterlogged and buried sediments (see **oxidation**).

Reflection: see **seismic reflection**.

Reflector: see **seismic reflector**.

Seabed: interface between the sea water and the underlying sediment or rock.

Seabed multiple: seismic reflection representing a double reflection through the water column.

Seismic character: description of the general appearance of a **seismic reflection** pattern for a particular **unit** on a **seismic profile**.

Seismic profile: transcription on paper of **acoustic pulse**s returned as **seismic reflections** that result from changes in **acoustic impedance** within the superficial deposits and rock beneath the seabed.

Seismic reflection: trace of an individual **acoustic pulse** portrayed on **seismic profile**s. The trace may be laterally extensive, or short and impersistent. The form and style of the reflections are important aids in delineating the depositional character of sedimentary **unit**s.

Seismic reflector: boundary within a rock or sediment that marks a change in **acoustic impedance**, and is inferred rather than directly observed.

Seismic stratigraphy: grouping and classification of superficial sediments and rocks into **unit**s based on their acoustic response and style of **seismic reflections**.

Semidiurnal tides: tides occurring approximately twice every day.

Sequence stratigraphy: system of identifying sedimentary successions by their geometrical relationships, usually from the interpretation of seismic profiles.

Side scan sonar: source of high frequency sound (**acoustic pulse**) directed so that it reflects off the seabed in a band on either side of a survey vessel. The returning signals are transcribed to produce a detailed representation of the seabed **morphology**.

Sparker acoustic source: an electromechanical source of low frequency sound (**acoustic pulse**). The device is towed in the water behind a survey vessel, and fired repeatedly to provide a **seismic profile** of the seabed sediments up to 150 m beneath the seabed (see **Boomer acoustic source** and **Pinger acoustic source**).

Spoil ground: area of seabed designated or used for offshore dumping.

Subcrop: that part of a rock or superficial deposit that occurs beneath an overlying superficial sediment or rock; *verb* to occur beneath overlying sediment or rock (see also **outcrop**).

Syn-: occurring contemporaneously with; as in **synvolcanic** sedimentation, occurring in a region of volcanic activity.

Systems tract: linkage of contemporaneous depositional systems (Posamentier, 1988).

Thermoluminescence: emission of light on heating; the basis of a Quaternary age-dating technique.

Transgressive: relating to **marine transgression.**

Unconformity: surface separating younger from older strata where there has been a substantial break in the geological profile, generally involving erosion.

Unit: informal division of a geological formation.

Glossary of place names

English / Pin Yin	Chinese Character	Sheet No.	Easting	Northing
Bays				
Big Wave Bay / Tai Long Wan	大浪灣	8 15	858600 843750	829000 811800
Cascade Bay / Kau Sai Wan	滘西灣	12	850280	822800
Castle Peak Bay / Tsing Shan Wan	青山灣	6	816060	826560
Causeway Bay Typhoon Shelter	銅鑼灣避塘	11	837170	816250
Chi Ma Wan	芝麻灣	14	817860	811000
Clear Water Bay / Tsing Shui Wan	清水灣	12	848070	814765
Crescent Bay / Ngo Mei Wan	娥眉灣	4	850500	843700
Crooked Harbour / Kat O Hoi	吉澳海	4	846750	845050
Deep Bay / Hau Hoi Wan	后海灣	2	816500	840750
Deep Water Bay	深水灣	15	836990	811500
Discovery Bay	愉景灣	10	819350	817810
Double Haven / Yan Chau Tong	印洲塘	4	849050	842500
East Arm (Long Harbour) / Chek Keng Hau	赤徑口	8	854300	832650
Eastern Harbour	東區海港	-	-	-
Ha Mei Wan	下尾灣	14	829480	807460
Hebe Haven / Pak Sha Wan	白沙灣	8	845300	824950
Hung Hom Bay	紅磡灣	11	837880	817960
Inner Port Shelter / Sai Kung Hoi	西貢海	8	846900	825500
Jones Cove / Pak Sha O	白沙澳	4	852320	836500
Joss House Bay / Tai Miu Wan	大廟灣	12	847500	813700
Junk Bay / Tseung Kwan O	將軍澳	11	844500	818350
Kellet Bay / Kai Lung Wan	雞籠灣	11	832350	812240
Lantau Channel	大嶼海峽	-	-	-
Lo Kei Wan	籮箕灣	4	850720	842700
Long Harbour / Tai Tan Hoi	大灘海	8	853900	835100
Luk Chau Wan	鹿洲灣	15	831000	810000
Ma Wan	馬灣	10	823930	823585
Middle Bay / Chung Wan	中灣	15	838400	810200
Mirs Bay / Tai Pang Wan	大鵬灣	4	856600	843500
North Lantau Harbour	北大嶼山港	9	-	-
Penny's Bay / Chok Ko Wan	竹篙灣	10	822000	820100
Picnic Bay / Sok Kwu Wan	索罟灣	15	831800	807850
Plover Cove / Shuen Wan Hoi	船灣海	7	841250	835500
Port Shelter / Ngau Mei Hoi	牛尾海	12	848000	822300
Pui O Wan	貝澳灣	14	815500	811000
Repulse Bay / Tsin Shui Wan	淺水灣	15	838430	811400
Rocky Bay / Shek O Wan	石澳灣	15	842850	809100
Rocky Harbour Leung Shuen Wan Hoi	糧船灣海	12	853100	822500
Sandy Bay / Sha Wan	沙灣	11	830550	814650
Sham Wan	深灣	15	832400	805150
Silver Mine Bay / Ngan Kwong Wan	銀鑛灣	10	818650	814300
Stanley Bay / Chek Chue Wan	赤柱灣	15	839700	808500
Tai Long Wan	大浪灣	13	806200	808690
Tai Pak Wan	大白灣	10	820750	818400
Tai Tam Bay / Tai Tam Wan	大潭灣	15	841850	808620
Three Fathoms Cove / Kei Ling Ha Hoi	企嶺下海	8	846700	832150
Tide Cove / Sha Tin Hoi	沙田海	7	840600	831300
Tolo Harbour	吐露港	7	840000	833500
Tuen Mun Coast	屯門海岸	6	817230	825730
Tung O Wan	東澳灣	15	833641	807491
Tung O Wan	東澳灣	4	848350	845830
Tung Wan	東灣	13	809260	802800

