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# HONG KONG GEOLOGIST

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# The New Hong Kong Digital Seismic Monitoring Network

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## Abstract

A new digital seismic monitoring network has recently been installed at the Hong Kong Observatory. The network consists of eight seismograph stations and three strong motion recorders located within the Hong Kong Special Administrative Region (HKSAR). Earth movements, including even small earth tremors, are detected, transmitted and analyzed instantaneously. The accurate position, depth and magnitude of earthquakes within or close to Hong Kong are computed automatically, and the data are published in monthly bulletins.

## 摘要

一種新的數碼地震監測台網現已在香港天文台內安裝好。該台網在香港特別行政區內包括八個地震儀台站和三個強震記錄儀。地殼運動甚至包括小的地殼顫動均可檢測到，即時傳達和分析。香港內部和其臨近地區發生地震的精確位置，震源深度和震級都是自動計算，同時其資料都在每月公報中公布。

## Introduction

The assessment of risk from earthquakes is of public concern. Engineers require accurate seismic data for the design of major facilities such as dams, power stations and bridges. Continuous monitoring of earthquakes is, therefore, necessary to calculate the design parameters for the construction of such structures (Lam and Fong, 1982). Geologists also rely on accurate seismic data to assess neotectonic movements on faults and to determine regional tectonic patterns. In order to meet these needs an upgraded local seismic monitoring network has recently been installed at the Hong Kong Observatory. This paper briefly discusses the recent seismic activity in the Hong Kong region, describes the new seismic monitoring network and explains the functions of the digital system.

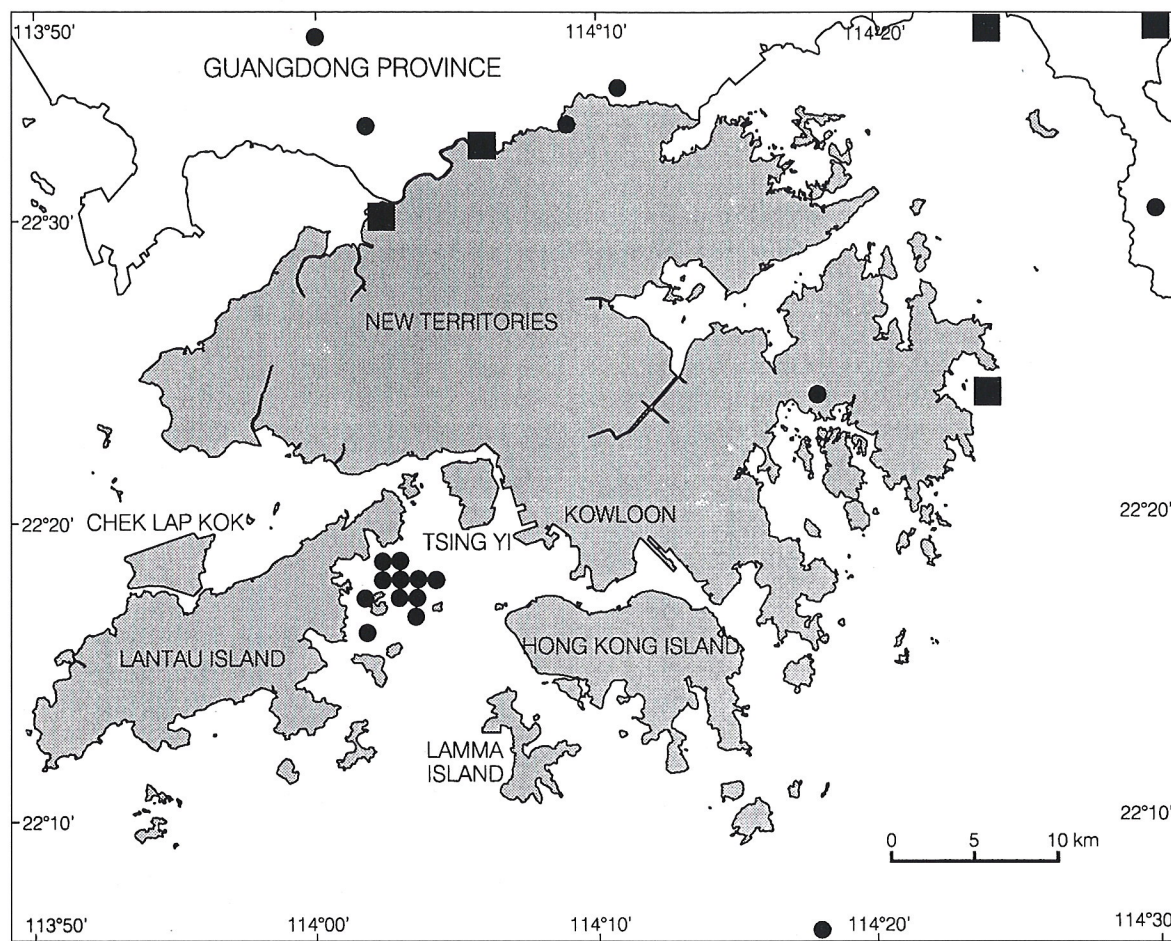
## Seismicity in the Hong Kong Region

In the recent past, only the 1918 Shantou earthquake has been reported to have caused any damage to buildings in Hong Kong (Lau, 1972). However, there have been approximately 40 earthquakes over the last 1000 years with magnitudes greater than 4<sup>3</sup>/<sub>4</sub> within a distance of about 350km of Hong Kong (Ding and Guo, 1989; Geotechnical Control Office, 1991;

Pun and Ambraseys, 1992; Whittaker et al., 1992; Lee and Workman, 1996, Chan and Zhao, 1996). Three significant earthquakes have occurred close to Hong Kong in the recent past: the magnitude 6.0 event in Honghai Bay (85km east of Hong Kong) in 1911, the 5<sup>1</sup>/<sub>2</sub> event near Macau in 1905 and the 5<sup>3</sup>/<sub>4</sub> event near the Dangan Islands in 1874. In addition, there have been several recorded microseismic events with magnitudes less than 3, in or very close to Hong Kong, between 1972 and 1995 (Figure 1). The epicentres of these events are not known accurately, due to the limitations of the old equipment.

## Earthquake Monitoring in Hong Kong

The Hong Kong Observatory began work on seismology in 1921 when a set of 3-component long-period seismographs was installed to detect distant earthquakes. In 1977, two 3-component strong motion accelerographs were installed at Tate's Cairn and the cellar of the Hong Kong Observatory to measure the maximum ground accelerations of severe tremors (Lam, 1980). The seismographs were upgraded in 1979 by a network of three short-period vertical seismographs that monitored the location and magnitude of earthquakes in the vicinity of Hong Kong



**Figure 1.** Microseismic events in Hong Kong 1972 to 1995 (after Ding and Lai, 1997). Black circles,  $1.0 \leq M_s < 2.0$ ; black squares,  $2.0 \leq M_s < 3.0$

(Shun, 1991). However, the seismographs had limited frequency and amplitude range, and the results relied mainly on measurements from drum recorders. In addition, the small number of stations also made the determination of epicentre positions difficult and inaccurate.

With advances in technology, it was decided that an upgraded system was required, and in 1997 the Hong Kong Observatory, in collaboration with the Geotechnical Engineering Office of the Civil Engineering Department of the Government of HKSAR and the British Geological Survey, installed a digital network. The new network uses advanced techniques of real-time data transmission and processing, with a Global Positioning System (GPS) as the timing standard, to determine the position, depth and magnitude of local or nearby earthquakes. Eight seismograph stations are situated within the territory of the HKSAR, an area of about 1000 square kilometres. These are located at Cape D'Aguilar, Cheung Chau, Keung Shan, Lead Mine Pass, Luk Keng, Siu Lam, Tsim Bei Tsui and Yuen Ng Fan (Figure 2).

The new seismic monitoring network will

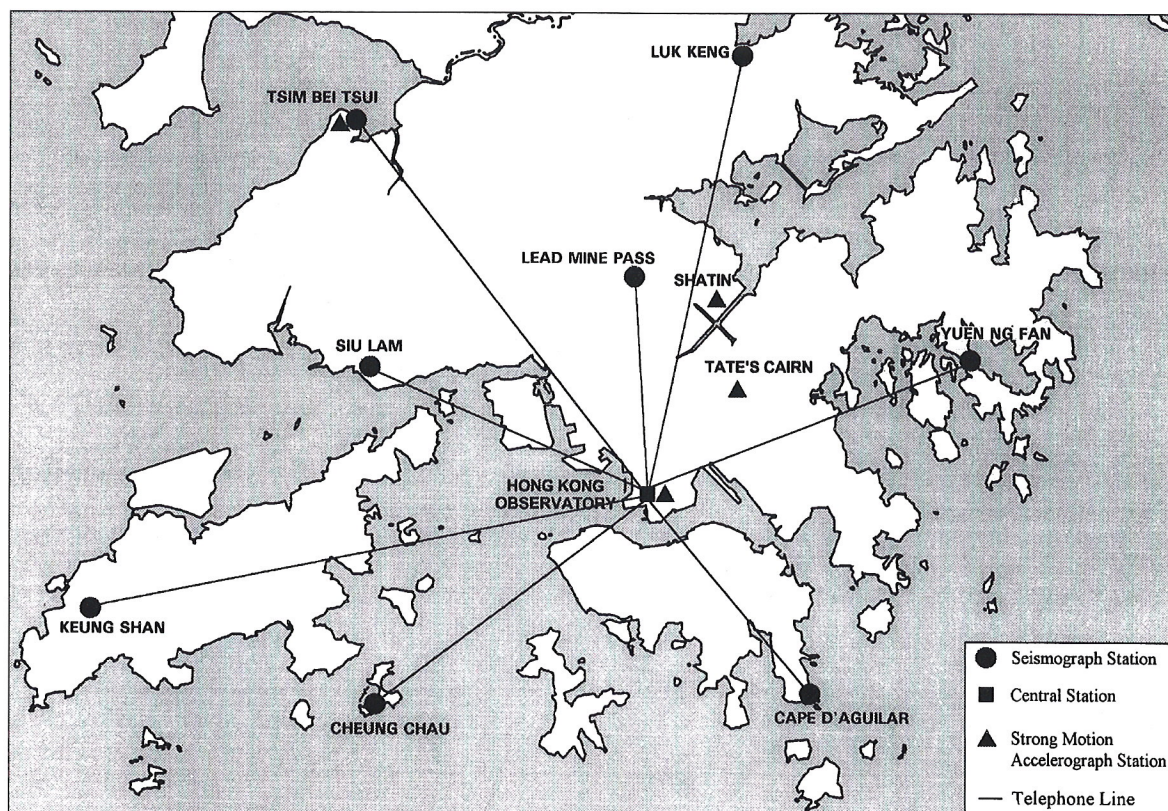
accurately record and locate even minor earth tremors, and it is hoped that they may be correlated with movements on faults that have been mapped at surface (Lai and Langford, 1996) or recognized at depth from the modeling of gravity data (Fletcher et al., 1997).

In addition to the seismographs, three advanced 3-component strong motion recorders have been installed on the roof of the Centenary Building at the Hong Kong Observatory, on reclaimed land at Sha Tin and on a concrete plinth at Tsim Bei Tsui. These sites were chosen to study the response of different ground conditions to strong earthquakes, and to provide data required in earthquake design. The strong motion recorders are activated by events with ground accelerations greater than 0.15% of the acceleration due to gravity.

### Siting and Construction of Seismograph Stations

The choice of suitable sites for the eight seismograph stations was dependent on several factors including: maximizing the lengths of baselines for





**Figure 2.** The Hong Kong seismic monitoring network

accurate location of the epicentres, good bedrock, low background seismic noise, easy site management and good security for the equipment.

The seismometers used are piezoelectric sensors. Three-component sensors are deployed at Tsim Bei Tsui and Yuen Ng Fan, whereas the rest only have single vertical component sensors. The seismometers and digital modulators, except at the Tsim Bei Tsui station, are contained within enclosed plastic chambers set into concrete on bedrock (Figure 3). The chambers protect the seismometers from rainwater, but drainage pipes have also been installed in the pits as an added precaution. All seismograph stations have lightning conductors to shield the instruments from power surges. At Lead Mine Pass and Keung Shan the seismometers are installed in boreholes, at depths of 24 and 33 metres respectively, to improve signal-to-noise ratios.

### System Hardware and Software

The equipment and software of the new network can broadly be divided into three parts: the seismograph stations, the central data reception and processing system, and the central data analysis system.

#### Seismograph Stations

Each seismograph station is equipped with a

robust seismometer and a digital modulator, that are installed in an underground instrument chamber, and an interface cabinet (Figure 4). The seismometers used in all eight stations are piezoelectric sensors which provide velocity and acceleration outputs. They have a dynamic range of about 100 dB, frequency response of 1 to 30 Hz, and are capable of detecting ground motions as small as  $10^{-9}$  metres, about the same size as a virus. The seismometers can be placed at any angle and are suitable for installation in boreholes. The signals recorded by the seismometers are digitized by the modulator at a rate of 75 samples per second and then transmitted through a dedicated telephone line at 9600 baud to the central station at the Hong Kong Observatory for data storage and analysis. The transmission of data in digital form lowers the chance of signal degradation.

