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A Proposed Revision of the Volcanic Stratigraphy and Related Plutonic Classification of Hong Kong

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Abstract

A revision of the existing volcanic stratigraphy and classification of plutons in Hong Kong is proposed. Recent geochemical interpretation of the volcanic formations and plutons has led to the recognition of discrete geochemical groupings within the Repulse Bay Volcanic Group (Campbell and Sewell, 1997) and of plutons within the Lion Rock Suite (Sewell and Campbell, 1997), as currently defined. High precision U-Pb zircon age dating (Davis et al., 1997) has further shown that these groupings reflect magmatism confined to comparatively short timespans separated by significant time breaks. In order to reflect these new data, modifications to the existing stratigraphic hierarchy of volcanic formations and plutonic suites are suggested. Specifically, the existing Repulse Bay Volcanic Group and Lion Rock Suite of granitoid plutons can both be split into three. This would require the creation of two new volcanic groups, suggested to be the Lantau and Kau Sai Chau volcanic groups, and of two new granitoid suites, for which the Kwai Chung and Cheung Chau suites are proposed. The modified Repulse Bay Volcanic Group is further divisible on the basis of geochemistry into 'Rhyolitic' and 'Trachytic' subgroups. The Lamma Suite is further divisible into 'I-type' and 'A-type' subsuites as is the modified Lion Rock Suite into 'Monzonitic' and 'Granitic' subsuites. Proposals are also made: for three new volcanic formations, the Che Kwu Shan, Sunset Peak and Pan Long Wan formations; for elevation of the existing Lantau Formation to the status of a group; and for reduction of the Silverstrand Formation to the status of a member within the new Che Kwu Shan Formation. Of the intrusions, eight are defined for the first time, four that were previously defined are revised and two are renamed.

摘要

本文建議對香港現行的火山沉積地層及侵入岩的劃分進行修訂。對火山岩和侵入岩最新的地球化學研究導致目前對淺水灣火山岩群〔Campbel & Sewell, 1997〕和獅子山侵入岩體〔Sewell & Campbell, 1997〕可進行一步地球化學劃分。高精度鈾一鉛石測年法的結果〔Davis et al., 1997〕 顯示這種新的劃分反映在相對較短的時間之隔離的岩漿活動具有明顯的間斷。為了反映這些新的資料，我們建議修訂現行的火山岩地層及入岩套的地層分類等級。特別是現在的淺水灣火山岩群及獅子山花崗岩套都可分別細分為三個地層單位。這要求增加兩個火山岩群的名稱：大嶼山群和滘西洲群及兩個花崗岩套的名稱：葵涌岩套和長洲岩套。修改後的淺水灣火山岩群根據地球化學特徵進一步細分為兩個亞群：粗面岩亞群和流紋岩亞群。南丫岩套要進一步劃分為"A型"和"I型"兩個次岩套 同樣，獅子山岩套也可分為二長岩相和花崗岩相兩個次級單位。目前的修訂還包括：新命名了兩個火山岩組：鷓鴣山組和檳榔灣組; 將原來的大嶼山組提升為群; 將原來的銀線灣組並入新建的鷓鴣山組之中。本文新建了8個侵入岩體的名稱; 4 個原有岩體名稱的定議被重新厘定; 另有兩個岩體被重新命名。

Introduction

The Middle Jurassic to Early Cretaceous geology of Hong Kong is dominated by comagmatic volcanic and intrusive rocks of high-K calc-alkaline intermediate to silicic composition (Sewell and Campbell, 1997; Campbell and Sewell, 1997). Prior to the recent geological remapping of Hong Kong by the Hong Kong Geological Survey, there had been a divergence of opinion as to the complexity of the volcanic stratigraphy. During the earliest comprehensive survey of Hong Kong (Williams, 1943; Williams et al., 1945), four formations were identified. Subsequently, however, Ruxton (1960) assigned all of these volcanic rocks to only one formation, the Plover Cove Formation, later renamed the Repulse Bay Formation by Allen and Stephens (1971). However, a complex volcanic stratigraphy has now been identified by the Hong Kong Geological Survey and mapped at 1:20 000-scale. This stratigraphy currently comprises 15 formations, all but one of which, the Tuen Mun Formation, have been assigned to two volcanic groups (Geotechnical Engineering Office, 1992, 1994, 1995 a and b), the Tsuen Wan and Repulse Bay volcanic groups.

With respect to the classification and interpretation of the granitoids, there has been broader agreement as to their complex history of intrusion. Systematic mapping of the granitoids began in the late 1960s with recognition of four main episodes of Jurassic plutonism (Allen and Stephens, 1971). Widely mapped intrusive units were assigned to a period of emplacement according to their lithology and cross-cutting relationships, but no attempt was made to distinguish individual plutons. Later, more detailed mapping of intrusive rocks (Addison, 1986; Strange and Shaw, 1986; Langford et al., 1989) used a grainsize-based classification but intrusive units were not formally defined or delineated. The first comprehensive pluton-based nomenclature for Hong Kong granitoids was introduced by Strange et al. (1991). Sewell and Langford (1991) and Sewell et al. (1992) refined this nomenclature and divided the granitoids on the basis of petrographic, geochemical and age criteria into two suites, an older Lamma Suite and a younger Lion Rock Suite, within which three subgroups were identified. Nd and Sr isotope studies (Darbyshire and Sewell, 1997), U-Pb zircon age-dating (Davis et al., 1997), and further geochemical studies (Sewell and Campbell, 1997) have led to more modifications of the pluton and suite nomenclature.

Proposed Reclassification of Volcanic Formations and Granitoid Intrusions

Campbell and Sewell (1997) have shown that the volcanic formations have characteristic trace element signatures, particularly with respect to their contents of relatively immobile elements (e.g. Zr, TiO_2, Nb). Consequently, the formations can be assigned to one of five groupings on the basis of similarities in these trace element signatures, and most notably TiO_2 vs Zr (Figure 1a). The Tuen Mun Formation was excluded from these groupings, and is similarly excluded from the following reclassification, as it is of broadly andesitic composition and is not comparable geochemically with the other volcanic formations. Furthermore, the formation has not yet been radiometrically dated, although it may be Lower or Middle Jurassic in age and as such, the oldest volcanic formation in Hong Kong.

Similar geochemical characteristics and groupings have been demonstrated for the granitoid intrusions (Campbell and Sewell, 1997) (Figure 1b). In addition, for each grouping of volcanic formations, there is a geochemically similar grouping of intrusions, suggesting that the paired volcanic and intrusive groups were comagmatic. High precision U-Pb dating (Davis et al., 1997) supports this as the paired volcanic phases and intrusive pulses are of virtually identical ages (Table 1) and are separated from other pairings, in all but one instance, by significant time gaps. Hence, distinct volcanic/magmatic episodes are identifiable, and it therefore seems logical to reflect this in both the stratigraphy of the volcanic rocks and the classification of the intrusive rocks.

The products of the individual phases and pulses are of sufficient volume and complexity to merit group status. In stratigraphic studies of other caldera-dominated volcanic terrains (e.g. Howells et al., 1991), it is common practice to give formation status to units forming single calderas, with group status reserved for clusters of caldera-related units having similar chemistry and mineralogy, and commonly, age. In the same manner, plutons which have similar chemistry, mineralogy, and age, are often grouped together in suites. Accordingly, we propose that the two existing volcanic groups be increased to four (Table 1). The Tsuen Wan Volcanic Group can be retained as currently defined, comprising the Yim Tin Tsai, Shing Mun, Tai Mo Shan and Sai Lau Kong formations. The four volcanic phases identified by Campbell and Sewell (1997) within the Repulse Bay Volcanic Group can be reclassified as three new groups, the Lantau, Repulse Bay and Kau Sai Chau volcanic groups. These are separated by unconformities. The revised Repulse Bay Volcanic Group is further divisible, on the basis of geochemistry, into 'Rhyolitic' and 'Trachytic' subgroups:

1. Lantau Volcanic Group, defined here - comprising the upper part of the Lai Chi Chong Formation, and the former Lantau Formation (Langford et al., 1995) with the exception of its basal

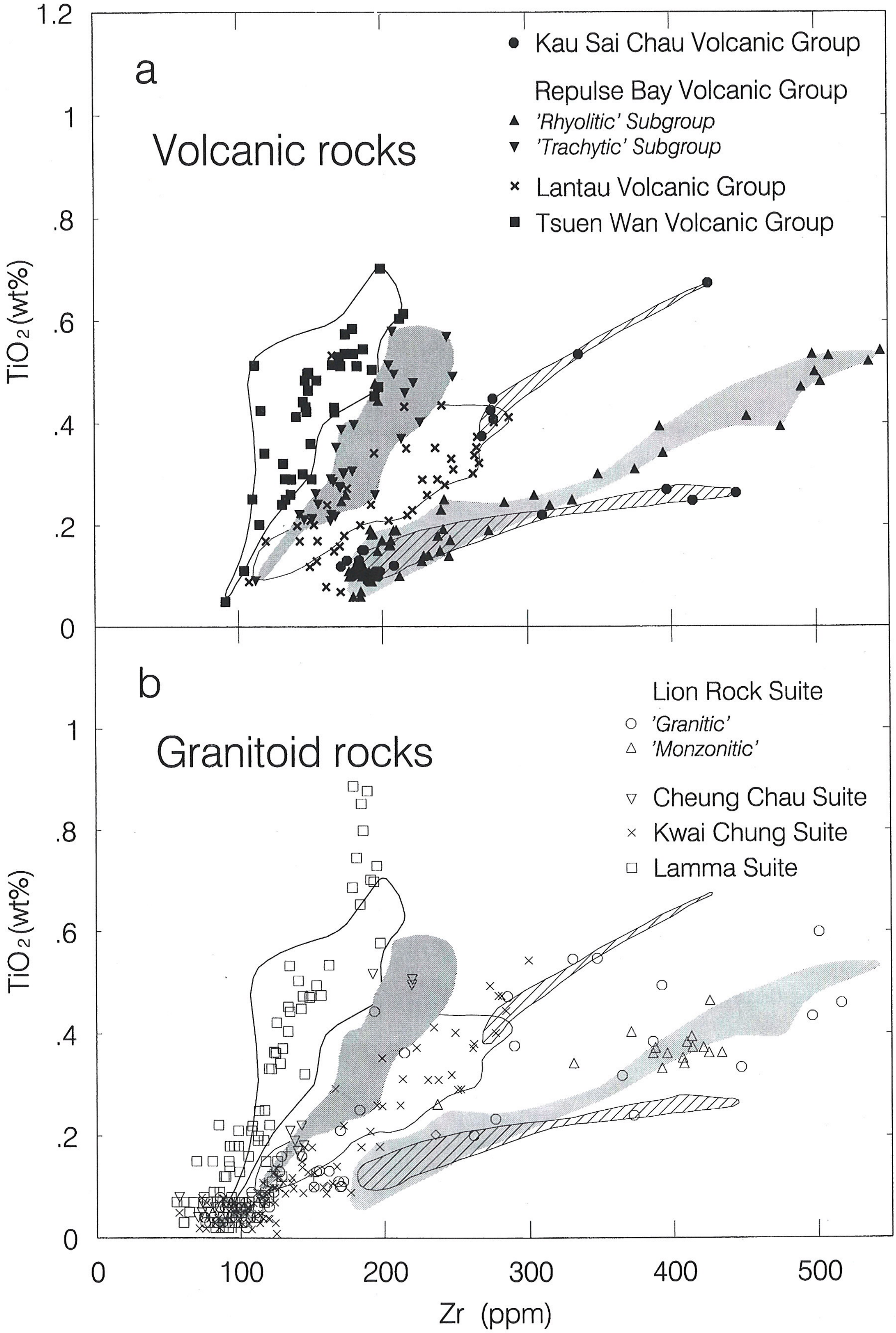

Figure 1. TiO_2-Zr plots (modified after Campbell and Sewell, 1997) for: **a**, Jurassic to Cretaceous volcanic rocks, excluding the Tuen Mun Formation; **b**, Jurassic to Cretaceous granitoid rocks with volcanic group boundaries for comparison

Table 1. Suggested revision to the volcanic-plutonic stratigraphy of, and U-Pb age date for, Mesozoic igneous rocks of Hong Kong[1,2]

VOLCANIC ROCKS				GRANITOID ROCKS			
Previous Group Nomenclature	**Revised Group Nomenclature**	**Formation (new formations in bold)**	**U-Pb Age (Ma)**	**Previous Suite Nomenclature**	**Revised Suite Nomenclature**	**Intrusion (new nomenclature in bold)**	**U-Pb Age (Ma)**
REPULSE BAY VOLCANIC GROUP	KAU SAI CHAU VOLCANIC GROUP	High Island	140.9 ± 0.2	LION ROCK SUITE	LION ROCK SUITE – 'GRANITIC' SUBSUITE	Mount Butler Granite	
		Clear Water Bay	140.7 ± 0.2			Po Toi Granite	
		Pan Long Wan				Kowloon Granite	140.4 ± 0.2
		Sunset Peak				**Fan Lau Granite**	
		Mang Kung Uk				**Sok Kwu Wan Granite**	
					LION ROCK SUITE – 'MONZONITIC' SUBSUITE	**Tei Tong Tsui Quartz Monzonite**	
						Tong Fuk Quartz Monzonite	140.4 ± 0.3
						D'Aguilar Quartz Monzonite	140.6 ± 0.3*
							140.6 ± 0.3*
	REPULSE BAY VOLCANIC GROUP – 'TRACHYTIC' SUBGROUP	**Che Kwu Shan**	142.5 ± 0.3		CHEUNG CHAU SUITE	**Luk Keng Quartz Monzonite**	
		Ap Lei Chau	142.7 ± 0.2			**Shan Tei Tong Rhyodacite**	
		Ngo Mei Chau	<143.7 ± 0.1*			Chi Ma Wan Granite	<143.7 ± 0.2
	REPULSE BAY VOLCANIC GROUP – 'RHYOLITIC' SUBGROUP	Long Harbour	142.7 ± 0.2			South Lamma Granite	
			142.8 ± 0.2				
		Mount Davis					
	LANTAU VOLCANIC GROUP	Undifferentiated	146.6 ± 0.2		KWAI CHUNG SUITE	Sha Tin Granite	146.2 ± 0.2
		Lai Chi Chong				**East Lantau Rhyolite**	146.3 ± 0.3
						East Lantau Rhyodacite	146.5 ± 0.2
						Needle Hill Granite	146.4 ± 0.2
TSUEN WAN VOLCANIC GROUP	TSUEN WAN VOLCANIC GROUP	Sai Lau Kong	164.1 ± 0.2*	LAMMA SUITE	LAMMA SUITE – 'A-TYPE' SUBSUITE	Tai Lam Granite	159.3 ± 0.3
		Tai Mo Shan	<164.6 ± 0.7			Tsing Shan Granite	<159.6 ± 0.5
		Shing Mun	164.2 ± 0.3*			**Chek Lap Kok Granite**	160.4 ± 0.3
			164.7 ± 0.3*		LAMMA SUITE – 'I-TYPE' SUBSUITE	Lantau Granite	161.5 ± 0.2
		Yim Tin Tsai	164.5 ± 0.2			Tai Po Granodiorite	<164.6 ± 0.2

[1]The Tuen Mun Formation, of broadly andesitic composition, is excluded from this classification.

[2]The Deep Bay Granite of Triassic age (Davis et al., 1997) is excluded from this classification.

*Unpublished data, Geotechnical Engineering Office.

Cheung Shan Member which is transferred to the Tsuen Wan Volcanic Group, and its uppermost Sunset Peak Member, which is tentatively transferred, as a new formation, to the Kau Sai Chau Volcanic Group.

2. Repulse Bay Volcanic Group, redefined here - comprising two subgroups: a) a 'Rhyolitic' Subgroup including the Long Harbour and Mount Davis formations; b) a 'Trachytic' Subgroup including the Ngo Mei Chau and Ap Lei Chau formations, and a new formation, the Che Kwu Shan Formation.

3. Kau Sai Chau Volcanic Group, defined here - comprising the Mang Kung Uk Formation, the new Sunset Peak and Pan Long Wan Formations, and the Clear Water Bay and High Island formations.

With respect to the granitoid intrusions, excluding the Deep Bay Granite which is of Triassic age (Davis et al., 1997), the Lamma Suite (Sewell et al., 1992) is retained but is subdivided on the basis of geochemistry and mineralogy into 'I-type' and 'A-type' subsuites. The 'I-type' Subsuite comprises the Tai Po Granodiorite and the Lantau Granite while the 'A-type' Subsuite includes the newly defined Chek Lap Kok Granite, and the Tsing Shan and Tai Lam granites. The four magmatic pulses recognised by

Campbell and Sewell (1997) within the Lion Rock Suite (Sewell et al., 1992) can form the basis of three suites, the Kwai Chung, Cheung Chau and Lion Rock suites, of which the lattermost is further divisible on the basis of geochemistry and lithology into 'Monzonitic' and 'Granitic' subsuites:

1. Kwai Chung Suite, defined here - including the Needle Hill and Sha Tin granites, and the newly defined East Lantau Rhyodacite and Rhyolite.
2. Cheung Chau Suite, defined here - comprising the South Lamma and Chi Ma Wan granites, and the newly defined Shan Tei Tong Rhyodacite and Luk Keng Quartz Monzonite.
3. Lion Rock Suite, redefined here - comprising two subsuites: a.) a 'Monzonitic' Subsuite including the revised D'Aguilar Quartz Monzonite and the newly defined Tei Tong Tsui Quartz Monzonite, in addition to the existing Tong Fuk Quartz Monzonite; b.) a 'Granitic' Subsuite including the Kowloon, Po Toi and Mount Butler granites, and the newly defined Sok Kwu Wan and Fan Lau granites.

The distribution of the proposed volcanic groups and subgroups and granitoid suites and subsuites, is shown in Figure 2. Further details of the individual volcanic formations and granitoid intrusions are given below, including those defined for the first time, those redefined and those renamed.

