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# HONG KONG GEOLOGIST

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*Editor:* Dr. R J Neller, Department of Geography, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong, Tel: (852) 2609 6527, Fax: (852) 2603 5006, e.mail: rjneller@cuhk.edu.hk
*Assistant Editor:* Dr. R B Owen, Department of Geography, Hong Kong Baptist University, Waterloo Road, Kowloon Tong, Kowloon, Hong Kong, Tel: (852) 2339 7188, Fax: (852) 2338 6005, e.mail: owen@ctsc.hkbc.hk

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# The Composition of Magnetite from the Ma On Shan Magnetite Skarn, Hong Kong

**K G McQueen and A J Cross**

*Centre for Australian Regolith Studies, Faculty of Applied Science, University of Canberra, PO Box 1 Belconnen, ACT, Australia 2516.*

**Abstract**

Magnetite from the Ma On Shan contact metasomatic replacement skarn contains minor Mn (0.7-1.4% MnO), Al (0.4-1.6% $Al_2O_3$), Mg (0.5-2.8% MgO) and Zn (0.1-0.3% ZnO) but very low contents of other elements such as Ca, Ti, V, Cr, Co and Ni. This compositional signature appears to be characteristic of magnetites from contact skarns of this type and could be useful in determining the source of magnetite in drainage systems and sedimentary deposits.

摘錄

來自馬鞍山的接觸交代矽卡岩的磁鐵礦，包含小量錳（0.7-1.4% MnO）、鋁（0.4-1.6% $Al_2O_3$）、鎂（0.5-2.8% MgO）及鋅（0.1-0.3% ZnO），但其他元素如鎢、鎂、釩、鉻及鎳則含量十分低。這個成份特徵似乎是來自此類的接觸矽卡岩的磁鐵礦的特性，並可能會在確定排水系統及沉積物內的磁礦來源方面很有用。

## Introduction

The Ma On Shan magnetite deposit is located on the western slopes of Ma On Shan approximately 5 km northeast of Sha Tin in the New Territories of Hong Kong. The deposit is a contact metasomatic replacement skarn developed between granite and calcareous sedimentary rocks, including dolomitic limestones, within a sequence of sandstones siltstones and felsic volcanic rocks (Strange and Woods, 1991). The intruding granite forms part of the Sha Tin Pluton (cooling age 148 ± 9 Ma; Strange, 1990) and is largely an equigranular, medium- to fine-grained, biotite- and pink K-feldspar-bearing variety.

Samples of magnetite from the deposit have been analysed for major and minor elements by electron microprobe in order to characterise the magnetite composition for comparison with magnetite from other skarn deposits and non skarn sources. Observations have also been made on hand specimens in the extensive collection of material from the Ma On Shan deposit held at the Earth Science Unit, University of Hong Kong.

## Nature Of The Skarn

The Ma On Shan skarn is zoned and consists of a lenticular mass of magnetite-rich material surrounded by calc-silicate assemblages which in turn grade into marble. Considerable amounts of greisen have been noted in the footwall to the deposit in underground mine workings (Strange and Woods, 1991). Magnetite occurs as irregular, fine- to medium-grained masses and disseminations intergrown with, or enclosed in, actinolite, tremolite, diopside and garnet-rich rocks. Other associated minerals described by Davis (1961) and Peng (1991) include calcite, quartz, epidote, vesuvianite, biotite, muscovite, olivine, stilpnomelane, serpentine, talc, wollastonite, rhodonite, palygorskite, chondrodite, apatite, fluorite, hematite, pyrite, pyrrhotite, chalcopyrite and galena. The senior author has also identified chlorite, rhodochrosite (as veins in magnetite) and minor sphalerite. Cross-cutting vein and skarn replacement textures indicate that minerals such as calcite, serpentine, fluorite and sulphides were introduced into the skarn at a late stage. Secondary minerals include malachite, azurite and goethite (Peng, 1991). Quartz-fluorite veins occur in the adjacent granite, and beryl-quartz veins in granite have been reported in dump material by Peng (1991). Davis (1961) described wolframite and molybdenite in quartz veins and stringers within the nearby country rocks.

Prior to mining, the magnetite-rich body was exposed at the surface over an area of 500 m by 100 m and extended for about 250 m along a northerly dip of between 35 and 55°. Between 1906 and 1976 the skarn was mined for magnetite with a total production of some 3 million tons. It has been estimated that there are still about 4 million tons of magnetite ore remaining in the deposit (Strange and Woods, 1991).

**Magnetite Composition**

Two samples of magnetite from the Ma On Shan deposit were sectioned and analysed using a Cameca Camebax electron microprobe analyser in wavelength dispersive mode. Representative analyses and selected minor element contents are presented in Table 1 and Figure 1. Magnetite from both samples consistently contains significant Mn (0.7-1.4% MnO) and Zn (0.1-0.3% ZnO, for 13 analyses). The MgO and $Al_2O_3$ contents are more variable (0.5-2.8% and 0.5-1.6% respectively) whereas Ca, Ti, V, Cr, Co and Ni contents are very low (mostly at or below the detection limit). The content of $SiO_2$ is also generally low with some higher values probably reflecting submicroscopic inclusions of silicates in the magnetite.

The magnetite compositions are very similar to those found for some other comparable magnetite skarns in Australia (e.g. Kreutzer and Nichol, 1984; McQueen et al., 1988; Table 1 and Figure 1).

**Discussion**

The minor and trace element chemistry of magnetite can be used to discriminate magnetites from different sources. Preliminary studies (e.g. Cross and McQueen, 1994) suggest that magnetites from contact skarn deposits commonly have relatively high contents of Mn and very low Ti, Cr and V compared to magnetites from associated igneous rocks (Figure 1). Some also show variable but commonly high contents of Zn and Si. These distinctive differences could be utilised in mineral exploration for skarn deposits by sampling and analysing magnetic heavy mineral fractions in stream and soil samples. The same principle could be applied in provenance studies of sedimentary formations. Characterisation of the skarn magnetite from Ma On Shan is particularly relevant to such studies in the Hong Kong area. If additional data could be obtained from other magnetite sources (e.g. granites and volcanic rocks) it may be possible

Table 1 - Representative analyses of magnetite in samples from the Ma On Shan skarn deposit.

| Wt% | 1. | 2. | 3. | 4. | 5. | 6. | 7. |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 0.01 | 0.01 | 0.01 | 0.20 | 0.01 | 0.01 | 0.01 |
| $TiO_2$ | 0.01 | 0.02 | <0.01 | 0.05 | <0.01 | <0.01 | 0.02 |
| $Al_2O_3$ | 1.59 | 1.60 | 1.40 | 0.44 | 1.15 | 1.26 | 0.46 |
| $Fe_2O_3$ | 67.19 | 67.46 | 67.66 | 68.23 | 67.64 | 69.87 | 69.97 |
| FeO | 28.17 | 28.71 | 28.71 | 29.13 | 25.30 | 27.55 | 26.66 |
| MnO | 1.14 | 1.11 | 1.24 | 0.79 | 0.79 | 0.83 | 0.75 |
| MgO | 1.02 | 0.81 | 0.67 | 0.61 | 2.78 | 2.12 | 2.40 |
| ZnO | 0.24 | 0.24 | 0.30 | 0.10 | 0.21 | 0.17 | 0.18 |
| Total | 99.37 | 99.96 | 99.99 | 99.55 | 97.88 | 101.81 | 100.45 |

1. Massive blocky magnetite, sample MOS1.
2. Disseminated subhedral magnetite, sample MOS1.
3. Massive blocky magnetite, sample MOS1.
4. Disseminated subhedral magnetite, sample MOS1.
5. Massive blocky magnetite, sample MOS2.
6. Massive blocky magnetite, sample MOS2.
7. Massive blocky magnetite, sample MOS2.

V, Co, Ni, Cr and Ca were also analysed and in all cases were <0.005% for $V_2O_5$ and $Cr_2O_3$; <0.01% for CoO, NiO and CaO. Analyses performed on a Cameca Camebax electron microprobe using an accelerating voltage of 25 kV and ilmenite, chromite, sphalerite and metallic Fe, Co and Ni as standards. $Fe_2O_3$ and FeO were calculated from total Fe assuming stoichiometry (i.e. $Fe^{3+} + R^{3+} = 2[(Fe\ total - Fe^{3+}) + R^{2+}]$ after subtracting sufficient Fe to accommodate any Ti as ulvöspinel). $SiO_2$ was not calculated into the magnetite formula.

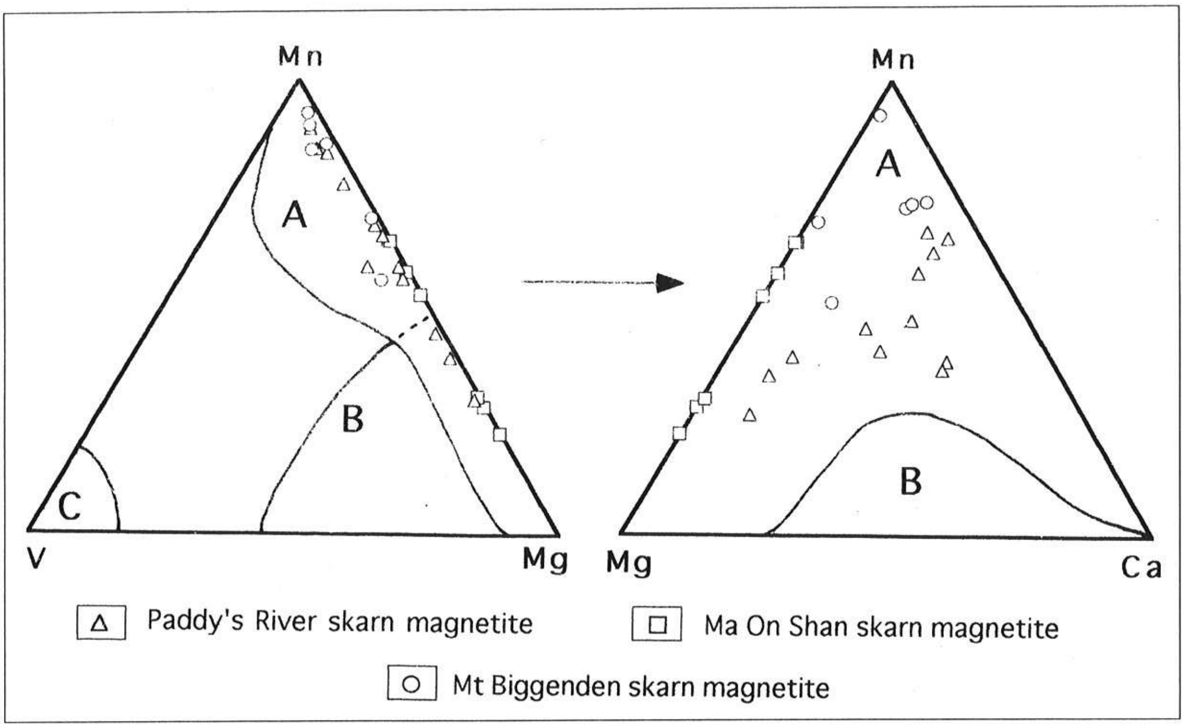


*Figure 1 - Ternary diagrams showing the compositional characteristics of skarn magnetites from Ma On Shan, the Paddy's River skarns (ACT) and Mt Biggenden (Queensland). The labelled fields show the compositions of different magnetites from the Paddy's River area: A is skarn magnetite, B is felsic volcanic-derived magnetite and C granite-derived magnetite. Elements are expressed as oxides.*

to determine the provenance of younger sediments (e.g. Pat Sin Leng Formation) by separating contained magnetite and determining the minor and trace element composition using electron microprobe analysis or other techniques (e.g. laser ablation ICP-MS).

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# Interpretation of the Regional Gravity Survey of Hong Kong

**J P Busby[1] and R L Langford[2]**

[1] British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK.
[2] Geological Survey of Western Australia, Perth, Australia. Formerly of the Hong Kong Geological Survey.

**Abstract**

Regional Bouguer gravity anomaly data in Hong Kong reveal a number of long wavelength anomalies. There is a deep gravity low over the western New Territories, with a large positive gradient to the southeast and east. Two dominant lineation directions are revealed by first horizontal derivative maps. One is northeast and the other northwest, and both reflect structural trends in the underlying geology. A number of intersections occur between these two sets of lineations, and these may be of significance when assessing the seismic risk of the territory. Quantitative modelling indicates that the thickness of granite beneath the central New Territories is generally about 2.5 km, but greater thicknesses, of up to 8.5 km, occur in places. Basic intrusive material has been introduced at depth into the models to account for the Bouguer gravity highs in the south and east. The majority of this basic material is most probably of Tertiary age, but to the west of Hong Kong Island it could be pre-Cretaceous. The absence of a gravity low over the Mirs Bay sedimentary basin is attributed to the negative anomaly due to the sedimentary rocks being offset by a positive anomaly due to basic intrusives.

摘要

香港分區 Bouguer 重力異常數據顯示一些長波長的異常情況。在新界西部出現很深的重力，在東南及東面有甚大的正量升降率。最初的水平衍生圖顯示了兩個主要的線理方向。一個是東北，另一個是西北，兩者均反映下伏地質結構傾向。在兩組線理之間出現多個交點，這在衡量本港地震險時也許有價值。量化模型顯示，新界中部下面的花崗岩一般厚度約 2.5 公里，但某些地方則厚達 8.5 公里。模型內深處引入基本侵入物，以解釋南面和東面出現 Bouguer 高重力的情況。這些基本物質大部分很可能屬於第三紀，但港島以西則可能屬於前堊紀。大鵬灣沉積盆地並無出現低重力。因此，設想與沉積岩有關的負量重力異常情形，是由屬於基本侵入物的正量重力異常情況所抵銷。

## Introduction

The deep geology of Hong Kong has been little investigated. A large number of boreholes have been drilled, but these are generally less than 30 m in depth, having been drilled for engineering purposes. Previous geophysical investigations have been restricted to a detailed gravity survey in the Yuen Long area (EGS, 1988) (northwest New Territories, Figure 1), and sparker and boomer seismic reflection surveys, carried out by EGS, for investigating the thickness of offshore superficial deposits. In contrast, the surface geology of Hong Kong has been extensively mapped, and geological memoirs have been published by Allen and Stephens (1971), Addison (1986), Strange and Shaw (1986), Langford et al. (1989) and Strange et al. (1990). A geological sketch map is shown as Figure 1.

The oldest rocks in the territory are Devonian sandstones and siltstones which outcrop in the region of Tolo Channel and Tolo Harbour. Carboniferous meta-sedimentary rocks, derived from limestones, mudstones, siltstones, sandstones and conglomerates (Frost, 1989), subcrop in a curved Hercynian basin around Yuen Long. Faulted Carboniferous outcrops are also known on The Brothers islands and on the northwestern shore of Lantau Island.

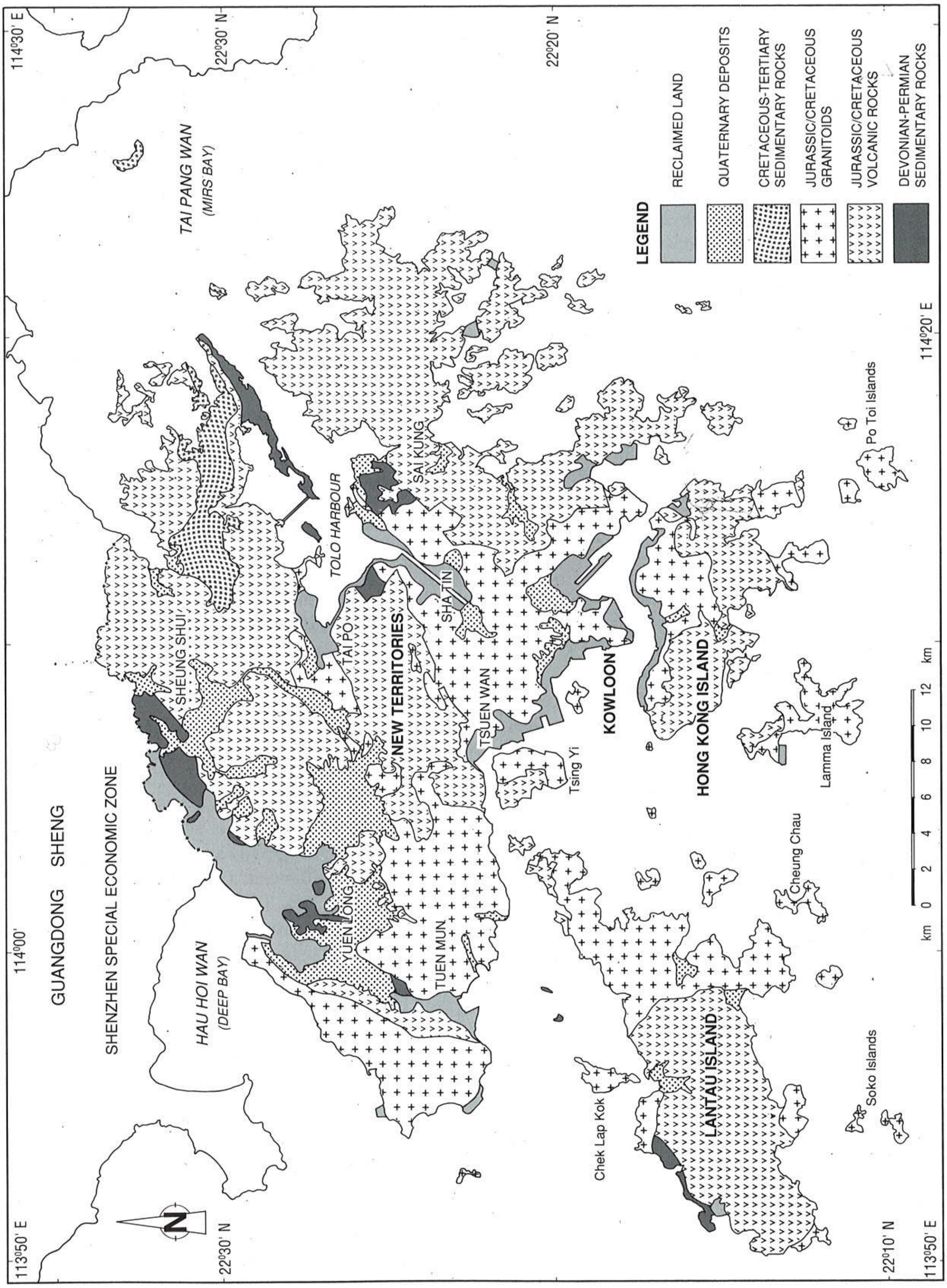


*Figure 1 - Geological sketch map of Hong Kong showing the positions of localities referred to in the text.*

The dominant geological strata are acid to intermediate volcanic rocks and granitoid intrusives of Upper Jurassic to Lower Cretaceous age. The volcanic rocks are a complex succession of crudely stratified pyroclastic rocks and lavas with interbedded sedimentary rocks. They are found in all parts of the territory, although rhyolite lavas are found mainly in the eastern New Territories and on Lantau Island. The volcanic rocks and granitoid intrusives are cut by acidic dykes. The ages of the volcanics and intrusives places them in the Yenshanian orogeny. The volcanics are overlain by Upper Cretaceous sedimentary rocks in the northeast New Territories.

A tensional regime was initiated in the Late Cretaceous and Tertiary that led to the formation of a sedimentary basin in Mirs Bay which may in part contain at least 3 km of sediments (Evans C. D. R., 1990). The dominant and oldest structural direction is associated with the Himalayan orogeny and is ENE. Two other fault sets are recognised; one trending NNE and the other NNW (Lee and Workman, 1991).

In the late 1980's the Hong Kong Civil Engineering Department Geotechnical Engineering Office (GEO) initiated a regional gravity survey of the territory. It was hoped that the survey would trace the possible continuation into Hong Kong of faults mapped in Guangdong Province, indicate the space form of the granites, and reveal the form of Mesozoic/Cainozoic offshore sedimentary basins.

*Densities of Hong Kong Rocks*

For both the reduction and interpretation of gravity data it is necessary to have a knowledge of the densities of the geological strata. The lack of deep borehole control in Hong Kong means that it is particularly important to have accurate density data to constrain the interpretation. Table 1 is a compilation of measured densities from Hong Kong which includes most of the known rock types. A number of density determinations were made for the present study by the Public Works Laboratories of the GEO on selected samples from the Hong Kong Geological Survey's rock collection.

## The Regional Gravity Survey

A gravity base station network was established in Hong Kong in the summer of 1990 and was linked to the International Gravity Standardization Net 1971 (IGSN71) (Evans R. B., 1990). Electronic and Geophysical Services Ltd. (EGS) measured gravity in the territory at a total of 632 stations which were also linked to the IGSN71. Of these, 499 were land stations at an average station density of one per $km^2$ and 133 were sea bottom stations, at an average station density of one per four $km^2$. These gravity data were reduced to Bouguer anomaly values using conventional procedures (see for example Telford et al., 1976) by EGS. The British Geological Survey (BGS) subsequently reduced the data using slightly different densities. The datum reduction surface was Hong Kong Principal Datum, which is 1.38 m below mean sea level. The parameters used in the reduction were a free air gradient of gravity of 0.3086 mGal $m^{-1}$, a Bouguer constant of 0.041929 mGal $m^{-1}$ and normal gravity calculated from the 1967 Geodetic Reference System (GRS 67). The Bouguer reduction density was 2.62 Mg $m^{-3}$ for land stations and 3.647 Mg $m^{-3}$ for the sea bottom stations, including a density for sea water of 1.027 Mg $m^{-3}$. The density of 2.62 Mg $m^{-3}$ represents the average density of the granitic rocks based on physical property data.