To ensure that seismic data will not be lost due to failure of the mains supply, each station has back-up batteries that can maintain normal operations for about 10 days. The system automatically sends a calibration pulse every 24 hours to the central data reception and processing system for routine checking. If the main power supply and/or telephone line fail, warning lights are displayed in the central station.

#### Central Data Reception and Processing System

The central data reception and processing



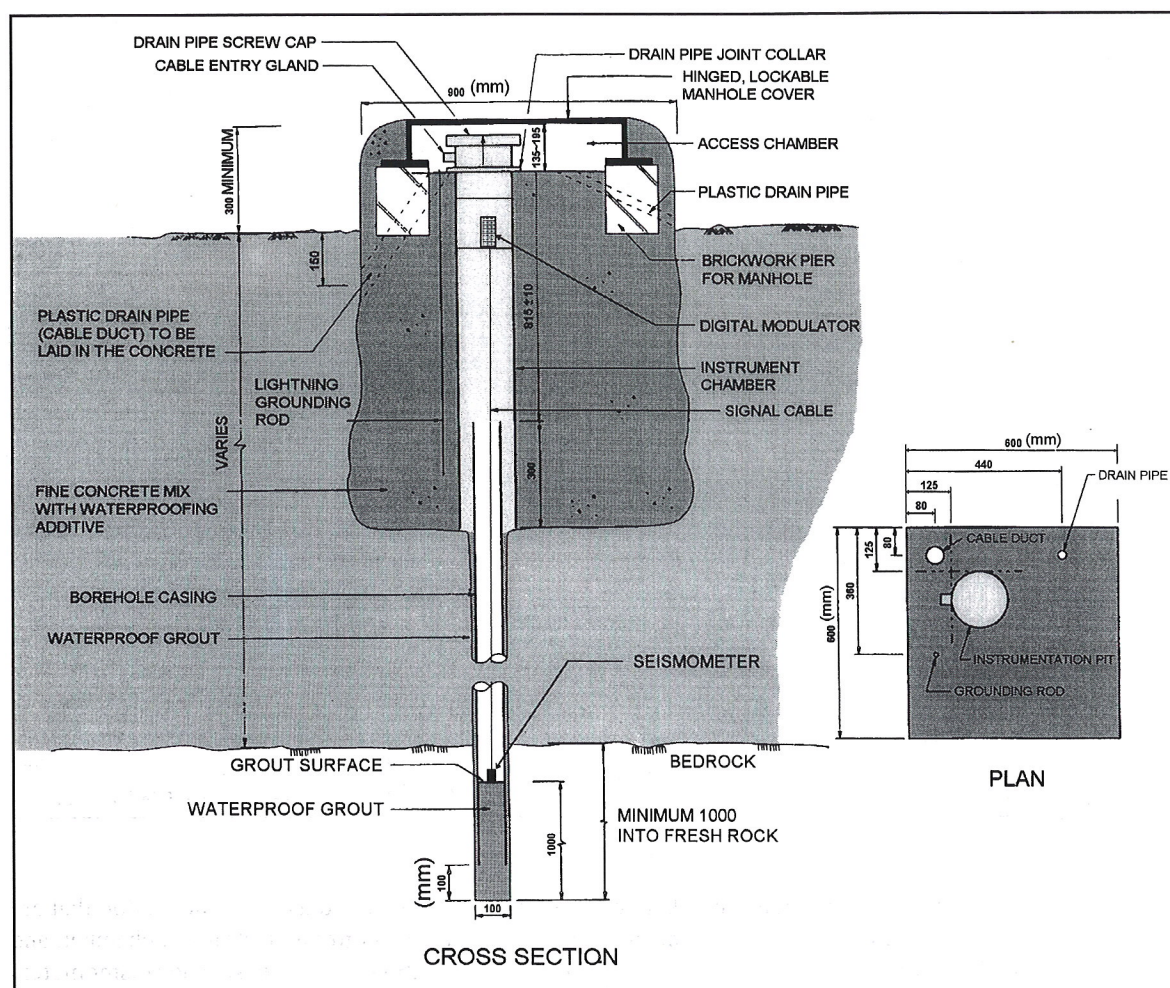


Figure 3. Construction specification of the seismograph stations and the borehole installations

system (SEISLOG) receives and stores the incoming data automatically (Figure 4). SEISLOG uses the Global Positioning System (GPS) to time-mark the digital data and converts them into 1-second buffers for storage as continuous files of 20 minutes each. The system automatically calculates the short term average (STA) and the long term average (LTA) of seismic signals of each station. If the ratio STA to LTA exceeds a pre-set value, the station is said to be triggered. If three stations are triggered simultaneously, the data is automatically stored as an event file and transferred to the computer workstation of the central data analysis system for further analysis.

Earthquake alarm software is also installed in SEISLOG. When the signal ratio STA/LTA of any three stations continuously exceeds the predetermined value for 30 seconds, the alarm is triggered to alert the analyst to inspect the automatic phase picking and epicentre computing results. The analyst can adjust the results when necessary, and can also use a dial-in modem to enter the system from a remote computer to monitor the system and analyse the seismograms.

### Central Data Analysis System

The central data analysis system consists of a computer workstation connected to SEISLOG through an Ethernet (Figure 4). The event file from SEISLOG is transferred automatically to the workstation every five minutes. Data analysis on the workstation uses the SEISAN software package. SEISAN consists of a set of computer programs and a database. It can analyze both analogue and digital data. It possesses automatic phase picking and magnitude calculation functions and can readily determine the location and depth of epicentre for plotting on a map. Besides the determination of fundamental earthquake parameters, SEISAN manages a database and prints the earthquake monthly bulletins. There are also other earthquake analysis-related programs in SEISAN for the calculation of additional seismic parameters.

### Conclusions

The new automatic seismic monitoring network is equipped with 'state-of-the-art' seismic



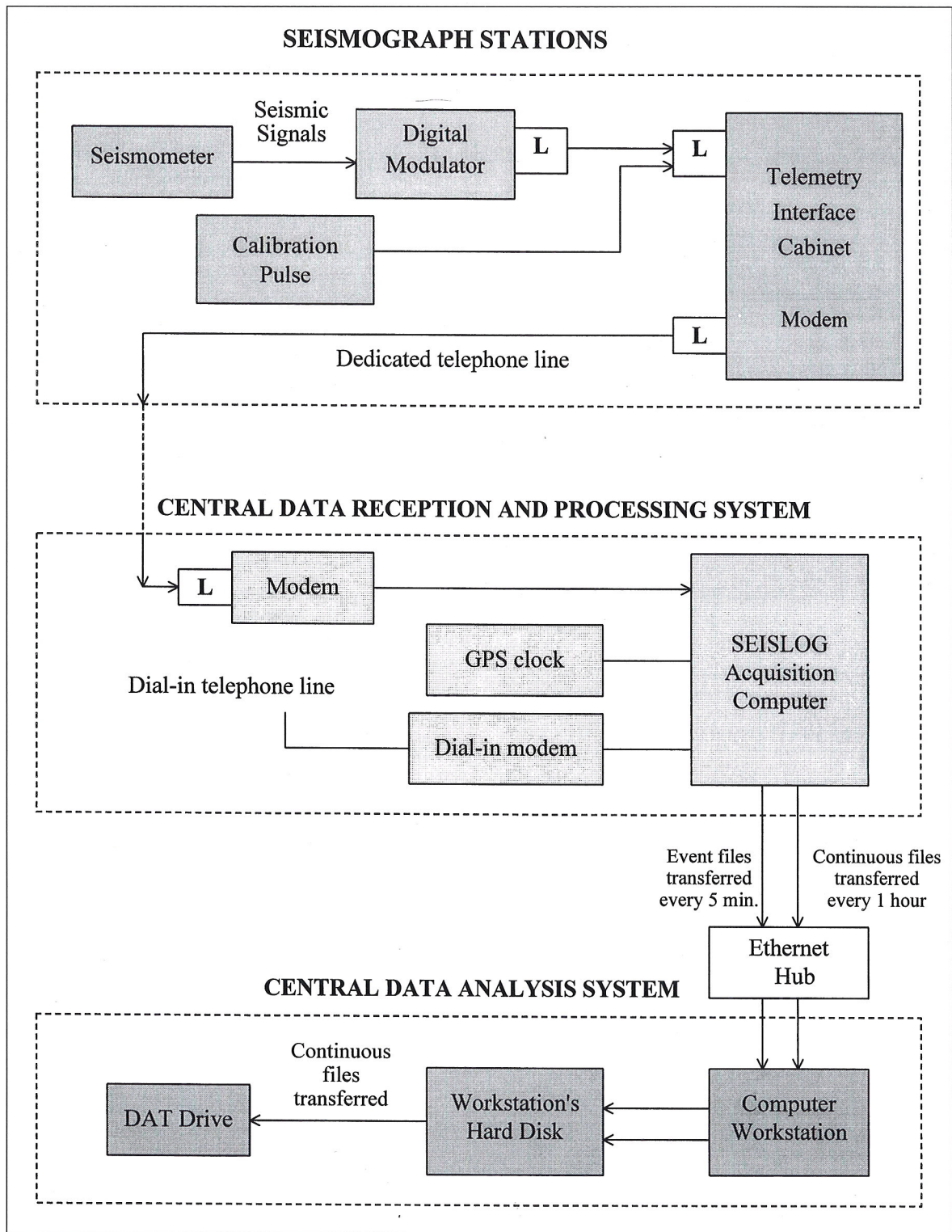


Figure 4. Flow diagram of the seismic monitoring network. L, lightning protection

instruments and a computer analysis system. Real-time seismic movement is detected, transmitted, processed and analyzed automatically. The network computes the origin time, location and magnitude of local or nearby earthquakes accurately. It will be able to collect data of very minor earth tremors, and this information will

be used in the location of faults at depth, seismic risk assessment, earthquake resistant design and other related research purposes.

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## A Stream Sediment Geochemical Atlas for Hong Kong

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### Abstract

This paper briefly describes the rationale and methodology behind a drainage-based geochemical survey of Hong Kong. The results of this survey will soon be published in the form of a geochemical atlas which will be made available to government, academic and private sector bodies.

### 摘要

本文簡要 述香港河流域地球化學調查的基本原理和方法。調查結果不久會印成地球化學圖集出版，供政府、學術和私人機構使用。

### Introduction

In 1993, the Geological Survey commenced a regional geochemical survey involving the systematic collection of fine sediment and panned concentrate from all of the major streams within the Hong Kong Special Administrative Region (SAR) at an average

sampling density of two samples per square kilometre (Figure 1). The main aim of this survey was to establish the overall natural background levels of a wide range of elements (Table 1) for use in determining contamination criteria for offshore contaminated-mud sites.

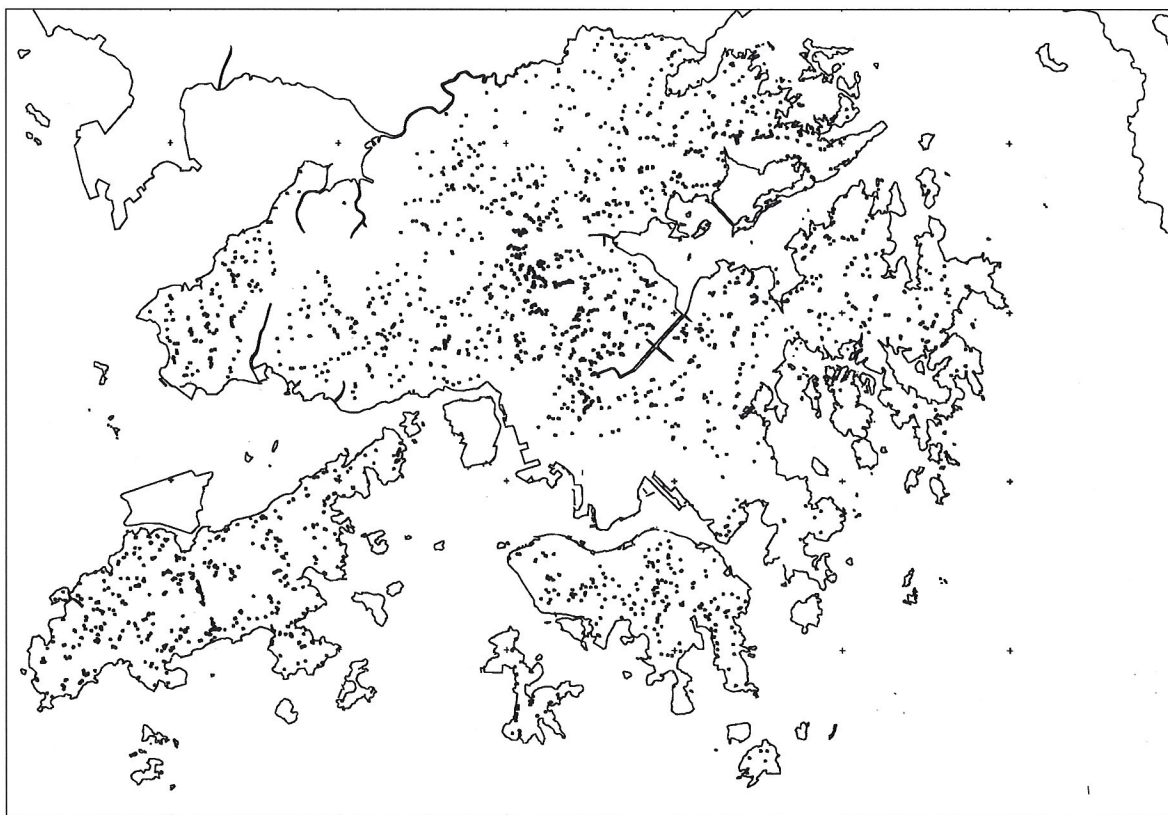


Figure 1. Map showing the location of stream sediment sample sites in the Hong Kong SAR



