EXPERT REPORT ON THE GEOLOGY OF THE PROPOSED GEOPARK IN HONG KONG

GEO REPORT No. 282

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CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT
THE GOVERNMENT OF THE HONG KONG
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PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

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H.N. Wong
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July 2013

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FOREWORD

Upon the request from the Agriculture, Fisheries and Conservation Department, the Hong Kong Geological Survey of the Geotechnical Engineering Office, Civil Engineering and Development Department was commissioned to prepare an Expert Report on the geology of the proposed Geopark. This Report is to be incorporated in the submission to the Ministry of Land and Resources for the proposed Geopark in Hong Kong to be listed as a National Geopark.

The information contained in this report is based on existing published geological maps and memoirs of the Hong Kong Geological Survey and other publications related to the geology of Hong Kong. It contains a summary account of the geological and geomorphological details of the proposed Geopark and is accompanied by geological and geomorphological maps of the two regions. The report was prepared by Dr. R J Sewell and Ms. D L K Tang of the Hong Kong Geological Survey. Mr. C W Lee of the Hong Kong Geological Survey assisted with preparation of geomorphological maps. Mr. Vincent C K Lau provided cartographic support on the map production. The Chinese version of the report was translated by Mr. C W Lee and Ms. D L K Tang.

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CONTENTS

1. INTRODUCTION

1.1 Background

In the 2008 Policy Address, the Chief Executive announced that the Hong Kong Special Administrative Region Government was proposing to establish a Geopark in Hong Kong for the purposes of conserving the world-class geological landscapes, promoting geoscience education, and popularising the geosciences.

The initial proposal was, in fact, the result of a feasibility study commissioned by the Environment Bureau in 2008. The feasibility study concluded that the Northeastern New Territories and Sai Kung regions together encompass landscapes that are representative of the geodiversity, ecology and cultural heritage of Hong Kong, while at the same time preserving world-class geological features. This area has been selected for nomination as the Hong Kong Geopark, to be protected under an integrated management scheme that will be structured both to conserve the contained geological attractions, and to promote the inherent geodiversity.

The Geopark will be registered under UNESCO's Geopark programme, which was launched in 2004. A Geopark is defined by UNESCO as a "geological site of special scientific significance, rarity or beauty; together with geological significance, these sites must also have high archaeological, ecological, historical or cultural value". Before being enlisted as an UNESCO Geopark, it is necessary to nominate the proposed area as a National Geopark under the Ministry of Land and Resources (MLR). Consequently, an important component of the Hong Kong nomination to MLR is an Expert Report on the geology of Hong Kong in general, and of the noteworthy features of the proposed Geopark in particular.

1.2 The Proposed Geopark

The proposed Geopark will comprise two regions, the Northeastern New Territories and Sai Kung, and eight areas, as detailed below:

(i) The Northeastern New Territories Region
This region is characterised by a range of sedimentary rocks.

- Ping Chau (Tung Ping Chau)
- Tolo Channel, Lai Chi Chong and Ma Shi Chau
- Double Haven
- Port Island and Bluff Head

(ii) The Sai Kung Region
This region is characterised by volcanic rocks exhibiting large hexagonal columns.

- High Island and Tai Long Wan
- Sharp Island, Kau Sai Chau and Jin Island
- The Ninepin Group
- Wan Chau, Basalt Island and Bluff Island

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1.3 Scope and Contents of the Report

This report is based upon the information contained in the existing published maps and memoirs of the Hong Kong Geological Survey, of the Civil Engineering and Development Department, and other publications related to the geology of Hong Kong. The accompanying geological maps for the two regions (Maps 1 and 3) are based on, and modified from, the existing Hong Kong Geological Survey 1:20,000-scale Geological Map Sheet Nos. 3, 4, 7, 8 and 12 (GCO, 1986, 1989a, 1989b & 1991; GEO, 1992). The accompanying geomorphological maps (Maps 2 and 4) have been prepared using the 1:100,000-scale Shaded Relief Map (GEO, 2000) as a base. The majority of the plates used in this report are from the Hong Kong Geological Survey large format photograph collection. No further fieldwork has been carried out.

A Bibliography is included as an Appendix that lists both technical and popular accounts of the geology and geomorphology of Hong Kong. These accounts are readily obtainable by interested parties. The most up-to-date synthesis of the geology of Hong Kong is contained in two memoirs published by the Civil Engineering and Development Department in 2000 (Sewell et al, 2000; Fyfe et al, 2000). A simplified geological map of Hong Kong is shown in Figure 1.

2. THE GEOLOGICAL SETTING OF HONG KONG

Hong Kong is situated on the southeastern margin of the Eurasian landmass. The unexposed continental basement of the territory is thought to be older than 550 million years (Fletcher et al, 1997). However, in neighbouring Guangdong Province, crystalline rocks as old as 2.5 billion years have been discovered (Wang & Mo, 1995).

The landmass of China is believed to comprise a series of three ancient crustal blocks. These blocks are known as the North China Block, the Yangtze Block and the Cathaysia Block. About 1,000 million years ago, the continental basement of Hong Kong (Cathaysia Block) collided with the Yangtze Block along a convergent margin tectonic setting (Chen et al, 1991; Xing et al, 1992). The amalgamated basement, known as the South China Block, then collided with the North China Block during the late Palaeozoic to early Mesozoic (c. 250 to 200 million years ago) to form the Eurasian continent (Zhang et al, 1984; Mattauer et al, 1985; Klimetz, 1983; Sengor, 1984; Lin et al, 1985).

The present-day tectonic setting of southeastern China is best described as a passive continental margin. Southeastern China forms part of the Eurasian Plate, which is in continent-continent collision with the Indo-Australia Plate along its southern border (forming the Himalayan Mountain Chain). In the east, the Philippine Plate is moving northwestwards forming a complex oceanic subduction zone system along the margin of the Eurasian Plate. North of Taiwan, the Philippine Plate is being subducted beneath the Eurasian Plate. South of Taiwan, both the Philippine and Eurasian Plates appear to be subducting beneath the islands of the Philippines, leading to a complex history of volcanism and earthquakes.

The dominant valley systems in Hong Kong are fault-controlled and trend northeastward in harmony with the overall structural grain of the Lianhuashan Fault Zone, which is one of the dominant geological structures of southeastern China (Chen, 1987).

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Hong Kong lies within the Lianhuashan Fault Zone at the southeastern margin of the Cathaysia Block on the Eurasian Plate. The Lianhuashan Fault Zone consists of a 30 km wide NE-trending zone of subparallel, anastomosing faults extending for several hundreds of kilometres through the maritime provinces of Guangdong, Fujian, and Zhejiang (Bureau of Geology and Mineral Resouces of Guangdong Province, 1988). The fault zone is bounded to the north by the Shenzhen Fault and to the south by the Haifeng Fault (Chen, 1987; Lai & Langford, 1996), and is characterised by numerous ductile shears and local areas of medium to high-grade dynamic metamorphism (Yang, 1996). A subordinate set of northwestward trending fault-related structures is also present in Hong Kong (Lai & Langford, 1996). Both sets of faults are considered to have been active during the Jurassic-Cretaceous Yanshanian Orogeny and probably represent reactivation of earlier structures (Sewell et al, 2000).

3. A BRIEF GEOLOGICAL HISTORY OF HONG KONG

Around 600 million years ago, a large part of southeastern China is thought to have been submerged beneath a shallow continental sea (Wang, 1985). By the Early Devonian to Middle Devonian Period (c. 416 to 385 million years ago), sediments from rivers and deltas were being deposited in the Hong Kong region. These now form the oldest rocks in Hong Kong and are known as the Bluff Head Formation (GCO, 1986 & 1989; GEO, 1992; Addison, 1986; Strange el al, 1990; Lai et al, 1996). The area was tectonically relatively stable. During the Early Carboniferous Period (c. 359 to 318 million years ago), the area became submerged beneath a warm shallow sea where lime muds were deposited (Li & Li, 1988). These are now preserved in Hong Kong as marble of the Yuen Long Formation (Lai & Mui, 1984; Langford et al, 1989). Re-emergence of terrestrial conditions is recorded by conglomerates, sandstones, and graphitic siltstones of the Lok Ma Chau Formation that were deposited during the Late Carboniferous Period (c. 318 to 300 million years ago) (Lai, 1977; Ha et al, 1981; Lai & Mui, 1984; Lee, 1985; Frost, 1992). A return to marine conditions in the Permian Period (c. 300 to 251 million years ago) is recorded by siltstones and mudstones of the Tolo Harbour Formation (Addison, 1986).