English / Pin Yin	Chinese Character	Sheet No.	Easting	Northing
Victoria Harbour	維多利亞港	11	836000	817000
Wang Mun Hoi	橫門海	4	849486	843852
Waterfall Bay / Pok Po Wan	瀑布灣	11	831700	812500
West Arm (Long Harbour) / Ko Tong Hau	高塘口	8	853000	833200
Western Harbour	西區海港	-	-	-
Wong Chuk Kok Hoi	黃竹角海	4	850000	841000
Yau Tong Wan / Kwun Tong Tsai Wan	觀塘仔灣	11	842000	817600
Yung Shue Wan	榕樹灣	14	829320	809650
Beaches				
Butterfly Beach	蝴蝶灣	5	813610	825870
Cafeteria Beach	咖啡灣	6	816460	826120
Camp Cove / Pak Sha Tau Wan	白沙頭灣	4	848650	843800
Cheung Sha	長沙	13	812560	810540
Golden Beach	黃金泳灘	6	816860	825830
Kellet Bank	奇力灘	11	832350	812240
Lo Fu Wat	老虎笏	4	846130	836600
Long Ke Wan	浪茄灣	8	847055	828645
Nam She Wan	蚺蛇灣	8	855630	833220
Po Yu Wan	鯆魚灣	14	819980	806700
Pui O	貝澳	14	815660	811320
Sham Wan	深灣	15	834780	811720
Shui Hau Wan	水口灣	13	810010	808960
Siu Ho Wan	小蠔灣	10	817600	819100
South Bay	南灣	15	838250	809650
Stanley Main Beach	赤柱正灘	15	840100	809200
Tai Kwai Wan	大鬼灣	14	820520	808000
Yam O Wan	陰澳灣	10	820590	821040
Yi Long Wan	二浪灣	14	816970	808460
Young Hebe Shoal	澳北淺灘	-	-	-
Channels				
Beaufort Channel / Lo Chau Mun	螺洲門	15	844000	804300
Brothers Channel	大小磨刀海峽	10	-	-
East Lamma Channel / Tung Pok Liu Hoi Hap	東博寮海峽	15	833000	810000
Fat Tong Mun	佛堂門	12	848807	813593
Kap Shui Mun	汲水門	10	825831	821791
Lantau Port	大嶼海港	-	-	-
Lei Yue Mun	鯉魚門	11	842931	816692
Ma Wan Channel	馬灣海峽	10	825280	824200
Middle Channel / Chek Chau Hau	赤洲口	4	855150	839200
North Channel / Tai Chek Mun	大赤門	4	853700	840750
Rambler Channel	藍巴勒海峽	10	829250	821900
Sheung Sze Mun	雙四門	15	843000	806500
South Channel / Tap Mun Hau	塔門口	8	855250	835850
Starling Inlet / Sha Tau Kok Hoi	沙頭角海	3	841100	844050
Sulphur Channel / Lau Wong Hoi Hap	琉磺海峽	11	830300	816050
Tathong Channel / Lam Tong Hoi Hap	藍塘海峽	16	845900	811000
Tolo Channel / Chek Mun	赤門	4	850400	837900
Tsing Yi Channel	青衣海峽	6	827160	825060
Urmston Road	龍鼓水道	5	807000	827500
West Lamma Channel / Sai Pok Liu Hoi Hap	西博寮海峽	14	826000	809600