| Element                        | Hong Kong      |      |        |                   |
|--------------------------------|----------------|------|--------|-------------------|
|                                | Geometric Mean | Min  | Max    | Analytical method |
| Ag                             | 0.28           | 0.07 | 46.4   | ICP               |
| As                             | 14.17          | 0.7  | 1145   | XRF               |
| Ba                             | 241.10         | 5    | 1158   | XRF               |
| Bi                             | 3.82           | 0.7  | 488.4  | XRF               |
| CaO                            | 0.37           | 0.02 | 85.38  | XRF               |
| Cd                             | 0.32           | 0.07 | 5.5    | ICP               |
| Ce                             | 112.88         | 5    | 1994   | XRF               |
| Co                             | 3.97           | 0.1  | 62     | XRF               |
| Cr                             | 28.51          | 2    | 1001   | XRF               |
| Cs                             | 8.69           | 0.7  | 60     | XRF               |
| Cu                             | 8.37           | 0.1  | 189460 | XRF               |
| Fe <sub>2</sub> O <sub>3</sub> | 3.67           | 0.01 | 23.94  | XRF               |
| Ga                             | 18.37          | 0.7  | 54.5   | XRF               |
| Ge                             | 1.28           | 0.7  | 12     | XRF               |
| Hg                             | 1.17           | 1    | 6.08   | XRF               |
| La                             | 42.85          | 3    | 4923   | XRF               |
| MnO                            | 0.10           | 0.01 | 2.03   | XRF               |
| Mo                             | 1.78           | 0.1  | 553.2  | XRF               |
| Nb                             | 33.21          | 5    | 386    | XRF               |
| Ni                             | 8.09           | 1    | 416    | XRF               |
| P <sub>2</sub> O <sub>5</sub>  | 0.07           | 0.01 | 14.72  | XRF               |
| Pb                             | 75.17          | 3    | 3080   | XRF               |
| Rb                             | 196.91         | 29   | 766    | XRF               |
| Sb                             | 1.75           | 0.7  | 188    | XRF               |
| Sc                             | 8.36           | 0.7  | 28     | XRF               |
| Se                             | 0.33           | 0.13 | 2.338  | ICP               |
| Sn                             | 17.22          | 0.1  | 11838  | XRF               |
| Sr                             | 27.34          | 3    | 283    | XRF               |
| Th                             | 38.22          | 2    | 248    | XRF               |
| TiO <sub>2</sub>               | 0.51           | 0.04 | 2.22   | XRF               |
| U                              | 7.80           | 0.7  | 41     | XRF               |
| V                              | 35.10          | 1    | 160    | XRF               |
| W                              | 7.48           | 1    | 661    | XRF               |
| Y                              | 42.86          | 2    | 3563   | XRF               |
| Zn                             | 91.38          | 2    | 17489  | XRF               |
| Zr                             | 638.97         | 85   | 6529   | XRF               |

**Table 1.** Summary of results from the Hong Kong regional geochemical survey. Oxides are expressed as %, elements as ppm

The basic data give valuable information on the distribution of trace elements in the weathering zone environment and also indicate areas of metallic mineralisation. The panned concentrates have helped in distinguishing between the natural distribution patterns of elements controlled by the underlying geology and those related to superimposed man-made contamination.

The published atlas will be in A3 landscape format, similar in style to the regional geochemistry

atlases produced by the British Geological Survey. The atlas will include detailed descriptions of the geochemistry of each element and its behaviour in the subtropical weathering environment, along with an interpretation of an accompanying geochemical map. The geochemical atlas is expected to be published in December 1997 and will be made freely available to government, academic and private sector bodies concerned with land use planning, human and animal health issues and environmental control.





**Figure 2.** Panning the sieved 2 mm fraction of stream sediment to concentrate heavy minerals

### Sampling Methodology

Approximately 2200 samples were collected over a three-year period by two teams of consultants. Each team used a sieve set comprising a wooden dulang-type pan, a coarse (2 mm) sieve and a 100 mesh (0.15 mm) fine sieve. Samples were collected from the middle part of the stream bed, as far as possible, upstream of any potential source of contamination, such as concrete weirs, human habitation, tracks, or roads. Approximately 50 g of material finer than 150 mm was collected in the pan after which a heavy mineral concentrate was obtained by panning 1-2 kg of stream sediment screened through the 2 mm sieve (Figure 2).

### Chemical Analysis

Concentrations of elements were determined for each sample by X-ray fluorescence (XRF) and Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) at the University of Nottingham and the University of Leicester, UK.

A series of standard representative and natural control samples were analysed in each batch of approximately 100 samples in order to monitor analytical drift between batches of samples. The standard representative samples were obtained by collecting five bulk (15 kg) samples at five designated

sites whereas the natural control samples represented by duplicates were collected a few metres from routine samples.

### Data and Image Processing

Data and image processing were performed at the British Geological Survey, Keyworth, UK, using an in-house application (GSPMapper) for handling vector-based data centred on the ARC-INFO Geographical Information System (GIS).

The location and geochemical data, together with a digitised geological base map, were sent in files compatible with the ARC-INFO system. Gridding was performed using the inverse distance-weighted method of interpolation using a search radius of 1500 m and a grid cell size of 250 m.

Geochemical maps have been produced showing the distribution and concentrations for each of 36 analysed elements (Figure 3). Each map is accompanied by a colour key, histogram and statistics box. The colour key and histogram describe the spatial grid, which represents a best-fit surface derived from the original data. In calculating these parameters, all the grid cells which have a value (interpolated from the original data) are sorted into descending order and are then represented by a colour based on their position in this percentile ordering.



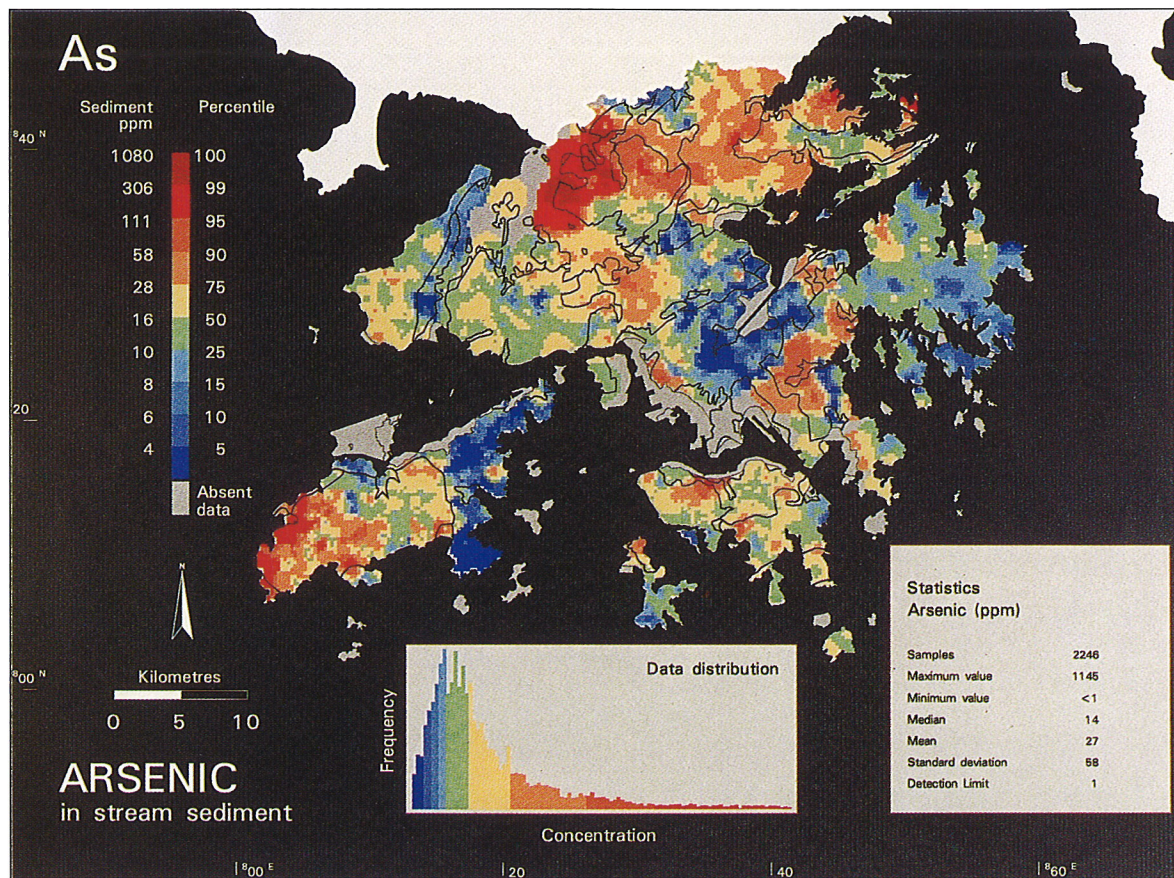


Figure 3. An example of a geochemical map for arsenic

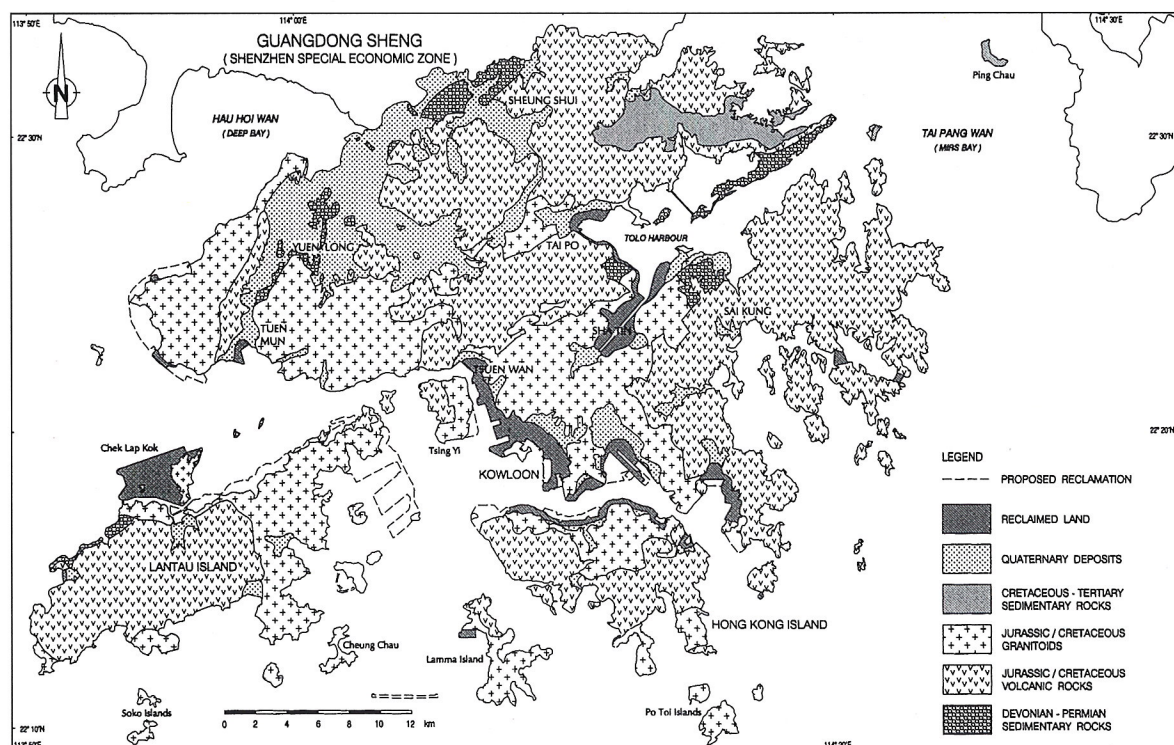


Figure 4. The geological base map used for major lithostratigraphic divisions on the geochemical maps



Class boundaries are set at, or as close as possible to, the 5, 10, 15, 25, 50, 75, 90, 95 and 99 percentile levels. At the low end of the range, there may be a large number of values which are close to the detection limit and it is sometimes necessary, as in the case of silver, to group as much as 75% of the data into the lowest category.

The distribution of the data is often highly skewed and there is a long drawn-out tail at the high end of the concentration scale. Histograms have been truncated to omit the top few percentiles, allowing the majority of the data distribution to be viewed more easily. The cut-off point is chosen to allow enough of the tail to be seen without constricting too much the low end of the histogram. The colouring of the histogram matches that of the colour key, so approximate ppm values (ranges) can be determined from the colour key.