Volcanic Rocks

Tsuen Wan Volcanic Group (c. 164.6 Ma)

The *Yim Tin Tsai Formation* (Addison, 1986) is the oldest unit of the Tsuen Wan Volcanic Group and consists mainly of medium or dark grey, lapilli- to coarse ash crystal tuff. It outcrops in four main areas: Tolo Harbour, northern Lantau Island including Ma Wan and Tsing Yi, southern Lantau Island, and northern Lamma Island. The formation rests unconformably on the Lower Jurassic Tolo Channel Formation and has been dated at 164.5 ± 0.2 Ma. The welded tuffs of the Yim Tin Tsai Formation are thought to have been erupted and emplaced as pyroclastic ash flows. Rare intercalated sedimentary horizons represent volcanic quiescence between eruptions.

The *Shing Mun Formation* (Addison, 1986) conformably overlies the Yim Tin Tsai Formation and

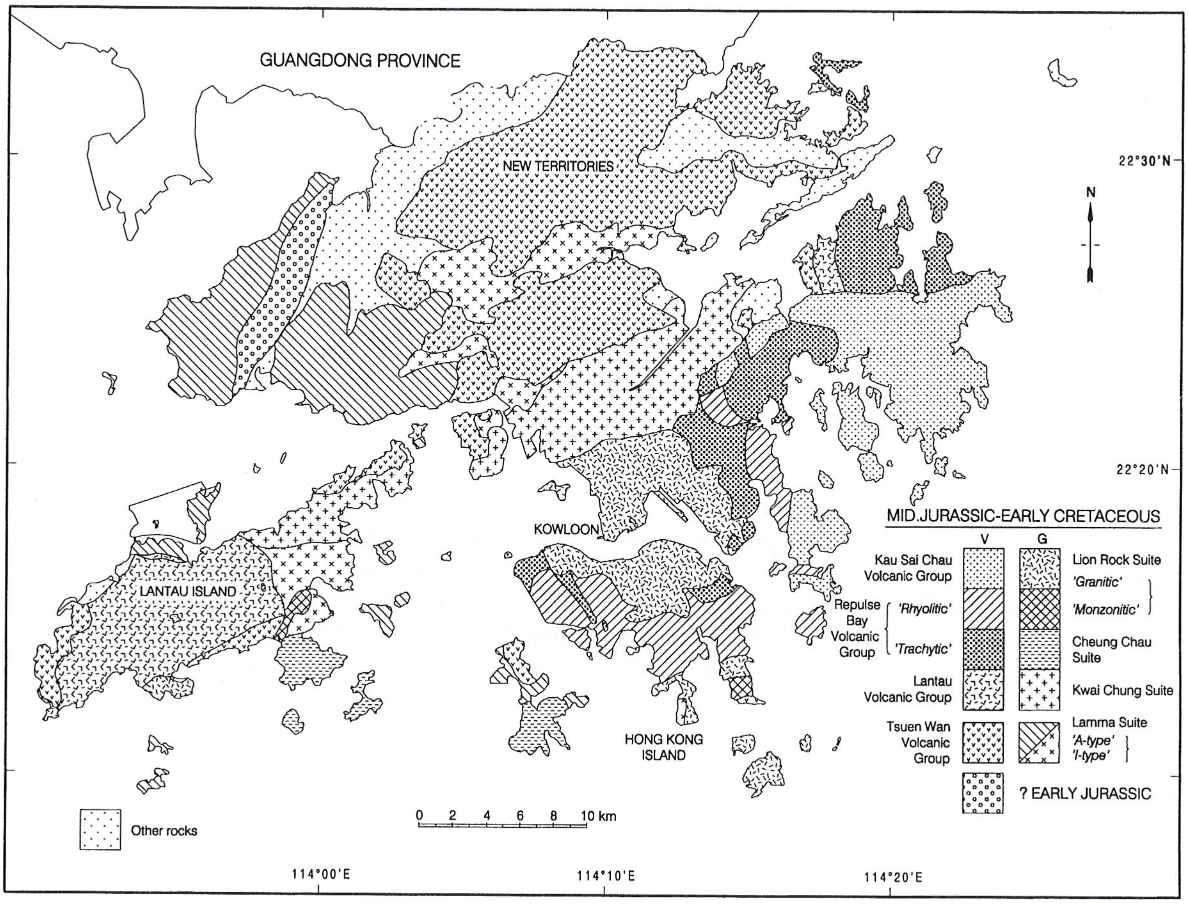

Figure 2. Distribution of revised volcanic groups and granitoid suites in Hong Kong

consists of volcanic breccia, lapilli-, coarse-, and fine ash crystal tuff, and intercalated siltstone and mudstone. The formation crops out principally around the Shing Mun valley, Tai Mo Shan and Tolo Harbour and also occurs in southern and eastern Lantau Island. The unit is commonly spatially related with the Tai Po Granodiorite and its heterogeneous volcanic character suggests that it could partly comprise vent-fill facies.

The *Cheung Shan Member*, which was formerly regarded as part of the Lantau Formation (Langford et al., 1995) and which comprises eutaxite up to 500 m thick, has recently been dated (U-Pb) at 164.2 ± 0.3 Ma (Geotechnical Engineering Office, unpublished data). This indicates that the member is considerably older than the Lantau "Formation" (146.6 ± 0.2 Ma) and is instead approximately coeval with the Tsuen Wan Volcanic Group to which it is assigned here. The member is tentatively correlated with the Shing Mun Formation (Table 1) which it directly overlies on the southern side of Lantau island. On the northwest side of Lantau island the member overlies sedimentary rocks, referred to as the Tai O Formation by Allen and Stephens (1971), of possibly Lower or Middle Jurassic age, or alternatively Carboniferous age by Langford et al. (1995). The Cheung Shan Member is lithologically similar to, and may be a correlative of, the Ngau Liu Member of the Shing Mun Formation whose outcrop lies to the north of Tsuen Wan.

The Lai Chi Chong Formation (Strange et al., 1990) is considered here to represent elements of both the Tsuen Wan Volcanic Group and the Lantau Volcanic Group. The lowermost 280-340 m of the Lai Chi Chong Formation, as previously described (Strange et al. op. cit.), which comprises coarse ash and other tuff and tuffite and rhyolite, has recently yielded a U-Pb date of 164.7 ± 0.3 Ma (Geotechnical Engineering Office, unpublished data). This part of the formation is considered to be part of the Tsuen Wan Volcanic Group and is tentatively reassigned here to the Shing Mun Formation (Table 1). This sequence unconfomably overlies sedimentary rocks including the Devonian Bluff Head Formation and the Lower Jurassic Tolo Channel Formation.

The *Tai Mo Shan Formation* (Addison, 1986) is the most voluminous pyroclastic unit of the Tsuen Wan Volcanic Group. It is composed dominantly of lapilli-ash to coarse ash crystal tuff with rare intercalated beds of tuffaceous sandstone. The formation conformably overlies the Shing Mun Formation and crops out near Tai Mo Shan and widely in the north and east New Territories. The Tai Mo Shan Formation has been dated at <164.6 ± 0.7 Ma. Its widespread distribution and dominantly uniform lithological character suggest it represents the product of several large pyroclastic ash flow eruptions.

The *Sai Lau Kong Formation* (Lai et al., 1996) consists mainly of dacite lavas with intercalated tuff breccia, lapilli tuff, siltstone and sandstone. These rocks, which conformably overlie the Tai Mo Shan Formation in the northeast New Territories, are at least 300 m thick. The formation is confined to a narrow northwest-trending rift that may have been a volcanic centre. Recently, a U-Pb date of 164.1 ± 0.3 Ma (Geotechnical Engineering Office, unpublished data) has been obtained from the formation, giving a constraint on the youngest age of the Tsuen Wan Volcanic Group.

Lantau Volcanic Group (c.146.6 Ma)

The Lantau Volcanic Group, defined here, comprises the former *Lantau Formation* as described by Langford et al. (1995), with the exception of the Cheung Shan Member, which is now regarded as significantly older and part of the Tsuen Wan Volcanic Group (see above), and the Sunset Peak Member, which is tentatively assigned, as a new formation, to the Kau Sai Chau Volcanic Group. Sedimentary layers have yielded Jurassic plant remains and the group has been radiometrically dated at 146.6 ± 0.2 Ma. As yet, the Lantau Volcanic Group is largely undifferentiated into constituent formations, but contains one formation, the revised Lai Chi Chong Formation, and one member, the Pak Kok Member (Langford et al., 1995). The group is mainly confined to Lantau Island, where it forms the central part of the island and is ringed by the Lantau Caldera Fault. The group is up to 1500 m thick and is composed predominantly of lapilli-bearing coarse ash vitric tuff with subordinate rhyolite flows and fine-grained sedimentary rocks. Flow-banding is common. Alternating crystal-rich and crystal-poor gradations within the upper part of the group indicate deposition from ash flows. The group is in fault contact with the Yim Tin Tsai and Shing Mun formations, and with intrusive rocks of various ages, around the caldera margins on Lantau.

The *Lai Chi Chong Formation*, as previously described by Strange et al. (1990) requires revision inthe light of a recently obtained U-Pb of 164.7 ± 0.3 Ma (Geotechnical Engineering Office, unpublished data) which indicates that the lower part of the formation is part of the Tsuen Wan Volcanic Group. By contrast, the upper part of the formation has yielded an Early Cretaceous flora (Atherton, 1989). Consequently, only the uppermost 130-180 m of the succession as formerly described by Strange et al. (1990) is considered here to be the Lai Chi Chong Formation and is tentatively referred to the Lantau Volcanic Group. The remainder of the formation, which must be separated from the former by an unconformity, is reassigned tentatively to the Shing

Mun Formation. The Lai Chi Chong Formation now comprises mudstone, siltstone, sandstone, several thick horizons of breccia and conglomerate, a rhyolite and a eutaxite.

Repulse Bay Volcanic Group (c. 142.7 Ma)

Two subgroups are identified within the Repulse Bay Volcanic Group: a 'Rhyolitic' Subgroup and a 'Trachytic' Subgroup. These are based on compositional groupings identified by Sewell and Campbell (1997) and referred to by them as Phases 3 and 4. The subgroups are broadly coeval and may reflect eruption from separate volcanic sources.

'Rhyolitic' Subgroup

The *Long Harbour Formation* (Strange et al., 1990) crops out in the northeast of the Sai Kung Peninsula north of the Cheung Sheung Fault. It is composed predominantly of uniform, clast-bearing coarse ash tuff with abundant pink alkali feldspar crystals and is at least 400 m thick. In the Sharp Peak area the formation rests unconformably on the Clear Water Bay and Mang Kung Uk formations whereas west of Long Harbour it rests unconformably on the Lai Chi Chong Formation. The formation is thought to represent a caldera infilling (Strange et al., 1990) and has been dated at 142.8 ± 0.2 Ma. North of Sai Kung, an ellipsoidal area of outcrop previously described (Addison, 1986; Strange et al., 1990) as Tai Mo Shan Formation, and interpreted mainly as a caldera infilling (Campbell and Sewell, 1997) is here correlated with the Long Harbour Formation. Smaller outcrops lie outside the main caldera to its northwest. These rocks dominantly comprise lapilli-bearing coarse ash crystal tuff, at least 600 m thick, and have been dated at 142.7 ± 0.2 Ma.

The *Mount Davis Formation* (Langford et al., 1995), exposed in the west of Hong Kong Island and in eastern Kowloon, consists predominantly of coarse ash crystal tuff with intercalations of eutaxitic fine ash tuff and volcaniclastic fine-grained sandstone. The formation conformably overlies the Ap Lei Chau Formation.

'Trachytic' Subgroup

The *Ngo Mei Chau Formation* (Lai et al., 1996) is juxtaposed against the Tai Mo Shan Formation along a northwest-trending fault in the northeast of Hong Kong and is exposed chiefly on Kat O Chau and Ngo Mei Chau in Mirs Bay. It comprises fine ash vitric welded tuff and lapilli tuff and minor intercalated sandstone and siltstone. The formation, estimated to be 450 m thick, has recently been dated at <143.7 ± 0.1 Ma (Geotechnical Engineering Office, unpublished data).

The *Ap Lei Chau Formation* (Strange and Shaw, 1986), which crops out widely on southern Hong Kong Island, is up to 2000 m thick but its base is not exposed. The formation is composed mainly of fine ash vitric tuff and interlayered eutaxites with subordinate tuff breccia, pyroclastic breccia, tuffaceous sedimentary rocks, coarse ash tuffs and discontinuous layers of epiclastic debris. The formation has been dated at 142.7 ± 0.2 Ma.

The *Che Kwu Shan Formation*, defined here, consists of relatively uniform eutaxitic fine ash vitric tuff of trachyte to alkali rhyolite composition, with rare bands of coarse ash crystal tuff, tuffaceous sedimentary rock and tuff breccia. The formation crops out in eastern Hong Kong Island and on the Clear Water Bay Peninsula, where it was previously mapped as the uppermost 500 m of the Ap Lei Chau Formation. Additionally, the formation includes the former Silverstrand Formation, consisting of 450-500 m of eutaxite with subordinate tuffite and tuff breccia, as the uppermost member of the new formation. In the Silverstrand Bay area, the formation conformably overlies fine ash tuff of the Ap Lei Chau Formation, but around Junk Bay, it rests conformably on the Mount Davis Formation. The formation has been dated at 142.5 ± 0.3 Ma.

Kau Sai Chau Volcanic Group (c.140.8 Ma)

The *Mang Kung Uk Formation* (Strange et al., 1990) is exposed chiefly on the Clear Water Bay and Sai Kung peninsulas. On the former, the formation comprises c.300 m of heterogeneous tuffs, tuffaceous sedimentary rocks, epiclastic breccia, conglomerate, siltstone and sandstone. Impersistent rhyolite lava flows occur mainly on the Sai Kung Peninsula.

The *Sunset Peak Formation*, defined here, was formerly defined as the Sunset Peak Member of the Lantau Formation (Langford et al., 1995). The new formation unconformably overlies the undifferentiated Lantau Volcanic Group, and comprises tuff breccia, lapilli lithic-bearing tuff and eutaxite.

The *Pan Long Wan Formation*, defined here, consists of trachydacite lava flows and tuffs exposed on Clear Water Bay Peninsula. The formation comprises the lower part of the Clear Water Bay Formation as previously mapped on the Clear Water Bay Peninsula between Siu Chung Lam Wan (Little Palm Beach) and Tai Miu Wan (Joss House Bay). It unconformably overlies the Mang Kung Uk Formation and is best exposed in the southern Clear Water Bay Peninsula where it reaches 350 m thick. The lava flows are commonly separated by thick (40–50 m) bands of fine ash tuff and tuffaceous sedimentary rocks. The Tai Miu Wan Member, which forms the basal member of the formation, is a feldsparphyric trachydacite lava up to 150 m thick.

The *Clear Water Bay Formation* (Strange et al., 1990) comprises banded tuffs and lava flows in the Sai Kung and Clear Water Bay peninsulas, and porphyritic rhyolite lava in the vicinity of Pyramid Hill and Shek Nga Shan. In the Clear Water Bay area, the formation conformably overlies the Pan Long Wan Formation. In the Sai Kung area, it unconformably overlies the Mang Kung Uk Formation and includes a distinctive parataxitic bed near the base of the sequence. In the southern Clear Water Bay Peninsula, the formation comprises rhyolitic tuff, tuff breccia, and rhyolite lava whereas in the Pyramid Hill and Shek Nga Shan areas, it consists of flow-banded, feldsparphyric rhyolite lava flows and eutaxitic crystal-bearing vitric tuff. Vertical flow-banding in some outcrops suggests that the lavas may represent dyke fissures. The formation has been dated at 140.7 ± 0.2 Ma.

The *High Island Formation* (Strange et al., 1990) crops out widely over the Sai Kung District and on islands in Port Shelter. It consists of massive, crystal-bearing fine ash welded tuff, with small-scale eutaxitic fabrics and well-developed columnar jointing. The formation rests unconformably on the Clear Water Bay Formation near High Island west dam and is up to 400 m thick. The High Island Formation has been dated at 140.9 ± 0.2 Ma.

Granitoid Rocks

Lamma Suite (c.164.6-159.3 Ma)

The Lamma Suite is divisible into two subsuites; an older 'I-type' Subsuite and a younger 'A-type' Subsuite, on the basis of whole rock geochemistry and mineralogy (Sewell and Campbell, 1997).

'I-type' Subsuite (c.164.6-161.5 Ma)

The *Tai Po Granodiorite* (Brock and Schofield, 1926) crops out across central and southern Hong Kong, the central New Territories and on Tsing Yi. It is thought to have been emplaced as a large, high-level, ring-shaped intrusion mainly centred around Tai Mo Shan, although it has been widely fragmented by subsequent intrusions and faulting. The granodiorite intrudes volcanic rocks of the Tsuen Wan Volcanic Group. Lithologies vary texturally from normal hypidiomorphic-granular granodiorite, through porphyritic microgranodiorite to densely porphyritic dacite without significant change in bulk composition. The Tai Po Granodiorite has been dated at <164.6 ± 0.5 Ma.

The *Lantau Granite* (modified after Sewell and Langford, 1991) forms a large, high-level, intrusion underlying much of south and west Hong Kong. The granite is composed dominantly of megacrystic coarse-grained and medium-grained biotite monzogranite and is intruded by all known plutonic lithologies except the Tai Po Granodiorite, with which contact relationships have not been observed. Large rafts of strongly modified Lantau Granite sometimes occur as xenoliths within younger plutons (e.g., Sok Kwu Wan Granite). The granite has been dated at 161.5 ± 0.2 Ma.

'A-type' Subsuite (c.160.4-159.3 Ma)

The *Chek Lap Kok Granite*, defined here, is an equigranular, fine-grained, leucocratic monzogranite that forms a subcircular pluton centred on the new airport at Chek Lap Kok. The unit was formerly exposed on the west side of Chek Lap Kok and on Lam Chau. Exposures are now confined to the northern coast of Lantau Island. The granite intrudes the Lantau Granite and has been dated at 160.4 ± 0.3 Ma.