English / Pin Yin	Chinese Character	Sheet No.	Easting	Northing
Headlands				
Bate Head / Tuen Tsui	短咀	8	859300	832950
Black Point / Lan Kok Tsui	爛角咀	5	807880	829700
Bluff Head / Wong Chuk Kok Tsui	黃竹角咀	4	852500	841400
Bluff Head / Wong Ma Kok	黃麻角	15	840050	806250
Boulder Point / Pak Kok	北角	15	830100	811300
Cape D'Aguilar / Hok Tsui	鶴咀	15	844800	807800
Cape D'Aguilar Peninsula	鶴咀半島	15	844650	807900
Cheng Shek Tsui	長石咀	4	848260	846020
Chi Ma Wan Peninsula	芝麻灣半島	14	817770	809940
Fan Lau	分流	13	802740	807360
Kau Ling Chung	九嶺涌	13	804170	807280
Kowloon Peninsula	九龍半島	11	835830	822850
Ocean Point / Kwun Tsoi Kok	棺材角	4	853200	839700
Pillar Point / Mong Hau Shek	望后石	5	812016	825506
Sai Kung Peninsula	西貢半島	8	845590	830890
Shek Kok Tsui	石角咀	14	828980	810560
Stanley Peninsula	赤柱半島	15	840270	807130
Tai Long Tsui / Fung Head	大浪咀	8	859700	830430
Tap Shek Kok	踏石角	5	809480	826675
Tathong Point / Nam Tong Mei	南堂尾	16	847900	811000
Tsim Bei Tsui	尖鼻咀	2	819300	838600
Islands				
Ap Lei Chau	鴨脷洲	15	834220	811190
Basalt Island / Fo Shek Chau	火石洲	12	855650	819550
Bay Islet / See Chau	匙洲	12	852400	822100
Beaufort Island / Lo Chau	螺洲	15	843900	805200
Bluff Head	沙塘口山	12	854160	820000
Bluff Island / Sha Tong Hau Shan	沙塘口山	12	854150	820150
Breaker Reef	浪花排	4	816300	837500
Bush Reef / Tang Chau	燈洲	7	844630	834135
Centre Island / A Chau	丫洲	7	840900	833350
Cha Kwo Chau	茶果洲	13	812520	808315
Cham Tau Chau	枕頭洲	8	847800	826700
Chek Lap Kok	赤鱲角	9	811015	819765
Cheung Chau	長洲	14	822000	807360
Cheung Muk Tau	樟木頭	13	810410	804420
Conic Island / Fan Tsang Chau	飯甑洲	8	858420	825000
Crescent Island / Ngo Mei Chau	娥眉洲	4	850400	843000
Crooked Island / Kat O Chau	吉澳洲	4	848300	844700
Double Island / Wong Wan Chau	往灣洲	4	850000	841500
East Brother / Siu Mo To	小磨刀	10	816200	822000
East Ninepin Island / Tung Kwo Chau	東果洲	12	855650	814100
Flat Island / Ngan Chau	銀洲	4	852200	837850
Flat Reef / Bun Sha Pai	磚沙排	8	847650	383500
Fun Chau	墳洲	4	846340	843865
George Island / Luk Chau	鹿洲	15	831810	809213
Grass Island / Tap Mun Chau	塔門洲	4	855350	837500
Green Island / Nam Fung Chau	南風洲	12	854280	821560
Green Island / Tsing Chau	青洲	10	829750	816200
Harbour Island / Pak Sha Tau Chau	白沙頭洲	7	843950	835100
Hei Ling Chau	喜靈洲	10	820840	812930
High Island / Leung Sheun Wan Chau	糧船灣洲	8	854500	824550
Hole Island / Wang Chau	橫洲	12	856580	821180
Hong Kong Island	香港島	11	-	-
Jin Island / Tiu Chung Chau	吊鍾洲	12	850800	822905
Junk Island / Fat Tong Chau	佛堂洲	12	845850	815500
Kau Sai Chau	滘西洲	8	850940	824540
Kau Yi Chau	交椅洲	10	825720	816200
Knob Reef / Che Lei Pai	扯犁排	4	848000	836100
Kung Chau	弓洲	4	856155	838270
Lamma Island	南丫島	15	831162	805920
Lantau Island	大嶼山	9	813000	814000
Little Green Island / Siu Tsing Chau	小青洲	11	830080	816300
Lung Kwu Chau	龍鼓洲	5	805720	826660
Ma Chau	孖洲	13	807485	803720
Ma Shi Chau	馬屎洲	7	841060	834510
Magazine Island / Fo Yuek Chau	火藥洲	15	832300	811600
Mat Chau	墨洲	15	843660	802490
Middle Island / Tong Po Chau	塘波洲	15	837000	810480
Ng Fan Chau	五分洲	15	844520	809640
Ninepin Group / Kwo Chau Kwan To	果洲群島	12	855220	813700
North Ninepin Island / Pak Kwo Chau	北果洲	12	854000	814250
Pearl Island	龍珠島	6	817010	825070
Peng Chau	坪洲	10	821450	816730
Ping Chau	平洲	4	862400	845000
Po Pin Chau	破邊洲	8	857000	824380
Po Toi Islands / Po Toi	浦台島	16	845260	803350
Port Island / Chek Chau	赤洲	4	855050	840200
Pyramid Rock / Fan Kwai Lun Chau	番鬼倫洲	12	855730	820300
Robinson Island / Ap Chau	鴨洲	4	845800	845700
Round Island / Ngan Chau	銀洲	15	837200	808500
Round Island / Pak Sha Chau	白沙洲	4	852000	844500
Sai Ap Chau	細鴨洲	4	845040	845735
Sha Chau	沙洲	9	806470	823205
Sharp Island / Kiu Tsui Chau	僑咀洲	8	848350	825000
Shek Kwu Chau	石鼓洲	14	817430	806270
Shek Ngau Chau	石牛洲	4	862100	836300
Shelter Island / Ngau Mei Chau	牛尾洲	12	848600	820650
Siu A Chau	小鴉洲	13	809055	804770
Siu Kau Yi Chau	小交椅洲	10	824210	816600
Soko Islands	索罟群島	13	810582	805505
South Ninepin Island / Nam Kwo Chau	南果洲	12	854700	812900
Steep Island / Ching Chau	青洲	12	850500	815150
Stonecutter's Island / Ngong Shuen Chau	昂船洲	11	832300	820300
Sung Kong	宋崗	16	847860	805245
Sunshine Island / Chau Kung To	周公島	10	823300	813650
Table Island / Ping Min Chau	平面洲	12	850830	819100
Tai A Chau	大鴉洲	13	809080	802445
Tai Chau	大洲	8	847300	827870
Tai O	大澳	9	803780	813140
Tai Tau Chau	大頭洲	15	844720	810080
Tang Lung Chau	燈籠洲	10	824500	822440
Tau Lo Chau	頭顱洲	13	810000	801800
The Brothers islands	大小磨刀	10	815700	821370
Tit Cham Chau	鐵箐洲	12	846425	813890
Town Island / Fo Tau Fan Chau	伙頭墳洲	12	855500	821800
Tree Island / Pak Chau	白洲	5	805100	824150
Trio Island / Tai Lak Lei	大癩	12	851150	817950

