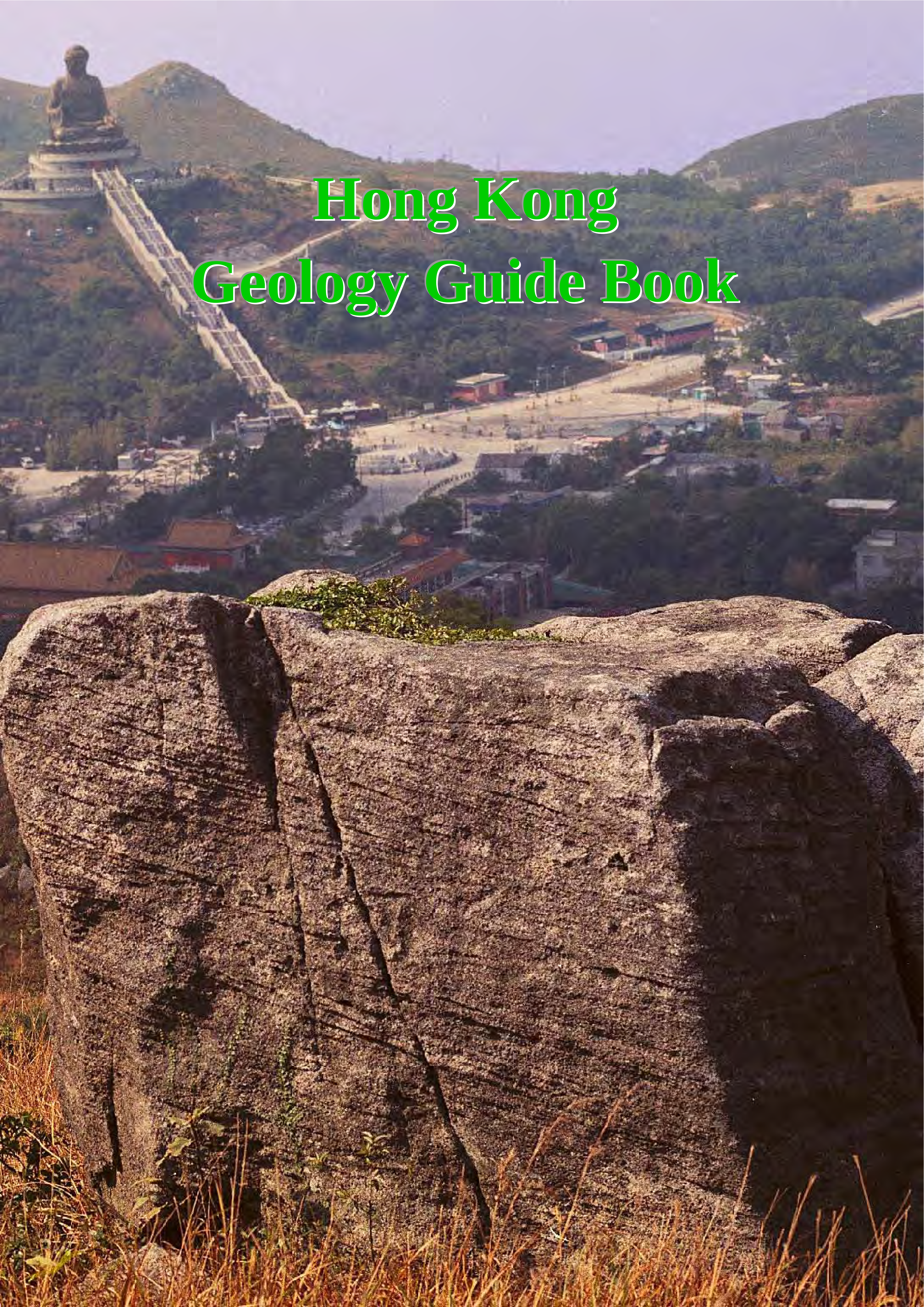
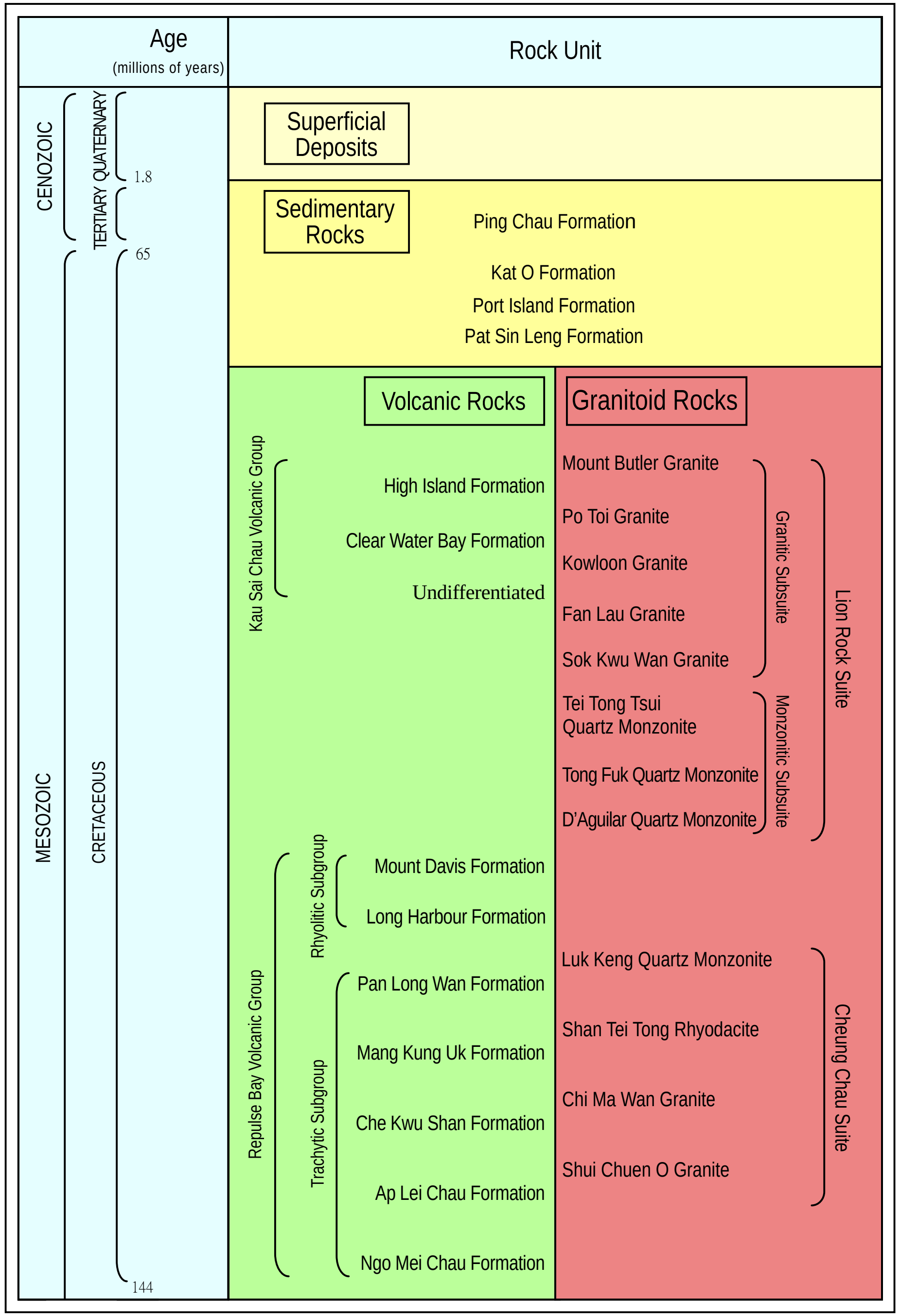
