GCO PUBLICATION No. 6/84

REVIEW OF TECTONIC HISTORY, STRUCTURE AND METAMORPHISM OF HONG KONG

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FOREWORD

This report provides a comprehensive review of the tectonic history, main structural geological features and metamorphic character of Hong Kong. It includes an outline of the general tectonic development of southeastern China, and it discusses the potential for present-day seismic activity in Hong Kong.

The Report is based largely on a review of the published information available up to 1984. In addition, it incorporates the provisional views of professional geologists engaged in the current geological survey programme of the Geotechnical Control Office. The primary aim of this programme is to remap geologically the entire Territory at a scale of 1:20 000 to replace the existing 1:50 000 map produced in 1972.

The draft of this Report was prepared in the Geotechnical Control Office by Dr J.D. Bennett, and it was finalised by Dr R. Addison. Both are staff members of the British Geological Survey who are working under Consultancy Agreement CE/29/82 awarded to the Natural Environment Research Council, UK by the Engineering Development Department of the Hong Kong Government.

E.W. Brand
Principal Government Geotechnical Engineer
December 1984

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1. INTRODUCTION

1.1 TERMS OF REFERENCE

The report is prepared in partial fulfilment of clause 3(1)(g) of the Brief to Agreement CE 29/82, signed by the Natural Environment Research Council (NERC) and the Geotechnical Control Office (GCO), Engineering Development Department, in September 1982.

The terms of reference require the Consultants :

> "to submit a Report on the Tectonic History, Rock Structure, and processes and products of Metamorphism ...... of Hong Kong rocks, and on the nature and history of Faulting in the Territory with particular reference to the potential for seismic activity".

1.2 SCOPE AND PROCEDURE

The report is based on a limited general reconnaissance and a review of the available literature. The review was highly selective in the case of material referring to southern China. The report does not anticipate the outcome of work currently in progress by Dr. R. Addison in the central New Territories, nor work recently initiated by Geological Survey staff in the Hong Kong Island - Kowloon and western New Territories areas. The views expressed in the report should be regarded as provisional and liable to modification as the 1:10 000 scale survey of the Territory proceeds. A fuller, more meaningful statement on the tectonic development of Hong Kong and its position in a regional context must await the completion and synthesis of that work.

The small land area of the Territory (c. 1 000 km^2) makes it unsatisfactory to view the tectonic evolution of Hong Kong in isolation from that of adjacent parts of southern China. Therefore, an outline is given of the regional tectonic setting. It is hoped that this will provide a framework within which the local structure can be more effectively considered. Previous work in Hong Kong is outlined and the major structural elements and metamorphic features are discussed. Important problems meriting further study are indicated. An attempt is also made to review and assess the seismic potential of the Territory in a Geological context. An outline monitoring scheme is suggested which is capable of further development if the geological remapping programme yields evidence for neotectonic activity.

2. REGIONAL TECTONIC SETTING

2.1 OUTLINE OF TECTONIC DEVELOPMENT OF SOUTHEASTERN CHINA

The general geology of southeastern China is shown in Fig. 1. In gross terms it comprises an internal zone of Palaeozoic and older rocks, flanked to the southeast by Mesozoic cover rocks, mainly volcanic, and plutonic intrusives assigned to the Yenshanian tectonomagmatic event. The bouldary between these major rock groups lies to the north of Hong Kong and intersects the present coastline a short distance west of the Pearl River estuary. The 1:15 000 000 scale geological map of China (Anon., 1973) differentiates between the granitoid intrusives and shows them to follow general NE (NNE to ENE) and NW trends, corresponding broadly with the major faults shown on the same map. These trend predominantly NE or, in the region west of 115°E, NNE. Shorter faults strike NW.

The major Yenshanian event tends to obscure the pre-Mesozoic history of the region, the main tectonic elements of which are shown according to Huang (1978) in Fig. 2 and according to Nanjing University (1980) in Fig. 3. Jahn and others (1976) recognised a number of individual tectonic units within Huang's South China Fold System, and Guoquiang (1980) interpreted the belt as a major Palaeozoic marginal basin-island arc system active during the late Sinian (c 1 700 to 600 Ma) and early Palaeozoic. He postulated the existence of a NW dipping subduction zone along the line of the prominent Lishui-Zhenghe-Dabu deep (gault shown in Fig. 3*,

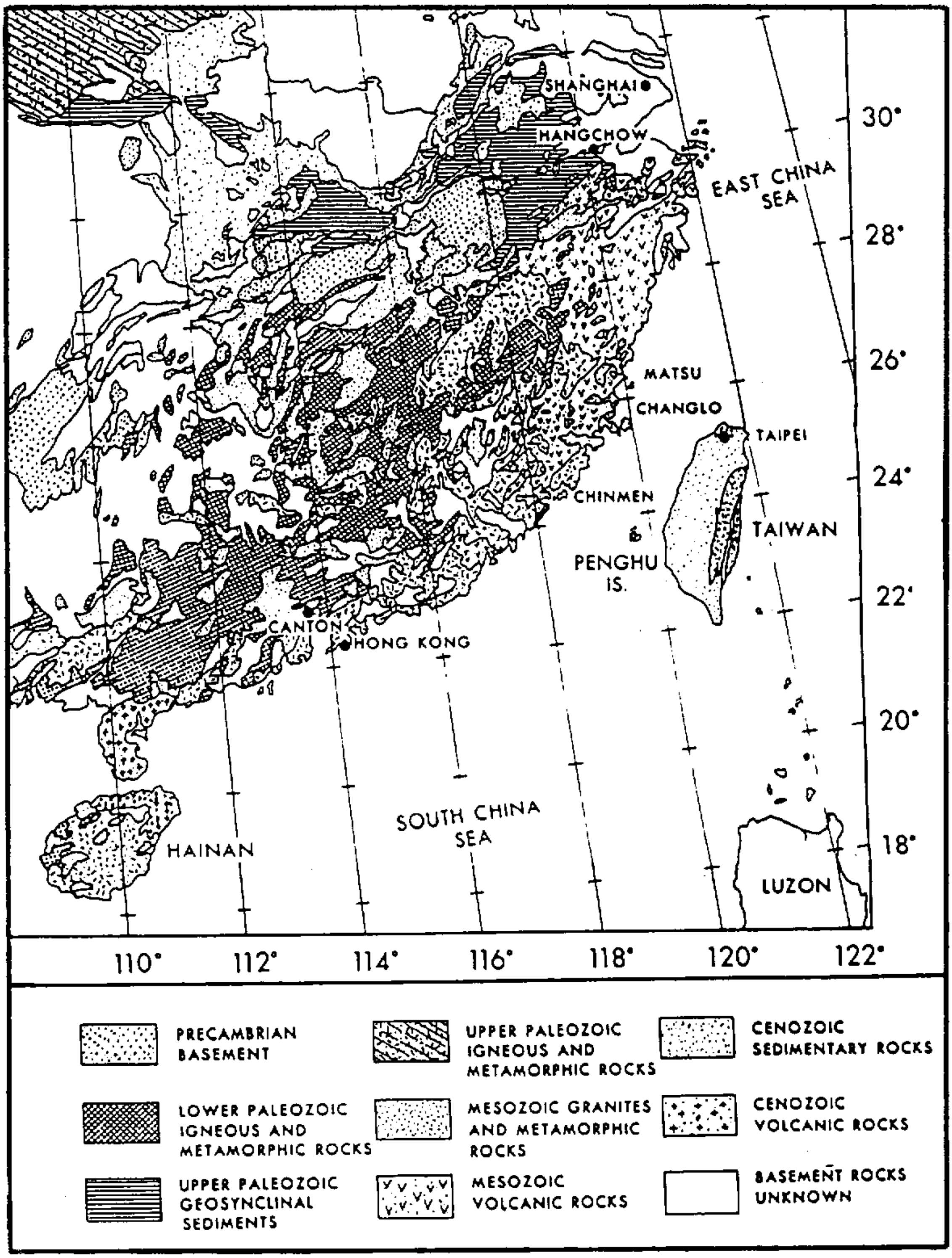

Fig. 1 Geology of southeastern China (based on Terman and Woo (1967) and Ho (1967), taken from Jahn et al. 1976, Fig. 2).

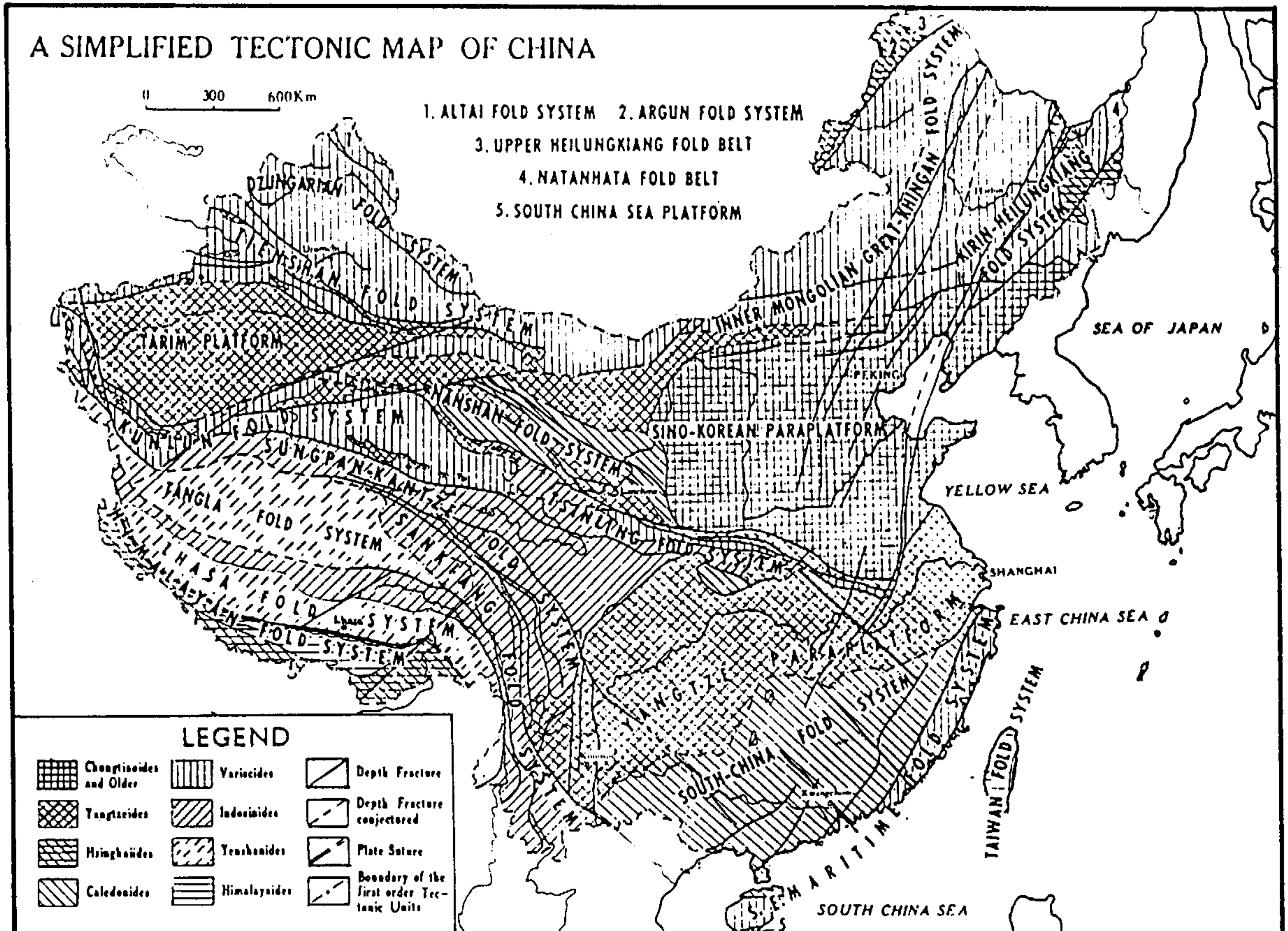

Fig. 2 Major tectonic units of China (Huang 1978).