During the Triassic Period (c. 251 to 199 million years ago), there was a major tectonic event in China, which was accompanied by the intrusion of granite magmas (Sewell et al, 2000). The older sedimentary rocks in Hong Kong were strongly deformed.

In the Early Jurassic Period (c. 199 to 190 million years ago), a convergent margin tectonic setting developed along the southeastern coast of China (Huan et al, 1982; Guo et al, 1983). Shallow marine to subtidal conditions existed in the Hong Kong region at this time and are preserved as the Tolo Channel Formation (Lai, 1989; Lee et al, 1990). By the late Early to Early Middle Jurassic Period (c. 190 to 175 million years ago), an alluvial plain had formed leading to deposition of sandstones and siltstones of the Tai O Formation (Ng et al, 1997; Sewell et al, 2000).

Volcanoes began erupting ash and lava in the Hong Kong region during the Early to Middle Jurassic Period (c. 180 to 175 million years ago) (Evensen & York, 1998). These older volcanoes were of andesitic composition and are preserved as the Tuen Mun Formation (Langford et al, 1989; Sewell et al, 2000). The main period of volcanism in Hong Kong occurred during the Middle Jurassic to Early Cretaceous periods (c. 165 and 140 million years ago), and was accompanied by extensive intrusion of granitic magmas (Davis et al, 1997;

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Campbell & Sewell, 1997 & 1998; Sewell et al, 2000). Four main phases of magmatic activity are recognised and their age are based on high precision radiometric dating: Tsuen Wan Volcanic Group and Lamma Suite (c. 165 to 160 million years), Lantau Volcanic Group and Kwai Chung Suite (c. 148 to 146 million years), Repulse Bay Volcanic Group and Cheung Chau Suite (c. 143 to 142 million years) (Figure 2) and Kau Sai Chau Volcanic Group and Lion Rock Suite (c. 140 million years) (Figure 3) (Campbell & Sewell, 1998). The volcanic rocks are mainly of trachydacitic to rhyolitic composition, whereas the intrusive rocks are mainly granite, with subordinate granodiorite and quartz monzonite (Sewell & Campbell, 1997).

Between the Early Cretaceous Period and early Eocene Epoch (c. 140 and 50 million years ago), the tectonic setting of the Hong Kong region was relatively stable except for development of a few block-faulted basins (Sewell et al, 2000). The climate was hot and dry. Conglomerates, breccias, sandstones and siltstones, belonging to the Pat Sin Leng Formation, Port Island Formation, and Kat O Formation, were mainly deposited as sediments in river channels on an alluvial plain, and also as alluvial fan deposits probably eroded from fault scarps (Jones, 1995; Lai et al, 1996). During the early Eocene Epoch (c. 55 to 50 million years ago), a shallow lacustrine lake is thought to have developed in eastern Hong Kong leading to deposition of thin layers of siltstone now preserved as the Ping Chau Formation (Lai, 1991; Jones, 1995; Lai et al, 1996).

There is no record of sediments deposited in the Hong Kong region between the early Eocene Epoch to the beginning of the Quaternary Period (c. 50 to 2.6 million years ago).

During the Quaternary Period, from about 2.6 million years to present, Hong Kong was affected by cyclical climatic changes during which world sea level periodically fell and rose in response to glacial and interglacial episodes. Although no ice covered Hong Kong, the offshore sediments in Hong Kong waters record indirect evidence of major fluctuations in global climate (Fyfe et al, 2000). The current sea level was attained at around 8,000 years ago. Since then, weathering processes have continued to break down the solid rocks, resulting in a weathered soil profile of variable thickness and characteristics, while erosion processes have moved the sediments and re-deposited them in different environments. These processes have assisted in shaping many natural landscapes that are found in Hong Kong today.

4. GEOLOGICAL AND GEOMORPHOLOGICAL FEATURES OF THE TWO REGIONS

4.1 The Northeastern New Territories Region

4.1.1 An Overview of Geomorphology of the Northeastern New Territories Region

The geomorphology of the Northeastern New Territories region is principally controlled by two underlying geological structures: the Tolo Channel Fault, which is responsible for the development of Tolo Channel and Tolo Harbour, and the fault-bounded Tai Pang Wan Basin, forming Mirs Bay (Lai et al, 1996). These geological structures also distinguish two major structural domains, one of which is dominated by highly deformed Late Palaeozoic rocks, and one of which mostly contains slightly tilted, weakly deformed Late Mesozoic and Early Cenozoic rocks (GCO, 1986 & 1989; GEO, 1992; Addison, 1986; Stange et al, 1990; Lai et al, 1996).

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The northeast-oriented Tolo Channel opens out southwestward into Tolo Harbour which is occupied by a few small islands, including Ma Shi Chau, Centre Island and Yeung Chau. Strong tidal flows through Tolo Channel have produced a rocky shoreline with minimal beach development, whereas the tranquil waters of Tolo Harbour have promoted sediment deposition and the development of sandy beaches and tomboloes (e.g. Ma Shi Chau).

Double Haven on the western shores of Mirs Bay is largely protected from the open ocean by the three main islands of Double Island, Crescent Island and Crooked Island. Its indented coastline suggests a drowned landscape, inundated by rising sea levels following the last glacial period. The calm waters of Double Haven have led to the development of constructional landforms, such as sandy beaches and lagoons.

On the east side of Mirs Bay, the island of Ping Chau (Tung Ping Chau) is exposed to strong wave action, and consequently is dominated by destructional landforms, such as wave-cut platforms and stacks. In a similar manner, Port Island, at the mouth of Tolo Harbour, has a rocky coastline due to exposure to strong ocean waves and currents.

The rugged topography of the northeast-trending ridge forming Fung Wong Wat Deng on the north side of Tolo Channel reaches a high point of 218 m at Ngor Kai Teng. This contrasts markedly with the relatively low-lying topography of the islands of Double Haven and Mirs Bay which have a maximum elevation of 154 m (Wong Wang Pak Teng).

4.1.2 An Overview of Geology of the Northeastern New Territories Region

The Northeastern New Territories region is characterised by a variety of sedimentary rocks of Late Palaeozoic, Mesozoic and Cenozoic age (GCO, 1986 & 1989; GEO, 1992; Addison, 1986; Strange et al, 1990; Lai et al, 1996). They include the oldest rocks, as well as the youngest rocks exposed in Hong Kong. Many of these strata are exposed along the shores of Tolo Channel, around Double Haven and in Mirs Bay (Tai Pang Wan).

The NE-trending Tolo Channel Fault is a prominent structure that extends through Hong Kong for about 60 km (Plate 1; Lai & Langford, 1996; Sewell et al, 2000). In the Northeast New Territories Region, it runs from the tip of Bluff Head along Tolo Channel to Tolo Harbour. To the northeast of Tolo Channel, it either peters out or is truncated by a northwest-trending fault bounding the Tai Pang Wan Basin. The Tolo Channel Fault is thought to have been periodically active since the Late Palaeozoic, and is considered to have played an important role in controlling Mesozoic magmatism (Campbell & Sewell, 1997).

Devonian sedimentary rocks are exposed principally north of Tolo Channel where they are structurally complex and show evidence for multiple phases of faulting and folding. The northeast-oriented, steep-sided ridge north of Tolo Channel has its widest occurrence in the vicinity of Fung Wong Wat, but narrows considerably to the northeast (Addison, 1986; Lai et al, 1996; Sewell et al, 2000).