The *Tsing Shan Granite* (Sewell and Langford, 1991) forms an elliptical pluton in the western New Territories. All contacts with adjacent rocks are faulted but offshore boreholes suggest the Tsing Shan Granite has intruded the Tai Po Granodiorite. The granite is composed of variably deformed and recrystallised, equigranular to inequigranular two-mica monzogranite and has yielded a U–Pb zircon age of <159.6 ± 0.5 Ma.

The *Tai Lam Granite* (Sewell and Langford, 1991) forms a large subcircular pluton in the northwest New Territories, between Yuen Long, Tsuen Wan, Lantau Island, and Castle Peak. It intrudes the Lantau Granite, Tai Po Granodiorite, Palaeozoic sedimentary rocks and Jurassic volcanic rocks. The pluton consists of porphyritic medium-grained to equigranular fine-grained leucogranite and biotite monzogranite and has been dated at 159.3 ± 0.3 Ma.

Kwai Chung Suite (c.146.3 Ma)

The *Needle Hill Granite* (revised after Allen and Stephens 1971) forms an elliptical biotite monzogranite pluton on the northwest side of the Shing Mun Valley. The granite is composed of porphyritic fine-grained monzogranite and equigranular medium-grained monzogranite and includes numerous fine grained granite dykes which intrude the Sha Tin pluton. The unit intrudes the Tai Po Granodiorite and the Sha Tin Granite. A U–Pb single zircon age of 146.4 ± 0.2 Ma has been obtained for the Needle Hill Granite.

Feldsparphyric dykes forming a dense, eastnortheast-trending swarm in northeast Lantau Island (Lantau Dyke Swarm) are the most voluminous dyke rocks in Hong Kong (Geotechnical Engineering Office 1991, 1994; Langford et al., 1995). Two main generations of dykes are recognised (Sewell and James, 1995). The older swarm comprises broad dykes

(>5 m thick) of dominantly rhyodacitic composition, the *East Lantau Rhyodacite*, defined here, whereas dykes of the younger swarm, the *East Lantau Rhyolite*, defined here, are narrower (<5 m thick) and dominantly rhyolitic in composition. The rhyodacite dykes have been dated at 146.5 ± 0.2 Ma and the rhyolite dykes at 146.3 ± 0.3 Ma indicating that these dykes are largely coeval with the Sha Tin Granite.

The *Sha Tin Granite* (Strange, 1990) forms an irregular elliptical-shaped biotite monzogranite pluton centred on Sha Tin, extending to Tsing Yi in the southwest and Wu Kwai Sha in the northeast. The granite is intruded by the Kowloon and Needle Hill granites. The Sha Tin Granite comprises a coarse-grained central core surrounded by medium- to fine-grained lithologies and has been dated at 146.2 ± 0.2 Ma.

Cheung Chau Suite (c.143.7 Ma)

The *South Lamma Granite* (Sewell and Langford, 1991) forms a subcircular, equigranular biotite monzogranite pluton centred on the south of Lamma Island, and possibly near Kam Lo Hom also. The granite intrudes the Lantau Granite. The South Lamma Granite is typically equigranular and medium-grained although fine-grained equivalents are found near contacts with older units and as late-stage aplite dykes. An absolute age for the granite has not yet been determined.

The *Chi Ma Wan Granite* (Sewell and Langford, 1991) forms a subcircular, biotite monzogranite pluton centred on the Chi Ma Wan Peninsula on the east side of Lantau Island and extends south and east to the islands of Shek Kwu Chau and Cheung Chau. The Chi Ma Wan Granite intrudes the Lantau Granite and the East Lantau Rhyodacite dykes at Chi Ma Wan. However, on Cheung Chau, the granite is cut by rhyolite dykes suggesting that it may be partly coeval with dyke emplacement. The granite is dominantly equigranular and medium-grained and has yielded a U–Pb single zircon age of <143.7 ± 0.2 Ma.

The *Shan Tei Tong Rhyodacite* dykes, defined here, include all feldsparphyric and porphyritic microgranite dykes intruding the Chi Ma Wan and South Lamma plutons. These dykes occur mostly in a zone extending from the Chi Ma Wan Peninsula to Lamma Island and southern parts of Hong Kong. The dykes contain large feldspar megacrysts within a fine-grained granular matrix of quartz, feldspar and biotite. The rhyodacite dykes have not been radiometrically dated.

The *Luk Keng Quartz Monzonite*, defined here, crops out on the southeast margin of the Lantau Caldera. The unit is typically K–feldspar megacrystic and fine grained. The contact with older intrusive units is not exposed. On the basis of petrographic and geochemical comparisons, the Luk Keng Quartz Monzonite is thought to have an emplacement age of around 142 Ma.

Lion Rock Suite (c.140.5 Ma)

The Lion Rock Suite is divisible into two subsuites, a 'Monzonitic' Subsuite and a 'Granitic' Subsuite, on the basis of geochemical subgroupings identified by Sewell and Campbell, 1997) and referred to as pulses 4 and 5 and in addition includes plutons assigned to an unconstrained pulse 6.

'Monzonitic' Subsuite

The *D'Aguilar Quartz Monzonite* (revised after Allen and Stephens, 1971) includes a large intrusion of quartz monzonite on the D'Aguilar Peninsula, along with minor intrusions of quartz monzonite on Stanley Peninsula, at Chung Hom Kok, and on Lamma Island. The unit intrudes the Yim Tin Tsai Formation, Lantau Granite and Tai Po Granodiorite. A broad zone of fine-grained porphyritic quartz monzonite is present at the contact with the Yim Tin Tsai Formation in the southern part of the D'Aguilar Peninsula. The D'Aguilar Quartz Monzonite is typically porphyritic and fine- to medium-grained and has yielded an Rb-Sr whole-rock isochron age of 147 ± 8 Ma (Sewell et al., 1992) and more recently a U-Pb date of 140.6 ± 0.3 Ma and 140.6 ± 0.3 Ma (unpublished data, Geotechnical Engineering Office).

The *Tong Fuk Quartz Monzonite* (previously the Lantau Syenite of Sewell and Langford, 1991) crops out chiefly along the margin of the Lantau Caldera at Sha Lo Wan, Tong Fuk, Fan Lau and Pui O but also includes several small stocks and dykes of quartz monzonite on the nearby islands of Cha Kwo Chau, Hei Ling Chau and Chau Kung To. It is typically fine-grained and porphyritic, with roughly equal abundance of alkali feldspar and plagioclase phenocrysts, although alkali feldspar usually predominates. The Tong Fuk Quartz Monzonite intrudes the Lantau Granite, the Tai Po Granodiorite and the Lantau Formation and it has been dated at 140.4 ± 0.3 Ma.

The *Tei Tong Tsui Quartz Monzonite*, defined here, comprises several stocks and dykes of quartz monzonite and monzonitic granite in the central and southeast New Territories and on Hong Kong Island which vary compositionally from porphyritic fine- to medium-grained quartz monzonite to non-porphyritic monzonitic granite. In the Sai Kung area, small stocks of quartz monzonite form a discontinuous ring around the Sai Kung Caldera while between Sha Tin and Kowloon, dykes of quartz monzonite form a NE–SW swarm extending from Three Fathoms Cove to Lai

King. Absolute ages for the quartz monzonite dykes have not been determined. However, compositionally, they appear most closely related to the Lion Rock Suite.

'Granitic' Subsuite

The *Kowloon Granite* (Strange, 1990) forms a subcircular biotite monzogranite pluton centred on Kowloon and Hong Kong Island. The granite is remarkably uniform in texture and composition, is typically an equigranular medium-grained, biotite monzogranite, and has been dated at 140.4 ± 0.2 Ma.

The *Po Toi Granite* (previously the Stanley Granite of Sewell and Langford, 1991) forms a subcircular pluton centred on the southeast tip of Hong Kong Island, Sung Kong Island, Beaufort Island, Po Toi and Castle Rock reef. The pluton incorporates coarse-, medium- and fine-grained biotite monzogranite and is texturally zoned with coarse-grained megacrystic lithologies predominating in the south and east, and equigranular medium- and fine-grained lithologies in the north and west. The granite intrudes the Tai Po Granodiorite and the D'Aguilar Quartz Monzonite. The Po Toi Granite has not yet been isotopically dated but it is geochemically similar to the Kowloon Granite.

The *Mount Butler Granite* (Strange, 1990, 1991) forms small, subcircular leucocratic monzogranite intrusions on the southeast and east margins of the Kowloon granite on Hong Kong Island and around Kwun Tong in eastern Kowloon respectively. It is dominantly equigranular and fine grained, but varies to fine- to medium-grained. The unit intrudes the Kowloon Granite and the Ap Lei Chau and Mount Davis formations. A Rb-Sr whole-rock isochron age of 136 ± 1 Ma has been obtained for the granite (Sewell et al., 1992) but the Rb-Sr system may have been affected by interaction with water during post-emplacement hydrothermal activity (Evans, 1995). Field and compositional relationships suggest that the Mount Butler Granite may be only slightly younger than the Kowloon Granite.

The *Sok Kwu Wan Granite*, defined here, is a small porphyritic monzogranite pluton near Sok Kwu Wan in the north of Lamma Island. The granite intrudes all lithologies except for quartz monzonite dykes. The Sok Kwu Wan Granite is typically porphyritic and medium grained featuring large megacrysts (5-10 mm) of alkali feldspar but may vary to non-porphyritic fine-grained lithologies. An absolute age for the Sok Kwu Wan Granite has not yet been determined.

The *Fan Lau Granite*, defined here, comprises a small porphyritic monzogranite exposed near Fan Lau on the southern tip of Lantau Island. The unit is fine grained and porphyritic with phenocrysts of quartz and alkali feldspar set in a fine-grained matrix. An absolute age for the unit has not been determined. However, the Fan Lau Granite intrudes the Tong Fuk Quartz Monzonite at Fan Lau. Therefore, the age is thought to be less than 140.4 Ma.

Conclusions

The stratigraphic modifications proposed here reflect the volcanic and magmatic evolution of Hong Kong more accurately than previous stratigraphic groupings. In particular they emphasise the significance of time-breaks and associated unconformities between each of the volcanic groups. They also reflect the current level of understanding achieved with regard to the co-magmatism of volcanic deposits and subvolcanic intrusions. However, within the broader context of volcanic stratigraphy in southeastern China, as regional correlation improves, it may be necessary to reassess the hierarchical significance of these groupings.

Future work is likely to extend further the process of stratigraphic refinement as more high-precision dating becomes available and the detailed evolution of individual volcanic centres becomes clearer. It should also be possible to identify more volcanic members that record individual volcanic eruptions and these should form the basis of further improvements in our understanding of the nature and controls of the volcanism.

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Tidal Flat Sedimentation in Hong Kong

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Abstract

Short cores, in a series of profiles, and grab samples of surface sediment have been studied at the Mai Po and Ting Kok tidal flats. Differences in sedimentation between the supratidal and intertidal zones can be recognised on each flat. In addition, the Mai Po and Ting Kok deposits can be distinguished from each other by their grain size characteristics, organic content and biogenic composition. Mai Po is a wide muddy tidal flat with a high organic carbon content, as well as fluvio-tidal and seepage creeks. Ting Kok is a narrow sandy tidal flat with moderate to high organic carbon levels, fluvio-tidal creeks, and an absence of well-developed seepage creeks. The differences between the two tidal flats relate, at least in part, to slope angle and wave energy. Sediment characteristics such as sorting and mean grain size show a gradual transition from typical beach deposits to tidal flat (Mai Po type) sediments, with the Ting Kok sandy tidal flat

摘要

作者從米埔和汀角潮灘的海床泥芯和表層抓挖樣本發現沉積物在高中位潮滯有不同沉積模式，從沉積物的粒徑特徵、有機物含量和生物組合，分辨出兩者的不同。米埔屬高量有機物大泥灘，有小河流過潮灘，反之，汀角屬中至高量有機物的窄細沙灘，沒有完整小河流過潮灘。兩者不同的沉積是跟坡度和海浪動力有關。 從沙粒的分類和平均粒徑，可顯示出米埔沉積物是從普遍沙灘沉積致(米埔型)泥潮灘，汀角的沉積則屬中期發展型。

Introduction

Depositional coastlines with steep gradients and small tidal ranges are usually associated with beach facies that accumulate in relatively narrow coastal zones. As the shoreline gradient becomes gentler and/or the tidal range increases, there is a gradual transition to tidal flat environments, dominated by muddy materials (van Straaten, 1954; Evans, 1975). Hong Kong experiences a mesotidal regime, with a tidal range of about 1.5 to 2.5m. The mountainous character of the territory generally produces steep coastlines and thus favours beach formation in many areas. However, tidal flats do occur locally, being best developed in northwestern Hong Kong where coastal slopes are unusually gentle.

Three tidal flat sub-environments are usually recognised: supratidal, intertidal and subtidal. Supratidal flats occur above the mean high tide level and are flooded only during the highest spring and neap tides, and occasionally during storms. These largely subaerial zones are particularly sensitive to climate controls. Consequently, temperate regions tend to develop salt marshes, whereas tropical areas tend to favour mangrove stands (Reineck, 1963).

Intertidal flats are located between the mean high and low tide levels and are alternately submerged and exposed by the ebb and flood tides. Sediment composition can be very variable, with both mud and sand flats occurring in Hong Kong. Mangroves and grasses are usually absent, although there may be extensive accumulations of seaweed and algal mats, especially on the lower tidal flat. Other organisms such as shrimps, crabs, gastropods and bivalves are common. Consequently, bioturbation of the sedment is extensive (Schafer, 1956; Reineck, 1963; Seilacher, 1953; Hertweck, 1970). Due to the loss of energy as waves cross the gentle intertidal slopes, fine-grained facies are usually found on the upper flat, whereas sandy sediments tend to occur seawards (van Straaten, 1961). Tidal creeks are often generated by rivers that cross the flat during low tide, and by headward erosion related to groundwater seepage. Reineck (1958) showed how lateral erosion and point bar deposition along meandering tidal creeks reworks tidal flat sediments. Lateral migration of such creeks may proceed at rates of several tens of metres per year. Vertical incision by tidal creeks is limited, due to the dominance of depositional processes. The intertidal flat may also contain a wide range of micro-morphologies caused by sedimentological or biological agents, or both. Ripple bedforms are common and reflect the energy and direction of tidal currents and sea waves, the water depth, bedding morphology, and sediment grain size. Where a suitable admixture of fine sand and mud occurs flaser bedding may develop. Hummocky micro-terrain is often present, due to the burrowing activities of organisms such as crabs, and due to the collection of clams by people. As sediment accumulates on the tidal flat the coastline progrades seawards and a fining-upward sequence is generated (Evans, 1975; Harrison, 1975), although this may be interrupted by deposition of coarser materials laid down in tidal creeks at any stage (Mackenzie, 1972).

The subtidal environment lies below the mean low water level and is effectively permanently submerged. It is characterised by relatively coarse-grained materials, off-shore sand bars and tidal-scoured channels, and mega-ripples may be present locally. Generally, the slope of the subtidal zone is steeper than that of the intertidal flat.

Tidal flats and sea level in Hong Kong

At the end of the last ice age sea level in Hong Kong began to rise rapidly. Yang and Xie (1984) suggest a slow initial rise of 3.3 mm per year between 18 000 and 15 000 years before present (BP), which accelerated to 18.2 mm per year between 15 000 and 10 500 years BP. Huang and Chen (1988) infer that the rate of sea-level rise in southern China between 11 000 and 7000 years BP slowed to about 8.9 mm per year. Sea level eventually reached its modern height, and was stabilised, by about 6000 years BP (Owen et al., 1998). During the late Pleistocene and early Holocene phase of rapid sea level rise aggradation became relatively important (Owen et al., 1998). In contrast, the middle and later Holocene stable base level tended to favour progradation. Feng & Shi (1997) have, for example, reported large scale progradation (>60 km) in the upper Pearl River Estuary during the last 5000-6000 years.

The stabilisation of sea level had important implications for intertidal sedimentation. In the Deep Bay area (northwestern Hong Kong), progradation has advanced the coastline by about 4 km during the last 6000 years (Irving and Morton, 1988). In part, this is due to high local weathering and erosion rates in the hinterland, but may also reflect the abundance of fine-grained sediment carried by the Pearl River. Wang and Aubrey (1987) report an annual sediment discharge of 370 x 10^9 m^3, which contrasts strongly with the sediment regime of eastern Hong Kong, where large, sediment-laden rivers are absent.

Two contrasting intertidal flats were selected for this study: Mai Po and Ting Kok. The Mai Po tidal flat is a gently sloping estuarine mud flat located at Deep Bay (Fig. 1). It is has an approximate length of 4 km (which extends further into mainland areas) and a variable width of about up to 2 km. Irving and Morton (1988) note that in 1924 much of the area was swamp and marsh, with some brackish water paddy fields. By 1945 an extensive system of gei wei (shrimp ponds) had been introduced. In 1985 much of the area consisted of fish ponds, with the original swamp and marsh zone having been reduced to a narrow coastal fringe at Mai Po. The Ting Kok tidal flat lies within Tolo Harbour (Fig. 1) and is a much smaller feature with an elongate and sinuous form (50-120 m wide, 1.6 km long). In contrast to Mai Po, Ting Kok is dominated by sand flats, is comparatively steep, and is protected from high wave energies by a near complete ring of peninsulas and islands.

Methods

Base maps were compiled using air photographs. These were then used to plot field sampling locations. Short cores were obtained by gently hammering a 50 cm (5.5 cm diameter) perspex tube into the sediment. The cores were collected along a series of profiles, perpendicular to the coast. At Mai Po, four transects (200-500 m long) were cored at 50 m intervals, although supplementary samples were also collected at sites of particular interest. Five profiles, generally <150 m long, were studied at Ting Kok, with cores collected at 25 m intervals. Mangrove samples consist largely of grab materials, due to the difficulty of penetrating the root systems with the perspex tube.

