Geology of Site Investigation Boreholes from Hong Kong

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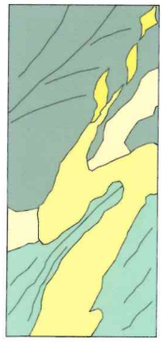
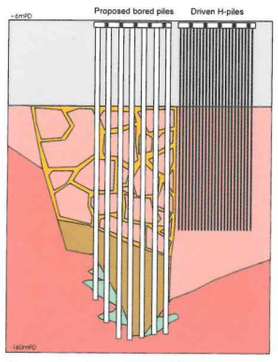
The book includes chapters on the main rock types, tectonic structures, superficial deposits and weathering features, which have been found in Hong Kong. The chapters are introduced by sections on the distribution, composition, geological setting, and characteristics of the various phenomena. The sections on characteristics provide lists of the main diagnostic features, and highlight their importance in the development of geological models and their possible engineering significance.

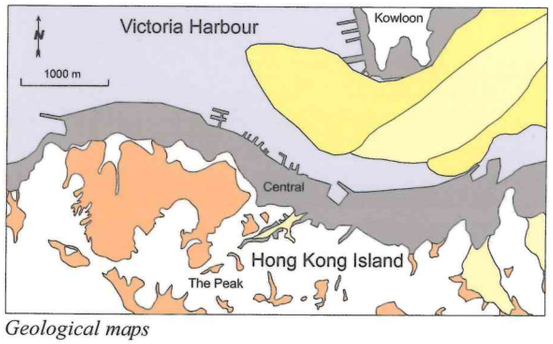
The book contains over 400 plates and 50 colour figures. It will be of interest to geologists, engineering geologists and geotechnical engineers involved with urban development.



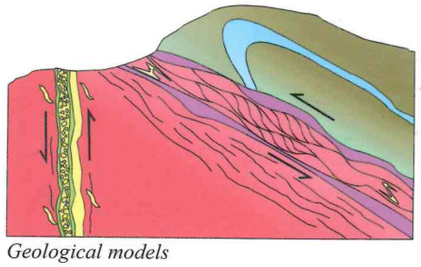
Core sketches



Engineering examples



Geological maps



Geological models

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Geology of Site Investigation Boreholes from Hong Kong

Chris J N Fletcher

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Chris J. N. Fletcher

Geology of Site Investigation Boreholes from Hong Kong

With over 400 plates and 50 colour figures

Front Cover

Photographs of core and mazier samples from site investigation boreholes in Hong Kong.
Left to right: laminated cavity-fill deposit (mazier sample, Plate 16.20); medium- and fine-grained granite (rock core sample, Plate 3.9); weathered volcanic rock (rock core sample, Plate 14.55); quartz vein in completely decomposed granodiorite (mazier sample, Plate 14.26); solution cavities in marble-bearing sedimentary breccia (rock core sample, Plate 14.66); thinly bedded, impure marble cross-cut by brittle faults (rock core sample, Plate 10.7)

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Chris J. N. Fletcher, Ph.D., M.Sc., C.Eng., FGS, MIMMM

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Preface

The concept for this book was conceived from discussions with the presenters and participants at a series of corelogging courses organized for practising geologists and engineers by the Applied Geoscience Centre (Hong Kong University) and the Institution of Materials, Minerals and Mining (Hong Kong Branch). It is was apparent that, in general, most logging geologists provided systematic descriptions of borehole samples, including rock type, weathering grade, and joint characteristics, but gave less consideration to other geological features that could be important in the formulation of geological models, or have possible engineering significance. Most of the engineers, on the other hand, focused primarily on very few items in the borehole log, most commonly the Standard Penetration Test (SPT) values and the rockhead levels, as they were uncertain of the relevance of geology to their speciality. From my geological consultant work on a variety of development and infrastructure projects in Hong Kong, I have found that much more information can be gained from boreholes, and that this information has geological, engineering and cost implications. I am hopeful that this book will provide a bridge and a greater understanding between the two professions, thereby enhancing our overall site investigation practice. Hong Kong must have one of the greatest densities of site investigation boreholes in the world, it is imperative that we study, describe and interpret them to our advantage.

