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HONG KONG GEOLOGIST

The Journal of the Geological Society of Hong Kong

This journal publishes research articles, short communications and reviews related to Hong Kong, Macau and the South China region, and details of field trips, meetings, training courses and other activities of the Geological Society of Hong Kong. This journal incorporates the previously published Newsletter of the Geological Society of Hong Kong.

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THE INAUGURATION OF THE HONG KONG GEOLOGIST

Raynor Shaw

Chairman, Geological Society of Hong Kong

Subsequent to the founding of the Geological Society of Hong Kong on the 26 July 1982 (the date of the official registration) the Geological Society of Hong Kong Newsletter was begun as a bimonthly publication, the first issue appearing in November 1982. Originally it was designed to notify members of forthcoming meetings and field trips, to report on these events and to publicize items of local geological interest. The Newsletter grew in size, from around 16 pages to 50 pages, and in 1985 (volume 4) was reduced to a quarterly publication (with the exception of 1988 when only one 60 page volume 6 was issued).

Over the years, the focus and the content of the Newsletter have changed, attracting more short technical and scientific articles. Concomitantly, the standard of production and presentation has been significantly improved and notices are less in evidence; these are now circulated as separate mailings.

More recently Hong Kong has witnessed the emergence of its first independent school of earth science, the Earth Science Department at Hong Kong University, with several academic appointments being made over a two-three year period.

As an almost inevitable consequence of these trends the General Committee, after careful delib-

erations, decided in 1994 that the Newsletter would be discontinued, ceasing publication at Volume 11, No's 3-4 (September-December 1993), a new publication that reflected the nature of these changes. This is the first issue of the *Hong Kong Geologist*, a more journal-style publication that will feature short technical and scientific articles pertinent to both Hong Kong and the surrounding region. The publication is intended to convey the full scope and interests of Hong Kong geologists.

Publication is to be twice a year, in Spring and Autumn. Notices concerning other activities of the Society, such as field trips and lecture meetings will rely entirely on separate mailings.

To reflect the increased offshore developments in Hong Kong the first issue is exclusively devoted to marine geology topics. Subsequent issues will be less specialised and articles on any subject area within the earth sciences are welcomed. A new series of short articles, called the Hong Kong Landform Series, is also planned. Sponsored by the Geomorphological Studies Group, this series will document distinctive landforms of the Territory. These articles will eventually be assembled as a guide to the Territories landforms.

THE HONG KONG LANDFORM SERIES

Raynor Shaw

Convenor, Geomorphological Studies Group

The Geomorphological Studies Group (GSG) was inaugurated at the Annual General Meeting in May 1993 (reported in the Geological Society of Hong Kong Newsletter, 1993, 11 (1-2), 20). One of the objectives of the GSG is to systematically document the interesting and varied landforms of Hong Kong in an irregular series, the Hong Kong Landform Series. The first example appears in this issue.

Each is being prepared to a consistent format that includes the name of the landform or process, a concise definition or description, a broader description of details, characteristics, varieties and other pertinent items. Photographs of one or more illustrative

examples will also be included. Where possible, a map or map references of occurrences will be incorporated to guide study groups to exemplary features.

All Society members are encouraged to contribute towards the series, describing features in which they specialise or have a particular interest. Ultimately, the GSG intends to compile the articles into a comprehensive guide book that will fill a vacant niche in the geological literature on the Territory. It is anticipated that the series will be of value to schools, colleges, universities, amateur geologists and professionals, as well as providing a useful summary for visitors to Hong Kong.

Results of an Offshore Engineering Geological Investigation in the Pearl River Mouth Basin of the South China Sea

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ABSTRACT

The Pearl River Mouth Basin is an area with one of the highest potentials for hydrocarbon resources in the northern South China Sea. Since 1985 the Second Marine Geological Investigation Brigade has carried out marine engineering geological investigations of nine sheet areas (1:200,000 scale) in the basin, covering about 70,000 km². This project has been supported, both financially and technologically, by the UNDP.

摘要

珠江口盆地是北部南中國海碳氫化合物(烴)資源最大潛在地區之一。自一九八五年以來,第二海洋地質調查大隊在該盆地的七萬平方公里範圍內進行了九幅一比二十萬圖幅的海洋工程地質調查。本項目得到聯合國發展計劃(UNDP)財務和技術上的支持。

Methods of Survey

Modern, advanced techniques of geophysics, geology and geotechnology have been combined in the survey. These techniques include (Table 1):

- (a) high resolution geophysical exploration systems; including bathometric surveys, side scan sonar, 3.5 kHz sub-bottom profiling and single and multi-channel seismic methods. The surveyed grids were 4 x 8 km for bathometric surveys, sub-bottom profiling and single-channel seismic, 8 x 16 km for side scan sonar, and 12 x 24 km for multi-channel seismic.
- (b) seafloor coring systems, including gravity coring, gravity piston coring and vibrocore.
- (c) engineering geological boring, including geological and geotechnical sampling.
- (d) in-situ testing (seafloor and downhole) and laboratory geotechnical testing.

Topography, Morphology and Quaternary Geology

The seafloor topography of the survey area (Figure 1) falls from northwest to southeast with wa-

ter depths ranging from 20 m to 1200 m. Two Grade I Morphological Units were identified: the continental shelf and the upper continental slope. Grade II Morphological Units include the modern marine accumulation plain, modern-relict accumulation plain, relict accumulation plain, sea knolls and deep slope areas. Grade III Morphological Units comprise several features such as pockmarks, sand waves, shelf shallow troughs, landslides, erosional valleys, shelly beaches and deltas (Table 2).

In addition, a 2 x 2 km area of the continental shelf margin was selected as a typical side scan survey mosaic. A 200 m line spacing was used and the scanning range was 150 m. The survey produced a side scan sonar mosaic map with apparent characteristics.

The detailed Quaternary stratigraphy of the basin was established using data from four boreholes (120 m) and seabed coring together with geophysical profiling. The sequence, from bottom to top comprises early Pleistocene, middle Pleistocene, late Pleistocene and Holocene units (Table 3). A study of sedimentary environments and sea level changes provided fundamental information for geohazard analyses and engineering geological evaluation.

Table 1 - Methods of Survey

Item	Objective
Navigation	to ensure vessel survey along planned grids
Bathymetry	to observe water depth & sea floor topography
Side scan sonar	to observe sea floor geomorphology
Subbottom profiling	to understand the sequences, structures and geohazards within 30m of sea floor
Single channel seismic	to understand the sequences, structures and geohazards within 100m of sea floor
Multi-channel seismic	to understand the sequences, structures and geohazards within 1000m of sea floor
Coring	to determine the bottom soil type and its physical & mechanical properties
Boring	to determine the subbottom sequences & their buried depths & ages, to prove the relevant geophysical data.
In situ testing	to determine the in situ engineering testing geological properties of the strata

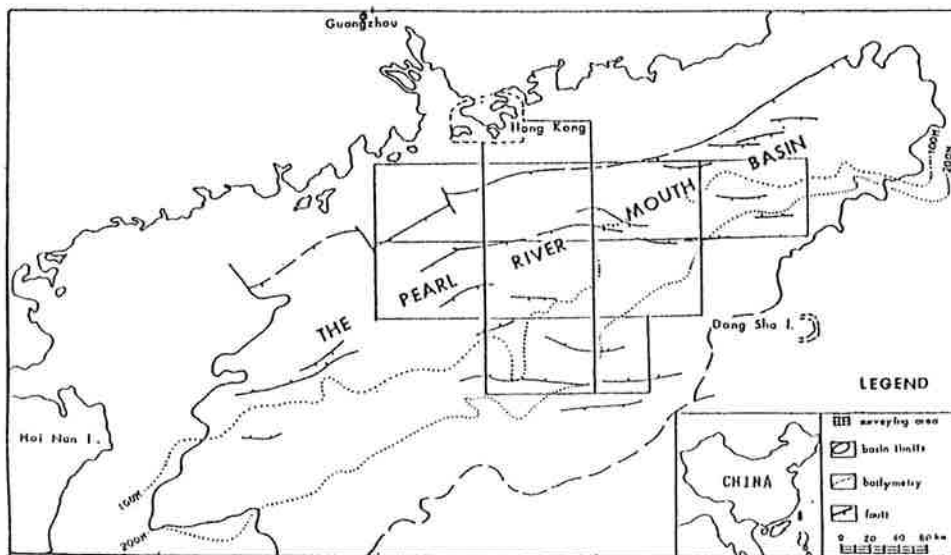


Figure 1 - Location map.

Characteristics of the Submarine Geohazards

The geohazards that exist in the basin have been identified from a large amount of geophysical profiling and geological data. These include such features as active faults, shallow gas, landslides, diapirs and sand wave movements, etc. (Table 4). There are also some potential constraint factors, such as buried channels, pockmarks, shelf shallow troughs, buried valleys and seafloor erosional valleys, etc.

(Figure 2).

Types of Submarine Geohazards

Several types of geohazard could cause direct damage to offshore facilities, particularly in the event of an earthquake.

(i) Active Faults

Active faults in the surveyed area fall into two

Table 2 - Types of Geomorphology

Grade	I	II	III
Types of Geomorphology	Continental shelf	modern marine accumulation plain	pockmarks sand wave
		modern relic accumulation plain	shelf trough
		relict accumulation plain	erosional valley
	Upper continental slope	sea knoll	shelly beach delta
		deep slope area	steep cliff

Table 3 - Synthetic Stratigraphy

Strata symbol	Seismic unit	Ages (ka)	Sedimentary environment
Q ₄	A	10	littoral-neritic
Q ₃ ³			fluvial-littoral
Q ₃ ²		32	littoral-neritic
Q ₃ ¹	B	75	neritic
Q ₂ ³		128	fluvial-estuarine-littoral
Q ₂ ²	C	270	littoral-neritic
Q ₂ ¹		458	estuarine-littoral-neritic
Q ₁	F	730	lacustrine-littoral

predominant groups that trend NW and ENE, being especially well developed in the NW in direction. From the extent of the faults and their period of formation, two types of active faults have been identified. One type developed in Tertiary or upper basement rocks and are very extensive. The second type are seafloor faults, with variable amounts of uplift or downthrow, that were active during the Quaternary. These two types of faults will directly cause geohazards in the event of an earthquake (Figure 3).

(ii) Shallow Gas

Because of the extensive development of Quaternary deltaic deposits, shallow gas is very common in the basin (Figure 4). High pressure gas generated

in the Tertiary oil-bearing structures that moved upward through faults and accumulated in shallow layers poses the most danger to offshore oil platforms.

(iii) Landslides

Landslides occur mainly at the continental shelf break and the steeply sloping upper continental slope. Modern seafloor landslides, older buried landslides, other types of mass movements and folded strata caused by interlayer slides are clearly identifiable on geophysical profiles (Figure 5).

(iv) Seabed Diapirs

Seabottom diapirs that occur at sea knolls in the upper continental slope area may originate from

Table 4 - Types and development of potential constraints

Type	Shallow area off islands	Shelf	Transition belt-slope	Data source
active fault	VC	R	VC	single & multichannel
hallow gas	VC	C	R	single channel
slides			C	subbottom, single & scan sonar
sand waves		R	VC	scan sonar, sub-bottom, p-single c.
diapir			C	subbottom profiler, single channel
pockmarks		VC		side scan sonar
cliffs			C	bathymetry & single channel
seafloor gully			C	bathymetry & single channel
buried channel	C	VC		subbottom profiler, single channel
shallow trough		VC	R	subbottom profiler, single channel
buried ridge	VC		C	subbottom profiler, single channel
buried valley	C	C	C	single channel
earthquake	VC	R	C	story record

R - rare; C - common; VC - very common

volcanic rocks or mud (Figure 6).

(v) Seabed Sand Waves

An extensive NE-striking sand wave zone was located in 130-200 m water depth in the southeastern part of the basin. It consists of micro, medium and large sand waves and some sand ridges. They are probably moved by storm currents, and could liquefy during earthquakes.

Constraint factors

Attention should also be paid to geological factors that may not cause direct damage to offshore facilities. These include multiphase buried channels that developed in response to sea level changes during the Quaternary. The bearing capacity of the sediments is different inside and outside the channel. Deeply buried channels will not seriously affect engineering structures, but buried channels located within 30 m of the seafloor will restrict some engineering facilities (Figure 7).

Pockmarks are relict morphological feature

that are most commonly caused by gas relief from gas-bearing strata. They exhibit a range of different forms and are widespread over the continental shelf. They may affect pipeline installations.

The features described above are developed to varying degrees over different parts of the basin (Table 3). Shallow troughs of NE and ENE trend developed on the continental shelf and erosional and buried valleys on the continental slope will all influence engineering structures. Active faults and shallow gas occur particularly in the shallow water coastal area. Active faults, landslides and seabottom diapirs are very common on the continental shelf margin and on the upper continental slope, where neotectonic activity is most pronounced. Constraint factors are more important than geohazards on the continental shelf.

Induced Geohazards

Geological activity in the northern South China Sea is strongly controlled by tectonic structures trending NE and NW. There are three earthquake belts: the northern continental margin, the northern conti-

Geohazard

Constraint

active fault

buried channel

seabottom sand wave

pockmarks

landslides

shallow trough

diapirs

buried ridge

shallow gas

erosional valley

steep cliff

buried valley

deltaic forest



shallow valley

sand wave

bed rock rise

landslide

Figure 2 - Generalized perspective diagram showing the distribution of geohazardous factors in the Pearl River Mouth Basin.



100

200

300

0 2 km

Figure 3 - Active faults.

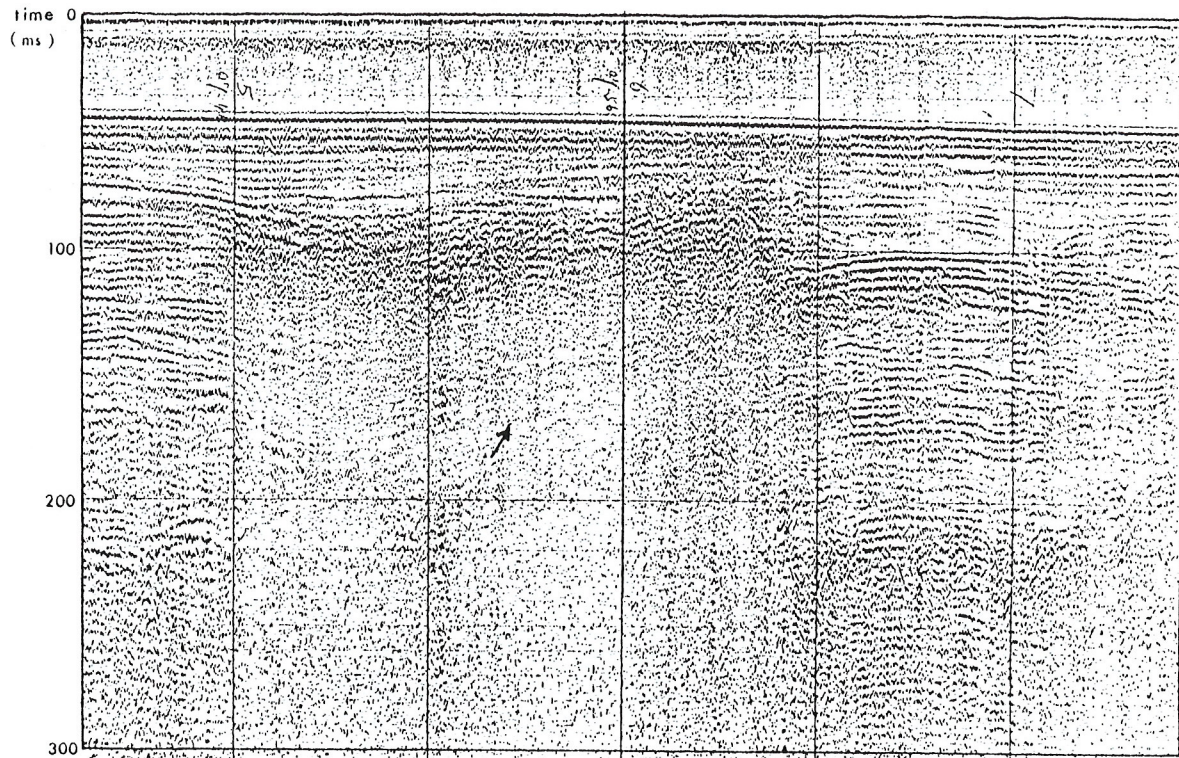


Figure 4 - Shallow gas.

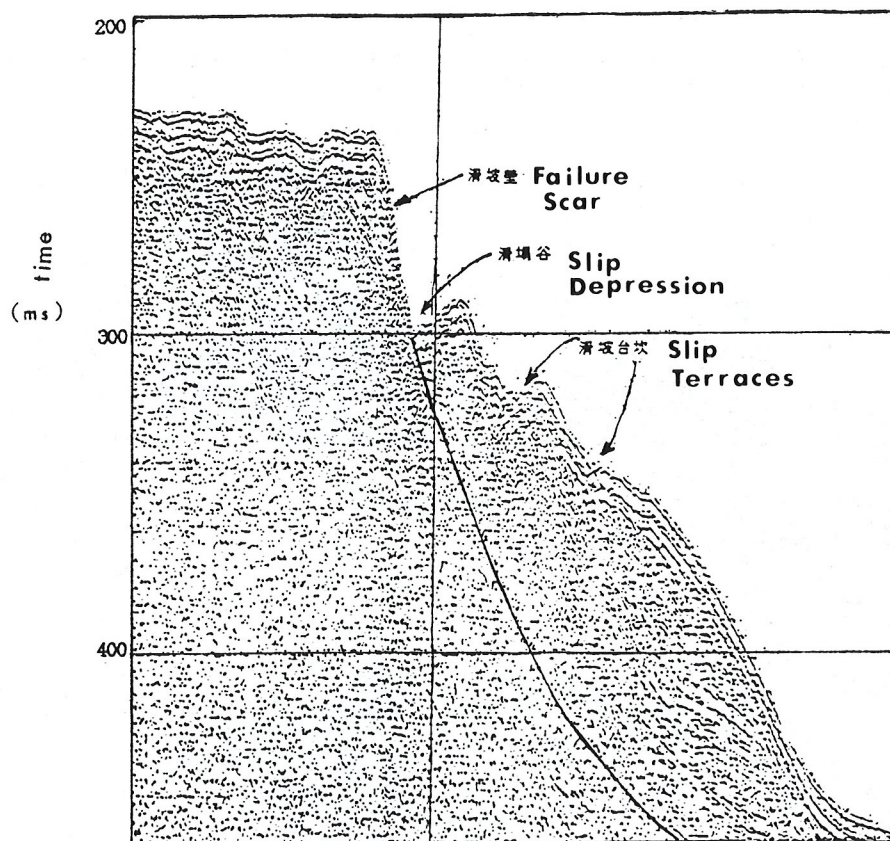


Figure 5 - Landslide

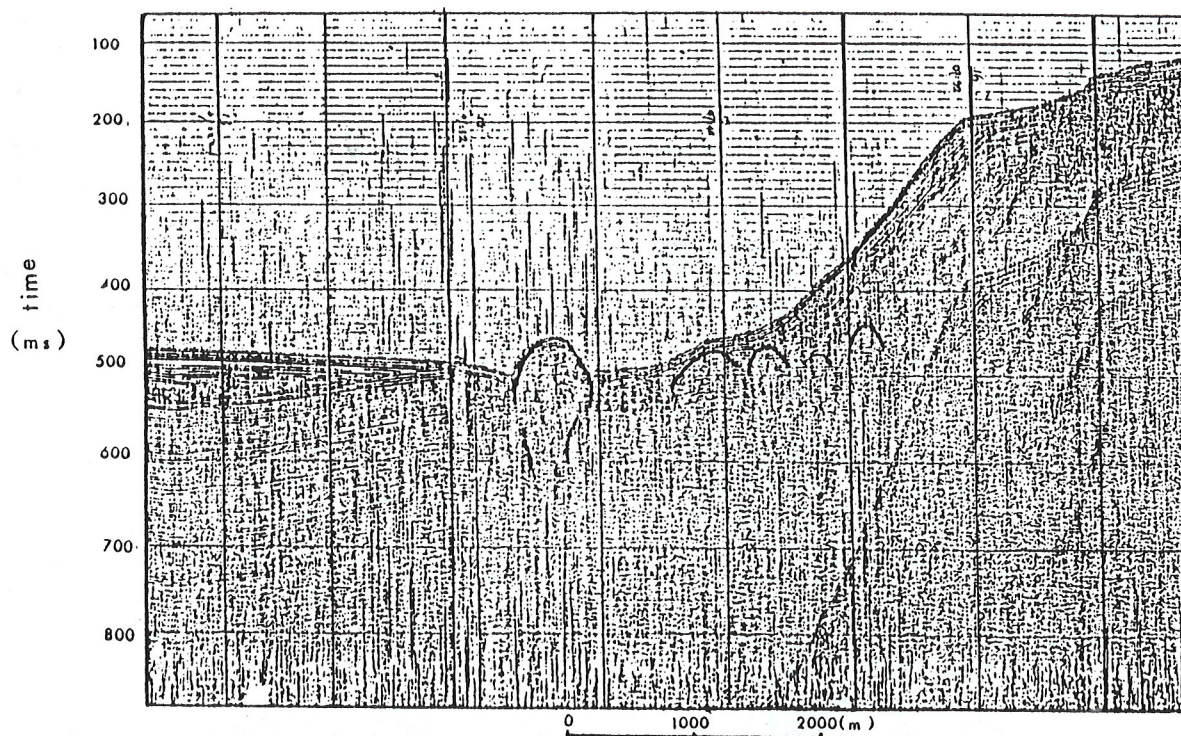


Figure 6 - seabottom diapiers.