Rocks of Permian age are mainly exposed in the vicinity of Tolo Harbour (Addison, 1986; Lai et al, 1996; Sewell et al, 2000). The outcrops are on Ma Shi Chau, Centre Island, the area northeast of the Chinese University and the southwest side of Three Fathoms Cove (Nau, 1981; Addison, 1986; Strange et al, 1990; Lai et al, 1996; Sewell et al, 2005;

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Wong et al, 2005).

In the vicinity of Tolo Channel, the Early Jurassic rocks occur at four principal localities: Fung Wong Wat and adjacent sections of the coastline to the east-northeast and west-southwest, Sham Chung, Ma Shi Chau, and Nai Chung (Addison, 1986; Strange et al, 1990; Lai et al, 1996; Sewell et al, 2005; Wong et al, 2005). The sedimentary rocks belong to the Tolo Channel Formation, which dominantly consists of grey to greyish white, laminated siltstones with rare sandy lenses alternating with thinly-bedded fossiliferous black mudstone containing pyritous nodules (Addison, 1986; Sewell et al, 2000). These rocks are mainly exposed on shore platforms and they are not easily traced away from the coast. On the northern side of Tolo Channel, the exposures are bounded by a fault that strikes east-northeast, subparallel to the coastline (Addison, 1986; Lai et al, 1996).

A well-bedded succession of pale grey cherty tuffite, coarse ash crystal tuff, thin eutaxitic fine ash tuff, flow-banded rhyolite, conglomerate, tuffaceous sandstone and dark grey laminated mudstone is exposed on the intertidal platform at Lai Chi Chong on the southern shore of Tolo Channel (Strange et al, 1990; Sewell et al, 2000). These volcaniclastic sedimentary rocks are of Late Jurassic age and are of similar age to the volcanic rocks on Lantau Island (Sewell et al, 2000). The presence of common slump folds, syn-sedimentary faults and dewatering structures within the sedimentary strata have confirmed that they were deformed prior to consolidation, and may have partly accumulated from rapidly emplaced mass flows (low and high concentration turbidites and debris flows) (Campbell & Shaw, 2002).

Late Mesozoic and Cenozoic sedimentary rocks are largely confined to the Tai Pan Wan Basin (Mirs Bay) in the northeast of Hong Kong (Lai et al, 1996; Sewell et al, 2000). The Tai Pang Wan Basin is northwest-trending, approximately 10 km long and is centred on Mirs Bay (Lai, 1985 & 1991; Lai et al, 1996). Sedimentary strata within the Tai Pang Wan Basin include the Late Cretaceous Port Island Formation, exposed on Round Island, Port Island and Shek Ngau Chau, and the Early Tertiary Ping Chau Formation, exposed on Ping Chau (Tung Ping Chau).

The geometry of Mirs Bay is inferred to be controlled mainly by two sets of orthogonal faults bounding the Tai Pang Wan Basin. These probably represent the margins of a pull-apart basin that developed during Late Mesozoic to Cenozoic time (Lai, 1985; Sewell et al, 2000; Leung, 2004). Cretaceous and Eocene sediments were deposited within the basin and are exposed as red-coloured conglomerates on Port Island, and siltstones on Ping Chau (Tung Ping Chau) (Lai et al, 1996). A smaller fault-bounded basin, known as the Ap Chau Basin, occurs in the northwest corner of Mirs Bay and is also infilled by red-coloured sediments. The sedimentary rocks beneath Mirs Bay are tilted and folded at a shallow to moderate angle (10 - 20º) and forming an overall syncline plunging gently (20º) towards the northeast (Lai et al, 1996; Sewell et al, 2000).

The Cretaceous sedimentary rocks in Hong Kong have long been recognised as comprising a continental red bed succession (Heanley, 1924; Brock & Schofield, 1926; Heim, 1929; Williams, 1943; Davis; 1952; Ruxton, 1960; Lai et al, 1996). Their main outcrops are present along the Pat Sin Leng escarpment and on several islands in the west of Mirs Bay, including Port Island, Round Island, Channel Rock and Shek Ngau Chau (Lai et al, 1996). On Port Island, the Cretaceous sedimentary strata comprise mainly very thickly- to

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thickly-bedded, reddish brown conglomerate and sandstone, with interbedded thickly- to thinly-bedded siltstone (Lai et al, 1996). These red beds generally dip moderately to the east and southeast.

In the vicinity of Double Haven, Cretaceous sedimentary rocks are exposed in scattered areas at the northern tip of Crooked Island, on Robinson Island, Ap Lo Chun, Sai Ap Chau, Pak Tun Pai, Ledge Point and North Point (Lai et al, 1996). The Ap Chau Basin, extending 5 km from Robinson Island to Crooked Island, contains reddish brown calcareous breccia of the Late Cretaceous Kat O Formation (Sewell et al, 2000).

Cenozoic sedimentary rocks in Hong Kong are only exposed on the island of Ping Chau (Tung Ping Chau) in Mirs Bay (Lai, 1991; Lai et al, 1996). However, based on seismic interpretation they are inferred to underlie a large part of eastern Mirs Bay and to rest conformably on Late Cretaceous red beds of the Port Island Formation (Lai, 1991). The Ping Chau Formation comprises a succession of thinly-bedded dolomitic and calcareous siltstones with rare chert interbeds (Lai et al, 1996).

4.2 The Sai Kung Region

4.2.1 An Overview of Geomorphology of the Sai Kung Region

The Sai Kung region is dominated by two main harbours, Port Shelter and Rocky Harbour, and is bounded to the north by the Sai Kung Peninsula, and to the west by the Clear Water Bay Peninsula. It is a very popular maritime recreational area featuring numerous islands that are largely unpopulated.

The geomorphology of the area is largely a function of coastal processes acting upon the underlying volcanic rock type and its associated geological structures. East facing coastlines, are generally highly irregular and characterised by steep cliffs, sharp headlands, sea stacks and arches. These landforms have been produced by high energy conditions associated with exposure to strong waves from the southeast, coupled with differences in the resistance of the rocks to weathering and erosion. West facing coastlines, and those in sheltered waters surrounding islands in Port Shelter and Rocky Harbour, are generally less rocky, and feature some sandy shorelines that have been produced by constructional wave action. The main channels separating the islands in Port Shelter and Rocky Harbour are dominantly fault-controlled, reflecting the major influence of geological structures, such as north- and west-trending faults, on the topography and geomorphology.

Columnar-jointing is widespread in the underlying volcanic rocks. Individual columns are mostly pentagonal to hexagonal, and are up to 30 m high and 2 m wide. Their long axes generally plunge to the west between approximately 75° and 80°. Originally, the columns are inferred to have formed subvertically, and have since been tilted to the east at approximately 10 to 15° along with the accompanying strata (Langford et al, 1995; Campbell et al, 1999).

Coastal erosion has undermined the stability of the columns leading to slumping, toppling, and translational sliding (Campbell et al, 1999). Stress relief of the columns during weathering can lead to development of low-angle joint sets. Shearing at the base of the column along these low angle joints can induce the columns to kick out causing vertical

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slumping. Toppling of individual columns or groups of columns may occur as a result of destabilization by hydraulic fracturing. Translational slide failure of groups of columns may also occur on the coast where stress release occurs on pre-existing low-angle joint sets. The presence of very thin soil profiles on the columnar jointed volcanic rocks has been interpreted as evidence for relatively rapid erosion.