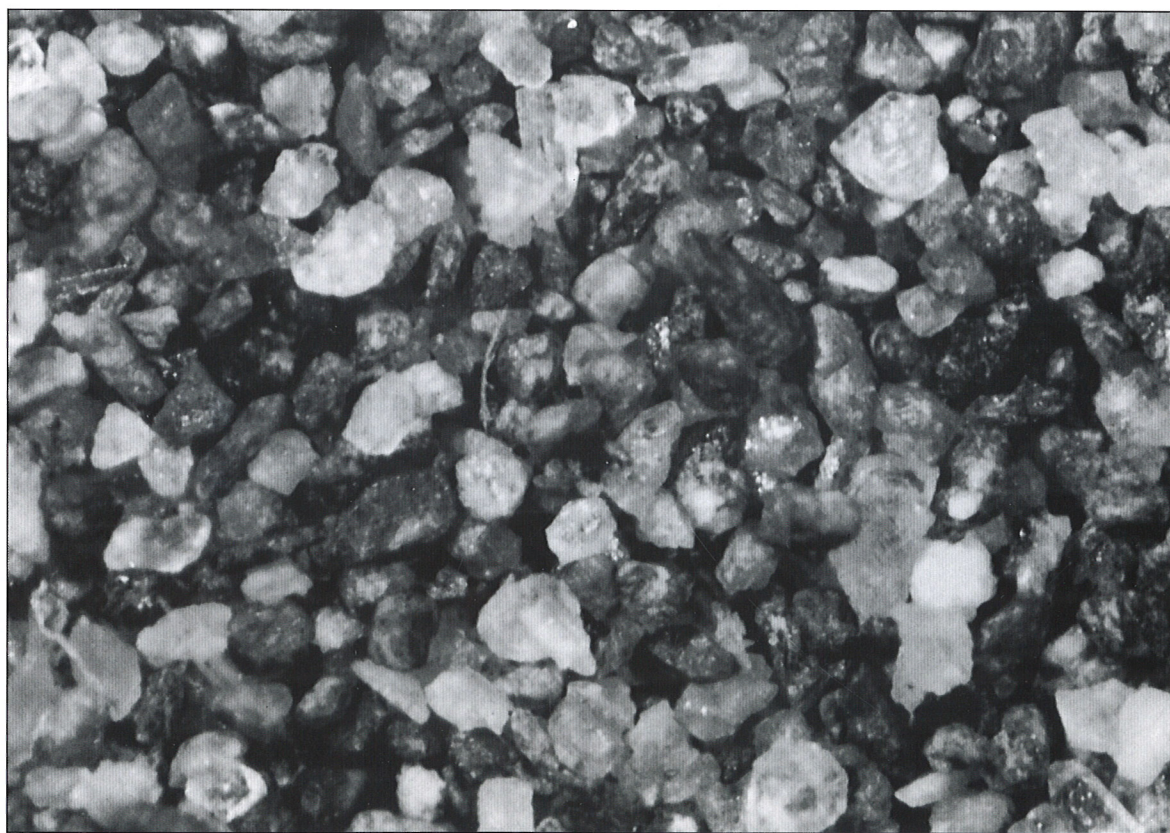
### Data Interpretation

The distribution of each element is described in relation to the major lithological, stratigraphical and structural divisions of the region (Figure 4). The extent to which the data reflect known metalliferous mineralisation is also discussed.

The geochemical maps show the concentra-

tions of the chemical elements (expressed as oxides for major elements) in the <150 mm fractions of stream sediment. The chemical compositions of the samples generally give an indication of the composition of the bedrock subject to the following conditions.

1. A small volume of compositionally unusual rock type may have detectable influence on the sediment chemistry downstream. The influence of metalliferous mineralisation may be artificially enhanced as a consequence of mining.
2. Chemical and physical weathering has a strong influence on the derivation of stream sediment from its parent rocks. Primary rock-forming minerals such as feldspars and ferromagnesian silicates may be replaced by low temperature minerals such as clays and chlorites, and certain elements such as Mg, Ca, Mn, Fe and Sr may be mobilised in surface and ground waters. As a result, concentration of residual minerals, such as Fe-Ti oxide and zircon, may be reflected in unusually high values for Ti and Zr.
3. Stream sediment may contain material unrelated to the bedrock upstream due to anthropogenic contamination of the stream and its catchment. This



**Figure 5.** Close-up view of panned heavy mineral fraction prior to further laboratory separation





**Figure 6.** Heavy mineral assemblage in an uncontaminated sample showing ore minerals of cassiterite (tin) and wolframite (tungsten)



**Figure 7.** Heavy mineral assemblage of a strongly contaminated sample showing particles of tramp iron, magnetic spherules, and solder balls

includes pollution from agriculture, industry, sewage treatment, domestic sources and illegal dumping of material.

### **Percentile Classes**

In most cases, 10 percentile colours and classes have been used as default for the images. However, a reduced number of classes were determined for elements in which significantly more than 5 % of the results were below detection. The lowest percentile class is always coloured dark blue, but other classes have the standard high colours downwards so that the same colour is used for the same percentile range in each key.

### **Interpretation**

The geochemical images are interpreted in relation to the occurrence of anomalous, enhanced concentration of metals. These enrichments can often be explained through microscope study of the heavy mineral concentrates (Figure 5). In some cases, the anomaly is accounted for by the presence of ore minerals such as cassiterite (tin) and wolframite

(tungsten) (Figure 6). Alternatively, man-induced contamination in the form of tramp iron, magnetic spherules or particles of solder (tin and lead) are responsible (Figure 7).

### **Conclusion**

The survey has established the natural background levels of a wide range of elements. These data have been of great value in increasing our understanding of geological processes at the surface, and are assisting in waste management assessments, geological mapping and research.

Knowledge of the background geochemical parameters will also be of assistance in pollution detection and management, recognition of the effects of trace element deficiency or toxicity on crops and various aspects of human and animal health. Geochemical data are also valuable in determining mineral resource occurrence and evaluating related industrial or other development activity.

**Acknowledgement.** This paper is published with permission of the Director of Civil Engineering, Hong Kong SAR Government.



## The Discovery of *Leptophloeum rhombicum* Dawson from Ma On Shan, Hong Kong

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### Abstract

This paper describes a floral assemblage that was recently found in the Bluff Head Formation rocks at Ma On Shan. The floral assemblage contains an important species *Leptophloeum rhombicum* Dawson, which is usually used as an index for correlation and indicates an Upper Devonian age.

### 摘要

本文介紹在香港的馬鞍山地區首次發現重要的植物化石組合斜方薄皮木，為晚泥盆世的標準化石，因而證實該區的黃竹角咀組地層屬上泥盆系。

### Introduction

This paper reports some of the discoveries from a collaborative study between the Geological Survey of Hong Kong and the Nanjing Institute of Geology and Palaeontology, Academia Sinica, to investigate the palaeontology of selected strata in Hong Kong. The palaeontological field investigation was carried out in the Ma On Shan area in the northeast of Hong Kong from 18th September to 28th October 1996. The survey was concentrated on the area surrounding Kwun Hang Water Treatment Works north of Ma On Shan, and included Sai Keng and Tai Tung Wo Liu to the east, Nai Chung and Sai O to the north and Wu Kai Sha to the west.

The sedimentary rocks at Ma On Shan form a series of isolated exposures along the hillside, constituting a vertical sequence greater than 100 m thick (Jones, 1995). Although the existing geological maps, at scales of 1:5000 (Sewell, 1996a, b) and 1:20 000 (Addison, 1986a, b), and their related reports have tentatively assigned the rock sequence to the Bluff Head Formation (Addison, 1986a; Frost, 1991; Jones, 1995; Sewell, 1996a), the age and correlation of these rocks with those of the Bluff Head Formation north of Chek Mun Hoi Hap (Tolo Channel) remained uncertain.

Fossil plants are reported for the first time from a road cutting (4446 3187) within purplish-grey and greenish-grey clayey siltstone at the Kwun Hang Water Treatment Works (Figures 1 and 2). Sixteen fossil

plant specimens (P882-894 and P897-899) have been collected from this locality. The fossil plants, with sterile leaf cushions of the rhombic type, have tentatively been identified as *Leptophloeum rhombicum* Dawson.

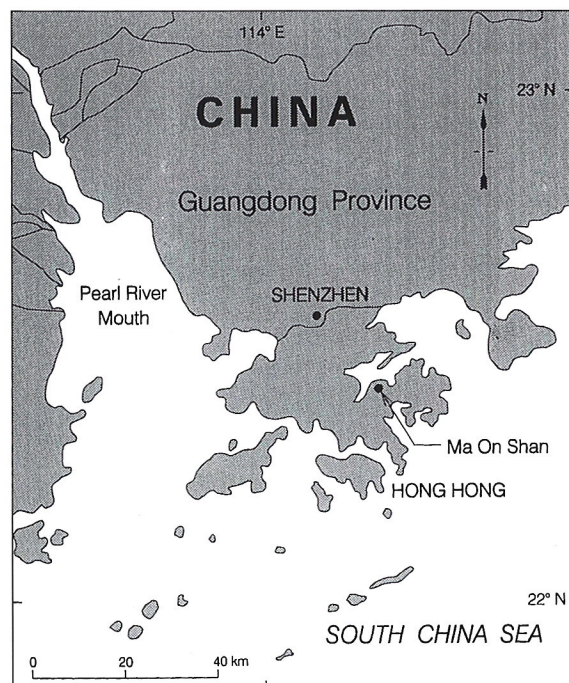


Figure 1. Location of the Kwun Hang Water Treatment Works, Ma On Shan

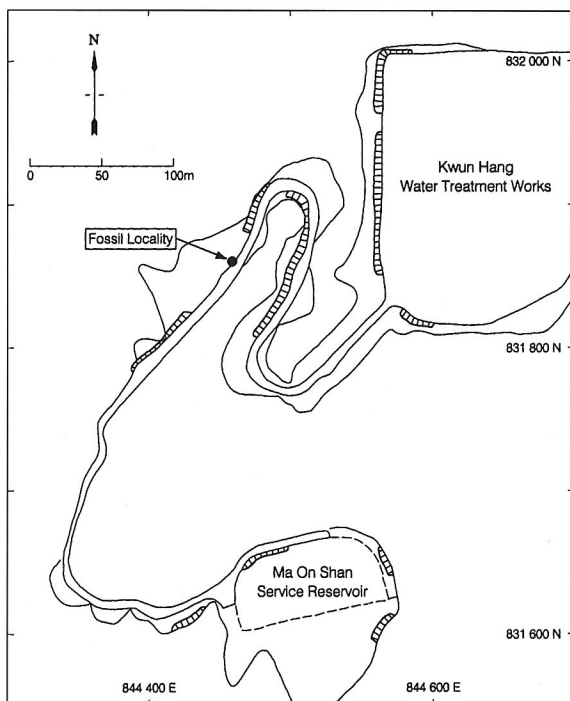
## Description of *Leptophloeum rhombicum* Dawson

Lepidodendrales  
Leptophloeaceae  
*Leptophloeum* Dawson  
*Leptophloeum rhombicum* Dawson  
Plates I and II

Lepidophytic plant of considerable size, morphologically similar to arborescent lepidodendrids. Trunks are about 10-15 cm in preserved length and 4-8 cm in diameter (Plate I, figs. 1,4; Plate II, figs. 1,2). Trunk surface of vegetative part in bare state completely covered by leaf cushions (Plate I, figs. 1,4; Plate II, figs. 1,2,5,6) disposed in a closely spiral manner (Plate I, fig. 2; Plate II, figs. 1,2,5,6), and some with slightly imbricate appearance (Plate I, fig. 4). Leaf cushions are generally rhombic to rhombic-quadrate in outline, about 8-10 mm long and 10-12 mm wide (Plate I, figs. 2,3,5; Plate II, figs. 3,4). A fan-shaped type of leaf cushion may be developed (Plate I, fig. 4). Leaf cushions are separated by slightly elevated narrow strips, about 10-12 mm wide (Plate I, figs. 1-5; Plate II, figs. 1-6). Leaf scars are very small, vertically oval in shape, 0.6-0.8 mm wide and 1-2 mm long, located a little above the centre of the leaf cushions (Plate I, figs. 2,3, arrows; Plate II, fig. 4, arrow).

## Comparison with Known Species

The specimens from Hong Kong are positively



**Figure 2.** Location map of the fossil *Leptophloeum rhombicum* Dawson, Ma On Shan area (modified from original site map supplied by Water Supplies Department)

identified as *Leptophloeum rhombicum* Dawson. From the manner of preservation, the specimens are very similar to those from the Sanmentan Formation, Jiangxi; Wutung Formation, Jiangsu; Maozifeng Formation, Guangdong (Cai and Li, 1996; Cai et al., 1988; Li and Cai, 1978).

## Discussion of the Geological Age

*Leptophloeum rhombicum*, which appears to have a worldwide distribution, possibly made its first appearance in the latest Middle Devonian, fully flourished in the Late Devonian, and persisted until the passage from the end of the Devonian to the beginning of the Carboniferous. This plant is considered an Upper Devonian index fossil plant (Cai and Li, 1996), and in China, the Upper Devonian flora has been named the *L. rhombicum* flora (Li and Cai, 1978).