The reader of this book should be aware that, unless stated otherwise, all the photographs in this book are of rock core. Other photographs from site investigations depict soil (decomposed rock and superficial deposits) recovered from split mazier tubes, SPT liners and other sampling equipment. Note that the edges of the rock core samples will appear distorted on the photographs, due to the curvature of the core surface, whereas the surfaces of split soil samples are approximately flat and therefore their photographs show little distortion. However, some disturbance of the margins to the soil samples may be present due to the sampling procedures.

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Hong Kong
May 2004

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Acknowledgements

This book could not have been written without the considerable assistance from professional societies, private companies, Government departments, academic institutions, and many individual geologists and engineers. I am particularly indebted to the Association of Geotechnical and Geoenvironmental Specialists (Hong Kong), the Hong Kong Construction Association (Site Investigation Contractors Committee) , Applied Geoscience Centre (The University of Hong Kong) and the Department of Building & Construction, City University of Hong Kong under whose auspices the book has been published. Additional financial support for the production of the book has been given by Fong On Geotechnics Ltd, Bauer (Hong Kong) Ltd, and Electronics & Geophysical Services Ltd through donations to the Applied Geoscience Centre.

Access to site investigation material and permission to use photographs of borehole samples and the results of engineering and geological investigations have been given by several departments and authorities of the Government of the Hong Kong Special Administrative Region, in particular: Architectural Services Department, Civil Engineering Department, Drainage Service Department, Highways Department, Housing Department, and the Airport Authority Hong Kong. The Hong Kong Geological Survey (Geotechnical Engineering Office) has given permission to use extracts from their published geological maps and memoirs, and allowed photographs to be taken of selected rock core from their collection. Many private companies in Hong Kong have contributed in different ways at all stages in the preparation of this book: allowing access to material, giving their permission to photograph material, using site investigation results, and providing essential assistance and advice. They include: Atkins China, Bachy Soletanche Group, Bauer (Hong Kong), Benaim, Fong On Geotechnics, Driltech Ground Engineering, Fugro (Hong Kong), Geotechnical Consulting Group, Geotechnical and Concrete Engineering Company, Halcrow China, Kowloon-Canton Railway Corporation, Lam Geotechnics, Maunsell Geotechnical Services, Maeda-Chun Wo Joint Venture, MTR Corporation, Newfoundworld, Ove Arup (Asia), Tysan Foundation and Vibro (HK). The help and assistance provided by all these organizations have been paramount in the completion of this book. To all of the above, other companies and individuals that have encouraged and assisted me, I express my sincere gratitude and thanks. However, it should be noted that the views expressed in this book are my own, and do not necessarily reflect those of the organizations from which the materials and information were obtained.

I would also like to highlight the contributions of several individuals to the book.Greg Pinches, Steve Parry, Patrick Cox and Mark Hatley presented, with myself, the course on corelogging that was organised by the Applied Geoscience Centre and the Institution of Materials, Minerals and Mining (Hong Kong Branch). These courses were the catalyst for the writing of the book, and discussions with the presenters and many of the participants provided the essential basis for the content and focus of the book. Diarmad Campbell and Jack Mulgrew provided rigorous scientific comment and editorial suggestions on drafts of the book, and their input has greatly enhanced the quality, clarity and accuracy of the final version. Additional comments were also provided by Sam Ng, Marie Tsang and Rod Sewell. Finally, the support and advice of the committee members of the Association of Geotechnical and Geoenvironmental Specialists (Hong Kong) and the Site Investigation Contractors Committee, particularly Mike Lacy, C. K. Lau, and Jeff James, are gratefully acknowledged.

The Airport Authority Hong Kong gave permission to use the photograph of the Hong Kong International Airport during its construction (Plate 15.2). Two landscape photographs (Plates 1.1 and 16.1), and the Shum Wan Road landslide (Plate 5.11) are published with the permission of the Civil Engineering Department and the Apple Daily newspaper respectively. Two photographs of marine deposits (Plates 15.6, 15.7) are taken from the Memoir on the Quaternary Geology of Hong Kong (Fyfe *et al.*, 2000). Additional photographs were provided by Calvin Tsang (Plates 10.1, 12.2,12.3), Steve Parry (5.12, 5.13, 15.15, 15.16), Patrick Cox (Plate 10. 11) and Terry Tang (Plate 15.18). Several new photographs have been included in the second edition. Sean Soo gave assistance in the drafting of the figures.

Finally, I dedicate this book to Helen, my wife, who has shared my geological journeys throughout the world. She has inspired me with her own vision of achievement, always provided me with sound advice and has given me constant encouragement.