4.2.2 An Overview of Geology of the Sai Kung Region

The main rock type underlying the Sai Kung region is columnar-jointed fine ash vitric tuff of the High Island Formation (Langford et al, 1995; Sewell et al, 2000). The tuff is of high-silica rhyolite composition (Sewell & Campbell, 1997). Except for minor eutaxitic fabrics at the base, it is remarkably uniform both in structure and texture suggesting that it was deposited as an ignimbrite during a cataclysmic eruption. High (c.850°C) eruption temperatures are thought to have led to intense welding of the tuff. Post-emplacement devitrification and vapour phase crystallisation completely destroyed many of the original pyroclastic characteristics (Tam, 1970; Tam & Chan, 1983). About 20% of the crystals in the matrix are composed of euhedral alkali feldspar (Langford et al, 1995). This has caused some debates over identification of the unit as a lava or a tuff. The great heat retained within the volcanic ash unit, along with escaping gas, is thought to have promoted the post-eruptive crystallisation of quartz and feldspar in the vitric tuff. The well-developed columnar jointing suggests that the tuff accumulated and cooled in a depression, probably associated with caldera collapse (Figure 3). Single crystal U-Pb zircon dating has yielded an age of 140.9 ± 0.2 million years (Ma) for the unit (Davis et al, 1997).

Volcanic rocks of the Clear Water Bay Formation also crop out in the Sai Kung region (Strange et al, 1990). The formation is at least 400 m thick and contains several trachydacite to high silica rhyolite lava flows interbedded with fine ash tuffs, tuffaceous mudstones, and tuffites (Strange et al, 1990; Sewell et al, 2000). High precision U-Pb zircon age-dating has returned an age of 140.7 ± 0.2 Ma for the formation (Davis et al, 1997). The lack of ordered structure in rocks of the Clear Water Bay Formation may have made them slightly more resistant to weathering and erosion compared to the strongly jointed High Island Formation producing the high topography across the Sai Kung Peninsula compared with the low topography of the Port Shelter and Rocky Harbour areas. Exposure to strong wave action from the ocean to the southeast may have promoted the erosion of the columnar-jointed coastline cliffs by undermining and toppling of the tilted columns.

5. DETAILED GEOLOGICAL AND GEOMORPHOLOGICAL FEATURES OF THE EIGHT AREAS

5.1 Ping Chau (Tung Ping Chau)

The rocks exposed on Ping Chau (Tung Ping Chau) comprise a sequence of gently north- to northeastward-dipping, thinly bedded dolomitic and calcareous siltstones with rare chert interbeds (Lai, 1991). They have a minimum thickness of 450 m and belong to the Ping Chau Formation, which is the youngest known rock unit in Hong Kong. The Ping Chau sediments are thought to have been originally deposited in a lake under semi-arid conditions during early Eocene Epoch (c. 55 to 50 million years ago). The lake periodically dried up, allowing salts to crystallise. A diverse assemblage of fossil insects and bituminised

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plant fragments have been described from the rocks on Ping Chau (Tung Ping Chau) (Lai et al, 1996; Lee et al, 1997), including the insect Coleoptera sp. (Williams, 1943), and angiosperm, gynosperm and pteridophyte plant genera.

The zeolite-bearing siltstone is well developed along the east coast between Wong Ye Kok and Lam Uk. The zeolite occurs as abundant, rosette-shaped crystal aggregates resting on bedding planes, or forms prismatic and granular crystal aggregates that infill cracks and "birds eye" structures. Pyrite is present as subspherical nodules and laminae. On some horizons, aegirine and zeolite (rosette-shaped) crystals occur as pseudomorphs of gypsum. These minerals are probably related to low temperature (< 200°C) alteration by alkaline fluids (Kemp et al, 1997).

Inclined, bedded sedimentary rocks on Ping Chau (Tung Ping Chau) form a large escarpment, dipping to the northeast (Plate 2). The rocks exposed on the wave cut platforms around the island form a parallel series of minor escarpments.

Two sea stacks, "rock towers" or Kang Lau Shek, sit at the southeastern corner of Ping Chau (Tung Ping Chau) (Plate 3). They represent the eroded stumps of rocks left behind from a collapsed sea arch formed by wave erosion (GEO, 1997). An extensive wave-cut platform has developed below sea cliffs along the southwestern coast of Ping Chau (Tung Ping Chau). During high tides, the wave-cut platform is flooded by seawater, and thus the location is called Lan Kwo Shui, which means "difficult to pass". The wave-cut platform has been eroded by continuous wave action. Locally, huge blocks of rock have fallen from the sea cliffs and are scattered along the coast.

At Lung Lok Shui, a prominent resistant layer of cherty siltstone (Plate 4) is known locally as a "Dragon" diving into the sea. The layer is about 0.8 to 1 m thick and is composed of mostly very fine-grained quartz and feldspar, with subordinate secondary carbonate. The presence of fresh albite in the matrix, together with volcanic rock fragments, has been interpreted as indicating a volcaniclastic origin, with subsequent diagenetic modification (Kemp et al, 1997).

Intercalated, pale yellowish brown, dolomitic siltstone is well exposed at Cham Keng Chau. The narrow passage across the headland at Cham Keng Chau is the geomorphological expression of a local fault (Plate 5).

5.2 Tolo Channel, Lai Chi Chong and Ma Shi Chau

The Tolo Channel is the gemorphological expression of one of the major NE-trending faults in Hong Kong (Plate 1). Late Palaeozoic and Mesozoic sedimentary rocks are exposed along both the northern and southern coasts. The clearest exposures of these rocks occur at Fung Wong Wat, Lai Chi Chong and Ma Shi Chau.

Inclined, alternating layers of pale siltstone and black mudstone are exposed along the coastal rock platform at Fung Wong Wat, on the northern coast of Tolo Channel (Plate 6). The sedimentary rocks have yielded a diverse assemblage of fossils, such as ammonites, bivalves and crinoids (Heanley, 1924; Lai, 1989; Lee et al, 1990) indicating that they are of Early Jurassic age (about 200 million years old). The sediments are thought to have been

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originally deposited in a shallow marine, sub-tidal environment (Jones, 1995). The Early Jurassic sedimentary rocks are in fault contact with the Devonian sedimentary rocks to the northwest.

Between Fung Wong Wat and Wong Wan Tsai, the Tolo Channel Formation outcrop varies from 30 to 120 m wide. The strata dip at about 20° to the southeast, and comprises sandstone and black fossiliferous mudstone containing abundant pyrite nodules (Lai et al, 1996). On the adjoining hillside, however, the bedding dips steeply and is strongly contorted along the faulted contact with the Devonian Bluff Head Formation.

A well-bedded succession of cherty tuffite, ash tuff, flow-banded rhyolite, conglomerate, tuffaceous sandstone and laminated mudstone is exposed along the coast at Lai Chi Chong (Strange et al, 1990). Individual beds vary from 0.1 to 6 m thick. A range of sedimentary structures, including soft sediment deformation features such as flame structures and load casts, occurs in the rocks (Plate 7). These characteristics indicate the rapid emplacement of mass flow deposits onto unconsolidated sediments (Campbell & Shaw, 2002). Intercalated ash tuff has yielded a U–Pb single zircon age of 146.6 ± 0.2 Ma (Campbell et al, 2007) and the sediments probably accumulated in a lake that was situated close to a volcanic centre during the Late Jurassic (Sewell et al, 2000). Locally, the sedimentary layers are highly contorted. The overall dip of the strata is approximately 30° towards the southeast.

Permian sedimentary rocks on Ma Shi Chau comprise purplish grey to dark grey mudstones, siltstones and sandstones. They belong to the Tolo Habour Formation, which has an estimated thickness of 500 m (Addison, 1986). They show many syn-sedimentary folds (Plate 8) and have yielded a large variety of fossils, including marine fauna and plant fragments (Ruxton, 1960; Lam, 1973; Nau, 1980; Yim et al., 1981; Addison, 1986). The original sediments were probably deposited in a shoreside tidal flat (Jones, 1996). A series of northerly plunging minor anticlines and synclines, the limbs of which are often sheared and overturned, are exposed along the southeastern wave-cut platform of Ma Shi Chau.