The steep terrain of Hong Kong produces a large topographic effect in the gravity data and must be allowed for by a terrain correction. EGS had already produced a Digital Terrain Model (DTM) of Hong Kong which, with some additional digitization of the topography of the Chinese mainland, meant that they were well placed to carry out the terrain corrections. The techniques used are described in EGS (1991). The further processing and interpretation of the data were undertaken by the BGS.

## Regional Gravity Interpretation

The term "regional" is applied to the survey because the station spacing only allows the accurate resolution of long wavelength features. These features will generally occur at depth, and the interpretation cannot reflect the detail seen in the surface geological map. The interpretation presented below consists of a qualitative assessment of the data followed by quantitative two and half-dimensional (2.5D) and three-dimensional (3D) modelling.

*The Bouguer Gravity Anomaly Map*

The Bouguer gravity data have been gridded using the Interactive Surface Modelling (ISM) package (Dynamic Graphics Inc., 1986) at a grid interval of 0.5 km. The resulting Bouguer anomaly map, contoured at 2 mGal intervals, is given as Figure 2.

The Bouguer gravity anomaly values cover the range -33.5 to +5.0 mGal. The map shows a deep low in the northwest New Territories, with the minimum values to the southeast of Yuen Long and to the west of Castle Peak. These two lows are split by a ridge of slightly higher values. There is a steep positive SSE gradient towards Lantau Island and Hong Kong Island. This gradient slackens and has a more southerly trend in the eastern half of the map. In the southeastern corner of the territory the Bouguer gravity anomaly values are positive. In the northeast, local gradients result in a gravity maximum in Mirs Bay, although the Bouguer anomaly values are still negative.

The high gradient across the centre of the map cuts volcanic and granitic rocks. However, the change of direction of these contours to north-south across Tolo Harbour does coincide with the expected contact between granite and Devonian basement. On Lantau Island, to the north of the Chi Ma Wan peninsula, there is a gravity maximum with a steep negative gradient to the NW. This is unexpected as this region consists of volcanic rocks intruded by a series of granitic plutons. There is a single point gravity high to the west of Hong Kong Island and north of Lamma

Table 1 - Densities of Hong Kong superficial materials and rock samples in Mg $m^{-3}$.

| Sample Description | Weathering Grade | Average Density | Density Range | Source |
|---|---|---|---|---|
| Marine deposits | | 1.76 | | EGS, 1989 |
| Fill | | 1.95 | 2.14-1.79 | EGS, 1989 |
| Alluvium | | 1.97 | 2.10-1.70 | EGS, 1989 |
| Siltstone (Ping Chau) | | 2.61 (D) | | * |
| Siltstone (Ping Chau) | | 2.62 (S) | | * |
| Siltstone (Ping Chau) | | 2.63 (GD) | | * |
| Sandstone (Devonian) | | 2.52 (S) | 2.61-2.43 | * |
| Sandstone (Permian) | | 2.69 (S) | | * |
| Sandstone (Carboniferous) | | 2.72 (S) | | * |
| Siltstone | | 2.79 | 3.05-2.60 | EGS, 1989 |
| Metaconglomerate | | 2.90 | | EGS, 1989 |
| Metasandstone (Carboniferous) | | | 2.63 (S) | * |
| Metasiltstone | | 2.91 | | EGS, 1989 |
| Metasiltstone | 11 | 2.63 | | EGS, 1989 |
| Phyllite | | 2.60 (S) | 2.64-2.56 | * |
| Marble (Yuen Long) | | 2.72 | 2.76-2.69 | EGS, 1989 |
| Silicified marble | 1 | (S) | 3.09-3.24 | Irfan, 1989a |
| Silicified marble | 11 | 3.15 | | EGS, 1989 |
| Silicified marble | 2 | (S) | 3.10-3.23 | Irfan, 1989a |
| Banded marble | 11 | 2.77 | | EGS, 1989 |
| Banded marble | 2 | (S) | 2.71-2.80 | Irfan, 1989a |
| Banded marble | 11/111 | 2.74 | | EGS, 1989 |
| Grey marble | 1 | 2.70 | | EGS, 1989 |
| Grey marble | 1 | (S) | 2.69-2.85 | Irfan, 1989a |
| Grey marble | 11 | 2.83 | | EGS, 1989 |
| Grey marble | 2 | (S) | 2.81-3.10 | Irfan, 1989a |
| Grey marble | 3 | (S) | 2.60-3.08 | Irfan, 1989a |
| White marble | 1 | 2.73 | | EGS, 1989 |
| White marble | 1 | (S) | 2.68-2.79 | Irfan, 1989a |
| Granitized marble | 11 | 3.17 | | EGS, 1989 |
| Tuff breccia | 2i | (S) | 2.65-2.85 | Irfan, 1989a |
| Tuff breccia | 2ii | (S) | 2.62-3.03 | Irfan, 1989a |
| Tiff breccia | 2 | (S) | 2.62-3.03 | Irfan, 1989a |
| Tuff breccia | 3 | (S) | 2.37-2.70 | Irfan, 1989a |
| Tuff breccia | 1 | 2.84 | | EGS, 1989 |
| Tuff breccia | 11 | 2.86 | | EGS, 1989 |
| Tuff breccia | 111 | 2.62 | | EGS, 1989 |
| Tuff | 1 | 2.72 | | EGS, 1989 |
| Tuff | 11 | 2.68 | | EGS, 1989 |
| Crystal tuff | | 2.68 (D) | 2.71-2.65 | Gilbert & Irfan, 1989 |
| Crystal tuff | | 2.68 (S) | | * |
| Vitric tuff | | 2.64 (S) | 2.64-2.63 | Gilbert & Irf an, 1989 |
| Ash tuff | | 2.62 (S) | 2.64-2.60 | * |
| Rhyolite | | 2.66 (S) | 2.68-2.64 | * |
| Trachyandesite | | 2.68 (S) | | * |
| Porphyritic dacite | | 2.68 (S) | | * |
| Coarse grained granite | | 2.62 (S) | 2.62 | Irfan, 1987a |
| Medium grained granite | | 2.61 (S) | 2.62-2.61 | Cipullo & Irfan, 1988 |
| Medium grained granite | | 2.62 (S) | 2.63-2.60 | Irfan & Nash, 1987 |
| Medium grained granite | Decomposed | 2.59 (S) | | # |
| Medium grained granite | Fresh | 2.62 (S) | | # |
| Medium grained granite | | 2.63 (S) | 2.63-2.62 | Irfan, 1989b |
| Megacrystic granite | | 2.61 (S) | 2.62-2.61 | Irfan, 1989b |

Table 1 - Densities of Hong Kong superficial materials and rock samples in Mg m$^{-3}$ (Continued)

| Sample Description | Weathering Grade | Average Density | Density Range | Source |
|---|---|---|---|---|
| Fine-medium granite | | 2.60 (S) | 2.60 | Irfan, 1987b |
| Fine-medium granite | | 2.60 (S) | 2.60 | Irfan & Cipullo, 1987 |
| Fine grained granite | | 2.61 (S) | 2.61-2.60 | Irfan, 1989b |
| Fine grained granite | | 2.62 (S) | 2.63-2.62 | Irfan & Cipullo, 1987 |
| Granodiorite | I | 2.78 | 2.78-2.77 | Irfan & Powell, 1985 |
| Granodiorite | II | 2.72 | 2.85-2.66 | Irfan & Powell, 1985 |
| Granodiorite | III | 2.63 | 2.69-2.45 | Irfan & Powell, 1985 |
| Granodiorite | III/IV | 2.67 | 2.76-2.52 | Irfan & Powell, 1985 |
| Granodiorite | IV | 2.62 | | Irfan & Powell, 1985 |
| Monzonite | | 2.63 (S) | 2.63 | Irfan, 1987c |

S = Saturated Density, D = Dry Density, GD = Grain Density; otherwise type of density measurement not known.

* = Sample densities measured for this study.

# = Source unknown.

Weathering grade varies from I (fresh) to IV (decomposed)

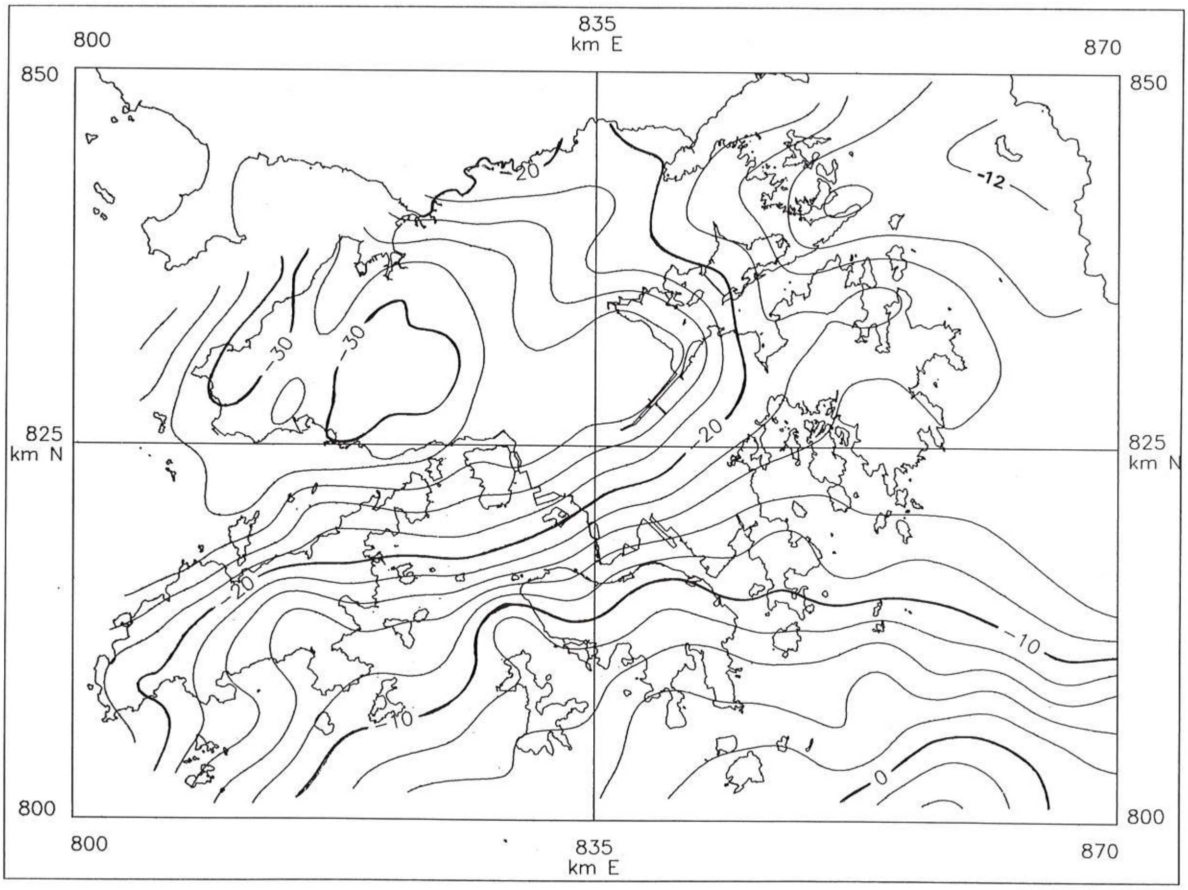


*Figure 2 - Bouguer gravity anomaly map of Hong Kong contoured at 2 mGal intervals. The Bouguer reduction density was 2.62 Mg m$^{-3}$.*

Island which coincides with a short wavelength magnetic anomaly with an amplitude of over 1000 nT (EGS, 1990). The more positive gravity values in the south are unexpected, as all of the islands to the south of Hong Kong Island are known to consist mainly of low density granitic rocks. The ridge of slightly higher values to the north of Tuen Mun coincides with the Hercynian basin and indicates that the granites to the west and east may be separate intrusions. There is little correlation between the Bouguer contours and the western and southern boundaries to the Mirs Bay sedimentary basin. The more positive values are unexpected over a basin of this age as the sediments would generally be expected to be less dense than the Devonian basement.

*Upward Continued Bouguer Anomaly Field*

Figure 3 is a Bouguer gravity anomaly map produced by continuing the measured field upwards by 2 km. The result is to simplify the map and create two distinct anomalies, a low over the western New Territories and a high in the southeastern corner. The two troughs of the anomaly low can still be seen, and the maxima on southern Lantau and to the west of Hong Kong Island still produce kinks in the contours. The large low implies that there is a plutonic mass (or series of plutons) which are less dense than the enclosing basement material beneath the western New Territories. In the southeast, assuming that the positive gradient in the Bouguer anomaly values cannot be accommodated by deep crustal effects, the outcropping granites cannot extend to any great depth.

*Horizontal Gradient of the Bouguer Anomaly Field*

Trend directions in the data can be highlighted by calculating horizontal gradients. Figures 4 and 5 are shadowgrams of the magnitude of the first order (first derivative) horizontal gradient with the light sources from the NW and SW respectively. Prominent lineations revealed in the shadowgrams are plotted in Figure 6. In Figure 4 the region to the east of Castle Peak shows a NNE trend. Particularly prominent is the lineation across Tolo Channel, through Shatin to Tsing Yi and the lineation running southwest from Starling Inlet (see Figure 6). These lineations are mainly restricted to the area of more negative Bouguer values. In Figure 5 the WNW lineation running from western Hong Kong Island to The Brothers islands is prominent. Also apparent is the NW trend from eastern Hong Kong Island which can be traced to the east of Tsing Yi to Yuen Long and beyond (see Figure 6). This major lineation is in the approximate position of the NW-trending inferred fault referred to by Bennett (1984). This is shown on the 1979 *Tectonic Map of China* and appears to control the eastern side of the Pearl River estuary. Thus, the northeastern tip of Tsing Yi is at the intersection of major NE and NW trending lineations.

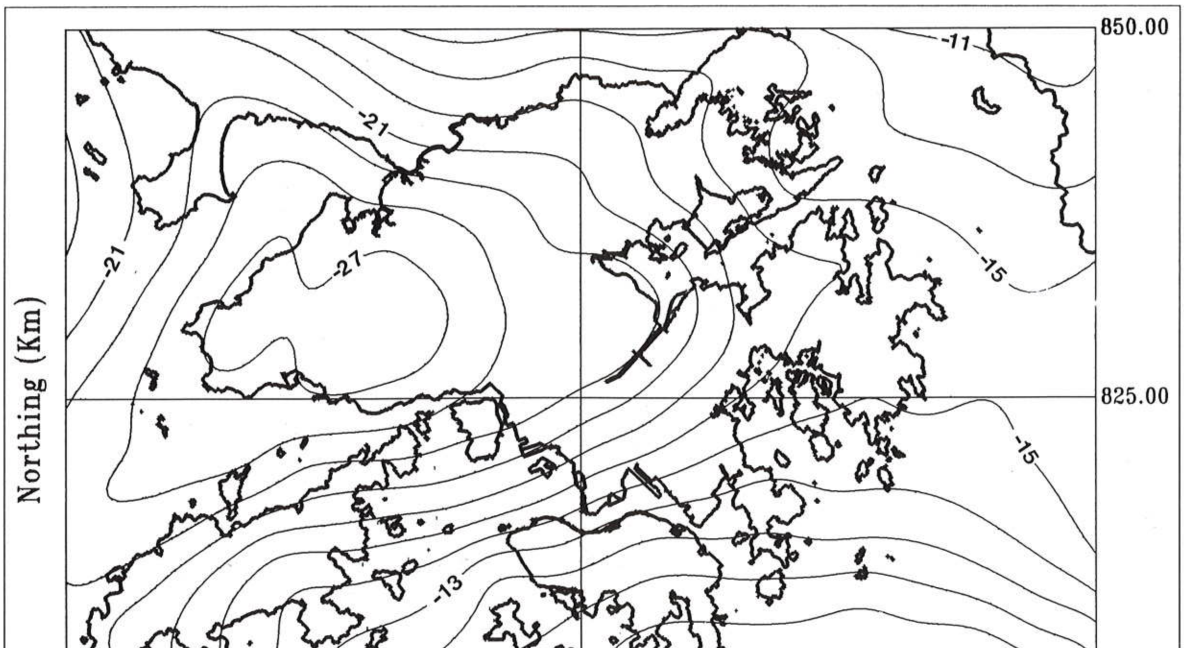


*Figure 3 - Bouguer gravity anomaly data upward continued by 2 km and contoured at 2 mGal intervals.*

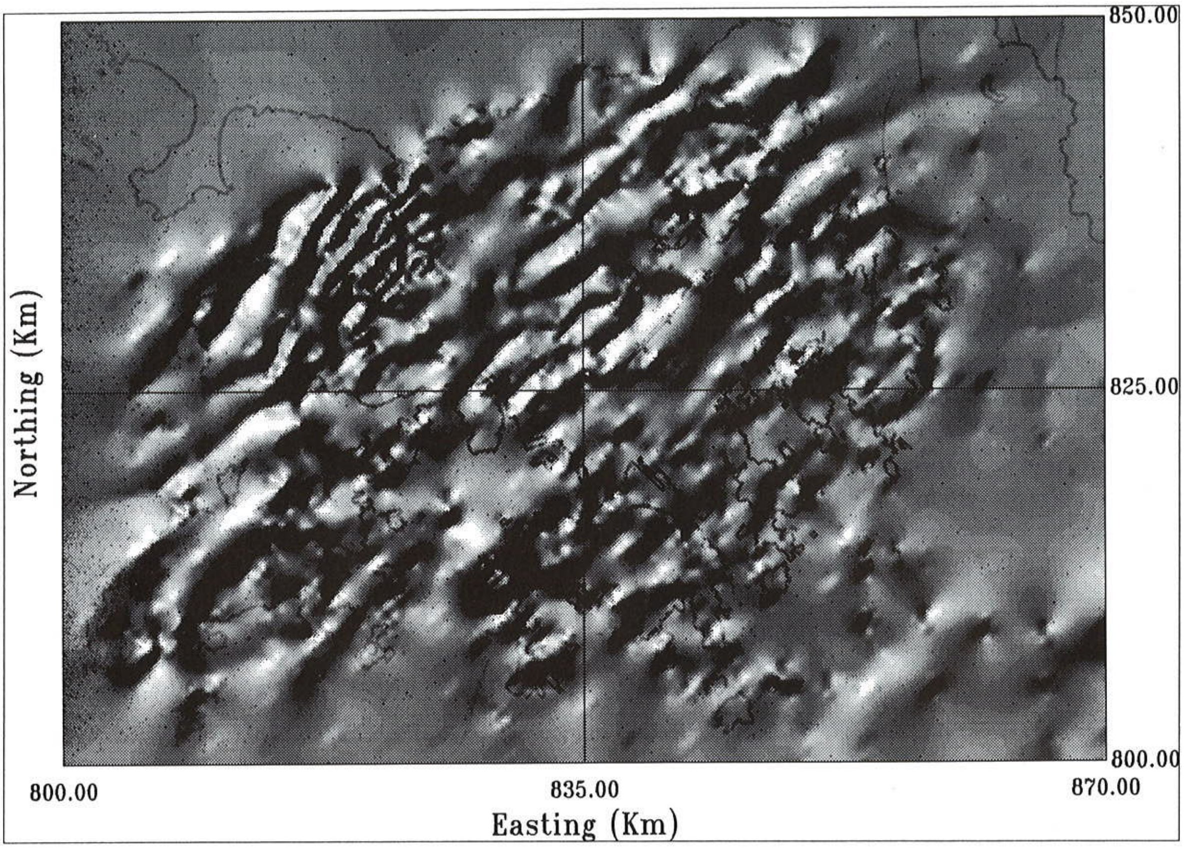


*Figure 4 - Shadowgram of the magnitude of the first order horizontal gradient illuminated from the NW.*