English / Pin Yin	Chinese Character	Sheet No.	Easting	Northing
Tsim Chau	尖洲	8	857810	829110
Tsing Yi	青衣	6	828960	824560
Tung Lung Chau	東龍洲	12	848000	812000
Tweed Island / Lo Chau To	羅洲島	15	841000	807600
Urn Island / Tai Tau Chau	大頭洲	8	851800	825900
Victor Rock	七星排	-	-	-
Waglan Island	橫瀾島	16	849240	804290
West Brother / Tai Mo To	大磨刀	9	814600	830400
Wong Mau Chau	黃茅洲	8	858650	834320
Wong Nai Chau	黃泥洲	12	856100	822900
Yeung Chau	洋洲	4	849600	844300
Yeung Chau	洋洲	7	840900	835850
Yim Tin Tsai	鹽田仔	8	849400	826500
Yuen Chau	圓洲	13	808140	803885
Yuen Kong Chau	圓岡洲	13	800400	802590
Mountains				
Brick Hill	南朗山	15	835760	811380
Castle Peak	青山	5	813430	827100
Fei Ngo Shan	飛鵝山	11	841000	822210
High Island	糧船灣	8	854750	824430
High Junk Peak	釣魚翁	12	847500	817350
Hung Fa Leng	紅花嶺	3	837650	844630
Jardine's Lookout	渣甸山	11	837900	814400
Kai Kung Leng	雞公嶺	2	827170	836180
Lantau Peak	鳳凰山	9	810060	812400
Lion Rock	獅子山	11	837340	823650
Mid-Levels	半山區	11	833090	815800
Mount Butler	畢拿山	11	839670	814420
Needle Hill	針山	7	834750	827550
Nei Lak Shan	彌勒山	9	808710	813780
Pak Tai To Yan	北大刀屻	3	831550	836430
Pat Sin Leng	八仙嶺	3	841590	838510
Peaked Hill / Kai Yet Kok	雞翼角	13	810200	808700
Piper's Hill	琵琶山	11	833760	823080
Sharp Peak	蚺蛇尖	8	856500	832510
Sunset Peak	大東山	9	813310	813040
Sze Shan	獅山	9	805200	812630
Tai Lam Chung	大欖涌	6	821040	825490
Tai Mo Shan	大帽山	7	830560	830110
Tai To Yan	大刀屻	7	830370	834520
Tate's Cairn	大老山	7	840480	824390
Tung Chung Au	東涌坳	9	811910	812260
Victoria Peak	扯旗山	11	833110	815370
Wong Kong Shan	黃崗山	3	832900	838950
Chinese Mainland				
Beijiang	北江	-	-	-
Dangan Island Group	担杆群島	-	-	-
Dongjiang	東江	-	-	-
Fanshi	矾石	-	-	-
Fanshi Channel	矾石水道	-	-	-
Guangdong Province	廣東省	-	-	-
Guangzhou	廣洲	-	-	-
Lianhuashan	蓮花山	-	-	-

English / Pin Yin	Chinese Character	Sheet No.	Easting	Northing
Lingding	伶仃	-	-	-
Lingding Channel	伶仃洋	-	-	-
Macau	澳門	-	-	-
Neilingding	內伶仃	-	-	-
Pearl River	珠江	-	-	-
Pearl River Delta	珠江三角洲	-	-	-
Pearl River Estuary	珠江口	-	-	-
Sham Wan Tsuen	深灣村	-	-	-
Shekou Peninsula	蛇口半島	-	-	-
Shenzhen / Sham Chun	深圳	-	-	-
South China Sea	南中國海	-	-	-
Tai Sha River	大沙河	-	-	-
Xijiang	西江	-	-	-
Yangchun	陽春	-	-	-
Yunfu	雲浮	-	-	-
Zhaoqing	肇慶	-	-	-
Zhuhai	珠海	-	-	-
Plains				
Fanling	粉嶺	3	832330	839510
Mai Po	米埔	2	823490	840020
New Territories	新界	-	-	-
Sheung Shui	上水	3	830920	841070
Yuen Long Plain	元朗平原	6	821620	833660
Reclamation				
Chek Lap Kok Airport	赤鱲角機場	9	811160	818930
Hung Hom	紅磡	11	837170	818670
Kai Tak Airport Extension	啓德機場擴建	11	838490	821060
Victoria Park	維多利亞公園	11	837480	816030
West Kowloon Reclamation	西九龍填海	11	834640	818700
Reservoirs				
High Island Dam	萬宜水壩	8	854220	826140
High Island Reservoir	萬宜水塘	8	854220	826140
Jubilee Reservoir	城門水塘	7	833190	827320
Kowloon Reservoirs	九龍水塘	11	834000	823950
Plover Cove Reservoir	船灣淡水湖	3	844250	837180
Shek Pik Reservoir	石壁水塘	13	807550	810250
Rivers & Valleys				
Happy Valley	跑馬地	11	837190	814430
Ho Chung Valley	蠔涌谷	11	842970	823640
Kam Tin River	錦田河	6	825180	833260
Kau Lung Hang Valley	九龍坑谷	3	834530	837700
Lam Tsuen River	林村河	7	834500	835500
Lam Tsuen Valley	林村河谷	7	831260	833710
Ng Tung Ho	梧桐河	3	831850	841080
Sha Tin Valley	沙田谷	7	-	-
Sham Wat Valley	深屈谷	9	806630	814440
Shan Pui River	山背河	6	821350	835200
Shek Pik Valley	石壁谷	13	-	-
Shenzhen River / Shum Chun River	深圳河	2	832540	844780
Sheung Yue Ho	雙魚河	2	828710	840150

English / Pin Yin	Chinese Character	Sheet No.	Easting	Northing
Shing Mun River	城門河	7	838260	827220
Tung Chung Valley	東涌谷	9	-	-