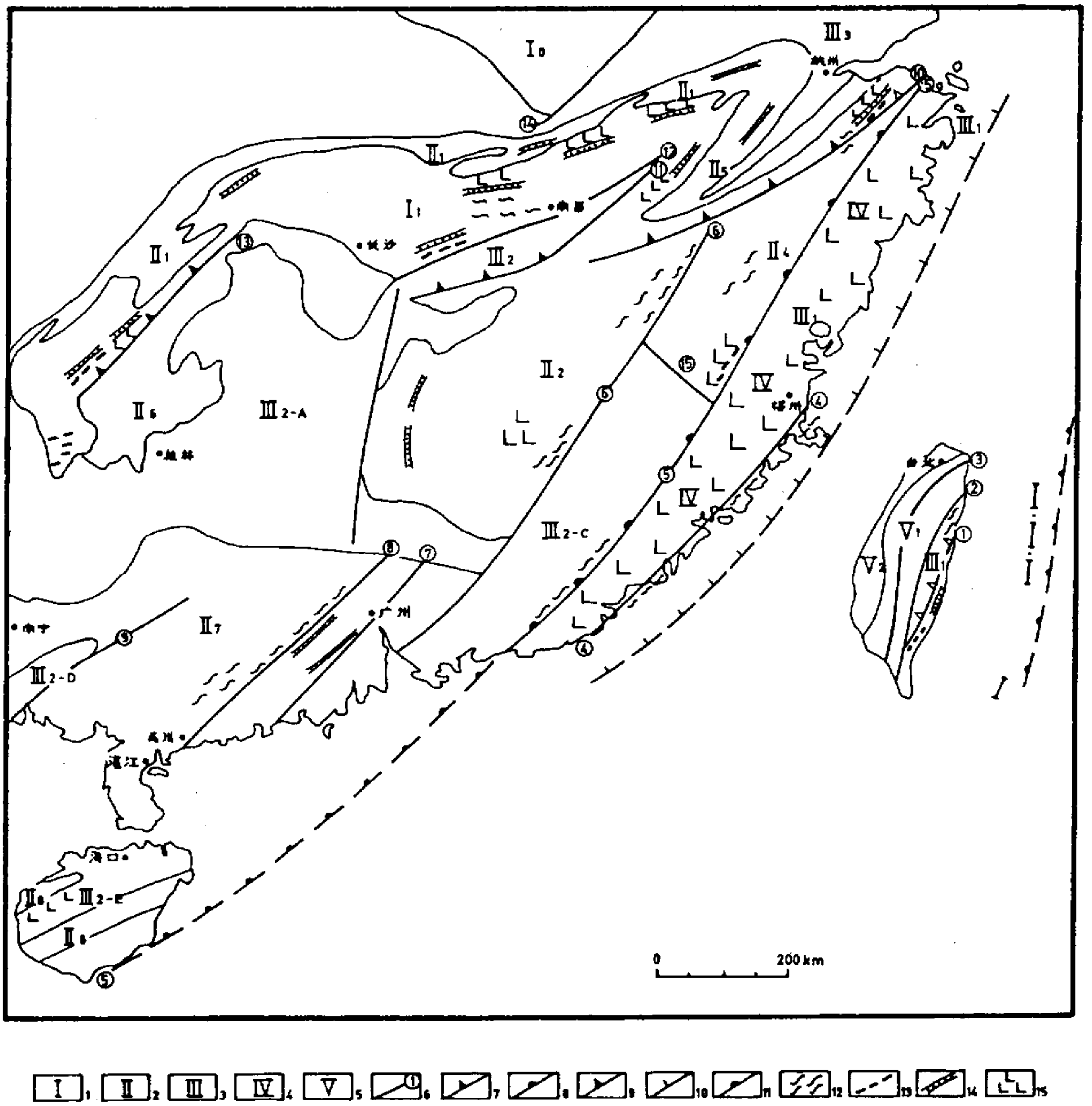

Fig. 3 Tectonic elements of southeastern China (Nanjing University Geology Department 1980). Selected key : I_1 Jiangnan geanticlinal belt; III_{2-c} Southwest Fujian-East Guangdong Hercynian-Indosinian depression; IV Zhejiang-Fujian-Guangdong coastal Yenshanian volcanic belt; (4) Changle-Nan'ao deep fault; (5) Lishui-Zhenghe-Dabu deep fault and boundary of the Caledonian fold belt; (6) Shaowu-Heyuan deep fault; (7) Lianping-Guangzhou-Enping deep fault; (8) Sihui-Wuchuan deep fault (the Sihui-Wuzhou rift belt of Anon. 1973?); L ornament signifies volcanic rocks; pecked, ticked lines offshore indicate the boundaries of the Yenshanian volcanic belt (—⊥— —⊥—) and the Himalayan mobile belt (—⌂— —⌂—); triangular symbol (—△— —△—) marks the boundary of the Hercynian-Indosinian fold belt in eastern Taiwan.

the southwestern extension of which passes to the south of Hong Kong. Huang (1978) considered that the same structure defines the southern front or boundary of the Caledonian mobile belt, and that the South China Fold System was active during this time. The Caledonian orogeny in China culminated during the Silurian and resulted in a major unconformity between the Lower Palaeozoic and Devonian, and younger strata.

To the southeast of the Lishui-Zhenghe-Dabu fracture, Huang (1978) distinguished the Southeastern Maritime Fold Belt in Eastern Guangdong, Fujian and Zhejiang, which he regarded as being of Variscan (Carboniferous-Permian age. He noted that because the zone was strongly transformed by Mesozoic tectonism and extensively covered by Jurassic-Cretaceous continental volcanics, its true significance and character had long been mistaken. Other workers (e.g. Nanjing, 1980) recognised only a composite Hercynian-Indosinian-cycle (c. 340 to 185 Ma, Carboniferous - Early Jurassic), and noted that the effects of the event are not restricted to the maritime zone, but are present to the north of the Caledonide front where they are superimposed on the Caledonian basement.

The Silurian (Caledonide) hiatus was followed by renewed, largely structurally controlled deposition. Nanjing (1980) described three structural patterns which they regarded as characteristic of the Hercynian-Indoxinian cycle : Hercynian-Indosinian fault depressions, Hercynian-Indosinian basins superimposed on zones of post-Caledonian uplife, and Hercynian-Indosinian remnant geosynclines. Hong Kong is situated within the Southwest Fujian-Eastern Guangdong Hercynian-Indosinian fault depression (Fig. 3). This NE trending zone is bounded to the southeast by the Lishui-Zhenghe-Dabu fracture and to the northwest by the Shaowu-Heyuan deep fault, which crosses the Pearl River estuary between Hong Kong and Guangzhou. Lee (1981) referred to this depression as the Zijin-Boluo Rift and considered

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*This line is also referred to as the Shaoing-Lishui-Nanping-Haifeng line and as the Dapu-Haifeng line (Anon 1973). Lee (1981) terms it the Eastern Zone of the Lianhua Shan Great Rift and considers that it represents a rift bundle of nine major, broadly parallel faults.

that it extends southwest to intersect the coast approximately 80 km WSW of Macao. The rift coincides in a general sense with the boundary between the Mesozoic and pre-Mesozoic zones noted previously. Other workers (e.g. Anon 1973) also noted the tectonically active nature of the area during this period, and particularly strong movements during the Late Triassic and Early Jurassic which marked the close of this second major Phanerozoic cycle. This view agrees broadly with Holloway (1982), who recognised a regional unconformity developed throughout the South China Sea during the Triassic. Holloway postulated the collision of the Indochina and South China continental blocks along the Red River suture at this time.

Deposition in southern China during the Jurassic and Cretaceous is believed to have been controlled by differential uplift and faulting following the Hercynian-Indosinian cycle, and subsequently by the polyphase Yenshanian movements. The Yenshanian has been broadly ascribed to large scale subduction of the Mesozoic Pacific Ocean floor along the eastern edge of the Asian continental margin (Jahn and others, 1976). Larsen and Pitman (1972) demonstrated particularly rapid seafloor spreading during the mid-Cretaceous (110 to 85 Ma). Ben Avraham (1978) featured a Cretaceous subduction zone between the China continental block and the Kula oceanic plate, the convergence zone being located close to the present coastline and coinciding approximately with the southeastern boundary of the Yenshanian volcanic belt shown in Fig. 3.

Two other important regional unconformities were recognised by Holloway (1982). The first of these occurred during the Late Jurassic and was correlated tentatively with the early Yenshanian magmatism and deformation taking place at the continental margin. Holloway (1982) related the magmatic and tectonic activity to NNW directed plate convergence and attempted the reconstruction shown in Fig. 4. The postulated NNW and NW trending left-lateral transcurrent faults shown on these reconstructions are parallel to important structural directions onshore. The known distribution of the Mesozoic igneous rocks in southern China requires a broader magmatic arc than shown by Holloway, or some northward adjustment

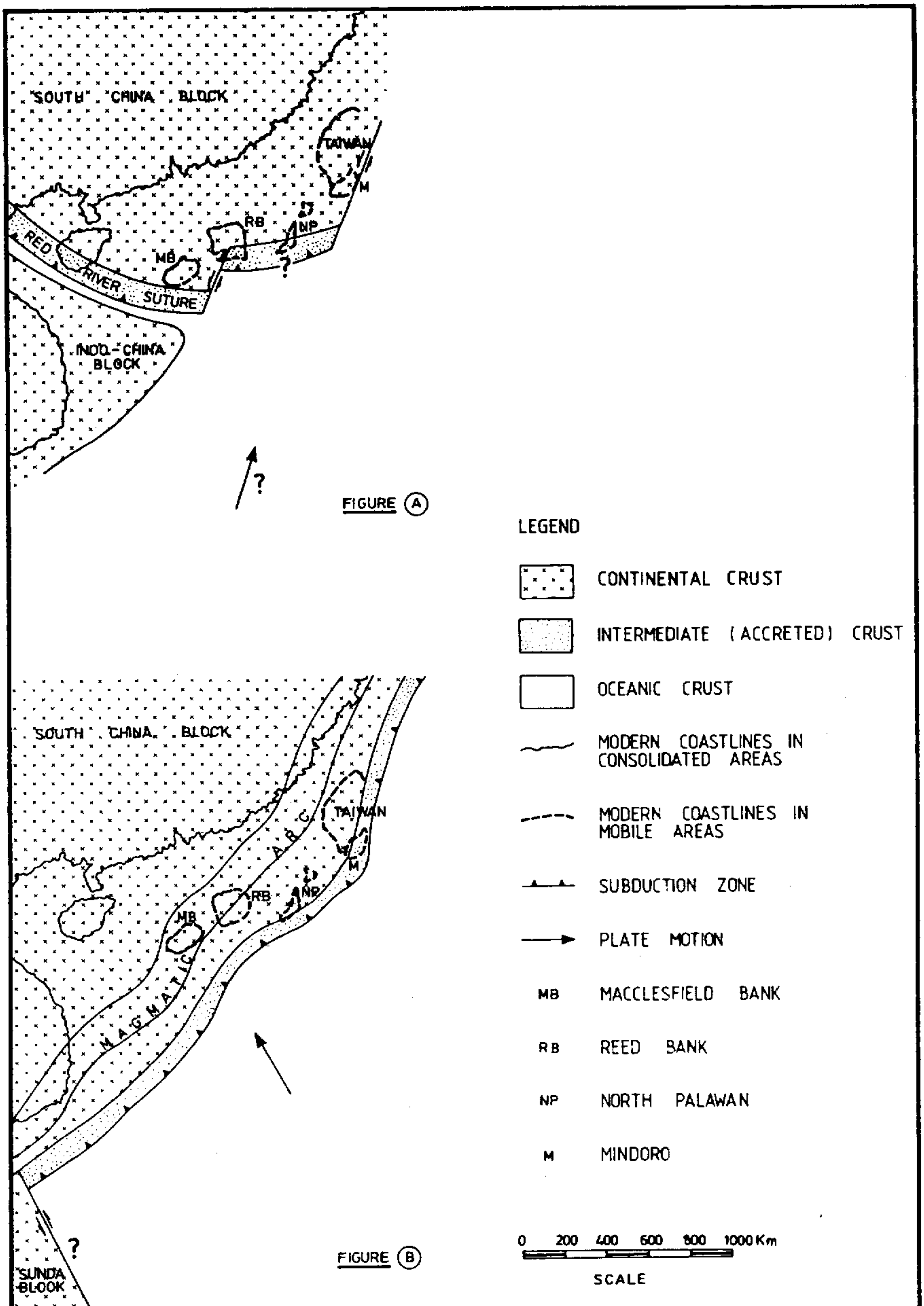

Fig. 4 Reconstructions of the South China Sea area a) during the Late Triassic, b) during the Middle Jurassic to mid-Cretaceous (Holloway 1982).

of its position. This may possibly be accounted for by variations in the dip of the subduction zone (a shallower dip resulting in a broader zone of magmatism in the overlying continental crust), or the displacement of the subduction zone by transcurrent faulting along structures comparable with that offsetting the Sunda block in the southwest of the diagram, or a combination of both.

The third unconformity occurred during the Cretaceous-Paleocene and was possibly related to the late Yenshanian activity. Holloway (1982) believed that it marked the inception of tensional conditions and block faulting of the continental margin. Such conditions would have been ideally suited to the accumulation of thick sequences of molasse-type deposits. Recent work in the South China Sea has demonstrated the presence of 6 000 to 9 000 m of Tertiary clastics sedimentary rocks in structurally controlled troughs and basins with an overall ENE trend (Feng and Zheng 1982; Workman 1983). These deposits rest on a continental basement of Palaeozoic, or possibly older metamorphic rocks, and Mesozoic (Yenshanian) granitoids. The thickness of the accumulated Tertiary sequence indicates a tectonically active zone within which deposition was accompanied by significant contemporaneous downwarping and down faulting. Holloway (1982) estimated that stretching by up to 85 per cent occurred in the continental margin adjacent to the western part of the South China Sea during the end-Cretaceous to mid-Oligocene. During the same interval, continental break-up occurred at an E-W spreading centre situated to the west of Luzon. The spreading resulted in the generation of oceanic crust from the mid-Oligocene to Middle Miocene (c. 32 to 15 Ma, although D.R. Workman, (pers. comm. 1983) noted that some Chinese workers consider that the spreading continued until 7 Ma (Late Miocene).

It is thought that crustal stretching occurred by S-dipping listric normal faulting which gave rise to rift and semi-rift troughs in which the Tertiary sediments accumulated. The continental crust along the present southern seaboard of the China is some 35 km thick (Huang 1978) and it seems that most of the extension occurred in areas now offshore. However, it is reported that fault-controlled deposition occurred onshore during the Tertiary and that the rifting was sufficiently deep-seated and long lasting to permit Late Tertiary to Quaternary basic volcanic activity in the Hainan area.

Current seafloor spreading in the Pacific Ocean is pushing the Philippine Island arc westwards, causing it to override the South China Sea floor (Fig. 5 and Workman, 1983). The northern part of the arc (Taiwan) collided with the Asian continent during the late Pliocene (4 Ma) and it may be conjectured that increased compressional stresses imposed on the continental block as a result of this collision may account for the greater frequency and intensity of seismic activity recorded in Fujian and eastern Guangdong relative to central Guangdong.