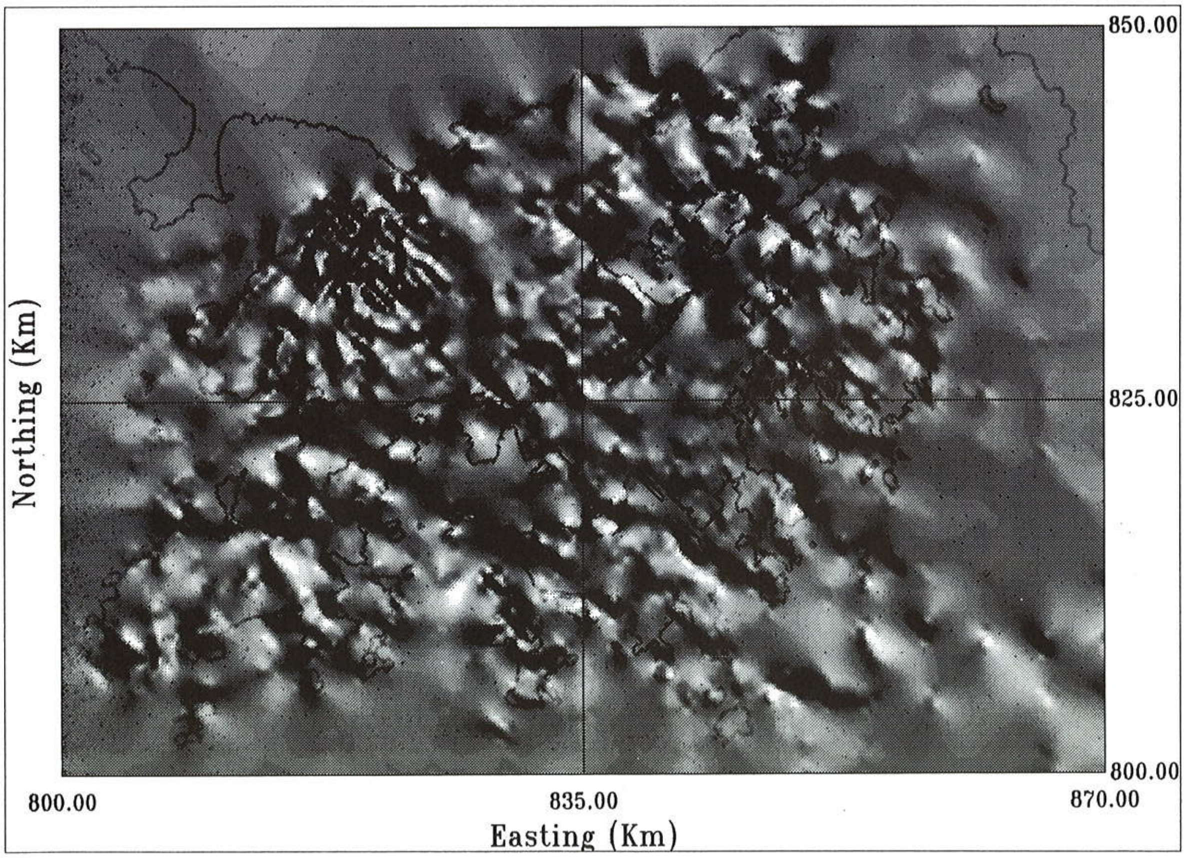


*Figure 5 - Shadowgram of the magnitude of the first order horizontal gradient illuminated from the SW.*

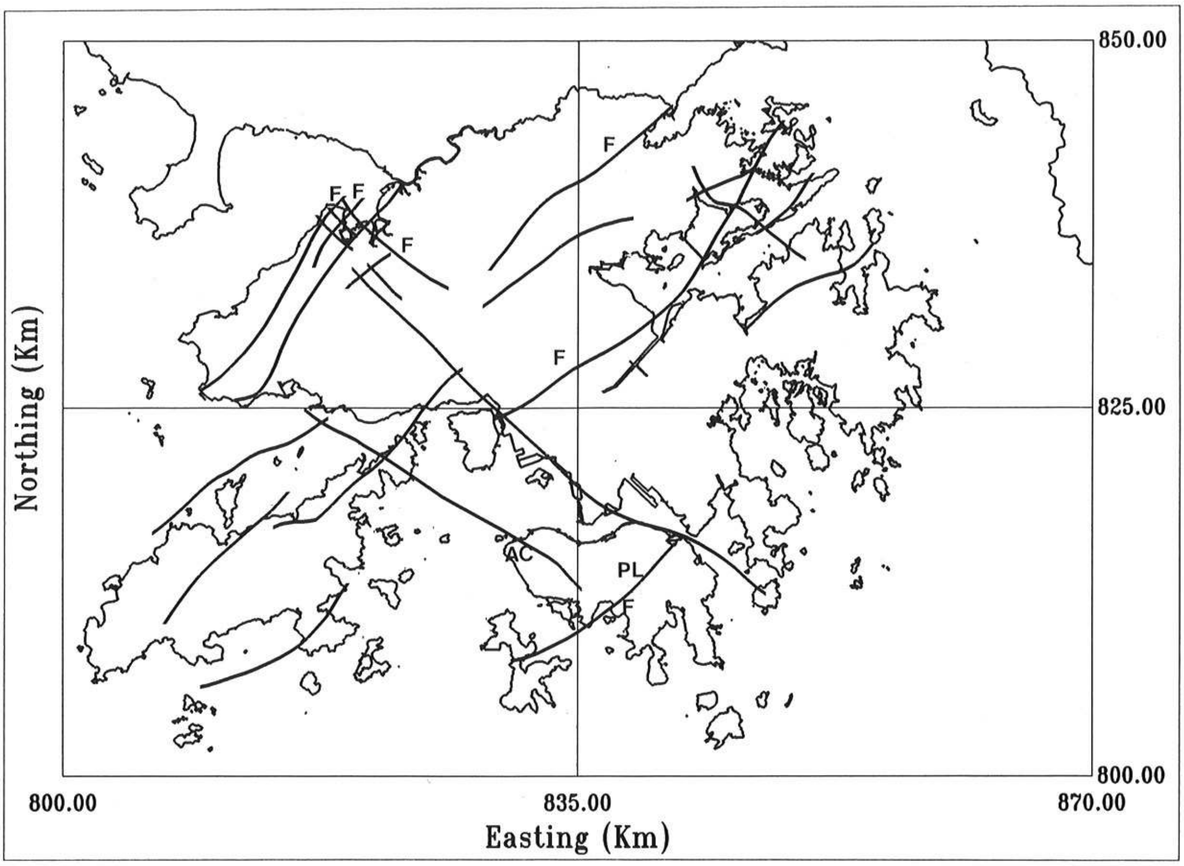


*Figure 6 - The main geophysical lineaments identified from the shadowgrams. The codes indicate correlation with faults (F), anticlines (AC) and photogeological lineaments (PL).*

*Quantitative Interpretation*

The quantitative interpretation has been kept deliberately simple because of the lack of control from borehole information and other geophysical data such as magnetic surveys or deep seismic profiles.

For the purpose of modelling, Bouguer anomaly values were calculated using the basement density. The effect of parts of the model lying above the reduction datum are then modelled correctly at the required density. The Bouguer anomaly data have therefore been recalculated using a reduction density of 2.7 Mg $m^{-3}$.

Ideally, a regional interpretation should model the entire Bouguer field in terms of geological structure down to the base of the crust. Clearly, unless there is control from deep seismic reflection or refraction data such a model would be highly speculative. In practice, therefore, it is necessary to remove some kind of regional field representing the deep crustal and regional isostatic effects which are to be excluded from the model. A regional field has been estimated from the Bouguer gravity anomaly map, at a scale of 1:2,000,000, from the Atlas of Geology and Geophysics of the South China Sea (Ministry of Geology and Mineral Resources, 1984). The wavelengths of the anomalies seen at this scale are of the order of hundreds of kilometres, and the Bouguer anomaly contours generally lie parallel to the Chinese coast. In the Bouguer data reduction for the map, the 1930 International Gravity Formula (IGF 1930) and the Potsdam base (P) were used. To convert to Bouguer anomalies referred to GRS 67 and IGSN71 it was necessary to add 1.2 mGal to the values shown on the map. The regional field defined is planar with a value of 4.0 mGal at easting 870 km and northing 800 km, and has a gradient of -0.5 mGal $km^{-1}$ on a bearing of 340°. This field has been removed from the Bouguer anomaly map of Hong Kong to produce the residual field shown in Figure 7. The major anomaly patterns have not changed, but the magnitude of the large negative anomaly over the New Territories is reduced and the anomaly over Mirs Bay is now positive. A new negative anomaly is seen in the east. In the modelling, the calculated gravity field is compared to the residual field.

*Two and a Half Dimensional (2.5D) Modelling*

Two south-north profiles have been modelled using the 2.5D modelling procedure described by Busby (1987). Models comprise a set of polygons in the x, z plane (along the profile) with a finite strike length in the y direction (perpendicular to the profile). Such 2.5D models are effectively three-dimensional, but with an abrupt termination in the y direc-

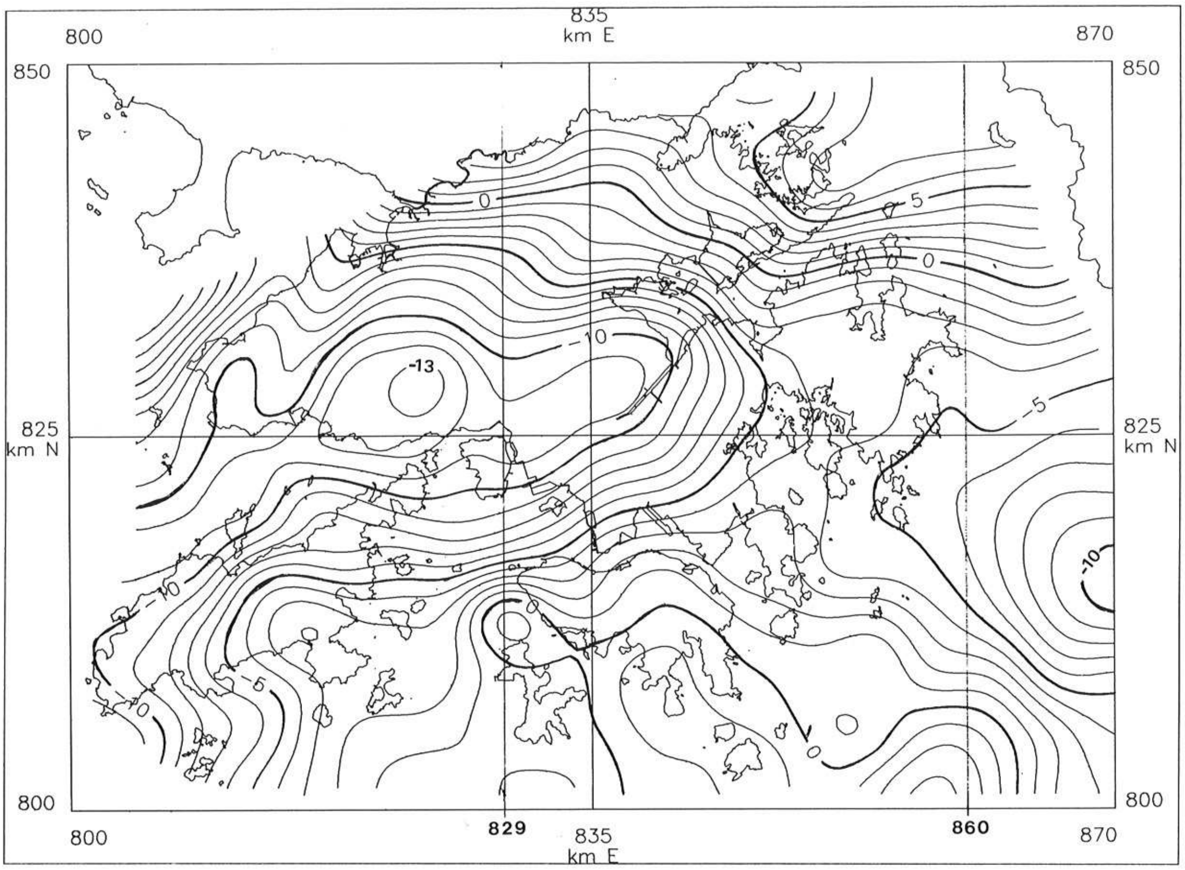


*Figure 7 - Residual Bouguer gravity anomaly map of Hong Kong contoured at 1mGal intervals. Gravity profiles along eastings 829 and 860 have been modelled.*

tion at an equal distance on either side of the profile. Densities are assigned both to the polygons and to the background material in which the polygons are placed.

The first profile is along easting 860 km and crosses the marine area in the east of the map, with Mirs Bay at its northern end (see Figure 7). The gravity anomaly at each end of the profile is positive with a broad gravity low between (see Figure 8). The model has a central granite mass (body 1), of half strike length 6.0 km, which extends to a depth of 2.0 to 2.5 km. A polygon representing the Mirs Bay sedimentary basin has been included from northing 832 km to the northern end of the profile (body 4). This extends to a maximum depth of 3.0 km, has a half strike length of 5.0 km and has been given a density of 2.63 Mg $m^{-3}$ (see Table 1). Against a background density of 2.7 Mg $m^{-3}$ this basin produces a negative anomaly. It has therefore been necessary to introduce additional material of high density at depth to produce the observed positive anomaly. Jiawei and Weixing (1988), describe basalts of Neogene to Quaternary age from the Pearl River Delta which are associated with the seaside arc of southeast China. There is some evidence of Tertiary intrusive activity below Mirs Bay. Lee et al. (1990) in a description of the geology of Ping Chau island report the occurrence of zeolites and acmite. R. J. Merriman (pers. comm.) states that these minerals in mudstone and shales indicate temperatures of at least 250° Centigrade. Thus the area must have had a high heat flow. There is no evidence in Mirs Bay for major subsidence followed by inversion (C. D. R. Evans, pers. comm.) so the high heat flow is most probably due to intrusive activity. A polygon representing basic rock (density 2.9 Mg $m^{-3}$ ) of half strike length 10.0 km has been introduced at the northern end of the profile (body 3). It is not possible to model the exact form of this body as the observed residual anomaly is caused by the interaction of the anomalies due to the Mirs Bay sediments and the high density body. However, it must be extensive and may be several kilometres thick. A polygon of basaltic density, 1.0 km thick and of half strike length 3.0 km, at a similar depth has been included at the southern end of the profile. Again its exact form is unknown as there may well be near-surface granitic material.

This model is dependent upon the level of the regional field that has been removed. The geological map from the Atlas of Geology and Geophysics of the South China Sea (Ministry of Geology and Mineral Resources, 1984) indicates that the geology in the region adjacent to Hong Kong is complex, ranging in age from Cambrian to Jurassic. Thus, it is possible

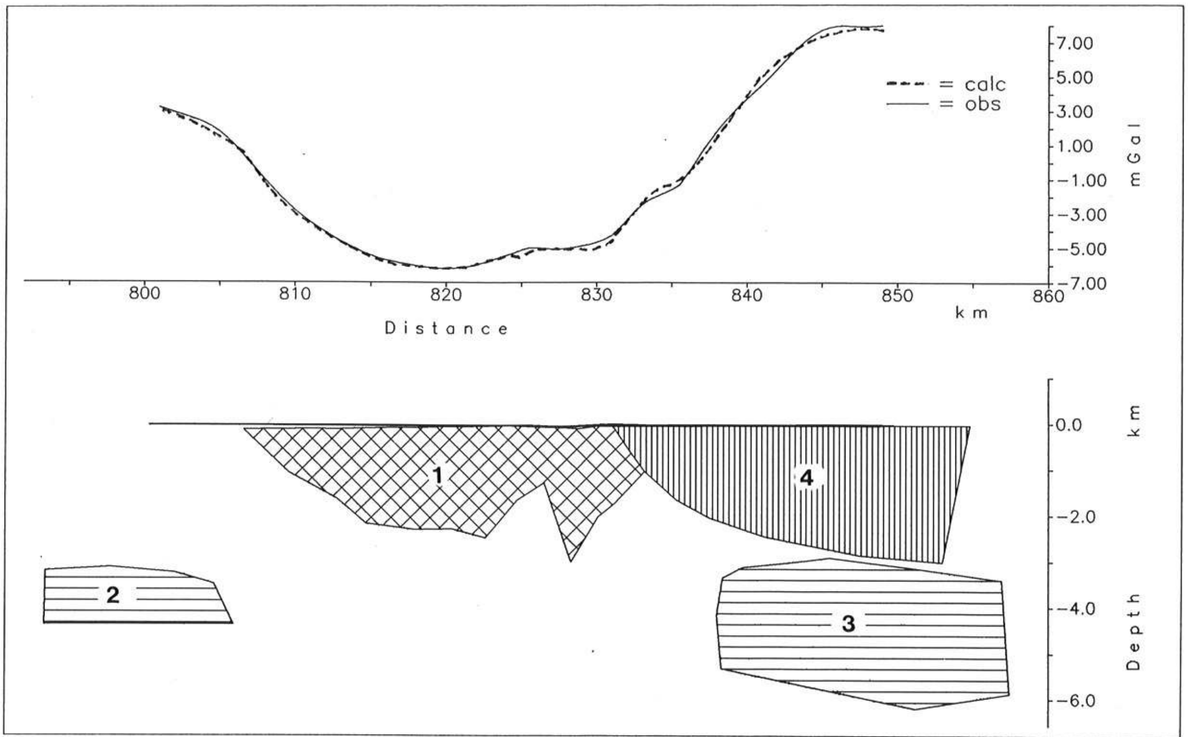


*Figure 8 - 2.5D model along easting 860 km. Polygon 1 is granite of density 2.62 Mg m$^{-3}$, polygons 2 and 3 are basic intrusives of density 2.9 Mg m$^{-3}$ and polygon 4 is the Mirs Bay sedimentary basin of density 2.63 Mg m$^{-3}$. The background density is 2.7 Mg m$^{-3}$.*

that some middle to upper crustal effects have not been removed by the regional field and that it could be made more positive. If 4.0 mGal is added to the regional field then a modified model (see Figure 9) is produced. The basement density has been altered to 2.75 Mg m$^{-3}$, a value commensurate with a Caledonian basement, which results in little change to the granitic body (body 1). However, the basic material at the southern end of the profile is removed and there is a considerable expansion in the volume of the basic body at the northern end of the profile (body 3), which now has a half strike length of 12.0 km.

The second profile, along easting 829 km, passes through the positive anomaly to the west of Hong Kong Island which, although only constrained by one gravity station, corresponds with a large magnetic anomaly. The model (see Figure 10) consists of a large granitic mass of half strike length 15.0 km and a maximum depth of 7.0 km (body 1). At the southern end of the profile the granite is thin, although this could also be achieved by thickening the granite and introducing basic material at depth. At the northern end there is a polygon of half strike length 2.0 km and density 2.64 Mg m$^{-3}$ which represents Carboniferous meta-sandstone (body 4). Granodiorite is included as a small polygon of half strike length 2.0 km (body 5). The low at northing 825 km has not been completely modelled as it requires the inclusion of near surface low density material, for which there is no evidence on the geological map. The positive anomalies are again modelled by polygons representing basic rocks, the one at the northern end of the profile having a half strike length of 5.0 km (body 3). The other, which models the positive anomaly to the west of Hong Kong Island has a half strike length of 1.0 km and comes close to the surface in the area of thin granite (body 2). It extends to a depth of several kilometres. Geological evidence supporting a basic intrusion is found on northern Lamma Island where large, angular basalt xenoliths are found in the granites (Strange and Shaw, 1986).

This model has also been repeated with a more positive regional field (+ 4.0 mGal) and the result is shown in Figure 11. The effect is to produce a thickening of the granite in the south and a reduction in the depth of the main granitic mass. There is again an expansion in the volume of the basic body (body 3) at the northern end of the profile.

*Three Dimensional (3D) Modelling*

The main negative anomaly in Figure 7 corresponds to the volcanic and granitic outcrop over the New Territories. These acidic rocks have densities of around 2.62 Mg m$^{-3}$ which, when compared with the basement density of 2.7 Mg m$^{-3}$, can account for the negative anomaly. The situation in the south of Figure 7 is clearly more complicated where the anomaly becomes positive, but there are still outcropping granitic rocks. The 3D modelling has been used to establish the space form of the acidic mass causing the

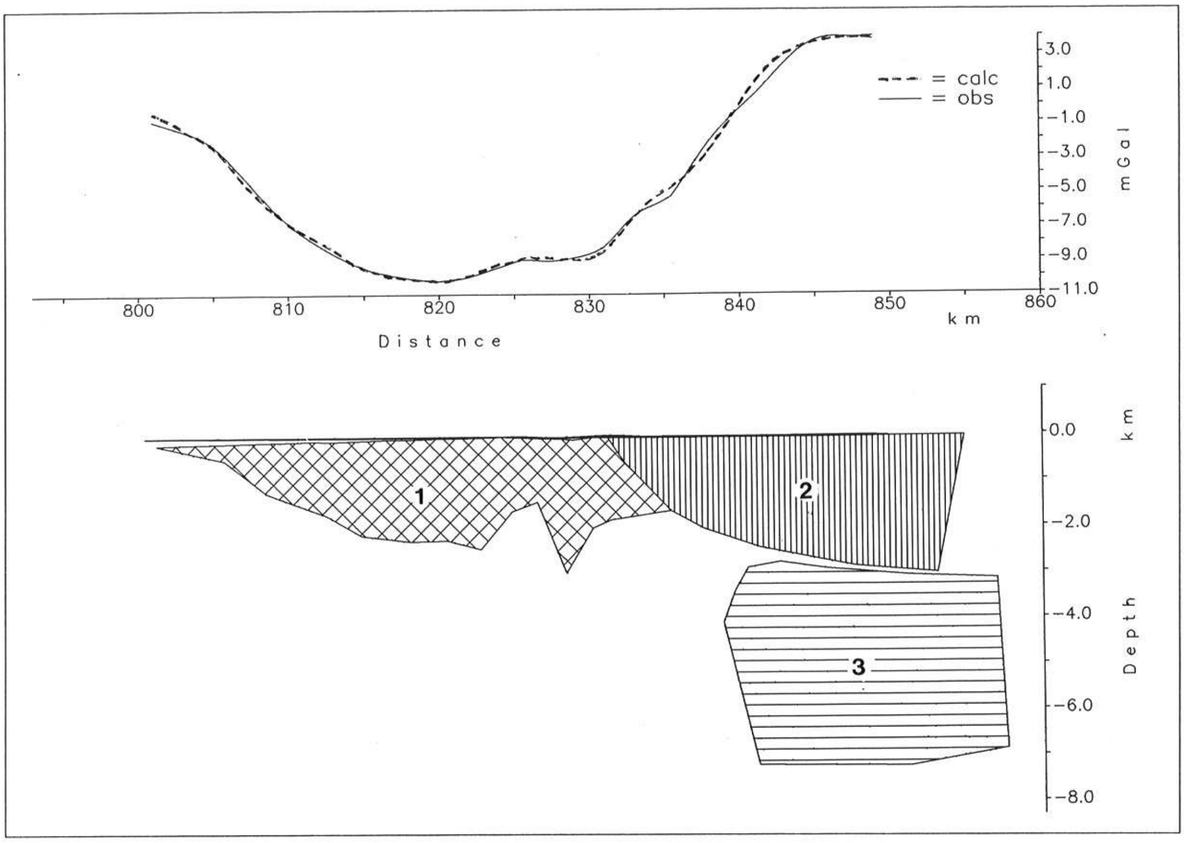


*Figure 9 - Modified 2.5D model along easting 860 km based on a more positive regional field. Polygon 1 is granite of density 2.62 Mg $m^{-3}$, polygon 2 is the Mirs Bay sedimentary basin of density 2.63 Mg $m^{-3}$ and polygon 3 is basic intrusive material of density 2.9 Mg $m^{-3}$. The background density is 2.75 Mg $m^{-3}$.*

main negative anomaly. The body is defined as being contained within the area outlined between the -3.0 and -15.5 mGal contours.