Mesozoic volcanic rocks and sedimentary breccias are also present at the southern corner of Ma Shi Chau and nearby at the eastern end of Yim Tin Tsai (Addison, 1986). The volcanic rock is pale grey lapilli-ash crystal tuff of the Middle Jurassic Yim Tim Tsai Formation. The volcanic rock is underlain by sedimentary breccia that consists of angular clasts of siltstones and sandstones. The breccia layer is about 5 m thick and rests conformably on the Tolo Channel Formation on Ma Shi Chau (Allen & Stephens, 1971).

5.3 Double Haven

Double Haven is a tranquil harbour in the northeast New Territories enclosed by Crooked Island, Crescent Island and Double Island. The area is underlain by Middle Jurassic and Early Cretaceous volcanic rocks (Tai Mo Shan Formation and Ngo Mei Chau Formation) and reddish brown Cretaceous sedimentary rocks (Pat Sin Leng Formation) (Lai et al, 1996). The indented coastline suggests a drowned landscape, inundated by rising sea levels following the last glacial period.

Many picturesque islands are scattered throughout Double Haven. For example, Chap Mo Chau, which looks from a distance like a hat floating in the sea. The island

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consists of a wide wave cut platform encircling a residual mass of rock that forms a sea stack (Plate 9) (GEO, 1997).

Tung Wan, or Governor's Beach, is a crescent-shaped sandy beach on Double Island (Plate 10). A lagoon has formed within the narrow river valley behind the beach bar, which is now partly filled with fine sediment to create a flat marshy area. During periods of heavy rainfall, the marsh floods to create a lagoon.

The island of Ap Chau (Robinson Island) consists of reddish breccia and sandstone belonging to the Early to Late Cretaceous Kat O Formation (Lai et al, 1996). Faint sedimentary layering, which dips gently to the northeast and northwest, can be observed in these rocks. Viewed from a distance, Ap Chau looks like a giant duck drinking water from the sea. The feature is a natural arch formed by the differential erosional action of waves on relatively weak zones (Plate 11) (GEO, 1997). The minimum thickness of the Kat O Formation is estimated to be 100 m (Lai et al, 1996).

The geology of Crooked Island (Kat O Chau) is dominated by Mesozoic volcanic rocks (Lai et al, 1996). They comprise coarse ash crystal tuff of the Middle Jurassic Tai Mo Shan Formation, and eutaxitic fine ash tuff and lapilli tuff of the Lower Cretaceous Ngo Mei Chau Formation. At the eastern end of Crooked Island, a distinctive notch occurs in the ridgeline (Plate 12). This notch is formed by preferential erosion of the weathered rocks along a fault. Caves formed by wave action exploiting local joints and faults in the rocks are also present along the base of sea cliffs.

5.4 Port Island and Bluff Head

On Port Island, grey-coloured early Cretaceous volcanic rocks assigned to the Long Harbour Formation (Lai et al, 1996) are overlain unconformably by reddish brown sedimentary rocks belonging to the Port Island Formation (Ruxton, 1960). The Port Island Formation consists of a succession of thickly bedded conglomerates and pebbly sandstones that dip at approximately 30° to the east and southeast. It is estimated to have a minimum thickness of 1200 m (Lai et al, 1996). The sedimentary rocks are thought to have been laid down in river channels under semi-arid climatic conditions around 100 million years ago (Jones, 1995). The distinctive reddish colour of the rocks gives the island its Chinese name, meaning “Red Island”. The reddish sedimentary rocks are typically thickly-bedded and dip at about 30° to the east and southeast. This gives the island an asymmetrical appearance (Plate 13).

Cross-bedding, created by fluvial deposition, can be seen in many sandstone layers on Port Island (Plate 14). Individual cross-bedding sets vary from 0.3 to 3 m thick. Differential weathering of the graded-beds emphasizes these gently curved structures. The orientation of these structures show that the streams probably flowed towards the east-southeast at the time the sediments were deposited (Jones, 1995).

A number of faults cut across the rocks on Port Island. In Plate 15, a 3-metre vertical offset of the sedimentary layers along a fault can clearly be observed. Faults commonly have a strong geomorphological expression in the area, either because they are partly silicified and therefore more resistant to weathering, or they delineate zones of weak rock, and

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therefore are more easily weathered than the surrounding rocks. A series of eroded sea stacks are present at the northern tip of Port Island (GEO, 1997).

The oldest rocks in Hong Kong are well-exposed at Bluff Head at the mouth of Tolo Channel. They comprise pale grey, fine- to coarse-grained quartzitic sandstone, with subordinate reddish brown and purple sericitic siltstone and greyish white, quartz - pebble conglomerate of the Bluff Head Formation (Ruxton, 1960). A fossil Placoderm found in these rocks (Lee, 1982) indicates that they were deposited during the Devonian period (about 416 to 385 million years ago). The Bluff Head Formation has a minimum thickness of 800 m. The sediments are thought to have originally accumulated in deltaic and alluvial environments (Jones et al, 1997). At Bluff Head, the strata dip subvertically and show evidence of intense folding (Plate 16) as a result of a complex deformation history.

5.5 High Island and Tai Long Wan

Volcanic rocks exposed near the East Dam of the High Island Reservoir are compositionally homogeneous and massive (Plate 17). They are densely welded, high-silica rhyolite tuffs, containing small tabular-shaped alkali feldspar crystals, and some larger broken fragments of quartz and feldspar (Tam & Chan, 1983; Strange et al, 1990). Near the East Dam of the High Island Reservoir, hexagonal columns of volcanic rock are exposed. These columns are from 1 to 2 m in diameter and individual columns may be up to 30 m in height.

Most of the hexagonal columns are slightly inclined. However, at certain locations, the columns have developed mesoscale kink bands (Plate 18). During cooling, local subsidence of the caldera floor is thought to have caused the ash layer to deform plastically (Sewell et al, 2000).

Adjacent to the East Dam at High Island Reservoir, a thin mafic dyke has intruded along a kink bank in the welded tuff (Plate 19) (GEO, 1997; Campbell et al, 1999). ^{40}Ar-^{39}Ar laser microprobe dating of this dyke has yielded an integrated age of 105.3 ± 0.5 Ma (Campbell & Sewell, 2005) suggesting that it is of mid-Cretaceous age.

The shoreline of Tai Long Wan in Sai Kung is particularly well-known for its clean sandy beaches. Extensive alluvium has been deposited behind several of the beaches which also feature lagoons (Plate 20). Mong Yue Kok, a prominent headland sandwiched between Ham Tin Wan and Tai Wan beaches, consists of autobrecciated reddish brown lava of the Clear Water Formation (Strange et al, 1990).

5.6 Sharp Island, Kau Sai Chau and Jin Island

Constructive coastal processes dominate the islands in Inner Port Shelter (Sai Kung Hoi), which is sheltered from the destructive waves of the open sea to the south and east (Plate 21). Beaches have built up in the bays and several tomboloes, represented by narrow ridges of sand, connect isolated islands, such as Pak Sha Chau to Siu Tsan Chau, and Ham Lun Kok to Sharp Island. Jin Island, which is underlain by columnar-jointed tuff and exposed to strong wave action, is surrounded by steep cliffs penetrated by sea caves. In contrast, the sheltered waters surrounding Sharp Island, combined with the relatively weaker

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underlying rocks, have led to the development of beaches and tomboloes.

Volcaniclastic sedimentary rocks are exposed at the northern end of Sharp Island and the nearby Pak Sha Chau and Cham Tau Chau. They include tuffite, breccia, conglomerate, sandstone, siltstone and mudstone (Plate 22) belonging to the Mang Kung Uk Formation (Strange et al, 1990). These sediments have been dated at around 142 million years old (Davis et al, 1997) and probably accumulated in a volcanotectonic depression between major episodes of eruption.

On the northwestern Yim Tin Tsai, purple-coloured autobrecciated rhyolite lava belonging to the Clear Water Bay Formation is exposed (Strange et al, 1990). The lava is overlain by the fine ash tuff of the High Island Formation. Similar rhyolite lava can also be found on Sharp Island, where the lava locally displays flow banding.