2.2 MAJOR STRUCTURAL ELEMENTS OF CENTRAL AND EASTERN GUANGDONG

The major structural elements shown in Fig. 6a are abstracted from the Tectonic Map of China (scale 1:4 000 000) compiled by the Structural Geology Section of the Institute of Geology (1979).

The area is dominated by major NE trending faults, most of which are interpreted as S dipping thrusts, active during the Mesozoic and Cainozoic. As noted in Section 2.1, they are generally considered to represent older, fundamental zones of crustal weakness which have been reactivated periodically since the Proterozoic. In addition to the structures named previously, attention should be drawn to the Meixian-Shenzhen Fault which intersects the Pearl River estuary at Deep Bay (Fig. 6). This fault is not shown in Figs. 2 and 3, but it corresponds with the Western Zone of the Lianhua Shan Great Rift (Lee, 1981). Some of the faults shown are accompanied by zones of dynamic metamorphism.

The length and general rectilinear nature of the faults favours the inference of strike-slip movement, although no indications of this were given on the 1979 Tectonic Map for the area under consideration in this report. However, Huan and others (1982) related the NE and NNE structures in eastern China to movement of the Pacific plate

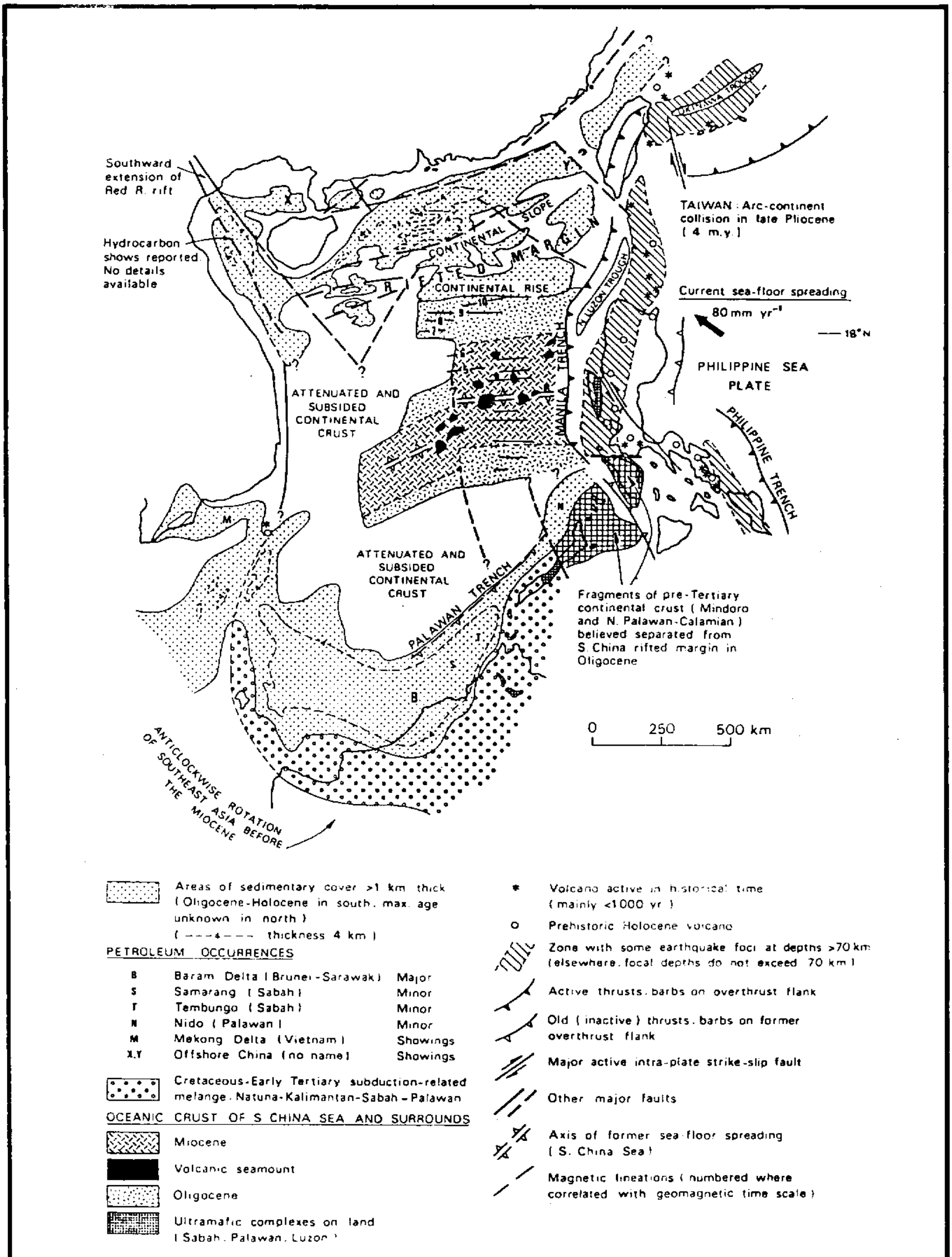

Fig. 5. Major structural features of the South China Sea Basin (Workman 1983).

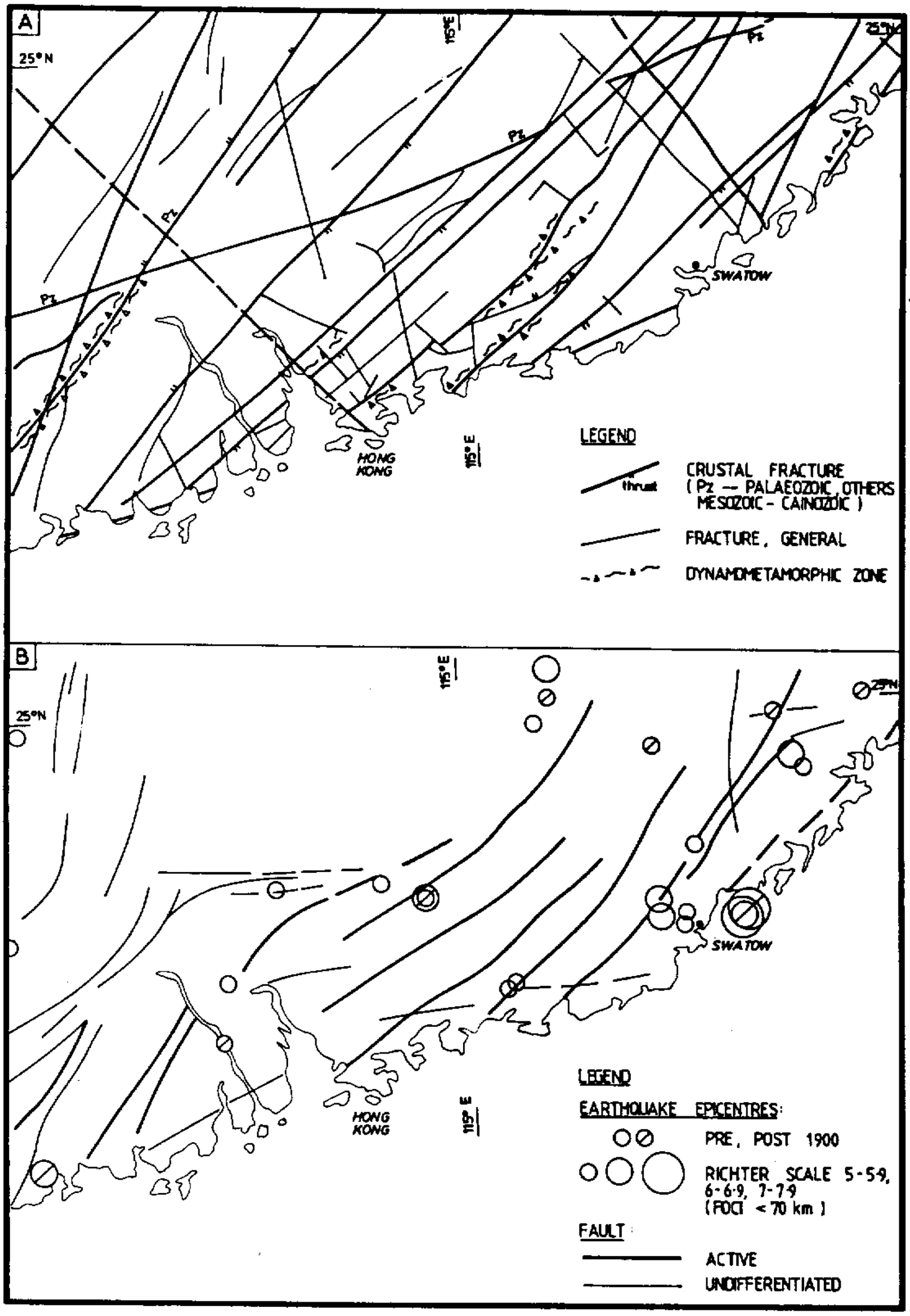

Fig. 6 Major structural elements and earthquake epicentres, Guangdong and western Fujian : (a) from the Tectonic Map of China (1979) scale 1:4 000 000; (b) from the Tectonic and Seismic Map of China (1979), scale 1:4 000 000

since the Mesozoic. They described an early phase of compressive shear, a late phase of compressive shear, and an intervening extensional phase. Lai (1976) was also impressed by the continuity of the faults (up to 1 000 km) and by their longevity, noting their inception in pre-Caledonian times. In a later paper Lai (1981, Fig. 1) indicated a sinistral movement component on, among others, the Zhenghe-Haifeng and the Meixian-Shenzhen faults. Movement on the latter fault he interpreted as indicating overthrusting to the south. Lai regarded many of the faults as having been active during the Cainozoic and, in the cases of the Meixian-Shenzhen and Zhenghe-Haifeng faults, also during the Quaternary.

The NE trending faults are part of a set including more weakly developed NW striking structures. In one case a fault belonging to this set cuts and displaces the Meixian-Shenzhen fault. The age and character of many of the NW trending faults is neither specified nor determinable. Of interest in the context of the geological remapping programme is the NW trending inferred fault, shown on the 1979 Tectonic Map, which appears to control the eastern side of the Pearl River estuary, and which is shown transecting the western New Territories. This line does not accord with any major fault shown on the 1:50 000 map (Allen and Stephens 1971) although note may be taken of the Kam Tin embayment and the presence of numerous photogeological lineaments which lie parallel to the fault in the granite terrain to the east of Tuen Mun. Alternatively, a minor westward adjustment of this fault trace would allow it to pass to the west of the Castle Peak peninsula and to align with the NNW-SSE lineament seen in Central Lantau.

3. TECTONIC HISTORY OF HONG KONG

3.1 REVIEW OF PREVIOUS WORK

3.1.1 Regionally orientated structural investigations pre-1967

The first major geological survey of Hong Kong was that conducted in the 1920s and 1930s by the Canadians. The survey resulted in the 1936 1:84 480 scale geological map (Brock and others 1936) and in subsequent publications by Williams (1943) and Williams and others (1945). However, no report specifically accompanying the geological map was ever published, and Davis (1952) sought to remedy this deficiency in his book entitled 'The Geology of Hong Kong' which was based on the Canadian work.

None of these publications emphasised the structural aspects of the local geology, other than providing a general interpretation of the geological history and noting some of the major structural features. The 1936 geological map provides sparse indications of the orientation of the strata, mainly in the Tolo Channel and Lok Ma Chau areas, but gives no indication, for example, of the strongly faulted nature of the terrain.

The first real attempt to improve the understanding of the structural geology and tectonic development of Hong Kong was that made by Ruxton (1957a, 1960). Ruxton reviewed the subject and incorporated his own observations with those of the earlier workers, noting particularly the contributions made by W. Schofield and A. Heim, as well as those made by the Canadians.

Heim (1929) described two main fold phases; one during the Jurassic (post-Liassic, pre-red beds) which he termed the Yenshanian No. 1 phase, the other taking place after the deposition of the red beds which was referred to as Yenshanian No. 2. He correlated the latter with the Alpine orogeny and noted that the deformation was accompanied by dynamic metamorphism. The same general sequence of events was subsequently accepted by the Canadians, and by Williams and others (1945), who also referred to the broad anticlinal folding, about an axis trending northeast along the Tolo Channel. Schofield (1923 unpublished report, cited by Ruxton 1957a) had earlier reported the existence of a major SE verging syncline in rocks now mapped as the Lok Ma Chau Formation.

Based on the existing data, and as a result of his own researches, Ruxton (1957) proposed the following structural history :

(i) NE-SW folding, Middle Jurassic;

(ii) igneous intrusion and renewed NE-SW folding, Upper Cretaceous;

(iii) thrusting, mid-Tertiary;

(iv) faulting, ?pre-late Pliocene.

Ruxton noted that an earlier period of folding and faulting probably separated the deposition of the Permian strata and the Lower Jurassic sedimentary formations.

Ruxton expanded his ideas in his 1960 paper which was accompanied by a sketchmap showing the major geological and structural features of the Territory. Faults and regional dips were indicated, the latter particularly in the older sedimentary rocks with generally steep NW dips, and the Port Island red beds with low N dips. The main fault directions are NE to NNE and NW to NNW. Of greater interest, however, is the emphasis that Ruxton placed on thrust faulting in the tectonic development of the Territory. He showed a major thrust along the western flank of the Castle Peak-Yuen Long valley defining the contact between the granite and the older metamorphosed sedimentary rocks which are now included for the most part in the Lok Ma Chau Formation. He inferred thrusting along the Lok Ma Chau-Repulse Bay formation contact in the northern New Territories, and described in some detail the cataclasis and mylonitisation which accompanies the overthrust outcropping to the north of Plover Cove. These thrust faults all post-date the major magmatic activity in the Territory, and the movements in the northeast, at least, occurred after the deposition of the red beds and conglomerates which are now considered to be of ?early Cretaceous age. No direct evidence exists for the age of these beds, or for the age of the older volcanic rocks overlying the thrust.