The iterative modelling procedure (Rollin, 1988) used here builds the model from a series of vertical square prisms. The fit to the residual Bouguer field is achieved by either altering the top or bottom surfaces of the prisms or by changing their densities. The horizontal dimensions of the prisms (x and y directions) have been set to 0.5 km. After some initial modelling runs, the densities were assigned to the prisms on the basis of the residual Bouguer value. Prisms between the -15.5 and -12.0 mGal contours have been assigned a density contrast of -0.1 Mg $m^{-3}$ (a density of 2.6 Mg $m^{-3}$ ) and those between the -12.0 and -3.0 mGal contours a density contrast of -0.08 Mg $m^{-3}$ (a density of 2.62 Mg $m^{-3}$ ). These densities represent typical granitic densities (see Table 1). Therefore, these have not been altered in creating the final model. Over most of the model, the top surface is the topographic surface, since volcanics and granites crop out. The majority of the changes to the model by the iterative procedure are therefore to the depth of the bottom surface.

Figure 12 shows the calculated gravity field from the model. Depths to the bottom surface are shown in Figure 13. The main deviations to the top surface are around Tuen Mun, where the top of the model drops to a depth of nearly 2.0 km. Further northeast, the outcrop of the Carboniferous meta-sedimentary rocks is marked by a fall to a depth of between 0.66 and 1.0 km. In the region of The Brothers islands the top of the model falls to a maximum depth of 1.4 km, which implies that the Carboniferous outcropping on The Brothers islands could be over 1 km thick.

Over much of the central New Territories the thickness of granite is about 2.5 km. Greater thicknesses are found in a line from Tolo Harbour to Tsing Yi, with a thickness of 8.5 km on the edge of Tolo Harbour. Below the Castle Peak area the thickness is 6.5 km. Two areas with thicknesses to 8.5 km are centred on [824, 830] and [820, 833] respectively. The second area is just to the south of Yuen Long and suggests that there is deep granite beneath the Carboniferous meta-sedimentary rocks. This region and the Castle Peak area are probably two separate intrusions. On southern and northern Lantau Island thicknesses of granitic material lie in the range 2.0 - 2.5 km. The situation on central Lantau Island is complicated by the anomaly maximum. In the eastern New Territories the thickness of the volcanics varies from very thin (zero thickness in the model) to around 1.0 km. The true thickness due to the anomaly on the east

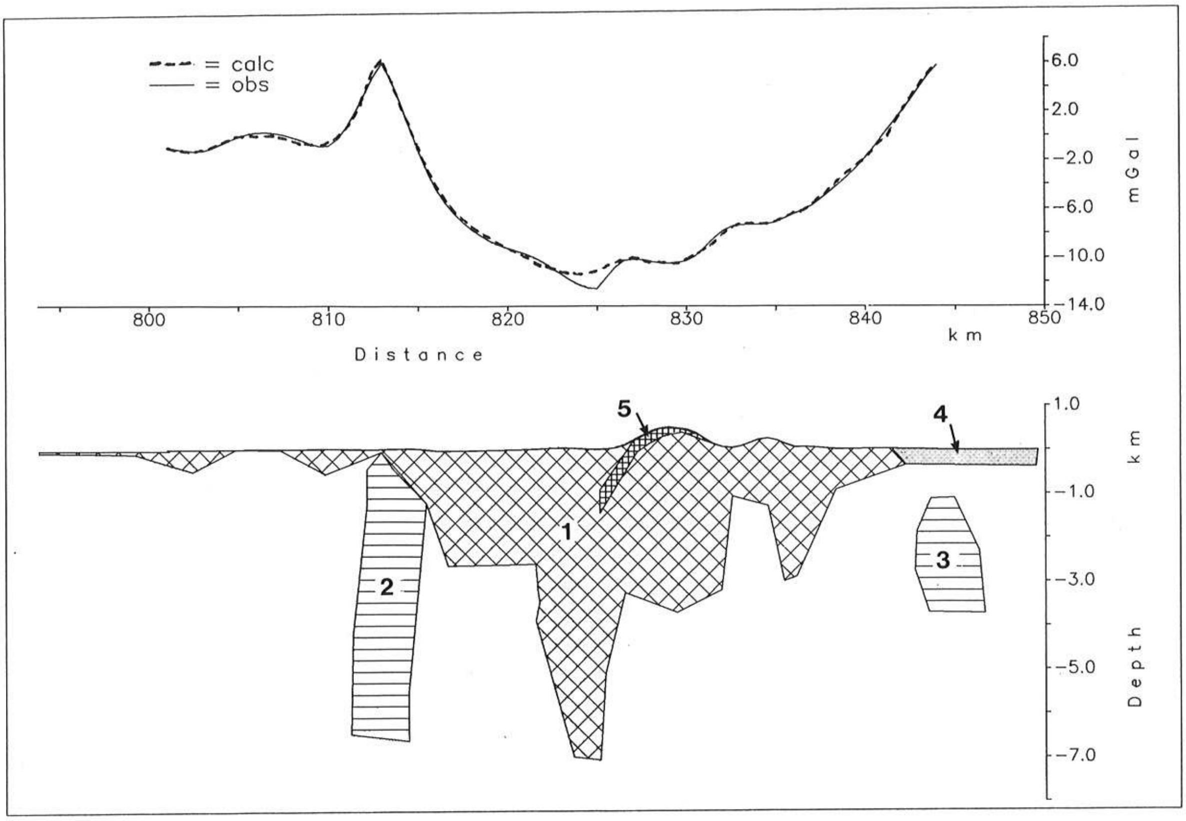


*Figure 10 - 2.5D model along easting 829 km. Polygon 1 is granite/volcanics of density 2.62 Mg $m^{-3}$, polygons 2 and 3 are basic intrusives of density 2.9 Mg $m^{-3}$, polygon 4 is Carboniferous metasandstone of density 2.64 Mg $m^{-3}$ and polygon 5 is granodiorite of density 2.72 Mg $m^{-3}$. The background density is 2.7 Mg $m^{-3}$.*

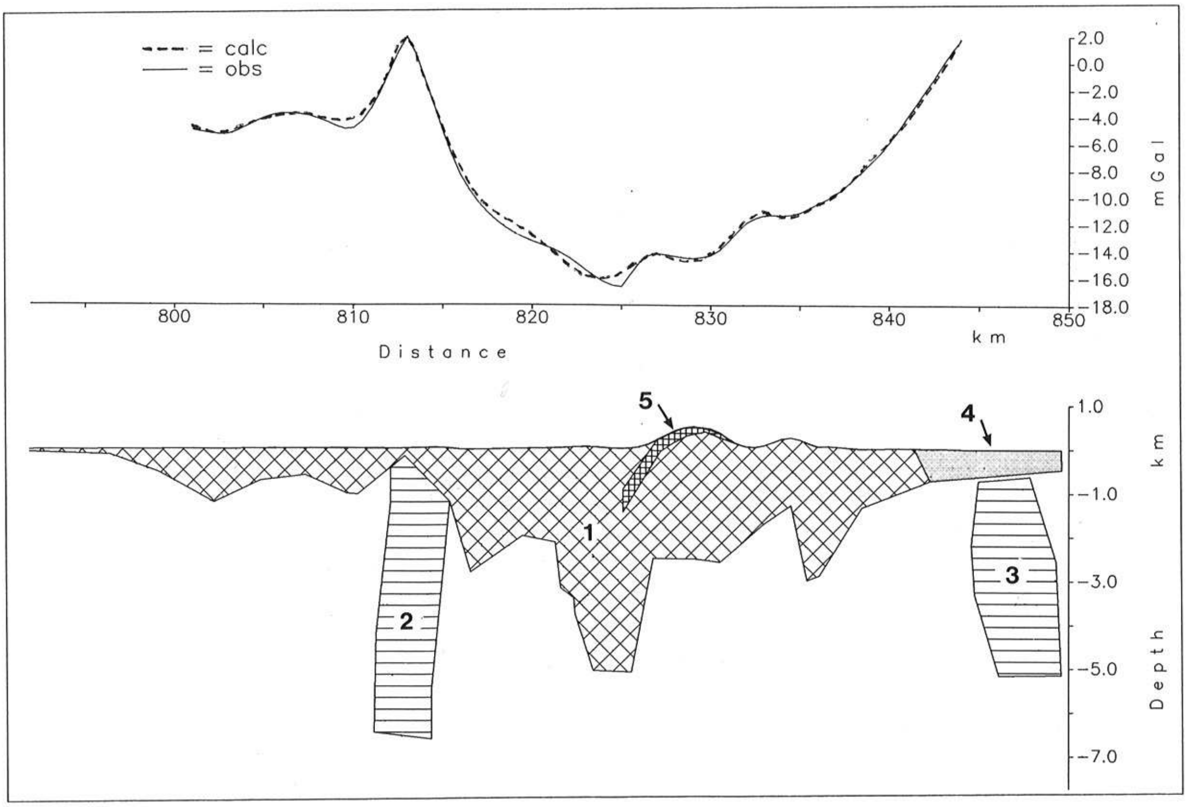


*Figure 11 - Modified 2.5D model along easting 829 km based on a more positive regional field. The polygons are the same as in Figure 10, but the background density is 2.75 Mg $m^{-3}$ .*

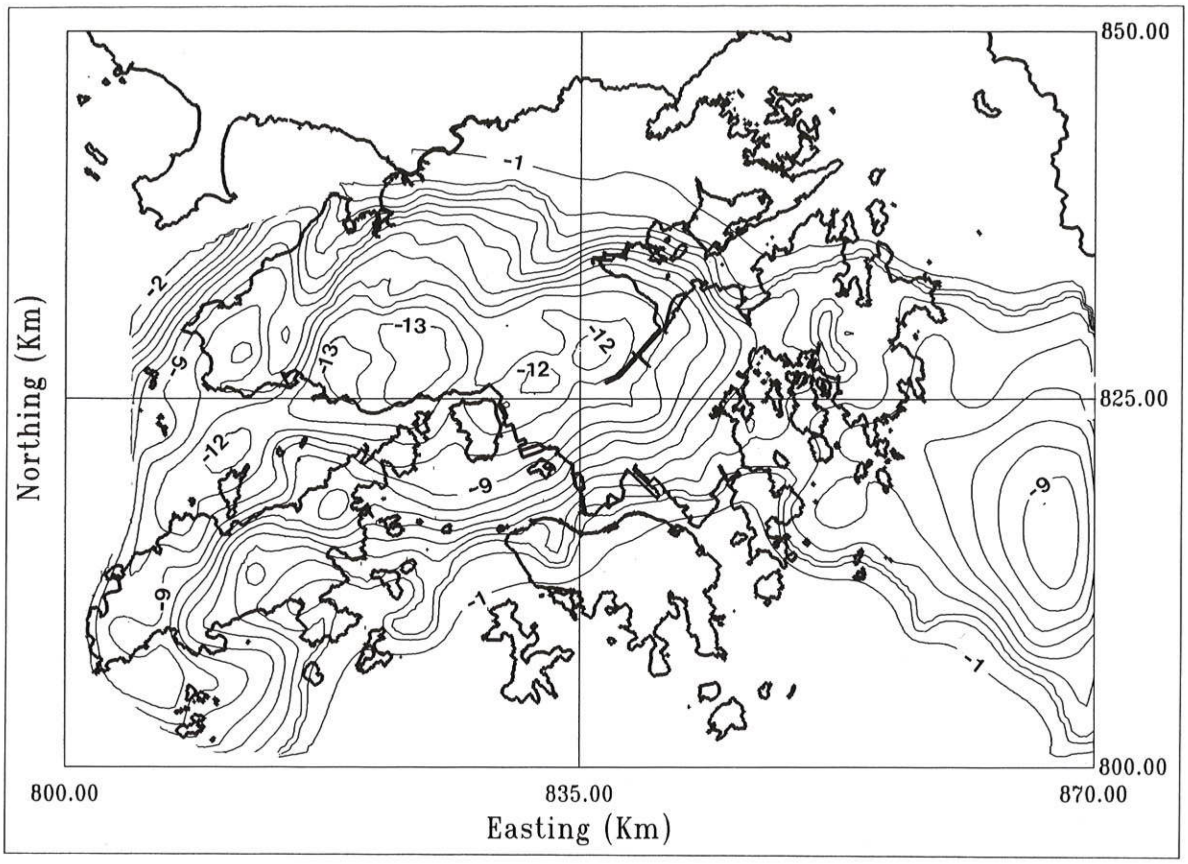


*Figure 12 - Calculated gravity field from the 3D granitic model contoured at 1mGal intervals.*

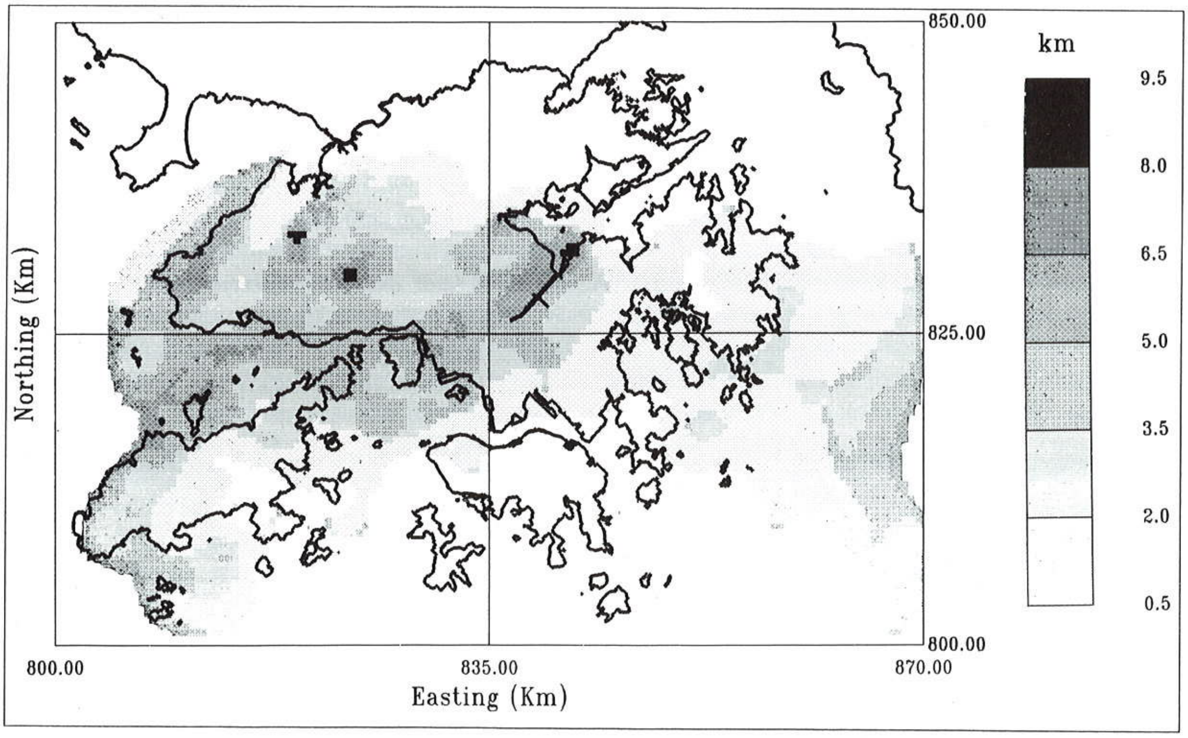


*Figure 13 - Depths to the bottom surface of the 3D granitic model from Principal Datum.*

of the survey area is not resolved by the modelling because granitic material extends beyond the area included in the model.

Three dimensional modelling has not been repeated with a more positive regional field because its effect would be compensated for by introducing a higher density basement. This has to be the case because the maximum depth of the granite is approaching mid-crustal dimensions. Any extension in depth would push the model into an area which has already been accounted for by the regional field.

**Conclusions**

The regional gravity data have been reduced to Bouguer gravity anomaly values. The resultant Bouguer gravity anomaly map is dominated by a deep low over the western New Territories and a high in the southeastern corner of the territory. The gradient which separates these two regions has an east to northeasterly trend. A smaller, easterly trending maximum crosses Mirs Bay.

Shadowgrams of the horizontal gradient highlight lineations and structural trends. The geophysical lineations identified correspond with the known northeasterly and northwesterly structural trends. However, many of the lineations do not correlate with mapped geological features.

A planar regional Bouguer anomaly field has been estimated from the Bouguer gravity anomaly map from the Atlas of Geology and Geophysics of the South China Sea (Ministry of Geology and Mineral Resources, 1984), and removed from the data to produce a residual Bouguer anomaly map.

Two and a half dimensional models have been created along two south to north profiles. To account for the positive anomalies in the south and in the Mirs Bay region, basic intrusive material, of probable Tertiary age, has been introduced at depth into the models. However, the exact form of this basic intrusive material cannot be determined because of the lack of deep geological information from boreholes or other geophysical methods.

The gravity anomaly based on a single station to the west of Hong Kong Island coincides with a large magnetic anomaly and has been modelled as a basic intrusion which comes very close to the surface. This intrusion may be Tertiary in age, but the basalt xenoliths in Cretaceous granite on northern Lamma Island indicate that it is possibly older.

The selection of a more positive regional field alters the amount of basic intrusive material in the models. There is a reduction in the south, but an expansion in the north.

The main negative residual anomaly has been modelled as a three dimensional granitic intrusion. Over much of the central New Territories, granitic thicknesses are about 2.5 km, but in several areas thicknesses of 6.5 to 8.5 km are inferred, e.g., between Tolo Harbour and Tsing Yi, and underlying Yuen Long and Castle Peak. On southern and northern Lantau Island thicknesses of granitic material vary between 2.0 and 2.5 km.

**Acknowledgements**

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# Shore Zone Fandelta Deposition At Ting Kok, Plover Cove

**B Chan, L Y Chan, S C Chan, K W Cheung, C M Keung, M Kwan, M Y Lam, M F Lee, S P Liu, L W Lo, R B Owen, O Y Seto, F S Sin, Y C Wan, and Y N Yiu**

*Department of Geography, Hong Kong Baptist University, 224 Waterloo Road, Kowloon Tong.*

**Abstract**

A study of shore zone sedimentation on the margins of a fandelta at Ting Kok has revealed the development of several facies types in the upper tidal zone. These include sand bars, pebble cobble bars, littoral silts, sands and granules, tidal muddy sands and gravels, coquinas and fluvial pebbles and cobbles. Possible causes for their formation and distribution include: the tidal regime, the direction of maximum wave energy, fandelta switching, longshore drift and typhoon events.

摘要

由汀角扇形三角洲邊緣海岸帶沉積作用的研究顯示在上層潮汐帶中，發育有幾種類型的沉積相。它們包括沙洲、印石一大卵石沙洲、濱相粉砂、砂和細礫，潮間淤泥質砂和礫石，貝殼灰岩和河流卵石及大卵石。它們的形成和分佈的原因可能包括潮汐動態，波能最大方向，扇形三角洲的擺動、沿岸漂移和颱風活動結果。

**Introduction**

Previous studies of the sedimentology and geomorphology of the Hong Kong coastline have often involved examinations of beach deposits (Wong, 1984; Williams, 1974). However, the shoreline is also characterised by a wide range of geomorphic environments that, for example, include erosional shore platforms and sea cliffs as well as wave-winnowed debris flows, tidal mud-flats, beaches and backshore sand dunes. In this paper, we report the major facies characteristics of a series of sub-environments associated with the shore zone of a medium scale fandelta.