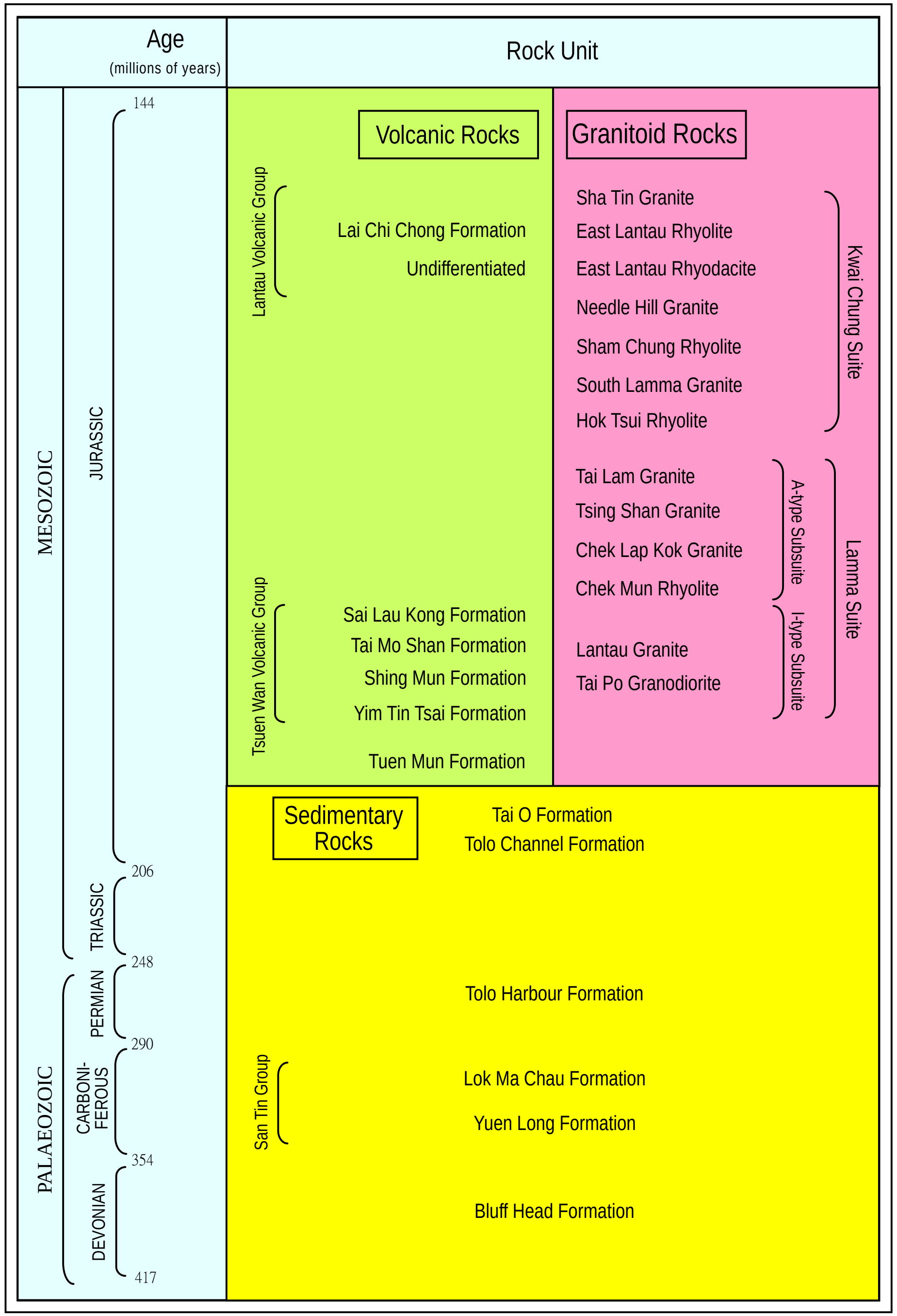
Hong Kong Geology Guide Book