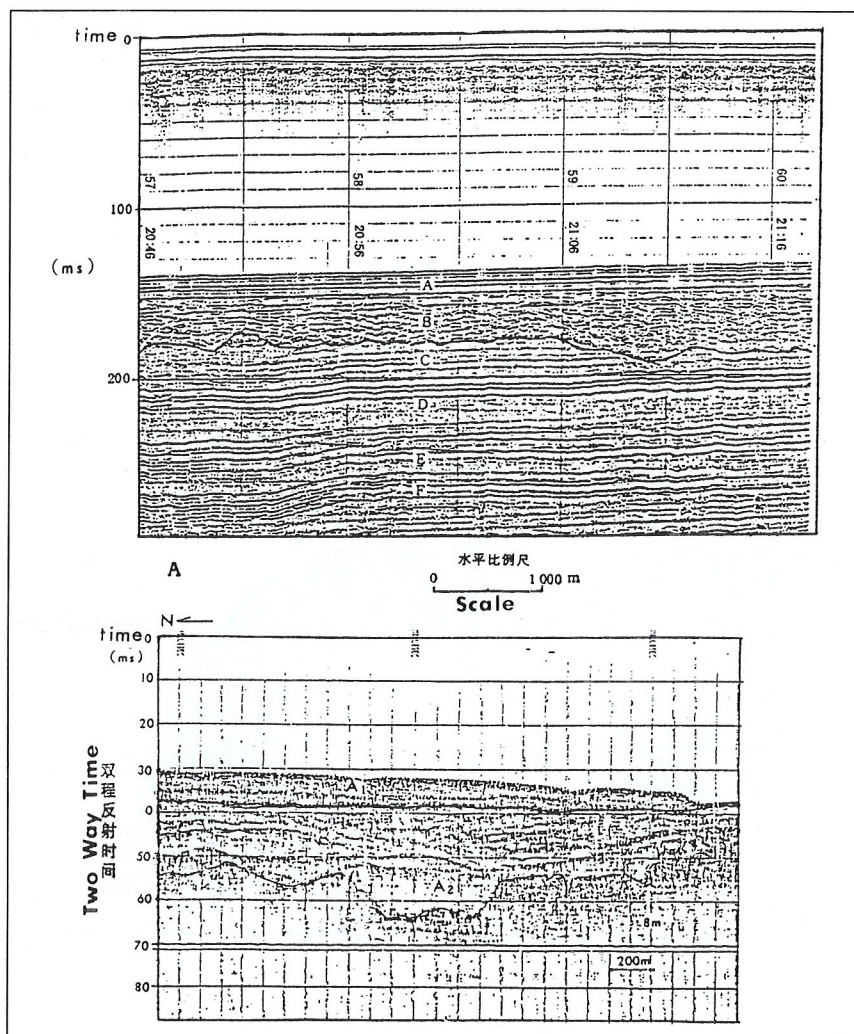


Figure 7 - A: buried channel on single-channel seismic profile; B: buried channel on seabottom profile.

mental slope and the Taiwan-Philippine arc. Earthquake intensity does not normally exceed 5 within the basin. The northern and eastern parts of the surveyed area, adjacent to these earthquake zones, will be affected when strong earthquakes occur. There is a strong possibility that geohazards will be induced.

The survey located several hundred NW trending, left-lateral active faults along the continental shelf margin and upper continental slope (Figure 8). Some of the faults developed from the Tertiary to the middle or lower Quaternary and some affected the seafloor. These recently active faults were located in the area adjacent to the north marginal earthquake zone of the continental shelf. It is recommended that more attention be focused on this area during future earthquake studies.

Typhoons are very common in the South China Sea. On average they occur 16.3 times annually with maximum wind speeds of 75 m/s. Typhoons are an important kind of hazardous weather.

Waves are controlled by wind. The highest waves of up to 14.2 m occur during typhoons. Tides are also influenced by wind, and are divided into full-time tides and half-time tides. Data on wind, waves and tides should be considered when analysing geohazards and carrying out geotechnical computations.

Engineering Geological Evaluation

Geotechnical Classification

Engineering geological classification of the seabed deposits was accomplished by in-situ geotechnical testing and laboratory testing. Nine geotechnical strata were distinguished by integrating the data from four boreholes (Figure 9).

Engineering Geological Divisions

The basin was subdivided into three engineering geological zones based on geophysical, geological, geotechnical and meteorological conditions (Figure 10).

(i) Zone I : Shallow water area (water depth < 30 m). Characterised by complicated engineering geological conditions. Geohazards such as active faults and shallow gas exist. Bedrock is buried to different depths below sea level. Strong coastal currents occur. This area is adjacent to the earthquake belt of the continental margin of the South China Sea.

(ii) Zone II : The continental shelf characterised by simple engineering geological conditions. The seafloor is flat and fewer geohazards were found. Buried channels, shallow troughs and pockmarks are developed. There is no evidence of neotectonic movement with only weak earthquake activity.

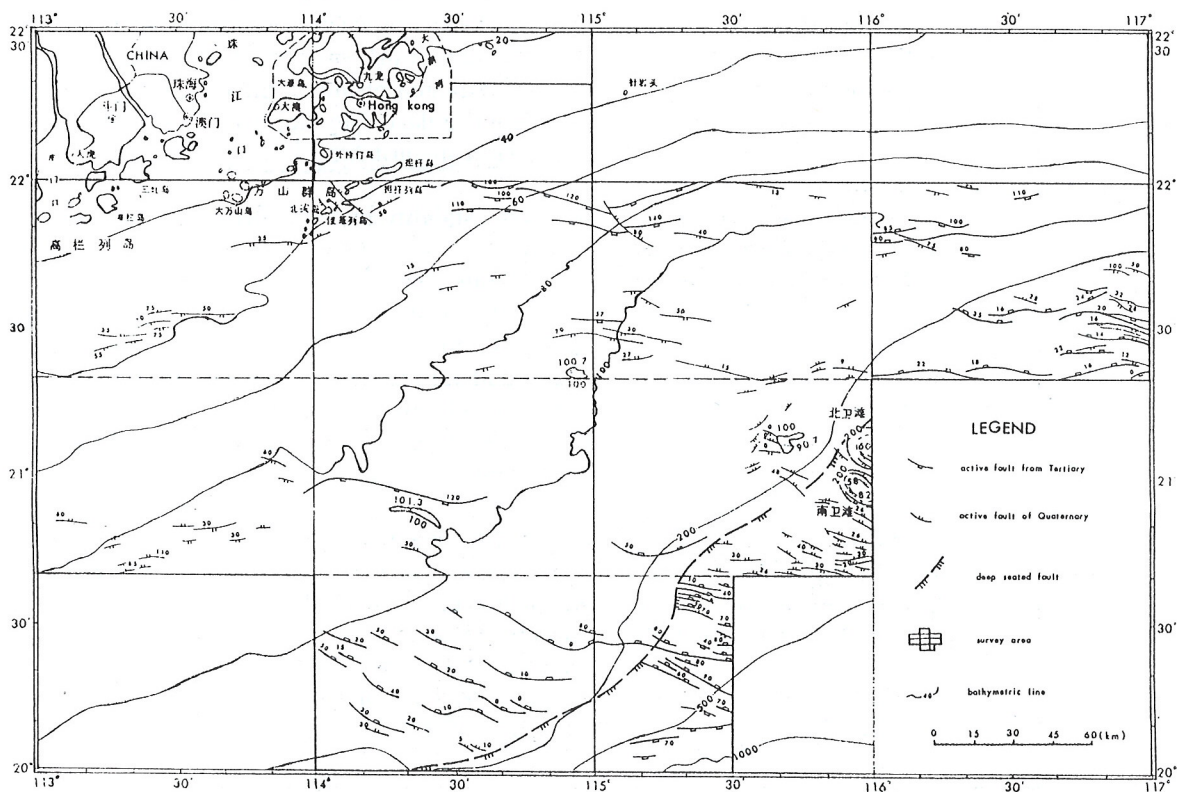


Figure 8 - Map of active faults.

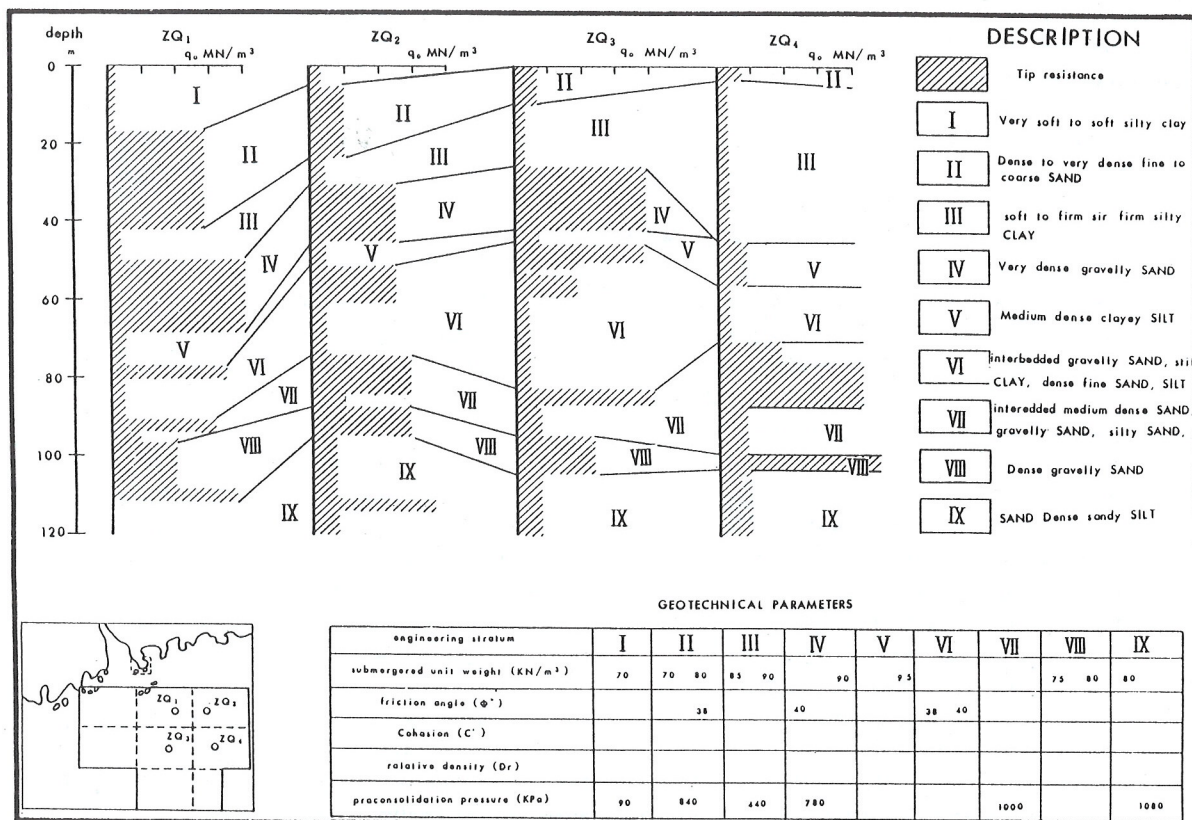


Figure 9 - Engineering stratum classification between four boreholes.

(iii) Zone III : The slope break belt - upper continental slope characterised by complicated engineering geological conditions. Neotectonic movement is very active in this area, with active faults, landslides, seabottom diapirs, steep cliffs and mobile sand waves. This area is adjacent to the continental slope earthquake belt.

Engineering Geological Evaluation

Four types of engineering geological evaluation have been made. These include the assessment of soil liquefaction potential induced by earthquakes and three analyses of slope stability under various forces :

(i) Soil Liquefaction Potential Induced by Earthquakes

Following Seed et al. (1983) and Iwasaki et al. (1984), the cyclic shear stress ratio due to earthquakes and the in-situ cyclic shear strength were computed from CPT and borehole data. Based on these computations, soil liquefaction potential was assessed by computing the liquefaction resistance factor and liquefaction potential index under various earthquake intensities.

(ii) Analysis of Landslide Potential

a. Slope Stability under Gravity Forces

Finite slope stability analysis methods were

used to compute slope stability under gravity forces, the seafloor being very flat in the surveyed area. Based on an analysis of the soil shear stress and shear strength, factors of safety were computed to assess slope stability in the surveyed area. From the geophysical data and results of the computations, it is estimated that the clayey slopes in the southeast part of the basin are unstable.

b. Slope Stability under Gravity and Earthquake Forces

Finite slope stability analysis methods were also used to assess slope stability under gravity and earthquake forces. The results showed that on the continental shelf the slopes are stable under the force of gravity and with earthquakes of magnitude less than 5, whereas slopes in the southeast part of the basin are unstable.

c. Slope Stability under Wave Forces

Pressure induced by waves was calculated using the highest wave in 100 years, then the factor of safety for an arcuate sliding surface was calculated to evaluate slope stability under wave forces. In addition, pile bearing capacity and anchoring capacity were calculated.

Summary and Conclusions

During five years of marine engineering geo-

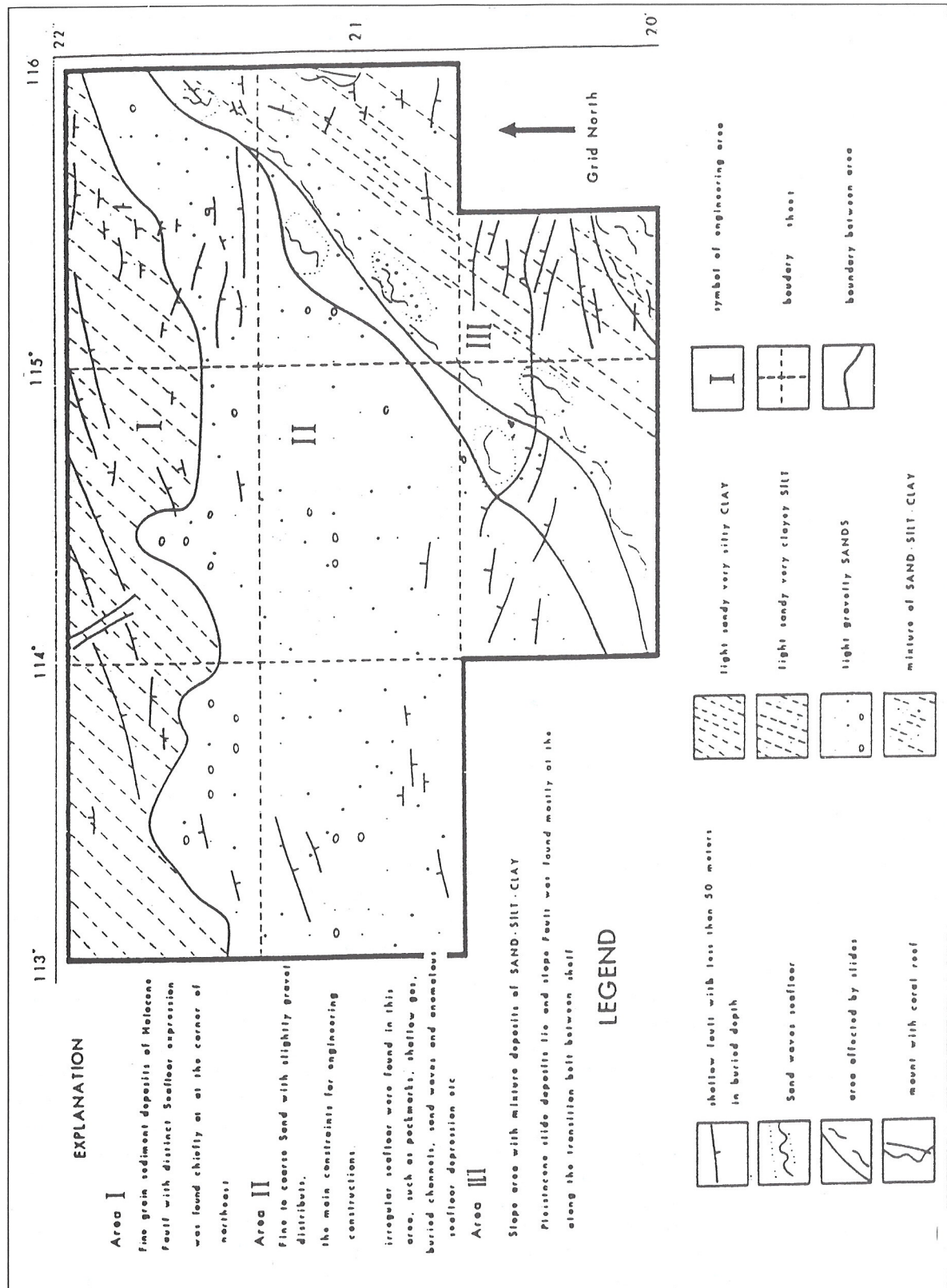


Figure 10 - Area division of engineering geology

logical surveying in the Pearl River Mouth Basin various types of potential geohazards have been determined. The geography, geology and induced mechanics of the geohazards have been studied. Engineer-

ing geological evaluations have been carried out specifically to provide a geological foundation for the prediction and avoidance of identified geohazards. This project is an important preliminary basis for fur-

ther marine exploration.

The project has achieved considerable technical progress with technological and financial support from the Chinese government and the UNDP. It demonstrates the benefits of international cooperation in the development of science and technology, which it is hoped can be extended to cooperation with other countries.

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Sedimentology, Geochemistry and Micropalaeontology of Borehole A5/2, West Lamma Channel

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Abstract

Following extrusion and logging of the core from borehole A5/2 in the West Lamma Channel, the sediments were analysed for a number of attributes, including particle size, geochemistry and micropalaeontology. Selected samples were also dated (C^{14} , OSL and thermoluminescence) and the seismic record interpreted in an attempt to reconstruct late Pleistocene/Holocene depositional environments. A three fold interpretation of terrestrial, coastal (essentially marsh and estuarine) and marine deposits is recognised.

摘要

位於香港東博寮海峽的 A5/2 岩蕊沉積物樣品，經顆粒、化學古微生物及定年等分析，加上地震折射剖面分析，該沉積物應屬晚更新世及全新世，可分為坡積、海岸（主要為三角洲及河灣）和海洋等四組沉積屬。

Introduction

This paper presents a summary of the findings of a detailed study of sediments from Borehole A5/2 in the West Lamma Channel (Figure 1), which was drilled in September 1989 as part of the SEAMAT study carried out by the Geotechnical Engineering Office (Cheung and Shaw, 1993). Whilst preliminary data on a range of attributes were presented by Neller et al. (1992), full details and methods will soon be available in a CUHK Department of Geography Occasional Paper (Neller et al., 1995), to which the reader is referred for more detail.

Fyfe (1992) has summarised many of the controversies concerning the late Quaternary offshore stratigraphy of Hong Kong. The Hong Kong Geological Survey initially subdivided these deposits into the Holocene Hang Hau and the late Pleistocene Chek Lap Kok Formations (Strange & Shaw, 1986). The Hang Hau Formation consists of clayey silts, and locally sands, of Holocene age. The Chek Lap Kok Formation is considered to be a late Pleistocene unit of predominantly alluvial deposits that formed when the sea fell by about 150 m. It is likely that during numerous regressions, Pearl River distributaries extended across Hong Kong and reworked most of the existing superficial cover.

Yim (1992, 1994) and Yim and Yu (1993) suggest that there is evidence for up to five earlier marine horizons with intercalated terrestrial units. Although internationally-established sea level curves indicate that such cycles probably occurred, our detailed study of borehole A5/2, as summarized here, shows no PRESERVED record of any earlier marine events.

In western, southwestern and southeastern waters, an older, silty, marine unit has more recently been identified on seismic records, and is designated the Sham Wat Formation (Langford et al., 1995). On the basis of descriptions of seismic reflector styles, this was tentatively correlated by Shaw & Fyfe (1992) with the Late Pleistocene Middle Zhong Shan Formation (ca. 30,000 year BP), though its exact age remains uncertain (Fyfe and James, 1995; this issue).

Location and Seismic Units

Borehole A5/2 (-18.31 mPD; 79.90 m) was located over the crest of a presumed interfluvial in an early Holocene erosion surface (Figure 1), and did not penetrate the channel fills that were initially interpreted as Sham Wat Formation deposits (Shaw, 1992).

On seismic records the top 6 metres are typified by low amplitude, horizontal/subhorizontal, parallel and laterally persistent seismic reflectors.