The Ting Kok Fandelta was selected for study (Figure 1). This particular fandelta is fed by streams that drain the pyroclastics of the Repulse Bay Formation that form the southern slopes of the Pat Sin Leng Range. Quaternary debris flows and colluvial materials are also common in the drainage basin. The proximal part of the fandelta is incised into the Quaternary deposits and well-rounded boulders and pebbles of volcanic composition are abundant. The mid-fandelta has been heavily affected by the development of paddy fields, has few outcrops and consequently has not been studied here. The shore zone includes a variety of littoral pebbles, tidal sand dunes, tidal muds and fluvial pebble/cobble fields. Sediments are generally coarser to the east and finer to the west, and biological activity is significant as a sorting agent at the sub-environment level.

**Methods**

Eight profiles were selected for study along the coastal zone of the Ting Kok Fandelta (Figure 1). At each site slope angles were recorded using a clinometer and geomorphic block diagrams of the surrounding slopes and materials were compiled. Facies types were distinguished in the field and where the sediment was sand-size or smaller, samples were returned to the laboratory for analysis. Data for pebble and larger size material was recorded on site using a 1 $m^2$ grid. In each grid, the long, short and intermediate axes were recorded for 100 pebbles/cobbles using callipers (if sand was also present, this was returned to the laboratory). Sand and finer size materials were later dried and then sieved at 1/2 phi intervals.

**Results**

A wide range of facies types were recognised from the upper tidal zone of the fandelta. These are each described and assessed in the following sections.

I) The Sand Bar Facies

Discontinuous sand bars are common along the south-eastern shore, close to the modern mouth of the Ting

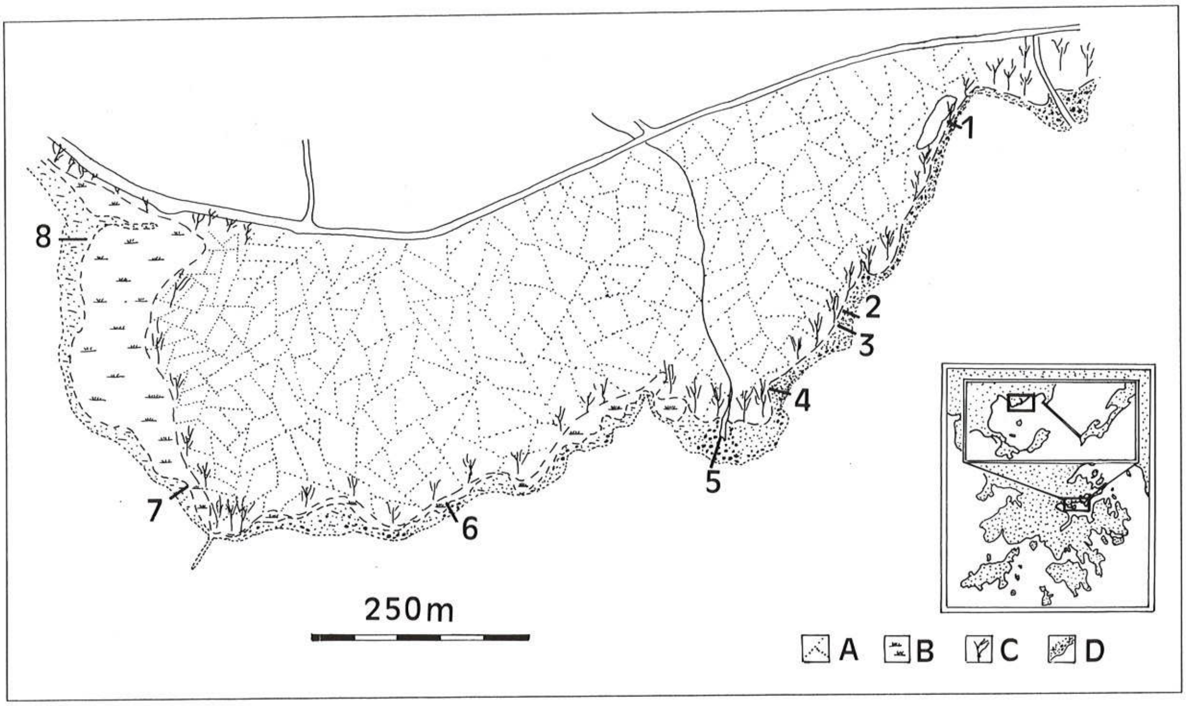


*Figure 1 - Location of the Ting Kok Fandelta and distribution of geomorphic sketch profiles. A: paddy fields, B: mangroves, C: woodland, D: shore zone sediments.*

Kok Fandelta, which probably represents a local sand source. Several bars are shown in profiles 3 and 4 (Figure 2). The sediments are very well sorted, with one sample having a SD=0.28 and a mean grain size of 0.39 mm (medium sand). In plan view, the bars range from straight crested to sinuous (Plate 1F), occasionally overtopping each other (profile 4), and appear to have migrated over other coastal sediments. Bar heights range from a few centimetres to about 80 cms. The longest straight crested bar extends for about 70 m. They are strongly asymmetric with the steep lee side facing towards the land. Shells are scarce and the sands are quartzofeldspathic. Wind blown ripples are common on the surface of many of the bars, though sediment structures were not visible due to the uniform grain size and lack of heavy mineral suites.

These deposits are interpreted as having formed under subaqueous conditions during high tides. Similar features were observed in areas that lay offshore during the time of sampling. Asymmetric bars are common features of nearshore sandy zones and are associated with the position of breaking waves. They can therefore be highly variable and change position with changes in tide, wave energy and direction. Wave energies at Ting Kok are probably quite low, given its sheltered location, the highest energies perhaps being associated with waves from the south east and typhoon conditions. Typhoons, in particular, may play an important role in the development of sandy shorelines (Williams, 1974) and may be more significant in accounting for the formation of sand bars close to or above the normal high tide level.

II) The Littoral Pebble/Cobble Bar Facies

Accumulations of pebbles and cobbles are common on most fandeltas. In Hong Kong, such accumulations are present along the shore zones of fandeltas at Nai Chung and along the western shore of Three Fathoms Cove (southern Tolo Harbour). Similarly, deposits of dispersed and concentrated pebbles and cobbles occur along the eastern and southern shores at Ting Kok (Plates 1A and 1B). This facies is largely absent from the western shore, but does occur within the relatively extensive mangrove areas landwards of the flats.

These deposits form linear accumulations parallel to the shoreline and occur as gently convex bars up to 10 m wide and several hundred meters in length. Two bars were clearly visible at profile 1 (Figure 2), with the lower bar extending offshore of profiles 2 and 3. The width of the lower bar is not known. The deposits consist of poorly sorted, subangular to subrounded clasts of volcanic tuff (the dominant source material) ranging in size up to about 10 cm. Zingg diagram plots of 100 clasts from several locations show a uniform pattern, with most particles falling into the spherical blade category. The density of clasts exposed at the surface is highly variable, ranging from a few percent to a total armouring of the surface. Pebbles and cobbles often have an outer, iron-stained, weathered zone of a few mm width. In some locations a dark weathered varnish (Mn?) coats pebbles.

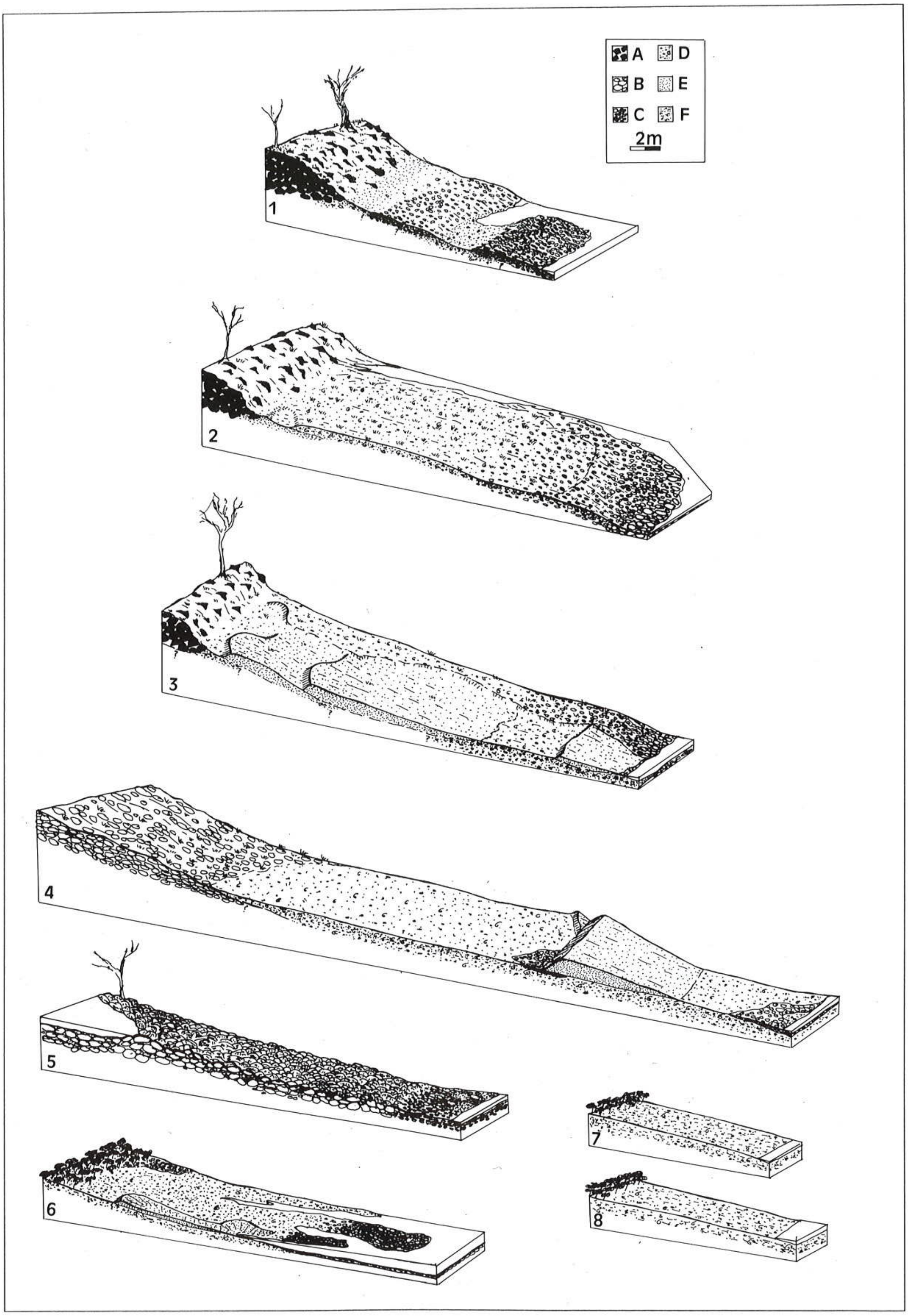


*Figure 2 - Geomorphic sketch profiles of the Ting Kok Fandelta. A: sea wall construction blocks, B: pebble to boulder size accumulations, C: pebble to cobble size accumulations, D: poorly sorted silts, sands and granules with shells, E. well sorted sands, F: muddy sands and granules.*

Sedimentary structures are poorly developed. In cross section the pebbles and cobbles range from clast to matrix supported and are normally massive in appearance. The linear, convex nature of the deposits suggest that wave action must exert an influence on the formation of the bars. Hjulstrom data suggest that water velocities of at least 40-50 cm per sec. are required to move pebbles of 10 cm size. However, pebble and cobble accumulations may in part be brought about by winnowing of fines rather than by the direct movement of the larger clasts. This latter possibility would imply that this facies represents a lag deposit.

III) The Littoral Silts, Sands and Granules Facies
Broad gently sloping spreads of silts, sands and granules are common on the eastern and southeastern shores of the fandelta. This facies consists of very coarse, very poorly sorted (mean=1.20 mm; SD=2.51 for profile 1) silts, sands and granules. Feldspar dominates and lithic fragments are common. Tall-spired gastropods are very common locally. In many areas sand bars and littoral pebble and cobble bars rest on these sediments, partially blocking off areas from the sea and forming lagoonal conditions during high tide.

These deposits represent mixed sediments that have been heavily bioturbated by organisms such as molluscs and crabs (Plate 1C). They occur in relatively high energy sectors of the fandelta and give way westwards to the Tidal Muddy Sands and Granules Facies discussed below.

IV) The Tidal Muddy Sands and Granules Facies
Tidal muds, sands and granules are common to the west and southwest of the Ting Kok Fandelta. There is a high degree of biogenic sorting in these areas. In some cases hollow crab (?) tubes are coated with clay linings. However the most obvious feature is the separation of sandy mud from granules. Sandy muds occur at abundant, slightly raised, mounds that are centred on hollow crab (?) tubes (Plate 1D). These mounds are surrounded by gravel accumulations with clasts of up to 6cm size, though with most particles being <1 cm. Two samples, not including gravel, gave mean grain sizes of 0.43 mm (SD=0.5) and 0.54 mm (SD=0.69) or medium to coarse sands. There is generally little relief in these sheltered areas, with flat slopes gently shelving seawards at an angle of <1°.

V) The Coquina Facies
Significant localised accumulations of shells occur along parts of the southern and western shores. These include two types: reworked and in situ materials.

i - Deposits consisting of almost entirely reworked shells occur in association with a few of the sinuous sand bars that are found close to the current river mouth. The sand bodies themselves contain relatively few shells and this association suggests a strong degree of sorting by wave and/or current action. The shells are quite well preserved, of uniform size and include bivalves and small oysters (Plate 1E).

ii - In situ growth of oysters is common along the upper tidal zone. Two sites appear to be favoured. These are the exposed aerial roots of mangroves and the large clasts found in the Pebble/Cobble Bar facies.

VI) The Fluvial Pebbles/Cobbles/Boulders Facies
Accumulations of poorly sorted subrounded to subangular pebbles, cobbles and boulders are common close to the mouth of the modern river of the Ting Kok Fandelta. Maximum clast size is about 40 cm, though most are considerably smaller. Plots of particle shape on Zingg diagrams indicate a broadly similar pattern to that found in the Pebble/Cobble Bar Facies (spherical blades), presumably reflecting lithological control of shape. Clasts have a very fresh appearance and none of the dark varnish seen on the surfaces of some particles from the Pebble/Cobble Bar Facies. This is likely to reflect differences between the dominantly erosional (abrasion) fluvial situation and exposure to marine and subaerial weathering processes (and erosion) in the shore zone environment.

**Discussion**

Several thorough studies of beach deposits have already been carried out within Hong Kong. However, the Territory contains a highly diverse set of coastal environments ranging from erosional headlands to depositional situations such as tidal flats, lagoons, estuaries and mangrove swamps. This study attempts to report on one of these "other" environmental settings. Such studies will be increasingly needed if Hong Kong's infrastructural developments continue to destroy much of the remaining depositional environments.

The Ting Kok Fandelta is a geographically small area that contains a wide range of depositional sub-environments. Such fandeltas are common in Hong Kong as a result of Holocene flooding of what is a particularly mountainous terrain. This has resulted in many steep slopes in close contact with marine shorelines. This study has concentrated on only the shore zone of the Ting Kok Fandelta, largely due to human agricultural interference with the mid and upper fandelta regions. Study of parts of fandeltas, lacking human impacts, would be needed before a complete model of sedimentation can be developed.

The dominant sediment types along the shoreline form the Littoral Pebble/Cobble Bar, the Littoral Silts, Sands and Gravels and the Tidal Muddy Sands and Granules Facies. Sediments are generally coarse in the eastern fandelta and become finer westwards. This also correlates with a change in slope angle, with steeper shores in the east and gentle flats occurring to the west. Possible causes of these patterns include

A

B

C

D

E

F

*Plate 1 - Major facies types from the shore zone of the Ting Kok Fandelta. See text for discussions. A & B: Littoral Pebble/Cobble Bar Facies, C: Littoral Sands and Granules Facies, D: Tidal Muddy Sands and Granules Facies, E: Coquina Facies, F: Sand Bar Facies.*

delta switching processes, the direction of maximum wave energy and long shore drift.

Switching processes occur on all alluvial fans, deltas and fandeltas. The process involves periodic shifts in channel position as successive streams and rivers attempt to find the shortest, steepest, route to the local base level. Currently the Ting Kok channel enters the sea to the southeast of the fandelta, close to the area of coarsest sediments. Conversely, abandoned areas, away from the channel, tend to accumulate fines in most models of fandelta sedimentation (Leeder, 1982). This is the situation that occurs today to the west of the Ting Kok Fandelta.

In general, the fandelta lies in a low wave energy setting, being well protected from most storms by the peninsulas and islands that surround Plover Cove. The strongest waves are likely to approach from the southeast, and perhaps be associated with typhoons, given the current land configuration. These waves would tend to winnow fine sediments from the eastern and southeastern shores and perhaps drive long shore drift processes in a westerly direction, carrying finer materials along the coast. The western-facing shore is well protected from southeasterly waves, producing calm, quiet water conditions. Both the sediment source and land configuration would therefore favour the formation of finer-grained facies in these parts of the fandelta.

The distribution of fine and coarse sediment types and the processes that cause such distributions may have some important practical implications for Hong Kong. Fine grained deposits, and particularly clays, show a high capacity for adsorbing pollutants from the water column. In one sense they are useful in removing such contaminants from the water, but alternatively they concentrate harmful materials in surface sediments that may be the homes of benthic organisms that lie at the base of the food chain. An understanding of the distribution of fine and coarse sediments may therefore be of more than academic significance.

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# An Example Of River Bank Erosion In Hong Kong

**M Peart**

*Department of Geography and Geology, University of Hong Kong, Pokfulam Road, Hong Kong*

**Abstract**

A reach of the Kam Tin River in the vicinity of Kam Tin recently experienced accelerated bank erosion. The reach had previously been modified by the Water Supplies Department for gauging station purposes and it appears that this cleaning and reshaping of the channel may have contributed to these failures. Examination of the site suggests that hydraulic action and mass movement were two dominant processes.

摘要

錦田河在錦田附近的河段，現正在加速遭受岸蝕作用，此河段先前曾由水務局施工修整過，用作計量站的，同時水道所呈現新的沖刷方式可能會對河流的坍塌起一定的作用，現場調查提出了水力作用和土體移動是兩個主因。

**Introduction**

River bank erosion has been investigated in many regions of the world and under a variety of conditions (c.f. Sundborg, 1956; Wolman, 1959; Twidale, 1964; Coleman, 1969; Klimek, 1974; Scott, 1978; Hooke, 1979; Simmons and Li, 1982; Neller, 1988; Xu and Shi, 1992; Thorne, 1992).

The literature reveals a number of reasons for investigating bank erosion. These include the fact that it influences changes in river channel course, flood plain development and therefore landscape evolution (e.g. Klimek, 1974; Hooke, 1980; Howard, 1992). It can result in loss of land and property and therefore has economic considerations (e.g. Hooke, 1979; U.S. Army Corps of Engineers, 1981). Bank erosion has also been found to be an important contributor of sediment to rivers (e.g. Kirkby, 1967). It may also impact upon river engineering (e.g. Thorne and Osman, 1988; Leeks et. al., 1988).

In Hong Kong there have been no reports of channel bank erosion. This may be due to the channels apparent stability and lack of obvious examples. It may also reflect the failure to recognise until recently the sedimentation problem in Hong Kong. However, following the study by Port Works (1988) concern over the sedimentation problem and erosion control have increased because they have an important bearing on recurrent maintenance of river engineering works undertaken for flood control.

The aim of this paper is to describe and explain the channel bank erosion observed during the summer and autumn of 1993 in a reach of the Kam Tin River which flows westwards past Kam Tin in the northwest New Territories to discharge into Deep Bay. The river channel is developed in alluvium which forms a floodplain. Erosion occurred just upstream of the Water Supplies Department gauging station (map reference JV985849) and at this point the basin has an area of around 12 $km^2$.

**The Study Reach**

Figure 1 shows the location of the study reach on the Kam Tin River which is around 200 metres in length and (after engineering works) had a width of around 8.7 metres at the water surface under baseflow conditions. At its deepest, channel bank height is around 3 metres. The bank material has a low clay content with 7% being the highest of five bulk samples. No material coarser than 2 mm was present in the samples and sand content ranged from 38% to 80% while the amount of silt ranged from 15% to 65%.