3.1.2 Regionally orientated structural investigations 1967-71

Allen and Stephens (1971) extended Ruxton's understanding of the

Table 1 - Summary of the geological history of Hong Kong (Allen and Stephens 1971).

Period	Age in m.y.	Geochronological Data in m.y.	Event
Quaternary			Deposition of superficial deposits and Kat O Formation
			. . . Unconformity . . .
Tertiary			
Palaeocene		63±6	Intrusion of dolerites of Phase 5b
	65		
		76±2	Intrusion of dolerites of Phase 5a
Upper		92±2	Earth Movements: Folding and cleavage in Port Island Formation. Secondary cleavage in Lok Ma Chau Formation. Thrust faults, tear faults; widespread shearing
Cretaceous	100		
Lower			Deposition of Port Island Formation
			. . . Unconformity . . .
	135	135	Completion of cooling of granites
		140±7	Intrusion of granites of Phase 4
Upper		163±35	Intrusion of granites of Phases 1 to 3
	160		
Jurassic			Earth Movements: Folding and regional metamorphism of Repulse Bay Formation and older rocks.
Middle			Extrusion of Repulse Bay Formation lavas and tuffs;
and			deposition of mainly continental sediments including, possibly, the Tai O Formation
Lower			Deposition of deltaic Bluff Head Formation and, possibly, the sediments of the Lok Ma Chau Formation
Lower Lias	195		Deposition of marine sediments of the Tolo Channel Formation
			. . . Unconformity . . .
Triassic			
	225		? Folding of Tolo Harbour Formation
Permian			Deposition of Tolo Harbour Formation

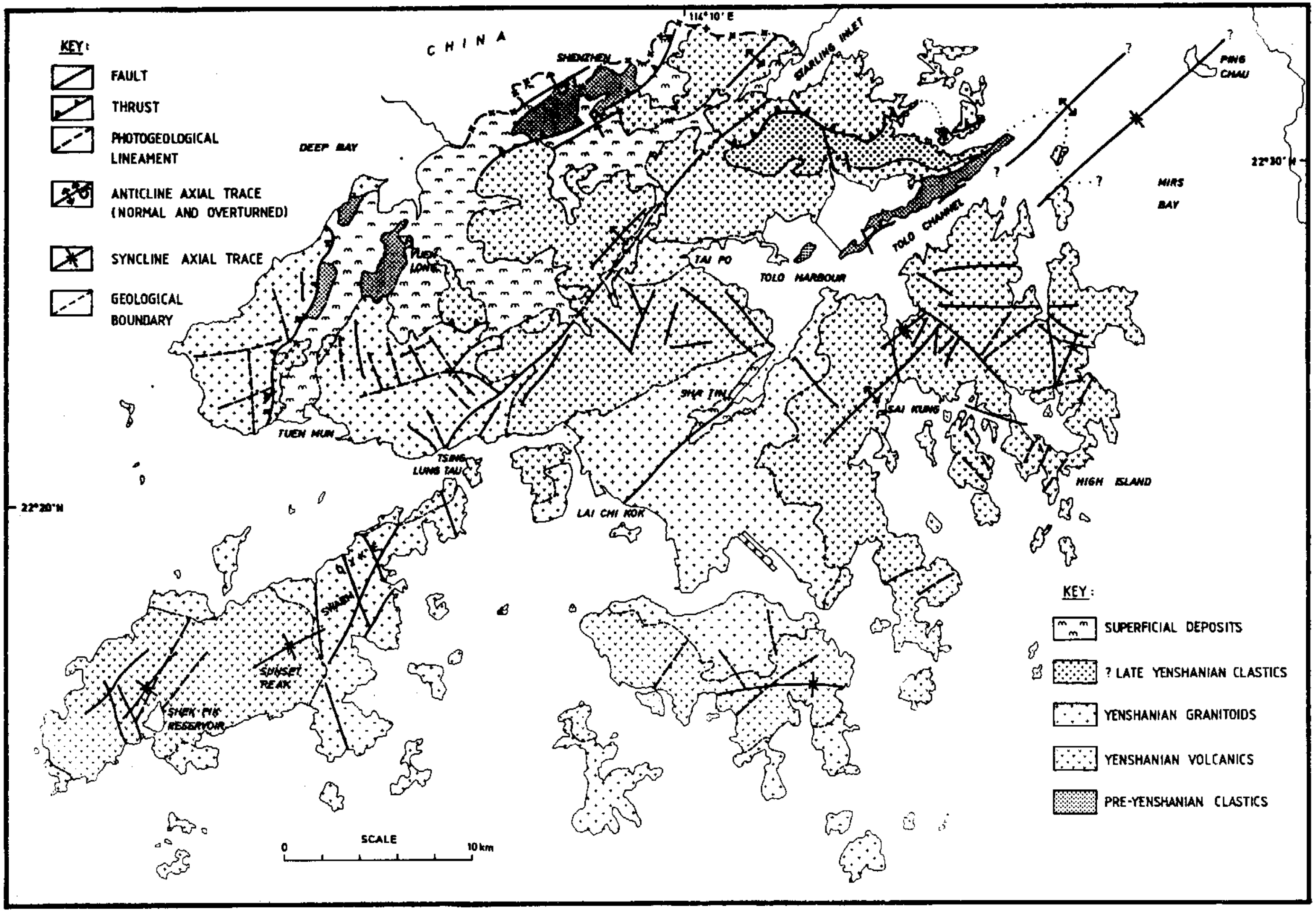

Fig. 7. Structural sketchmap of Hong Kong - I. Based on Allen and Stephens (1971) and Ruxton (1960). Showing the major structural elements, including the Tolo Channel Anticline - Ping Chau syncline fold pair, and the main structure - stratigraphic rock groups

geology and summarised the geological history of the Territory, drawing attention to differences with the model previously proposed by Davis (1952), based on the Canadian work. The sequence of major events recognised by Allen and Stephens is shown in Table 1, but they did not emphasise the structural aspects of the geology nor did they attempt a structural synthesis. Only the faulting is given separate consideration; other structural features were described in the text in the sections covering the various lithological units (see below).

The 1:50 000 scale geological map shows considerably more structural information than the previous map (Brock and others 1936), and differences of detail and interpretation when compared with Ruxton's (1960) sketchmap. The representation of fracture lineaments is not consistent and there is no attempt to define the importance of such features. However, the major NE and NW trends are clearly demonstrated. The fracturing, in its latest expression at least, obviously post-dates the Yenshanian magmatic activity, and some structures transect the Port Island Formation (?Lower Cretaceous). Allen and Stephens (1971) followed Ruxton's (1960) interpretation of thrust faulting in the northeastern New Territories (post-dating the Port Island Formation sequence) but had reservations about the presence or importance of the other thrusts mapped by Ruxton. A sketchmap based on the 1:200 000 scale version of the 1:50 000 scale geological map is shown in Fig. 7. It shows the main faults and the major fold axial traces referred to in the map report as opposed to the few shown on the 1:50 000 map.

Allen and Stephens (1971) attempted a preliminary structural analysis of the minor folding in the Tolo Harbour Formation and the Bluff Head Formation. They identified a more complex two-phase sequence in the Tolo Harbour Formation, which they believed to be the older of the two formations. It was suggested that the minor folding observed in the Bluff Head Formation was coaxial with the Tolo Channel anticline, and that the Formation was down-faulted to the south along a major fault following the line of the anticlinal axial trace. In this way the non-appearance of the

Bluff Head Formation to the south of Tolo Channel was explained. The disposition and attitude of the Port Island Formation beds on Port Island, and of the sedimentary rocks on Ping Chau in Mirs Bay, were ascribed respectively to the NE plunge of the Tolo Channel anticline, and to related synclinal folding. Analysis of bedding-schistosity relationships in the Lok Ma Chau Formation led Allen and Stephens to believe that the succession in those rocks was inverted, and they interpreted this as evidence for recumbent isoclinal folding in the north of the Territory. However, bedding-schistosity relationships do not indicate way-up without sedimentological or stratigraphic evidence.

The gross structure of the Repulse Bay Formation was described by Allen and Stephens (1971) and the major folds are shown in Fig. 7. They noted the difficulties and dangers of attempting a structural interpretation of the often massive, homogeneous volcanics and the intercalated, relatively incompetent sedimentary horizons, but recognised two major directions of folding, trending roughly NE and NW. The NE folds are dominant, and are broad and open. The main structures are described by Allen and Stephens (1971) and they concluded that the NE trending structures represent contemporaneous crossfolds, although no convincing structural model was put forward. They state that there is no clear evidence to indicate that the two fold trends affecting the Repulse Bay Formation are of different generations, so this possibility cannot be dismissed.

The last significant deformation recorded by Allen and Stephens (1971), apart from faulting of the Kat O Formation north of Lau Fau Shan, is that preserved in the Port Island Formation, which is generally cleaved and locally intensely sheared. The beds display a low regional northward dip but they are strongly folded adjacent to the overthrust volcanics in the north. The cleavage is steeply dipping, and is assumed to be axial planar to major folds concealed by the overthrust mass to the north. The cleavage pre-dates the shearing related to gently dipping thrusting sub-parallel to the bedding. Allen and Stephens postulated a possible decollement at the base of the Port Island Formation in view of the common occurrence of planes of movement in this zone.

The fractures analysed by Allen and Stephens (1971) are grouped into normal faults, tear (strike slip) faults and thrust faults. Undifferentiated structural lineaments were also mapped. Histograms indicate the dominant NE and NW trends of the lineaments, and differences in detail between the plots for the granitoids and the volcanics are apparent. The major normal faults identified are :

(i) the Tsing Lung Tau-Lam Tsuen Valley-Hop Tau Valley (NE) faults;

(ii) the Turret Hill-Chinese University (NW) faults;

(iii) the Three Fathoms Cove-High Island (NW) faults;

(iv) the NW fault following the line of the channel between the mainland and the islands of Kau Sai Chau and Urn Island in Port Shelter; and

(v) the fault trending eastwards from Three Fathoms Cove (Yeung Shue Au) to Sharp Peak, which is considered to have a major throw to the south.

The traces of these faults are not emphasised on the 1:50 000 map; commonly only portions of the structures are shown. Allen and Stephens (1971) also referred to the presence of a major fault along the Tolo Channel, and to mention made by Heanley (see Ruxton 1957a) of a fault linking Lai Chi Kok and Tide Cove. With the exception of the fault to the southwest of Fung Wang Wat Bay on the western shore of Tolo Channel, these structures are not shown on the 1:50 000 scale map.

Thrust faulting is reported in the north, northwest and west of the New Territories, while shear zones in the granites between Castle Peak Valley and Tai Lam Chung Reservoir on NNE, ENE and NNW trends are generally interpreted as strike slip faults. All these structures, and the normal faults, transect the Yenshanian magmatic rocks, but no account was given of the detailed history of their movements or of their relation to an overall structural model for the Territory.

3.1.3 Regionally oriented structural investigations, post-1971

The fullest attempts at more comprehensive analyses of the tectonics the Territory, relating them to the regional tectonics of southeastern China, were those undertaken by Lai (1976, 1977). Lai's structural sketchmap, incorporating information taken additionally from his 1981 reference, is shown as Fig. 8.

Lai (1976, 1977) stressed the fact that Hong Kong is situated within a major NE trending fault block bounded to the north and south by the fundamental crustal fractures referred to in section 1, i.e. the Zhenghe-Haifeng and the Meixian-Shenzhen fault zones. The intervening block was referred to by Lee (1981) as the Lianhua Shan Great Rift Zone. Lai further subdivided the fault block into three subsidiary structural units, also bounded by NE trending faults. These faults with their complementary (conjugate) NW trending set of fractures, form part of the Neocathaysian structural system which dominates the geology of eastern and southern China. The second order NE trending faults are those extending southwestwards from Starling Inlet possibly to Shek Pik (Lantau), and from Tolo Channel to Lai Chi Kok. Lai (1976, 1977) also recognised E-W structures which he assigned to the second major structural system widely recognised by Chinese geologists; the latitudinal structural system. He ascribed the structural complexity of certain areas within Hong Kong to the interference of the two systems (see section 3.1.4). Evidence for the relative ages of the two systems is equivocal. Lai noted the latitudinal system to be dissected by the NE faults, but also referred to the Starling Inlet-Shek Pik fault as cutting the E-W structures.

The NE faults have an important sinistral component (see also Lai 1981, Fig. 1). The NW faults are transtensional structures, and there is some evidence that these offset the NE set. Both the Neocathaysian and latitudinal faults as presently expressed are post-Jurassic and possibly post-Early Cretaceous in age, but the NE structural trend in particular was considered by Lai to be a fundamental crustal feature initiated during the Palaeozoic.