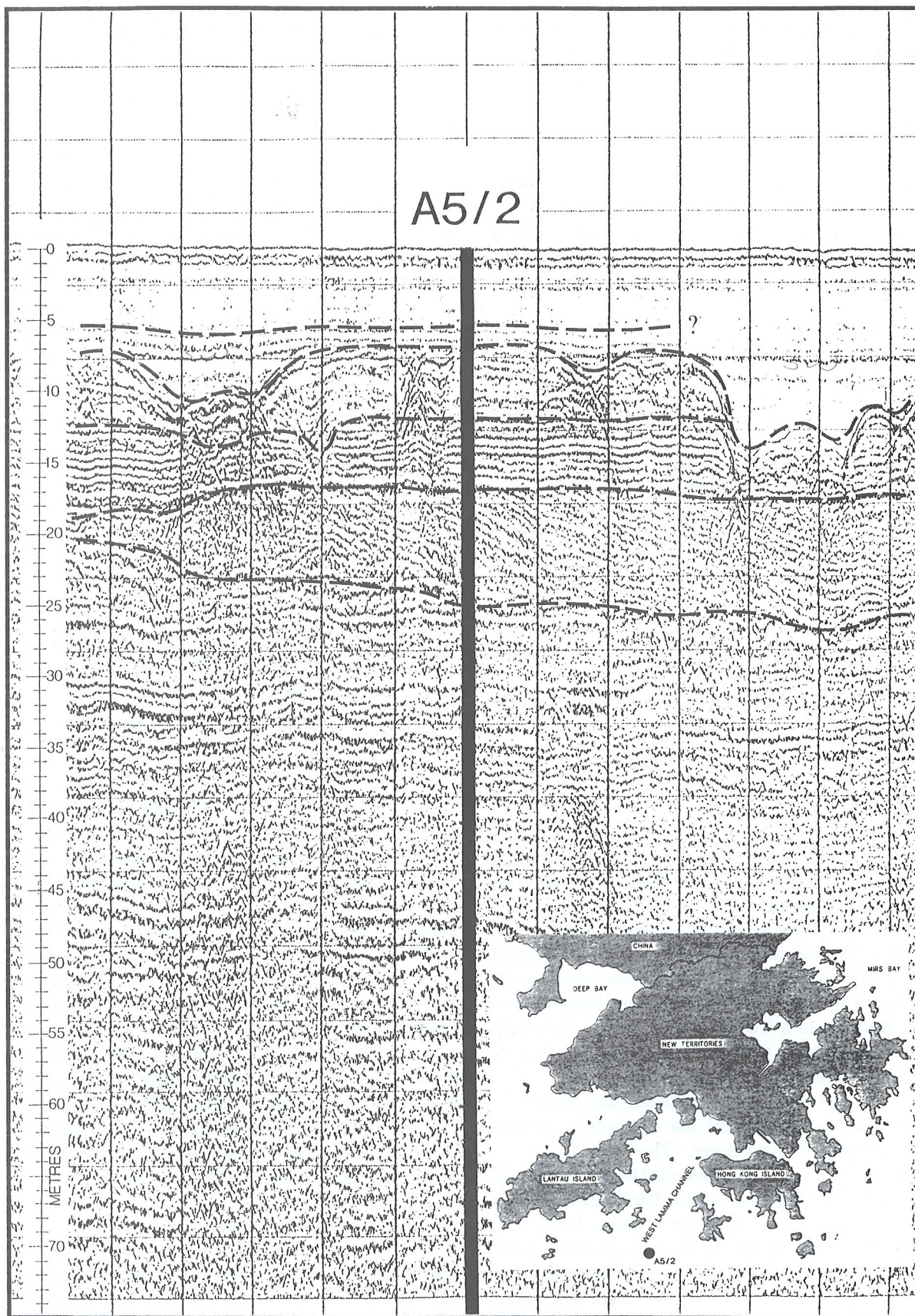


Figure 1 - Location of Borehole A5/2 and seismic profile of the adjacent area.

Brighter, higher amplitude reflectors towards the base suggest increasingly sandy deposits with depth. These reflectors extend horizontally to the west and east over adjacent channel fill deposits, and in the west over unequivocal Sham Wat Formation sediments.

Underlying this unit, below the interfluvial crest, is a complex pattern of subhorizontal, laterally persistent high amplitude reflectors (7-16 m core depth). The reflectors are bright, closely spaced, sub-parallel and laterally persistent. They overlie another distinctive unit, comprising inclined, bright reflectors (16-23 m core depth). This unit has a planar upper surface but wedges out to the west and east, suggesting a laterally accreting sandy channel fill, prograding eastwards with a finer channel plug to the east. Below this level the reflectors are difficult to separate into distinctive units. Bedrock lies below the seismic section, at depths >80 m below the seabed.

Geological Description of Borehole A5/2

From 79.90-64.50 m, the core consists of partially iron-stained, massive, quartz sands (Figure 2) with subangular clasts (<10 mm) and lenses of silty clay. An abrupt particle size change, at 64.50 m, separates this unit from overlying fine-grained sediments. Very stiff mottled clays occur between 64.50-57.00 m, with dark olive grey silts and fine sand laminae present from 57.00-52.50 m (Plate 1). Organic staining and thin organic bands occur at 52.80 m.

A sharp boundary separates these clays from the overlying sands that dominate between 52.50-25.50 m. The sands are dark grey or dark greenish/olive grey, with occasional weakly laminated silts, silty pockets and nodules. Scattered angular gravel clasts (<20 mm) and scattered gravel pockets are common. Thin organic lenses, wood fragments and rootlets are also observed at 36.60 m and a fine dark silty bed occurs at 33.40-31.73 m. Oxidised patches, nodules and fine sand beds (both horizontal and inclined) are also present.

Upward-coarsening massive sands occur from 25.50-19.00 m (Plate 2). These pass into a fining upwards unit (19.00-11.97 m), which transitionally passes into dark grey silts. Subangular gravels (2-23 mm) are scattered throughout. The fining-upwards unit includes lenses of clay, silt, sand and gravel. Leaves, seeds and wood fragments are also found and organic staining is common. Upward coarsening, organically stained, olive grey silts occur between 11.97-7.00 m. These contain wood fragments in the lower 3 m (11.97-9.00 m) and some shell debris in the upper 3 m (10.00 - 7.00 m). A sharp boundary occurs at 7.00 m, where the silts are overlain by a thin shelly sand with subangular gravels.

From 5.80-0.00 m are homogeneous dark grey, structureless silts with occasional fine sand laminae. An unusual feature of the silts, which is as yet unexplained, is that they have a bimodal particle size dis-

tribution, with modes at 4 and 20-30 microns. Articulated, disarticulated and broken bivalves with gastropods are scattered throughout.

Geochemical Results

Detailed analyses were undertaken of total organic carbon (TOC), soil reaction pH, electrical conductivity and carbonates to provide a basic geochemical data base, to measure the variability of sediment geochemistry, and to examine possible relationships between these attributes and the physical character of the sediment.

Since there appears to be little direct relationship between these geochemical attributes and the sediments below 25 m, probably due to changes caused by compaction, dewatering and ageing (diagenesis), the focus of the following discussion is on the upper 25 m of the core.

Soil Reaction pH

Below 19 m the soil reaction pH oscillates between 5 and 7 with a slight tendency to neutral with depth (Figure 3). The overlying silts are, however, strongly to extremely acidic (19-12 m) though tending towards moderately acidic in the upper parts (12-7 m). In stark contrast the structureless silts in the upper 5.8 m are the only consistently alkaline sediments in the core.

Total Organic Carbon (TOC)

Throughout the core TOC fluctuated considerably (0-2.12%). One of the most significant features, however, was the virtual absence of TOC from 25-19 m, corresponding to a unit of coarse massive sands (Figure 3). TOC appears to be correlated with texture above 19 m, increasing as the silts become finer (19-12 m), then decreasing when they coarsen (12-7 m). A consistently high TOC of around 1% was measured throughout the overlying structureless silts (<6 m).

Electrical Conductivity

This parameter, more so than any other, responds strongly to depth, with a pronounced decline from 7 ms/cm at the surface to between 1 and 2 ms/cm at 12 m, below which there is little change (Figure 3). But whether this reflects a declining marine influence or is the result of diagenesis is difficult to determine.

Carbonates

The analysis of carbonate proved difficult because in many cases the variability in the duplicates remained high because of the fragmented nature of the carbonate material.

Below 19.00 m the carbonate content was relatively low (usually <1%) with occasional peaks at 32.70 and 52.24 m. A fluctuating pattern is evident

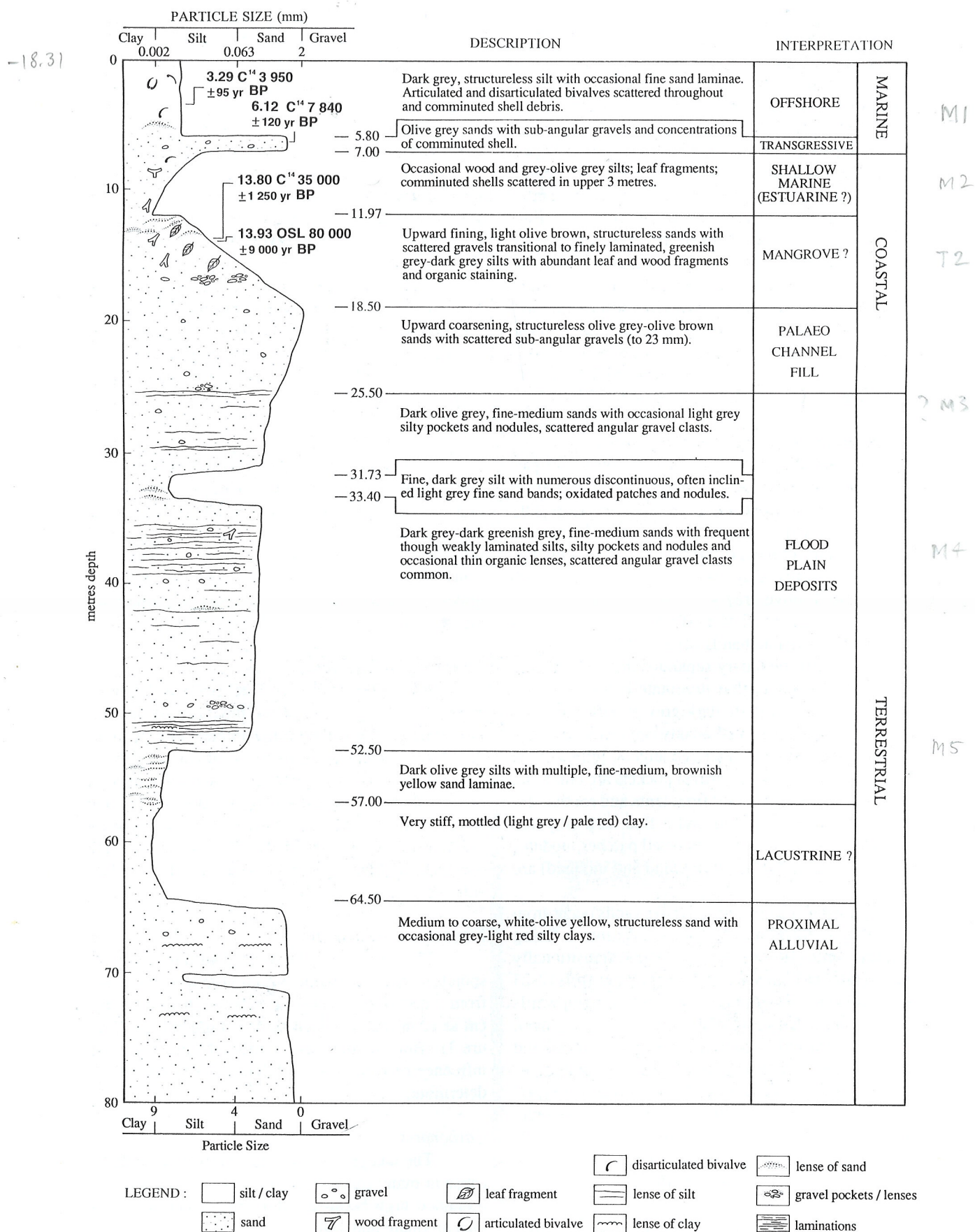


Figure 2 - Summary sediment log for Borehole A5/2.

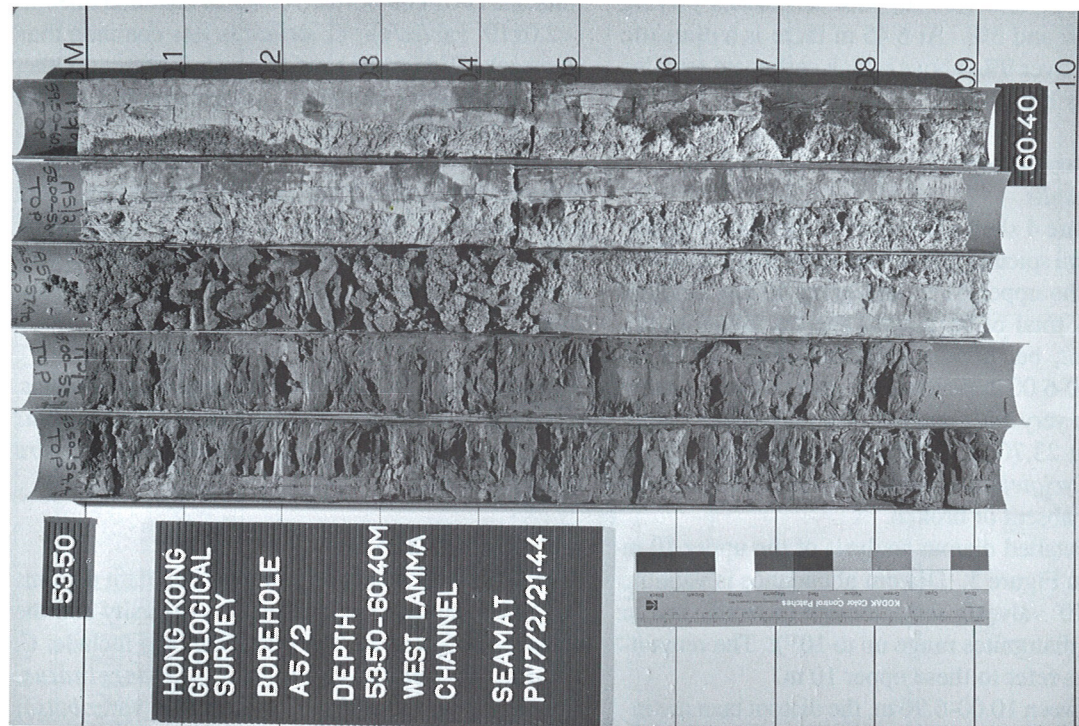


Plate 1 - Extruded A5/2 sediments, 53.50 - 60.40 m. Olive grey silts and fine sand laminae overly very stiff mottled clays

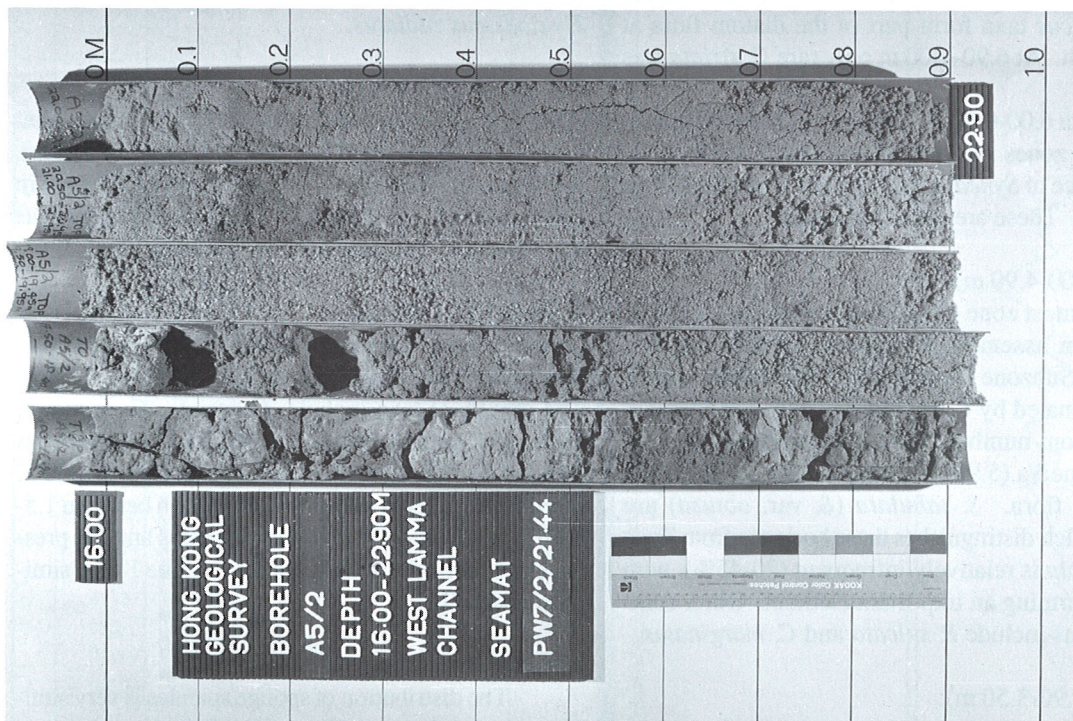


Plate 2 - Extruded A5/2 sediments, 16.00 - 22.90 m. Coarse massive sands transitionally fining upwards from 19.00 m.

between 19.00 and 7.06 m, with carbonates varying between 1% and 3%. At 6.45 m there is a dramatic increase to over 9%, above which carbonate remains consistently high.

Micropalaeontology

Diatom Results

Figure 4 shows the relative abundance of diatoms, sponge spicules and foraminifera (sampled every 10 cm in the upper 61 m and every 50 cm at lower levels). A total of 65 diatom species (Shaw et al., 1995) occur, but none are present below 29.70 m. From 29.70-6.00 m diatoms are only present at a few intervals in very low numbers. They are slightly more common at 23.70 m, 16.20 m and 10.40 m. In all intervals *Cyclotella striata* dominates. Other diatoms are rare or absent or broken.

A detailed diatom analysis of the upper 10 m is shown in Figure 5. Diatom abundance is variable (0 to 7.5×10^5 valves/g sed.), though generally low to moderate (diatomites range up to 10^{12}). The remaining sections refer to these upper 10 m.

Between 10.00-6.90 m, the diatom taxa are infrequent ($<3.6 \times 10^4$ valves/g) and species diversity is low. The dominant taxon is *Cyclotella striata* with *C. comta* and *Paralia sulcata* also important in a few horizons. *Coscinodiscus marginatus* and other *Coscinodiscus* taxa form part of the diatom flora at 9.50-9.40 m. At 6.90-6.00 m only rare *C. striata* was recorded.

From 6.00-0.00 m diatoms are generally abundant. Five zones are recognised, based on the presence/absence of *Synedra* spp. and the total abundance of diatoms. These are described below.

Zone V (6.00-4.90 m):

This lowermost zone contains abundant and species-rich diatom assemblages and is divided into two subzones: Subzone Vb (6.00-5.90 m) is transitional, being dominated by *C. striata*, but with considerably higher diatom numbers than is found below (> 6.00 m). Subzone Va (5.90-4.90 m) contains an abundant and varied flora. *S. tabulata* (& var. *obtusa*) are present, which distinguishes these horizons from Zone IV. *C. striata* is relatively infrequent (20-45%), with *C. comta* forming an important element. Other common diatoms include *P. sulcata* and *C. marginatus*.

Zone IV (4.90-3.50 m):

This is highly variable and characterised by large fluctuations in diatoms ($0-2.3 \times 10^5$ valves/g), a low species diversity and rare *Synedra* spp. Four subzones are recognised:

Subzone IVd (4.90-4.60 m) contains scarce diatoms and no *Synedra*. *C. comta* declines and species diversity is low. The dominant diatom is *C. striata* (75-80%), with *P. sulcata* as the only other common species.

Subzone IVc (4.60-4.40 m) contains common diatoms ($<2.0 \times 10^5$ valves/g). *C. striata* is less common than in subzone IVd ($<40\%$) and *C. comta* is present. Other common diatoms include *C. marginatus* and several other *Coscinodiscus* spp.

Subzone IVb (4.40-3.75 m) contains few diatoms, with none between 4.10 - 3.90 m. *C. striata* is again dominant ($>70\%$), as it was in subzone IVd, which is very similar. *C. comta* has declined and *P. sulcata* is common.

Subzone IVa (3.75-3.50 m) contains common diatoms. *C. striata* is dominant. *P. sulcata* and *C. marginatus* are also common. As with the other subzones, *Synedra* spp. are absent.

Zone III (3.50-2.25 m):

Zone III is undivided and contains abundant diatoms ($<3.8 \times 10^5$ valves/g), a high species diversity and the presence of *Synedra*. The dominant taxa include: *C. striata*, *C. comta*, *P. sulcata*, *C. marginatus*, *Coscinodiscus centralis*, *S. tabulata* (& var. *obtusa*) and *S. ulna*. *Skeletonema costatum* becomes common at two horizons. Other diatoms, rare in lower zones, are slightly more common and include *Arachnoidiscus ornatus*, *Actinocyclus ehrenbergii* and *Hyalodiscus radiatus*.

Zone II (2.25-1.60 m):

Zone II is undivided and contains slightly fewer diatoms than Zones I and III. *Synedra* spp. are absent. *C. striata* is dominant and more common than in Zones I or III. *C. comta*, *P. sulcata*, *C. marginatus* are common. Species diversity is moderate.

Zone I (1.60-0.00 m):

Zone I is undivided and contains a varied and relatively abundant flora. *Synedra* spp. are very common. The dominant taxa include: *C. striata*, *C. comta*, *P. sulcata*, *C. marginatus*, *C. centralis*, *Coscinodiscus lineatus*, *S. tabulata*, *S. tabulata* var. *obtusa* and *S. ulna*. *Skeletonema costatum* is common between 1.5-1.00 m and 0.80-0.60 m. These features and the presence of other centric diatoms make Zone I very similar to Zone III.

Other Microfossils

The distribution of sponge spicules is very similar to that of diatoms (Figure 4). Spicules are absent below 29.70 m and occur only in a few discrete horizons (usually with diatoms) between 29.70-6.00 m. They are common from 6.00 m to the core top, and even between 4.10-3.90 m, where diatoms are absent.