Contents

1 Introduction

Plate 1.1 General view of the development on the northern side of Hong Kong Island. The cliffs of volcanic rock dominate the high ground, whereas the lower areas and the harbour are underlain by granite

This book covers the geological description, understanding and interpretation of borehole samples, which have been recovered during site investigations for urban infrastructure and development projects in Hong Kong. Comprehensive suites of rock and soil photographs are presented in the context of their general geological settings, which are illustrated by geological maps and idealised geological models. Examples of actual geological models at recent project sites are also presented, in order to highlight the importance of particular geological features. Although all the photographs and geological models in this book are taken from Hong Kong, they are very similar and relevant to many geological and engineering settings in other parts of Asia and elsewhere, particularly where comparable faulted rock assemblages have been exposed to tropical weathering conditions (Plate 1.1).

The book includes chapters on the main rock types, tectonic structures, superficial deposits and weathering features, which have been found in Hong Kong. The chapters are introduced by sections on the distribution, composition, geological setting, and characteristics of the various phenomena. The sections on characteristics provide lists of the main diagnostic features, and highlight their importance in the development of geological models and their possible engineering significance. It is stressed that not all features will be present in every sample, nor will each feature be relevant for every geological model and engineering situation. They are listed so that their relevance can be assessed in each specific ground investigation. In addition, descriptions and diagrams of actual ground conditions encountered in some recent site investigations (Plate 1.2) are presented, including: a landslide, a cut-slope, building and bridge foundations, an airport reclamation, and a tunnel. These examples provide the essential link between what is observed in boreholes, the geological setting and the engineering ground conditions. The introductory sections are followed by representative photographs of borehole samples. Throughout this book the terms rock and soil are used in the engineering, rather than geological, sense. Thus, rock is defined as any solid, naturally occurring earth material that cannot be broken by hand, whereas soil includes all altered rocks and superficial deposits, including fill, that can be broken into their component grains by hand.

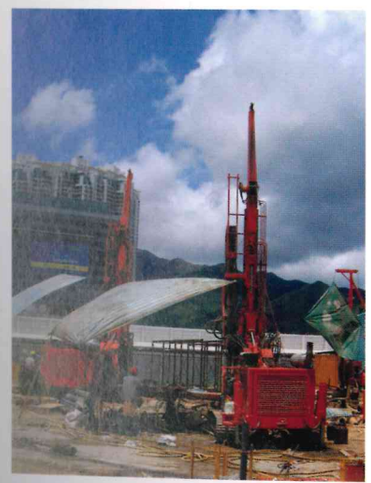


Plate 1.2. Drilling rigs at a development site on a reclamation close to the new international airport, Lantau Island

Geological features observed in borehole samples provide critical information for the development of geological models, assist in the prediction of ground conditions and may be important for engineering design. Logging and engineering geologists should be able to recognise, describe and understand the geological features covered in this book, and should be able to assess their importance in engineering terms. The engineer, on the other hand, should be aware of the main geological situations that might arise in any particular site investigation and have a basic understanding of the critical geological phenomena that contribute to the generation of the geological models. Several geological features that are described in drillhole logs may not be important or particularly relevant for engineering analysis, but could be highly significant for the engineering geologist, who is responsible for the geological model.

Although this book will be a valuable reference for corelogging geologists, it does not attempt to cover all the requirements of that specialty. Readers are referred to the standard site investigation and corelogging references for a full coverage of these disciplines; for example - Guide to Rock and Soil Descriptions (Geotechnical Engineering Office, 1994), Guide to Site Investigation (Geotechnical Control Office, 1987a) and Code of Practice for Site Investigations (British Standards Institution, 1999).

In order to gain maximum benefit from site investigations, it should be remembered that the logging of borehole samples should fulfill three main objectives:

- Classify and interpret the material
- Provide a factual record
- Highlight features of engineering and geological importance

However, it is emphasised that the logging of boreholes must be undertaken in collaboration with the geological modeller and the engineer. In addition, the borehole logs should be studied in the context of the regional geological setting of the site under investigation. This is ascertained through the study of available geological maps and memoirs, synthesis of relevant site investigation data from previous site investigations, and walkover surveys. Boreholes must not be taken as two-dimensional, isolated data sets, but should be considered within the framework of the total ground condition.