At the northern tip of Sharp Island, weathering has penetrated along joints in the granitic rocks that are exposed along the coastal rock platform (Plate 23). Several sets of intersecting joints have been emphasised by weathering processes, either by widening of the joint spaces, bleaching of the joint surfaces, or deposition of iron minerals (GEO, 1997). Weathering is promoted by the periodic wetting and drying of the platform between tides, and by the physical action of crystallising salt.

5.7 The Ninepin Group

The Ninepin Group comprises two major islands and a cluster of smaller islands in southeastern Hong Kong waters lying to the east of the Clear Water Bay Peninsula (Plate 24). They are underlain by hexagonal columnar-jointed fine ash vitric tuff of the High Island Formation (Strange et al, 1990) which formed as a result of a catastrophic eruption about 140 million years ago (Davis et al, 1997). The width of the columns is up to 2 m on the Ninepin Group (Plate 25).

Weathering and erosion have led to the collapse and toppling of some columns. Examples can be seen on North Ninepin Island, where some toppled columns are now overhanging and extend out almost horizontally (Plate 26). The Cannon Rock is one of these toppled hexagonal columns found on North Ninepin Island. In some places, inclined fracture planes (stress relief joints) have developed in the rocks. The upper sections of columns have collapsed along these planes and created some intriguing polygonal facets that tilt towards the sea.

Vertical cliffs along the coast of North Ninepin Island are the product of preferential erosion along weaker zones in the rocks. All the landforms in this area show a strong structural control, dominated by the pronounced vertical jointing. This leads to individual column slumping which is the dominant mode of slope failure affecting the High Island Formation (Campbell et al, 1999). Sea arches and stacks have developed as a result of continuous attack by strong waves along this exposed coastline. Big Stove Arch is an example of sea arch developed at the northern tip of North Ninepin Island.

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Coastal erosion has resulted in a number of sea caves on South Ninepin Island. They are the famous Jacob's Ladder Cave, Backwash Cave, Y-shaped Cave and Cat's Eye Cave.

5.8 Wan Chau, Basalt Island and Bluff Island

Columnar-jointed rhyolitic tuffs are exposed along the coastline of the many islands in the Rocky Harbour area. These columns form very steep or vertical cliffs that rise abruptly out of the sea (Plate 27). Cliff recession occurs by the undercutting, leading to rock slumping and translational failure of individual columns or sections of a column (Campbell et al, 1999). This mechanism gives the cliffs a distinctive striated appearance.

The shape of Town Island (Fu Tau Fau Chau) shows the strong influence of structural control on the landscape. Wave erosion along weak zones in the rocks (such as faults) has resulted in the collapse of sections of columns and the formation of sea caves (Plate 28) (GEO, 1997). In some places, sea caves have developed from opposite sides of a headland. Over time, the opposing caves merged to create a sea arch through the promontory.

The English name of Basalt Island probably arose because the distinctive hexagonal columns were mistakenly assumed to be formed in a basalt lava flow, which is more commonly associated with basalt traps elsewhere in the world. However, columnar joints can develop in rocks formed from magma of any composition, and can occur in intrusive as well as extrusive rocks, and more rarely in tuffaceous rocks.

6. LOCAL, REGIONAL, INTERNATIONAL SIGNIFICANCE OF THE EIGHT SITES

6.1 Ping Chau (Tung Ping Chau)

Rock sequences on the island of Ping Chau (Tung Ping Chau) preserve an outstanding array of sedimentary structures, including fossil raindrop impressions and muds cracks, and contain a very important assemblage of fossils, including the only known insect fossils in Hong Kong. This is one of the best-preserved Cenozoic lacustrine sequences along the south China coast. The sedimentary rocks form tilted, thinly bedded layers that create a fascinating landscape. Owing to its ease of access, the island is an important location for field studies by students from schools, colleges and universities. Ping Chau (Tung Ping Chau) is one of the designated Marine Parks in Hong Kong.

6.2 Tolo Channel, Lai Chi Chong and Ma Shi Chau

The Tolo Channel includes outcrops of the oldest sedimentary rocks in Hong Kong (Devonian Bluff Head Formation) as well as the site of Hong Kong's first ammonite fossil discovery (Hongkongites hongkongensis) from the Early Jurassic (Lee, 1982). The area is of special importance in the study of Hong Kong's early geological history. It contains superb exposures of strongly folded and faulted sedimentary rocks which provide excellent examples for educational and scientific purposes.

The Lai Chi Chong site reveals a spectacular coastal section through fossil-bearing lake deposits which are thought to have accumulated in a volcano-tectonic depression during

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the Late Jurassic. The variety of sedimentary structures preserved, including spectacular slump folds, make this an exceptional area for field studies by students of schools, colleges and universities. The site is of special importance for the study of Hong Kong's geological history and has been the subject of several key scientific papers over the years.

The sedimentary rocks on the south coast of Ma Shi Chau are rich in fossils, and include a variety of well-preserved geological features that are of special geological interest for studies of stratigraphy, palaeontology, and geomorphology. The site has been the focus of several detailed scientific studies. The island of Ma Shi Chau and Yim Tin Shai Peninsula have been designated as the "Ma Shi Chau Special Area" under the Country Park Ordinance for the presence of various special geological features.

6.3 Double Haven

The harbour of Double Haven hosts an impressive array of geomorphological features that have been featured in many books on the natural beauty of Hong Kong. It is one of the designated Marine Parks in Hong Kong. In addition to preserving a spectacular example of a drowned coastline, the Cretaceous red-bed sequences add colour and vitality to the range of impressive landforms including sea stacks, wave cut platforms, sombrero-shaped islands, beach bars and lagoons. The tranquil waters of Double Haven have become a refuge for Hong Kong's last remaining fishing villages, and is a favourite location for recreational activities and water sports. Double Haven also hosts Hong Kong's sole outward-bound educational centre.

6.4 Port Island and Bluff Head

The rocks on Port Island are of high scientific value because they preserve a spectacular example of a river floodplain succession laid down under desert conditions. The tilted layers of red sandstone, mudstone and conglomerate are similar to rocks in neighbouring Guangdong Province that have yielded dinosaur egg fossils.

The intensely folded Devonian sequence at Bluff Head exposes a detailed cross-section through Hong Kong's oldest sedimentary rocks. This site is popular for scientific and educational activities among schools, colleges and universities because of its high degree of preservation and impressive landform development. The Devonian Bluff Head Formation records a variety of sedimentary structures indicating aeolian, fluvial and deltaic depositional environments (Jones et al, 1997).

6.5 High Island and Tai Long Wan

The magnificent columnar-jointed landforms exposed near the East Dam of the High Island Reservoir are of international scientific interest because they preserve an excellent example of rheomorphic ignimbrites. These rocks were the product of extremely violent volcanic ash eruption, possibly of the order of hundreds of cubic kilometres. The eruption that was so hot and intense that the juvenile ash particles welded together obliterating almost all evidence of their pyroclastic origin. Subsequent post-depositional hydrothermal

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alteration processes led to growth of new crystals. Kink-bands in the columns at the East Dam indicate that the volcanic pile was tectonically disturbed prior to complete solidification. The site is the only one in Hong Kong where the columns are accessible by road. Therefore, High Island East Dam has become very popular for educational studies by schools, colleges, and universities.

The natural sandy beaches of Sai Wan, Ham Ting Wan, Tai Wan and Tung Wan along the shore of Tai Long Wan in the Sai Kung Peninsula preserve excellent examples of constructional coastal landforms. These beaches, with associated lagoons, have been constructed in a series of stages through a combination of wave, current, and storm activities. The natural setting and relative remoteness of the beaches have made them popular for scientific and educational activities.