Upon return to the laboratory, the cores were split. Sub-samples for analysis were extracted at 2 cm intervals and stratigraphic variations in organic carbon, calcium carbonate, and micro-fossils were determined. Grain-size analyses were carried out using a scanning photo sedimentograph (Analysette 20) suitable for sediments with fine to medium grain sizes (1-1000 μm). Coarser materials were hand sieved. Selected samples were impregnated with resin, sectioned, and examined with a petrological microscope. Several sets of samples were mounted

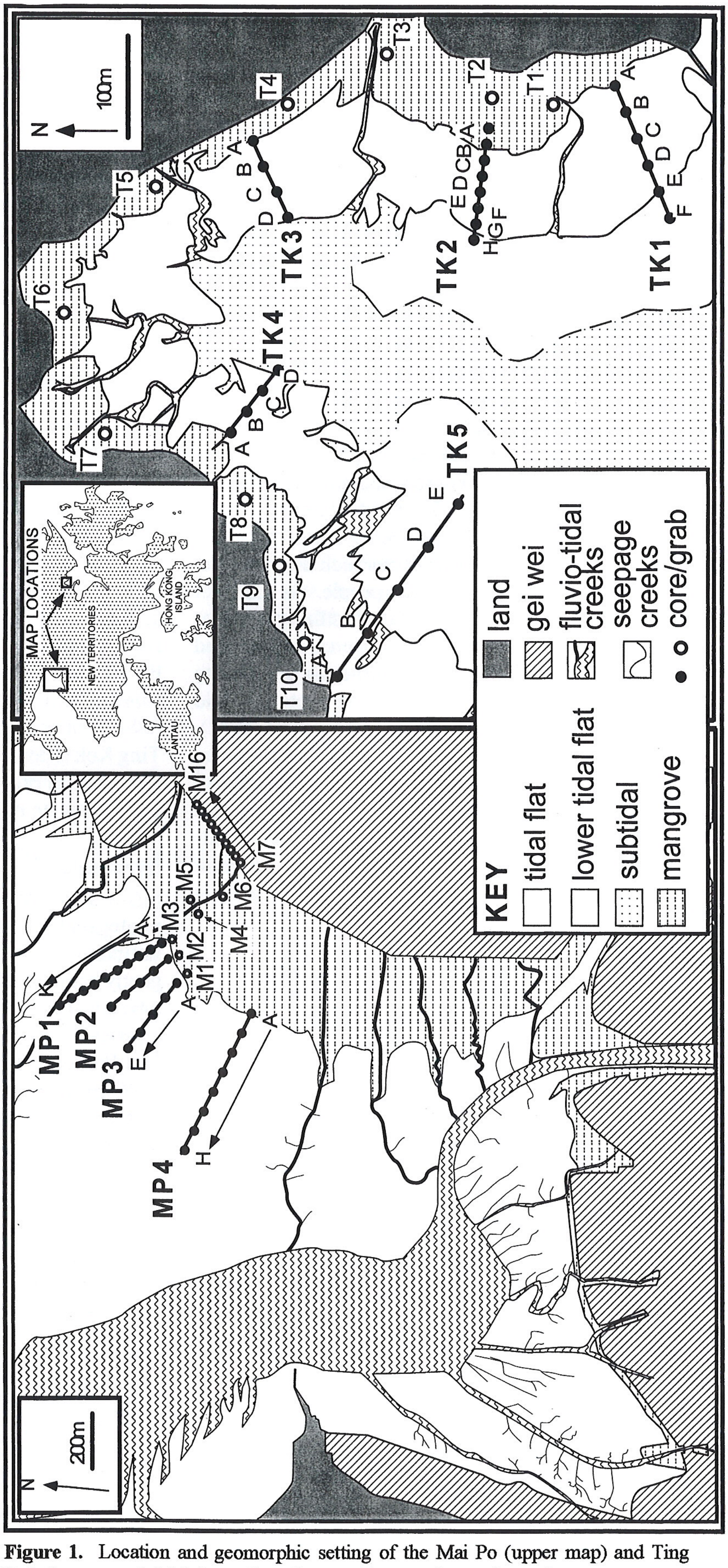

Figure 1. Location and geomorphic setting of the Mai Po (upper map) and Ting Kok (lower map) tidal flats. Sampling profiles are shown for each area

on stubs, gold plated and then analysed by scanning electron microscope.

Geomorphology of the Tidal Flats

Figure 1 shows the geomorphic setting and location of sampling sites at both Mai Po and Ting Kok. The supratidal zones of both sites are dominated by mangroves (Fig. 1), which pass into man-made fish ponds at Mai Po, and into a fandelta system (or colluvium) at Ting Kok.

The intertidal zone at Mai Po is dominated by a wide muddy flat with very gentle gradients (<1°). Subtidal environments were located beyond the study area. Two types of creek system are present. The first consists of fluvio-tidal creeks that carry river water across the flat at low tide, but which flood at high tide. A major fluvio-tidal creek crosses the study site in the west, and acts as a local base level during low tides. Northwest of the creek, mud spits suggest that the dominant sediment movement is upstream and associated with the flood tide. Typically the fluvio-tidal creeks meander on a variety of scales, although straight sections are present. Often the latter sections relate to human activities, especially in the supralittoral mangrove zone. Lateral accretion and erosion processes along the sinuous creeks cause reworking of the sediments and introduce a fluvial component to the deposits.

The second creek system type comprises seepage creeks. These are typically straight (often forming parallel groups), short, erosion dominated, and do not reach the supralittoral zone. Several seepage creeks are served by a dendritic series of feeder rills towards the headward section of the creek. They begin to form where the high groundwater table intersects with the surface of the mudflat, and incise both headwards and downwards to the local base level (the nearest fluvio-tidal creek).

The Ting Kok tidal flat contrasts with Mai Po in several ways. It is much narrower (100-150 m), has a steeper gradient (0.5-2°), and is dominated by sand. Fluvio-tidal creeks cross the flat at several locations, but seepage creeks are small or absent. This may be due to the steeper gradient preventing the water table from intersecting with the ground surface, and may also be due to the presence of sand-size materials, which allows greater infiltration and consequently less overland flow.

Sediment Grain Size

Mean grain size and maximum grain size are closely related to the average and maximum energy in a depositional environment, although the availability of particles of a particular size may also be an important control. In contrast, sorting tends to reflect the persistence of a sedimentary process more than the actual energy in an environment. Consequently, sediment reworking and long transport

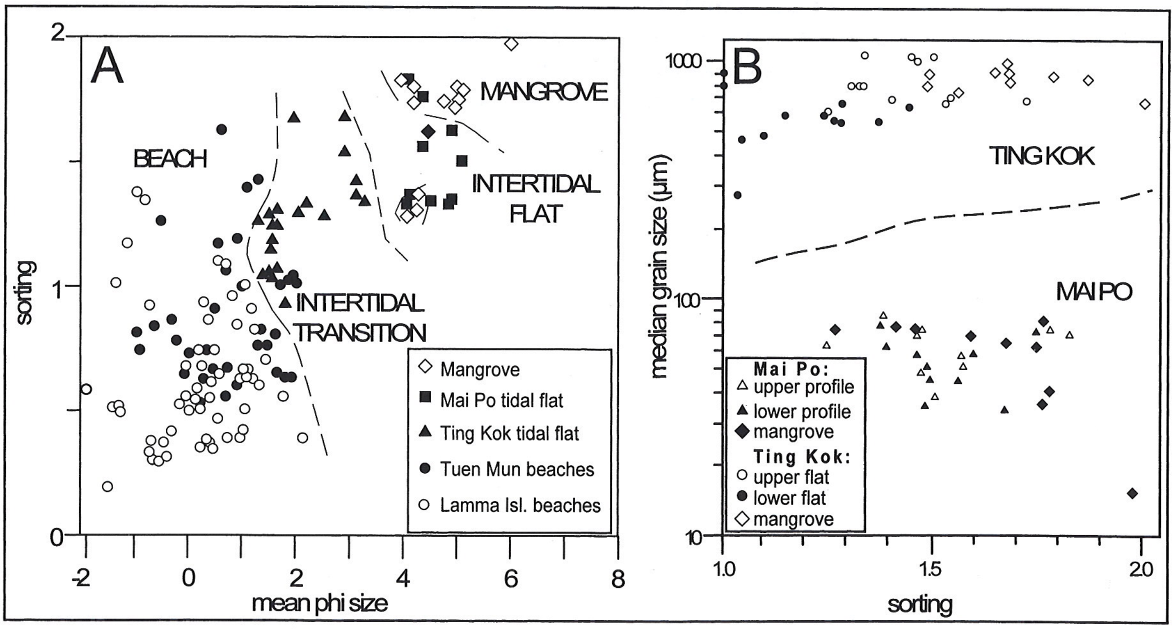

Figure 2. Grain size characteristics of the tidal flats. *A*, mean grain size and sorting showing the transition from typical beach, through Ting Kok type tidal flats to Mai Po type tidal flats; *B*, median grain size and sorting showing the distinct difference in coarseness between Mai Po and Ting Kok. Note the regular transition from lower tidal flat through upper tidal flat and into mangrove zone sediments. Lower tidal flat sediments were NOT sampled at Mai Po, the upper and lower profiles being confined to the wide upper tidal flat

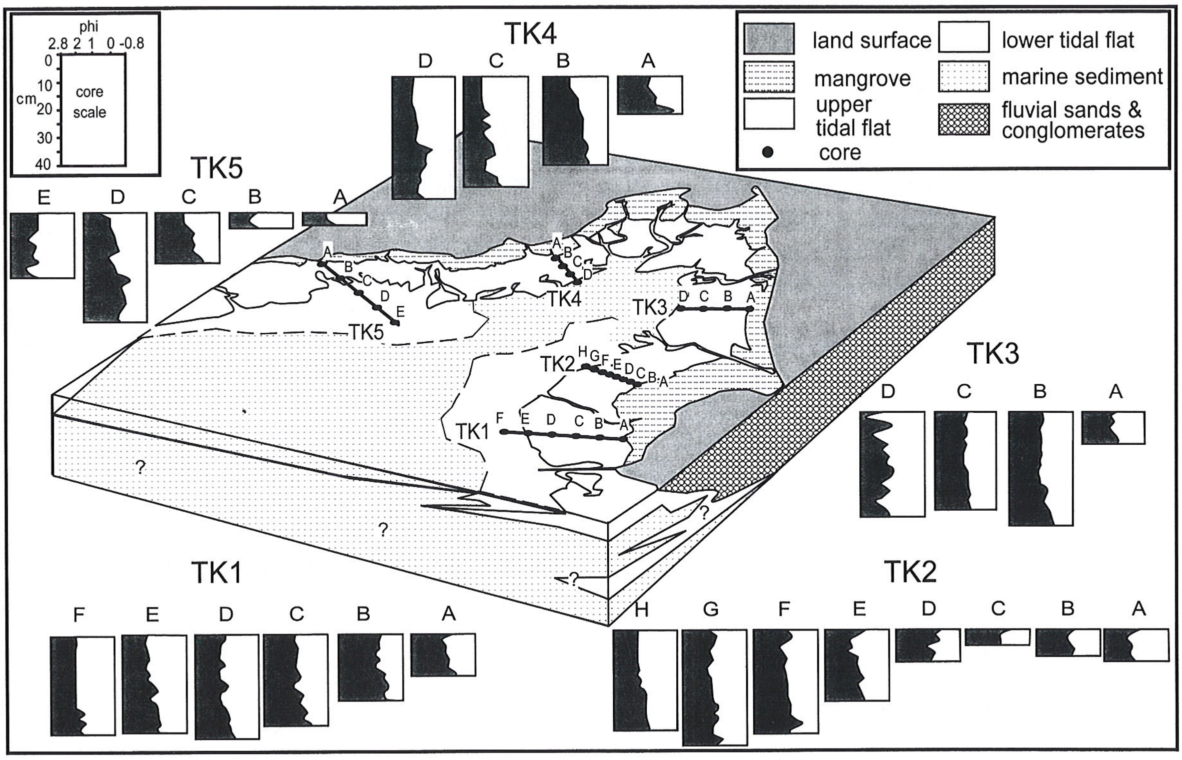

Figure 3. Short core data showing variation in mean phi grain sizes at Ting Kok. See text for discussion

distances have an important effect on sorting, and deposits laid down in environments such as beaches and aeolian dunes are particularly well sorted.

Figure 2A shows the relationship between sorting and mean phi grain size for tidal flat environments studied here, and also includes data for beaches in the western New Territories and Lamma Island for comparison. Overall there is a good relationship between sorting and mean phi grain size. Beaches show coarse sediments and good sorting. The Ting Kok samples plot in an intermediate region, suggesting that they were laid down in an environment that is somewhat transitional in character between beach and true (muddy) tidal flat situations. The Mai Po intertidal samples are fine-grained and relatively poorly sorted, with sediments from the supratidal mangrove zone forming an extreme end member of the series shown in Figure 2A.

The contrast between the Mai Po and Ting Kok Flats is also clearly shown in Figure 2B, which plots median grain size against sorting. While there is a considerable overlap in sorting characteristics (Mai Po tending to be more poorly sorted), Ting Kok sediments are much coarser. Also, there is a strong differentiation between the supratidal (mangrove), upper tidal flat and lower tidal flat sediments, the latter being better sorted and finer. At Mai Po, supratidal and intertidal flats show considerable overlap and are not easily distinguished. Samples from the seaward end of sampling profiles also show little differentiation from the landward materials. This essentially reflects the scale of the Mai Po area, with true lower flat environments lying beyond the study area.

Contrasting sedimentary environments often show differences in the symmetry of grain size distributions. Fluvial sediments, for example, are often positively skewed, due to the large amounts of clay and silt that are commonly transported. Aeolian dunes also tend to be positively skewed, because coarse sand cannot be carried by the wind, which results in an excess of finer sand once deposition occurs. In contrast, beach deposits tend to be negatively skewed (an excess of coarse material), due to winnowing processes that remove fine-grained sediment. The intertidal flat environments at Ting Kok and Mai Po both show near-symmetrical and fine skew (-0.08 to 0.22) grain size distributions. They also tend to be more finely skewed towards the supratidal zone. This indicates an excess of fine-grained materials, which in turn reflects the low energy status of the tidal flats.

Figures 3 and 4 show the stratigraphic and spatial variation in mean grain size for the intertidal zones of Ting Kok and Mai Po respectively. At Ting Kok (Fig. 3), there is a tendency for surface samples to become coarser towards the land, which with

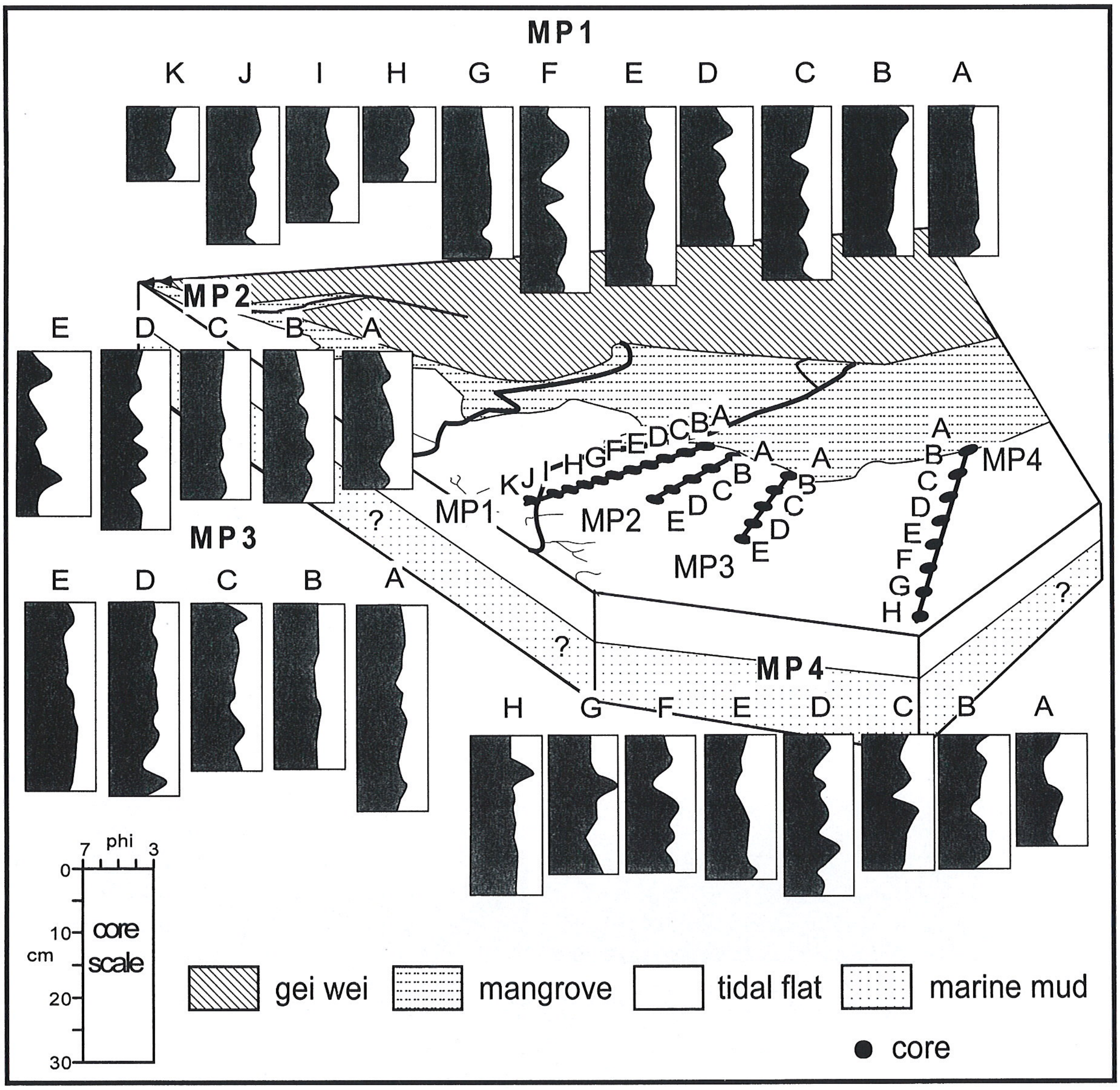

Figure 4. Short core data showing variation in mean phi grain sizes at Mai Po. See text for discussion

progradation should generate a coarsening-upward sequence. This does not appear be the case along profiles TK1, TK4 and TK5, where sediments tend to become finer upwards. At some locations (TK2, A-E) this pattern appears to be reversed, and at others (TK3) grain size appears to be broadly uniform. Coarsening-upward sequences are often generated by prograding beaches. It would appear that the relatively narrow sandy (between 0-2 phi) flats of the Ting Kok type are actually complex transitional landforms. Features such as positive skew and local fining-upward profiles reflect tidal influences, whereas characteristics such as coarsening-upward profiles and relatively coarse mean grain size probably reflect the slightly steeper gradients (and beach related processes) as well as deposition from fluvio-tidal (river-like) systems.