Several types of straight and curved siliceous spicules, indicative of the monaxonid desmosponges, occur. Some have flared terminal expansions. The occurrence of tetraxons suggest the presence of some

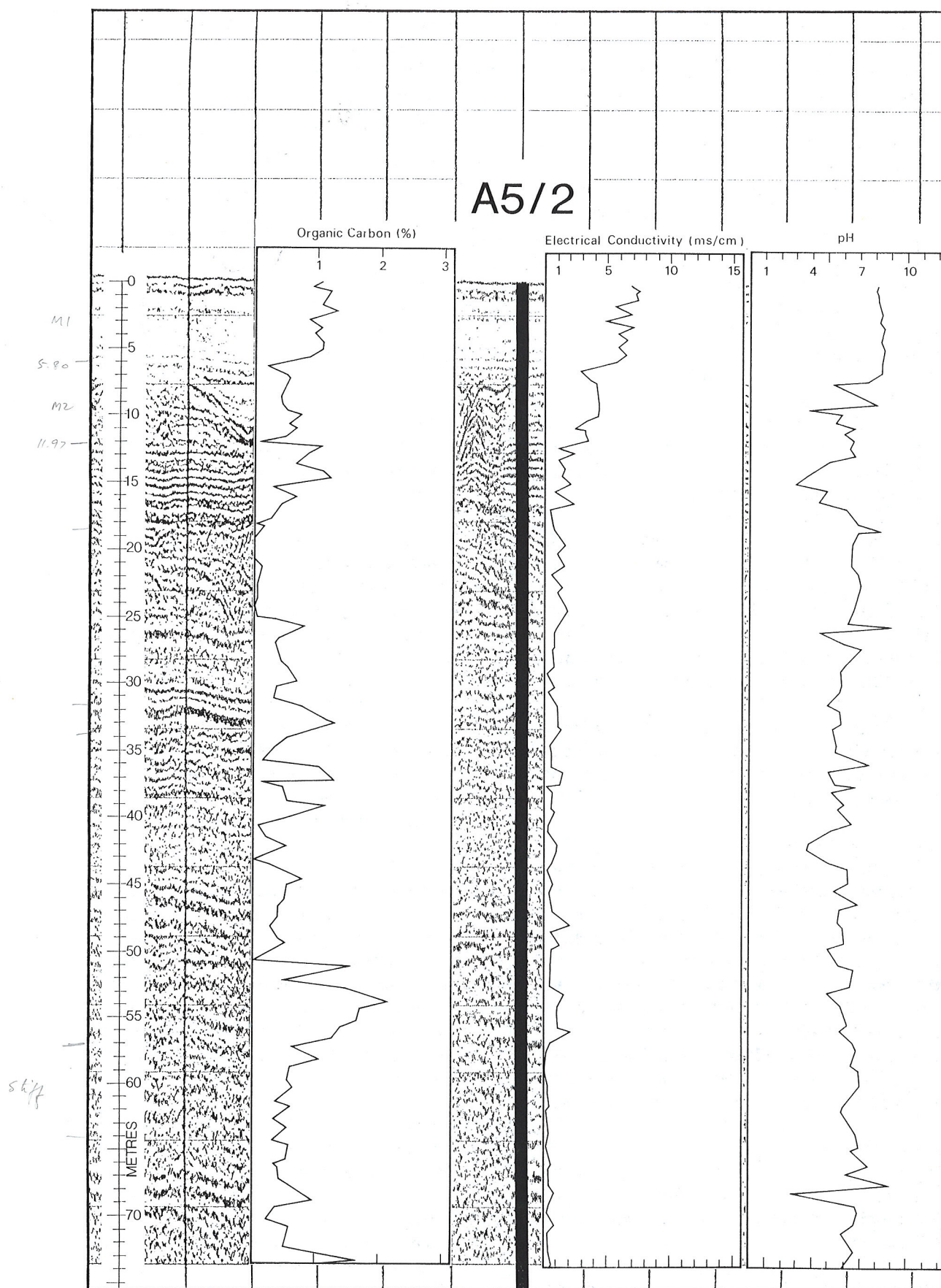


Figure 3 - Detailed pH, conductivity and organic carbon logs for A5/2. Sampling interval = 50cm.

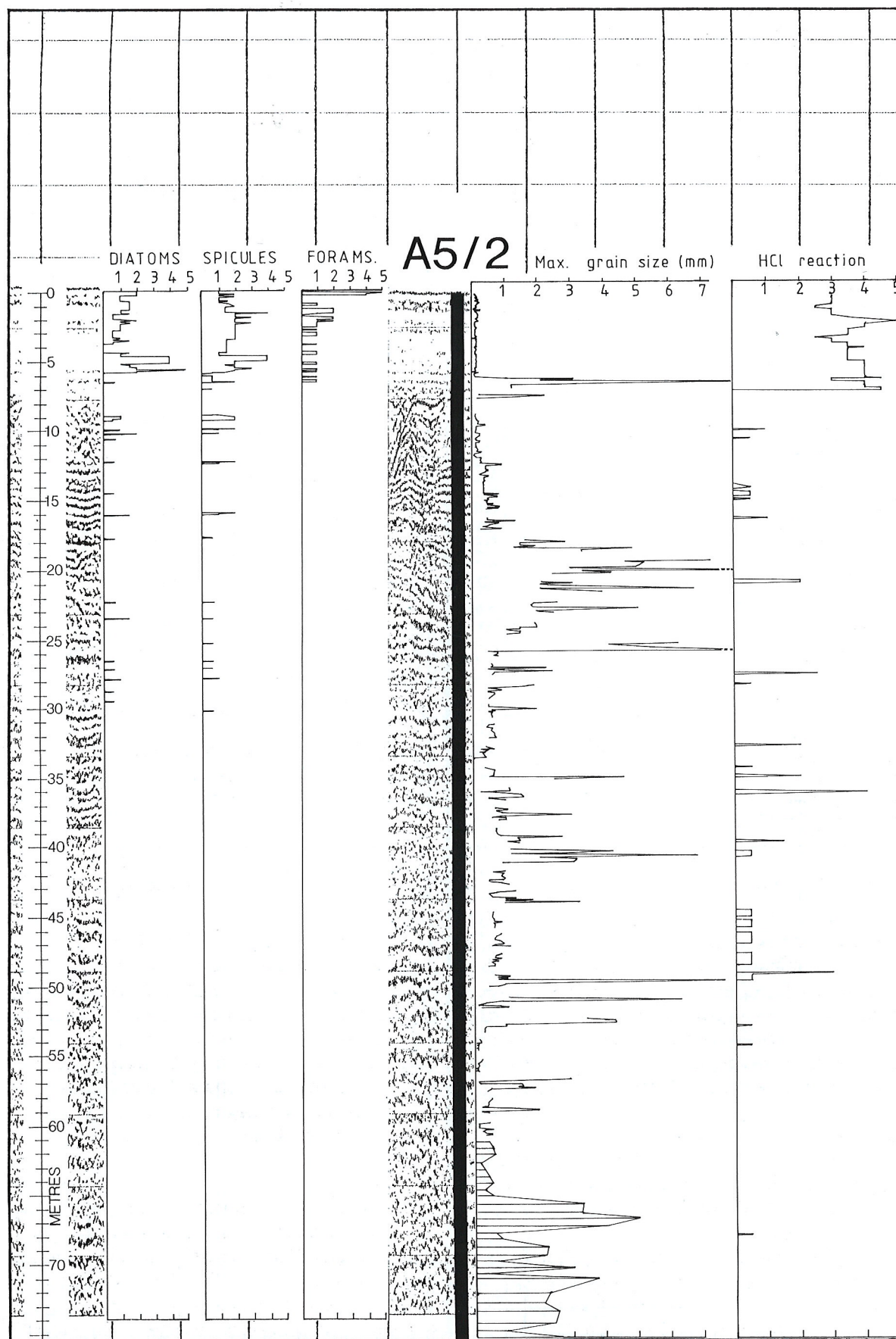


Figure 4 - Summary of microfossil stratigraphy for diatoms, sponge spicules and foraminifera. Details of maximum particle sizes and a simple HCl reaction test are also given (1 weak, 5 very strong). Sample interval = 10cm in upper 61m; 50cm at lower levels.

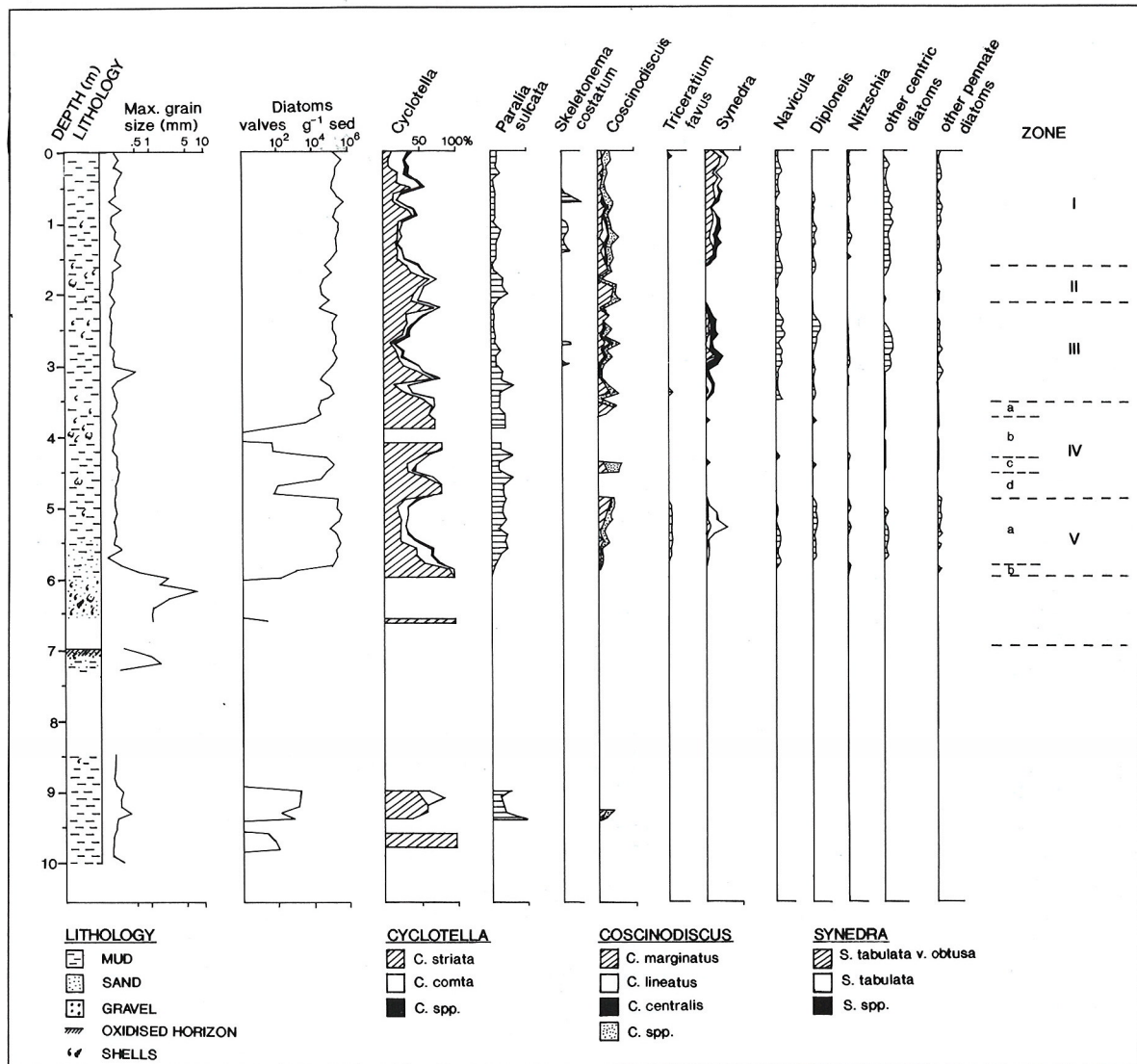


Figure 5 - Detailed diatom stratigraphy of the upper 10m of Borehole A5/2. Sampling interval = 10cm.

tetractinellid desmoponges.

Foraminifera are more restricted than either diatoms or spicules (Figure 4), only occurring between 6.70-0.00 m. Their greatest frequencies occur from 2.30-1.40 m (approx. diatom Zone II). Foraminifera are also common between 0.20-0.10 m, which does not seem to correspond with any diatom changes.

Mollusca

Shells and shell fragments are restricted to the upper 10 m and are common only above 6.60 m. In particular, two shell concentrations occur at 6.50-6.00 m and 4.10-3.50 m.

The molluscs were identified by Prof. B. Morton of Hong Kong University. Molluscs from 6.50-6.45 m show a low species diversity (three taxa) and common fragmentation, which may reflect high energy, shallow water, conditions. Species diversity is greatest at 6.15-6.09 m, with eleven taxa and none showing clear dominance. *Placuna placenta* and

Anomiachinensis are present here, but are absent in other samples. In modern environments, they are associated with shallow subtidal muds, the latter often occurring on rocks. *Solen* sp. are also present between 6.15-6.09 m. Molluscs from 3.80-3.76 m and 3.34-3.23 m are dominated by *Paphia undulata*, with few other taxa occurring and with abundant fragmentation. *P. undulata* is cited as favouring sheltered marine embayments (B. Morton, pers. comm.).

Dating Results

Shell fragments from two levels were extracted for radiocarbon dating. The 3.34 - 3.23 m interval yielded an age of $3,950 \pm 95$ yBP, with shells from 6.15 - 6.09 m giving an age of $7,840 \pm 120$ yBP. These dates would suggest average (marine) sedimentation rates of about 8.4 cm / 100 yrs for the upper 3.30 m of borehole A5/2, and 9.7 cm / 100 yrs for the 2.8 m interval between 6.10 - 3.30 m.

A wood fragment at 13.80 m depth yielded a

radiocarbon age of $35,000 \pm 1,250$ yrs. BP (Beta - 49993). However, an OSL date of $80,000 \pm 9,000$ yrs. BP was obtained for a sample at 13.88 to 13.97 m depth (Radio-isotope Unit, University of Hong Kong). A further sample from 13.95 to 13.98 m depth yielded a TL date of 78,000 yrs. BP $\pm 15\%$ (Yeung Shui Sang Laboratory for Thermoluminescence of Ancient Ceramics). It is clear that both the OSL and TL techniques are in broad agreement. However, the radiocarbon date from the same level (13.80 m), was less than half of that suggested by TL and OSL techniques. Unfortunately none of the dates can be considered reliable as the radiocarbon date is close to the limit of the technique, whilst problems still remain with the use of TL and OSL in marine environments where the effects of sea water and bleaching (zeroing) of sediments remains unresolved.

Environmental Interpretations

This section synthesises the various data in an attempt to reconstruct palaeoenvironments. In order to divorce the record from prevailing nomenclatural controversies, at this stage no attempt is made to relate these deposits to formations previously recognised. Three sequences are recognised (Figure 2): a basal TERRESTRIAL sequence, a COASTAL sequence and an uppermost MARINE sequence. These include a variety of sediments formed under differing sub-environments.

The Terrestrial Sequence (79.90-25.50 m)

Three main subdivisions can be recognised: a lower proximal alluvial unit, a lacustrine unit and an upper floodplain unit (Figure 2).

The basal unit from 79.90-64.50 m consists of medium to coarse sands and silty clays probably derived from nearby weathered granites. Fluctuations between coarse and fine deposits suggest pulsating seasonal or periodic cyclic increases in fluvial discharge. The decrease in particle size at 64.50 m is dramatic and suggests a reduction in energy, possibly due to the migration of master channels, progressive ponding or reduction in channel gradient (caused by a rise in sea level or basin infilling).

Lacustrine deposits dominate from 64.50-52.50 m. These consist of very stiff, mottled, white, clays (64.50-57.00 m) that formed from weathered feldspars with scattered angular quartz. Conductivities, organic carbon and carbonate are all comparatively low (Figure 3). The pH values are generally circum-neutral to slightly acidic. These clays probably settled out on an intermontane basin or semi-arid floodplain. Silts with fine sand laminae (57.00-52.50 m) suggest shallowing or progradation of distal river materials into the palaeolake basin.

The upper unit (52.50-25.50 m) consists of floodplain deposits perhaps resulting from a sea level change, channel migration or even a minor tectonic

warping. A variety of microenvironments are represented by the sediments in this interval of the borehole. Sedimentologically, the unit ranges from gravel lenses to dark grey silts, reflecting channel lag, backswamp and other overbank deposits, characteristic of either an anastomosing or meandering river system. Laminations occur in many parts. Evidence of well developed palaeosols is lacking though various patches, balls and nodules of oxidised sediment are suggestive of pedogenic processes. Wood, rootlets and thin organic lenses are also common. Vertical and near vertical lenses, perhaps former root pathways, are further evident, though the possibility that these may also reflect core disturbance cannot be overlooked.

The unit is characterised by higher organic carbon contents and conductivities than the proximal alluvial or lacustrine units below. The pH is more acidic, which is consistent with a floodplain setting. Carbonates fluctuate between 0 and 5.3% and rare cosmopolitan diatoms occur in the upper parts.

Coarse laminations are present at two intervals (i.e. 44.90-44.50 and 42.20-41.50 m). These laminated units occasionally contain leaf debris and are interpreted as backswamp and lacustrine (oxbow?) facies.

The dark grey silts between 33.40-31.73 m are of particular interest, because the particle size distribution is similar to that of the overlying marine muds, with a bimodal distribution and peaks at 2 and 15 microns. A sample from 31.75 m has these peaks also, but with an additional peak at 350 microns. However, this unit also contains numerous discontinuous horizontal and vertical fine sand bands, oxidised patches, relatively large maximum particle sizes and no marine microfossils, none of which would suggest a marine setting. These deposits may represent distant backswamps or lacustrine environments.

The seismic profile indicates a minor unconformity at the top of this sequence, suggesting a period of erosion between the formation of the floodplain sediments and the succeeding coastal sequence.

The Coastal Sequence (25.50-7.00 m)

This consists of sediments formed in very shallow marine to coastal marsh environments and can be subdivided into three parts (Figure 2): a nearshore sand environment, a coastal marsh setting and a shallow marine/estuarine environment.

The lower most unit at 25.50-18.50 m consists of "clean" sands with uniformly dipping, prograding seismic reflectors that appear to represent deposits infilling a broad palaeochannel. Maximum grain size data (Figure 4) show it to be a coarsening upwards sequence. Organic carbon values are low and the pH is neutral. The clean and well-sorted character of these deposits suggests a nearshore environment, whilst the seismic traces show distinct asymmetry that re-

sembles a lateral channel fill. Thus it is probable that these deposits are transitional, perhaps formed by lateral accretion on the margins of a meandering estuary in a palaeoembayment setting.

The second unit (18.50-11.97 m) is an upwards-fining sequence, with abundant leaf and wood fragments. Organic carbon content is the second highest in the core (av. 0.57%). Calcium carbonate and electrical conductivity are slightly elevated. The pH is strongly acidic, which probably results from organic decomposition under anaerobic conditions. The lower part of the sequence contains a broad range of particle sizes, but with slight peaks at 2 and 100-150 microns. The upper part shows much stronger bimodality at the same peaks, with fewer particles of intervening size. The 2 micron peak probably reflects a marine influence whereas the coarser mode reflects possible flushing from a nearby fluvial system. These features plus the extreme acidity and high organic content suggest a marshy coastal area. This might have been a mangrove setting though definitive pollen evidence is lacking.

No shells were recorded, however, given the acidity of the sediments any shells that might have originally been present would probably have been dissolved. Cosmopolitan diatoms and sponge spicules are present in very low numbers within both the nearshore sands and marsh sequences (Figure 4). This would be consistent with nearshore brackish waters. OSL and TL dates suggest that these sediments were deposited about 80,000 years ago.

The shallow marine/estuarine unit occurs between 11.97-7.00 m. (Figure 2). Seismic reflectors are faint and subhorizontal to irregular. An upward coarsening (though maximum particle sizes remain constant), olive-grey, silt occurs in the core. Cosmopolitan and rare marine diatoms, sponge spicules and molluscs are present. The pH is acidic, but fluctuates widely and conductivities are high. The slightly higher pH and conductivities suggest a greater marine influence. The particle size data and diatoms are inconsistent with deep open waters, but rather suggest shallow mud flats or perhaps estuarine conditions.

The coastal sequence is terminated by a strongly oxidised layer. Seismic reflectors show this to be part of a major erosion surface dissected by wide channels up to 8 metres deep. This probably indicates a period of lowered base levels.

The Marine Sequence (7.00-0.00 m)

The marine sequence rests on an erosion surface that is clearly visible in seismic sections. The deposits consist of two major parts separated by a sandy transitional boundary.

The lower part of the marine sequence (Figure 1) is essentially missing from borehole A5/2. However, it is visible in seismic profiles for the surround-

ing area, as faint draped reflectors that infill channels. These are interpreted as muds, probably deposited under low energy conditions, such as estuarine or embayment settings.

As sea levels rose these embayments would have been enlarged and adjacent areas flooded. The reduced protection from the loss of these embayments could have increased wave energy and allowed lateral sand sheets to develop. These sediments give rise to the prominent reflectors at about 7 metres in the seismic profiles. In borehole A5/2, this is represented by coarse, olive grey sands and subangular gravel (<10 mm) between 7.00 and 5.80 m. The pH is alkaline and conductivity and organic carbon are low compared with the succeeding marine muds (Figure 4). Calcium carbonate is abundant due to broken bivalves and gastropods. Occasional diatoms, sponge spicules and rare foraminifera also occur. These sands appear to confirm a shallow nearshore transitional environment. Radiocarbon dating suggests these sediments were deposited about 7840 years BP.

The upper part of the marine sequence (5.80-0.00 m) is characterised by medium- to fine-grained, structureless, olive grey silts with scattered fine sand laminae. These silts have a bimodal particle size distribution, with a prominent peak at 4 microns and a sub-dominant peak at 20-25 microns. Diatoms and sponge spicules are abundant, and foraminifera are common. The pH values are consistently moderately alkaline. Conductivities are at their highest in the borehole and organic carbon is also high. Carbonate is abundant, reflecting the presence of shells.

Although the above data confirm a fully marine setting, in detail, the environment was subject to periodic changes. Five diatom zones (Figure 5) suggest fluctuating sea levels and the influence of fresh/brackish water are evident from the core.

Zones Va, III, and I contain abundant and varied diatoms. *C. striata* is present, but is less common than in other zones. *P. sulcata*, *Synedra* and *Coscinodiscus spp.* are all common. Yu (1989) cited *P. sulcata* as a planktonic marine diatom. Today, it is more common to the east of Hong Kong than to the west, which suggests that it favours higher salinities. *Synedra spp.* occur in Tolo (Lam and Ho, 1989) and Aberdeen Harbours (Thompson, 1986). *S. tabulata* occurs in the Taiwan Straits and Okinawa trough (Chin et al, 1980). Yu (1989) reported *Coscinodiscus spp.* as more common in offshore areas. Crosby and Wood (1959) reported *C. centralis* from both oceanic and estuarine areas off Australia. These data, together with the abundance and diversity of the flora, suggest fully marine conditions.