The discovery of *L. rhombicum* from the Ma On Shan siltstone suggests that these strata are Late Devonian in age. Lithologically similar *L. rhombicum*-bearing strata in Guangdong Province are also considered to be Late Devonian (Cai and Li, 1996).

## Distribution of *L. rhombicum*

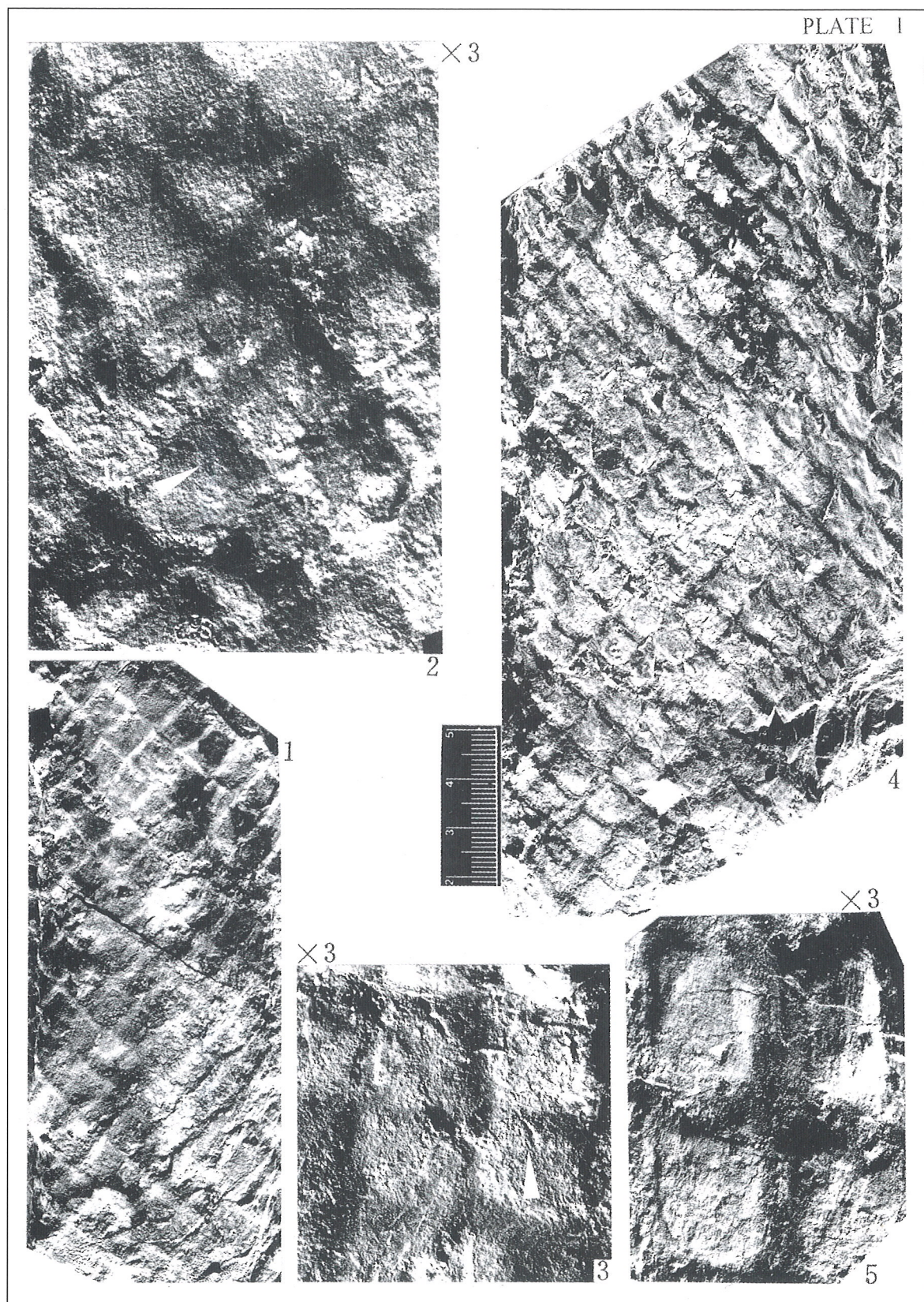
*L. rhombicum* was a Late Devonian lepidophytic plant with almost cosmopolitan distribution. Confirmed Late Devonian occurrences of this plant include those from America, Kazakhstan, Iwate Prefecture in Japan, China (exclusive of the Sino-Korean platform), Spitsbergen, Western Europe, Siberia, Argentina, Bolivia, Cape Province in South Africa, and Queensland, Victoria and New South Wales in Australia. In particular, *L. rhombicum* is scattered widely across China, and it occurs almost wherever Late Devonian non-marine beds are present. There are more than a hundred known localities in China (Cai et al., 1988; Cai and Li, 1996).

## Discussion of the Palaeoenvironment

The *L. rhombicum*-bearing sediments in Hong Kong comprise greyish-yellow sandstones and siltstones, and in general these plant fossils were transported. According to Li et al. (1986), the habitat of *L. rhombicum* was similar to that of Carboniferous lepidophytic plants, the climate being mild and relatively humid. However, the climate of the late Devonian, as a whole, may have been warmer and less humid than that of the Carboniferous. Hence, the *Leptophloeum* flora may have flourished only locally and during restricted periods.

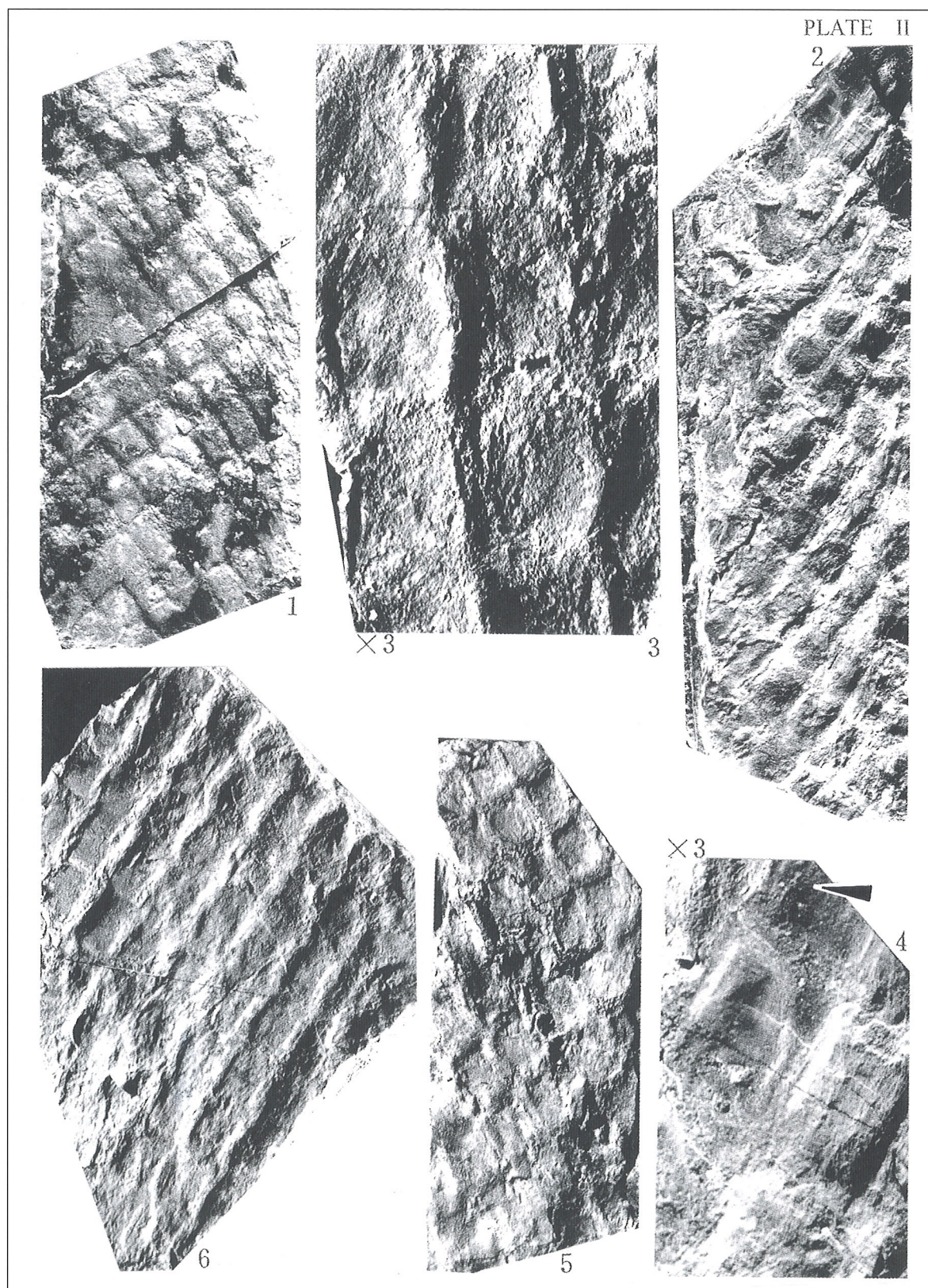
**Explanation of Plates.** All specimens are held by the Nanjing Institute of Geology and Palaeontology, Academia Sinica, and were collected from the Ma On Shan area, Hong Kong. Illustrations actual size, unless otherwise stated.





**Plate 1.** Figs. 1 to 5, *Leptophloeum rhombicum* Dawson; figs. 2 and 3, arrow showing the leaf scar, x3; fig. 5, x3





**Plate II.** Figs. 1 to 6, *Leptophloeum rhombicum* Dawson; fig.3, x3; fig. 4, arrow showing the leaf scar, x3;



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## Heavy Metal Deposition in Tolo Harbour

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### Abstract

Six heavy metals, Cu, Pb, Zn, Ni, Cr and Cd, have been studied in a cores and grab samples in Tolo Harbour for spatial and stratigraphic variability. The highest concentrations of these metals occur near Tai Po, and to a lesser extent near Shatin, with a gradual decrease towards Tolo Channel. Core profiles showing heavy metal concentrations suggest increasing levels of Cu, Pb, Zn and Ni in recent times. The evidence for such temporal and spatial changes is lacking for Cr. In contrast, Cd generally occurs at very low levels.

### 摘要

作者對從吐露港海床泥芯和抓挖樣本進行了銅，鉛，鋅，鎳，鉻和鎘等六種重金屬含量分析。結果顯示該等金屬含量，以近沙田和大埔地區為最高，且向吐露海峽漸減。泥芯樣本顯示銅，鉛，鋅，鎳四種金屬，在近代沉積物中含量漸增。鉻含量則沒有明顯的分佈規律，而鎘含量在各樣本中則普遍偏低。

### Introduction

Tolo Harbour was once a pristine environment, with unpolluted marine waters and rich floral and faunal assemblages that included a rich pearl fishery, fringing corals and a variety of other marine organisms (Morton, 1996; Scott & Cope, 1990; Taylor & Shin,

1990). Over the past few decades the aquatic environment has been physically altered by man, and subjected to poorly treated sewage and industrial inputs. In the north east, the former Plover Cove has been dammed and converted into a freshwater reservoir (Fig 1). In the north west, reclamation has

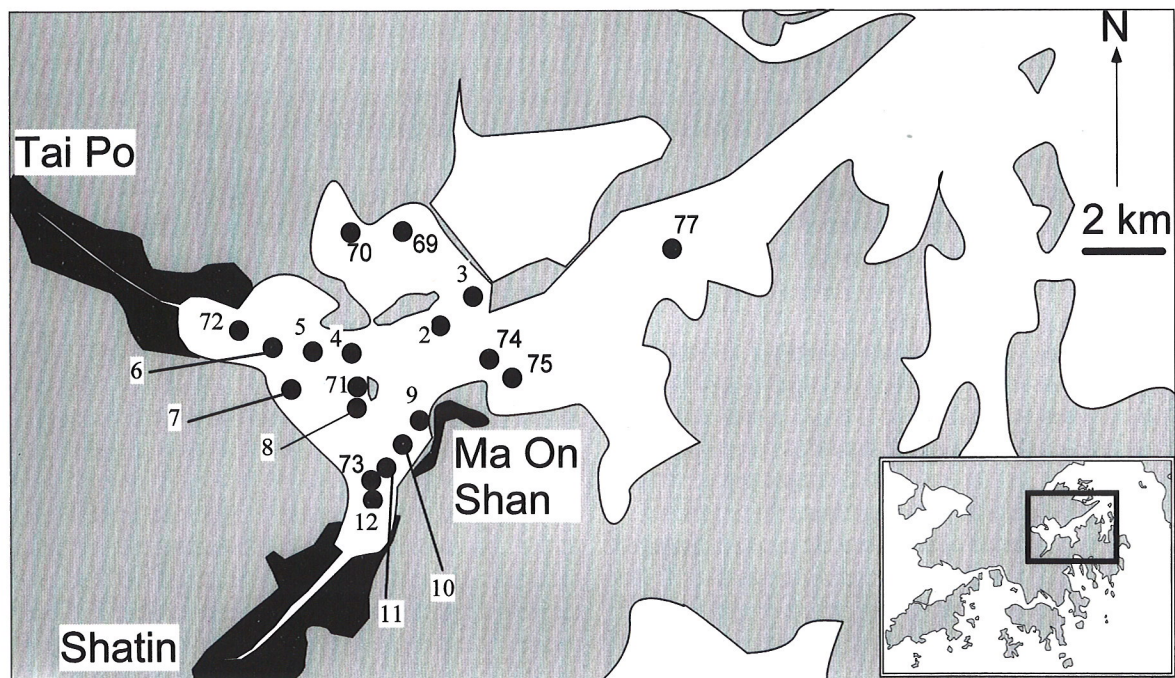


Figure 1. Location of Tolo Harbour and core samples (black dots)



been carried out and river systems altered as Tai Po has grown. To the south west, the new town of Shatin has expanded rapidly. To the south, urban growth continues with the recent development of Ma On Shan, filling in further littoral portions of Tolo Harbour. The only relatively unaffected areas lie to the south east, where the Saikung Country Park has exerted a protective influence. Today, both the Lam Tsuen (Tai Po) and Shing Mun Rivers (Shatin) are significant contributors of urban runoff pollution.