Towns, Villages, Country Parks & Other General Locations

English / Pin Yin	Chinese Character	Sheet No.	Easting	Northing
Au Ha	凹下	3	838200	843060
Bride's Pool	新娘潭	3	842510	840450
Causeway Bay	銅鑼灣	11	837100	815840
Cha Kwo Ling	茶果嶺	11	841700	818000
Choi Wan Estate	彩雲邨	11	840330	821570
Clear Water Bay Road	清水灣道	11	842000	821650
Container Terminal 6	六號貨櫃碼頭	11	-	-
Fanling Centre	粉嶺中心	3	-	-
Hang Hau	坑口	12	845600	819580
Ho Chung	蠔涌	7	843400	824150
Kai Tak Airfield	啓德機場	11	838240	820830
Kam Tin	錦田	6	822380	835380
Kam Tin Village	錦田村	6	824880	833530
Kei Lun Wai	麒麟圍	6	815290	830310
Kennedy Town	堅尼地城	11	831420	815910
Kong Lok Yuen	康樂園	7	834030	835830
Kornhill	康怡花園	11	840500	815300
Kowloon	九龍	11	835830	822850
Kowloon Bay	九龍灣	11	840130	820470
Kowloon Tong	九龍塘	11	836560	821520
Kwai Chung	葵涌	7	832270	825430
Lam Kam Road	林錦公路	7	831710	834100
Lau Fau Shan	流浮山	2	816310	836460
Lei Cheng Uk	李鄭屋	11	834480	822180
Lo So Shing	蘆鬚城	15	831100	807360
Lo Wu	羅湖	2	829770	843190
Luk Keng	鹿頸	3	840180	841970
Ma On Shan	馬鞍山	7	841580	831360
Nam Chung	南涌	3	838980	842440
Ngau Tam Mei	牛潭尾	2	823520	840000
North Lantau Island	北大嶼山	9	-	-
North Point	北角	11	838670	816930
Sai Kung	西貢	8	845590	830890
San Hui	新墟	6	815560	828790
San Tin	新田	2	825300	840300
Sea Ranch	澄碧村	14	816970	808570
Sha Po Tsuen	沙埔村	6	823600	834840
Sha Tau Kok	沙頭角	3	840950	845570
Sha Tin	沙田	7	837820	826730
Sham Wat	深屈	9	806630	814440
Shan Ha Tsuen	山下村	6	819630	832500
Shan Pui	山背	6	821990	834730
Shau Kei Wan	筲箕灣	11	841250	815400
Shek Kip Mei	石硤尾	11	835280	821710
Shek O	石澳	15	843870	810530
Shek Pik	石壁	13	806790	809720
Sheung Tong	上塘	6	826380	827880
Sheung Wan	上環	11	833510	816240
Shing Mun Mine	城門鑛	7	-	-
Shuen Wan	船灣	3	839250	836520
So Uk	蘇屋	11	834440	822480
Tai Lam Country Park	大欖郊野公園	6	821040	825490
Tai Po	大埔	7	836330	834670
Tai Shek Mo	大石磨	2	829140	842550
Tin Shui Wai	天水圍	6	817960	835710
Tin Shui Wai New Town	天水圍新市鎮	6	817960	835710
Tsuen Wan	荃灣	6	829610	826040
Tsz Wan Shan	慈雲山	11	838750	823680
Tuen Mun	屯門	6	815430	827890
Tuen Mun New Town	屯門新市鎮	6	815430	827890
Tung Chung	東涌	9	811500	815640
Tung Chung New Town	東涌新市鎮	9	811500	815640
Wai Tau Tsuen	圍頭村	7	833090	835900
Wan Chai	灣仔	11	835890	815420
West Kowloon	西九龍	11	834640	818700
Western District	西區	11	-	-
Yi O	二澳	13	802570	810200
Yuen Long	元朗	6	821620	833660

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廣東省
GUANGDONG PROVINCE

新界
NEW TERRITORIES

青衣
TSING YI

九龍
KOWLOON

赤鱲角
CHEK LAP KOK

大嶼山
LANTAU ISLAND

香港島
HONG KONG ISLAND

南丫島
LAMMA ISLAND

850 000N
840 000N
830 000N
820 000N
810 000N

810 000E
820 000E
830 000E
840 000E
850 000E
860 000E
870 000E

HONG KONG GEOLOGICAL SURVEY
香港地質調查
QUATERNARY GEOLOGY
第四紀地質

MAP 1 : TOPOGRAPHY AND BATHYMETRY
圖一： 地形和等深線

Bathymetric contours in metres
below Hong Kong Principal Datum
香港水平基準面下之
等深線以米為單位

mPD
0
-10
-20
-30
-40
-50

Onshore contours in metres
above Hong Kong Principal Datum
香港水平基準面上之
陸地等高線以米為單位

mPD
> 800 m
400 - 800 m
200 - 400 m
100 - 200 m
0 - 100 m

Limit of the offshore survey
近海調查範圍

Pre-reclamation coastline
填海前海岸線

Datum levels used on marine charts and drawings
在航海圖和各圖中香港水平基準面和其它基準面的關係



SCALE 1:100 000 比例尺

This is Map 1 in a set of six that accompanies the Hong Kong Geological Survey publication :
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The full set of maps comprises :

MAP 1 : TOPOGRAPHY AND BATHYMETRY
MAP 2 : PLACE NAMES, FILL AND BORROW AREAS
MAP 3 : ONSHORE AND COASTAL QUATERNARY DEPOSITS
MAP 4 : BASE OF THE OFFSHORE QUATERNARY FORMATIONS
MAP 5 : LATE PLEISTOCENE - EARLY HOLOCENE EROSION SURFACE OFFSHORE
MAP 6 : SEABED SEDIMENTS

此圖為香港地質調查組出版之香港第四紀地質圖一套六張之圖一：
《香港第四紀地質》作者為范耀雷, 蕭偉立, 甘沛霖, 黎權偉和郭偉傑
全套地圖包括：

圖一： 地形和等深線
圖二： 地名, 填土區和採砂區
圖三： 陸地和海岸第四系沉積
圖四： 近海第四系底部
圖五： 晚更新世一早全新世的近海侵蝕面
圖六： 海底沉積物