At Mai Po (Fig 4), coarsening-upward profiles are scarce (e.g. MP1, B). Most sequences show a largely uniform pattern of fine mud (4-6 phi), reflecting the upper tidal flat setting, with minor increases in grain size at particular horizons (e.g. MP2, D), perhaps related to tidal creek sedimentation. The cores are probably not sufficiently long to incorporate the coarser-grained lower tidal flat deposits that should be present, given the prograding situation at the study site.

Sediment Composition

The tidal flat sediments are dominated by clastic components (generally >80%), with a mineralogy that reflects their hinterland compositions. At Mai Po, clay is an abundant constituent together

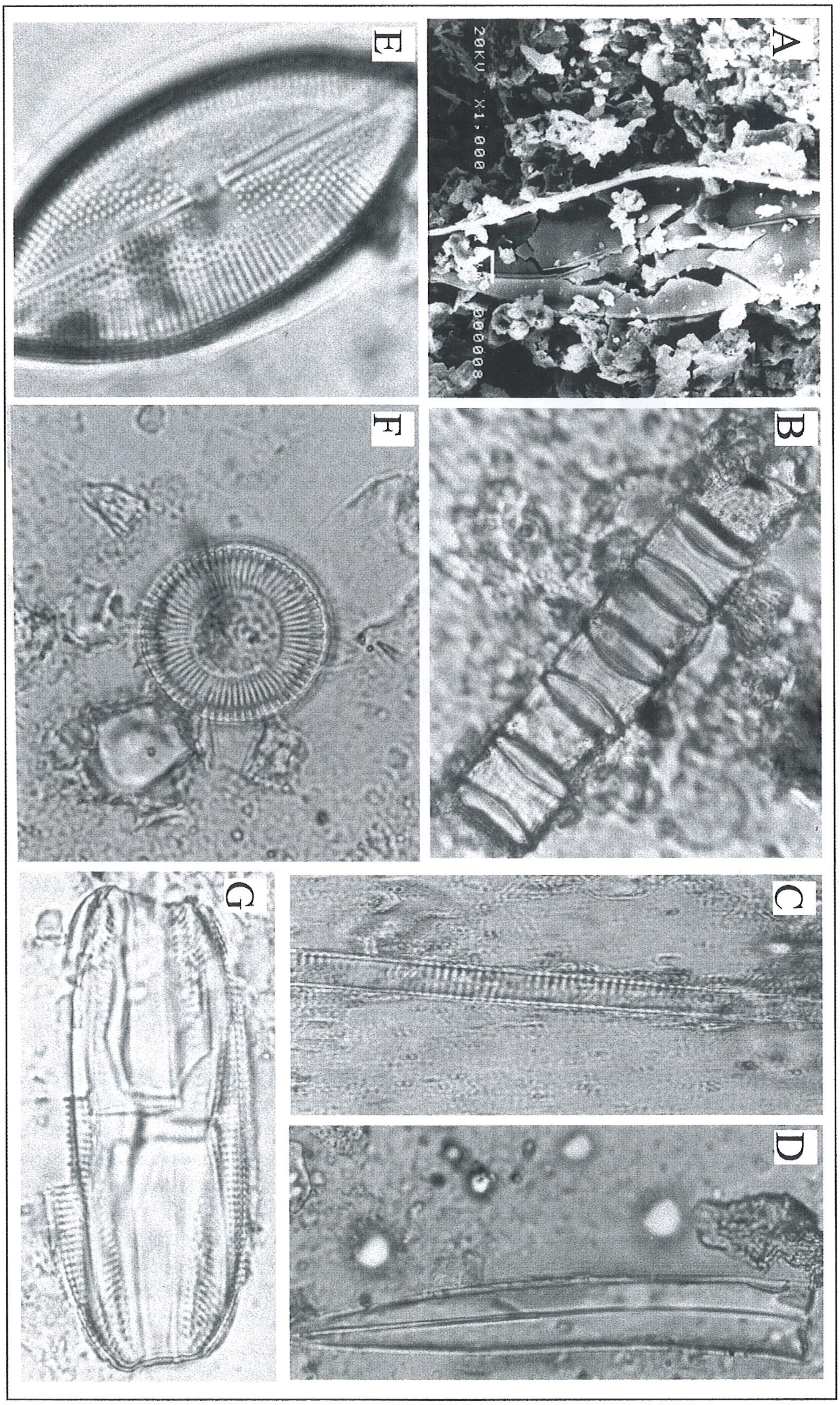

Plate 1. Typical microfossils in the tidal flats. *A*, SEM with *Gyrosigma* and abundant clay particles; *B-G*, smear slides, x1000. B, *Paralia*; C, *Synedra*; D, sponge spicule; E, *Navicula*; F, *Cyclotella*; G, *Amphora*

with silt-sized feldspar, and, less commonly, quartz. Clay is less abundant at Ting Kok, where feldspar derived from the volcanic materials of Pat Sin Leng tends to dominate. No distinctive trends in mineralogy have been observed, other than those that can be attributed to grain size factors.

Biogenic material (excluding organic carbon) forms a relatively minor component (mainly <2-5%). Pollen grains are present though not considered here. The dominant siliceous organisms (Plate 1) are diatoms, with sponge spicules being of secondary importance. The most common forms are pennate (bilaterally symmetric), contrasting strongly with diatoms from offshore areas of Hong Kong which are dominantly centric (radially symmetric). A variety of species are present on the upper tidal flat and mangroves zones of Mai Po, with *Gyrosigma*, *Cyclotella*, and *Mastogloia* being the most common genera. Other taxa include *Nitzschia*, *Synedra*, and small *Navicula*. Rare freshwater *Aulacoseira* have also been observed. The tidal flat and mangrove zones at Ting Kok are more varied and tend be dominated by *Amphora*, with *Achnanthes*, *Fragilaria*, *Nitzschia*, *Cyclotella*, *Synedra* and *Cocconeis* also occurring, as well as rare and usually broken planktonic *Coscinodiscus* and *Paralia*.

Carbonate percentage data reflects the presence of intact and broken bivalves and gastropods, which are common at both Ting Kok and Mai Po. The surficial tidal flat sediments at Ting Kok are comprised of 0.5-16% carbonate, with most samples containing <5% CO_3. In some cores (e.g. TK5E) this rises to 15-30%. The various surficial materials sampled tend to show increasing carbonate towards the lower flat. The supralittoral mangrove zone contains 0-11% CO_3. Mai Po shows a similar pattern. There, surficial sediments generally contain 0.5-15.5% CO_3, with most samples consisting of <5% CO_3. In contrast with Ting Kok, the carbonate content of all Mai Po core samples falls into the same range as the surficial sediment. The supralittoral mangrove zone contains 6-12% carbonate, which is consistently higher than that in the Ting Kok mangrove deposits.

Organic carbon (OC) is an important constituent (between 0.8 and 9.7% on the two tidal flats; Fig. 5) that shows distinctive distribution patterns. At Ting Kok, OC ranges between 0.82 and 3.90% on the intertidal flat. This rises to 1.41-4.60% in the supratidal mangrove zone. A similar pattern is evident at Mai Po, but with OC being more abundant. The Mai Po intertidal flat contains between 2.56 and 6.03% OC, which rises to 4.04-9.71% in the supratidal mangrove sediments.

Profiles of the upper tidal flat studied at Mai Po (Fig. 5B) show no particularly strong trend in OC content. At Ting Kok (Fig. 5A), there is a strong tendency for OC to vary along profiles (in part due to the presence of a contrasting lower tidal flat zone). In some cases, there is little variation (e.g. TK4 and TK5), in other profiles (e.g. TK1 and TK3) there are elevated concentrations close to the mangrove zone or on the lower flat, or both (e.g. TK1 and TK2). The latter increase in OC may be due to algal matter and seaweed, which commonly occurs near the subtidal to lower flat transition zone, while the former high OC values probably relate to mangrove source

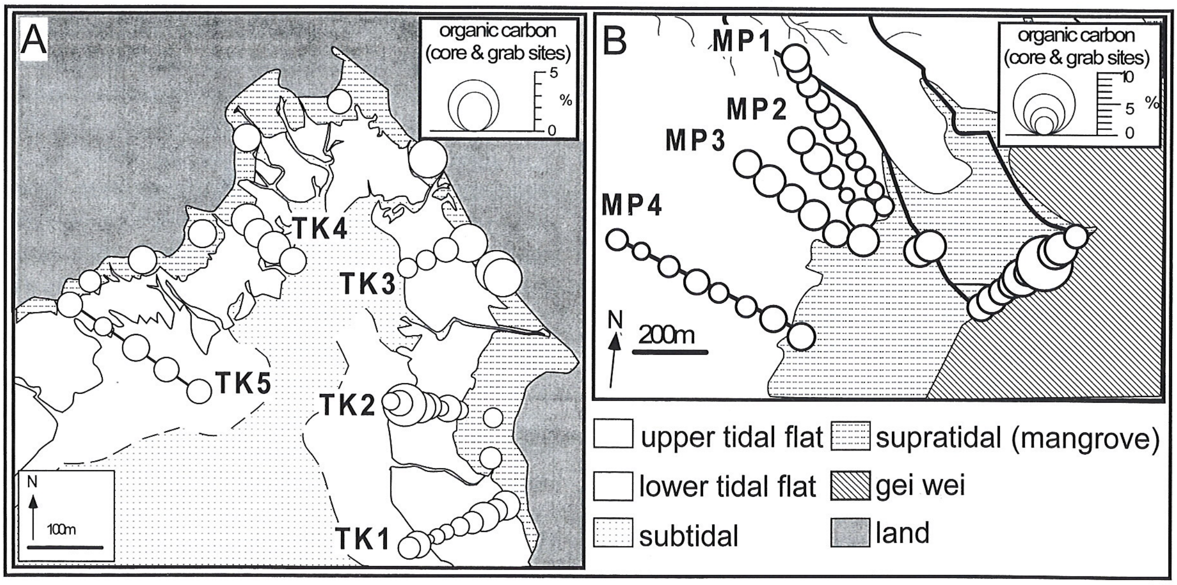

Figure 5. Organic carbon distribution. *A*, Ting Kok tidal flats; *B*, Mai Po tidal flats

materials.

Conclusions

Hong Kong coastlines include a wide range of facies types. A number of factors are important in controlling the nature of the sediments that accumulate. These include wave energy and direction, sediment sources, proximity of river inputs, slope gradient, and coastal configuration, which controls wave refraction. As a result of these controls the most common local shoreline types are comprised of erosional coasts, fandelta systems, beaches and a variety of tidal flats. The data presented here indicate that beaches and muddy tidal flats represent end members of a series of morphological situations that reflect slope gradient, wave energy, and available source materials, with sandy tidal flats representing an intermediate stage.

Supratidal, upper tidal flat and lower tidal flat zones can be distinguished using grain-size characteristics, organic carbon and diatom content. Carbonate data appear to be more variable, although possible trends were present at Ting Kok. In general, the tidal flat and mangrove sediments contain >80% clastic material, 0-30% carbonate, 0.8-9.7% organic carbon, and <2-5% siliceous microfossils. Mean grain sizes on the Mai Po type tidal flat are typically in the range of 4-6 phi, whereas the Ting Kok type deposits range between 0 and 2 phi. Data for sediments of both types of tidal flat is nearly symmetrical, or positively skewed, with sorting values ranging from about 1-1.8.

While Mai Po type muddy tidal flats may be distinguished with relative ease in the geological record, there may be problems where sediments were laid down in a Ting Kok type sandy tidal flat. In these cases, there is a need to carefully consider the details of grain-size parameters, such as sorting, mean and median values, as well as kurtosis. By also using data on biological components (organic carbon, carbonate, diatoms) it should, nevertheless, be possible to refine interpretations of Hong Kong's Quaternary palaeoenvironments.

Acknowledgements. This research was supported by a Hong Kong Baptist University studentship.

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Observations on Suspended Sediment Concentrations in Some Hong Kong Streams and Rivers

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Abstract

Some measurements have been made of suspended sediment concentrations in four Hong Kong watercourses. Under baseflow conditions the Kam Tin River has upper quartile, median and lower quartile values for suspended matter that are much higher than recorded in other streams or rivers. During stormflow events high suspended sediment levels can be observed in all four watercourses, but the median values for the Kam Tin and Lam Tsuen Rivers exceed 200 mg l^{-1}. In contrast two well vegetated upland basins each have stormflow median values of less than 25 mg l^{-1}. Soil paper sediment concentrations are generally low.

摘要

本研究對香港四條河流（小溪）的懸浮物濃度進行了若干測試。在基流情況下，錦田河流的第三四分位、中位及第一四分位懸浮物濃度值大大高於其它河流（小溪）。在暴流情況下，四條河流（小溪）均有很高的懸浮物濃度，但錦田河和林村河的中位值則超過了 200 mg/1。相比之下，二個植被良好的山原盆地在暴流情況下，其中位值均低於 25 mg/1。總體上說，土壤排水管的沉積物濃度比較低。

Introduction

Information on suspended sediment concentrations in streams and rivers can be of considerable value to the engineer, ecologist, planner and environmentalist. For example, high sediment concentrations can affect fisheries (e.g. Braune and Looser, 1989) and benthic macroinvertebrates (e.g. Welch, 1992, p. 292). Suspended matter, especially organic material, is also a source of food for animals able to utilise such material (e.g. Payne, 1986) and it also affects photosynthesis by phytoplankton through its influence on light penetration (e.g. Payne, 1986). Phytoplankton carrying capacity is therefore also related to turbidity and hence sediment levels (e.g. Reynolds, 1996). Sediment impacts upon water supply and may, as shown by Braune and Looser (1989), necessitate special equipment such as presedimentation tanks. Operational costs are also increased. Sediment is also a physical pollutant and may be one determinand monitored (e.g. Markham and Repp, 1992). The Environmental Protection Department (EPD) of Hong Kong also monitors suspended solids and this parameter is included in water quality objectives. Suspended sediment production and levels are also considered in monitoring the effects of land use change and practices, especially those associated with forestry (e.g. Johnson, 1994, Ferguson et al., 1991). Despite the potential significance of suspended solids levels in watercourses they have received little attention in the territory. Only Lam (1974) and Peart (1992), along with the EPD monitoring programs, have to date afforded much data for Hong Kong. In an investigation of sedimentation in man-made channels in Hong Kong the Port Works Division (1988) felt constrained to develop a generalised sediment rating curve for the whole territory due to the paucity of data available for individual channels.

This study reports some observations made for a number of streams and rivers in the New Territories and attempts to expand the data base.