The Drainage basins that lead into Tolo Harbour cover a major part of Hong Kong and include a variety of rock types ranging from granites, through pyroclastics to sedimentary conglomerates and shales. The Quaternary sediments underlying Tolo Harbour include Pleistocene fluvial materials (formed by a north eastward draining river system), and Holocene and modern marine sediments dominated by quartzofeldspathic sand, silt and clay (Fig. 2). Nearshore silt, sand, and conglomerate have been deposited in a variety of shoreface, beach, fandelta and intertidal environments. In a number of areas, the sea floor sediment contains extensive accumulations of bivalves, together with less abundant gastropods.

While a large number of marine geochemical studies of heavy metals have been reported internationally, there are relatively few published works on Hong Kong's marine sedimentary environment. Yim and Fung (1981) analysed heavy metal contamination and its seasonal variability in grab samples, noting that relatively high values were found in protected inshore areas such as Victoria Harbour. Well away from the shore zone metal concentrations were reported to be at lower than crustal averages. They also suggested, in 1981, that urban and industrial development around Tolo Harbour would favour heavy metal build up at a rapid rate, because of its estuarine setting and protected nearshore location. Lo and Fung (1992) examined marine sediments in eight cores from Hebe Haven (Sai Kung) and reported significant enrichment in heavy metals near the Ho Chung River. In comparing same depth intervals, they observed a significant reduction in heavy metals and organic matter away from the shore.

Today, Tolo Harbour remains an area of significant natural beauty, but serves a variety of uses that are often contradictory. These include shipping activities and waste disposal functions, which conflict strongly with the long established trawling activities and more recently developing aquaculture practises. This paper attempts to examine the accumulation of heavy metal pollution in the sediments of Tolo Harbour, through a study of the spatial and stratigraphic variation of metal pollutants in a series of short gravity cores.

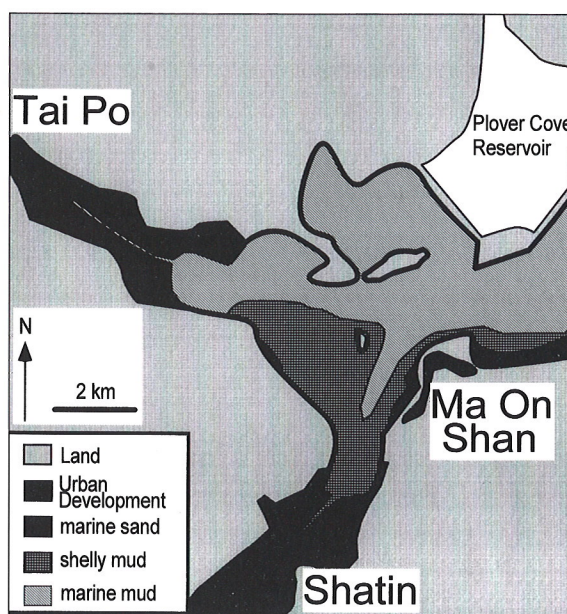


Figure 2. Simplified facies variations in Tolo Harbour

## Methods

Sediments were sampled using a simple gravity corer, capable of penetrating up to 30 cm. This system failed to recover sediments with a high proportion of sand or shell material, and in such cases grab samples were obtained instead. Figure 1 shows the distribution of 19 cores that were collected in 1994 and 1995, 17 of which were analysed for heavy metals. All were kept upright during transport to the laboratory.

In the laboratory, visual characteristics such as grain size, colour, composition, and textures were logged. Sub-samples, at 2 cm intervals, were extracted for geochemical and sedimentological analyses. In the case of grab materials, the sediment was mixed thoroughly to get a homogenous sample that would better represent the bulk composition. The sub-samples were air dried, powdered and mixed to achieve further homogeneity.

Laboratory investigations included particle size, Total Organic Carbon (TOC), and heavy metal analyses. Grain size was determined with the aid of a photo scanning sedimentograph and a laser sedigraph, having removed shell material with HCl. Sedimentograph samples were dispersed with 4% sodium hexametaphosphate before analysis, whereas dispersion was carried out by a built in ultrasonic stirrer for the laser system. Organic carbon was digested using 1M potassium dichromate solution and  $H_2SO_4$ . The solution was then filtered to obtain a 30ml sediment-free filtrate. Determination of TOC was carried out by titration with o-phenanthroline indicator and 0.5M ferrous sulphate. Heavy metal analysis involved extraction by refluxing the sample for 30

minutes in a mixture of  $\text{HNO}_3$  and  $\text{HCl}$  acids. After cooling, the samples were diluted with distilled water and allowed to stand overnight, in order to separate any insoluble material. The resulting solution was then analysed by atomic absorption spectrophotometry.

## Results

### Sediment Facies

Figure 2 shows a simple facies map for the study area. Three main sediment types are recognised: marine mud, shelly mud and littoral siliclastic sand. The marine mud displays consistent grain size patterns, with clay ranging between 20.5 and 38.6% and silt forming 61.3 to 79.5% of the clastic component. Sand generally forms 0-0.7% of the sediment, except at very rare, discrete, sandy intervals (<1cm thick), where the proportion reaches a maximum of 24.7%. Organic carbon typically ranges from 4-4.9%, rarely attaining a maximum of 5.9% of the total sediment.

The shelly mud consists of similar clastic components (with the same proportions of silt and clay) to those described for the marine mud facies. However, these deposits are clearly distinguished by their high content of shell material, locally >90% of the sediment. In most cores, the shells occur in distinct layers or in thin horizons, and may be variously well-preserved or fragmentary. Locally, echinoid spines form an important constituent. Bivalves are the dominant group, although gastropods also occur.

Littoral siliclastic sands are dominated by quartz, feldspar and less common lithic fragments. They are best developed in shallow areas on the south side of Tolo Harbour and extend well out into Three Fathoms Cove. In the latter area, sand percentages typically range from 64-97%, reaching 100% in the beach zone. Landwards, these deposits usually merge into fan-delta-fluvial systems, which deliver the material from the primary sediment sources in the Ma On Shan area.

### Heavy metals

Tolo Harbour sediment was examined for variations in Pb, Zn, Cu, Co, Cr and Cd content. This was done for the surficial sediment layer (Fig. 3) and for downcore studies (Fig. 4). Clay minerals usually possess higher natural metal contents than sand, and also have a higher active surface area onto which heavy metals may be adsorbed. Consequently, metal concentrations are frequently higher in areas richer in clays than in sandy regions, which may profoundly influence heavy metal distribution patterns in marine sediments. Often this variability is simplified by examining only a particular grain size fraction.

Nevertheless, there remain problems with this methodology, since the fraction examined may be either a minor or a major component of the total sediment, thereby exaggerating or underestimating the real total flux of metals present in the deposit.

Grain size studies show that the clay fraction, in the cores examined here, varies within a moderately small range (a maximum of 16%, but mainly within 10%). Since this means broad comparability between cores, we have presented data in terms of the amount of heavy metals actually present in the bulk sediment. However, this approach will tend to yield lower reported concentrations than for studies that focus on clay and/or silt fractions only (for example: Yim & Fung, 1981; Lo & Fung, 1992).

### Surficial variations in heavy metal concentrations

Figure 3 shows the spatial variation in Tolo Harbour of Cu, Cr, Ni, Zn and Pb for the top 2-cm slice from each of six selected cores (Cd occurred at very low, or below detection levels). In general, there is a decline in Cu, Zn and Pb with distance from Tai Po. Zn, for example, reaches a maximum concentration of 270ppm in core 72, near Tai Po. This declines to 158ppm near Center Island (core 71) and 100ppm at core 75, where Tolo Harbour passes into Tolo Channel. The trend continues beyond Tolo Harbour, with Zn falling to 69ppm in the top of core 77 in Tolo Channel (see Fig. 1 for location).

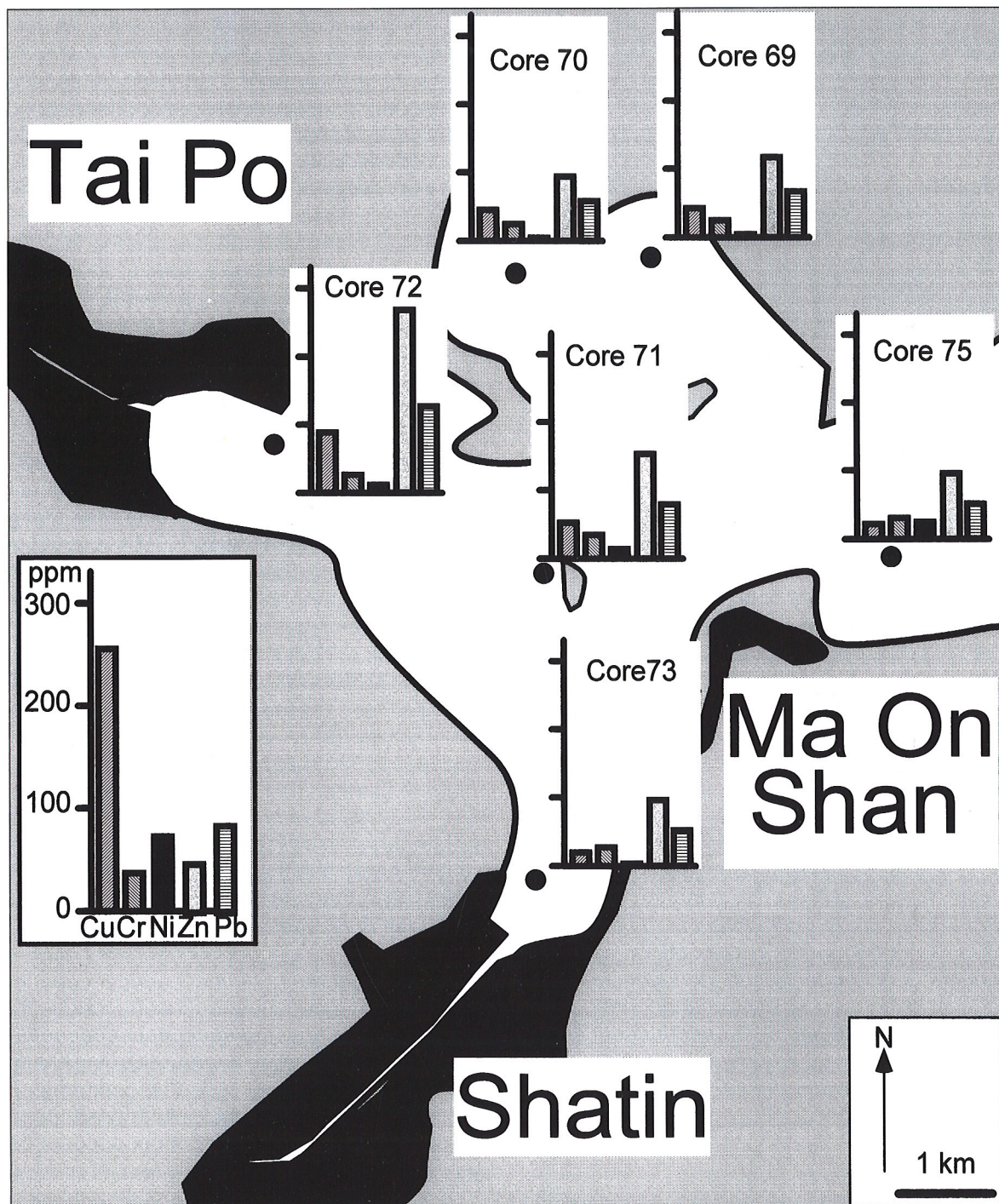
The overall concentration gradient for the various heavy metals, based on all cores and supporting grab sample, supports this basic spatial pattern, and is strongly suggestive that the Tai Po area is a major source of contaminants.