The main overthrusts recognised by Lai (1976, 1977) share the

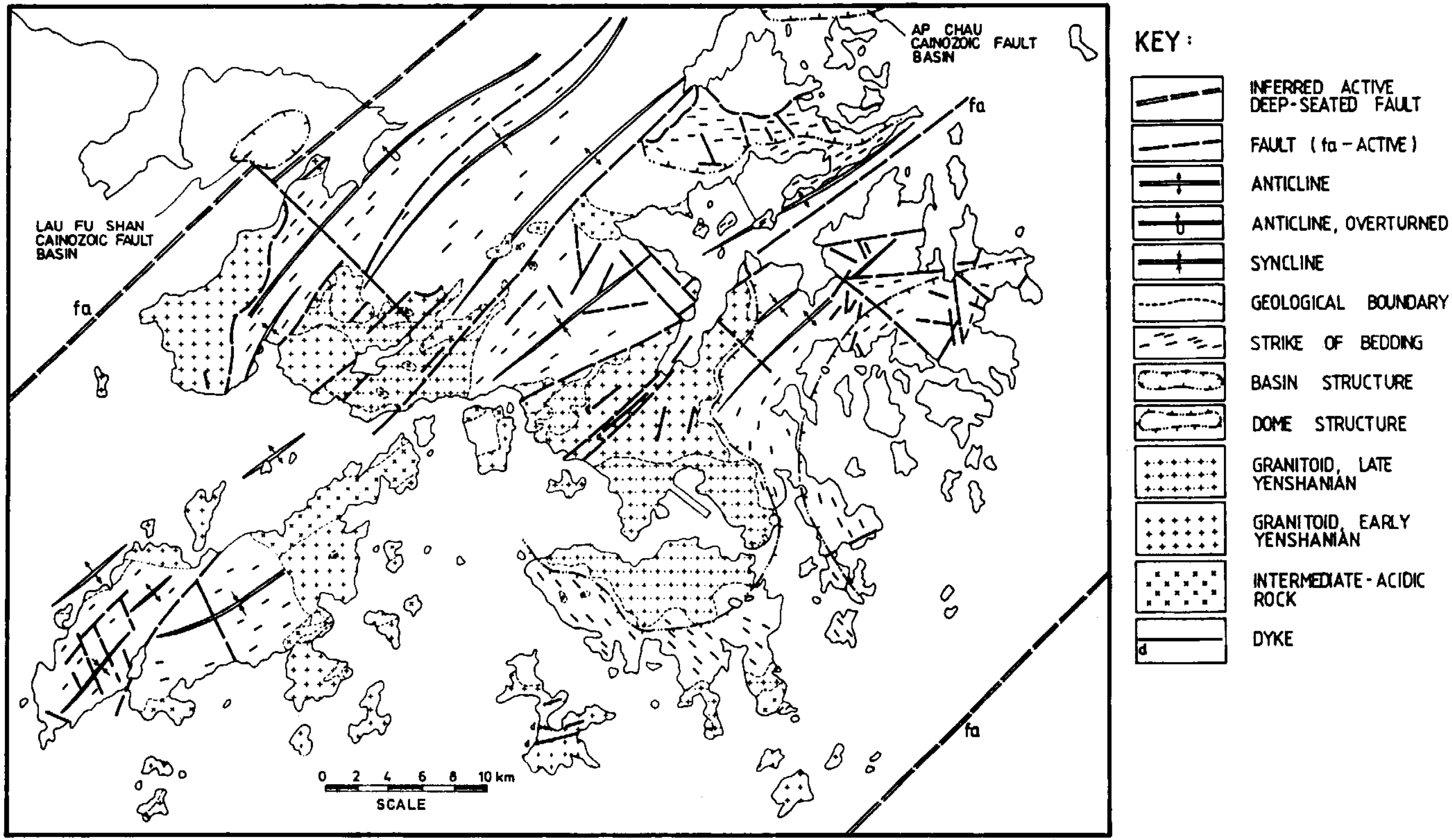

Fig. 8. Structural sketch map of Hong Kong - II (Lai 1977, 1981).

general E-W trend. They occur in the northeastern New Territories (Repulse Bay and Port Island formations) and in the area southeast of Yuen Long (Repulse Bay Formation and Cheung Chau-Needle Hill granites). Lai considers that the thrusting (presumably part of the latitudinal system) post-dates the conjugate Neocathaysian system.

Four major fold events of differing styles are described by Lai (1976, 1977), but unfortunately they are not differentiated on his structural sketch map. The oldest structures identified (Indosinian) are faults. During the Yenshanian a series of tight anticlines and more open synclines was formed. Deformation gave rise to dome and basin structures (presumably comparable with the NE/NW crossfolding noted in section 3.1.2). Lai (1976, 1977) also identified a deformation episode during the Cainozoic which involved tilting and the development of monoclinal structures.

The deformation during the Palaeozoic is believed to have given rise to the first formation of the deep seated NE faults (and the dynamic metamorphism of the Lok Ma Chau Formation). Gradual uplift, broadly associated with the Indosinian cycle, occurred during the Triassic-Jurassic interval. However, major tectonic activity influenced by the older, fundamental structural pattern, particularly the NE trending faults, was restricted to the Yenshanian cycle. The late Yenshanian is considered to have resulted in a significant rejuvenation of the deep-seated (first-order) and second-order NE faults, and the southward translating overthrusts.

3.1.4 Local investigations in Hong Kong

In addition to the regionally orientated tectonic studies of the Territory noted in the previous sections, there exists a limited number of structurally orientated publications referring to specific areas or problems.

Davis (1963) described the structural geology of the Lion Rock Tunnel, and mapped NE faults particularly at the southern end of the tunnel. The faults are accompanied by breccia, cataclasite and mylonite zones varying from a few inches to more than 20 feet (6 m) in thickness; NW trending structures were also recorded. It was considered that E-W trending dyke emplacement was associated with the faulting. Davis (1963) also reported the presence of E-W faults passing through Hong Kong harbour.

Considerable interest has been shown in the structural geology of Ma Shi Chau. Nau (1981) recorded NE trending dextral slip faulting, NNW ?sinistral slip faulting, and structures with WNW and W trends. The rock units which he described were assigned to the Tolo Channel Formation, broadly equivalent to rocks previously mapped on Ma Shi Chau as Bluff Head Formation by Allen and Stephens (1971). He showed that their structure was simpler than that shown by the Tolo Harbour Formation (cf. Allen and Stephens, 1971), implying a more complex structural history for the older unit.

Lai and others (1982), also reporting on work carried out on Ma Shi Chau, identified the main structural trends ('systems') noted in section 3.1.3. There is evidence at this locality that the NW structures offset the NE faults in a sinistral sense. The island was regarded as a fault block within a major fault zone which was uplifted during post-Permian times. The island is also an intersection of the Neocathaysian and latitudinal systems. Lai and his colleagues considered the tectonic development of Ma Shi Chau in terms of :

(i) Indosinian faulting initiating the Neocathaysian system;

(ii) the early Yenshanian deformation, during which the conjugate fault system was established and the latitudinal system begun;

(iii) the late Yenshanian (end-Early Cretaceous) deformation, which saw the mature development of the Neocathaysian system, the formation of the Tolo Channel anticline, reactivation of the main NE fault zone and the full development of the latitudinal system.

3.2 DISCUSSION OF MAJOR STRUCTURAL ELEMENTS

3.2.1 Introduction

Hong Kong is underlain by pre-Yenshanian, Yenshanian (Jurassic-Cretaceous) and post-Yenshanian rock units, all of which bear a tectonic imprint of variable intensity and style. The gross structural features are now identified, but the more detailed aspects of the tectonic development of the Territory remain imperfectly understood. The recent efforts, reviewed in the previous section, to consider the structural geology of Hong Kong in the context of the regional tectonic framework, represent a valuable advance.

The uncertainties which remain are a result, to an extent, of the small amount of research carried out to date, as well as the lack of a local graduate/post-graduate geology school. The nature of the dominant rock groups, the volcanics and granitoids, is also significant. Neither of these groups is particularly amenable to detailed structural analysis and they have generally responded to deformation in a gross and relatively competent manner. Other contributory factors include the often limited and isolated outcrop, the deep weathering, and the extensive cover of superficial deposits. Uncertainties are still attached to the stratigraphic relationships and ages of some of the rock units (see Bennett, 1984a) and these, too, hinder the more rigorous understanding of Hong Kong's tectonic development.

The important and widespread Yenshanian tectono-magmatic event appears to have involved mainly brittle deformation at a high crustal level, not characterised by strong folding or pervasive regional metamorphism. The last major folding recognised appears to have occurred after the Permian (Tolo Harbour Formation) and prior to the onset of the Jurassic volcanicity. Nevertheless, significant late- to post-Yenshanian deformation also occurred. This is represented by faulting, thrusting and gentle or open folding which took place after the deposition of the ?Lower Cretaceous Port Island Formation. The absence of a Tertiary succession, with the possible exception of the scattered outcrops assigned to the Kat O Formation, makes it difficult to place an upper (younger) limit on the activity.

In the remainder of section 3.2 the main structural features will be outlined and discussed. Present understanding is indicated and attention is drawn to major unresolved problems. The discussion utilises information available in the literature, a recent statement of the present position by Workman and others (in press) and general reconnaissance by the Consultants.

3.2.2 Folding

Most of the older, pre-volcanic sedimentary rocks are strongly folded, as demonstrated by their moderate to steep dips and local inversion (e.g. Bluff Head Formation, which appears to young fairly consistently to the north). However, no clear picture has emerged of the general pattern of the folding responsible for the present attitudes of the rocks owing to the scattered and often faulted nature of the outcrops.

The older formations represent the pre-volcanic basement of Hong Kong. They are exposed in structural highs in the Tolo Harbour - Tolo Channel area and in the northwest of the Territory. Pre-volcanic rocks also occur along the regional strike of the Tolo Harbour - Tolo Channel high in western Lantau (Tai O Formation). Elsewhere, the older rocks appear to be effectively masked by the volcanics and post-volcanic cover. Nevertheless, the possibility of discovering basement inliers during the remapping programme cannot be excluded.

The pre-volcanic basement exposed in the Tolo Harbour - Tolo Channel section displays a regional NE strike. The beds dip at variable amounts to both the north and the south but no major fold pattern has been identified. Nevertheless, the deformation of these older sedimentary rocks has generally been ascribed to major anticlinal folding aligned along the Tolo Channel, i.e. the Tolo Channel anticline. Minor folds in the Bluff Head Formation were considered by Allen and Stephens (1971) to be coaxial parasitic folds, directly related to the formation of the Tolo Channel anticline. However, it seems possible that many of the minor folds in the Tolo Harbour Formation could also be interpreted as fault-related structures, while others may possibly be syndepositional or early post-depositional structures.

The Tolo Channel anticline will be referred to again later in this section. However, in the present context it should be noted that the anticline involves the gentle to open folding of the volcanic and post-volcanic cover, and the younger rocks show a gross symmetry across the axial trace of the structure. It is difficult to reconcile this simple structural pattern with the more intensive deformation of the basement rocks, or with the apparent lack of symmetry about the axial trace that is shown by the older rocks. The Bluff Head and Tolo Harbour formations have not yet been recognised on the southern limb of the anticline, although it is possible that they may occur in the Ma On Shan - Three Fathoms Cove section (see Bennett, 1984a).

The absence of these formations on the southern side of Tolo Harbour and Tolo Channel would not in itself disprove the existence of the Tolo Channel anticline.

It is provisionally concluded that two deformational episodes are represented in this area. The first remains imperfectly defined but was more intense and is considered to have pre-dated the deposition of the volcanic rocks. The second involved the weak folding of the volcanic and post-volcanic cover, and probably had relatively minor effect on the already strongly folded basement succession.

The basement rocks in the Tolo Harbour - Tolo Channel structural high generally lack penetrative deformation fabrics (e.g. slaty cleavage, schistosity) although they are widely sheared and faulted. Only incipient low-grade regional metamorphic effects are apparent, although the Bluff Head Formation (Devonian) is more strongly indurated than either the Tolo Harbour (Permian) or Tolo Channel (Liassic) formations. The general characteristics of the older sedimentary rocks indicate brittle, cataclastic deformation at a high crustal level, unaccompanied by significant recrystallisation.

An understanding of the status and structure of the Lok Ma Chau Formation, and of its relationship to the Repulse Bay Formation, remains one of the more pressing geological problems. Knowledge of the southern part of the arcuate outcrop of the Formation is slight.

The structural model of the Formation, involving the presence of gently to moderately inclined overfolding accompanied by a well developed penetrative metamorphic axial planar fabric, may be simplistic. It is certainly unlike the model proposed for the deformation of other pre-volcanic sedimentary formations. Little is known at present about any major period of folding prior to the late Permian - early Jurassic event proposed above. Although the possibility of regional deformation and metamorphism during the late Palaeozoic cannot yet be ruled out, it would be expected that some effects of this would have been detected in rocks of the Bluff Head Formation (Devonian).

An appropriate isotopic age determination programme should permit the metamorphism to be dated and thus a minimum age limit to be set for the Lok Ma Chau Formation. At present the ?early Carboniferous age proposed for the Formation depends on correlations with rocks in the Shenzhen Economic Zone where no Palaeozoic metamorphic event of this kind is recognised. Metamorphic rocks of ?Devonian and early Carboniferous age in the Economic Zone are succeeded by Upper Carboniferous fossiliferous limestones. Many Chinese geologists relate the metamorphism to Mesozoic tectonism, noting it to be confined to major NE trending fault zones where high pressure and moderate temperature conditions were generated. The rocks which occur in these zones (garnet- and staurolite-bearing pelitic schists and tremolite-bearing marbles) possess the characteristics of prograde regional metamorphism, although they occur in juxtaposition with non-metamorphic rocks. Allen and Stephens (1971) favoured such an event for the Lok Ma Chau Formation, prior to the emplacement of the granitoid bodies.