The information contained within this book will provide practical guidance to both the geologist and engineer, and will encourage dialogue and understanding between these two professions. Such cooperation will inevitably lead to cost and time savings in projects, through more efficient and targeted ground investigations, reducing the potential for unforeseen ground conditions, and the recognition at an early stage in the project of significant adverse geological features that could affect engineering design.

In conclusion, this book will help the geologist to provide the project engineers with the following essential data:

- A geological model with a statement of its reliability in the regional context
- Geological maps of the *in situ* bedrock materials
- Representative geological cross-sections to illustrate the nature and structure of the rocks, and the distribution of the superficial deposits
- Geological descriptions of all rock units and tectonic structures
- The three-dimensional distribution of the weathered rocks, including a rockhead contour map, and an analysis of the controls on the weathering
- An assessment of the possible engineering problems that could result from the geological model, and identification of high risk areas
- An evaluation of the distribution of the low risk ground
- Recommendations for geological targets for further drilling

The book will also enable the engineer to have a better understanding of the materials recovered from site investigation boreholes and to be aware of the following:

- Importance of a well-documented and researched geological model and its limitations
- Possible three-dimensional make up and distribution of a variety of rock units and superficial deposits
- Composition and continuity of materials and tectonic structures in faulted ground
- Controls on the distribution of weathering grades
- Location, size and nature of any potential adverse geological features
- Limitations on weathering grade systems to rocks other than granite and volcanic rock
- Interpretation of 'no recovery' zones, including possible cavities in calcareous rocks

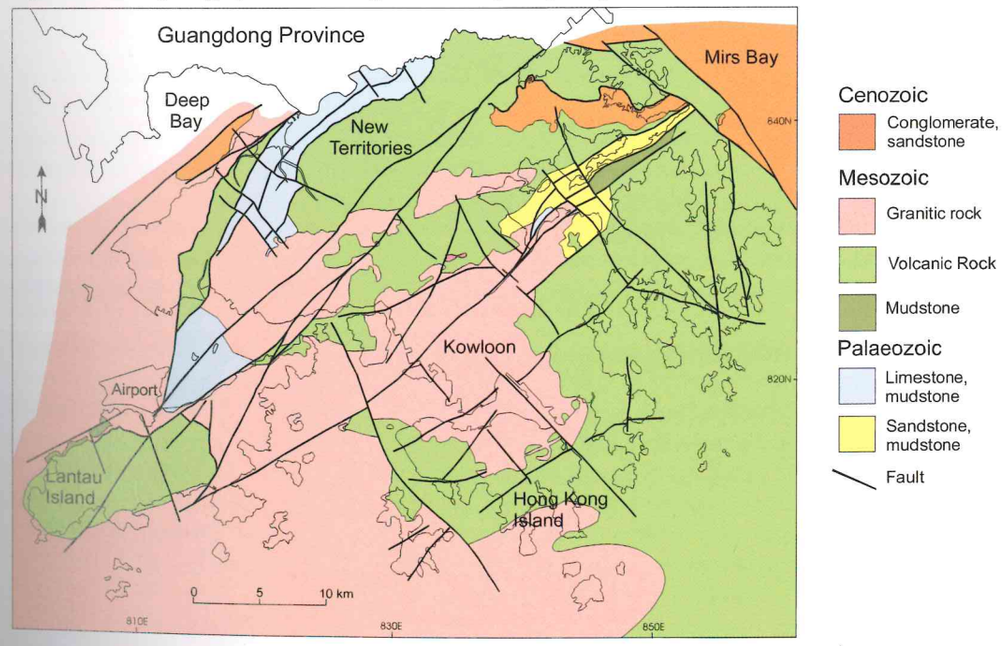
2 Geology of Hong Kong

Comprehensive accounts of the Quaternary and Pre-Quaternary geology of Hong Kong have recently been published by the Hong Kong Geological Survey, Civil Engineering Department (Sewell *et al.*, 2000; Fyfe *et al.*, 2000). These memoirs provide descriptions of all rock and superficial deposits, weathering phenomena and tectonic structures, together with interpretations of their origin. They are accompanied by a set of 1:20,000-scale geological maps and, in certain key development areas, a series of sheet reports that describe the geology on 1:5,000-scale maps. This chapter presents the essential geological framework within which the various rock types, alteration features, geological structures and superficial deposits, commonly observed in site investigation boreholes, should be referenced.