Zones Vb, IV and II are dominated by *C. striata*, contain few diatoms and have a low species diversity, with *Synedra* absent. Jin et al. (1985) described *C. striata* as marine and Yu (1989) noted that it is common in sea floor sediments of the northern

South China Sea and is abundant in the Pearl River Estuary. Modern samples from Hong Kong show *C. striata* forming a part of the flora near Yim Tin Tsai (19%), Long Harbour (26%) and Kat O Chau (31%), all "fully" marine settings. In contrast, a mud sample from shallow brackish waters at Deep Bay, near Mai Po, contained 100% *C. striata*. It therefore seems that this taxon, and the zones in which it is dominant, are associated with brackish waters, perhaps due to lower sea levels bringing the influence of rivers closer to the borehole site. Alternatively, wetter climatic conditions may have increased river discharge and reduced basal salinities

Stratigraphical Interpretation

In this section an attempt is made to relate the environments of deposition described in the preceding sections with those stratigraphical units referred to in the introduction.

The Hong Kong Geological Survey have subdivided offshore deposits into three formations (Langford et al., 1995), two of marine or shallow marine origin (the Hang Hau and Sham Wat Formations) and an underlying, predominantly alluvial, Chep Lap Kok Formation.

The Chep Lak Kok Formation comprises predominantly fluvial silts, sands and gravels (based on a predominance of terrestrial pollen) of late Pleistocene age with a chaotic and highly variable seismo-stratigraphy (Shaw and Arthurton, 1988). Upward fining fluvial sequences have been identified, as have laterally and vertically impersistent sand bodies. The presence of mangrove pollen in the upper parts also suggests that estuarine or littoral conditions prevailed more recently. The surface of the Chep Lak Kok Formation is dissected by what appears to be a dendritic pattern of channels.

Seismically and lithologically both the terrestrial and coastal sequences identified in A5/2 appear to belong to what is currently defined as the Chep Lak Kok Formation. The upper coastal sequence comprising channel fill, marsh and estuarine units are consistent with the estuarine/littoral conditions of the Chep Lap Kok Formation inferred from mangrove pollen. The lower terrestrial sequence of A5/2 is also consistent.

Sham Wat sediments are typically medium grey silty clays, similar to the overlying Hang Hau sediments. Nevertheless the Sham Wat Formation is distinguished seismically from Hang Hau Formation by its draped intraformational reflectors, and lithologically by occasional pale yellowish grey oxidation layers, a higher shear strength and soft and corroded shell material (Fyfe and James, 1995). Such sediments appear to have been deposited either side of A5/2 and particularly to the west, but are not readily identifiable in A5/2.

The Hang Hau Formation is characterised by

olive grey silts (and occasionally sands in local high energy environments) and uncorroded (commonly intact) shell material. This is identical to the Marine sequence described in this article.

The depositional sequences identified within A5/2 agree in general with the three fold regional model, though there do remain a number of uncertainties. Further progress on interpreting the Chep Lap Kok Formation will rely on more detailed palynological, lithological and dating analyses from other boreholes. Neither basic geochemistry nor seismic interpretation were sufficiently sensitive indicators of the lower Chep Lap Kok sediments to allow further interpretation. Moreover, this borehole did not penetrate Sham Wat sediments and the authors are therefore unable to comment on a number of unresolved issues pertaining to this Formation. It should be pointed out, however, that the underlying Chep Lap Kok sediments within A5/2 were dated by TL and OSL at approximately 80,000 years BP, suggesting that the overlying Sham Wat sediments are considerably younger than that proposed by Fyfe and James (1995).

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Sedimentology and Surficial Stratigraphy of Three Fathoms Cove, Hong Kong

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Abstract

Grab samples and short cores show that organic material varies spatially in Three Fathoms Cove, with high organic levels occurring off fan delta locations. Clays and silts are most common along a north-south axis in the eastern side of the bay. Three microfossil zones can be recognised in the upper few tens of cm's. These show that mixing of the sediment column is restricted. The zones suggest environmental change and several possible causes, eg. deforestation, pollution, basin changes related to dam construction, are discussed. The time scale for these changes remains problematic.

摘要

從挖掘樣本和岩心樣本所知，有機物質是不均地分佈在企嶺下海一帶，以扇形三角洲有較多有機物。沿東部海灣之南北軸，沉積物以黏土和粉沙較為普遍。此外，在樣本表層數十厘米，可辨認到三層微體化石（Microfossil），它們顯示沉積物之混合是受到限制，亦顯示環境之變化。本文探討一些它們可能之成因，如森林砍伐、污染及築堤引致的河盤變化。但這些變化發生的時間仍是一個問題。

Introduction

Several studies of grab samples of Hong Kong marine muds have been carried out previously (e.g. Cheung & Shaw, 1993), as has research into long off-shore cores (e.g. Shaw et al., 1995). However, relatively few studies have examined the comparison between grab materials and short core data. This paper presents such results together with a facies map of Three Fathoms Cove.

The research was carried out by 3rd year Baptist University Geography students as part of a series of studies into the sedimentology and micropalaeontology of the bays and channels of Tolo Harbour. In this first article, we concentrate on the major particle size characteristics, diatom flora and organic content of sediments in Three Fathoms Cove. It is hoped that this undergraduate effort will stimulate other university students in Hong Kong to publish valuable data obtained during their field exercises and as part of final year student projects.

Three Fathoms Cove (Kei Ling Ha Hoi) is located between the Sai Kung Peninsula and Ma On Shan, on the south side of Tolo Harbour (Figure 1).

The local geology is dominated by the Jurassic Repulse Bay Volcanic Formation. This consists of lavas and pyroclastic materials, with minor sedimentary rocks. Palaeozoic sediments are present to the west of the bay. Also to the west, are a series of large scale fan-deltas that are derived from Ma On Shan. Smaller fluvial valleys enter the bay to the south and east.

Methodology

Twenty-two grab samples and two short cores were collected in February 1994. The grab samples were collected along an approximate grid pattern in order to determine spatial facies variations. Cores were recovered in order to examine recent stratigraphic variability.

Particle size was determined by hydrometer methods. 50g of sample was mixed with sodium hexametaphosphate and left to stand for 10-16 hours to deflocculate the muds. Hydrometer techniques were used to determine particle size, with readings taken at fixed time intervals. Organic matter was determined, after drying at 105°C overnight, by ignition loss at 600°C.

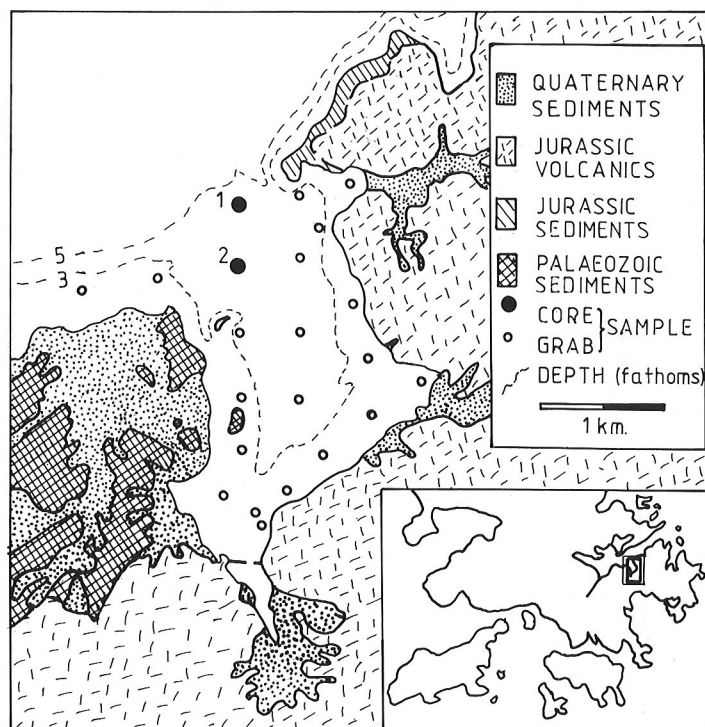


Figure 1 - Location and simplified geology of Three Fathoms Cove.

Cores were logged while wet and subsamples collected at regular intervals and at lithological boundaries. Similar quantities of mud were smeared onto slides and allowed to dry. The dried mud was then mounted in naphrax, a high refractive index medium, for microfossil studies. Species identifications were beyond the scope of this work, but the numbers of diatoms, sponge spicules, foraminifera and ebridians per two transects of each smear slide were recorded at a magnification of 400x. The results are semiquantitative only.

Results

Grab sample data

The samples consist predominantly of silt (averaging about 75% in central parts of the bay) and clay. Sand is usually a minor component, except in samples in western parts of Three Fathoms Cove. Figure 2 shows a summary of clay content in the grab samples. The bay shows an asymmetrical distribution pattern with clay predominating towards the east. The highest clay contents occur in the low energy environments of the southern bay. This asymmetric pattern probably reflects the influence of several fan deltas, with a coarse sediment load, that issue from the Ma On Shan area. Low clay values are also associated with two stream systems that enter Three Fathoms Cove along its eastern shore, but these are more local in their areal extent.

Organic matter varied from 3-5% in most samples (Figure 2). Elevated values of 17.3 to 18.3% were recorded in five samples. All were associated with sediments that had a low clay content. Four of

these samples were located close to fan deltas entering the western shore of Three Fathoms Cove and one sample is associated with a small delta entering the southeastern shore (Figure 2). There would therefore seem to be a close link to stream sources. One marine source might be Red Tides, which could conceivably hug the coastline, though this would not explain high organic contents being confined to areas close to streams.

Core data

Two cores were recovered from the entrance to the bay (Figure 1). Core 1 is 17 cm long. It consists of loose, dark olive green (7.5GY/4/2) muds, with black (perhaps organic) spots in the upper 11.5 cm (Figure 3). This rests, with a sharp boundary, on more compact, sticky, very dark grey (5Y/3/1) muds. Broken shells are scattered through the lower layers, but with a distinct concentration at 17 cm.

Core 2 (Figures 1 and 3) is 30 cm long and includes several distinct horizons separated by sharp boundaries. These vary in shade of colour and degree of stickiness. From 0 to 8.5 cm occur relatively less sticky, black (5Y/2.5/1) muds, with scattered shells. A distinct layer of broken shells occurs at 8 cm. Between 8.5 and 13 cm are sticky, relatively clay-rich, very dark grey (5Y/3/1) muds. From 13 to 14.5 cm are sticky, (5Y/2.5/1) muds that include a few complete molluscs. Very sticky (5Y/3/1) muds then occur down to the core base at 30 cm. Scattered shells occur throughout but with distinct layers of complete shells at 15 and 29 cm and broken shells at 23 cm. Upon drying this lower layer experiences much less

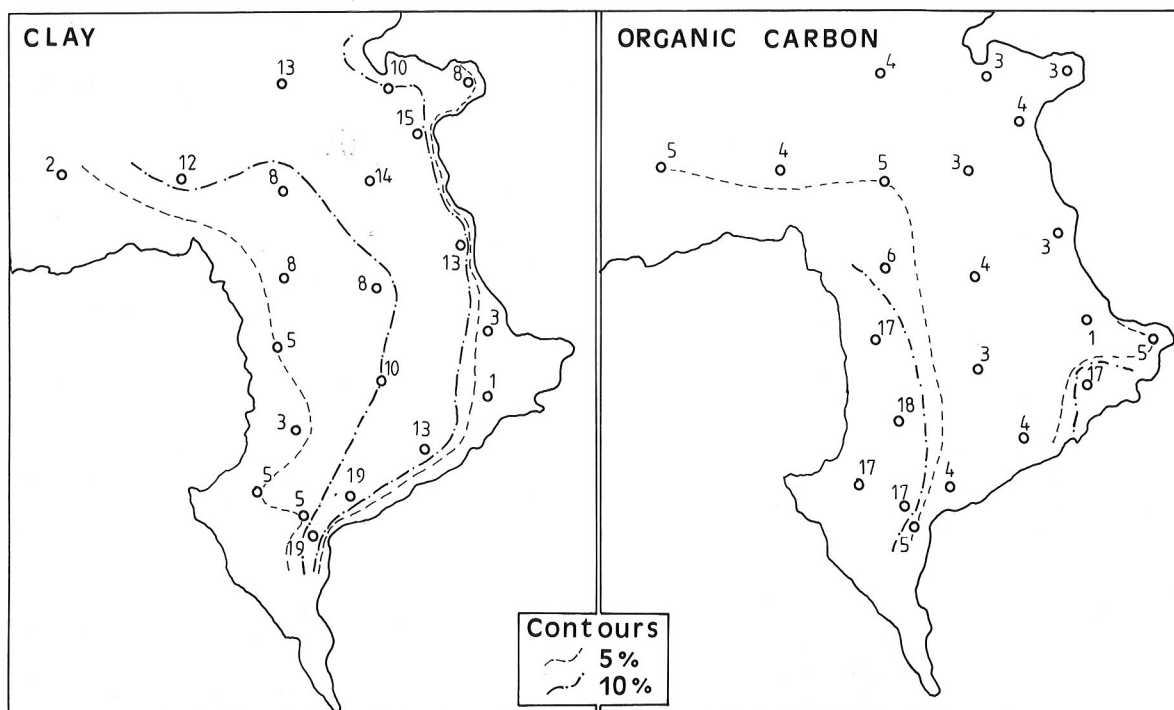


Figure 2 - Clay and organic content (=total organic matter) of marine sediments in Three Fathoms Cove.

shrinkage than the upper layers, probably because the lower layers are more consolidated with a more compact structure and lower water content.

The microfossil data is shown in Figure 3. A general two fold division can be noted in both cores, though these are given differing interpretations and are termed Zones A, B and C.

Core 1 consists of an upper layer (Zone A, Figure 3) that contains common diatoms and sponge spicules. Ebrideans are rare and absent in most of this sequence. Foraminifera are absent. However the sample size for these latter microfossils is very small and absence in the smear slides does not necessarily imply their total absence from the sediments. Molluscs are also absent and the lower microfossil boundary coincides closely with a lithological boundary at 11.5 cm. The lower layer (Zone B, Figure 3) contains variable diatom and sponge spicule abundances, though they are always common. The zone differs mainly in the presence of ebrideans and foraminifera. The sediments are sticky clays.

Core 2 is also divided into an upper and lower layer (at 14 cm). The upper layer consists of sticky clays, with molluscs present and a variable microfossil assemblage of diatoms, spicules, ebrideans and foraminifera. Because of the microfossil and sediment similarities, we suggest that this is the equivalent of Zone B in core 1 and have assigned it to this level in Figure 3. Zone A is therefore missing in core 2. Below 14 cm (Zone C, Figure 3) diatoms and spicules show less variability, ebrideans are absent and foraminifera are present. The lithological contrast

between Zones B and C in core 2 is less marked than that between Zones B and A in core 1. A distinct layer of whole molluscs occurs at the top of Zone C in core 2.

Discussion

A number of marine mud surficial investigations have been carried out in Hong Kong waters, but these have mostly concentrated on grab sample data. Such information "averages" the sediment composition from the upper few cm's of the sea floor and loses a considerable amount of detail. One surprise result of the study is the good preservation of layering in the marine muds. The environment is a low energy setting, but with oxygenated bottom conditions should be subject to benthic organism activity. It was also believed prior to sampling that typhoon induced turbulence on the sea floor and perhaps the trawling activities of fishermen would also cause mixing of the mud layers.

This study has used a combination of grab and core sampling to compile a simple facies map of Three Fathoms Cove and has shown that the upper few 10's of cm's show a considerable degree of stratigraphic variation. Studies of this type need to be carried out in Hong Kong in order to develop local models of sedimentation that can be used to assist in interpretation of late Quaternary core materials, of which there is an abundance available. In the context of palaeoenvironmental reconstruction, it is therefore noteworthy that high organic matter contents were associated with the distal parts of the fan deltas (proximal areas were not sampled) and that clay contents reached

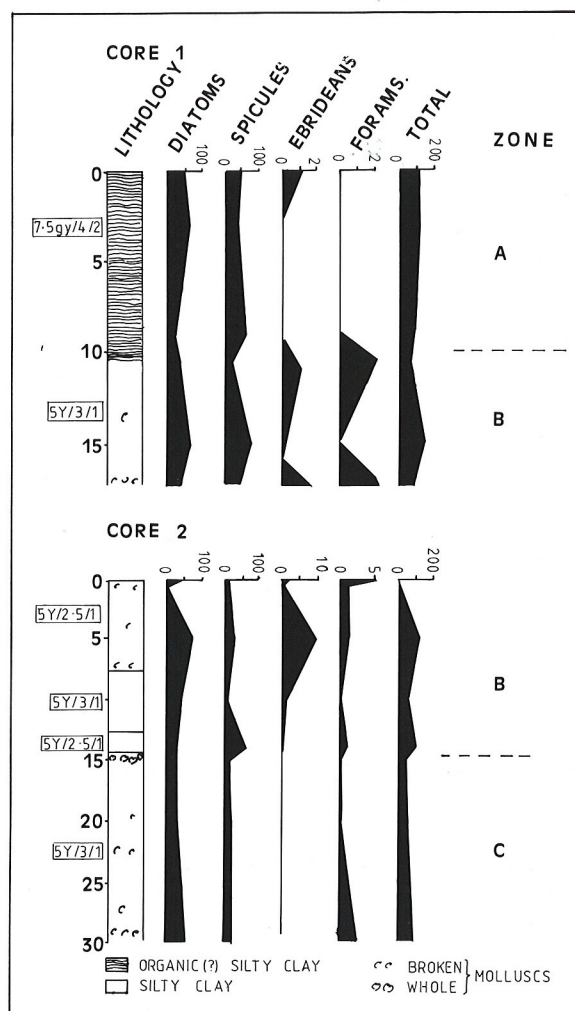


Figure 3 - Microfossil stratigraphy of Cores 1 and 2. Core scale is in cm's. Numbers to right refer to Munsell soil colours.

maximum values in the deep channel axis.

The cores at Three Fathoms cove show a basic two fold division into an upper organic rich mud with considerable microfossil variability in terms of numbers of diatoms, sponge spicules, ebrideans and foraminifera (Zone A). The lower layer is relatively clay rich, more compact, and shows greater stability of microfloras and microfaunas (Zones B and C). Why the differences? Microfossil identifications in this study were only carried out at a crude level and spe-

cies-environment relationships are of little assistance. The significant feature to note and explain is the variability of the upper layer and its greater organic loading.

Several possible explanations can be advanced. Variations in microfossils suggest variations in the environment in which they originally lived. It would therefore appear that the time represented by the sediments below 14 cm in TFC/1 was stable, with little environmental change. Above 14 cm the sediments seem to suggest a more recent period of environmental instability and perhaps increased nutrient loading, given the higher organic content.

What has happened that might have caused such a change? The environment has become subject to fluctuations. Perhaps related to natural changes such as sea level variability, or climate effects related to rainfall might be the cause. However, in Hong Kong, man is of at least equal or, more likely, of greater significance in determining environmental change.

Two possibilities may relate to this influence on two very different time scales. Firstly, if the boundary at 14 cm is recent (last few decades), then the changes may be related to increasing chemical pollution and increasing nutrient loading in Tolo Harbour and its adjacent areas. An alternative explanation, at this time scale, may exist with possible changes in basin (& current) configuration caused by the development of the Plover Cove Reservoir to the north of Tolo Harbour/Channel. Secondly, if the time scale involved is longer, then the increasing environmental instability and increased nutrient loading, might relate to deforestation several hundreds of years ago. This would have caused increased soil erosion and changed fundamentally the marine system.

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The Offshore Quaternary Sham Wat Formation of Hong Kong

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Abstract

Seismic interpretation during offshore mapping by the Hong Kong Geological Survey has identified a Quaternary stratigraphic unit which has been designated the Sham Wat Formation. The seismic character and lithology of the formation are described and the depositional environment and possible age discussed. It is suggested that the formation comprises marine sediments laid down during a late Pleistocene high sea level stand.

摘要

香港地質調查組在離岸地區進行測繪工作期間所作的地震解釋，已鑑定出一個第四紀地層的單位，並將之稱為深屈組。該組的地震特徵和岩性經已說明，而沉積環境和可能的年代亦作了討論。所得的看法是，深屈組是由晚更新世高海面時留下的海相沉積所組成。

Introduction

The stratigraphy of Hong Kong's offshore Quaternary deposits has been the subject of recent discussion (Fyfe, 1992; Yim & Fyfe, 1992). In 1986, the Hong Kong Geological Survey erected a stratigraphy based on interpretation of borehole and seismic data (Strange & Shaw, 1986). The stratigraphic units defined can be mapped with confidence over the Territory using boomer seismic profiles. The Chek Lap Kok Formation is considered to be largely fluvial, with subordinate estuarine and marine sediments and represents deposits of late Pleistocene and earlier age. The overlying Hang Hau Formation is considered to be a Holocene marine deposit, possibly with latest Pleistocene littoral or intertidal sediments at the base.

During mapping north of Lantau, the Hong Kong Geological Survey (James, 1993) identified a further formation which was named the Sham Wat Formation. A similar seismic unit has been identified by Evans (1993) in mapping of the eastern waters of Hong Kong. Stratigraphically, the formation occurs between the Chek Lap Kok and Hang Hau formations. Although it has been increasingly referred to in recent literature, and described in detail by James (1993), the formation has not yet been formally defined in the public domain. This article provides that definition.

The Sham Wat Formation is present in the

west of Hong Kong territorial waters and is inferred to occur to the south of the territorial limit and westwards into the Pearl River estuary (Figure 1). In the east, it is present southeast of the Ninepins but is believed not to extend into Mirs Bay (Evans, 1993). The formation rests with major unconformity on the Chek Lap Kok Formation and is unconformably overlain by the Hang Hau Formation. It is named after the village of Sham Wat on the north coast of Lantau, north of which the type section was recovered in the continuously sampled marine borehole ESC17. Its thickness varies considerably as dictated by the irregular nature of the basal surface and reaches 35 m in the deepest troughs in the southwest of the Territory.