The mapped relationships of the Lok Ma Chau and Repulse Bay formations in the northern New Territories indicate a phase of Late Jurassic or younger compressional tectonics. The overfolding and regional metamorphism of the Lok Ma Chau Formation and the adjacent volcanic rock may be a direct consequence of this, as maintained by Allen and Stephens (1971). However, it is perhaps more likely that the strong metamorphic and deformational fabric is developed in response to dominant upthrusting and overthrusting of the Lok Ma Chau beds rather than simply to overfolding. An alternative interpretation would be that the folding and metamorphism are relicts of an earlier tectonic event, and that the Formation owes its present position to later, independent upthrusting. That is, that the Lok Ma Chau Formation is an allochthonous tectonic slice with a fabric which was originally imposed at a rather deeper crustal level. The complex contact between the Formation and the volcanic rocks, reported in tunnel sections (e.g. P.G.D. Whiteside, oral comm., 1984), support a predominantly tectonic relationship between the two units.

The other major thrusts mapped by Allen and Stephens (1971) post-date the emplacement of the granitoids and the deposition of the Port Island Formation (Lower Cretaceous?). Both the Lok Ma Chau beds and the volcanics rocks which have been thrust over the Port Island Formation are backed at no great distance by major NE trending faults, and they may owe their presence to complex movements in these fracture zones.

The Repulse Bay Formation, by contrast with the Lok Ma Chau Formation and the other pre-volcanic formations, is weakly folded on the regional scale, although more intense folding is recognised locally e.g. the overfolding postulated by Allen and Stephens (1971) in the northern New Territories. Over large areas, strata dip at moderate angles of between 20° and 40°, predominantly to the east and southeast. At the 1:50 000 scale the base of the Formation often appears to be sub-horizontal or gently dipping. This attitude contrasts with the dips indicated for the underlying older sedimentary formations, and while this may reflect local structural variations and decollement it is difficult to escape the general conclusion that a significant angular discordancy separates the pre-volcanic and volcanic units. The inference is that the younger sequence is only relatively weakly deformed on the gross scale and that this deformation post-dated an earlier, more intense fold episode affecting the older rocks.

The folds described from the Repulse Bay Formation outcrop by Allen and Stephens (1971) and by Lai (1976, 1977) appear to be best explained by vertical movements at depth. It is possible that the dome and basin structures reported by Lai and the cross-folding described by Allen and Stephens are a result of the rise of the underlying, irregularly-surfaced granite batholith into the relatively competent, mainly volcanic cover. The deformation may also perhaps be related to ?contemporaneous or later faulting.

Except for the titling of the Kat O Formation (?Tertiary), presumably related to Lai's (1976, 1977) Cainozoic monoclinal structures, the youngest major folding identified in the Territory is that affecting the Port Island Formation. The deformation resulted in the development of an open NE trending and plunging anticline. The axial trace of the anticline is aligned along the Tolo Channel and has been termed the Tolo Channel anticline. As stated earlier, it is considered that this folding took place independently and was superimposed on the more highly deformed pre-volcanic basement which now outcrops in the structurally high core zone of the Tolo Channel anticline.

The rocks on Ping Chau define the hinge of a NE plunging syncline of similar style to the anticline and the two structures are considered to form a complementary pair. The presence of the complementary syncline appears to explain satisfactorily the absence of the Port Island Formation from the southern side of Tolo Channel. However, this model would require the Ping Chau Formation to overlie the Port Island beds. Since the Ping Chau rocks are indurated (possibly thermally metamorphased) it seems unlikely that they are younger than Jurassic in age (Allen and Stephens, 1971). This being so it is necessary then to invoke NW trending cross-faulting between Port Island and Ping Chau, downfaulting the succession to the west after the folding took place.

The folding of the Port Island Formation amounts to little more than broad warping and it is therefore difficult to reconcile this with the strong penetrative cleavage developed in parts of the mainland outcrop of the Formation, or with the thrusting responsible for the southwards translation and superposition of the volcanic rocks which flank the Port Island beds to the north. The cleavage is steeply dipping, and Allen and Stephens (1971) report that it extends downwards for some metres into the Repulse Bay Formation. It is cut by locally intense minor thrusts and shears which dip gently to the north. The major thrusting mapped by Allen and Stephens also post-dated the cleavage; bedding and cleavages are both folded in the thrust zone.

Allen and Stephens noted the possibility of a major decollement at the base of the Port Island succession.

This would be consistent with the theory that the mainland outcrop of the Port Island Formation represents a tectonic slice, upthrust and subsequently overthrust in a manner similar to that already suggested for the Lok Ma Chau Formation. The cleavage may be related to the earlier period of this emplacement, and the gently dipping thrusts and shears (and possibly the open warping?) to a late phase in the process. Some indication of the extent of this phase of high- and low-angle thrust tectonics may possibly be gauged by the presence of the low N dipping kink structures observed in the Tolo Harbour Formation rocks on Ma Shi Chau.

3.2.3 Faulting

The strongly faulted nature of the Hong Kong terrain is well known and the remapping programme will undoubtedly permit a more realistic representation of these structures on the 1:20 000 scale maps than was achieved at the 1:50 000 scale.

Most of the fractures shown on the existing map are related to

Mesozoic or younger tectonism and affect rocks of Jurassic and ?Cretaceous age. Some of these structures almost certainly represent rejuvenated, older faults or zones of weakness but, given the absence of adequate stratigraphic or time markers, a rigorous assessment of their movement histories is difficult.

The dominant structures trend NE and NW. The NE faults are the more prominent and can be related in general terms to the major structures mapped in southern China. The length and rectilinearity of the Chinese structures strongly favour the inference of dominant strike slip, but in the local (i.e. Hong Kong) context the interpretation of displacements is complex. There is evidence for both lateral and vertical displacement on the outcrop scale. The main NE trending fault zones in the Territory are the Starling Inlet - Tsing Lung Tau/Tai Lam Chung Reservoir (- Shek Pik?) structure and the Tolo Channel-Tide Cove-Lai Chi Kok fault. The major Meixian-Shenzhen fault is believed to follow the lower Shenzhen valley and to pass into Deep Bay. It is conceivable that the prominent Castle Peak Valley feature is major splay to this structure.

The older sedimentary rocks exposed in the Tolo Harbour - Tolo Channel structural high are strongly faulted, in a broadly anastomosing pattern, which reconnaissance suggests forms part of a major braided fault or shear zone, possibly of strike slip type. Nau (1981) interpreted the NE trending faults on Ma Shi Chau as dextral strike slip structures. However, high angle thrusting and imbrication, and the development of tectonic melange, are also reported from the Tolo Harbour Formation (e.g. Nau, 1981, Lai and others, 1982), the deformation style reflecting the relative incompetency of the rocks. The relatively more competent Bluff Head Formation rocks also show imbrication and thrust structures, but preserve a gross structural integrity. Interpretation of the postulated fault zone awaits further work but a compression-shear regime is indicated.

The age(s) of the deformation responsible for the development of the zone of weakness along the Tolo Channel - Tide Cove axis is uncertain. The deformation certainly post-dated the Permian, and the more diffuse zone of shearing may have been imposed prior to the Jurassic volcanic activity, although this remains conjectural. The only discrete structure mapped by Allen and Stephens (1971) in this section is the fault contact between the Bluff Head and Tolo Channel formations. This may represent a post Liassic rejuvenation of an early fracture. A high angle, upthrust relationship is indicated if both a N dip of the fault (Allen and Stephens 1971) and a Devonian age for the Bluff Head Formation (Lee 1982) are accepted. Along the structural strike, in the area southwest of Tide Cove, K.W. Lai (oral comm., 1984) reports a breccia zone in the granitoid rocks of the order of 20 m in width, providing evidence for powerful movement after the emplacement of those rocks, while R. Addison (oral comm., 1984) has observed the development of strongly foliated granite in narrow shear zones on NE and NW trends in the southeastern quadrant of 1:20 000 map sheet 7. The shear zones appear to be broadly contemporaneous with the emplacement of the granitoids and of very different character to the brecciation and cold cataclasis reported by Lai.

Mapped evidence for significant lateral displacement on the NE faults at the 1:50 000 scale is unconvincing. The distribution of the Tai Po Granodiorite outcrops in the central section of the Starling Inlet - Tsing Lung Tau/Tai Lam Chung Reservoir faults suggests a relative sinistral displacement. Relative offset in the same apparent sense is seen in the Needle Hill Granite to the north-east of the Tai Lam Chung reservoir. In the Tide Cove - Tolo Harbour area a plot of the submarine outcrop of the granite should help to elucidate the nature of the post-granite movements in that sector of the Tolo Channel - Lai Chi Kok fault.

The likelihood of high-angle movement related to horizontal compression (low-angle not high-angle/reverse fault) movement along the Bluff Head - Tolo Channel formation contact, already noted, is supported by the presence of minor imbricate structures of this type in the older sedimentary rocks. The upper (younger) age limit for the significant displacement on the main fault is uncertain, but the structure coincides in a general sense with the axial trace of the Tolo Channel anticline. It is conceivable that the movement along the fault generated a weak fold response (i.e. the Tolo Channel anticline and its paired syncline) in the younger cover rocks.

The structural elements (folds and faults) reviewed in this section have all been considered in terms of compression, compression-shear or vertical movements. On a regional scale the presence of extensional tectonics has been described only in respect of the early Tertiary opening of the South China Sea (section 2.1).

There is evidence in Hong Kong that conditions of relative tension existed at an earlier stage, certainly during the Yenshanian magmatic event. In addition to considerations of the space requirements of the extensive granitoid bodies themselves, the development of major dyke swarms must also be accounted for. The dykes commonly strike between NE and ENE and between N and NW. The most prominent swarm in the Territory trends ENE and is concentrated in eastern Lantau and, on a reduced scale, on Tsing Yi. The crustal extension required for the emplacement of this swarm is significant, but it is not reflected on Lantau in the overlying volcanic cover. If this is a real, rather than an apparent impression (i.e. one reflecting the limitations of the existing mapping), then some form of structural discontinuity and independence between the two main rock groups is essential.

Whether this discontinuity is a broadly horizontal decollement between the intrusive and the cover rocks (a scenario difficult to visualize when the intrusive rocks had already cooled significantly and had responded to extension by brittle deformation) or a NNW fault permitting the extension of one block independently of the adjacent block (R.S. Arthurton, oral comm., 1984) requires further study. Alternatively, it would be necessary to suppose that the volcanic rocks constituting the Sunset Peak block were deposited unconformably on the granitoids and their associated, often dominant, dyke rocks. Both models are problematical, and a satisfactory solution of this apparent anomaly merits attention during the remapping of Lantau.

The broad alignment of the Lantau dyke swarm with the Tolo Channel feature favours the existence of an essentially continuous zone of weakness, but a zone of extension rather than compressive shear as was postulated earlier in this section. The present-day physiography of Tolo Channel accords with a rift structure, although no southern boundary fault has yet been mapped, and a thrust rather than a normal displacement has been suggested for the northern boundary fault mapped by Allen and Stephens (1971). Whether compressional or tensional, however, the net result of the latter fault has been to drop (relatively) the rocks to the south so that they now underlie the superficial deposits which floor the channel.

There is also some doubt as to the continuity of the postulated zones of dyke intrusion and faulting. The Tolo Harbour-Tide Cove-Lai Chi Kok sector of the Tolo Channel-Lai Chi Kok fault zone represents a southward deflection from the direct line. No major faulting is known along the granitoid-volcanic contact to the east and west of Jubilee Reservoir, despite its mapped rectilinearity. The available evidence (R. Addison oral comm., 1984) indicates this contact to be a normal intrusive contact dipping rather gently to the north, and around the Chinese University the granite has a well developed thermal metamorphic aureole. No satisfactory explanation yet appears to exist for the apparent poor development of structures and dykes in this sector compared with the sections to the ENE (Tolo Harbour-Tolo Channel) and WSW (Tsing Yi and Lantau).

The extensional phase required for the dyke intrusion may represent relaxation following the strong regional folding and compressional faulting of the pre-volcanic basement, such as might be associated with subduction-related, continental accretion prior to and during the Yenshanian event.

There is as yet scant evidence within the Territory for tensional movements which can be ascribed to the opening of the South China Sea during the early Tertiary, although some of the rifting tentatively postulated for the Tolo Channel could equally relate to this event rather than to the Yenshanian. Dolerite dyke emplacement, assigned by Allen and Stephens (1971) to phases during the later Cretaceous and in the Paleocene, provides some evidence for extensional movement at about the required time. Once again, this period of extension appears to have followed a period of rather strong compression associated with the post-Port Island Formation thrusting noted in section 3.2.2.

The scattered outcrops of the Kat O Formation have also been subject to faulting and tilting, but the occurrence of active Quaternary faulting in the Territory remains unproven.

4. METAMORPHISM

4.1 GENERAL STATEMENT

Reference is made in the literature to regional, contact and dynamic metamorphism of the rocks of Hong Kong, with emphasis being given to the second and third of these categories. The subject has, however, received scant attention, mainly because, with the important exception of the Lok Ma Chau Formation, the effects of metamorphism are usually only weakly developed.

Allen and Stephens (1971) reviewed the subject, referring to earlier studies by, e.g. Schofield (1924), Williams and others (1945), Davis (1952, 1961 a, b), and Ruxton (1957b, 1960). A more recent study undertaken as part of the Mid-levels investigation resulted in the mapping of thermal metamorphic isograds in the Repulse Bay Formation adjacent to the granitoid contact (Hong Kong Government, 1982). Ou Yang (1979) reported on skarn mineralisation and the development of a variety of garnet types in a contact zone at Sha Lo Wan on Lantau.