Plate 2.1 Apartment blocks on a reclamation site at Tung Chung, Lantau Island. The mountains in the background are composed of volcanic rocks. These are faulted against metasedimentary rocks and granite, which underlie the reclamation and offshore areas. Alluvium and marine deposits blanket the seafloor.

The distribution of the major rock types and the location of the main geological structures beneath the superficial deposits in Hong Kong are presented in Figure 2.1. This geological map displays the solid geology of both the onshore and offshore areas, and is mainly based on published maps and the interpretation of magnetic and other marine geophysical surveys undertaken for the Geotechnical Engineering Office (e.g. Sewell *et al.*, 2000, Fletcher *et al.*, 2000a, Sewell & Kirk, 2002). The offshore solid geological map is of particular importance for bridge, tunnel and reclamation engineering projects that are located in offshore areas, as it depicts, not only the distribution of the main rock types but also the main geological fault zones. It is common that rock types change radically from land to the offshore areas, for example at Tung Chung (Plate 2.1, Figure 16.6), since the positions of coastlines are in many places determined by faulted contacts between different rock types.

Figure 2.1 Solid geology of the land and offshore areas of Hong Kong



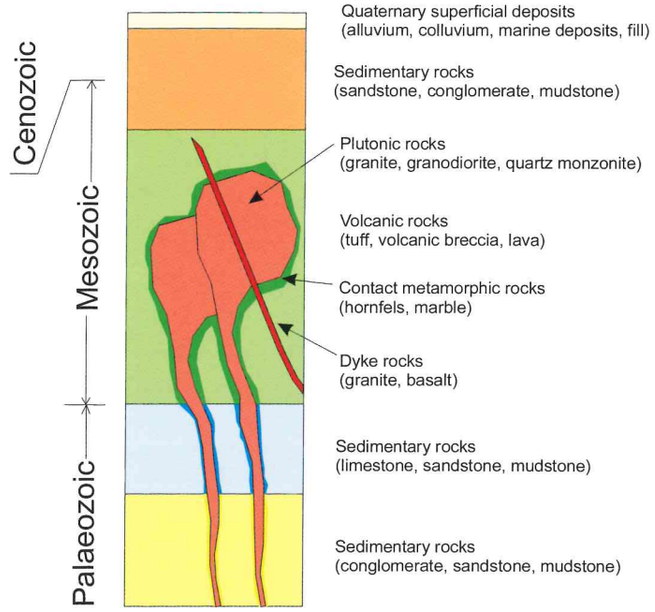


Figure 2.2 Schematic columnar diagram of the main components of the rock and superficial deposits in Hong Kong (not to scale)

Figure 2.2 displays graphically a simplified time column of the three major rock forming events in Hong Kong: an early (Palaeozoic) sedimentary event, a (mid- Mesozoic) volcanic and igneous intrusive event and a late (late Mesozoic to Cenozoic) sedimentary event.

The relative timing of geological events, such as sediment deposition, volcanic eruptions, igneous intrusions and tectonic activity is of critical importance to the development of any geological model, for it allows realistic extrapolations of data from outcrops and boreholes into cross-sections and three-dimensional models to be made. Without such a knowledge-base only straight-line interpretations are possible, which oversimplify and distort the subsurface geology and increase the risk of encountering unforeseen ground conditions.

The early sedimentary event consists essentially of the sequential deposition of sandstone and conglomerate, followed by limestone, which is in turn overlain by mudstone. These sediments were mainly deposited in a marine environment. Because of the later intrusions and faulting these sequences are now mainly restricted to isolated fault slivers in the northeastern New Territories, and a NE- to NNE-trending fault-bounded zone in the western New Territories and offshore north Lantau Island.

The volcanic and igneous intrusive event consists of four largely contemporaneous eruptive and intrusive cycles. Each cycle has been dated and is characterised by distinct chemical compositions of the intrusions and volcanic rocks (Sewell *et al*., 2000, Davies *et al*., 1997; Sewell & Campbell, 1997). Thus, earlier volcanic sequences were intruded by later intrusive igneous plutons. The volcanic rocks, which cover over 50% of Hong Kong's land surface, consist predominantly of tuffs (pyroclastic deposits) with some lavas. Several eruptive centres for the explosive volcanic rocks have been located in Hong Kong. The plutonic igneous intrusions consist predominantly of granite with subordinate granodiorite and quartz monzonite. Over fifteen plutons and small igneous bodies have been mapped in Hong Kong. Dykes are also common and include a wide granitic dyke swarm on Lantau Island and many narrow basalt dykes.