Index of 1:20 000 - scale Geological Maps
1:20 000 地質圖索引



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HONG KONG GEOLOGICAL SURVEY
香港地質調查
QUATERNARY GEOLOGY
第四紀地質

MAP 2 : PLACE NAMES, FILL AND BORROW AREAS

圖二： 地名, 填土區和採砂區

廣東省
GUANGDONG PROVINCE

新界
NEW TERRITORIES

850 000N
840 000N
830 000N
820 000N
810 000N

810 000E
820 000E
830 000E
840 000E
850 000E
860 000E
870 000E

Starling Inlet 沙頭角海
Sha Tau Kok 沙頭角
Robin's Nest 紅花嶺
Lo Wu 羅湖
Sai Ap Chau 細鴨洲
Ap Chau 鴨洲
Shek Tsui 長石咀
Cheung Yeung Chau 洋洲
Crooked Island 吉澳
Crooked Harbour 吉澳海
Wang Mun Hoi 橫門海
Round Island 白沙洲
Fun Chau 墳洲
Crescent Island 鐵眉洲
Double Island 往灣洲
Double Haven 印洲塘
Nam Chung 南涌
Luk Keng 鹿頸
Wong Chuk Kok Hoi 黃竹角海
Bluff Head 黃竹角咀
Bride's Pool 新娘潭
Ping Chau 平洲
Mirs Bay 大鵬灣
North Channel 大赤門
Port Island 赤洲
Middle Channel 赤洲口
Kung Chau 弓洲
Grass Island 塔門
South Channel 塔門口
Long Harbour 大灣海
Shek Ngau Chau 石牛洲
Wong Mau Chau 黃茅洲
Tuen Tsui 短咀
Sharp Peak 躺船尖
Tai Long Tsui 大浪咀
Tai Long Wan 大浪灣
Tai Chau 大洲
Tsim Chau 尖洲
Conic Island 飯籠洲
Long Ke Wan 浪柯灣
Po Pin Chau 蒲泥洲
Kong Tau Pai 光頭排
Wang Chau 橫洲
Wong Nai Chau 黃泥洲
Basalt Island 火石洲
Trio Island 大纜廟
Ping Min Chau 平面洲
Bluff Island 沙塘口山
Town Island 仔頭墳洲
Jin Island 吊鐘洲
Bay Islet 監洲
Rocky Harbour 糧船灣海
High Island 糧船灣
High Island Reservoir 萬宜水庫
Shelter Island 牛尾洲
Port Shelter 牛尾海
Sharp Island 橋咀洲
Inner Port Shelter 西貢海
Sai Kung 西貢
Yeung Chau 羊洲
Cham Tau Chau 枕頭洲
Yim Tin Tsai 鹽田仔
Kau Sai Chau 滘西洲
Ho Chung Valley 蠔涌谷
Tate's Cairn 大老山
Lion Rock 獅子山
Tsz Wan Shan 慈雲山
Fei Ngo Shan 飛鵝山
Tseung Kwan O 將軍澳
Junk Bay 將軍澳
Clear Water Bay 清水灣
Joss House Bay 佛堂灣
Fat Tong Chau 佛堂洲
Tit Cham Chau 鐵掌洲
Fat Tong Mun 佛堂門
Steep Island 青洲
North Ninepin Island 北果洲
East Ninepin Island 東果洲
Ninepin Group 果洲群島
South Ninepin Island 南果洲
Tung Lung Chau 東龍洲
Tathong Channel 鰲磡石水道
Buoy Wave Bay 大浪灣
Shek O 石澳
Tai Tau Chau 大頭洲
Ng Fan Chau 五分洲
Cape D'Aguilar 鶴咀
Kau Pei Chau 狗脾洲
Stanley Bay 赤柱灣
Lo Chau To 羅洲島
Tai Tam Bay 大潭灣
Repulse Bay 淺水灣
Deep Water Bay 深水灣
Happy Valley 跑馬地
Causeway Bay 銅鑼灣
Wan Chai 灣仔
Quarry Bay 鰂魚涌
North Point 北角
Lei Yue Mun 鯉魚門
Kwun Tong 觀塘
Kowloon Bay 九龍灣
Kowloon Tong 九龍塘
Kai Tak 啟德
Kowloon 九龍
KOWLOON
Victoria Harbour 維多利亞港
Hung Hom Bay 紅磡灣
West Kowloon Reclamation 西九龍填海
Stonecutters Island 昂船洲
Tsing Yi 青衣
Tsing Yi Channel 青衣海峽
Tsing Yi South Bridge 青衣南大橋
Tsing Yi North Bridge 青衣北大橋
Kwai Chung 葵涌
Kwai Shek 掘石
Ma Wan 馬灣
Tsing Lung Chau 青龍頭
Rambler Channel 藍巴勒海峽
Tsuen Wan 荃灣
Shing Mun River 城門河
Needle Hill 針山
Sha Tin 沙田
Tai Wai 大圍
Ma On Shan 馬鞍山
Tai Mo Shan 大帽山
Sha Tin Hoi 沙田海
Centre Island 丫洲
Three Fathoms Cove 企鵝下海
Tolo Harbour 吐露港
Tai Po 大埔
Tai Po Hoi 大埔海
Ma Shi Chau 馬屎洲
Pak Sha Tau 白沙頭
Plover Cove 船灣海
PLOVER COVE RESERVOIR 船灣淡水湖
Yeung Chau 洋洲
Tolo Channel 赤門
Pat Sin Leng 八仙嶺
Wong Kong Shan 黃崗山
Kau Lung Hang Valley 九龍坑谷
Ng Tung Ho Valley 梧桐河谷
Fanling 粉嶺
Hong Lok Yuen 康樂園
Wai Tau Tsuen 圍頭村
Pak Tai To Yan 北大刀咀
Tai To Yan 大刀咀
Lam Tsuen Valley 林村谷
Lam Kam Road 林錦公路
Kam Tin River 錦田河
Kam Tin 錦田
Shan Ha Tsuen 山下村
Yuen Long 元朗
Yuen Long Plain 元朗平原
Kai Kung Leng 蟾公嶺
Ngau Tam Mei Valley 牛潭尾谷
Tin Shui Wai 天水圍
Lau Fau Shan 流浮山
Tsim Bei Tsui 尖鼻咀
Deep Bay 后海灣
Pak Nai 白泥
Black Point 爛角咀
Urmston Road 龍鼓水道
Tap Shek Kok 踏石角
Lung Kwu Chau 龍鼓洲
Pillar Point 望后石
Pearl Island 龍珠島
Castle Peak 青山
Castle Peak Bay 青山灣
Tuen Mun 屯門
Tuen Mun San Hui 屯門新城
Tai Lam Chung 大欖涌
Brothers Point 大欖角
The Brothers 大小磨刀
Tai Mo To 大磨刀
Siu Mo To 小磨刀
Pak Chau 白洲
Sha Chau 沙洲
Kwai Shek 掘石
Kwai Shek Kok 掘石角
Tsing Kwai Tan 青葵潭
Penny's Bay 竹篙灣
Siu Ho Wan 小蠔灣
Discovery Bay 愉景灣
CHEK LAP KOK 赤鱲角
Tung Chung New Town 東涌新市鎮
Por Kai Shan 婆髻山
Tung Chung Valley 東涌谷
Sham Wat 深屈
LANTAU ISLAND 大嶼山
Nei Lak Shan 彌勒山
Tai O 大澳
Tai Ho 大東
Sunset Peak 大東山
Lantau Peak 鳳凰山
Cheung Sha 長沙
Pui O Wan 貝澳灣
Shek Pik Reservoir 石壁水塘
Yi O 二澳
Shui Hau Wan 水口灣
Tai Long Wan 大浪灣
Lo Kai Wan 蘆荻灣
Cha Kwo Chau 茶果洲
Chi Ma Wan Peninsula 芝麻灣半島
Chi Ma Wan 芝麻灣
Silver Mine Bay 銀礦灣
Mui Wo 梅窩
Tung Wan 東灣
Cheung Chau 長洲
Shek Kwu Chau 石鼓洲
Soko Islands 索罟群島
Siu A Chau 小鏵洲
Cheung Muk Tau 樟木頭
Yuen Chau 圓洲
Ma Chau 牙洲
Tai A Chau 大鏵洲
Yuen Kong Chau 圓崗洲
Tau Lo Chau 頭顱洲
Lantau Channel 大嶼海峽
Peng Chau 坪洲
Kau Yi Chau 交椅洲
Siu Kau Yi Chau 小交椅洲
Hei Ling Chau 喜靈洲
Sunshine Island 周公島
Green Island 青洲
Sulphur Channel 硫磺海峽
Kennedy Town 堅尼地城
Victoria Peak 扯旗山
Central District 中環
Aberdeen 香港仔
Wong Chuk Hang 黃竹坑
HONG KONG ISLAND 香港島
Brick Hill 南朗山
Ap Lei Chau 鴨脷洲
Yung Shue Wan 榕樹灣
Luk Chau Wan 鹿洲灣
Luk Chau 鹿洲
Picnic Bay 東頭灣
LAMMA ISLAND 南丫島
Ha Mei Wan 下尾灣
Tung O Wan 東瀦灣
Sham Wan 深灣
East Lamma Channel 東博寮海峽
West Lamma Channel 西博寮海峽
Sheung Sze Mun 橫四門
Lo Chau Mun 橫洲門
Beaufort Island 鰏洲
Mat Chau 蟹洲
Sung Kong 崇崗
Waglan Island 橫瀾島
Po Toi 蒲台
Po Toi Islands 蒲台群島