6.6 Sharp Island, Kau Sai Chau and Jin Island

A variety of landforms characterize the islands of Inner Port Shelter that are largely protected from the destructive waves of the open sea. The presence of tomboloes, coastal rock platforms, and sandy beaches together produce a stunningly picturesque coastline, which is enjoyed as a recreational haven by generations of Hong Kong people. While the geology of Kau Sai Chau and Jin Island is dominated by columnar jointed rhyolitic tuff, the northern and eastern coastlines of Sharp Island are underlain by variable rock types, including volcaniclastic sedimentary rocks and igneous intrusions.

Of particular scientific interest on the northern end of Sharp Island, and nearby Pak Sha Chau and Cham Tau Chau, is the range of sedimentary structures present in the volcaniclastic rocks. These are indicative of lacustrine sedimentation in a volcano-tectonic depression. Local intrusions of quartz monzonite indicate close proximity to a vent complex. Brecciated rhyolite lava exposed on Yim Tin Tsai and Sharp Island immediately underlying fine ash tuff of the High Island Formation may represent basal breccias associated with caldera collapse.

6.7 The Ninepin Group

The Ninepin Group of islands hosts the most spectacular examples of columnar-jointed rhyolitic tuff landforms in Hong Kong. In addition to preserving all the features of rheomorphic ignimbrites from the other Sai Kung sites, the most impressive aspect of the Ninepins site is the sheer size of the columns, which are up to 2 m in diameter. Such large-scale development of columnar joints in pyroclastic rocks is extremely rare in the geological record; therefore, the Ninepins site is of international scientific interest. In addition, the columns show evidence for toppling and rotation which reveal opportunities to study the kinematics of natural rock failures. Other geomorphological features on the Ninepin Islands provide excellent examples of coastal landforms resulting from destructional processes.

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6.8 Wan Chau, Basalt Island and Bluff Island

The eastern coasts of Basalt Island and Bluff Island exhibit impressive examples of retreating coastal landforms. The undercutting and collapse of the columns gives fascinating insight into the mechanisms of rock cliff failures in strongly jointed rocks. These landforms also provide rare opportunities to study in detail the development of sea arches and stacks along a high energy coastline.

As well as being scenically eye-catching, the coastline of Wan Chau provides opportunities to study the effects of intersecting tectonic and columnar joints on controlling the resulting landforms. In addition, soil profiles on the columnar-jointed landforms are unusually thin, despite ample evidence for chemical weathering of the rocks. Given the rarity of the scale of landform development, such features are of international scientific interest.

7. CONCLUSION

The proposed Hong Kong Geopark encompasses two regions of outstanding natural beauty in southeastern China, which feature eight sites of special geological and geomorphological significance. From the spectacular columns of rhyolitic tuff forming the rugged coastline of the outer islands, to the tranquil beaches and island waters of Double Haven, the Sai Kung and Northeast New Territories regions offer limitless opportunities for educational studies, cultural appreciation and recreational enjoyment. The size and preservation of the rhyolitic tuff columns, variety of red-bed sequences, and diverse fossil assemblages, make the region scientifically noteworthy from regional and international perspectives. The magnificent grandeur of the landscape and unparalleled beauty of the rocks, formed from a combination of tumultuous volcanic eruptions, sedimentation, and incessant geomorphological processes, make Hong Kong a worthy contender for Geopark status.

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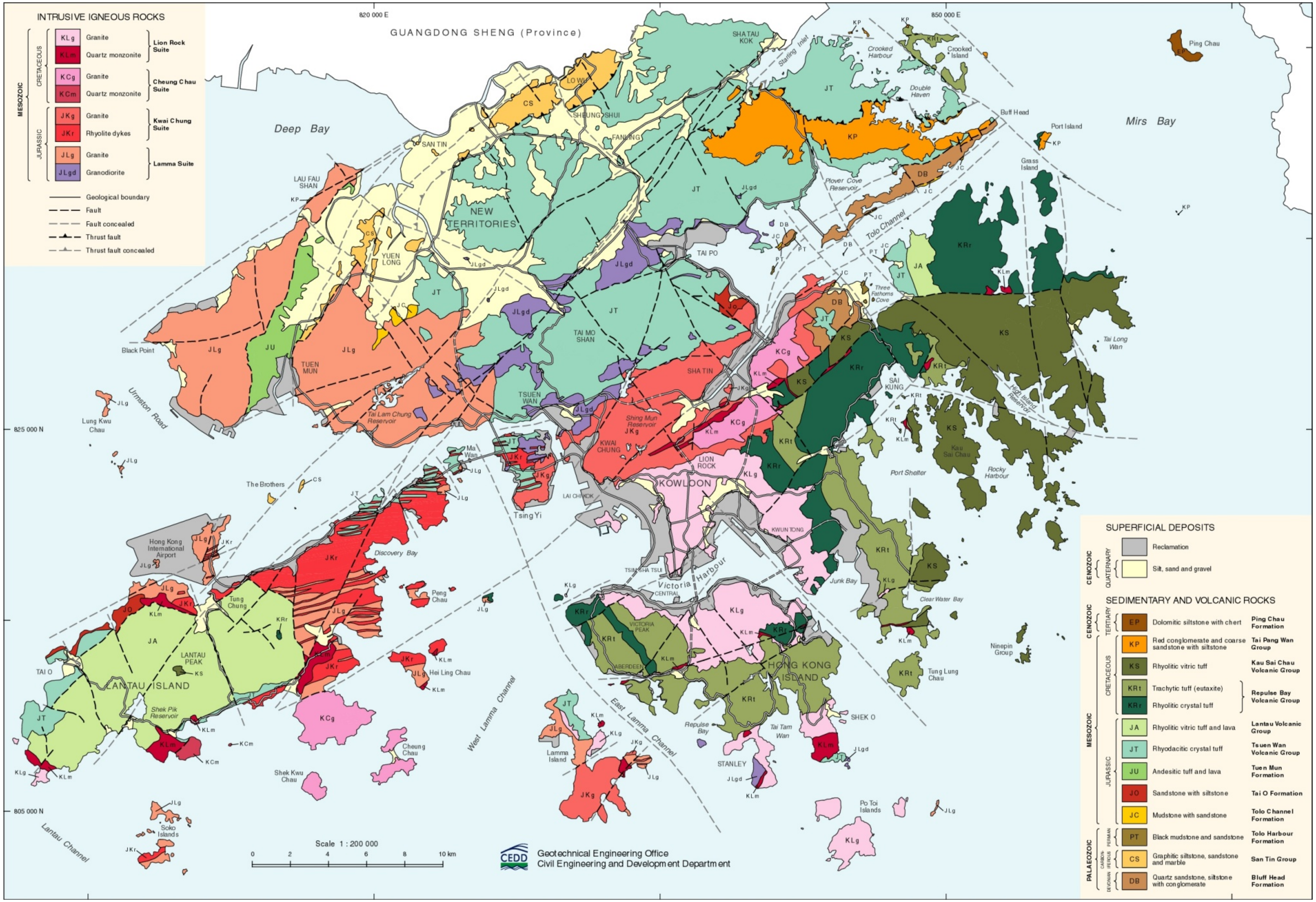