The late sedimentary event post-dates the cessation of the volcanic and associated intrusive activity in the region. The sediments were mainly derived from the erosion of volcanic hills and the debris accumulated in valleys and lakes. The main sedimentary rocks of this event are red conglomerate, sandstone and mudstone, which were deposited under desert and flash flood conditions.

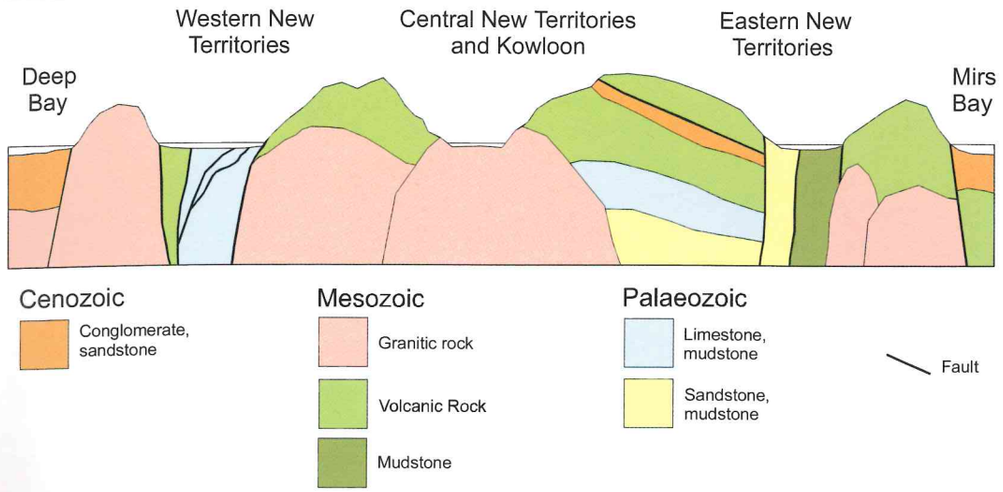


Figure 2.3 Composite, schematic geological cross-section of Hong Kong. The vertical scale of the section is exaggerated.

Hong Kong lies within a major NE-trending fault zone that stretches along the eastern seaboard of China. This fault zone has been active throughout the Mesozoic and possibly earlier, and therefore the rocks of Hong Kong are transected by numerous faults. Movement along this major fault zone has generated numerous steeply dipping NE- to NNE-and NW trending faults, which display both lateral and vertical displacements. Low-angled thrust faults have also affected the sedimentary and volcanic sequences in places. All rocks are jointed.

A schematic geological cross-section of Hong Kong is displayed in Figure 2.3. This composite NW to SE section, which is based on the geological maps published by the Hong Kong Geological Survey (Civil Engineering Department), highlights the relationships between the various rock units and faults.

Cenozoic and recent superficial deposits have accumulated in offshore areas, along valleys and on hillslopes, and are still being deposited today. In offshore areas, they consist predominantly of an older thick sequence of alluvial sands and gravels that is overlain by silts, and a younger layer of marine mud, which forms most of the present day seafloor. Over the land area, the superficial deposits consist of several stages of colluvium deposition, which includes landslide debris, talus and hillwash. In the valleys, alluvium and pond deposits were deposited. Continuing instability of the hillsides due to tropical weathering and heavy rainfall perpetuates the accumulation of landslide debris on and at the base of hillsides today. Tropical weathering of the rocks over many thousands, if not millions, of years through times of much reduced sea levels has resulted in the extremely deep decomposition of the rocks, in places up to 200 metres below present day sea level, and the formation of karst with subterranean cave systems in marble areas.

In conclusion, the geologist should be knowledgeable of the stratigraphic and intrusive framework of Hong Kong, as described in the geological memoirs and sheet reports, in order to formulate comprehensive geological models. However, many of the details contained within these publications are not directly relevant to most engineering projects. Consequently, this introduction to the geological setting of Hong Kong and the descriptions of the various rock types in subsequent chapters do not refer to the nomenclature of the volcanic and sedimentary formations or igneous plutons. Generally, the alteration, weathering characteristics and geological structures of rock and soil masses are more important in engineering projects than the age, slight compositional and mineralogical differences, depositional environments or stratigraphic settings of the igneous or sedimentary rocks.