At Kam Tin the river has a maximum recorded daily discharge for the period of 1986 of 4.3 million $m^3$/day according to the Water Supplies Department (1989). For the same period the median daily discharge is around 24,000 $m^3$/day. The Kam Tin River responds quite rapidly to rainfall and there is at most only a few hours delay between maximum rainfall and the hydrograph peak. In September 1993 Typhoon Dot caused widespread flooding and the maximum recorded water level was just over 7 metres above prin-

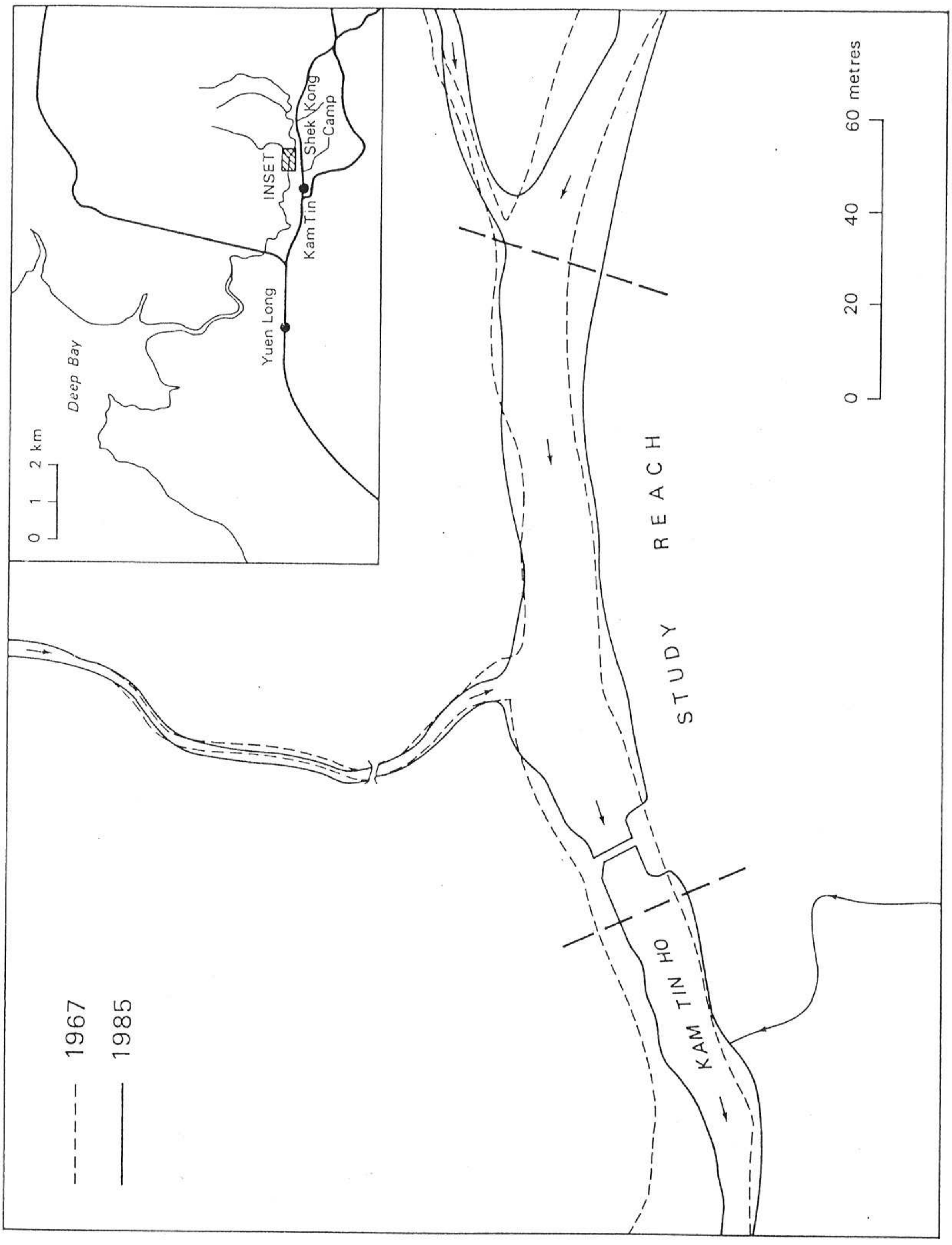


*Figure 1 - The study reach on the Kam Tin River*

cipal datum.

Comparison of the channel location for 1965 and 1985 in Figure 1 reveals the reach to be quite stable with no large changes in channel position being evident. Some of the differences between the two periods probably reflect the fact that the maps are produced photogrametrically.

During August 1993 the reach was cleaned or dredged in order to improve water level monitoring at the Water Supplies Department gauging station. It, and subsequent work in early 1994, may also have been carried out in order to improve drainage. The

*Plate 1 - The Kam Tin River before maintenance works*

work caused a significant change in the nature of the channel as shown in Plates 1 and 2 (a and b) which represent before and after channel maintenance. Channel maintenance resulted in the removal of vegetation and construction of a trapezoidal channel cross section with the banks sloping at around 30°. In Plate 2 there is also evidence of channel bank erosion. It appears that one of the consequences of the modification of the channel has been to promote erosion of the channel margin. This will be discussed in the following section.

**Erosion Mechanism**

Erosion of the channel margin at Kam Tin has occurred by hydraulic action. Following the passage of the first major flood wave (water levels rose from around 4.5 m PD to just over 7 m PD and caused flooding) after channel maintenance the banks had a pitted appearance. Prior to the flood of September 1993 their appearance was much smoother following compaction by machinery.

Plate 2 reveals that the most significant failure mechanism in the banks of Kam Tin has been by slumping following channel maintenance and removal. A number of explanations for the slumping exist. A major contributing factor may be the disturbance of vegetation cover, because, prior to clearance, floods in May and June 1993 caused no bank collapse. Maximum water levels in May are not available but on June 11th and 18th water level maximums of at least 6.4 m PD and 6.3 m PD respectively were recorded. Whilst these are not as high as for September 1993 they might have caused failure of the disturbed bank. This is evidence by the renewed failure of banks observed in June 1994 following a flood peak of at least 6.29 m PD comparable to those of 1993 which did not result in bank collapse.

Previous literature points to the stability conferred by vegetation. For example, Smith (1976) reports that bank sediment with a 5 cm root mat and a root volume of 16-18% had 20,000 times more resistance to erosion than banks lacking vegetation. Klimek (1974) has also stated: "The vegetation cover protects the Wisloka banks effectively against erosion. The root system of trees and shrubs plays a decisive role. The roots bind loose alluvial deposits and prevent them from liquefying or slumping." However, Smith (1976) has cautioned that the stabilising effect of vegetation may be absent in the lower areas of high river banks where root systems are absent.

During the winter of 1993/94 the tall grass vegetation cover returned to much of the channel. As reported above in June 1994 one of the first sizeable hydrographs of the year occurred causing a significant amount of bank failure by slumping. This could be evidence that vegetation is not a major factor in bank stability. More likely is the fact that the vegetation was not sufficiently well developed to confer stability.

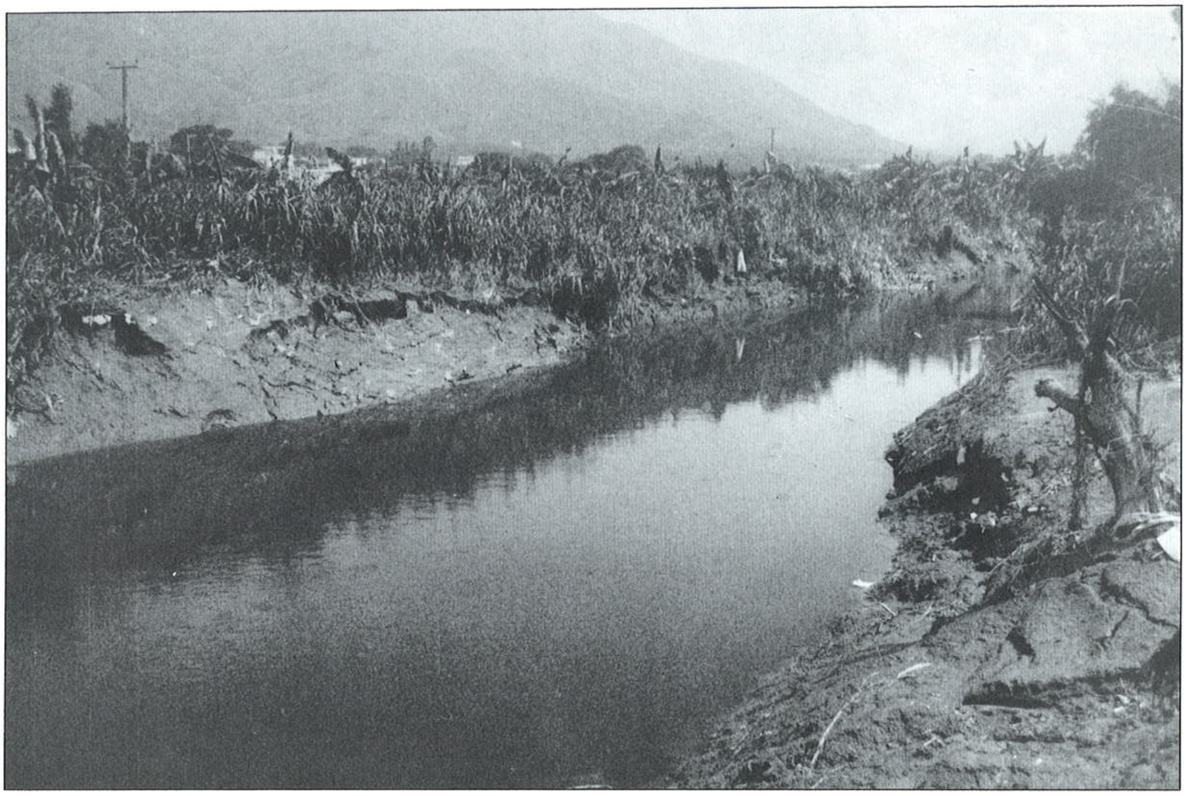

*Plate 2a - Bank failure along the Kam Tin River after maintenance works.*

*Plate 2b - Bank failure along the Kam Tin River after maintenance works.*

Bank geometry must also have played a part in failure. As Thorne (1982) remarks " the stability of cohesive banks is strongly dependent on both the bank angle and height." The failure at Kam Tin of the bank indicate that critical limits of one or both these factors was exceeded.

It seems likely that strength reduction associated with water content of the banks played a part in bank failure. As Thornes (1982) states: "In poorly drained banks, positive pore water pressure can weaken a bank by reducing its effective strength."

He suggested that one favourable time for failure would be after high water level during rapid drawdown. Klimek (1974) has also reported that groundwater efflux may cause slumping of channel banks after the passage of the flood wave while Twidale (1964) also reports slumping after passage of the storm hydrograph. There is evidence for slumping occurring after passage of the flood wave. On some failures the scar is well defined: if failure had occurred during high water levels the failure plane would have been eroded and therefore less well defined. The presence of the failed material also suggest collapse after the flood wave. In contrast some slumps exhibit a lack of failed material suggesting failure during the flood hydrograph. However, even if no pore water pressure effect occurs, Thorne (1982) has indicated that the rise in water content on the bank causes an increase in the unit weight of the bank and a decrease in bank strength thereby promoting bank failure. That high river levels may be needed to generate failure is evidenced by the study reach. Failure occurred in September 1993 following disturbance with some further modification in November 1993 in the next sizeable storm. However, from November 1993 to June 1994 no significant increases in water levels above baseflow occurred. No slumping of the banks was noticed and vegetation began to establish itself. However, following the rise of the river to well over 6 m PD on June 18th, 1994 mass movement was again visible on the channel margins. This suggests that saturation of the lower banks under baseflow does not cause mass movement and that high water levels in the river are needed to cause slumping. Hooke (1979) has reported that block collapse and slumping occurred predominantly at the lower bank. She suggests that this may be due to the fact that it may be that the lower bank is more rapidly and frequently wetted. Therefore, bank moisture may also explain the location of the failure of the bank. However, in the study reach failure occurs near the top of the banks but it does seem linked to wetting as implied by Hooke (1979).

In some cases the structure of the bank material influences erosion. For example, Thorne and Lewin (1979) describe how the composite nature of river banks on the River Severn in the United Kingdom (non-cohesive sand, gravel and cobbles overlain by cohesive sandy, silt sediments) may influence the erosion process. However, in the study reach at Kam Tin no such large textural change exists. Hooke (1979) also suggests bank material texture may govern susceptibility to failure by mass movement.

This example of bank erosion relates to a reach of river disturbed by humans. However, Plate 3, taken upstream on the same river, reveals that failure can also occur on undisturbed reaches. Plate 3 further highlights the existence of block collapse and hence mass movement failure on natural sections. Subsequent field work has revealed other evidence of bank failure by mass movement on natural reaches. However, it is not known if failure is more frequent on the disturbed section in comparison to the natural reaches.

**Conclusion**

Channel bank erosion has been little documented in Hong Kong. Channel maintenance near Kam Tin has led to the erosion of channel banks by both hydraulic action and mass movement. The example indicates that bank stability needs to be considered in river engineering especially if undertaken at a larger scale than the work at Kam Tin. The renewed erosion observed in June 1994 indicates that achievement of equilibrium or stability after disturbance may take time.

**Acknowledgement**

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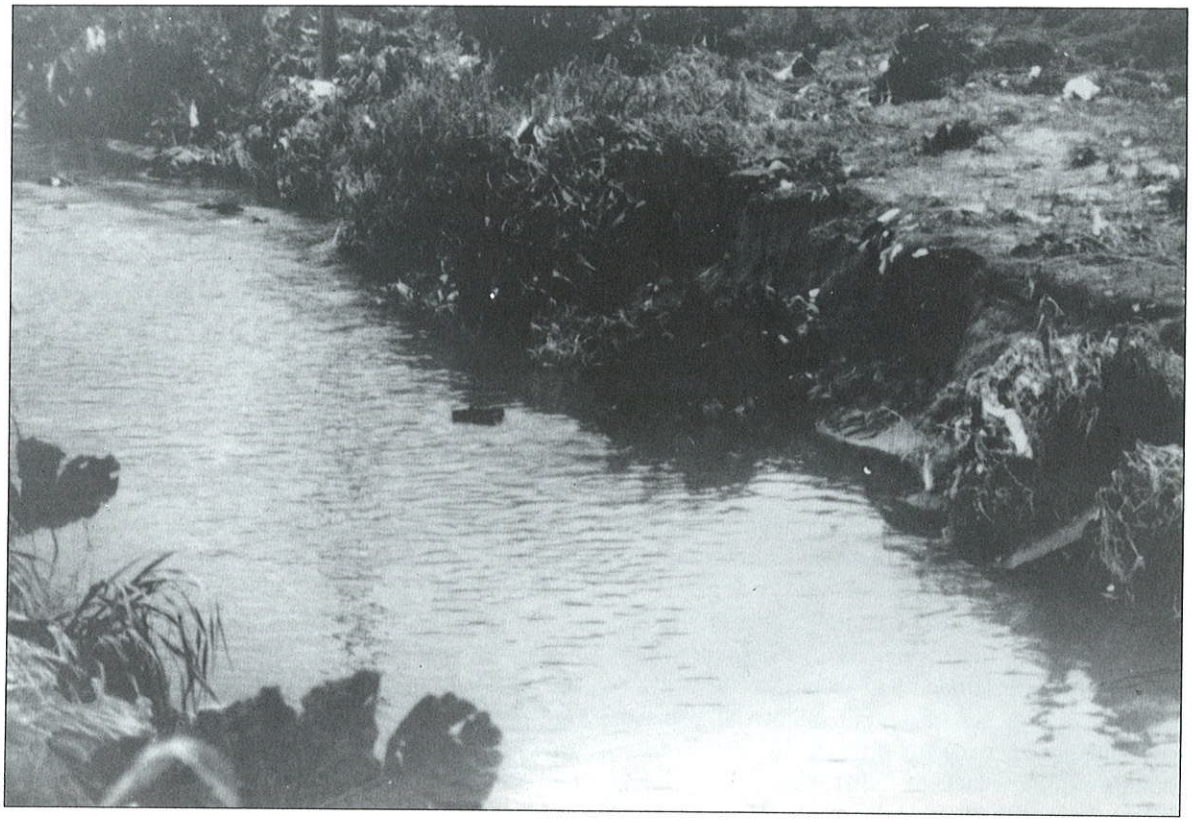

*Plate 3 - Channel bank collapse by mass movement along an undisturbed reach of the Kam Tin River.*

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# Trail Degradation Along The Pat Sin Range: An Example of Environmental Geomorphology

**Y F Leung[1] and R J Neller[2]**

[1] *Department of Forestry, Virginia Polytechnic Institute and State University, Virginia, USA*
[2] *Department of Geography, The Chinese University of Hong Kong, Shatin, NT, Hong Kong*

**Abstract**

This study investigated the extent, forms and environmental relationships of trail degradation along the Pat Sin Range in the New Territories of Hong Kong. Results showed that the trail was in good condition except for a few localities. There were significant poositive relationships between slope gradient and different degradation measures, though the strength of these relationships varied greatly between volcanic and sedimentary parent rocks. Implications for country park and trail management are discussed in light of these research findings.

摘要

本研究旨在調查香港新界八仙嶺遠足山徑的侵蝕退化狀況、特點、及其與環境的關係。結果顯示除個別地點以外，此山徑的退化情況並不算嚴重。多種退化指標均與山徑坡度有顯著的正關係，而此關係的強度卻在火山岩和沉積岩之間存在很大的差異。我們根據本研究的結果，對郊野公園及山徑管理提出了一些建議。

**Introduction**

The earth sciences are pertinent to many aspects of environmental management and perhaps this is no where better illustrated than in Hong Kong. Within the urban context, engineering geology, land planning, slope stability, underground constructions and waste management are a few of the many areas within which earth scientists have played major roles. However, the discipline can also contribute to the management of the surrounding non-urban countryside. Indeed one of the neglected applications of earth sciences in environmental management has been the management of country parks in the Territory.

Unfortunately, high visitation rates to Hong Kong's country parks causes detrimental impacts on the resource components that constitute the very environment to which visitors are attracted. Fire, trampling, littering and vandalism have major adverse impacts (Jim, 1986). These problems are further exacerbated by the uneven patterns of patronage, both spatially and temporally (Jim, 1989).

Trails (footpaths) are the main travel arteries within Hong Kong's country parks and many of these were created by villagers for convenience rather than with recreation or resource protection in mind. Many of these have degraded over time because of poor initial siting, recreational overuse and a lack of maintenance. The degradation of such trails represents a depletion of a non-renewable resource and a failure to maintain the character of an area. They are an eyesore, are unsafe, and are costly to repair. Erosional material from trail treads can also be a significant source of sediment which may cause adverse effects on aquatic life. Whilst aspects of trail degradation have been mentioned recurrently in Hong Kong, there remains a lack of published objective information that unfortunately precludes any systematic evaluation of the severity of the problem. This article therefore attempts to characterise the extent and forms of degradation of trails within the Pat Sin Leng Country Park in Hong Kong as an example of how earth scientists, particularly geomorphologists, can contribute to environmental management.

**Study Area**

This study focuses on the degradation of trails (compaction, widening, incision, erosion and multiple treads; as defined by Leung and Marion, in press) along the Pat Sin Range in the New Territories of Hong Kong (Figure 1). This is one of the most popular hiking routes in the Territory because of the out-

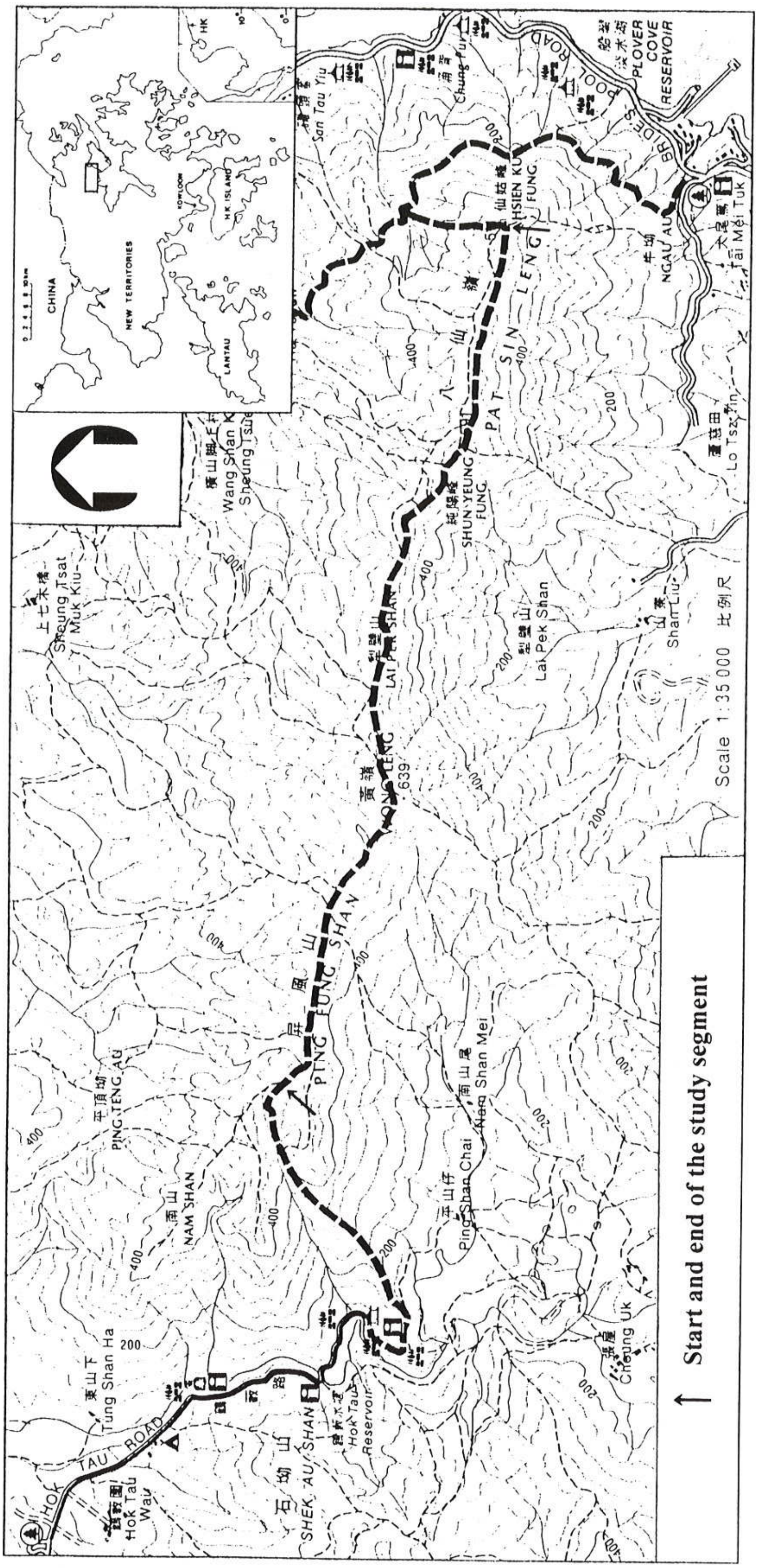


*Figure 1: Location of the Pat Sin Range Trail.*

standing panoramic views. The country park features an escarpment dramatically rising from the northwest shores of Tolo Harbour. The trail traverses a number of ridges and provides a variety of relief, from level passes to steep slopes. The total length of the trail is eight kilometres, though this study focused on the six kilometres from Hsien Ku Fung to Ping Fung Shan (Figure 1).