Study Sites

Since 1989 a small instrumented basin has been monitored for water quality at the Kadoorie Agricultural Research Centre (KARC) near Shek

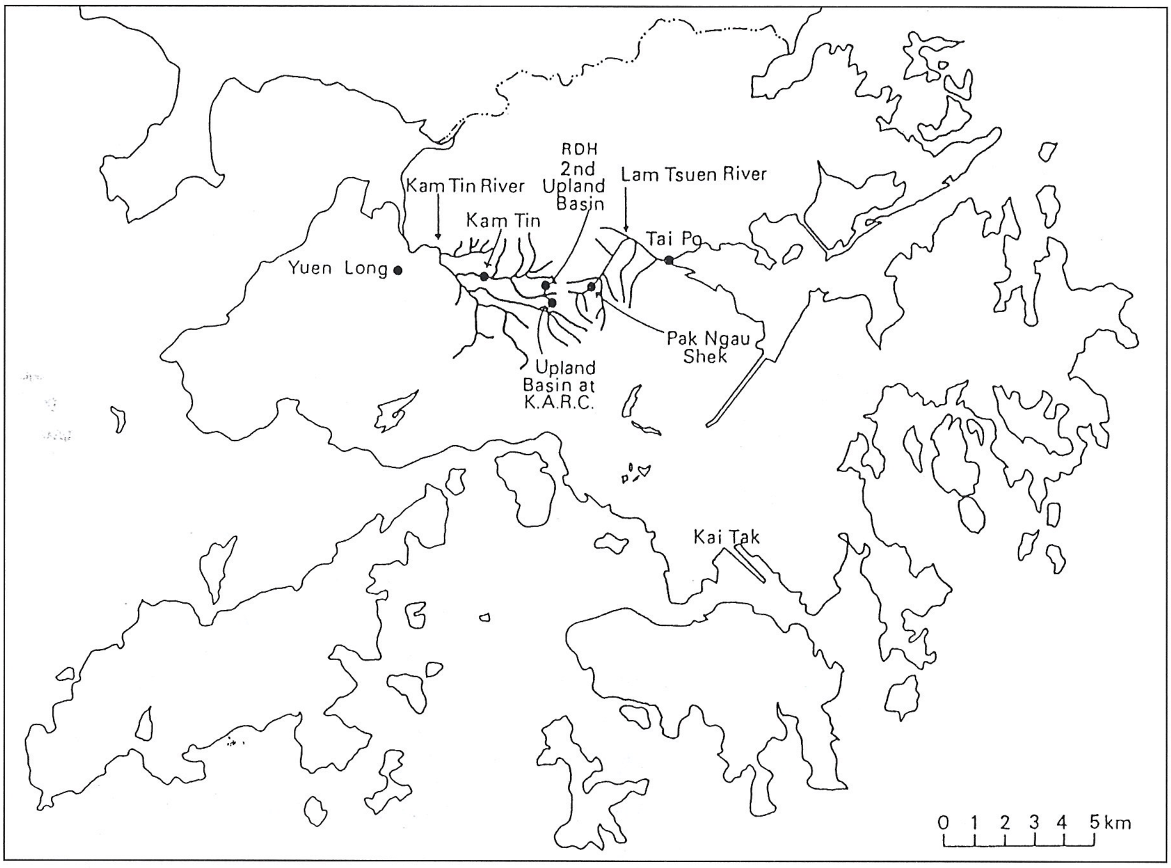

Figure 1. Location of sampling sites

Kong in the New Territories. It was selected for study to form a baseline in terms of water chemistry and sediment production. During 1991 a road improvement scheme began impacting water quality in the Lam Tsuen river and it was decided to monitor this. From 1991 a small permanent soil pipe system was noticed on the hillside at KARC and water quality observations began on this system. In 1993 two further monitoring points were started. One was an upland basin near KARC at Sheung Tsuen where Prof. R.D. Hill was monitoring hillslope erosion. Perhaps of most significance was the beginning of sampling in the Kam Tin River near Kam Tin in 1993 at a point near the Water Supplies Department gauging station. This station afforded the opportunity to sample one of the bigger watercourses in Hong Kong and one which was impacted by development. Finally, in 1995 suspended sediment data were gathered on a second soil pipe system, located near the Lam Tsuen River not far from Pak Ngau Shek. The major characteristics of the drainage basins can be summarised as follows: the basin at KARC is small (less than 1 km^2), has steep slopes, a full vegetation cover, (mainly woodland) and is developed on granodiorite bedrock which in places is covered in colluvium. The measurement point is around 200 m PD (meters above Principal Datum). The second upland basin (called RDH) at Sheung Tsuen is similar to that at KARC except that the vegetation cover is grassland and the weir is located at 125 m PD and the highest point is around 400 m PD. The Lam Tsuen River, which is sampled in its upper reaches near Pak Ngau Shek for this study, can also be regarded as an upland basin with steep slopes and a largely undisturbed vegetation cover consisting of grassland, shrubland and woodland. It also contains the Kadoorie Botanic Garden and has an area a little larger than the two small basins at around 2.0 km^2. Bedrock geology is a mix of pyroclastic and granodiorite rocks, although colluvium drapes the slopes in some areas. The monitoring point is about 84 m PD. The biggest basin is that of the Kam Tin River which at the monitoring station has an area of around 18 km^2, approximately half of which may be considered steep uplands. These uplands are covered in woodland, shrubland and grassland, developed on either granodiorite or pyroclastic rocks. This contrasts with the intensively developed alluvial plain of the lowland portion of the basin. It has been developed for settlement, agriculture (including livestock rearing), industry and open storage, and also includes

Table 1. Sample size for the study streams and rivers, and beginning of sampling

STREAM RIVER	SAMPLE SIZE STORMFLOW	BASEFLOW	START DATE OF MONITORING
KARC	660	495	April 1989
Lam Tsuen River	346	289	February 1991
Kam Tin River	190	234	April 1993
Sheung Tsuen	187	228	April 1993

KARC: Kadoorie Agricultural Research Centre.

the Shek Kong military camp. This basin has the greatest altitudinal range, from 957 m PD at Tai Mo Shan to around 8 m PD at the gauging station. The sampling points are shown in Figure 1.

Sampling and Laboratory Methods

The hydrological regime of the streams and rivers is such that baseflow conditions dominate for the winter dry season and a higher baseflow occurs in summer. Superimposed upon this are a number of storm hydrographs. Sampling was carried out such that both baseflow and stormflow conditions were covered. Stormflow samples were collected on both rising and falling limbs of the storm hydrograph and for a wide range of water levels. Table 1 provides information on the sample size for each study basin. For the soil pipe system at KARC 250 samples were collected from 1991-1995 while at the Lam Tsuen River soil pipe 67 samples were analysed in 1995.

Hand sampling was adopted given the lack of automatic samplers for each site. However, as for example Ward (1984) and Johnson (1992) recognise, this places limits upon the number of samples that can be obtained. A water/sediment sample of around 500 ml was obtained by dipping a wide-mouthed bottle into the flow. Upon return to the laboratory the samples were filtered through pre-weighed GFC filter papers. These were then dried to a continuous weight, re-weighed and the sediment concentration determined.

Results

Presented in Table 2 are the maximum, minimum, median and upper and lower quartile values of suspended sediment concentrations under baseflow conditions at the sampling sites. All sites exhibit a considerable range between maximum and minimum values with those of the Kam Tin and Lam Tsuen Rivers being the greatest. Kam Tin has the highest inter-quartile range (56.6 mg l^{-1}), which is far higher than the other streams, suggesting this river is the most variable in terms of baseflow sediment levels. In respect of median values the highest to lowest ranking goes from Kam Tin → KARC → Lam Tsuen River → Sheung Tsuen (RDH). However, the median value of the Kam Tin River is over six times greater than the second ranked station, the stream at KARC. The upper quartile concentration value in the Kam Tin river is over eight times higher than the next highest basin. Very high baseflow suspended sediment levels have occurred in both the Kam Tin and Lam Tsuen river basins.

Frequency distributions of baseflow suspended sediment concentrations at the study sites are presented in Figure 2. All stations exhibit positively skewed distributions and only at the Kam Tin River is the modal group higher than the lowest category of sediment concentration. Figure 2 also reveals the greater variability of suspended solids in the Kam Tin River, as well as some high baseflow sediment concentrations in the Lam Tsuen River.

Table 2. Baseflow suspended sediment concentration data (mg l^{-1})

	MAX	MIN	MEDIAN	UPPER QUARTILE	LOWER QUARTILE	INTER-QUARTILE RANGE
KARC	91	0.2	5.3	9.1	3.0	6.1
Lam Tsuen River	2 378	0.2	2.5	6.95	1.4	5.55
Kam Tin	2 372	1.3	36.3	75.2	18.6	56.6
Sheung Tsuen	275	0.2	1.6	3.1	0.6	2.5

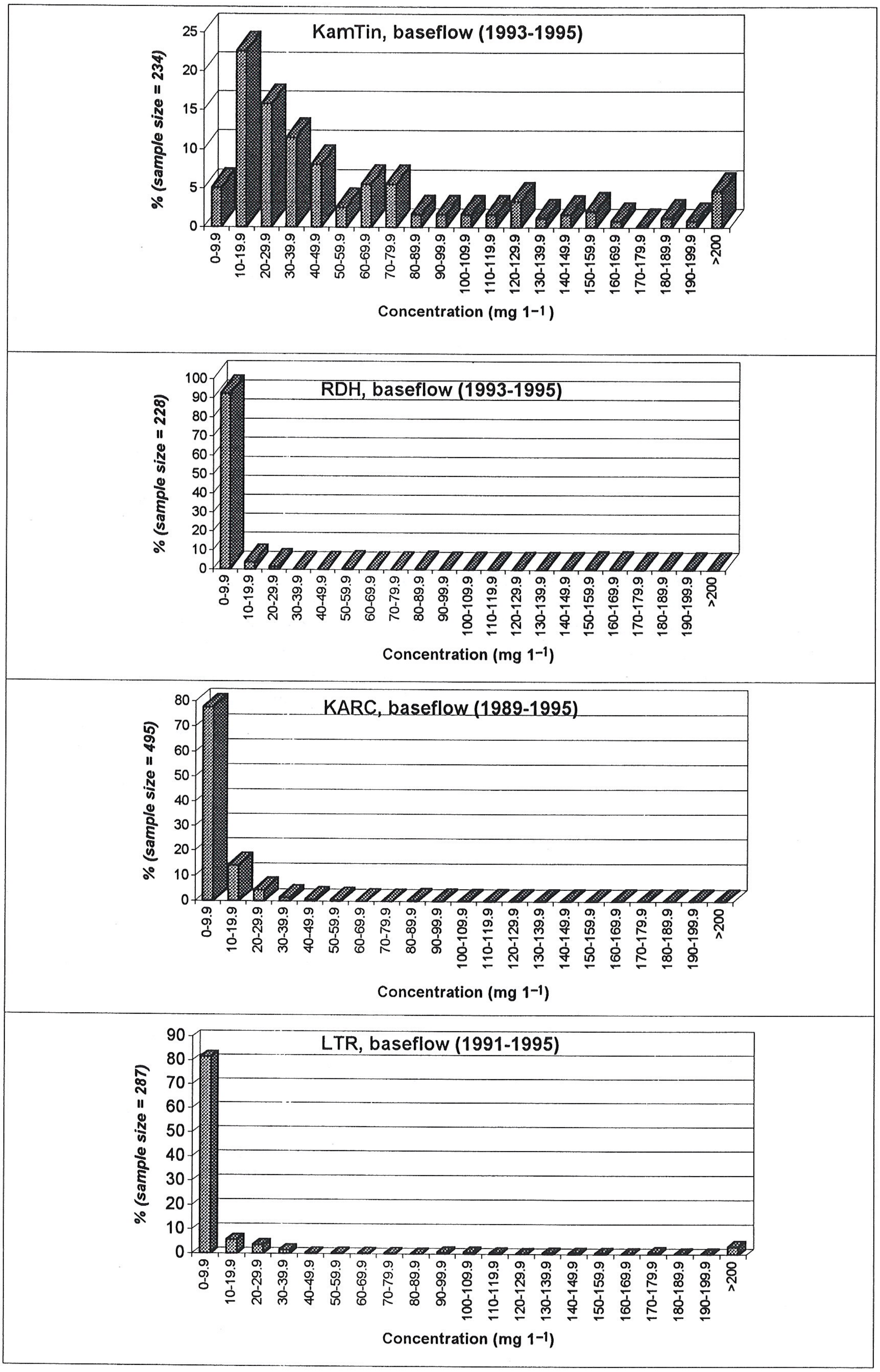

Figure 2. Frequency distributions of baseflow suspended sediment concentrations. *RDH*, Sheung Tsuen; *KARC*, Kadoorie Agricultural Research Centre; *LTR*, Lam Tsuen River

Table 3. Stormflow suspended sediment concentration data (mg l^{-1})

	MAX	MIN	MEDIAN	UPPER QUARTILE	LOWER QUARTILE	INTER-QUARTILE RANGE
KARC	2 677	1.0	21.2	52.7	9.9	42.8
Lam Tsuen River	18 222	0.2	256.3	954	41.1	912.9
Kam Tin	1 853	7.16	225.6	472.6	122.5	350.1
Sheung Tsuen	1 419	0.2	5.4	19.6	2.1	17.5

Descriptive statistics of suspended solids concentrations obtained for stormflow conditions in the study basins are presented in Table 3. Maxima can be very high, over 18 000 mg l^{-1} in the Lam Tsuen River, but all basins exceed 1400 mg l^{-1}. However, all basins have very low levels of suspended matter as recorded minima, and for the Kam Tin basin this signifies the cleaning or flushing effect of storm events. The median values reveal a clear contrast between the basins, the Kam Tin and Lam Tsuen Rivers having median values over 200 mg l^{-1} while in contrast the median values in the KARC and RDH basins do not exceed 25 mg l^{-1}. Using the inter-quartile range as an indication of storm period variability the Lam Tsuen basin exhibits a range of a little over 900 mg l^{-1} while that of the Kam Tin basin is 350 mg l^{-1}. The two small basins exhibit markedly less variability with inter-quartile ranges of 43 mg l^{-1} and 18 mg l^{-1} respectively for the KARC and RDH catchments.

The frequency distributions of stormflow suspended sediment concentrations presented in Figure 3 reveal negative skewness for the KARC and RDH basins, while those of the Kam Tin and Lam Tsuen Rivers exhibit positive shewness with the modal class being greater than 200 mg l^{-1} in each case.

Information on pipeflow suspended sediment concentrations is presented in Table 4. It can be seen that median values are low, being 8.5 mg l^{-1} for the KARC system and only 1.8 mg l^{-1} in the Lam Tsuen valley pipe. The inter-quartile ranges are also low, being 18 mg l^{-1} and 6.2 mg l^{-1} respectively for the KARC and Lam Tsuen systems. Occasional high values do occur, for example three samples exceeded 1000 mg l^{-1} in the KARC system.

Discussion

In terms of baseflow suspended solids concentrations it is clear that Kam Tin has higher levels than the other basins as shown by comparing, for example, median with upper and lower quartile values. These comparatively high values at Kam Tin almost certainly reflect the disposal of livestock, domestic, and to a lesser extent, industrial waste in the river as recognised by, for example, the EPD (1995). In all other basins the baseflow suspended sediment levels are generally low. Occasional high values can occur, especially in the Lam Tsuen valley, when construction equipment being used on a road improvement scheme would sometimes generate very high suspended sediment levels whilst being used in the stream. The very low suspended matter levels in the basin suggests that under baseflow conditions flowing water alone is generally not sufficient to erode and entrain sediment.

Under stormflow conditions the two undisturbed upland basins in general record lower suspended sediment levels than the other rivers. This is well illustrated by Figure 3 which provides a good indication that low suspended sediment levels dominate in the undisturbed basins with 63% of the samples in the KARC basin and 75% in the RDH basin being less than 20 mg l^{-1}. In contrast, for the Kam Tin basin and the Lam Tsuen River suspended matter levels in excess of 200 mg l^{-1} dominate. The absolute maxima is recorded in the Lam Tsuen River and it exceeds 18 000 mg l^{-1}. This, and other high values, reflects the fact that disturbed cut slopes, at times during the road improvement work, led right to the channel system. Rills could be seen delivering

Table 4. Suspended sediment concentrations observed in pipes (mg l^{-1})

	SAMPLE SIZE	UPPER QUARTILE	MEDIAN	LOWER QUARTILE	INTER-QUARTILE RANGE
Lam Tsuen Pipe	67	6.6	1.8	0.4	6.2
KARC Pipe	250	22.1	8.5	4.1	18.0

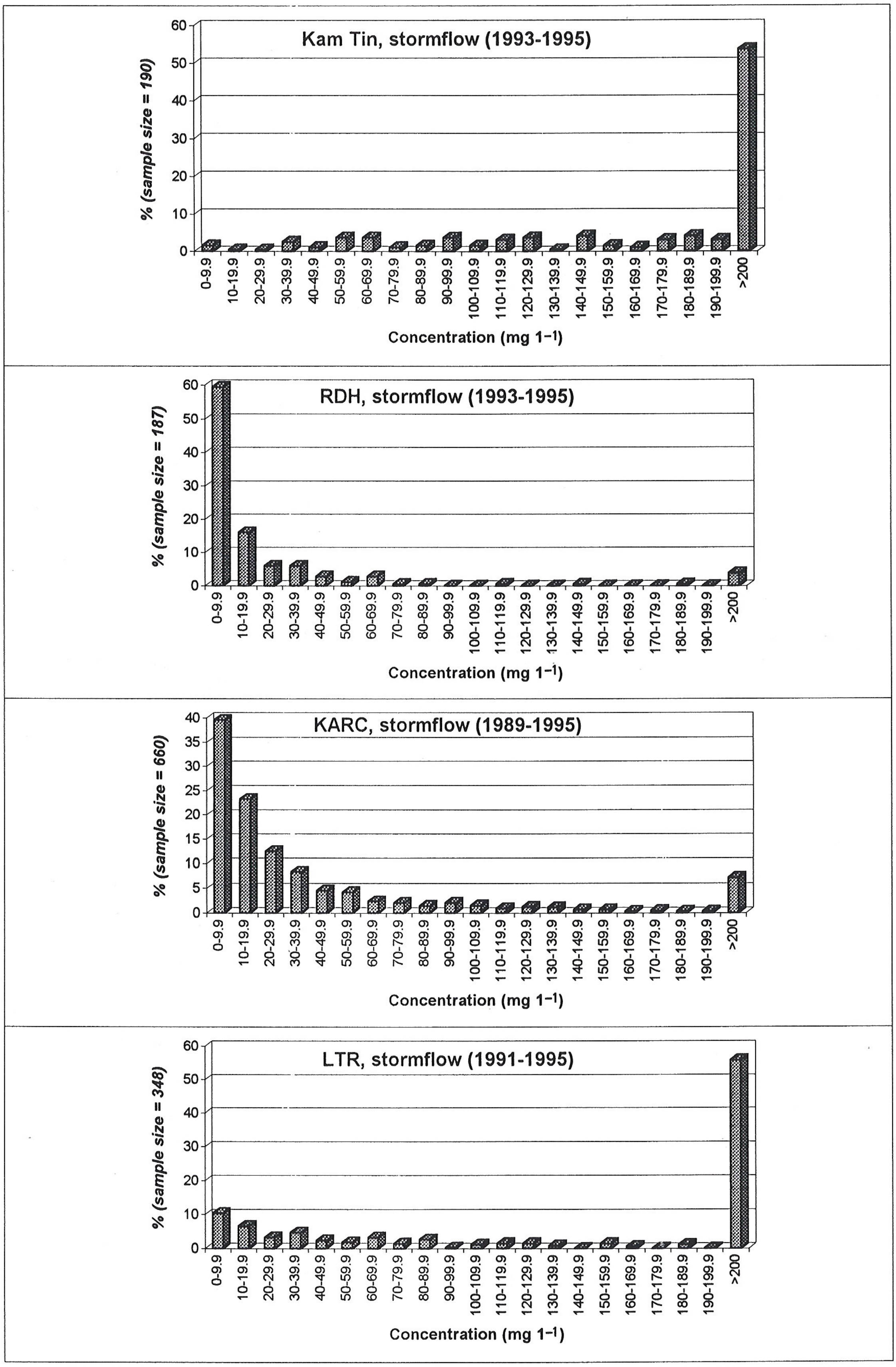

Figure 3. Frequency didtributions of stormflow suspended sediment. *RDH*, Sheung Tsuen; *KARC*, Kadoorie Agricultural Research Centre; *LTR*, Lam Tsuen River

sediment straight into the river. The high median and upper quartile values for the Lam Tsuen River reflect the influence of roadworks. In terms of median value the Kam Tin River is very similar to the Lam Tsuen River. It also has an upper quartile value of 473 mg l^{-1}, considerably higher than the two undisturbed basins. In part this must reflect the livestock waste that a recent reconnaissance walk along the channel system showed to exist in many places. The same survey also revealed several areas where channel bank erosion may provide sediment. Moreover there was plenty of agricultural land which could also provide sediment during rainstorms especially when not covered with flower or vegetable crops. Other studies, such as Kelbe et al. (1991), have revealed that disturbance can produce high suspended sediment levels in comparison to "natural" basins.