Allen and Stephens (1971) placed greater emphasis on the role of regional metamorphism in Hong Kong than previous workers. They confirmed the regionally metamorphosed nature of the Lok Ma Chau Formation, considering this to represent a metamorphic event which occurred prior to the emplacement of the granitoid bodies. Some earlier workers had ascribed the metamorphic character of the Formation to later thermal metamorphism associated with the granitic activity. Allen and Stephens (1971) observed that the regional metamorphism extends into the adjacent volcanic rocks, particularly in the north of the Territory, and they related it to major folding during the Middle Jurassic. The presence of a penetrative cleavage in part of the Port Island outcrop, implying associated low-grade metamorphic recrystallisation, was also described, and was related to Cretaceous folding prior to a phase of overthrusting and associated shearing. The thrusting and shearing were somewhat cautiously dated at 92 ± 2 Ma (Late Cretaceous).

Dynamic metamorphism, whether of widespread occurrence or associated with the more important faults is quite commonly referred to in the literature, but few details are given. It is an essentially cataclastic phenomenon leading to the development of breccias and, in more extreme cases, mylonitic rocks. In addition to this essentially cold breakdown of rocks under reltaively high-pressure, low-temperature conditions, the development of strongly foliated, schistose zones in the granitoid rocks may be noted. These presumably occurred under higher temperature conditions and possibly reflect ductile shearing and faulting broadly contemporaneous with the intrusion of the granitoids.

4.2 DISCUSSION

Hong Kong rocks have generally responded to deformation in a brittle manner at a high structural level. The effects of regional metamorphism are accordingly limited. Only the Lok Ma Chau Formation merits description as a regionally metamorphosed unit, although cleaved and incipiently recrystallised rocks occur in the Port Island Formation.

The regional metamorphism of the Lok Ma Chau Formation is of greenschist facies. Despite its low metamorphic grade the Formation is distinctive, and may be considered to be anomalous when compared with the other main rock units of the Territory.

The provisional assignment of an Early Carboniferous depositional age for the Lok Ma Chau Formation does not preclude the possibility of its metamorphism during the late Palaeozoic although this may be considered unlikely. There appears to be no evidence for such an event in Guangdong, or in the other Palaeozoic rocks in Hong Kong. A suitable radiometric dating programme for the Lok Ma Chau Formation should permit the metamorphism to be dated and, at the same time, provide a minimum depositional age for the sequence.

Rocks in the Shenzhen Economic Zone which are broadly contiguous with the Lok Ma Chau Formation are beleived to pre-date a sequence of Upper Carboniferous fusulinid-bearing limestones, but correlations are tenuous. What is more, the time interval permitted for deposition and metamorphism prior to the deposition of the fossiliferous limestones is unacceptably short. Most Chinese geologists working in the Economic Zone ascribe the metamorphosed Lower Carboniferous rocks to dynamic metamorphism in the vicinity of major NE trending faults at some time during the Mesozoic. However, Devonian rocks in this zone include garnet and staurolite-bearing pelitic schists and tremolite marbles, with assemblages and textures more characteristic of regional, prograde metamorphism than of cataclastic (retrograde?) breakdown.

It is possible to interpret the metamorphism of the Lok Ma Chau Formation as a regional facies associated with the Mesozoic deformation (cf. Allen and Stephens, 1971), although the fabrics may possibly reflect dominant thrust tectonics rather than folding. Alternatively the Formation could be a relict of an older, more deeply-seated but now allochthonous basement unit which was emplaced tectonically during the Jurassic. These interpretations are speculative and the status of the Formation and its relationships require considerable further study.

The non-metamorphic nature of the other Palaeozoic formations contrasts with that of the Lok Ma Chau Formation. Only incipient recrystallisation has occurred in the Tolo Harbour Formation although the Bluff Head Formation is more indurated. The Bluff Head Formation is presently considered to be the oldest unit in the Territory. Detritus in the Formation must have originated from an older (pre-Devonian ?) source, and a study of the petrofabrics of the clasts (predominantly quartzites) and matrix of conglomerate horizons might reveal whether or not the clasts were already recrystallised prior to their incorporation in the Bluff Head sedimentary rocks.

The regional metamorphism of the Repulse Bay Formation is not well documented although Allen and Stephens (1971) refer to weak recrystallisation of the fine-grained matrix of the various pyroclastic rocks, and to the growth of new phyllosilicate phases, especially chlorite and sercite. The identification of very low grade metamorphism is difficult and any future study, whether in the volcanic rocks or in the sedimentary formations, will require careful sampling to avoid complications involved in the interpretation of fabrics resulting from the overprinting of thermal and dynamic effects or secondary alteration and breakdown in the zone of weathering.

The effects of thermal metamorphism are not conspicuous in the volcanic rocks. Allen and Stephens (1971) ascribed this to a broad temperature equilibrium between the granitoids and their country rocks; the mineral assemblages present in the volcanic rocks proved to be stable at temperatures as high as those generated at the time of intrusion. The more detailed study of volcanic rocks in the contact zone in the Mid-levels area (Hong Kong Government, 1982) permitted the recognition of a series of thermal metamorphic isograds in the volcanic rocks. Here the recrystallisation gave rise to distinctive quartz aggregates which are prominent on the weathered surfaces of the volcanics.

The sedimentary formations show the effects of induration and hornfelsing more strongly, with the development in argillaceous lithologies of spotting and white andalusite porphyroblasts. General induration is reported in the Tai O Formation (Allen and Stephens, 1971), and the presence of underlying intrusive rock at no great depth is inferred. Allen and Stephens (1971) also invoked this explanation to account for the presence of minerals such as andalusite at other locations apparently remote from present outcrops of intrusive rocks. The general induration of the Ping Chau beds (? Repulse Bay Formation) could be the result of baking by an underlying westward extension of the large granitoid bodies which occur on the eastern side of Mirs Bay. Hydrothermal activity associated with the inferred intrusive rocks could also account for the development of acmite pseudomorphs after gypsum in the Ping Chau sediments.

The widespread faulting which affected rocks of all ages and types throughout the Territory was accompanied by cataclasis and the development of breccias, shearing and, in extreme cases, mylonitisation. The different responses of the country rocks to deformation of this type presumably reflect variations in lithology and confining pressures, the latter being linked to the tectonic level at which the rocks were situated. It is difficult, however, to relate typical regional metamorphic fabrics and mineral assemblages to such deformation, although this is apparently favoured by many Chinese geologists. Ruxton (1960) described the development of penetrative slaty cleavage and phyllitic fabric in acid volcanics in the northern New Territories as a result of shearing. This process would have involved initial cataclasis, with subsequent recrystallisation and development of the penetrative fabric under moderate-pressure, low-temperature conditions.

Allen and Stephens (1971) also observed the intense but non-uniform development of cleaved volcanics in a zone several kilometres wide flanking the northern part of the Lok Ma Chau Formation outcrop. They preferred to relate this to regional metamorphism rather than to localised shearing, and noted the frequency and intensity of the cleaved zones to become weaker southwards from the Lok Ma Chau Formation contact.

Until the major overfold invoked by Allen and Stephens (1971) has been convincingly demonstrated, the relationships described would seem to be best explained by a major zone of shearing and upthrusting, such as already postulated in this report to account for the emplacement of the Lok Ma Chau Formation.

The metamorphic fabrics and mineralogical assemblages require further detailed study if the relationships and their timing are to be established unequivocally.

5. FAULTING AND SEISMIC ACTIVITY

5.1 INTRODUCTION

The major structural elements were outlined in sections 2 and 3 of the report. Attention was drawn to the existence of dominant NE trending structures and subordinate, essentially conjugate, NW striking fractures. The former are believed to represent deep-seated structures of considerable age (Palaeozoic or possibly older) but the history of their movements, which is undoubtedly complex, remains poorly known. The faults possess characteristics of major strike slip structures but there is evidence also for important vertical displacement of both compressional and tensional nature. If a predominantly N-S compressional stress field can be assumed, related in general terms to ocean-continent collision, then a dominant sinistral strike slip component would be expected on the NE faults. However, the satisfactory differentiation of the sense, scale and age of the movements on these faults remains uncertain.

The present southern seaboard of China was a focus of major tectonic and magmatic activity and high crustal mobility during the Jurassic-Cretaceous Yenshanian event. Since that time the region has become increasingly stable in gross terms. The age of the youngest important tectonic activity in Hong Kong and adjoining areas cannot be stated with certainty, but regional indicators suggest that this occurred during the early-to-mid-Teritary. Since that time, following the opening of the South China Sea, the focus of tectonic activity in response to plate movements has shifted to the presently extremely mobile, broadly N-S trending, Philippine arc and its northward prolongation into Taiwan.

This part of the report briefly reviews previous work and assessments of the seismicity and seismic potential of Hong Kong and adjoining areas.

5.2 SUMMARY OF SELECTED PREVIOUS WORK

The 1979 Tectonic Map of China (Structural Geology Section, Institute of Geology, 1979), and the Tectonic and Seismic Map of China (Section 562, Institute of Geology 1979), provide the most useful, readily available summary, at a small scale (1:4 000 000). On these maps (Fig. 6) the major NE faults, including those referred to in sections 1 and 2 of the present report, are indicated as structures active during the Mesozoic and the Cainozoic. A broad correlation is evident in Guangdong and West Fujian between these structures and the epicentres of historical earthquakes. The majority of the epicentres plotted on the seismic map, with the notable exception of some occurring in the Swatow area, range in magnitude from 5 to 6.9 on the Richter scale.

Hattori (1978) developed regional seismic risk maps for China and east Asia based on an analysis of maximum acceleration on the ground and maximum particle velocity on the base (bed) rock, and he assessed these data over return periods of up to 300 years. Even over the longest return period, Guangdong in general and Hong Kong in particular are not anomalous or considered to be at risk, certainly by comparison with Taiwan which shows regionally high values throughout the range of return periods examined. Lai (1981), however, noted that according to the 1977 Seismic Zoning Map of China (State Bureau of Seismology of China, 1977, scale 1:3 000 000) Hong Kong, with Guangdong and Fujian, lie within an area of moderately strong seismic activity, based on the recorded incidence of earthquakes in China.

The plots presented by Hattori (1978) feature a distinct westward bulge of the high value contours centred on Taiwan. This pattern is indicated for both the parameters he examined; regardless of return period chosen. The bulge extends into the Swatow area, in the general vicinity of the Fujian - Guangdong boundary. It is suggested that this supports the hypothesis that the greater incidence and intensity of seismic activity further east on the mainland is linked in a general way with the active collision of the Philippine arc with the continental plate, and reflects a greater build-up of stress in the contact zone.

Zhu (1982) reported the results of a geological study of earthquake hazards and prehistoric earthquakes in China. He noted the fundamental tectonic control exerted by faulting, but stressed that the destruction is caused by the shockwave spreading to the surface rather than the fault movement as such. The severity of the damage caused by the shockwave is affected by such factors as the geology and geomorphology of the area, and the groundwater conditions. Also, the lithology of poorly consolidated Quaternary superficial deposits, the relationship between sand saturation and liquefaction potential, the thickness of the cover, and slope gradient are all important.

For rugged terrain Zhu (1982) distinguished three categories of earthquake hazard : earthquake-gravitational, earthquake-tectonic and a third combining both gravitational and tectonic factors. He noted destruction due to gravitational factors to occur usually where slope angles exceed 35°. The second category, earthquake tectonic destruction, is controlled by seismic fractures and occurs along the associated fault or fault zone. Both categories result in rock falls, landslips, slope collapse and the deformation of alluvial terraces, etc. On the sedimentary plains earthquake hazards manifest themselves by ground fracturing in thick Quaternary sediments, landslips, and liquefaction of silts and fine sand horizons. Zhu (1982) concluded by indicating the various factors requiring consideration when applying the method of seismic vulnerability analysis. These include the vulnerability index of the foundation soil (soft clays and saturated silty sand are the most vulnerable), sand liquefaction, soil thickness (shock waves are of greater amplitude in soft, thick soils), and faults, which need not necessarily be expressed at surface.

In Hong Kong the responsibility for seismic monitoring is vested with the Royal Observatory, and Lau (1972, revised 1977) reviewed the potential for seismic activity based on the available historical data. He observed that shocks of intensity VI or above on the Modified Mercalli scale are capable of causing structural damage within a radius of 100 to 200 km of the epicentre. He also estimated that buildings designed to withstand seismic accelerations of 0.07 g would probably have survived all historical earthquakes which have occurred in the Guangdong area since 288 AD. The strongest shock recorded in Hong Kong since seismography was established was reported by Lau to be that occurring on 18 March 1962. The epicentre was located c. 145 km NNE of Hong Kong in the Heyuan area, and the US Coast and Geodetic Survey estimated the focus of this shock to have at a depth of 33 km, i.e. it was classed as a shallow earthquake. Lau reasonably concluded that the risk of a major, destructive earthquake affecting Hong Kong is small, but that it cannot be ruled out entirely. Shocks of Modified Mercalli scale VI or above can be anticipated every 400 years on average in Guangdong. The degree of risk is, of course, singificantly less than that in currently active seismic areas such as Taiwan and the Philippines.

Two papers adopting a structural approach to the potential for seismic activity in Hong Kong are those by Lai (1981) and Lee (1981). Both stressed the important role played by regional faulting, correlating historical earthquake epicentres with specific faults or fault intersections (NE and NW trending structures). Lee described seven major NE fault structures which can be associated with earthquakes. He emphasised particularly the Lianhua Shan zone, which has a length of more 1 000 km and a width of 20 to 40 km or more, and within which Hong Kong is situated (Fig. 9). Lai refers to the Shaowu - Heyuan fault, which passes within 50 km of Hong Kong at its nearest point. He considers that the major faults in the northern South China Sea, which were associated with the development of the Cainozoic sedimentary basins, are potentially dangerous structures (Fig. 10). He notes the presence of fault basins and associated weak seismic activity in the Pearl River estuary (the Zhujiang Delta Basin) and the small basins in Deep Bay and off Ap Chau.