The Pat Sin Range area is underlain by both volcanic rocks (coarse ash crystalline tuff) at Pat Sin Leng and sedimentary rocks (conglomerates, sandstones and siltstones) west of Lei Pek Shan. Weathering has proceeded more intensely on the volcanic rocks leading to a more developed red-yellow podsol, as opposed to the skeletal lithosols typical of the sedimentary areas (GCO, 1988). Vegetation is dominated by *Rhodomyrtus tomentosa* and *Arundinella nepalensis* on the volcanic rocks, whilst on the sedimentary rocks vegetation is characterised by *Baeckea frutescens*, *Dicranopteris dichotoma* and *Lepidosperma chinensis*.

**Methods**

A post-impact cross-sectional research approach was by necessity adopted. At systematically selected sample sites along the trail (100 metre intervals), degradation indicator variables were measured simultaneously on the trail and at adjacent off-trail control sites. Degradation indicators that were measured included penetration resistance (absolute and relative changes), trail morphology (width, incision, form), trail surface (roughness, cover) and the presence of multiple trails. Various site condition variables were also measured: trail and terrain slopes, aspect, position, underlying materials, textural characteristics, aggregate stability, pH and organic carbon. Of the 58 sample sites 23 were located on rocks of volcanic origin. Further details on the methods and procedures employed are available in Leung (1992).

**Degradation Condition**

There was considerable variability in width along the trail, from a 34 cm single tread at Ping Fung Shan, to the combined multi-treads of the Pat Sin Range (total width of 670 cm). Whilst strictly comparable data (similar usage, relief, geology and so on) from elsewhere were lacking, the average tread width of 100 cm along the Pat Sin Trail appears to be unusually wide when compared to a variety of other studies (Table 1). For example, the maximum tread width specified by various forest service departments ranges between 61 and 70 cm (Lucas, 1984; Cole, 1987). Although the Pat Sin Range Trail is not forested, this average figure still appears unusually high. This should be a matter of concern for resource managers, as the trail crisscrosses open grassland, causing visual irritation to recreationalists and exposing bare ground for soil erosion.

In contrast, the average incision depth along the Pat Sin Range Trail is not as great as that experienced in other countries (Table 1). Incision depth ranges between 0 and 26 cm with an average of 3 cm. Whilst there are no published guidelines on acceptable incision depths, comparisons with criteria used by other researchers to classify trails (Bayfield and Lloyd, 1973; Bratton et al., 1979; Cole, 1983a) as either good or poor, reveal that incision depths along the Pat Sin Range Trail are generally good. Incised tread surfaces can function as rills and small gullies within which flows are channelled. Therefore shallow incision depths are desirable.

Multiple treads, or secondary paths, are a form of trail widening and are essentially caused by either actual or perceived difficulties of walking. At only five of the sample sites (8.6%) did more than one tread exist and only at one of these sites were there more than two treads. The lack of multiple treading on the Pat Sin Range Trail can be attributed to steep sideslopes which discourage hikers from wandering off the established trail tread.

The mean penetration resistance recorded at seven locations across each of the 58 trail samples (Figure 2) illustrates that there were few differences amongst the off-trail sites, and few differences amongst the trail tread sites, but that there were major differences between trail tread and off-trail sites. This suggests that once the trail has been established and readily identified by hikers, compaction impact remains localised to the tread surfaces. The absolute compaction levels are not readily comparable with data from other studies (due to differing measurement techniques and soil character) so they were converted to relative changes in penetration resistance between the trail and the surrounding area. Comparisons with a variety of other studies from differing environments within the USA (Table 2) revealed that there is only a small relative rise in compaction along this trail, and that this probably reflects the relatively high penetration resistance of the natural soils.

62% of the sites along the Pat Sin Range were categorised as very stony to extremely stony, though there were clear differences between volcanic and sedimentary terrains. 65% of the sample sites within the volcanic terrain were categorised as moderately stony whereas 80% of the sample sites in the sedimentary terrain were classified as very to extremely stony.

Additional evidence of degradation was observed in the field, including two rutted trail segments that forced hikers to walk either side of the trail, large bare patches at trail junctions (group resting places; Figure 3), stony outwash deposits on steeper slope segments that induced off-trail wandering (due to unpleasant tread surface) and occasional informal shortcut trail segments.

Although the above summary provides valu-

Table 1: Comparison of the results of trail degradation studies in different environments

| Trail | Location | Number of Sites | Average Tread Width (cm) | Average Depth (cm) | Average Maximum Depth (cm) | Cross Section Area (cm²) | Data Source |
|---|---|---|---|---|---|---|---|
| Poor trails in GSMNP[1] | Eastern USA | 623 | 101-113 | NA | 7.4-7.7 | NA | Bratton et al. (1979) |
| Good trails in GSMNP | Eastern USA | 414 | 40-84 | NA | 1.2-2.3 | NA | Bratton et al (1979) |
| Bannerman's Hut Path | South Africa | 44 | 62.4 | 18.0 | NA | 132 | Garland et al. (1985) |
| Giant's Ridge Path | South Africa | 89 | 49.9 | 16.7 | NA | 76 | Garland et al. (1985) |
| Contour Path | South Africa | 51 | 40.7 | 12.5 | NA | 54 | Garland et al. (1985) |
| Appalachian Trail | Eastern USA | 221 | 76.5 (2.06) | 6.4 (0.29) | NA | 312.3 (22.35) | Burde & Renfro (1986) |
| Pangnirtung Pass | Arctic Canada | 25 | 28.7 | 4.3 | NA | NA | Welch & Churchill (1986) |
| Big Creek Trail in SBWW[2] | Western USA | 10 | 81 [9] | NA | 15 [3] | 1155 [43] | Cole (1991) |
| Pat Sin Range Trail | Hong Kong | 58 | 99.8 (11.39) | 3.3 (0.36) | 6.7 (0.71) | 333.4 (73.38) | Leung (1992) |

Note: (fig.) = standard error; [fig.] = 95% confidence interval; NA = not available
[1] GSMNP - Great Smoky Mountain National Park
[2] SBWW - Selway-Bitterroot Wilderness

able information, it would nevertheless be useful in the assessment of trail degradation if park managers were provided with an index that reflects the overall level of degradation indicated by these parameters. This index could also assist in identifying relationships between degradation and environmental site factors. Although an integrated index is not new in recreational impact research, particularly with campsite studies (Marion, 1986), there has been little attempt to produce an index for trail degradation. In this study the z-score standardization method was used, whereby the z scores for tread width, maximum incision depth, cross-sectional area and multiple treading were computed and then summed into a single index, here referred to as the Degradation Score.

The means of the z scores for each parameter were of course zero with a standard deviation of one. When these parameters were combined into a single value the mean of this newly formed Degradation Score remained unchanged, but the median changed to -0.15, indicating that the majority of sites had below average Degradation Scores and that exceptionally high Degradation Scores were limited to only a few sites. Altogether 67% of the sites had Degradation Scores less than zero and 33% had Degradation Scores greater than zero. These later sites can thus be classified as 'degraded' on the basis that the variables representing bare ground, rutting and erosion are above average, though from a management point of view they need not be of immediate concern. The relationship between these degraded sites and the environmental site conditions can now be examined in more detail.

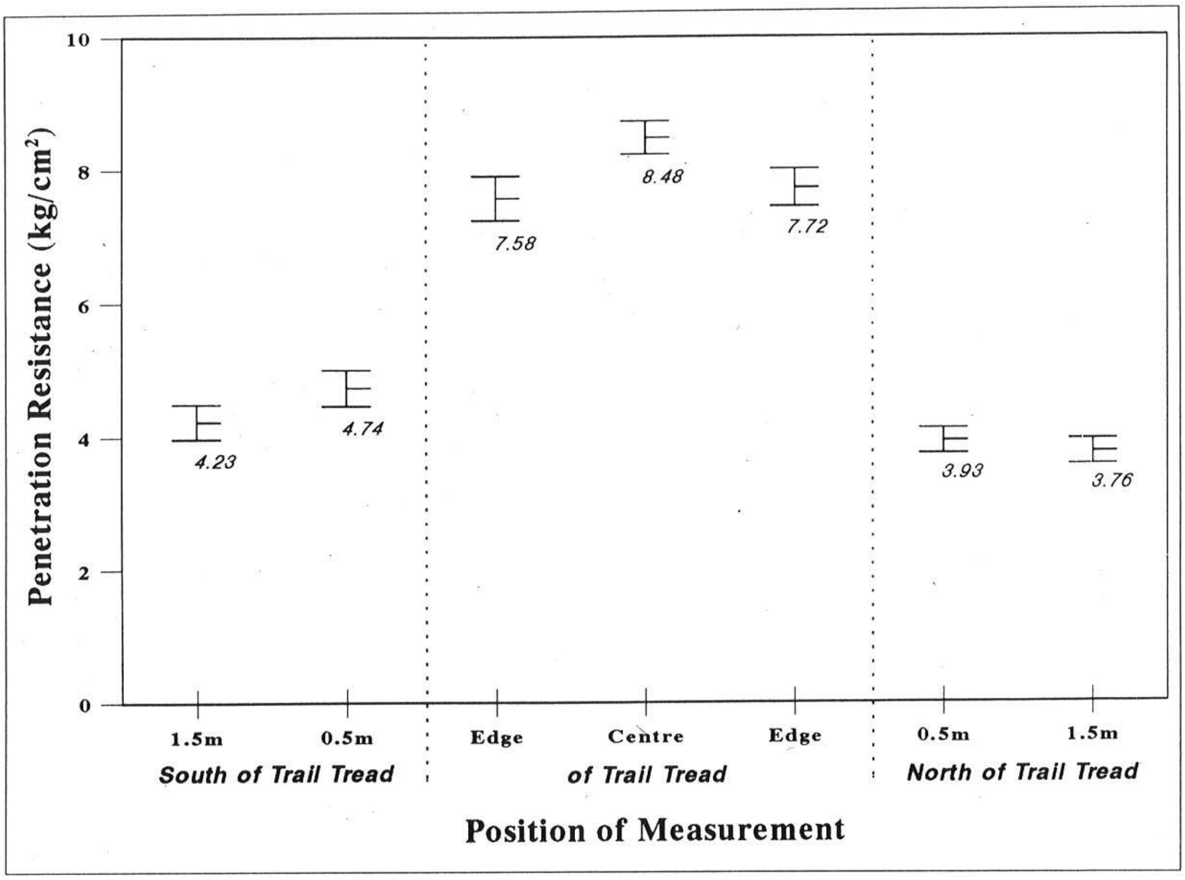


*Figure 2 - Mean penetration resistance (± 1 standard error) on and beside the tread of Pat Sin Range Trail.*

Table 2: Relative changes of penetration resistance reported in recreation impact studies (using pocket penetrometers)

| Geographic Location | Ecosystem Type | Location of Impact | Average Penetration Resistance at Control Sites ($kg/cm^2$) | Relative Increase in Pen.Res.[1] | Data Source |
|---|---|---|---|---|---|
| Michigan USA | Needleleaf Forest | Trail | 0.24 | 14.77 | Ward and Berg (1973) |
| Rhode Is. USA | Oak Forest | Picnic Site | 1.25 | 1.44 | Brown et al. (1977) |
| Montana USA | Subalpine Forest | Campsite | 2.20 | 0.71 | Cole (1983b) |
| Minnesota USA | Needleleaf Forest | Campsite | 1.40 | 1.64 | Marion and Merriam (1985) |
| Arizona USA | Desert Woodland | Campsite | 0.70 | 3.37 | Cole (1986) |
| Hong Kong | Subtropical Grassland | Trail | 4.22 | 1.09 | Leung (1992) |

[1] The increase in penetration resistance at the impact zone relative to its nearby undisturbed control site.

*Figure 3 - Extensive soil loss at a trail junction on Ping Fung Shan.*

**Relationship between Degradation and Site Conditions**

(a) Geological and soil factors

The influence of parent material was quite limited in this study area despite two contrasting underlying materials. Firstly, there was little difference in the degree of degradation between the two major rock types, 30% of the volcanic rock sites were classified as degraded as opposed to 34% of the volcanic rock sites. Similarly, there was little relationship between soil properties, such as aggregate stability and clay ratio, and the degree of degradation. This suggests that whilst these soil parameters might be useful indicators for estimating the susceptibility of agricultural soils to erosion, they may be ineffective as indicators of trail degradation in which rill- and gully-type erosional processes are important components.

Tread compaction on the other hand does bear some relationship to organic matter content and to a lesser extent to soil textural characteristics. A significant positive correlation ($r=0.38$; $p<0.01$) between organic matter content and percent increase in penetration resistance can be explained by the role of organic matter in facilitating the absorption of water and promoting lower soil density, hence increasing the susceptibility to compaction when trampled. There was also evidence that clay loams were less susceptible to compaction than were loams or sandy loams (the percentage of such sites exhibiting degradation being 27, 33 and 43 respectively).

(b) Locational Factors

Elevation, aspect, relief and slope position are attributes of location. Of these, elevation is often reported as a significant factor in trail degradation (Bratton et al., 1979; Cole, 1987), though its influence in this study is negligible as altitude varied little along the trail.

Aspect can generate a set of physiographical variations such as soil moisture, soil temperature and ecosystem type, though no immediate relationship between degradation and aspect was observed along the Pat Sin Range Trail. However an interesting association was observed when geology was included, with the proportion of degraded sites on western facing slopes being double that on eastern facing slopes within the volcanics. This association, whilst possibly reflecting the dip slope, is more likely to reflect user behaviour. Most hikers approach the trail from the east (from Hsien Ku Fung) and eastern slopes were mainly subject to uphill walking as opposed to the predominantly downward walking on the western slopes. It has been documented that downhill walking is more damaging to trails (Bayfield, 1973; Weaver and dale, 1978)

Both trail and terrain slopes were measured, of which trail slope statistically correlated significantly with trail width, maximum incision, trail cross-sectional area, surface roughness, trail compaction and the summary Degradation Scores within the volcanic rock environments, and with maximum incision depth and surface roughness within the sedimentary rock environments. An example of the sort of relationships that were derived is provided in Figure 4. Most of these relationships can be explained as a function of the increased erosion potential (Figure 5), though this does not readily explain the relationship between trail slope and trail width. Once again this more probably reflects user behaviour, as the shorter pace length and halting behaviour of people on steeper slopes has been observed to cause considerable damage. Moreover, when faced with the actual (or perceived) steepness of some slopes, hikers tend to seek the safer footing of the tread grass interface. This is particularly pronounced when hikers are looking downwards.

The contrasting observations for the volcanic and sedimentary environments are partly explained by the inherently higher susceptibility to erosion of the volcanic derived soil. Moreover, the finer texture of the volcanics would promote slippery conditions

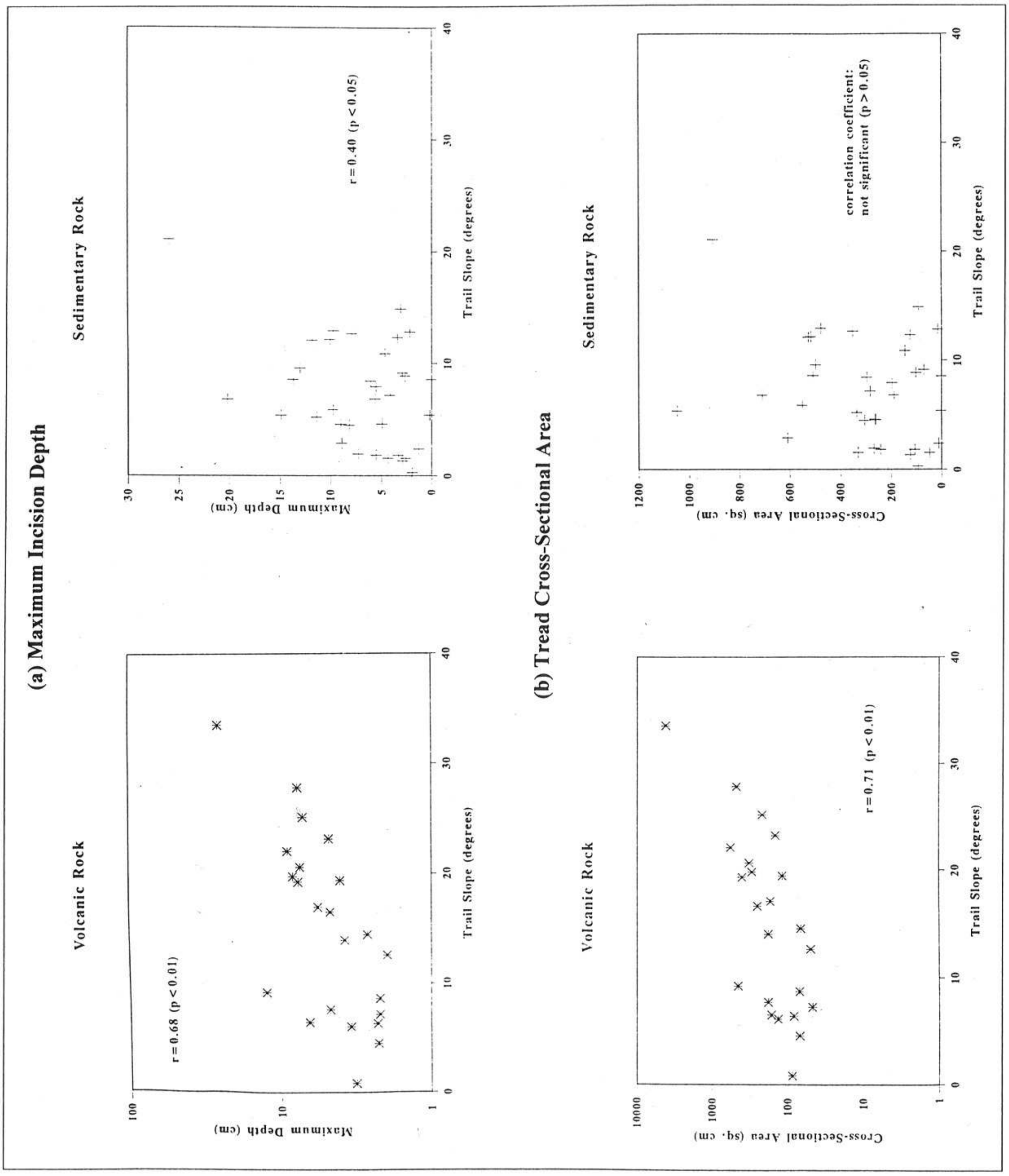


*Figure 4 - Relationship between trail slope and maximum incision depth, and between trail slope and tread cross-sectional area, by geology.*

*Figure 5 - Rutted trail segment on steep slopes in the vicinity of Wong Leng.*

when wet and encourage off-trail wandering behaviour on steeper ground.

Trail position is yet another locational factor that influences degradation and it has been generally observed that direct ascent trails (those that are aligned with the hillslope) are more prone to damage than the oblique or contour trails. At a general level this was also observed along the Pat Sin Range, though once again more so within the volcanic trail segments. It is, however, difficult to clearly separate trail position from trail slope and a high degree of inter-correlation between these two variables is possible.