Some long term studies of suspended sediment concentrations have revealed that variability is the central feature of the data set (e.g. Johnson 1994). Johnson (1994) has also found that variability can be used to assess the impact of land use change in drainage basins. Variability is present in the watercourses used in this study, both under baseflow and stormflow conditions. Considering baseflow first it is interesting to note that the two upland basins exhibit similar variability as defined by the inter-quartile range. Their variability can therefore be used to characterise sediment production in undisturbed upland basins. The basin at Kam Tin shows the highest variability under baseflow conditions and this probably reflects the highly variable nature of pollutant influx and possibly the scouring and flushing action of the river. A recent reconnaissance walk along the channel system reveals many possible point source inputs. The Lam Tsuen River also exhibits very low variability of suspended matter variation under baseflow conditions. This may be somewhat surprising given the disturbance present in the basin especially in 1991 and 1992. However, it could be that the years experiencing greatest disturbance were under-sampled and the variability hidden by the 1993, 1994 and 1995 data. Some support for this latter explanation can be found by the fact that in the 1991/92 data, baseflow inter-quartile range suspended sediment concentrations had a range of 96 mg l^{-1}, rather higher than for the complete data set. Suspended sediment variation does not, however, equate to the variability found in the Kam Tin River. If it is accepted that the Lam Tsuen River data reflect, at least for baseflow, a relatively undisturbed period, the low variability of baseflow sediment concentrations lends further support to this feature being characteristic of upland basins in Hong Kong. The data from Lam (1974) for his undisturbed basin C also supports small variability of suspended sediment concentrations under steady storage conditions. This basin has an inter-quartile range of 7.5 mg l^{-1} and a median value of 3.8 mg l^{-1} for 47 samples (Lam, 1974).

Under stormflow conditions the Lam Tsuen River exhibits the greatest variability of suspended sediment as measured by the inter-quartile range. The most likely explanation for this is the ready supply of suspended matter for entrainment during rainfall especially during the first few years of investigation when roadworks were in progress. The Kam Tin River also evidences a high degree of storm period variability (as defined by the inter-quartile range) compared to the two upland basins. It would be tempting to ascribe this to the pollutant loading from livestock and other waste but this would be too simplistic. Sediment may be produced by erosion of agricultural land and there are a number of channel banks in this basin which show clear signs of erosion. These may also contribute to the variability in this basin. The two upland basins have the lowest variability of sediment concentration during storm events. However, the range of suspended matter in the woodland basin at KARC is nearly 3 times greater than for the grassland basin, RDH. It is difficult to explain this contrast in variability, however, it may reflect the differing nature of the channels. RDH basin has a vigorous vegetation growth even in the watercourse. This almost certainly acts as a natural filter for the sediment. In contrast, in the woodland basin at KARC there is little vegetation development in the watercourse, although there is abundant plant litter. It may in part also be due to the smaller sample size for the RDH basin and the shorter length of record in this basin. However, comparison of 1993-95 data for the KARC basin reveals that the contrast still exists. The KARC basin has an inter-quartile range of 50.6 mg l^{-1} for 1993-95, rather higher than for RDH.

When sampling began in the Lam Tsuen River construction work was in progress and this had an impact upon sediment levels in the river. By 1995 much of the construction activity had finished. Table 5 presents maximum, median, and upper and lower quartile values for suspended sediment under storm conditions, along with annual rainfall at KARC. Accepting that the relatively small sample size is not limiting, it can be argued that the suspended sediment concentrations have declined, especially from the most disturbed years of 1991 and 1994, and that this might be due to recovery from the construction impact. However, the rainfall data indicate a certain degree of climatic variability. This needs to be remembered when evaluating recovery in the basin and assessing the initial impact. Johnson (1992, 1994) has highlighted the problems of identifying the impact of

Table 5. Temporal variation in stormflow suspended sediment concentrations in the Lam Tsuen River (mg l^{-1})

	1991/1992	1993	1994	1995
Maximum	18 222	6 426	10 844	2 652
Median	977.7	155.4	313.6	61.65
Upper quartile	1 666	772.8	782.7	311.4
Lower quartile	404.6	28.2	82.9	15.4
Sample size	57	148	84	57
Rainfall (mm)	1 830*/2 710**	3 180	3 380	3 050***

*1991; **1992; ***to the nearest 10 mm.

land use upon sediment production when meteorological and hydrologic conditions also vary. Olive and Rieger (1991) also report on the complications climatic contrasts can cause in evaluating the effects of logging and wildfires on sediment production. This will also complicate evaluating the impact of water pollution control measures upon the Kam Tin River. As the work of Johnson (1992, 1994) suggests, long-term records and intensive sampling are necessary. The complicating effects of variable hydrologic conditions, often driven by climate, need to be considered in evaluating land use effects.

Sample size needs to be considered in evaluating descriptive statistics. Table 6 presents information on different study periods for the KARC basin which give rise to samples of contrasting size. Unfortunately, the differing time periods over which data were gathered means that climate has not been held constant. Nevertheless, there is some evidence that for baseflow a sample size of around 200 does not generate very different descriptive statistics in comparison to a sample of nearly 500. Similarly, in the case of stormflow samples, little difference exists between the median and lower quartile concentration values of the three different sample sizes. The upper quartile value does show some difference, ranging from 61.6 mg l^{-1} down to 52.5 mg l^{-1}. An intensive sampling program is currently being undertaken to more fully evaluate the effects of sample size upon descriptive statistics of sediment production.

In terms of pipeflow sediment concentrations, other studies have indicated that concentrations associated with soil pipes can be low. For example, Ziemer (1992) reports that before logging "suspended sediment concentrations from all pipes were less than 20 mg l^{-1}". However, he does caution that "episodic erosion events are typical for sediment transport by pipes". Consequently, the high sediment concentration levels associated with pipe collapse or expansion may go unsampled. It is possible that the higher levels in the pipe system at KARC relate to such episodic events. It should also be noted that some investigators have reported higher suspended sediment concentrations associated with piping than found in this study (e.g. Swanson et al., 1989).

The data also have important implications for environmental monitoring. For example, in the Lam Tsuen River exposure of soil caused by roadworks generated very high suspended sediment levels during storm events. If sampling is carried out only during dry days this impact will be missed. The impact of roadworks upon sediments levels will in consequence be minimised.

In Table 6 some attention is given to the effects of sample size upon sediment levels. In this particular basin the smallest sample size has descriptive statistics similar to the larger samples. However, even the smallest sample used is much greater than those adopted in many EPA studies. More work is being planned on this aspect as it has important implications for monitoring in Hong Kong.

Conclusion

Some observations on suspended sediment levels in a number of watercourses in the New Territories have been made. They reveal considerable spatial and temporal variability reflecting, in part, the human impact. It would be beneficial to determine the source of suspended matter in lowland rivers such as Kam Tin, especially the relative importance of natural erosion processes as opposed to pollutant derived materials.

The variability of the data is important, and may help identify, especially under baseflow conditions, basins affected by human activity. The variability also has implications for environmental monitoring.

Table 6. Descriptive statistics of different study periods and sample size in the KARC upland basin (mg l^{-1})

	1989-1995	1991-1995	1993-1995
KARC STREAM BASEFLOW			
Median	5.3	5.4	4.85
Upper quartile	9.1	10.17	8.8
Lower quartile	3.0	3.0	2.7
Inter-quartile range	6.1	7.17	6.1
Sample size	495	418	291
KARC STREAM STORMFLOW			
Median	21.2	24.5	22.5
Upper quartile	52.7	61.6	52.5
Lower quartile	9.9	11.0	10.4
Inter-quartile range	42.8	50.6	42.1
Sample size	660	479	267

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Three New U–Pb Ages from Igneous Rocks in the NE New Territories of Hong Kong and Their Structural Significance

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Abstract

Three new high precision U–Pb zircon ages are reported from Middle Jurassic and Early Cretaceous volcanic and intrusive rocks from the NE New Territories of the Hong Kong Special Administrative Region (SAR). An age of 164.1 ± 0.2 Ma has been obtained from a rhyodacite lava within the Sai Lau Kong Formation, the youngest formation in the Tsuen Wan Volcanic Group, which is confined to a NE-trending volcanotectonic depression between Double Haven and Starling Inlet. A rhyolite dyke, which strikes NE and intrudes siltstone and mudstone of the Lower Jurassic Tolo Channel Formation, has yielded an age of 160.8 ± 0.2 Ma. The dyke crops out along the northern margin of Tolo Channel, and is parallel to the Tolo Channel Fault. A sample of welded fine ash vitric tuff belonging to Ngo Mei Chau Formation, which is confined to a NE-trending volcanotectonic depression in Mirs Bay, has yielded an age of <142.7 ± 0.1 Ma. The new ages constrain more tightly the timing of changes in the regional tectonic stress field which exercised a structural control on the distribution of volcanism and plutonism during the Late Mesozoic.

Introduction

Recently-acquired high precision U–Pb zircon ages (Davis *et al.*, 1997; Campbell & Sewell, 1998) have provided considerable insight into the evolution and emplacement of the Jurassic and Cretaceous silicic volcanic and granitoid rocks of Hong Kong. In combination with trace element geochemistry, it has been possible to identify discrete pairings of volcanic formations and their intrusive equivalents (Sewell & Campbell, 1997; Campbell & Sewell, 1997; this volume) and to demonstrate the nature and extent of the structural controls on their emplacement. This paper extends these studies by reporting three new U–Pb zircon ages from rhyolitic rocks in the NE New Territories of the Hong Kong SAR.

Geological Setting

Jurassic to Cretaceous silicic volcanic rocks and related granitoid rocks crop out over approximately 85% of the land area of Hong Kong (1050 km^2). They belong to a 400 km-wide belt of Mesozoic magmatic rocks exposed along the coastal region of SE China (Fig. 1) and have been divided into four main volcanic groups and corresponding granitoid suites based on petrographic, geochemical and age criteria (Davis *et al.*, 1997; Campbell & Sewell, this volume). The spatial distribution and geometry of the volcanic centres and related plutons in Hong Kong are strongly controlled by NW-trending and ENE-trending faults. These faults are thought to have been active during a period of rapid crustal extension with associated strike-slip movement along the NE-trending Lianhuashan Fault Zone during the Late Mesozoic (Campbell & Sewell, 1997).

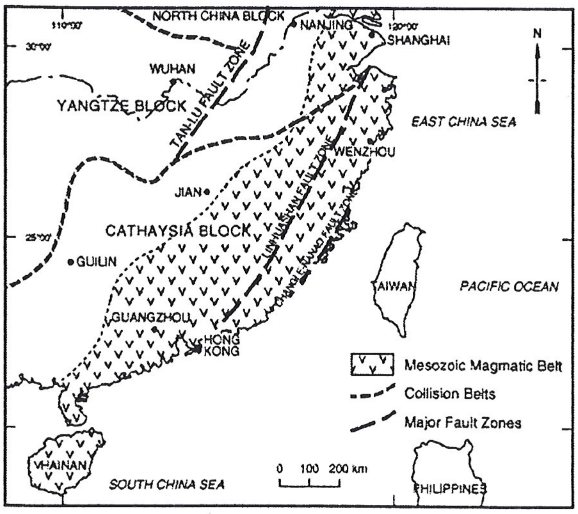

Figure 1. Regional geological setting for Hong Kong rocks showing the distribution of Mesozoic igneous rocks and position of the Lianhuashan Fault Zone

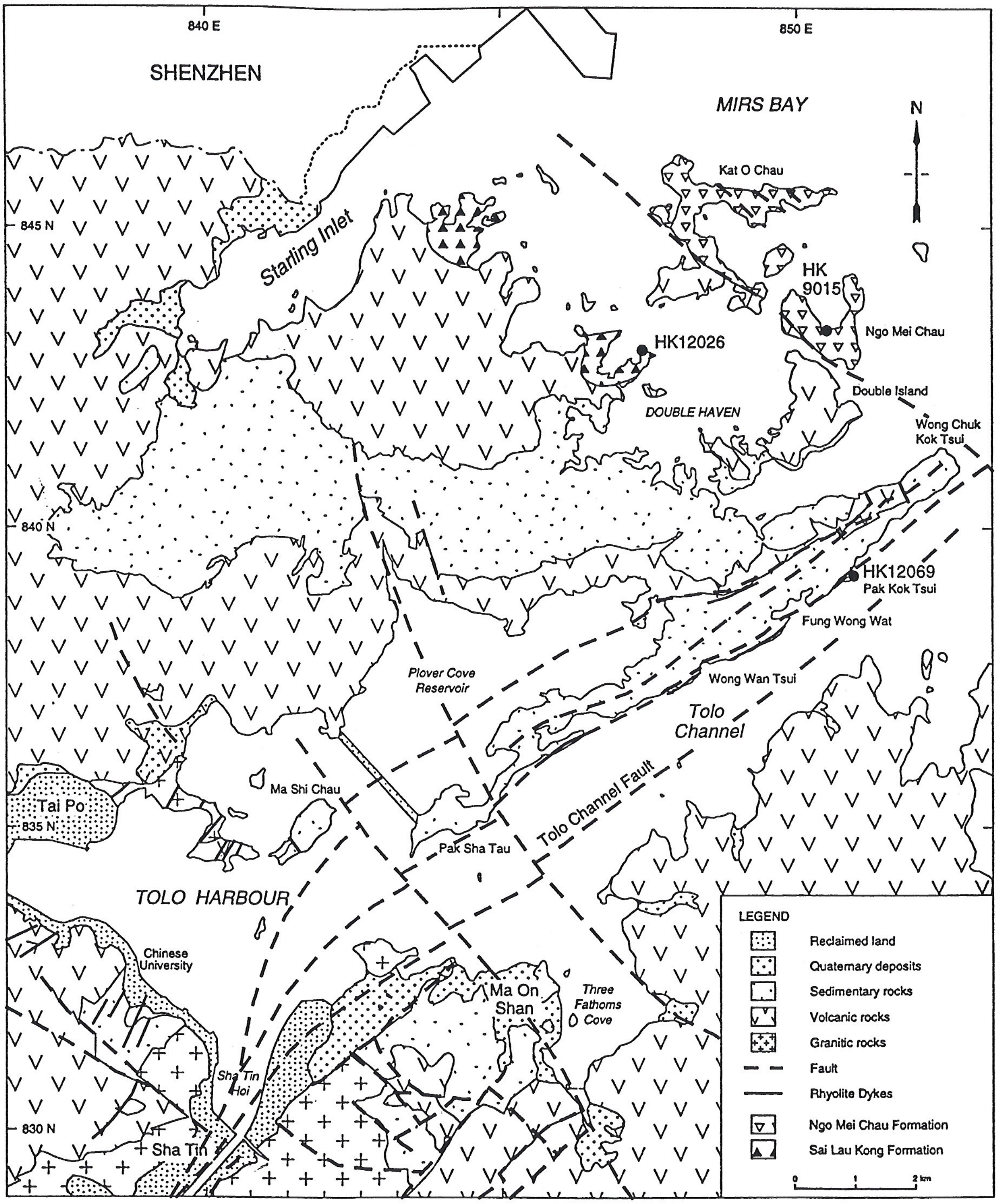

Figure 2. Simplified geological map of NE New Territories showing the location of analysed samples, outcrop of relevant volcanic formations, and major structural features (co-ordinates based on 1980 grid)

Sample sites

The three analysed samples all come from NE New Territories (Fig. 2). Sample HK12026 was collected from the Sai Lau Kong Formation, which is the youngest formation of the Tsuen Wan Volcanic Group. The formation is restricted to a NW-trending outcrop extending from Double Haven to Starling Inlet and comprises dominantly dacite lava with intercalated tuff-breccia, tuffaceous sandstone and siltstone.

Sample HK12069 was collected from a five metre-wide NE-trending rhyolite dyke which intrudes siltstone and sandstone of the Tolo Channel Formation at Pak Kok Tsui on the north side of Tolo Channel. This dyke extends parallel to the Tolo Channel Fault for approximately two km from Wong Wan Tsai to Pak Kok Tsui. The dyke is thought to belong to a swarm of broadly NE-trending rhyolite dykes which intrude volcanic rocks of the Tsuen Wan Volcanic Group and granitoid rocks of the Lamma Suite, and older rocks, in western, central and eastern New Territories.

Sample HK9015 was collected from the Ngo Mei Chau Formation exposed on Ngo Mei Chau in Mirs Bay. The Ngo Mei Chau Formation is bounded in the west against the Tai Mo Shan Formation (previously dated at <164.5 ± 0.7 Ma, Davis *et al.*, 1997) by a NW-trending fault and comprises dominantly welded fine ash vitric tuff, with subordinate lapilli tuff and rhyolite lava. The Ngo Mei Chau Formation was previously thought to be a constituent of the Tsuen Wan Volcanic Group (GEO,1993). However, Lai et al. (1996) raised doubts about this correlation and suggested alternatively that the formation might be part of the Repulse Bay Volcanic Group on the basis of petrographic and geochemical criteria.