Borrow areas - sand remaining
尚有海砂的採砂區
Borrow areas - worked out
已用完之採砂區
Contaminated mud pits
污泥卸置坑
Uncontaminated mud disposal grounds
非污染淤泥卸置區
Reclamation Area
填海區
Pre-reclamation coastline
填海前海岸線

Note: Status of features as of December 1999
註： 資料截至1999年12月之狀況為準

0 5 10 km 千米
SCALE 1:100 000 比例尺

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《香港第四紀地質》作者為范耀雲, 蕭偉立, 甘沛霖, 黎權偉和鄭偉傑

全套地圖包括：

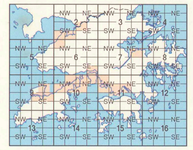
圖一： 地形和等深線
圖二： 地名, 填土區和採砂區
圖三： 陸地和海岸第四系沉積
圖四： 近海第四系底部
圖五： 晚更新世—早全新世的近海侵蝕面
圖六： 海底沉積物

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廣 東 省
GUANGDONG PROVINCE

九 龍
KOWLOON

香 港 島
HONG KONG ISLAND

大 嶼 山
LANTAU ISLAND

850 000N
840 000N
830 000N
820 000N
810 000N

810 000E
820 000E
830 000E
840 000E
850 000E
860 000E
870 000E

HONG KONG GEOLOGICAL SURVEY
香港地質調查
QUATERNARY GEOLOGY
第四紀地質

MAP 3 : ONSHORE AND COASTAL QUATERNARY DEPOSITS
圖三 ： 陸地和海岸第四系沉積

- Hang Hau Formation, beach (sand), intertidal (mud and sand), and estuarine deposits (mud, clayey silt and sand)
  坑口組, 海灘(砂), 潮間帶(淤泥和砂)和河口灣沉積(淤泥, 黏土質粉砂和砂)
- Fanling Formation, colluvium (sand, gravel, cobbles and boulders in silt matrix)
  粉嶺組, 坡積物(基質為粉砂的砂, 礫石, 中礫和漂礫)
- Fanling Formation, alluvium (silt, sand and gravel)
  粉嶺組, 沖積物(粉砂, 砂和礫石)
- Chek Lap Kok Formation, colluvium (sand, gravel, cobbles and boulders in silt matrix)
  赤鱲角組, 坡積物(基質為粉砂的砂, 礫石, 中礫和漂礫)
- Chek Lap Kok Formation, alluvium (silt, sand and gravel)
  赤鱲角組, 沖積物(粉砂, 砂和礫石)
- Reclamation Area
  填海區