### Downcore variations

Figure 4 shows downcore data for Ni, Cu, Pb, Zn and Cr in six cores that lacked sand layers and which were dominated by homogeneous mud (clay range = 23-38%; silt range = 62-77%; sand range = 0-0.7%). Variability in these cores is confined to colour differences (Fig. 4), the presence/absence of fragmentary and whole bivalves (common in cores 75, 73 & 71), and the occurrence of echinoid spines. Shell material tends to be most common in cores from the southern half of Tolo Harbour (see also Fig. 2). This uniformity of non-biogenic sediment composition allows for broad comparability between the heavy metal data.

Two patterns are evident (Fig 4). The first is shown by the distribution of Cr, which displays no consistent profile trends. This may indicate a dominance of lithospheric over anthropogenic processes as sedimentary flux controls. Accordingly, this would tend to suggest that this metal is unsuitable,





**Figure 3.** Variation in heavy metals in the surficial sediments of Tolo Harbour. Data based on the upper 2 cm of cores

in the local case, for the development of an urban/ industrial pollution history.

The second group of metals include Cu, Pb, Zn and Ni. These all tend show an upcore increase, to varying degrees, in heavy metal concentration in the sediments, which is particularly distinctive in cores 72, 75, 73, and 71 (Fig. 4). In some cases there appears to be a rapid increase in the relevant metal at particular horizons (for example Ni in core 72, at 16cm core

depth), whereas in other cases changes appear to be more gradual (for example Ni in core 73). The lack of a distinctive pattern in the remaining two cores (70 & 69) may be due to their short lengths (<8cm), or perhaps be caused by their physical separation, by peninsulas and islands, from the main part of Tolo Harbour.

The increases in Cu, Pb, Zn, and Ni, are suggestive of increasing anthropogenic influences.



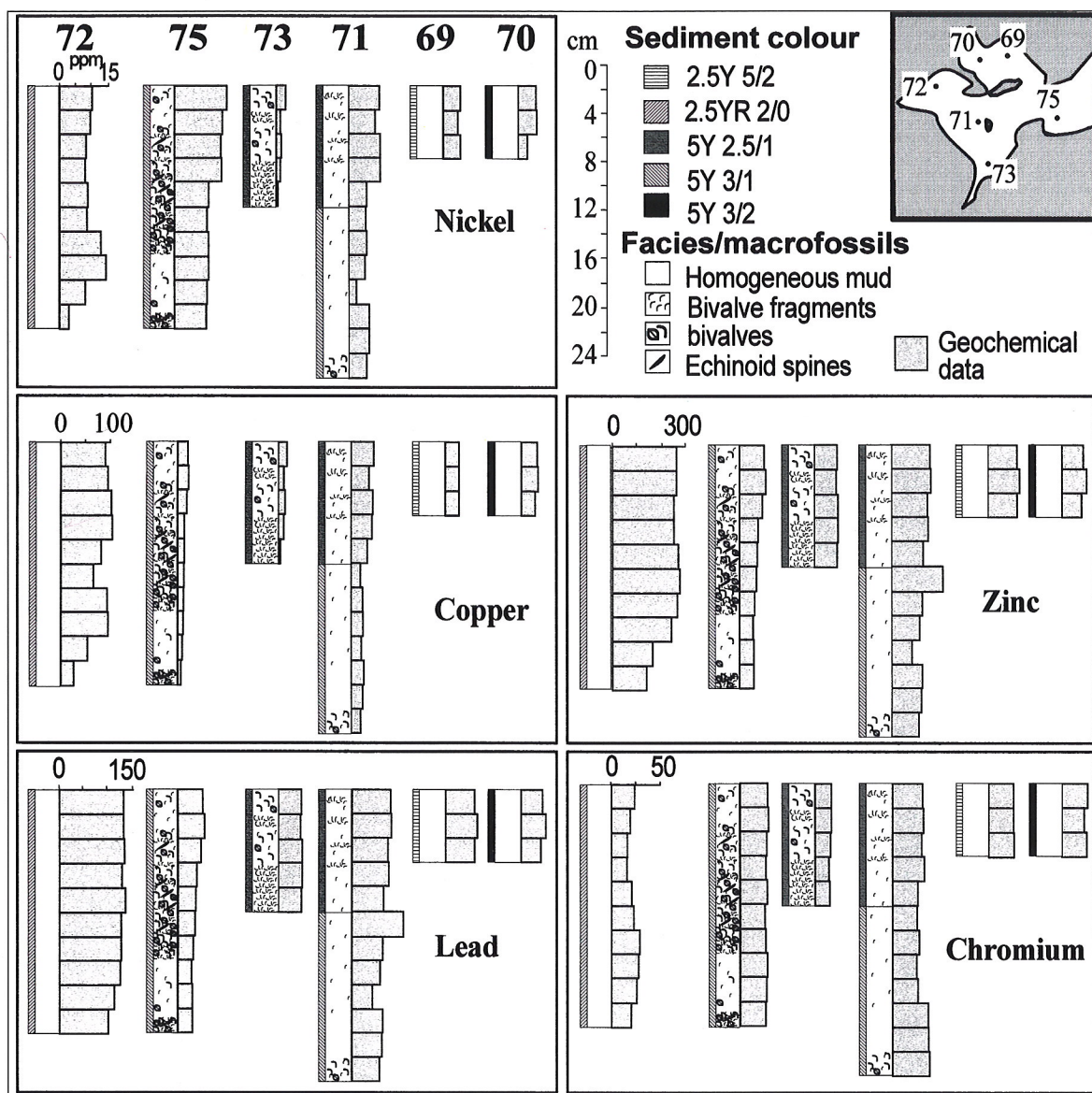


Figure 4. Downcore variations in Ni, Cu, Pb, Zn and Cr for six selected cores

However, quantification of such influences is complicated by several critical factors (Williams et al., 1997; Rees et al., 1996). Firstly, calculation of human-related inputs to the total Cu, Pb, Zn and Ni levels needs an assessment of the natural lithospheric fraction in the sediments. Williams (1991) describes how this may be attained by obtaining a "detrital background" value from the basal sediment in a core, assuming this predates the industrial inputs to the system. By comparing this background with other parts of the core it is possible to obtain an "enrichment factor" (Table 1). Secondly, where cores are heterogeneous, a normalisation process is required and often achieved by plotting the metal of interest against  $Al_2O_3$  (Williams et al., 1997). Thirdly, certain metals, Cu for example, show an affinity for organic matter

and may therefore be concentrated in organic-rich horizons. The study cores reported here are largely homogeneous in terms of clastic and organic contents and therefore normalisation procedures have not been carried out.

Core 72, the closest to Tai Po, shows the highest enrichment factors in Tolo Harbour (Table 1). Ni occurs at concentrations of 3.1 ppm at the base of the core and yields an enrichment factor for the core top of 3.3. Similarly, the core top is enriched by  $\times 4.2$  for Cu;  $\times 1.3$  for Pb and  $\times 1.9$  for Zn. Table 1 shows the variation between cores 72, 71, and 75 (the furthest core from Tai Po). Core 11, which lies near the mouth of the Shing Mun River, has the second highest enrichment factors for Ni and Cu.

The possible role of bioturbation in



| Metal          | Ni   | Cu   | Pb   | Zn  |
|----------------|------|------|------|-----|
| <b>Core 72</b> |      |      |      |     |
| 0-2 cm         | 10.2 | 90.1 | 135  | 270 |
| basal sample   | 3.1  | 21.6 | 101  | 139 |
| ER             | 3.3  | 4.2  | 1.3  | 1.9 |
| <b>Core 71</b> |      |      |      |     |
| 0-2 cm         | 9.0  | 48.4 | 83.8 | 158 |
| basal sample   | 5.8  | 20.8 | 88.7 | 117 |
| ER             | 1.6  | 2.4  | 1.5  | 1.3 |
| <b>Core 75</b> |      |      |      |     |
| 0-2 cm         | 16.3 | 20.6 | 54.2 | 101 |
| basal sample   | 9.8  | 8.6  | 37.3 | 79  |
| ER             | 1.7  | 2.4  | 1.5  | 1.3 |
| <b>Core 11</b> |      |      |      |     |
| 0-2 cm         | 14.8 | 43.2 | 76   | 129 |
| basal sample   | 7.3  | 11.9 | 67   | 87  |
| ER             | 2.0  | 3.6  | 1.1  | 1.5 |

**Table 1.** Heavy metal data and enrichment factors (*ER*) for the four longest cores recovered in Tolo Harbour

redistributing metals within the sediments also needs to be noted. A further complication might be the role of trawling activities in disturbing near surface sediment. However, the observation that there are vertical profile changes, and at some levels a sharp break from a lower background level to higher concentrations, suggests that processes of this type may be inefficient at totally mixing the sediment column. Diagenetic controls might also be of some importance, but have not been evaluated in this study.

## Discussion

Comparison of the data from this study with reported levels of contamination elsewhere can help in assessment of the severity of the pollution problem in Tolo Harbour. As noted above, our data are for bulk analyses. However, since the Tolo sediments are

predominantly clay and silt size, broad comparisons are possible, though our results will tend show lower reported values than those based on only clay/silt fractions.

One approach in assessing Tolo Harbour pollution is simply to compare the range of heavy metal concentrations with data for nearshore areas in other parts of the world. For example, minimum and maximum values for Pb in Tolo Harbour are 35-135ppm, which compares with ranges for New York harbour of 25-370ppm Pb (Carmody et. al, 1973). Other examples include San Francisco Bay (U.S.S.) with 9-174ppm Pb (Bradford & Luoma, 1980), Pool Harbour (U.K.) with 50-190ppm Pb (Boyden, 1975), Mombasa Harbour (Kenya) with 34-427ppm Pb (Williams et al., 1996), and Jakarta Bay (Indonesia) with a range of 9-438ppm Pb (Martin et al., 1983). Yim & Fung (1981) reported that Pb varies between 13 and 158ppm in Hong Kong marine sediments, with their highest Pb values being reported from Victoria Harbour.

Pb is clearly present at elevated and apparently rising levels in Tolo Harbour. Yim & Fung suggested that the natural background was partially related to Pb-mineralisation in the Lam Tsuen drainage basin, which enters Tolo Harbour near Tai Po. The declining seaward gradients in Pb, and other heavy metals, and their general elevation above background levels suggests a major anthropogenic input. However the concentrations are not, yet, as high as many other polluted water bodies, and still remain low compared with some extreme cases such as the Rio Tinto estuary and Sorfjord, where Pb values range between 1000-10,000ppm (Fergusson, 1994).

Other heavy metals in Tolo Harbour vary in their degree of enrichment, with Cu and Ni attaining the highest enrichment factors (4.2 and 3.3 respectively). Maximum concentrations attained were: 101.9 (Cu), 18.4 (Ni), 270 (Zn) and 29.2ppm (Cr). Cd was also analysed, but was generally below the detection limits. Standardised quality agreements for heavy metal contamination are not yet internationally established. However, Williams et al. (1997) have noted that quality criteria were proposed at an International Sediment Forum in 1982 (Van Veen and Stroetelder, 1988). This document suggests "target" (e.g. Cu 25ppm; Zn 180ppm), "standard" (e.g. Cu 70ppm; Zn 750ppm), and "limit" (e.g. Cu 400ppm, Zn 2500ppm) values for contaminants. Based on our data, 10 of the 17 core sites where heavy metals were analysed exceeded the "target" Cu value, 1 exceeded the "standard" value, and Cu did not exceed the "limit" criterion. Similarly, Zn exceeds the target in 5 cores, but fails to reach the standard value in any sample.

It would appear that Tolo Harbour currently has a pollution problem, and that heavy metal concentrations are rising. However, the present concentrations have not yet reached a level that could be considered "extreme". Unfortunately, urban/industrial pressures are rapidly rising and are likely to make the environmental problems of 1997 worse in the future. Yim and Fung's gloomy 1982 forecast of worsening heavy metal problems appears to be on target. Furthermore, it should also be noted that heavy metals are only one environmental issue that raises concern, with other problems such as organic pollution, eutrophication and reclamation also threatening the future of Tolo Harbour as a "natural" and formerly pristine resource.

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## Hong Kong Landform Series, No. 5

### The Meanders and Floodplain at Kam Hing Wai near Kam Tin

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#### Introduction

One of the most widespread fluvial landforms is that of the meander, the sinuous bends developed by a river channel. They are most common in the middle and lower courses. Figure 1a presents a map and Figure 1b an air photograph showing a sequence of meander bends on the Kam Tin river in the north-western New Territories. Comparison of the Kam Tin river with the mighty Mississippi in the U.S.A. suggests that meanders can develop in rivers of many sizes.

A river can be regarded as meandering if it has a sinuosity ratio equal to or greater than 1.5. This can be determined by dividing the distance along the river channel from A to B by the shortest distance along the valley from A to B. The section along the Kam Tin river from G.R. 825580 833675 to the bridge at Kam Hing Wai at G.R. 824380 833840, and shown

in Figure 1, has a sinuosity ratio of 1.628.

A meander can be regarded as a landform but in fact well-developed meanders consist of two distinctive components, namely, the meander scar or cliff and the point bar. These are respectively landforms of erosion and deposition and they are shown schematically in Figure 2a in which they are also illustrated by the Kam Tin meanders at G.R. 825350 833575, shown in Figure 2b.