Table 1. U-Pb isotopic data on zircon from Hong Kong rocks

	Fraction Analyzed	Weight (mg)	U (ppm)	Th/U	Pbcom (pg)	^{206}Pb / ^{204}Pb*	^{206}Pb/ ^{238}U†	^{207}Pb/ ^{235}U†	^{206}Pb/^{238}U‡ age (Ma)	2σ	^{207}Pb/^{235}U‡ age (Ma)	2σ	^{207}Pb/^{206}Pb‡ age (Ma)	2σ	Disc. (%)
HK12026															
1	3 AB ZR, LPR	0.008	139	0.52	0.7	2555.59	0.02574	0.17439	163.80	0.79	163.22	0.97	155	18	-5.9
2	1 AB ZR	0.004	301	0.67	1.7	1185.68	0.02577	0.17577	164.04	0.79	164.41	1.85	170	30	3.4
3	3 AB ZR	0.015	73	0.60	0.7	2480.61	0.02582	0.17439	164.31	0.81	163.23	1.76	148	26	-11.5
4	3 AB ZR, INCL	0.012	121	0.50	0.6	3872.67	0.02583	0.17522	164.38	1.20	163.94	0.89	158	20	-4.4
HK12069															
5	3 AB ZR, EQ, CK	0.010	326	0.65	13.4	413.0	0.02530	0.17363	161.07	0.92	162.6	10.5	184	163	12.8
6	5 AB ZR, SPR	0.012	241	0.68	0.8	5973.62	0.02526	0.17120	160.79	0.68	160.46	1.17	156	15	-3.4
7	3 AB ZR, LPR, INCL	0.008	380	0.79	5.6	890.5	0.02525	0.17220	160.77	0.70	161.3	4.5	170	69	5.2
8	3 AB ZR, SPR	0.007	312	0.76	0.9	3908.69	0.02521	0.17098	160.52	0.83	160.27	1.51	157	22	-2.6
HK9015															
9	3 AB ZR	0.008	415	0.67	1.5	3121.7	0.02238	0.15063	142.69	0.28	142.46	0.77	139	12	-2.9
10	1 AB ZR	0.010	246	0.40	2.5	1483.13	0.02332	0.15828	148.58	0.47	149.2	2.4	159	38	6.7
11	2 AB ZR	0.010	519	0.66	29.3	296.1	0.02466	0.16901	157.06	0.51	158.6	5.0	181	80	13.4
12	17 AB ZR	0.015	477	0.52	3.0	3856.44	0.02492	0.17124	158.68	0.31	160.50	0.64	187	9	15.5
13	4 AB ZR	0.014	325	0.68	123.6	76.08	0.02462	0.17081	156.80	1.87	160.1	29.7	210	426	25.5

Analytical Methods

Sample crushing was carried out with a jaw crusher followed by a disk mill. Samples were passed over a Wilfley table to concentrate heavy minerals. Further heavy mineral separation was carried out by density separations with bromoform and methylene iodide, and paramagnetic separations with a Frantz separator. Final sample selection was done by hand picking under a microscope. Exterior surfaces of selected zircon grains were removed by air abrasion (Krogh, 1982). Weights of mineral fractions were estimated by eye, a process that is found to be usually accurate to about ±50%. This affects only U concentrations, not age information, which depends on isotopic ratio measurements (Table 1).

Zircon was dissolved using HF in teflon bombs at 200°C, after being washed in HNO_3. ^{205}Pb-^{235}U spike was added to the dissolution capsules during sample loading. Purification of Pb and U was carried out in HCl using 0.05 ml anion exchange columns (Krogh, 1973).

Pb and U were loaded together on Re filaments using silica gel and analysed with a VG354 mass spectrometer in single collector mode. All of the measurements were made using a Daly collector. The mass discrimination correction for this detector has been monitored for several years and found to be constant at 0.4%/AMU. Thermal mass discrimination corrections are 0.10%/AMU.

Because of depletion of the shorter half-life ^{235}U isotope, there is much less ^{207}Pb than ^{206}Pb for relatively young samples. For Mesozoic and younger samples, ^{206}Pb/^{238}U ages are much more precise and reliable than

Footnotes to Table 1

Weights are based on visual estimates.

Abbreviations: Number of grains analysed is at beginning, AB, abraded; ZR, zircon; INCL, inclusions; EQ, equant; SPR, short prismatic; LPR, long prismatic; CK, cracked.

Th/U is calculated from measured ^{206}Pb/^{208}PB and ^{207}Pb/^{206}Pb age.

Pbcom is total measured common Pb assuming all common Pb has the isotopic composition of laboratory blank:

† ^{206}Pb/^{204}Pb - 18.221; ^{207}Pb/^{204}Pb - 15.612; ^{208}Pb/^{204}Pb - 39.360.

* ^{206}Pb/^{204}Pb are measured values corrected for fractionation and spike.

† ^{206}Pb/^{238}U and ^{207}Pb/^{235}U ratios are corrected for common Pb assuming laboratory blank composition.

‡ ^{206}Pb/^{238}U age, ^{207}Pb/^{235}U age and ^{207}Pb/^{206}Pb age are corrected for ^{230}Th disequilibrium assuming a magnetic Th/U of 4.2.

%Disc. is percent discordance for the given ^{207}Pb/^{206}Pb age.

U decay constants are from Jaffey *et al.* (1971).

2 sigma errors represent uncertainties in the last significant digits.

$^{207}Pb/^{235}U$ ages, and $^{207}Pb/^{206}Pb$ ages are quite imprecise because the concordia curve is nearly parallel to a line through the origin. Therefore, ages for these samples are calculated as $^{206}Pb/^{238}U$ ages. $^{206}Pb/^{238}U$ ages are sensitive to secondary Pb loss, but this is likely to have been eliminated by the abrasion treatment, at least for low–U zircons (limited radiation damage).

To minimise the possibility of inheritance a minimum number of zircons were analysed in a fraction, and zircons having characteristics typical of the igneous population, such as a euhedral shape and an abundance of melt or rod-like inclusions, were chosen for analysis. Inclusions may account for high common Pb values in some of the samples. Even fairly substantial amounts of common Pb (tens of picograms) have only a small effect on the $^{206}Pb/^{238}U$ age precision. Common Pb corrections below 10 pg are made assuming an isotopic composition similar to laboratory blank. Excess common Pb is corrected using the Stacey & Kramers (1975) value, which represents a crustal average. Concordia co-ordinates and ages in Table 1 are corrected for fractionation, blank and spike. $^{206}Pb/^{204}Pb$ values are corrected for fractionation and spike.

The plotted data (Figs. 3, 4 and 5), as well as the ages in Table 1, are corrected for ^{230}Th disequilibrium, assuming a Th/U ratio in the magma of 4.2, the terrestrial average. This increases the $^{206}Pb/^{238}U$ ages by about 0.09 Ma in all of the samples. The concordia co-ordinates in Table 1 are quoted as measured values, uncorrected for assumed disequilibrium. Th/U is calculated from the measured $^{208}Pb/^{206}Pb$ ratio and $^{207}Pb/^{206}Pb$ age.

Ages, errors and probabilities of fit are calculated from the Davis (1982) program, modified for fitting $^{206}Pb/^{238}U$ data. U decay constants are from Jaffey *et al.* (1971). Probability of fit is a measure of the likelihood that data points overlap within error. In a random distribution of coeval data with correctly assigned errors, this would be expected to be 50% on average. Values below 10% are generally considered to indicate non-coeval or disturbed data.

Results

All samples yielded zircon, in varying abundance. Crack-free zircons without evidence of cores or alteration were selected for abrasion. Averaged age errors are quoted at the 95% confidence level in the text. Error ellipses in Figures 3 to 5, as well as errors in Table 1, are given as 2 sigma.

1. HK12026 Rhyodacite lava within the Sai Lau Kong Formation from Sai Lau Kong (847510E, 842870N; Fig. 2)

This sample yielded a small amount of zircon as fresh, euhedral prismatic grains, some with well-

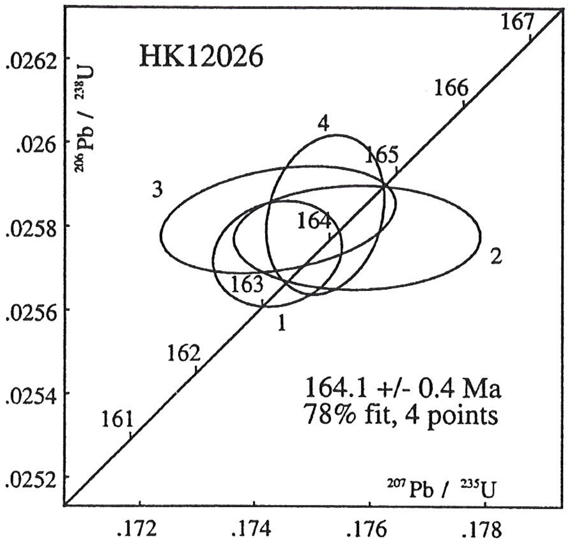

Figure 3. U-Pb concordia plot for the Sai Lau Kong Formation

developed high order crystal faces. Four fractions produced concordant overlapping data points that define a $^{206}Pb/^{238}U$ age of 164.1 ± 0.2 Ma (Fig. 3).

2. HK12069 Intrusive rhyolite within the Tolo Channel Formation, from the NW margin of Tolo Channel (850830E, 839130N; Fig. 2)

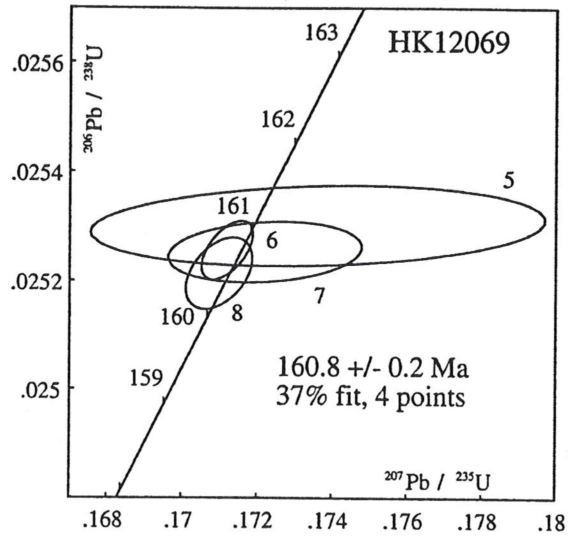

Figure 4. U-Pb concordia plot for the Tolo Channel rhyolite dyke

This sample yielded a moderate amount of zircon. The population consisted of long and short prismatic colourless crystals with poorly developed high-order faces. Many grains had abundant melt inclusions.

Analyses of four multi-grain fractions gave concordant data points that cluster within error. These define an average age of 160.8 ± 0.2 Ma with a 37% probability of fit (Fig. 4), which is the best estimate for the age of crystallisation of the rhyolite.

3. HK9015 Eutaxitic fine ash vitric tuff within the Ngo Mei Chau Formation from Ngo Mei Chau (850460E, 843230N; Fig. 2)

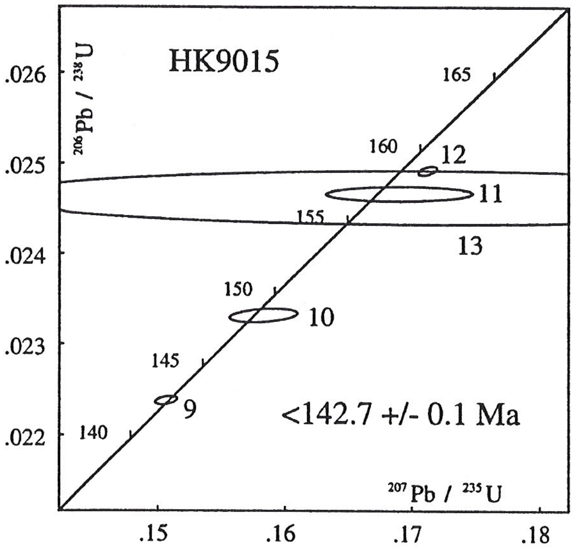

Figure 5. U-Pb concordia plot for the Ngo Mei Chau Formation

This sample yielded only a few hundred zircon grains, most of which were quite small and cracked. The zircons are typically euhedral with well-developed low-order crystal faces and abundant melt inclusions. In addition, there were small apatite crystals and some small opaque inclusions that appeared to be sulphides. No evidence of cores was seen.

Five zircon fractions were analysed but a reliable age estimate cannot be determined from this rock because none of the precise concordant data points overlap within error (Fig. 5). The concordia plot also shows that the zircons contain abundant inheritance, either in the form of xenocrysts or invisible cores. Two of the analyses also show common Pb well above blank levels (typically 0.5 to 2.0 pg). Fraction 13 (Table 1) contained a particularly large amount of common Pb, which greatly increases its $^{207}Pb/^{235}U$ age error beyond the scale of the figure. This may be due to high common Pb inclusions such as galena.

The youngest analysis, which is concordant, has a $^{206}Pb/^{238}U$ age of 142.7 ± 0.1 Ma and this is considered to be an older age limit for eruption of the rhyolitic tuff. The other data points are resolvably older, but still almost concordant, indicating that the source of inheritance is Phanerozoic. Inheritance of this kind was found to be common in Hong Kong with zircons from the 141–146 Ma episodes in previous studies (Davis *et al.*, 1997) and probably results from contamination with underlying rocks (e.g. 165–159 Ma). Davis *et al.* (1997) also reported inheritance but from a wide range of Mesoproterozoic and Archaean sources in Mesozoic volcanic and intrusive rocks of Hong Kong.

Discussion

Campbell and Sewell (1997) have demonstrated that ENE-trending and NW-trending faults have exerted a strong influence on the distribution and loci of Middle Jurassic to Early Cretaceous volcanic deposits and centres in Hong Kong. They postulated that as the regional tectonic stress field changed from an active margin, dominated by subduction, to a back-arc regime dominated by crustal attentuation, dextral strike-slip movement along ENE-trending faults gave way to sinistral strike-slip movement. This transition was accompanied by an increase of activity on NW-trending faults, punctuated by periods of unusually rapid extension.

The U–Pb age on the Sai Lau Kong Formation places an upper limit of 164.1 Ma on the age of the Tsuen Wan Volcanic Group. Moreover, the presence of tuff-breccia and rhyodacite lava flows suggests that the formation occupies a NW-trending depression related to a nearby volcanic fissure-vent. Therefore, the Sai Lau Kong Formation may mark the earliest expression of changes in the regional stress field leading to the onset of sinistral strike-slip fault movement and rapid extension in the Hong Kong area.

The 160.8 ± 0.2 Ma age of the Tolo Channel rhyolite dyke suggests that ENE-trending and NE-trending axes of extension and dextral transtension were again dominant in the late Middle Jurassic (Campbell & Sewell, 1997). Sporadic NE-trending rhyolite dykes also intrude the A-type Lamma Suite granitoids in western New Territories dated at *c.*159 Ma (Davis *et al.*, 1997) suggesting that dextral transtension continued to dominate the regional structural regime.

The <142.7 ± 0.1 Ma age of the Ngo Mei Chau Formation confirms the observations of Lai *et al.* (1996) regarding the stratigraphy of the Ngo Mei Chau Formation. The data are also in accord with available geochemical and petrographic data for the formation indicating close similarities with the Ap Lei Chau Formation of the Repulse Bay Volcanic Group. The Ap Lei Chau Formation has returned a concordant U–Pb zircon age of 142.7 ± 0.2 Ma (Davis *et al.*, 1997) and also occupies a NW-trending depression. Therefore, the geometry of the Ngo Mei Chau Formation is also consistent with earlier structural interpretations for the Repulse Bay Volcanic Group (Campbell & Sewell, 1997), which favour increased activity on NW-trending faults during the Early Cretaceous. Inheritance data yielded by this sample also support other recently-acquired age data which indicate a thermal event at around 148 Ma. This event may have been a precursor to the major period of volcanism and plutonism at 146 Ma (Davis *et al.*, 1997), which was dominated by a NE- to ENE-trending structural regime.

Conclusions

Three new high precision U–Pb ages for Jurassic to Cretaceous silicic volcanic and intrusive rocks from northeastern New Territories are consistent with previous age-dating studies, which have identified distinct periods of Middle Jurassic to Early Cretaceous magmatism at about 162 ± 3 Ma and 142.7 ± 0.2 Ma (Davis *et al.*, 1997). Combined with structural data, these new ages indicate that NW-trending and NE- to ENE-trending faults are likely to have exercised a strong influence on the distribution and loci of volcanic centres. Although dextral strike-slip movement on NE- to ENE-trending faults may have been dominant throughout the main episodes of Middle Jurassic to Early Cretaceous magmatism, sinistral strike-slip movement, indicating changes in regional tectonic stress field, seems to have commenced sporadically as early as the Middle Jurassic.

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The Geological Society of Hong Kong in collaboration with the Open University of Hong Kong is presently engaged in the production of a book on landforms. This is a multi-authored book, and will include all articles previously published as part of the Hong Kong Landform Series in *Hong Kong Geologist*.

As a consequence, the Hong Kong Landforms Series has been discontinued. The next edition of Hong Kong Geologist will carry the first article in a new series, Classic Geologic Locations of Hong Kong.

ADDENDUM

The following addendum concerns the paper entitled "A Proposed Revision of the Volcanic Stratigraphy and Related Plutonic Classification of Hong Kong" by Campbell & Sewell in this volume.

Since going to press, further absolute age dates and geochemical data have been obtained for several volcanic formations and intrusive units. These warrant slight modifications to the proposed stratigraphic and plutonic groupings. Therefore, the following amendments should be noted:

1) The Sunset Peak Formation is now considered to be unnecessary and the relevant strata are assigned instead to the Clear Water Bay Formation.

2) The Mang Kung Uk Formation has now been dated at 142.9 ± 0.2 Ma and is therefore presumed to be part of the Repulse Bay Volcanic Group. Although undated, the overlying Pan Long Wan Formation is geochemically similar to the 'Trachytic' Subgroup rocks of the Repulse Bay Volcanic Group and is, therefore, also assigned to the Repulse Bay Volcanic Group.

3) The South Lamma Granite has now been dated at 148.1 ± 0.2 Ma and, therefore, belongs to the Kwai Chung Suite.

4) The age of the Ngo Mei Chau Formation has been revised to <142.7 ± 0.1 Ma.

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