Quaternary deposit boundaries based on 1:20 000-scale geological map Sheets 2 to 16 (1986-1995)
第四紀沉積界線根據 1：20 000 地質圖第 2-16 幅（1986-1995）

- Watercourse 溪澗
- Major Faults 主要斷裂
- Pre-reclamation coastline 填海前海岸線
- Reservoir 水塘

0 5 10 km 千米
SCALE 1:100 000 比例尺

This is Map 3 in a set of six that accompanies the Hong Kong Geological Survey publication :

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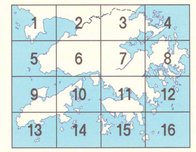
The full set of maps comprises :

MAP 1 : TOPOGRAPHY AND BATHYMETRY
MAP 2 : PLACE NAMES, FILL AND BORROW AREAS
MAP 3 : ONSHORE AND COASTAL QUATERNARY DEPOSITS
MAP 4 : BASE OF THE OFFSHORE QUATERNARY FORMATIONS
MAP 5 : LATE PLEISTOCENE - EARLY HOLOCENE EROSION SURFACE OFFSHORE
MAP 6 : SEABED SEDIMENTS

此圖為香港地質調查組出版之香港第四紀地質圖一套六張之圖三：
《香港第四紀地質》作者為范耀富, 蕭偉立, 甘沛霖, 黎權偉和郭偉傑
全套地圖包括：

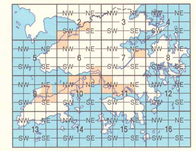
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圖六： 海底沉積物

Index of 1:20 000 - scale Geological Maps
1:20 000 地質圖索引



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已出版的主要發展區 1：5 000 地質圖（粉紅部份）。

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NEW TERRITORIES

青 衣
TSING YI

九 龍
KOWLOON

赤 鱲 角
CHEK LAP KOK

大 嶼 山
LANTAU ISLAND

香 港 島
HONG KONG ISLAND

南丫島
LAMMA ISLAND

850 000N
840 000N
830 000N
820 000N
810 000N

810 000E
820 000E
830 000E
840 000E
850 000E
860 000E
870 000E

-20
-40
-60
-80
-100
-120

HONG KONG GEOLOGICAL SURVEY
香港地質調查
QUATERNARY GEOLOGY
第四紀地質

MAP 4 : BASE OF THE OFFSHORE QUATERNARY FORMATIONS
圖四： 近海第四系底部

Contours on the eroded surface of weathered rock underlying the Quaternary sediments offshore in metres below Principal Datum

第四紀沉積覆蓋下之風化岩石侵蝕面等深線
（水平基準面下以米為單位）

mPD
0
-20
-40
-60
-80
>-100

Limit of the offshore survey
近海調查範圍

Pre-reclamation coastline
填海前海岸線

0 5 10 km 千米

SCALE 1:100 000 比例尺

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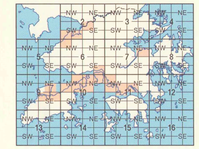
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HONG KONG GEOLOGICAL SURVEY
香港地質調查
QUATERNARY GEOLOGY
第四紀地質

MAP 5 : LATE PLEISTOCENE - EARLY HOLOCENE EROSION SURFACE OFFSHORE

圖五： 晚更新世－早全新世的近海侵蝕面

Contours on the Late Pleistocene - Early Holocene erosion surface offshore in metres below Principal Datum
晚更新世－早全新世近海侵蝕面等深線（水平基準面下以米為單位）

mPD
0
-10
-20
-30
-40
-50
-60

Areas of gas blanking (acoustic turbidity) within the Hang Hau Formation
坑口組內之測聲空白區（聲波混濁區）

Limit of the offshore survey
近海調查範圍

Pre-reclamation coastline
填海前海岸線

0 5 10 km 千米

SCALE 1:100 000 比例尺

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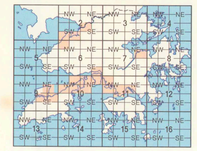
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HONG KONG GEOLOGICAL SURVEY
香港地質調查
QUATERNARY GEOLOGY
第四紀地質

MAP 6 : SEABED SEDIMENTS
圖六： 海底沉積物

- Thin gravel and gravelly sand
  礫石和礫質砂
- Mud, sandy mud
  淤泥，砂質淤泥
- Sand, muddy sand
  砂，淤泥質砂
- Clay, silt and sand (Chek Lap Kok Formation)
  黏土，粉砂和砂（赤鱲角組）
- Rock, undifferentiated
  岩石，未分類
- Seabed borrow areas and disposal ground
  海底採砂區和卸置場
- Fill (areas of former seabed now masked by reclamation)
  填海區
- Land area
  陸地

Data sources
資料來源

- Admiralty chart
  航海圖
- Seabed camera
  海底相機
- Seabed grab sample
  海底採挖樣本
- Limit of the offshore survey
  近海調查範圍
- Pre-reclamation coastline
  填海前海岸線

0 5 10 km 千米

SCALE 1:100 000 比例尺

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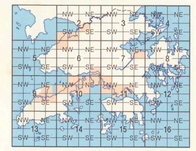
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