Seismic Character

The formation has a distinctive seismic signature. The base is represented by a strong reflector with a characteristic undulating profile that in part defines the seismic character. This basal surface is commonly deeply incised into the underlying Chek Lap Kok Formation (Figure 2). In some cases, the channel interfluvial exhibit a distinct planated crest, representing the remnants of an older erosion surface. In western waters, this dissected planar surface dips to the south and west. The channels themselves are characterized by steep (15°-20°) sides and usually have

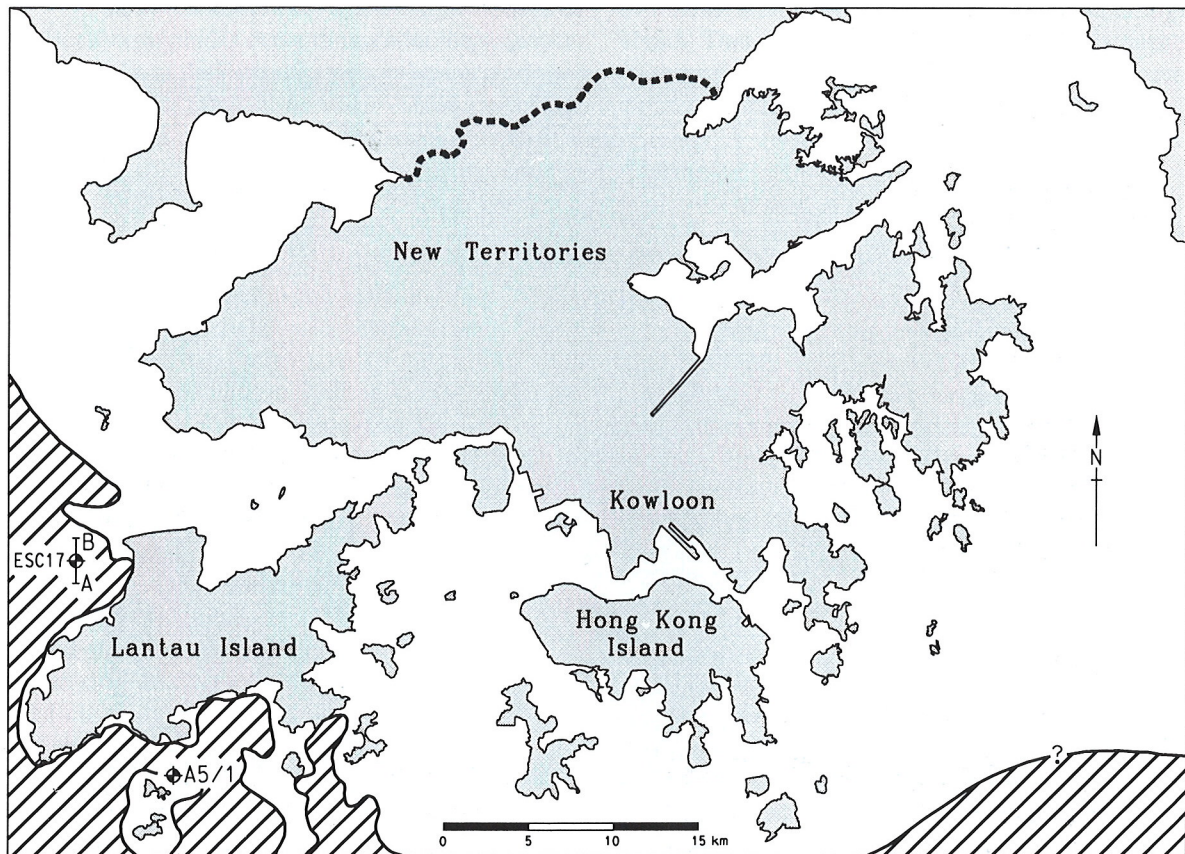


Figure 1 - Distribution of the Sham Wat Formation (shaded) in Hong Kong waters, showing the location of the seismic profile A-B in Figure 2 and borehole referred to in the text.

a symmetrical U-shaped profile.

The intra-formational reflectors are of low to moderate amplitude and their shape is controlled by the morphology of the channels. The reflectors are continuous, sub-parallel to the planated crest of the interfluvial and drape down into the deeper channels. This shape gives the formation its characteristic wavy appearance on seismic sections. In some profiles, a stronger reflector occurs within the sequence forming a subdued image of the basal surface. Near the top of the sequence, the reflectors are truncated by the erosional base of the Hang Hau Formation.

Where the formation is thinner, the intra-formational reflectors may not be seen. In such areas, it is easy to confuse the Sham Wat Formation with the lower unit of the Hang Hau Formation, which may also have an irregular channelled base. Resolution of this problem is usually achieved by close examination of the stratigraphical relationships along the same profile. Moreover, in some areas, the top part of the Chek Lap Kok Formation may exhibit channel features; these can usually be differentiated from Sham Wat Formation channels by the different intra-formational reflector style and the lower amplitude of the basal reflector.

The upper surface of the Sham Wat Forma-

tion is normally a low-angled unconformity and is overlain by the Hang Hau Formation, though in the deepest troughs, the succession may be disconformable. In the southwest, a four metre thick intensely-weathered layer, interpreted as a palaeosol, occurs at the top of the formation. The presence of similar horizons in other areas where pre-Hang Hau Formation erosion was minimal, cannot be discounted. Over the interfluvial, where the succession is thinnest, seismic evidence indicates that more than 10 m of sediment has been eroded. In the east of the Territory, the Sham Wat Formation appears to fill the base of troughs subsequently filled by Hang Hau Formation sediments. Whether significant erosion took place within these troughs is not clear but the absence of any palaeosol suggests that this is probably the case.

Lithology and Depositional Environment

The formation dominantly comprises soft to firm silty clay, medium grey in colour with pale yellowish grey oxidised bands and sparse mottles. Some of these bands are associated with the development of hard nodules. Small 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 problematical. Small

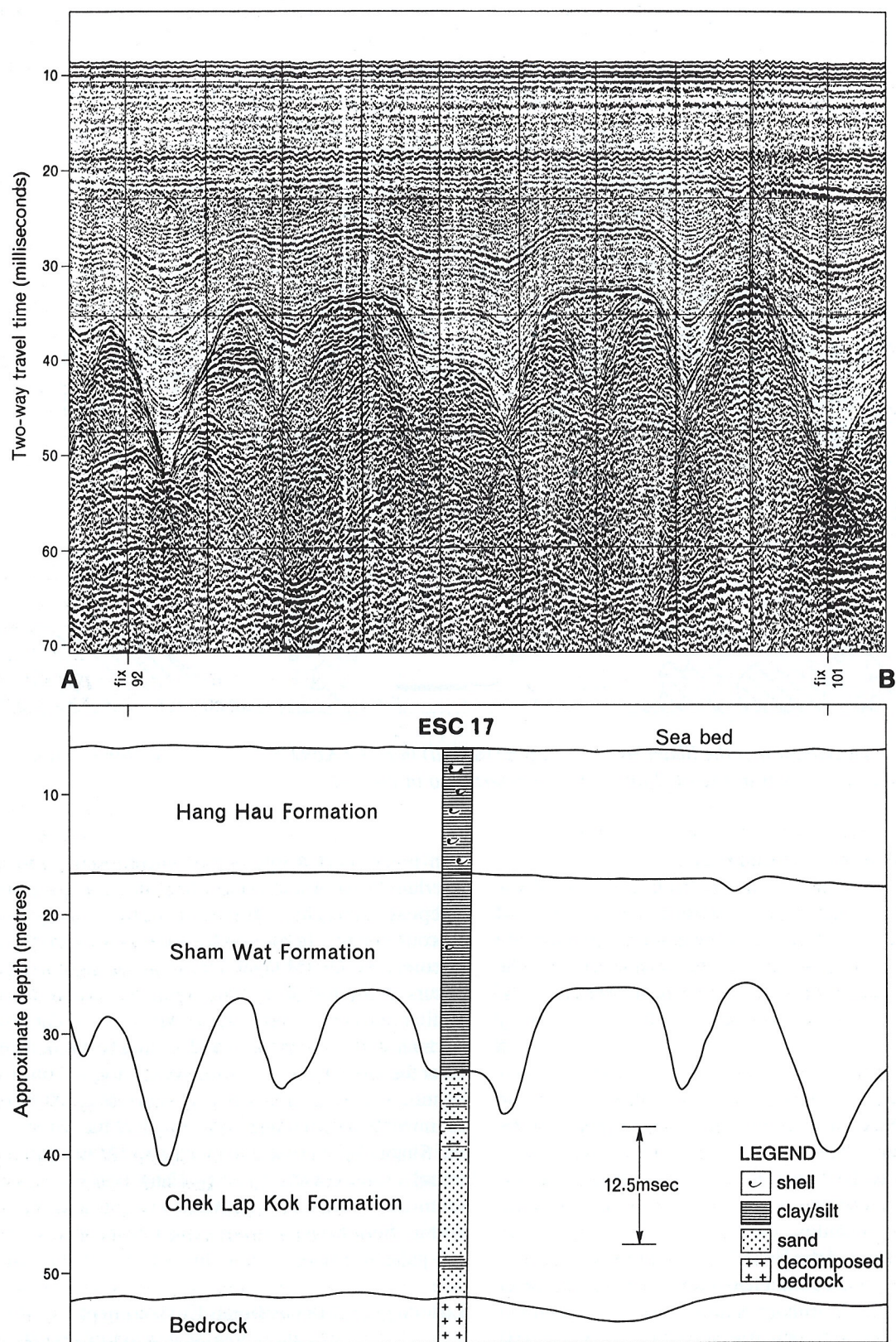


Figure 2 - Seismic profile of the Sham Wat Formation with interpretation and graphic log of Borehole ESC17.

disarticulated bivalves up to 6 mm across are also preserved, as are small organic plant fragments, though the latter occur infrequently. Towards the base of the

formation, the sediment is dominantly very fine to fine sand, which grades upwards into interbedded silty clay and sand.

In borehole ESC17, small concentrations of black monosulphides occur throughout the sequence. Thin streaks of dark organic material are recorded at the base of the core. In borehole A5/1, plant fragments occur at the base of the core together with a 60 mm-thick peat band. Plant remains are recorded at the top of the formation, associated with a sandy horizon. The sediments differ from those of the Hang Hau Formation in that they are firmer, with a shear strength of up to 60kPa, and have a lower silt:clay ratio. The characteristic pale yellowish grey oxidation layers and associated nodular development are not seen in the Hang Hau Formation. The shell content is much less well preserved and leached.

The Sham Wat Formation is interpreted as being deposited in a marginal marine environment. The manner of erosion of the basal surface is equivocal; the planated surface may represent a period of erosion associated with rising or falling sea level. The deeply incised channel features may have formed during a period of fluvial entrenchment, though the steepness of the sides suggests rapid downcutting as found in tidal channels during a rapid fall in sea level. The foraminifera (Wilkinson, 1992) suggest that the sediments were deposited initially in an estuarine environment which became fully marine when the upper sediments were deposited.

The draped intraformational reflector style may be caused either by post-depositional compaction or as a primary structure. The former theory is supported by the fact that the reflectors thin over the channel margins and that some degree of consolidation is seen in these sediments. However, the thinning is not as marked as might be expected if this were the sole factor and it may be that the reflector pattern in part represents a primary structure. Such would be caused by rapid sedimentation from highly sediment-laden water in relatively deep water with little reworking by currents.

The age of the Formation

The age of the Sham Wat Formation a matter of some conjecture. ^{14}C dating from marine shells in borehole ESC17 (Oxford University Radiocarbon Accelerator Unit) has yielded one absolute date of $41,700 \pm 1700$ years BP and another of $>43,700$ years BP. As these dates are so close to the limit for the method and as the likelihood of contamination is very high, it is probable that the formation is greater than 40,000 years old (James, 1993).

The sediments are considered to have been deposited during a high sea level stand. The major unconformity at the base of the Hang Hau Formation which has eroded up to 10 m from the top of the Sham Wat Formation, together with the ^{14}C dates suggests that this stand was certainly pre-Holocene. As the maximum elevation for the formation is -11 mPD and there is a degree of compaction, it is likely that the

sediments were deposited during the last major high stand. This occurred during the late Pleistocene, (Chappell & Shackleton, 1986) around 125,000 years BP (oxygen isotope stage 5e).

Summary

The Sham Wat Formation has been recognised in western and eastern waters of Hong Kong as a dominantly marine deposit of pre-Holocene age. Its distinctive seismic character, lithology and stratigraphic relationships mean that it can be defined as a separate formation. Seismically, it may be distinguished from the Hang Hau Formation by the distinctive wavy intraformational reflector pattern, and lithologically by its higher shear strength, its oxidation colour banding and the lack of fresh shell fragments. It is believed to represent an transgressive estuarine to marine sequence deposited during the latest Pleistocene high sea level stand.

Acknowledgements

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Exploration for Offshore Sand in Hong Kong: Reconnaissance Surveys and Geological Assessments

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Abstract

In 1986 the geotechnical Control Office (precursor to the Geotechnical Engineering Office) began a two year study to locate offshore granular deposits for use as fill in large urban reclamations. Following its successful completion, the SEAMAT study was initiated to investigate the remainder of Hong Kong's offshore areas. Techniques employed included seismic interpretation, borehole logging and laboratory testing of samples. Stage I of this survey involved almost 700 km of reconnaissance seismic traverses and 77 sampled holes. Fourteen target areas were identified, the three largest of which were investigated further by detailed Stage II studies. Several criteria were employed to assess the suitability of the selected targets as potential borrow areas and 588 Mm³ of fill resources were confirmed. Feasibility studies of the identified resources were then carried out as separate consultancies under subsequent phases of the Government's Fill Management Study.

摘要

土力工程處在一九八六年展開一項期兩年的研究，爲了找尋離岸粒狀沉積物用作市區大型填海工程的填料。此項研究完成後，該處開始進行全港性海上沙源研究，以便調查香港其餘離岸的地區。研究所採用的技術，包括地震解釋、鑽孔記錄及實驗室樣本試驗。此項研究的第一階段工作包括近700公里的踏勘地震區及77個取樣鑽孔。土力工程處已找出的預定沙源有14個，並對其中最大的三個進行詳細的第二階段研究。該處採用數項準則以評定所選擇的目標是否適合作爲潛在的採泥區，並確定有5億8800萬立方米的填料資源。有關經確定資源的可行性研究，其後根據政府的填料管理第二階段研究以獨立的顧問方式進行。

Introduction

Since its founding as a British settlement in 1841, the population of Hong Kong has steadily expanded from only 5650 to almost 6.5 million with a concomitant growth in the urban area. To accommodate the necessary infrastructure, reclamation began in 1851, mainly in Central District and the West Kowloon Peninsula, later expanding to Wanchai, Happy Valley, Kai Tak and the new towns. The airports at Kai Tak and Chek Lap Kok and the existing eight container terminals are also mainly on reclamation. Historically, the first areas were reclaimed by public dumping and using minor amounts of weathered rock

fill. This was followed by a period of large-scale hill-side cutting and removal. Subsequently, fill materials were obtained from the seabed, most notably for the Kai Tak runway extension in 1956 (Henry et al., 1961), Plover Cove Reservoir in 1963 (Dodd, 1966), Container Terminal 6 (Wragge-Morley, 1988) and Tin Shui Wai new towns (Dutton, 1987). These and other projects were reviewed by Guildford (1986, 1988) and Whiteside and Wragge-Morley (1988). In the mid 1980's, the then Geotechnical Control Office (GCO) began a systematic study of offshore fill resources in Hong Kong waters.

This is the first of two papers on offshore sand exploration in Hong Kong. It describes the scope and findings of the early geological work. A follow up paper (Whiteside et al., in prep.) will examine the subsequent phases.

Land Development

During the 1980's, a considerable number of new reclamations were planned in Hong Kong, many of which covered large areas and entered deeper water than previously. In order to meet the increased demand for reclamation fill, attention was focused on the offshore area. Offshore sources of fill were potentially more easily accessible than traditional onshore sources and could meet the requirements for a more rapid rate of supply. Therefore, in 1986 the Geotechnical Control Office (now the Geotechnical Engineering Office) began the Marine Sources of Fill Study, a geological project to locate 100 Mm³ of granular material suitable for use as fill for major urban reclamations in Victoria Harbour. A geological model of offshore sand occurrences was developed and three major sources of granular material were located; south of Tsing Yi Island, north of the Brothers islands in Urmston Road and at the southern end of the Tathong Channel (Shaw and Whiteside, 1987, 1988; Choot, 1988).

The concurrent Port and Airport Development Strategy (PADS) Study calculated that the known sources of marine fill were substantially less than the requirements for the proposed PADS developments (PADS Consultants, 1988). Their calculations concluded that the Territory's fill resources amounted to 390 Mm³, of which only 160 Mm³ were considered to be economically extractable. Consequently, the more comprehensive Territory-wide SEAMAT Study, designed to identify all remaining sources of reclamation fill within Hong Kong waters, was undertaken by the GCO between July 1988 and June 1991. Together, these two projects comprised Phase I of the Hong Kong Government's Fill Management Study, which is about to enter Phase VI.

The Offshore Geological Setting of Hong Kong

Hong Kong is situated at the southeastern corner of the eastern (Fanshi) channel of the Pearl River (Zhu Jiang), which has exerted a dominant influence on the offshore geology of the area. Surface sand occurs between the Humen Gap and Nei Ling Ting as tidal sand ridges, becoming muddy in its lower reaches near Hong Kong. A blanket of marine mud up to 20 metres thick covers the seabed in Hong Kong, although a network of tidal channels has developed that are sand- or rock-floored.

In the Late Pleistocene, sea level fell to -120 mPD and exposed a broad coastal plain up to 130 kilometres wide. This allowed the Pearl River to extend its branching distributary network southwards

and between the islands of Hong Kong, reworking earlier sediments and depositing fluvial channel sequences, the Chek Lap Kok Formation (Strange and Shaw, 1986), which rests on weathered bedrock. The formation is lithologically complex, exhibiting a chaotic seismic signature lacking laterally persistent seismo-stratigraphic units. Many of these sediments are sub-aerially weathered.

During the succeeding marine transgression that began about 18,000 BP, river channels were flooded by the advancing sea, forming tidal inlets that were infilled by finely-laminated intertidal sands and silts containing mangrove remains (Shaw and Arthurton, 1988; Shaw, 1990). The deepening marine waters deposited the Holocene marine muds of the Hang Hau Formation (Strange and Shaw, 1986), commonly with a basal transgressive sand resulting from the erosion and winnowing of pre-existing deposits.

Model of Sand Occurrences

Palaeoenvironmental interpretations of the offshore deposits from boreholes and seismic profiles carried out as part of the Hong Kong Geological Survey 1:20 000 scale mapping programme (Shaw, 1987; Shaw and Arthurton, 1988) established that sand deposits occur in six major geological settings (Shaw, 1988), namely :

- | | |
|-------|--|
| | Holocene |
| (i) | River channel sands (modern onshore rivers) |
| (ii) | Littoral and sublittoral sands (coastal) |
| (iii) | Seabed residual sands (sand sheets and sand banks) |
| (iv) | Marine channel sands (tidal channels) |
| (v) | Basal transgressive sands |
| | Pleistocene |
| (vi) | River channel sands (buried deposits) |

This geological model was used as the framework for the SEAMAT investigation, the details of which were modified and refined as the survey and interpretation progressed.

The SEAMAT Study

The SEAMAT Study was carried out by the Geotechnical Engineering Office between July 1988 and June 1991 with the objective of locating and investigating all major workable bodies of sand and gravel in the offshore Quaternary succession that could be used as reclamation fill or building aggregate. The study was designed to identify all bodies of granular material, to determine the quantity and quality of the deposits and to make a preliminary assessment of the economics and feasibility of dredging and transporting the materials.

The methodology adopted was that developed

and proved during the preceding Marine Sources of Fill Study. This involved geophysical surveys and drilling followed by borehole logging and laboratory testing carried out in two stages. During the first stage, a Territory-wide reconnaissance grid of seismic lines on a 3 kilometre by 3 kilometre grid was completed (Figure 1). Stage I seismic surveys provided reconnaissance profiles across the offshore superficial deposits. Initial interpretation of the seismic profiles identified a number of target bodies. Five criteria were used to define suitable prospecting targets, namely the seismic character of the body, the absence of any physical constraints such as seabed cables, the absence of extraction constraints such as water depth, the relative overburden thickness and the extent of interbedded clay layers. These target bodies were investigated by drilling (Figure 2) and logging. Based on the results of this first stage (Thorley et al., 1990), target resources were gazetted as marine borrow areas in February 1990.

Second stage investigations were directed towards selected target areas, in particular those that comprised extensive seabed or near surface sand. They were designed to define more accurately the extent of the target bodies, using closely-spaced geophysical traverses, and to assess the quantity and quality of the component material. Typically, a 500 metre by 500 metre survey grid was run (Figure 1). Seismic profiles were interpreted and additional vibrocores drilled (Figure 2). Vibrocores were subsampled for laboratory testing prior to the preparation of a dredging assessment for each target area. Field work was completed in April 1991 and the results provided the basis for further intensive investigations during Phase II of the Fill Management Study. The study has been fully reported by Cheung and Shaw (1993).

Study Areas

Prior to the commencement of the SEAMAT Study, the known marine fill resources were located north of Lantau Island (53 Mm³), Deep Bay (up to 480 Mm³), Urmston Road (50 mm³), south of Tsing Yi Island (up to 110 Mm³), Tathong Channel (50 Mm³), south of Stanley (80 Mm³) and in the Tolo Channel (27 Mm³). These resources were summarised by the PADS Consultants (1988), largely from the findings of the Marine Sources of Fill Study and other investigations for Tin Shui Wai and Container Terminal 6.

The reconnaissance geophysical survey completed during the Marine Sources of Fill Study covered about fifty percent of Territorial waters (Figure 1). During the SEAMAT Study, the reconnaissance grid was extended to cover all the previously unsurveyed areas. The exceptions were Deep Bay, which had been investigated earlier for the Tin Shui Wai project, and Victoria Harbour. The new areas included a strip along the western Territorial limit by Lung Kwu Chau, the

inshore areas between the south Lantau Coast, the Soko Islands and Cheung Chau, the inshore areas around the Soko Islands and Tai Tam Bay, an 11 kilometre-wide zone on the eastern Territorial limit, and the unsurveyed portions of Mirs Bay and the Tolo Channel.