**Management Implications**

Trail degradation, in its many forms, affects both the quality of the environment and the recreational experience. Within the grassy hill settings of many of Hong Kong's country parks, trails are clearly observable and degradation has an aesthetic impact well beyond its immediate locality. Park managers need information on the status, causal factors and processes of degradation, and geomorphologists clearly have a role to play in such investigations.

The Pat Sin Range trail is generally in good condition though severe degradation was recorded at a number of sites. As trail slope was the single most useful predictor of a range of degradation indicators immediate attention should be directed towards steep, direct-ascent trail segments (slopes > 20°), particularly within volcanic settings. Where possible, these trails should be realigned obliquely at sidehill locations and maintained in such a way that hikers perceive safe footing. With respect to practical management applications it is apparent that the government's educational 'package' for hikers focuses on the reduction of littering and hill fires, with minimal attention to a responsible 'hiking code' of behaviour that emphasises trail maintenance and off-trail conduct.

It is recommended that Country Park brochures and Visitors Centres should promote this aspect of environmental consciousness by including sections on individual responsibility for trail maintenance and erosional control. Given the rapidly increasing pressure on the countryside this educational campaign needs to begin as soon as possible.

Further studies are also under way. In particular a very detailed monitoring programme of Tap Mun Island trails is nearing completion (Ho, in prep.). Using a micro-profiler and sediment traps, very precise measurements of erosion have been related to user intensity. Nevertheless, some of the more severely eroded trails are to be found in granitic terrains and as yet there remains little information on trail degradation in these environments.

**Acknowledgments**

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*Hong Kong Geologist, 1995, 1 (Autumn), 88-92*

# Hong Kong Landform Series, No. 2: Granite Weathering and Deep Weathering Profiles

**R Shaw**

*Hong Kong Geological Survey, Geotechnical Engineering Office, 11/F Civil Engineering Building, 101 Princess Margaret Road, Homantin, Kowloon, Hong Kong.*

## Rock Weathering

Weathering is the destructive process, or group of processes, by which earthy and rocky materials on exposure to atmospheric agents at or near the earth's surface are changed in colour, texture, composition, firmness or form with little or no transport of the loosened or altered material (Bates & Jackson, 1987). It is an *in situ* process. It is generally considered to comprise two major subdivisions, mechanical disintegration and chemical decomposition. Biological action may assist or enhance mechanical or chemical processes. Weathering occurs predominantly at the ground surface, but in well-jointed rocks the effects may penetrate to considerable depths through the agents of atmospheric oxygen and circulating ground waters.

The main variables that effect the rate and extent of weathering are climate, parent rock, vegetation, topography and time (Jenny, 1941). High temperatures and high rainfall promote chemical weathering. Temperature influences the rate of chemical and biochemical processes, and water is important as it involved in most weathering processes (Birkeland, 1974). Thus in tropical and subtropical climates, chemical weathering produces thick layers of rotten rocks termed weathered mantles. Weathered mantles retain the texture and structure of the fresh parent rock, although the rock may crumble and individual minerals appear dull or be altered. Weathering extends down in the rock mass to a surface termed the weathering front (Mabbutt, 1961), below which partially weathered, massive rock occurs. The transition may be gradational or abrupt and is commonly irregular, descending down weathered joint planes. At the ground surface pedogenic, or soil forming, processes promote a secondary weathering stage. These are strongly influenced by biological activity, in particular the effects of vegetation, which results in the destruction of the original rock texture and structure, and the development of distinctive pedological soil horizons. In Hong Kong many of the upland areas have been terraced for cultivation, with considerably modified, agricultural soils at the surface. Particularly in hilly districts there is commonly a layer that has been disrupted by gravitational displacement, termed the creep layer (Photo 1).

## Deep Weathering Profiles

Between the weathering front at depth and the pedological soil at the surface a number of zones may be distinguished, which together comprise the weathering profile. A weathering profile is thus defined as the vertical sequence of weathered rock extending from the land surface to the unweathered parent rock. It was described by Ruxton & Berry (1957, p. 1267) as "the expression of the sequence of changes necessary to bring the fresh rock into equilibrium with the near-surface environment". In granitic rocks, or other corestone-forming lithologies, up to four major zones (I to IV) may be present (Ruxton & Berry, 1957), with three additional horizons common (a-c). These are (Figure 1) :

a. **The pedological soil** on the surface that is usually intensively bioturbated, contains relatively abundant organic matter and commonly displays distinctive pedological horizons. This was termed the soil profile by Ruxton & Berry (1957).

b. **A creep layer** or mobile zone that shows evidence of lateral, downslope, movement in the form of curvature of weathering-resistant veins and disruption of the original rock texture and structure (Photo 1).

I. **A zone of weathered rock** that is weak and friable, but preserves the original rock texture. It does not contain any corestones, that is rounded blocks of relatively fresh rock (Photo 1). In Hong Kong this zone is common, but the material may vary from being physically disintegrated, in which the feldspars are still hard and only the grain boundaries have become weakened through weathering, to a condition in which the feldspars are all weathered to soft clays. Weathered layers that are clay-rich and corestone-free are termed saprolite.

II. **A zone of rounded, spheroidally-weathered corestones** (Photo 2). These may be widely scattered or abundant, and they may increase in frequency down the profile or be concentrated in vertical bands. The corestone-bearing zone is not always present in weathering profiles in Hong Kong.

III. **A zone of rectangular corestones** with faces

*Photo 1 - The Zone of Corestone-free Weathered Rock (Zone I) with an Upper Creep Layer Indicated by the Curved Quartz Vein. Tai Tam Reservoir Road, Hong Kong Island (83905 81340).*

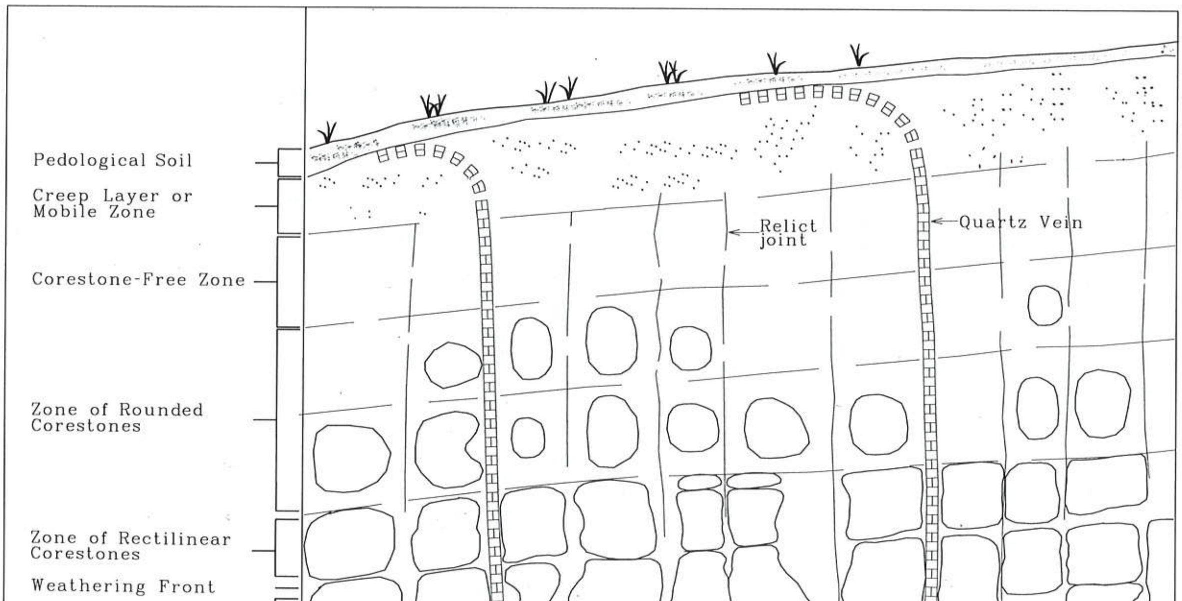


*Figure 1 - Diagrammatical Representation of the Zones of a Weathered Profile on Granite.*

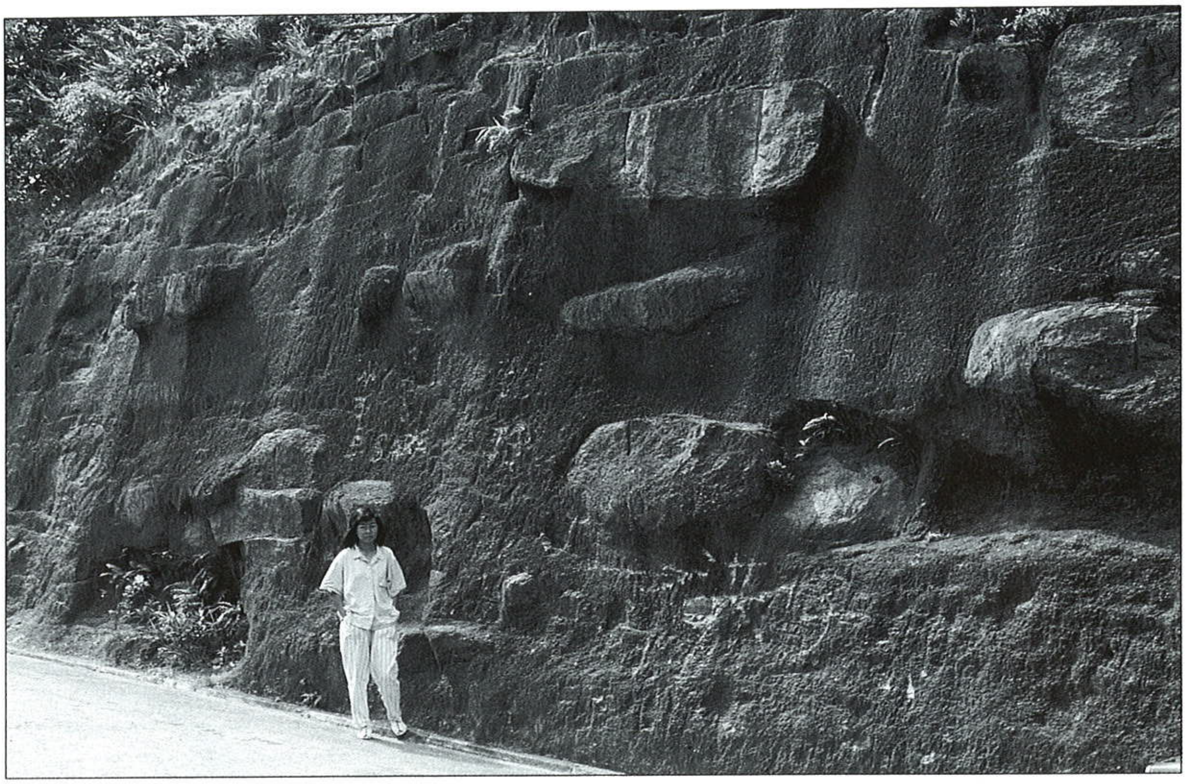

*Photo 2 - The Corestone-bearing Zone (Zone II). Tai Tam Reservoir Road, Hong Kong Island (83870 81340).*

that closely follow the original joint pattern (Photo 3). The bands of weathered matrix between the corestones generally decrease in width down the profile.

c. **The weathering front**, originally termed the basal platform by Linton (1955) and the basal surface by Ruxton & Berry (1959). This surface is usually undulating and irregular and, depending upon the joint spacing and weathering characteristics of the original rock, has pinnacles of sound rock separated by deep discontinuities widened by weathering.

IV. **The zone of relatively unweathered rock.** Atmospheric agencies, through the medium of groundwater, penetrate to great depths in rock masses, therefore the rock is almost invariably slightly discoloured and partially weathered well below the weathering front. Weathered joints also penetrate for considerable depths.

Weathering profiles are highly variable in their thickness and composition depending upon the original rock structure, weathering history, present topography and other controlling factors. They achieve their maximum development on the granitic rocks where they are commonly 30 m thick (Ruxton & Berry, 1957; Lumb, 1965) and may reach 100 m thick (Ruxton & Berry, 1959).

**Variations in the Weathering Profile**

The idealised zones described above rarely occur as a complete suite at any one location. Only the weathering front and zone of unweathered rock below it are unfailingly present. Several generalisations can, however, be made. A decrease in the proportion of solid rock up the profile is usually the case, unless high level bands of floating corestones occur. The angularity of corestones usually increases down the profile, and the proportion of unweathered mineral usually decreases down the profile.

In practise it is found that variations in the configuration of the weathering profile are largely controlled by the joint type and spacing (structure) (Figure 2) and the grain size of the rock. Closely-spaced joints tend to give rise to fewer corestones as, once weathering begins to widen the joints, the intervening small blocks are quickly consumed. Conversely, the large blocks are generally considerably less weathered. Thus ridges and uplands tend to occur in areas of widely-spaced joints (Figure 2). Valleys and lowlands are generally excavated from the more weathered belts of closely-spaced joints. Similarly, in areas of closely-spaced, sub-parallel topographic, sheeting or unloading joints that closely conform to the surface morphology, corestones are rare, or are thin and tabular. Rapid lateral variations in joint spacing, or the distinction between wider master joints and less well-defined subsidiary joint sets, causes lateral variations in weathering profiles in

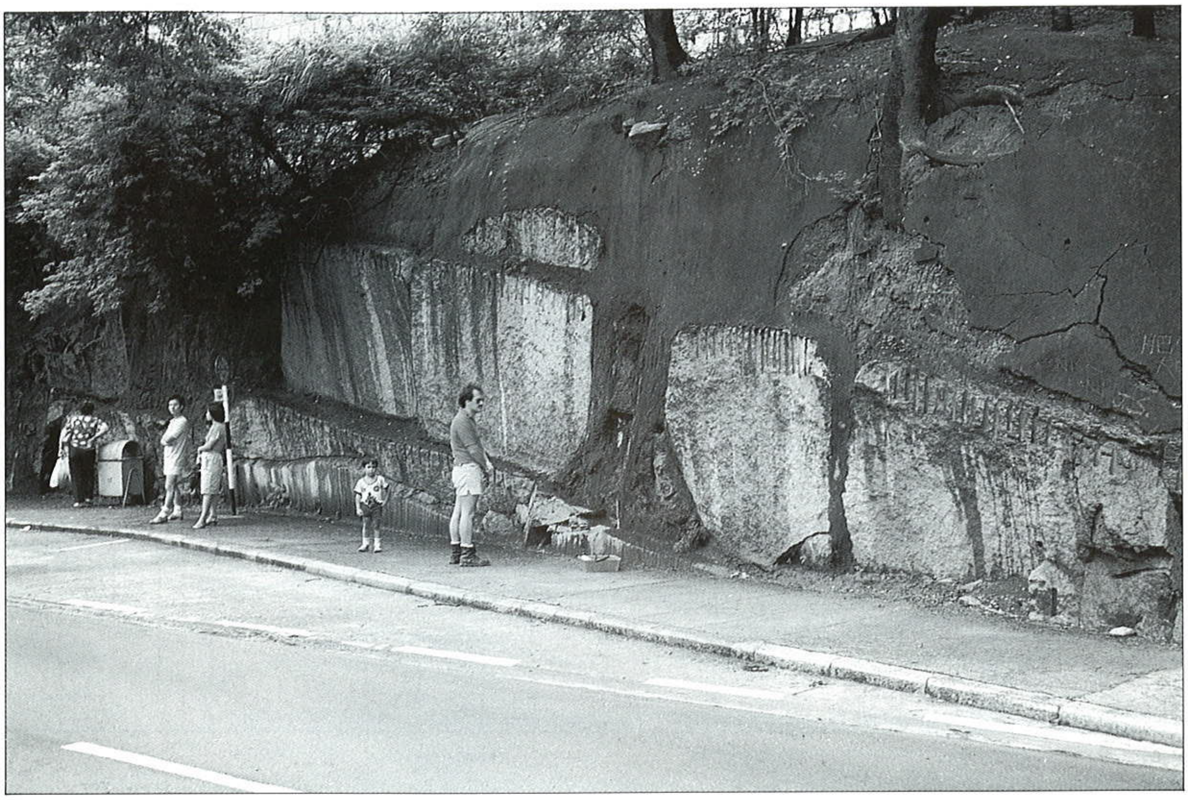

*Photo 3 - The Zone of Rectangular Corestones. Stubbs Road, Hong Kong Island (83705 81395).*

which vertical zones of abundant corestones are separated by intervening, corestone-free zones. In some cases, a weathered mantle may display a zone of corestones high in the weathering profile, below which is a zone of corestone-free matrix. These are termed floating corestones and give the impression of an inverted, or repeated, profile. In general the finer-grained granites weather less rapidly than the coarser grained varieties. Hence fine-grained granite caps such peaks as Lion Rock (Map Reference on the Hong Kong 1:20 000 scale topographical maps 83730 82375) and Needle Hill (83455 82750).

**Granite Landscapes**

Granite landscapes are usually very distinctive. They may be areas of coarse, sandy, acid soils that are poorly vegetated and gullied by erosion. Such areas occur in the Tai Lam Country Park (8188 8286), above Sha Tin on the flanks of Needle Hill (8368 8281), and to the north and west of Tsing Shan (8119 8285). Alternatively they may be characterised by rock outcrops, tors on the hill summits, spur ends or valley sides and boulders scattered over the hillslopes or concentrated as boulder trains in shallow valley lines.

Granite weathering profiles can rarely be seen well exposed in the natural landscape. Some faces occur in steep stream sections or near the top of natural cliffs. In the modern urban landscape of Hong Kong and Kowloon high, near-vertical, artificial cut slopes are commonplace and cross-sections of weathering profiles are particularly well displayed. It is common engineering practice in Hong Kong to cover the softer, more easily eroded matrix with a concrete or chunam coating. However the corestones are usually left protruding from the face so the pattern of corestone distribution can be readily observed.

Walks around much of central Kowloon or north-central Hong Kong Island will allow many of these sections to be examined. Particularly clear examples can be observed on Ho Man Tin Hill (8369 8192) or Kowloon Tsai Park in Kowloon (8370 8216), or along the country park access road from Wong Nai Chong Gap to Tai Tam Reservoirs (8388 8135) on Hong Kong Island.

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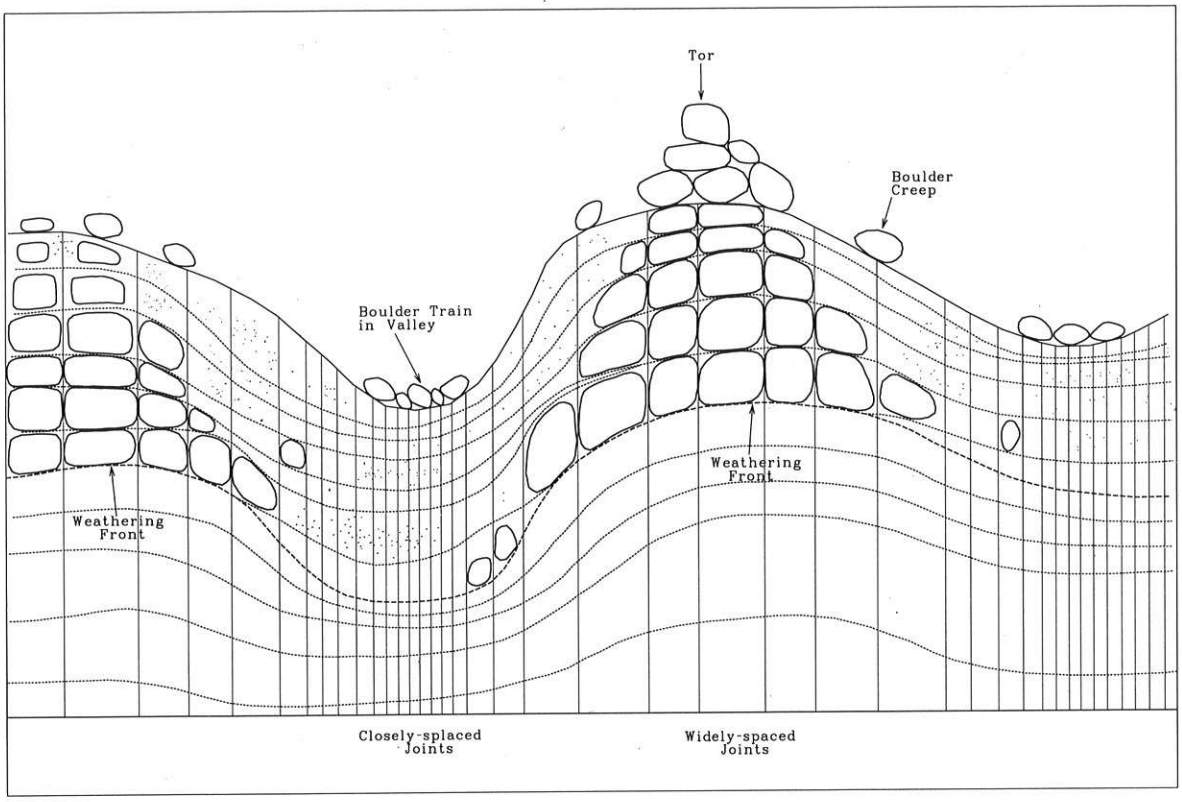


*Figure 2 - The Influence of Joint Spacing in Granite on the Morphology of the Weathering Profile and the Surface Topography.*


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