At Kam Tin the river flow is confined to its channel, that is to say between the channel banks. However, during certain storm events, generated by rainfall, the water discharge may exceed the channel capacity. At this water level, called bankfull discharge, the river will overflow its banks and inundate the floodplain, which is in itself a fluvial landform. Figure 2c shows the example of water at the bankfull stage for the river at Kam Tin.



Figure 1a. Map showing meanders on the Kam Tin river, and the section AB used to calculate the sinuosity ratio of 1.628





Figure 1b. Aerial photograph showing meanders on the Kam Tin river

### Why Do We Get Meanders?

The question of why meanders develop has received much attention in the literature. Early ideas involved the belief that chance irregularities or the occurrence of bands of resistant rock would act to deflect the stream and initiate meandering. However, many sequences of meanders are too regular for this to be an explanation. The most likely explanation for meander development involves energy expenditure. Meandering represents an equilibrium form in which the river both minimises resistance to flow whilst at the same time dissipating energy uniformly as water

moves downstream. Under conditions of high bedload availability with variable discharge and erodible banks, a braided channel pattern, rather than meandering, represents the equilibrium form. It has been suggested that environmental irregularities such as channel bank composition and flow pattern may act to distort a regular sequence of meander development.

### Water Flow Patterns in a Meander

The flow pattern of water in meandering rivers is quite distinctive. Through a series of meander bends

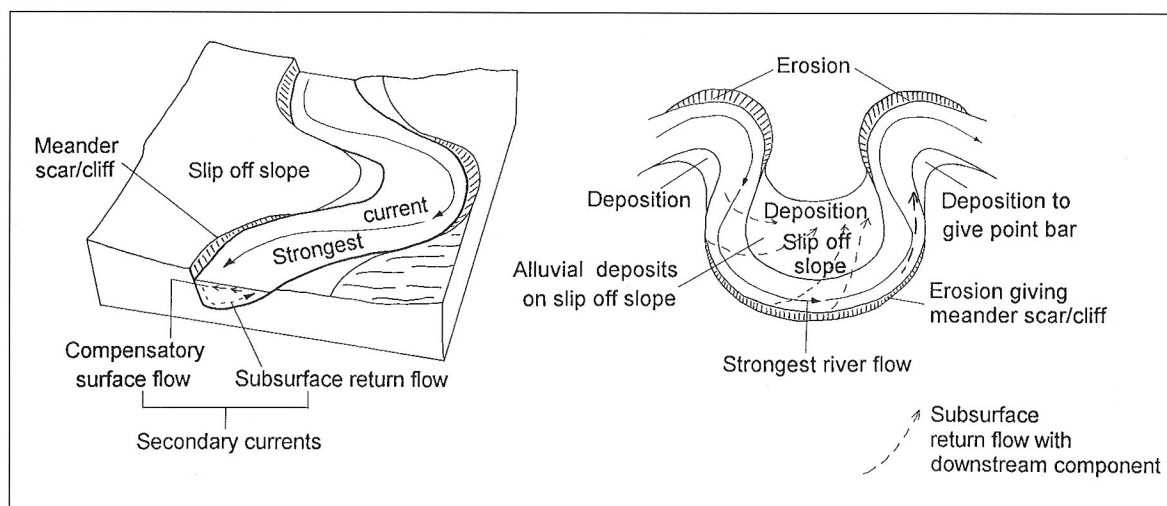


Figure 2a. Schematic depiction of point bar and meander scar/cliff





**Figure 2b.** Photographs of a point bar and meander scar or cliff on the Kam Tin river

the velocity of flow is fastest closest to the meander scar bank (and where a deep water pool develops) while velocity is least adjacent to the point bar. The line of fastest flow will cross over midway between the meander bends at the point of inflexion which is often marked by a riffle (an area of shallow water). Important secondary currents also develop in meander bends and these are, to a large extent, associated with the development of the landforms. The secondary currents develop in response to the fact that the water flows fastest at the outside of the bend, giving a super-elevation of the water which generates a pressure gradient. Consequently, at the bed of the river, water moves inwards over the bed towards the inner bank. A compensatory flow is developed at the surface in which water moves from the inner bank to the outer bank. This gives rise to a helicoidal flow pattern in meanders which is illustrated in Figure 2a, and it also means that both erosion and deposition can occur at the same time around the meander. This is because the secondary current acts to shift material eroded by the rapid downstream flow adjacent to the outer bend (the meander scar) towards the inner point bar where it is deposited, as shown in Figure 2a. However, if erosion takes place far enough downstream in the bend the secondary current does not carry it across the bed to the other side. Instead it becomes entrained in the zone of fast flow with a predominantly downstream

movement. Once it reaches the next bend the secondary current draws the materials to the point bar on the same bank from which erosion occurred (Figure 2a).

## Erosion

Erosion has occurred on the meanders at Kam Hing Wai and this can be achieved by a variety of processes. Given the high velocity of flow at the outside of the meander bend, direct removal of material can and does occur, as shown in Figure 3a. However, there is also evidence that mass movement plays a role in bank erosion and is illustrated in Figure 3b. This may be due to a number of factors including bank height and structure, but pore water pressures may play an important role. During the flood hydrograph water enters the bank thereby raising water content. After the flood peak recedes the banks are no longer competent and failure results. Tension cracks may also develop and help facilitate the failure. Other causes of erosion exist: during the winter of 1996/97 trampling by water buffalo and cattle occurred on this section of the river. However, compared with entrainment and mass failure the modification caused is relatively small. Erosion is important because it



**Figure 3a.** Erosion caused by high flow velocity at the outside of the meander bend



**Figure 3b.** Mass movement can play a part in bank erosion



can result in the movement or migration of the river channel in the floodplain.

At the Kam Tin site erosion is causing loss of agricultural land (see the photographs in Figure 2b). It has also caused a power transmission pole to be re-located and at the downstream end of the meander sequence the outside bend at Kam Hing Wai has been protected to try and protect the property located on this bend.

### Migration of Meanders

Meanders can be classified according to activity. Actively meandering channels can be identified by erosion of the meander scar/cliff and active deposition on the point bar. The air photograph of the meanders at Kam Hing Wai in Figure 1 along with the pictures in Figure 2 illustrate active point bar accumulation. Erosion pin observations made on the meander scar at G.R. 825350 833575 during the summers of 1995 and 1996 confirm active erosion and hence migration on this bend. For example, the highest rate of recorded erosion from the winter of 1995/96 to 6th July 1996 was around 240 cm, with a second site recording 129 cm. By the 20th September 1996 near the end of the wet season a further maxima of around 150 cm was recorded, with a second site giving 135 cm of erosion during this period. Furthermore, many 100-cm erosion pins were "lost" to erosion on this meander bend during 1996.

There is also evidence that the activity on this bend is not recent. At several locations plastic is incorporated into the sediments of the meander cliff, as shown in Figure 4. This dip towards the channel could be explained by slumping of the material, or perhaps it represents the remains of point bar accumulation. If this latter explanation holds it signifies considerable channel activity, and the fact that a former zone of accumulation has now become one of erosion.

Some evidence of active meanders can also be found from topographic maps. Figure 5 superimposes



Figure 4. Plastic incorporated into meander cliff sediments

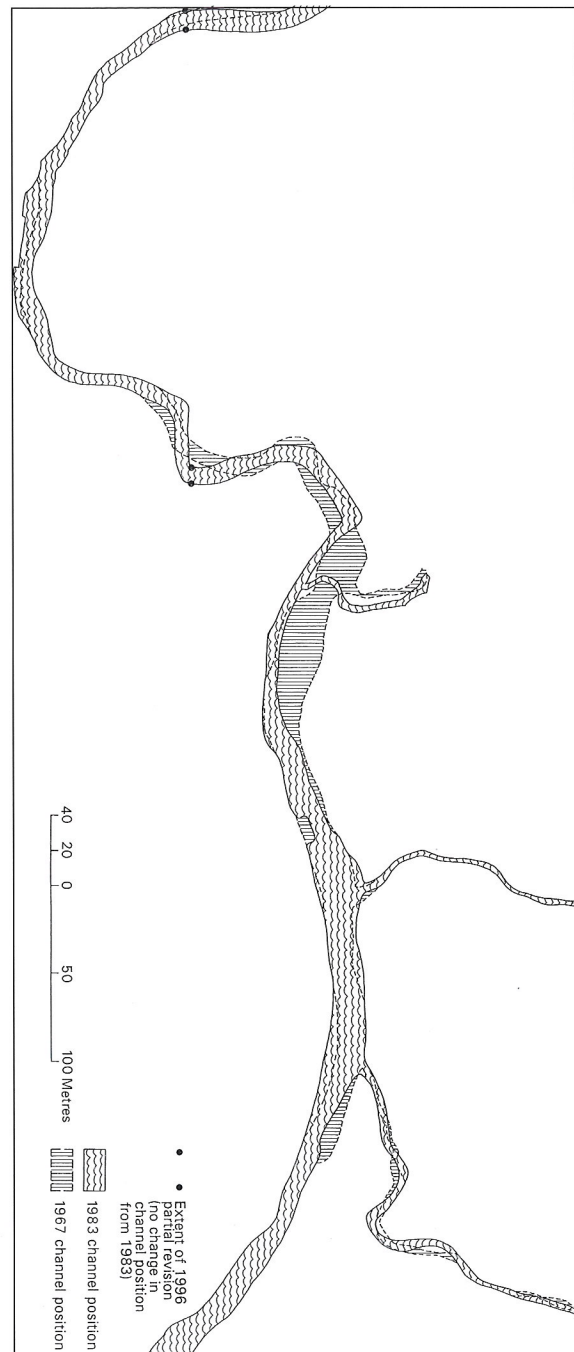


Figure 5. Changing channel positions of the Kam Hing Wai meanders

the channel course from 1953, 1983 and 1996 maps for the Kam Hing Wai meanders. They are based upon 1:1200 or 1:1000 scale maps and while mapping limitations must be recognised there is good evidence of movement of the meanders. The fact that the 1996 map shows no movement reflects the limited revision of the map : channel position has not been modified.

It is suggested that these meanders contrast strongly with an "inactive" channel which exhibit no signs of contemporary erosion or deposition on the



meander scar or point bar respectively.

### The Floodplain

A floodplain has been defined as the 'surface or strip of relatively smooth land adjacent to a river channel, constructed by the present river in its existing regimen and covered with water when the river overflows its banks' by Bates and Jackson (1980). Most of the materials of a floodplain consist of sediments deposited by the river, either within the channel in point or longitudinal bars or as overbank deposits during flood events. Lateral accretion (e.g. point bars) is now believed to dominate vertical accretation in floodplain development. The thickness of overbank deposits are to some extent governed by deposition rate, reflecting in part sediment concentrations. However, the rate of lateral movement of the meander also governs the thickness of deposits because it controls the time for deposition. Overbank deposits may be in evidence in Figure 6, which shows a distinctive band of sediment which is rather sandier than the underlying sediment. During 1995 after overbank flow sand was seen accumulating in this area. Particle size data reveal that the upper "accumulation" layer has a sand content of 81 percent, much higher than the lower bank material, which has



**Figure 6.** Sandy overbank deposits resting on less sandy sediment

a sand content of only 34 percent. Such a contrast indicates a change of depositional environment or possibly energy level in the river.

Migration of meanders across a floodplain may cause a series of troughs and ridges giving rise to "ridge and swale" topography or meander scrolls. These are not well developed at the Kam Tin site.

### Sediment Transport

The material in the bed of the Kam Tin river at this location is predominantly sand, however, finer material can be deposited at the margins. After a storm hydrograph, it is possible to see on the point bar evidence of bedload sediment transport. Ripples or larger scale features such as the dunes shown in the photographs of Figure 7, are sometimes present and



**Figure 7.** Dunes indicating downstream movement of sediment on the point bar

are good indicators of sediment transport. The dunes shown in Figure 7 evidence the downstream movement of sediment on the point bar. This indicates that during flood events sediment transport occurs over much of the point-bar and that sediment enters storage during the recession limb of the storm hydrograph and remains there until the next storm event. The size of ripples or dunes depends upon a number of factors including flow depth, velocity and sediment size. The features shown in Figure 7 were formed during a bankfull storm hydrograph in May, 1997. If the river is not too turbid with suspended matter it is sometimes possible to see ripples migrating downstream at low flow conditions. You should not try and enter the river if it is responding to rainfall and a storm hydrograph is occurring.

### Conclusion

The meanders at Kam Hing Wai have been described. It is important to remember that this is a dynamic landform reflecting the interaction of a number of variables. In this alluvial channel these variables are water discharge and velocity, sediment

transport, erosion and deposition, and the nature of the channel bank material. It has certainly changed with time as suggested in Figure 6 and the erosion observations. The importance of the river as an ecological habitat may also be exemplified by this reach. Contrast the variety of environments as compared with the concrete man-made channels that can be seen in many areas. This variety includes, for example, the differing water depths offered by the pool and riffle sequences, and the contrasting habitats of flood plain and channel margin.

**Acknowledgement.** Figure 1b is reproduced from a Lands Department (Survey and Mapping Office) photograph by kind permission of the Director of Lands, Hong Kong SAR Government.

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