Field and Laboratory Methods

Echo sounding and seismic reflection profiling were used for the field survey, to acquire bathymetric data and continuous seismic profiles. Echo sounding was used to determine water depth accurately. The device has an accuracy of 0.5 to 1 percent. Tide gauges were installed at several coastal locations to provide the tidal readings necessary to reduce the soundings to Principal Datum. Seismic reflection profiling was carried out using a surface-towed, high-resolution boomer with an energy level of 100 joules and a firing rate of 4 pulses per second. The maximum effective penetration depth was of the order of 80 metres below the seabed. Position fixes for the surveys were obtained using a trisponder that received signals from up to five accurately-positioned, temporary shore stations. A swell filter was used in areas that experienced a large swell.

Both vibrocoring and percussion boring techniques were employed during the Stage I drilling investigations. Vibrocoring was used to take successive 6 metre-long samples through casing (Smyth, 1988). This is a rapid technique that can take continuous samples through sand, clay or mixed deposits and is especially useful in navigation channels or busy areas, being faster than conventional borehole drilling. Good recovery was generally achieved, although some degree of compaction and consequent sample disturbance occurred. Continuously-sampled boreholes were specified in the thicker sequences of offshore deposits to establish the lithology of the seismic units. Recovery was usually very good and sample disturbance minimal, allowing good calibration. Pistons were used in the softer marine muds, U76 and SPT samples in the underlying deposits. Geological logging was carried out on the drilling barge, and later on extruded samples in the laboratory.

Bulk samples were sent to the laboratory for index testing according to BS 1377, namely particle size distribution, Atterberg limits, specific gravity and moisture content. Following detailed logging, further representative samples were also tested. A consultant was appointed to investigate the suitability of the offshore sands as construction aggregate.

Stage I and II SEAMAT Investigations

Stage I geophysical investigations comprised 674 kilometre of reconnaissance survey lines. The survey grids were designed with lines oriented north to south and east to west over the open sea areas. The grids were skewed into bays in coastal areas. In the main channels (Tolo Channel, Sheung Sz Mun, etc.),

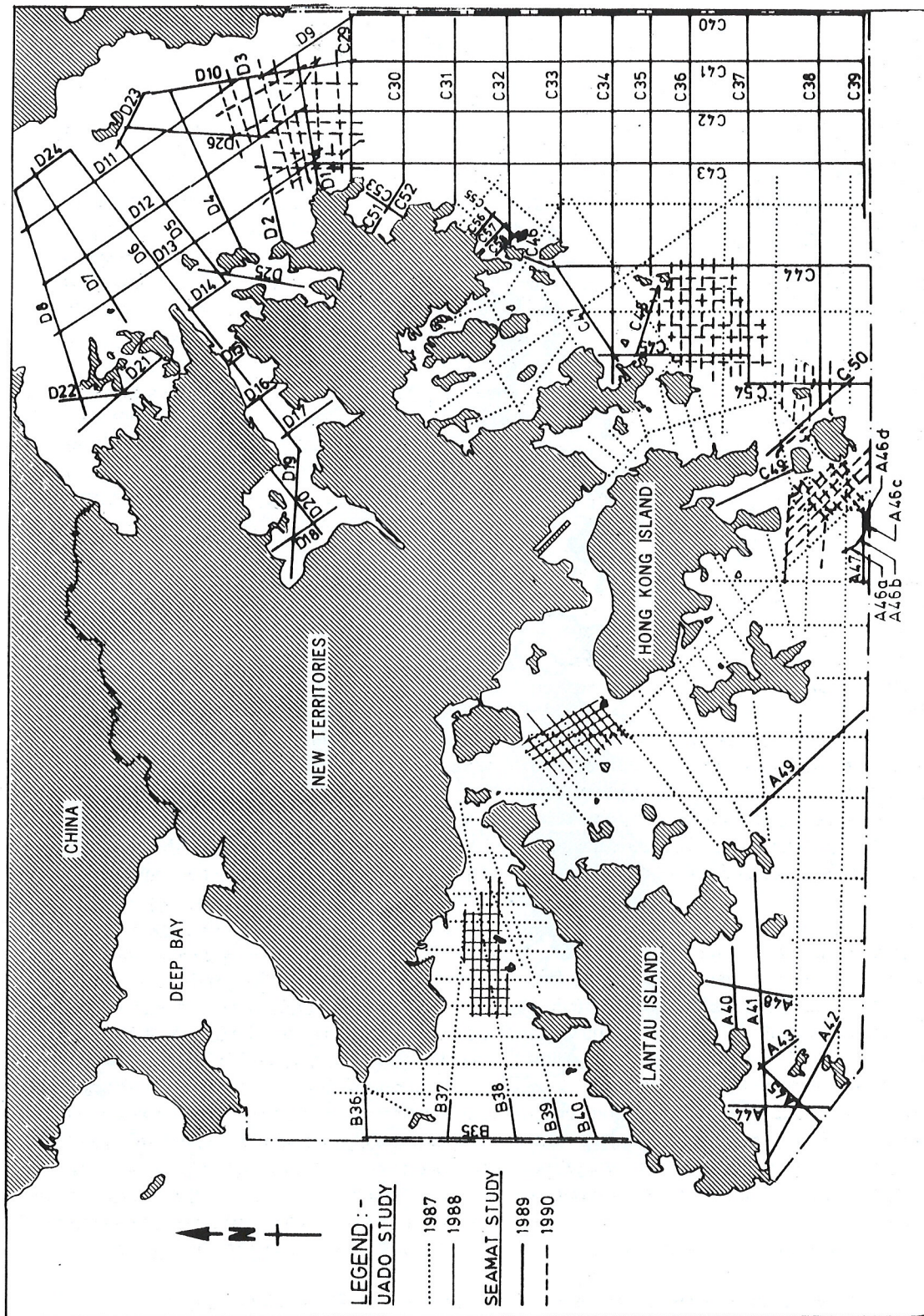


Figure 1 - Seismic grid map of the SEAMAT lines

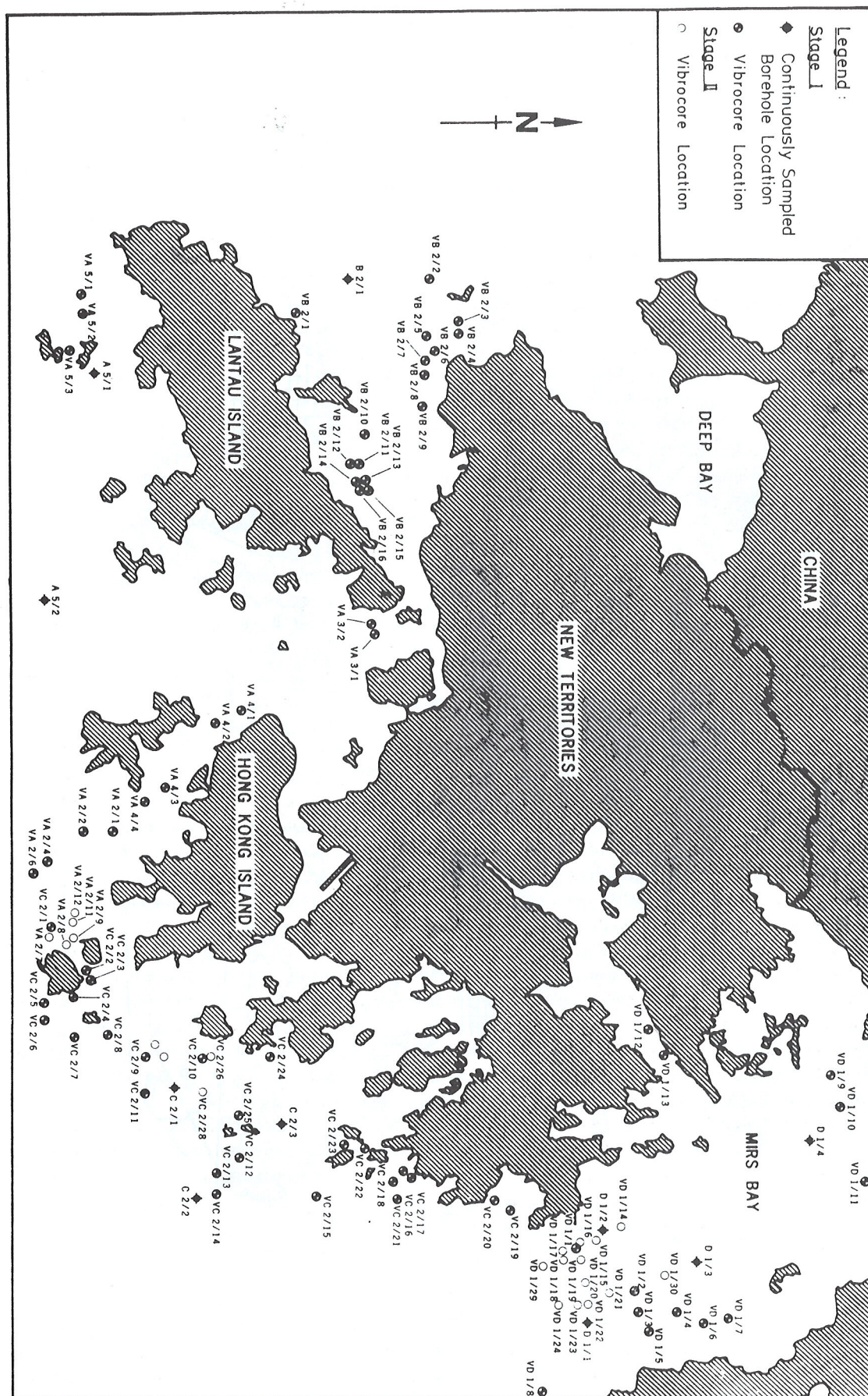


Figure 2 - Map of the SEAMAT borehole and vibrocore locations

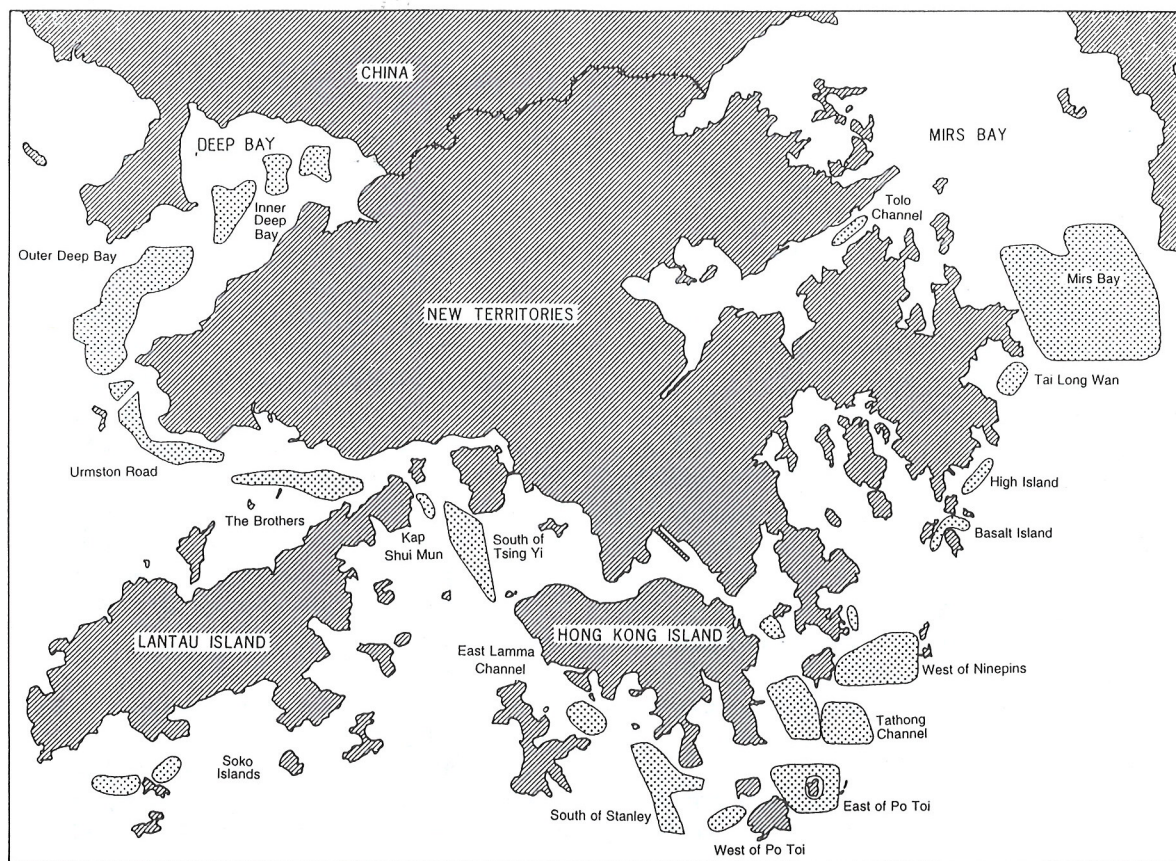


Figure 3 - Location of the SEAMAT target areas

spinal lines were run along the axes, with orthogonal lines placed to determine the channel cross-section (Figure 1).

Based on a range of seismic criteria, including inclined bedding, channel forms and signal amplitude, 17 target bodies were identified on the resulting seismic profiles. These seismic features were then investigated by 67 vibrocore holes and 10 continuously-sampled boreholes (Figure 2). Vibrocores sampled down to about 25 metres below seabed, and boreholes to around 70 metres.

Following the drilling investigation and sample logging, a total of 237 bulk samples were selected for laboratory analyses, and the detailed logs were used for accurate calibration of the seismic interpretations. These re-evaluations demonstrated that many of the targets were marginal, containing only limited potential resources, and commonly occurred below a thick overburden that, on balance, rendered them sub-economic. In general, targets having a mud cover of more than 10 metres or a mud/sand ratio greater than 1 were rejected during the Stage I selection process. Further attention was therefore focused on the largest seabed surface deposits and the thicker extensive concealed deposits in which the overburden ratio was lower. Of the initial 17 targets originally investigated, Stage II studies were carried out around the Po Toi Islands group, east of Tung Lung Chau and in south-

ern Mirs Bay (Figure 3).

Surface sands around the Po Toi Islands were investigated by 72 kilometres of seismic traverses and also several lines of side-scan sonar survey that was employed to determine the surface morphology of the deposits. Five vibrocores to the west of the Po Toi Islands confirmed a layer of surface sand about 3 metres thick covering an area of 536 hectares overlying a layer of mud of similar thickness which, in some areas, overlay another deposit of channel sands up to 10 metres thick. A further 72 kilometres of seismic lines were run in the southern part of the Tathong Channel between Tung Lung Chau and the Ninepins Group, supplemented by two vibrocores. The survey proved about 2 metres of surface sand and, in places, deeper channel sand deposits from 5 to 8 metres thick. The large target in the southwest of Mirs Bay was covered by 17 seismic lines, totalling 88 kilometres, and 14 vibrocores. Following detailed logging, another 170 samples were laboratory tested.

Basis of the Resource Assessments

Throughout the study, the suitability of the targets, or potential targets, as offshore borrow areas was continually reviewed. Assessments were based on practical dredging considerations, in particular the water depth (must be sufficiently deep for dredger access; the majority of dredgers have maximum work-

ing depths of 25 to 30 metres), level of the base of the body (less than minus 40 mPD), degree of site exposure (manifested as wave heights of less than 1 metre) and stratigraphical occurrence (ratio of overburden thickness to thickness of sand resources of less than 1, and the absence of intercalated layers of unsuitable material).

In addition, several material parameters pertinent to dredging and reclamation were considered (Ford, 1988), namely the mean and maximum particle size, particle size distribution (grading), SPT 'N' values and angularity (abrasiveness) of the coarser particles. Extreme stiffness and relative density ('N') values exert an important control on the suitability of a body, particularly as a stiff layer may cap or obstruct the underlying granular body. The general classes were defined as :

1. Easy dredging 'N' < 15
2. Easy to moderately difficult dredging
15 < 'N' < 30
3. Difficult dredging when extensive or encountered by small plant
30 < 'N' < 45
4. Difficult to impossible dredging except by larger or more specialised units:
'N' > 45

Based on the information gathered during Stage II of the study, the approximate quantities of granular material in each target body were estimated. Estimates were based on the thickness of suitable material identified in a borehole, i.e. granular material with a maximum of 40 percent fines. However, granular material with an SPT 'N' value of more than 45, that occurred beneath a stiff clay layer greater than 50 cm thick, was disregarded. Seismic interpretation was combined with drilling results to assess the extent of the resource and then to calculate the resource volumes. In areas where seismic data were not available or were difficult to interpret, volume estimates were made on the basis that the area influenced by a borehole was midway between it and adjacent boreholes.

Resource Assessments and Borrow Area Development

Stage I investigations showed that 14 of the 17 initial targets had favourable lithologies. The three largest were further surveyed in the Stage II investigations. These deposits were classified as potential resources (Addison et al., 1988). Until the grade, volume and location are accurately known, such deposits cannot be considered as reserves, but may be termed 'discovered resources'. Although the volumes of the potential targets were calculated, the results were largely interpretive and could only be considered as first estimates of the order of magnitude of the dis-

covered resources. They could be subject to considerable revision following a full-scale dredging evaluation. The provisional volume estimates (Cheung and Shaw, 1993) are presented in Table 1.

The SEAMAT Study (Cheung and Shaw, 1993) also examined the factors to be considered for full scale development of the marine borrow areas that were identified. The suitability of each target was assessed, based on practical dredging considerations. It was stressed that efficient and economic exploitation of a discovered resource requires a systematic and detailed site investigation to portray accurately the characteristics and extent of a mineral body and to determine any detrimental factors such as stiff clay layers, deleterious fines content or adverse depths that would affect the economic viability of the development. It was also pointed out that appropriate dredging equipment should be selected based on the characteristics of the deposit, its location and the required amount and rate of supply of material. According to Bray (1979), notwithstanding any major unforeseen problem in a deposit, the choice of dredger is the most important decision that will determine the economic efficiency of an extraction operation. In addition, careful management of the extraction is also considered to be an important factor so that distribution of the finite resources is optimally programmed to ensure efficient exploitation.

These and other questions were taken up by subsequent studies. In 1989, the Hong Kong Government established the Fill Management Committee to manage the supply and demand for fill materials in the Territory (Brand and Whiteside, 1990). Detailed investigations were conducted using the SEAMAT results as the basis for these borrow area development evaluations (Whiteside and Massey, 1992).

Summary

This paper is the first of two that describe the several phases of the Government's ongoing Fill Management Study. The initial Marine Sources of Fill Study and the SEAMAT Study (Cheung and Shaw, 1993) systematically surveyed the offshore area of Hong Kong to locate workable sources of sand and gravel for use primarily as reclamation fill and building aggregate. Fourteen potential targets were identified containing an estimated resource volume of 588 Mm³. Three major deposits were examined in detail, around the Po Toi Islands (estimated 74 Mm³), east of Tung Lung Chau (68 Mm³) and in the southern part of Mirs Bay (317 Mm³). Further surveys, including dredging evaluations, environmental impact assessments, and borrow area development studies, were recommended as being the next step in the development of the fill resources of the Territory. These subsequent stages were undertaken by consultants and timed to enable fill allocations to be made to several major reclamation projects. They are de-

Table 1 - SEAMAT Target Area Assessments

AREA	GROUP mPD	A+ <30	A <30	B 30-40	C 30-40	D 40-50	E >50	Totals M m ³
South of Stanley		-	-	-	-	-	-	-
Ma Wan		2	1	2	-	-	-	5
East Lamma Channel		-	-	12	20	22	-	54
Soko Islands		25*	-	-	-	-	-	25
Urmston Road		-	7	3	-	-	-	10
West of Po Toi		15	-	19	-	11	-	45
East of Po Toi		6	-	11	-	12	-	29
East of Tung Lung Island		21	-	47	-	-	-	68
Clear Water Bay		-	2	-	-	-	-	2
Basalt Island		9	-	3	-	-	-	12
High Island		2	3	-	-	-	-	5
Tai Long Wan		5	2	-	-	-	-	7
South Mirs Bay		-	107	94	5	79	32	317
North Mirs Bay		-	3	-	-	-	-	3
Tolo Channel		-	-	6	-	-	-	6
Totals:		85	125	197	25	124	32	588
			Easy to moderate recovery		407	Moderate to difficult recovery		181
								588
Notes: 1. A+ seabed material - easily dredged - A mixed with or under unsuitable material - B easy to moderate dredging - C moderate to difficult dredging - D difficult to dredge - E very difficult to dredge * above -20mPD 2. Volumes shown are geological resource volumes (based on information available as at 4.91) Final reserve quantities of Soko Islands, East Lamma Channel, Kap Shui Mun, West & East of Po Toi, Clear Water Bay and western portion of Mirs Bay given in the reports produced by BCL for the Fill Management Study - Phase II 3. No allowances have been made for the Territorial boundary (Mirs Bay) or marine environmental considerations								

scribed by Whiteside et al. (in prep.).

Acknowledgement

This paper is published with the permission of the Director of Civil Engineering of the Hong Kong Government.

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Hong Kong Landform Series No. 1

Shore Platforms - Characteristics and Origins

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Introduction and Definition

Shore platforms are horizontal or near horizontal features that are formed as a result of coastal slope retreat. They mark a zone of erosion and cliff recession. Although previously referred to as wave-cut platforms, it is now recognised that wave action alone is insufficient to create these platforms and that the non-generic term shore platforms is a more appropriate term.

A morphological classification of shore platforms by Bird (1968) identified horizontal high and low tidal platforms and gently sloping intertidal platforms. Slopes are typically in the order of 1-3° and widths can vary considerably. In Hong Kong, two major types of shore platform can be identified. Both are both characterised by low-angle platforms backed by steep cliff lines, but differ in their genetic origin

and height above sea level. These are referred to here as "Sub-tidal platforms" and "Supra-tidal platforms".