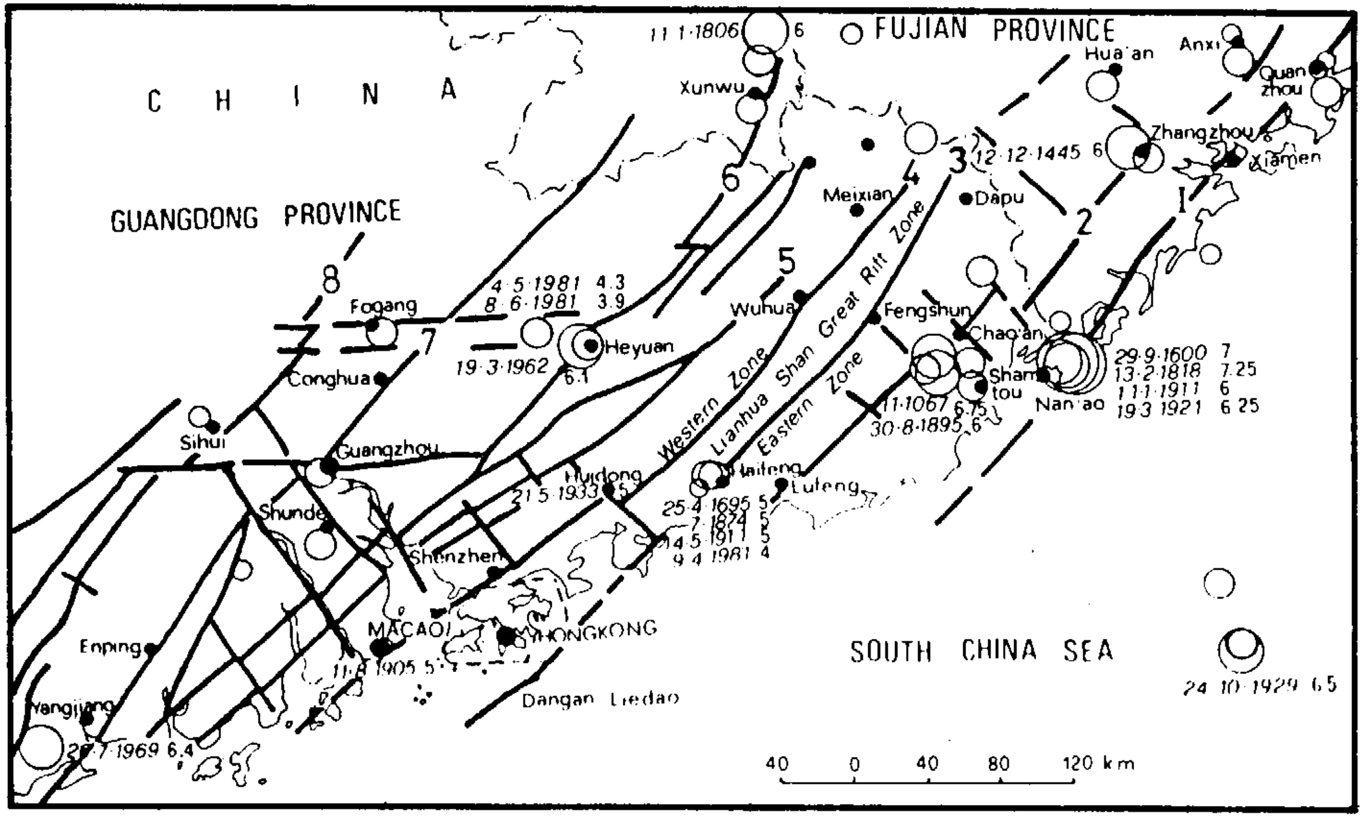

Fig. 9 Seismic Features of Guangdong and Fujian Provinces (Lee 1981). The Nan'ao Great Rift (No. 1), the Chao'an Great Rift (No. 2), the East Lianhua Shan Great Rift Zone - the Haifeng Great Rift Belt (No.3), the West Lianhua Shan Great Rift Zone - the Wuhua-Shenzhen (Shunchem) Great Rift (No. 4), the Zijin-Boluo Rift (No. 5), the Heyan Great Rift (No. 6), the Conghua-Enping-Yangjiang Great Rift (No. 7), and Sihui Great Rift (No. 8)

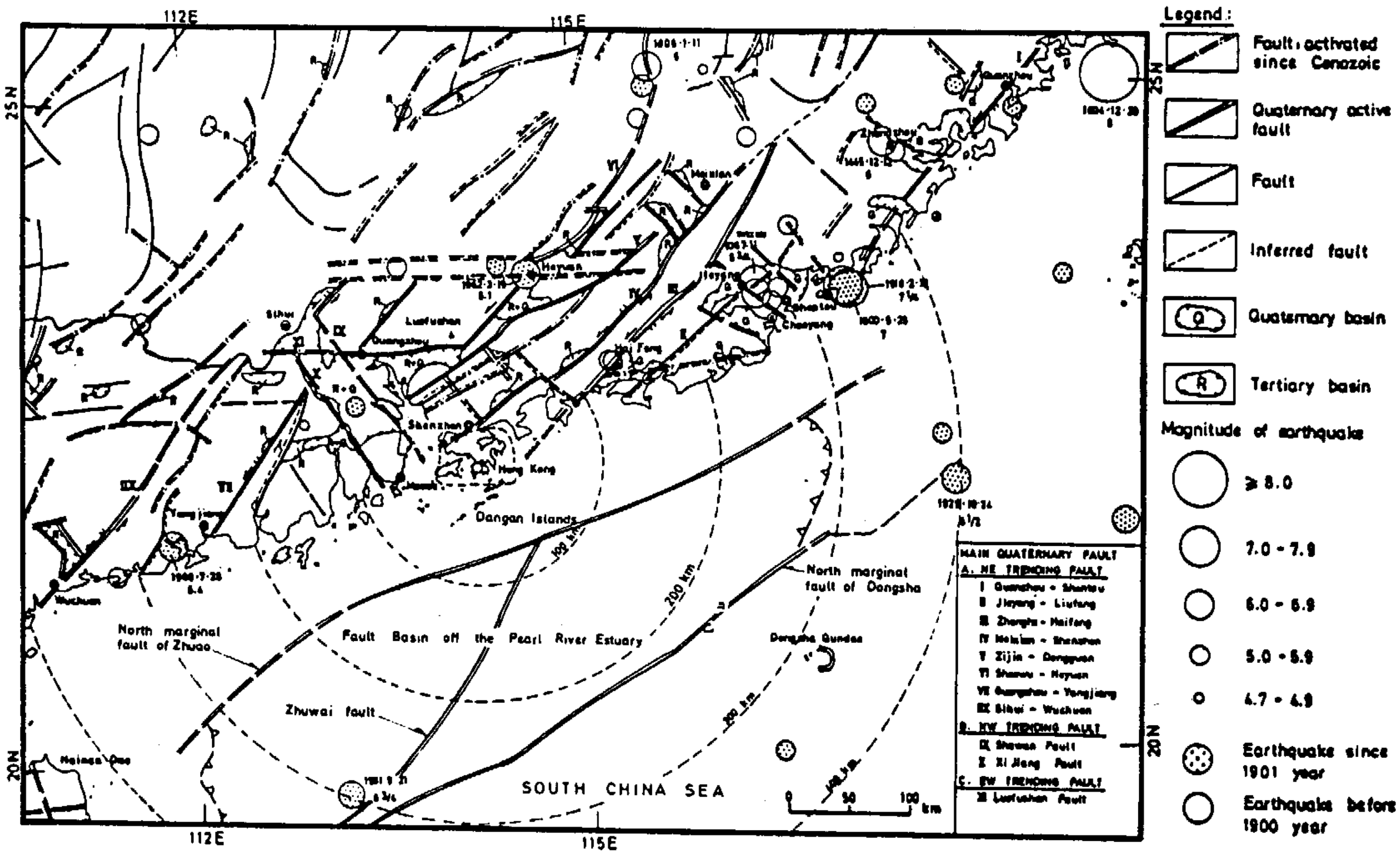

Fig. 10 Seismotectonic map of southern China (Lai 1981, modified from the Tectonic and Seismic Map of China 1979).

Lai (1981) concluded by noting the decline in tectonic activity in the Hong Kong area since the Mesozoic, although he regards the major fault structures as active during the Quaternary. On a regional scale he noted seismic activity to increase in strength towards the SE, and from SW to NE along the regional grain of S and SE China. The strongest activity is stated to occur on the Quanzhou - Shantou (Swatow) fault, although the frequency of activity is low.

Lee (1981) broadly concurred with this regional synopsis. He noted that the more powerful events occurred in the Nan'ao and Chao'an fault zones to the east of Haifeng, but he also observed a gradual increase in earthquake magnitudes northwestwards across the Lianhau Shan zone in the vicinity of the Heyuan and Yangjiang faults. On this basis, Lee concluded that Hong Kong lies within a central zone of weak seismic activity and he noted a positive correlation with the low background areas reported by Hattori (1978). In Lee's view, none of the seismic events occurring in the southwestern sector of the Lianhua Shan zone, with values of up to 5.0 on the Richter scale, would have been of engineering significance in Hong Kong. He did, however, emphasise the need for adequate mapping and analysis of the fracture system in Hong Kong, paying particular attention to the intersection of NE and NW trending structures.

5.3 DISCUSSION AND CONCLUSIONS

In general terms Hong Kong is situated on what is now a stable continental margin, removed from zones of current plate interaction. The continental plate was, however, highly active tectonically during the Mesozoic and through to the Mid-Tertiary, when the opening of the South China Sea is believed to have been essentially completed.

Tectonic activity continues in the region of Taiwan and the Philippines with the northwestwards subduction of oceanic plates and overthrusting of the northern sector of the Philippine - Taiwan arc onto the continental margin of southern China (Fig. 5) as a result of the arc-continent collison. It can be concluded that the seismic activity resulting from these crustal movements might be more intense in Fujian, the province of the mainland closest to the collision zone. This does not, however, readily account for the apparent increase in seismic activity northwestwards across the strike of the major fault zones (Lee, 1981).

Despite the general stability of the region around Hong Kong, the possibility of destructive seismic activity in the Territory cannot be entirely precluded, although it would be expected to be infrequent. The hinterland is characterised by major faults which are regional in character and are believed to be deeply seated structures of considerable longevity. In Hong Kong the main faults provide evidence of complex movements, and it has been suggested that they have undergone repeated reaction. Note may also be taken of the view (Hong Kong Government, 1982) that the more extensive development of mass wasting deposits in the Territory in the past (mid-Pleistocene to Recent; see Bennett, 1984b) might be related to more intense and/or more frequent seismic activity.

The observed association between faults and the epicentres of historically recorded earthquakes in southern China must also be considered. It should be noted, however, that the earthquake epicentres shown on the 1979 Seismic Map of China have shallow foci (< 70 km), and are apparently unrelated to present day subduction tectonics. They are not, therefore, likely to represent major seismic events (Das and Sholz, 1983). Nevertheless, even shallow earthquakes are potentially destructive. The foci of the shocks associated with the impounding of the Hsingfenkiang Reservoir, for example, were all in the range 1 to 11 km, and mostly occurred at depths of 4 to 7 km, but the shocks had wide-ranging effects (Shen and others, 1974). Hong Kong was located within intensity zone V (Modified Mercalli scale) of this earthquake.

Cainozoic faulting affected the distribution and possibly controlled the deposition of the Kat O Formation, which Lai (1981) regarded as having laid down in restricted fault basins of

Tertiary age. In the writer's opinion evidence in Hong Kong for younger faulting and displacement of the Quaternary superficial deposits has not yet been satisfactorily demonstrated. Typical neotectonic features such as recent fault scarps, offest drainage channels and displaced terraces have not been recorded, but there is some evidence for gradual variable uplift of the marine and alluvial deposits in different part of the Territory, and of terrace development and drainage incision.

Evidence for or against the existence of Quaternary fault movements may emerge from the remapping programme, but it is more probable that satisfactory resolution of the problem will require detailed follow-up geological studies of the superficial deposits of areas such as the Castle Peak Valley, the Lam Tsuen valley and Tide Cove.

A great amount of engineering development in Hong Kong has taken place on steep slopes, superficial deposits and reclaimed ground. In view of this, conclusive evidence of renewed tectonic activity would justify augmenting the Royal Observatory seismic monitoring system. This would probably be best achieved in the first instance by establishing a microseismic net to evaluate the frequency and intensity of movements on the critical structures. If the level of microseismic activity recorded is significant, appropriate geodetic monitoring should be considered. Studies of recent crustal movements are presented by Vyskocil and others (1983).

Until such time as geological evidence for active faulting is substantiated, the routine seismic monitoring should be continued, with epicentres and focal depths plotted in relation to regional geological structures. There is a lack of suitably scaled (e.g. 1:250 000 scale or larger) topographic, geological or structural maps of southern China to serve as a base for plotting and interpretation, but use could be made of satellite imagery with a superimposed geographic coordinate grid.

Liaison between Geological Survey Section and the Royal Observatory should be encouraged in order to help overcome the tendency, evident in the past, for seismic data to be considered in a context remote from geology. This collaboration could be linked with a regional fracture trace analysis based on the satellite imagery, which could provide better structural control than is available in the 1:4 000 000 scale geological, tectonic and seismic maps of southern China.

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