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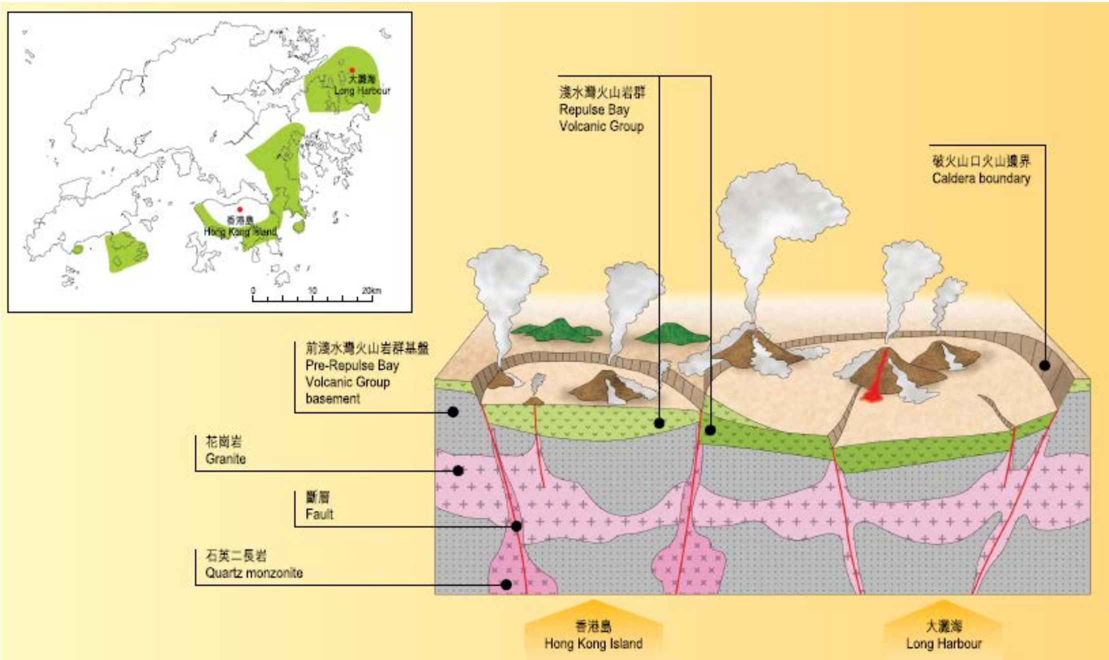
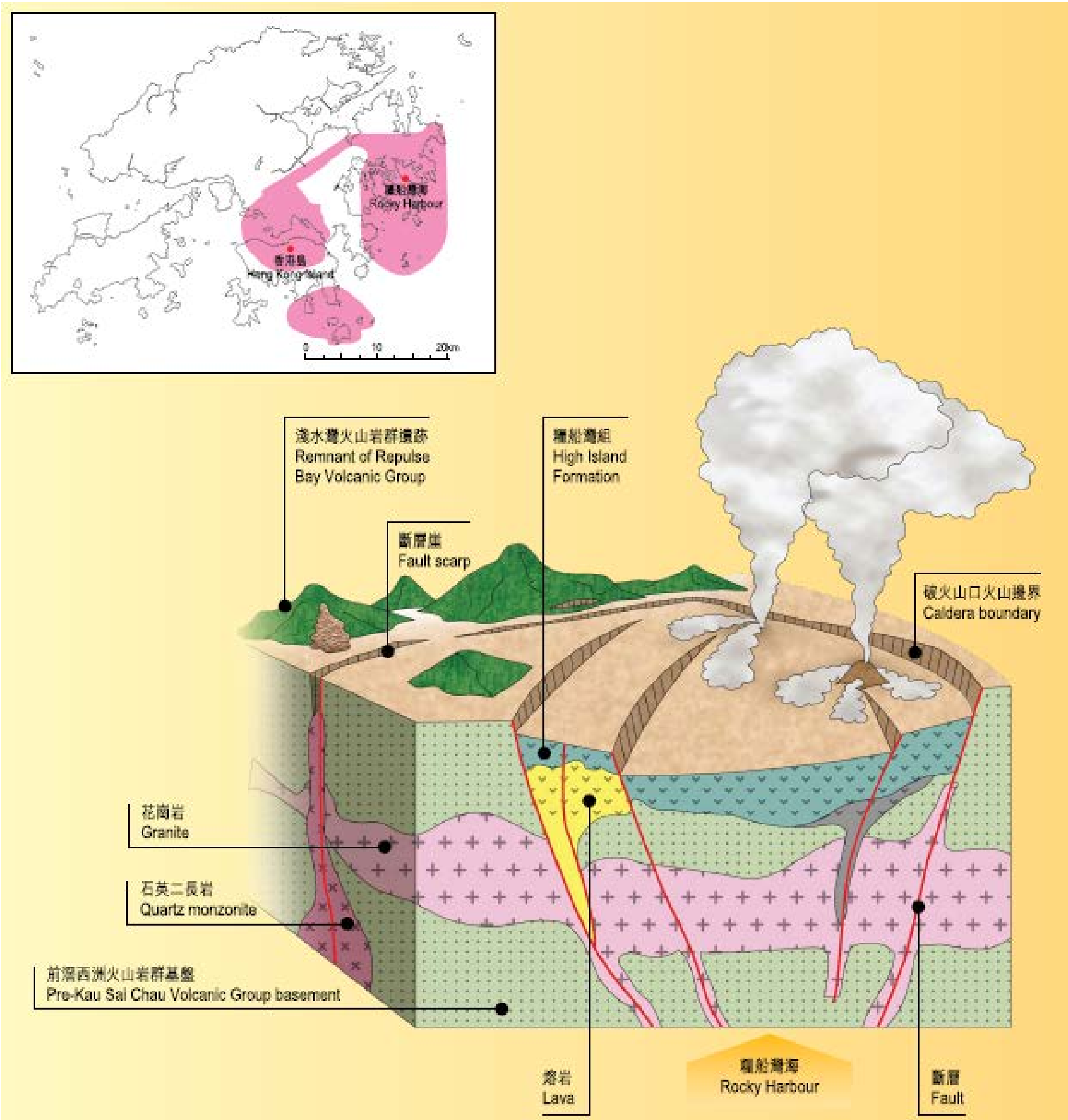


Figure 2 - Schematic Representation of Caldera Development and Related Subvolcanic Intrusions between 143 and 142 Million Years Ago. Insert Map Indicates the Distribution of Igneous Rocks in Hong Kong Associated with this Voclanic Episode. (After GEO, 2009)



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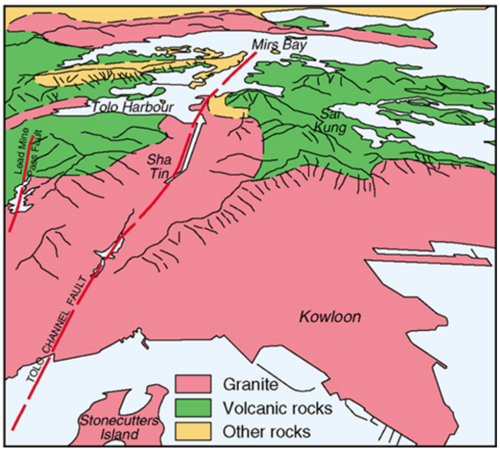

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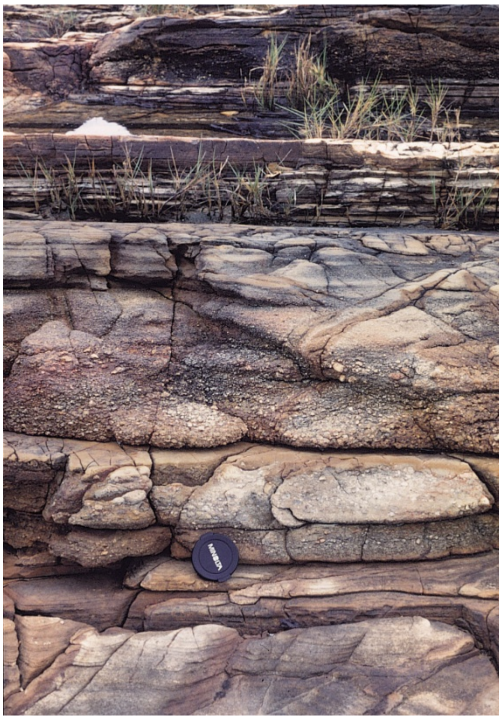

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GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 302 p. (English Version), (Reprinted, 2011).

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Highway Slope Manual (2000), 114 p.

GEOGUIDES

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Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
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Geoguide 7	Guide to Soil Nail Design and Construction (2008), 97 p.

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GEO Publication No. 1/2011	Technical Guidelines on Landscape Treatment for Slopes (2011), 217 p.

GEOLOGICAL PUBLICATIONS

The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

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