Sub-tidal Platforms

Sub-tidal platforms occur where shoreline slopes plunge steeply into marine environments, especially along coasts where high wave energies are experienced. Typically, they are found where rising sea levels (Holocene Transgression) have flooded a dissected mountainous area (Ria coastline) as occurred in the Territory approximately 6000 years ago.

According to standard models, described by Strahler (1994), once sea level has stabilized an initial NIP STAGE develops as wave action cuts into steep coastal slopes to produce a small cliff and seaward sloping platform (Figure 1A) that lies just below the high tide level. Hydraulic pressure generated

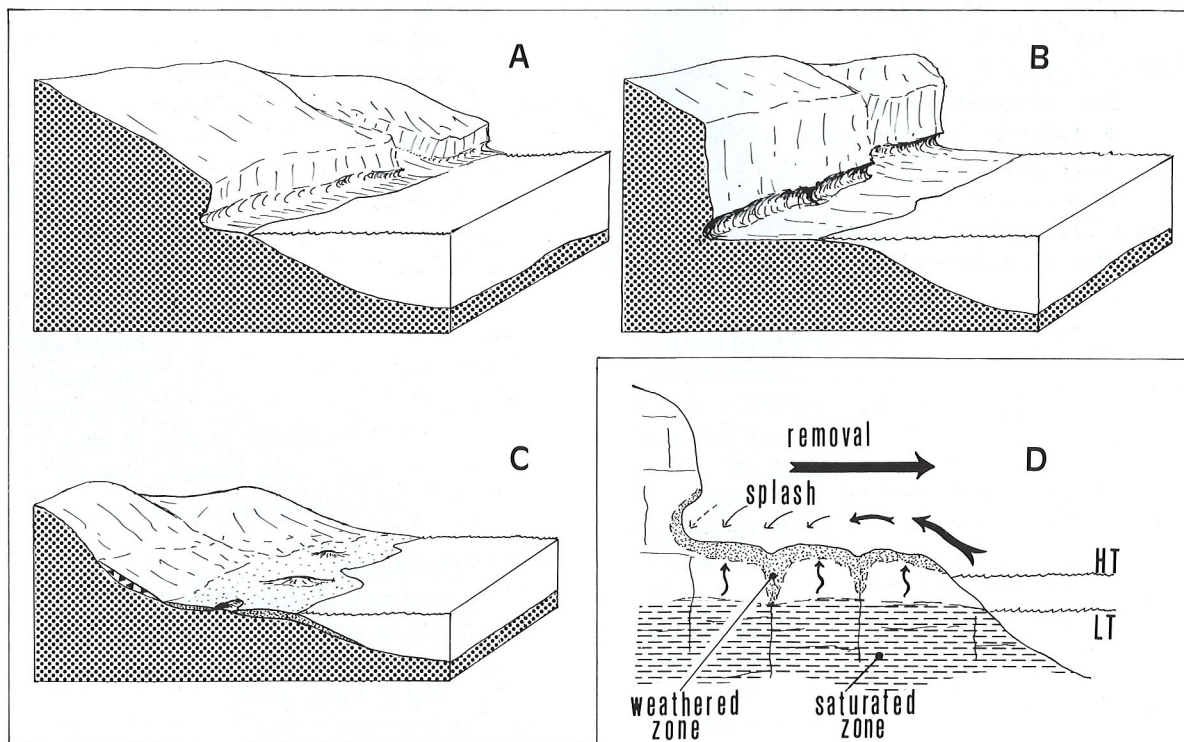


Figure 1 - Shore platform development in Hong Kong. Sub-tidal platforms shown in A to C. A: Nip Stage with narrow platform, undercutting and small cliff, B: Abrasion Stage with extensive rock outcrop on a broad platform, C: Degraded Stage with only occasional rock outcrops on platform (scree shown by filled triangles, sand shown as stipples). Supra-tidal platform shown in D (HT = high tide; LT = low tide). Salt weathering of rocks caused by splash and capillary rise from saturated zone. Material removed by storms and spring line processes.

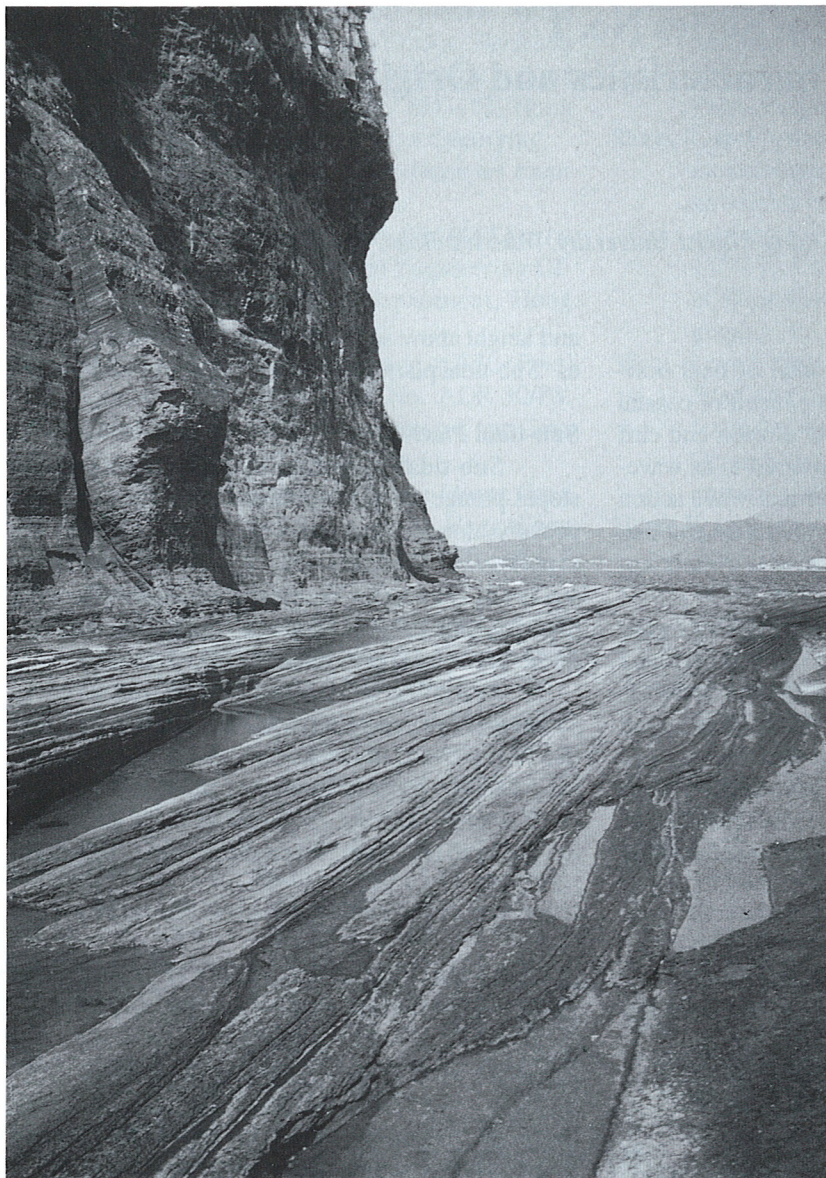


Plate 1 - Sub-tidal platform at low tide, Ping Chau. Note complete rock outcrop typical of the Abrasion Stage of development. The layered sedimentary rocks control the detailed micro-topography.

by breaking waves removes both weathered and joint-fragmented rock seawards and the platform becomes wider as wave action continues to undercut the cliff face. As the eroded material is transported laterally, the abrasion platform is further planed off. During this ABRASION PLATFORM STAGE (Figure 1B), the inner side of the platform is generally covered only during high tides. This is the common situation for abrasion platforms in Hong Kong (Plate 1), where widths of several tens of metres are common. Good examples occur at Ping Chau and Cape D'Aguilar, both of which are exposed to strong southerly, southeasterly wave action directed from the South China Sea. More sheltered waters tend to lack such features. With time the platform matures and becomes so wide that wave energies are expended due to friction as waves cross the platform. At this stage the cliff line at the inner edge of the platform is no longer undercut by wave action, but is subaerially weathered and reduced to lower slope angles by rain action and

mass wasting processes (Figure 1C). Stabilised scree accumulations may develop at the base of the inactive cliff. The platform may be in part covered by beach materials. This DEGRADED STAGE is not common in Hong Kong, probably because it is a relatively youthful flooded landscape.

Supra-tidal Platforms

In several parts of Hong Kong there are shore platforms that lie at, or just above, the high tide mark. These supra-tidal platforms are particularly well developed on Kat O Chau, Double Island and along several coastal sections around Double Haven (Plate 2). They develop on a variety of rock types: mainly volcanic ashes plus mudstones and sandstones. Bloom (1991) noted that this type of platform is especially common around the Pacific Ocean due to the abundance of pyroclastic rocks, which are especially susceptible to salt weathering just above high tide levels.



Plate 2 - Supra-tidal platform formed in pyroclastic deposits in Double Haven. The material on the platform is highly weathered.

Supra-tidal platforms tend to be less well developed in, or absent from, areas exposed to high wave energies. In Hong Kong, they typically lie at or just above the high tide level, are only a few metres wide and are backed by cliffs with a weathered notch at the base. They are normally located in low energy settings and just above high tide levels where salt weathering induced by splash during storms and by capillary rise processes through the rocks are important (Figure 1D). Salt weathering particularly occurs above the zone of permanent water saturation. Upon being loosened by weathering, rock material derived from both the platform and notch is removed during major storms and typhoons and perhaps also by streamlets originating from seepage at the base of the cliff. Similar salt weathering of shore platforms is reported from Hawaii (Wentworth, 1938), where platforms range up to 7 m above high tide level and tend to slope down towards bay-head locations. This reflects the height

to which spray can reach in different energy settings.

Examples

Shore platforms are best developed on the volcanic and sedimentary rocks of the Territory. Therefore good examples of sub-tidal platforms occur at Ping Chau (863000E, 840530N) and Cape D'Aguilar (442400E, 075000N) and supra-tidal platforms at Yan Chau (847610E, 842910N) and Wong Wan Chau (849000E, 840530N).

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Minutes of the Annual General Meeting of the Geological Society of Hong Kong, 27 May 1994

Present:

R B Owen, K W Lai, K M Wong, S T Gilbert, M Atherton, T Blower, R E Hale, D Yuen, C Chow, R J Neller, R Shaw, C H Tan, C M Lee, D R Workman.

Minutes of the Previous Meeting

R B Owen proposed and M Atherton seconded the minutes, which were accepted.

Chairman's Report

R. Shaw compared membership numbers with those of previous years and commented on the considerable number of talks organised over the past year. He invited comments on the lectures and their small attendances. It was suggested that a more central venue be considered and that the time of talks be changed to 19.00. The Chairman then requested the Secretary to give a report of past activities.

3. Secretaries Report

The Secretary gave the following report to the meeting:

There are currently 149 members compared with 126 in May, 1993. Membership fees have remained unchanged over the year and problems have occurred with late payments.

The Newsletter editorship has passed from R Langford to R Neller. There have been some discussions over the name of the Newsletter and whether it should be changed to reflect the improved quality of the publication.

The Seismicity Conference proceedings had been delayed due to a lack of central organisation. This responsibility has now been taken over by R B Owen and papers have now been edited (which has involved considerable English corrections), set into a pagemaker program and returned to the authors for final checking. They will be published as Bulletin No. 5 of the Society.

The Society has had to re-register with the Societies Officer of the RHKPF. The committee decided that it was necessary to obtain an up-to-date audit of Society accounts.

This has been a busy year in terms of field trips with expeditions to Kat O Chau, Ledge Point, Lai Chi Chong, Tsing Ma Bridge, Tai Long Wan and the Cheung Tsing Tunnel having been organised.

Two lecture series have been running in parallel, one being the Friday Lecture Series and the other being organised by the Geomorphic Studies Group. The Marine Studies Group has also been active and is planning a future seminar on offshore geological exploration methods. Talks have included the following:

October 1993

M. Atherton - Recent Geological disasters in the Philippines.

C. Ollier - Tectonics & the Geomorphology of Passive Continental Margins.

November 1993

K. Nicholls - Influence of Geology on the Economic & Social Development of S. Wales.

D. Martin - Some Applications of Geomorphology to Highway Engineering.

December 1993

N. Woods - Jungle Geology: Examples from Malaysia, Indonesia and Fiji.

January 1994

M. Short - Application of Optically Stimulated Luminescence to the Dating of Sediments.

S. Donaghue - Tephra Correlation in Volcanology.

February 1994

R.B. Owen & R. Shaw - The Geomorphology and Geology of Tibet.

March 1994

S. Occhietti - Aminostratigraphy

A. Sewell - Late Quaternary Landscape Evolution in SW North Island, New Zealand.

April 1994

K. Emery - Land Degradation Survey of New South Wales, Australia.

May 1994

R. Banks - Acid Sulphate Soils.

Other events have included a Teachers Group Seminar in January 1994, which included lectures by M. Atherton and K.Y. To on mass movements and a field trip to Cloudy Hill led by J. King.

Treasurer's Report

A certified account for the year ending 31st December 1993 was submitted (Table 1)

Editor's Report

The Newsletter editor pointed out that two issues have been combined in order to catch up on the late publication dates. While there has been a shortage of papers in the past, there are now plenty of submissions for the future. It was pointed out that the anniversary years colour covers would be stopped if

	<u>Income (HK\$)</u>		<u>Expenditure (HK\$)</u>	
	Bank Account	Cash	Bank Account	Cash
Subscription	27,925.60	1,950.00		
Bank Interest	5,029.86			
Publications	1,483.65		43,495.00	
Shenzhen Trip	4,320.00		3,750.00	
Local Trips	12,590.00		10,538.00	
Lecture Room	--		2,840.00	
General Expenses	--		3,953.00	1,115.30
	51,349.11	1,950.00	65,066.90	1,115.30
TOTAL		53,299.11		66,182.20
Excess of expenditure over income:		-12,883.09		

<u>Accumulated funds (HK\$):</u>			
<u>31.12.1992</u>		<u>31.12.1993</u>	<u>1993 Income</u>
150,160.67	Bank Deposit Acc.	155,190.53	5,029.86
32,696.28	Bank Current Acc.	13,948.63	-18,747.65
4,584.77	Petty Cash	5,419.47	834.70
		187,441.72	
		174,558.63	-12,883.09

no advertisers were found to support its costs. The editor will be actively seeking articles from Guangdong in the future. Issues for 1994 will include new series on "landscape" and on "Geological Type sections". The Editor has also applied for an ISBN number for Society use.

New 94/95 Committee

The following were elected for the new committee:

Chairman: R Shaw
Vice Chairman: C M Lee
Treasurer: K M Wong
Secretary: R B Owen
Editor: R Neller

General Committee Members:

C H Tan
C Chow
S Gilbert

K Y To
K W Lai
D R Workman
M J Atherton

Marine Studies Group Convenor:
A Fyfe

Any Other Business

R B Owen proposed that the membership fee be increased to \$200/annum to cover costs. The suggestion was seconded by R Shaw and accepted by the meeting. Student rates are to remain the same.

The Meeting received a delegation from the Organising Committee for the 1996 Geological Congress in Beijing. They explained the program and field trips and encouraged members of the society to attend.

The meeting closed at 19.30.

Notices - Forthcoming Meetings

15-17 September 1995 - British Geomorphological Research Group 1995 Annual Conference, University of Cambridge: Two thematic sessions will focus on landform monitoring, terrain modelling and terrain analysis. Details: Stuart Lane, BGRG 1995 Conference, Department of Geography, University of Cambridge, Downing Place Cambridge, CB2 3EN, England.

3-10 August 1995 - XIV INQUA Congress, Berlin, Germany. Approximately 60 symposia broadly categorised as palaeoclimatology and palaeoceanography, applied Quaternary geology, Quaternary stratigraphy, glaciotectonics and glacial sediments, glaciology, prehistory, human impact, palaeobiology, global change and palaeoecology and neotectonics. Details: Partner GmbH, Emma str. 220, 28213 Bremen Germany, Fax: (49) 421 216419

September 1995 - 4th European Paleontological/Palynological Congress, Heelen, The Netherlands.

Details: Dr. GFW Hengreen, Geological Survey of The Netherlands, PO Box 157 2000AD Haarlem, The Netherlands.

4-14 August 1996 - 30th International Geological Congress, Beijing, China. Approximately 22 symposia (see Geological Society of Hong Kong Newsletter v.11, no.3-4). Details: 30th International Geological Congress, PO Box 823, Beijing 100037, People's Republic of China.

20-22 September 1996 - Advances in Hillslope Processes, University of Bristol: Themes include soil erosion, soil chemistry, slope stability, soil development, tectonic influences, coastal hillslope processes, material testing and weathering, hillslope modelling, hillslope hydrology, gully development, vegetation/slope interaction, tropical hillslope processes, semi arid hillslope processes and periglacial hillslope processes. Details: Prof. Malcolm Anderson, Department of Geography, University of Bristol, University Road, Bristol BS8 1SS, England.

GEOLOGICAL SOCIETY OF HONG KONG PUBLICATIONS

- Bulletin* No 1 (1984) Geology of surficial deposits in Hong Kong, 177 p.
Yim W W S (Editor)
- Bulletin* No 2 (1985) Geological aspects of site investigation, 236 p.
McFeat- Smith I (Editor)
- Bulletin* No 3 (1987) The role of geology in urban planning, 601 p.
Whiteside P G D (Editor)
- Bulletin* No 4 (1990) Karst geology in Hong Kong, 239 p.
Langford R L, Hansen A and Shaw R (Editors)
- Bulletin* No 5 (1994) Seismicity in Eastern Asia
Lai K W and Owen R B (Editors)
- Marine Geology of Hong Kong and the Pearl River Mouth* (1985), 96, p.
Whiteside P G D and Arthurton R S (Editors)
- Marine Sand and Gravel Resources of Hong Kong* (1988), 221 p.
Whiteside P G D and Wragge-Morley N (Editors)
- Abstracts* No 1 (1983) Abstracts of papers presented at the meeting on "Geology of surficial deposits", September 1983, 79 p.
- Abstracts* No 2 (1984) Abstracts of papers presented at the conference on "Geological aspects of site investigation", December 1984, 50 p.
- Abstracts* No 3 (1986) Abstracts of papers presented at a meeting on "Sea-level changes in Hong Kong during the last 40,000 years", May 1986, 51 p.
- Abstracts* No 4 (1986) Abstracts of papers presented at the conference on "The role of geology in urban development", December 1986, 65 p.
- Abstracts* No 5 (1988) Abstracts/Extended Abstracts of six papers presented at a meeting on "Future sea-level rise and coastal development, April 1988, 79 p.
- Abstracts* No 6 (1990) Abstracts of papers presented at the conference on "Karst geology in Hong Kong", January 1990, 58 p.
- Abstracts* No 7 (1991) Abstracts of papers presented at the international conference on "Seismicity in Eastern Asia", October 1991, 63 p.
- Abstracts* No 8 (1992) "The logging and interpretation of transported soils in offshore boreholes." Proceedings of a workshop organized by the Geological Society of Hong Kong and the University of Hong Kong, June 1992, 78 p.

Newsletter

Vol 1 (7 issues) 1982-83	Vol 2 (6 issues) 1984	Vol 3 (6 issues) 1985
Vol 4 (4 issues) 1986	Vol 5 (4 issues) 1987	Vol 6 (1 issue) 1988
Vol 7 (4 issues) 1989	Vol 8 (4 issues) 1990	Vol 9 (4 issues) 1991
Vol 10 (4 issues) 1992	Vol 11 (2 issues) 1993	

Prices (including postage in Hong Kong)

Bulletin No 1	\$40 (\$60)	Newsletter, single issue	
Bulletin No 2	\$50 (\$70)	Vols 1-3	\$10 (\$20)
Bulletin No 3	\$100 (\$120)	Vols 4-6	\$20 (\$30)
Bulletin No 4	\$150 (\$180)	Vols 7-8	\$25 (\$40)
Bulletin No 5	\$150 (\$180)	Vols 9-11	\$30 (\$50)
Marine Geology....	\$30 (\$50)		
Marine Sand.....	\$100 (\$120)		
Abstracts No 2	\$10 (\$20)		
Abstracts No 3	\$15 (\$30)		
Abstracts Nos 4-6	\$20 (\$40)		
Abstracts No 7	\$30 (\$50)		
Abstracts No 8	\$40 (\$50)		
		Annual Society Subscrip	

Annual Society Subscription: \$200 (Students \$50)

Prices may increase without notice. Prices in parentheses are for non-members. Some publications may be temporarily out of stock. All prices and subscription include surface postage.

HONG KONG GEOLOGIST

- 1 The Inauguration of the Hong Kong Geologist and the Hong Kong Landform Series
R Shaw

Articles:

- 2 Results of an Offshore Engineering Geological Investigation in the Pearl River Mouth Basin of South China Sea
Liu ZH, Xue WJ and Li WF
- 13 Sedimentology, Geochemistry and Micropalaeontology of Borehole A5/2, West Lamma Channel
Owen RB, Neller RJ, Shaw R and Cheung PCT
- 26 Sedimentology and Surficial Stratigraphy of Three Fathoms Cove, Hong Kong
Cheng CY, Cheung CT, Cheung MS, Choy KL, Lau YY, Lee SS, Owen RB, Pang SC, Sandhu N, Tsang YF and Woo SW
- 30 The Offshore Quaternary Sham Wat Formation of Hong Kong
Fyfe JA and James JWC
- 34 Exploration for Offshore Sand in Hong Kong: Reconnaissance Surveys and Geological Assessments
Shaw R and Cheung PCT

Hong Kong Landform Series, No 1:

- 43 Rock Platforms - Characteristics and Origins
Owen RB

Activities of the Geological Society of Hong Kong:

- 46 Minutes of the Annual General Meeting, 27 May 1994
48 Notices