Time Scale of Solid Geology of Hong Kong



Time Scale of Solid Geology of Hong Kong (Continued)



Hong Kong Geology Guide Book

Geotechnical Engineering Office

Civil Engineering and Development Department

First published, June 2007

PREFACE

A wide variety of different rock types has been formed, and geological structures developed, during Hong Kong's long and fascinating geological history. These rocks and structures exert a fundamental control on the shape and characteristics of the diverse natural landscape of Hong Kong. They also strongly influence the pattern and nature of urban development.

Since it was established in 1977, the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department has applied geotechnical engineering methods to address the potential problems posed by landslides on steep terrain. During this time, GEO has acquired considerable geological expertise that has facilitated the application of geotechnical engineering to slope design. In 1982, the Hong Kong Geological Survey (HKGS) was established in GEO to carry out a comprehensive and systematic geological survey of Hong Kong, and to undertake associated geological studies. Over the years, the HKGS has made important advances in understanding the geological framework of Hong Kong, and has provided geological support to engineers to promote the safe urban development of Hong Kong, particularly with regard to the mitigation of landslide risks.

The year 2007 is the 30th Anniversary of the Geotechnical Engineering Office. Over these 30 years, the GEO has developed a comprehensive slope safety system with the objective of reducing landslide risks to low levels. Geological field mapping has provided an important foundation for improving the slope safety system. This "Hong Kong Geology Guide Book" introduces 24 sites in Hong Kong that display features of particular geological interest, features that have been mapped and interpreted by the Hong Kong Geological Survey Section over this period. The majority of these sites are easily accessible, providing safe and convenient venues for field studies. This book provides a useful guide not only for geologists who wish to learn more about Hong Kong geology, but it also provides scientific and geological reference materials for students, hikers and visitors.

The Chinese edition of the "Hong Kong Geology Guide Book" was written by Dr X.C. Li, under the supervision of Dr K.C. Ng of the Planning Division, GEO. Dr Li compiled this book from data held by the HKGS, supplemented by additional field reconnaissance and interpretation. Mr. K.W. Lai of the Geological Society of Hong Kong provided advice on some of the geological sites, and assisted with the field reconnaissance. Dr. G.F. Xing of the Nanjing Geological and Mining Research Institute also participated in some of the field reconnaissance, and provided advice on certain geological features. Technical support was provided by Messrs C.F. Chow, W.K. Ho, P.C. Chan and I.P. Yu of the Engineering Geology Section of Planning Division. Cartographic support was provided by Messrs K.W. Wong and Y.M. Tam. Final review was carried out by Messrs K.W. Lai and C.W. Lee.

(R. K. S. Chan)
Head, Geotechnical Engineering Office
June 2008

This original Chinese language edition was published in June 2007. This English language edition was translated by S.Y. Ho, C.W. Lee, D.L.K. Tang, and J.C.F. Wong, with technical and editorial assistance from R.J. Sewell and R. Shaw.

FOREWORD

Despite having a relatively small land area of only 1100 km^2, the HKSAR has a wide variety of interesting geological features and natural landscapes.

This Hong Kong Geology Guide Book introduces 24 localities that each display interesting geological features. These sites are notable for their importance to studies of the evolution, classification and characterisation of Hong Kong's geology. This field guide is subdivided as follows: Chapters 1 to 7: sedimentary and metamorphosed sedimentary rocks; Chapters 8 to 16: volcanic rocks; Chapters 17 to 20: intrusive rocks; and Chapters 21 to 24 describe weathering, Quaternary alluvial terraces, and an iron ore mine.

Descriptions of the field localities in this guide cover five topics: (1) Introduction: a general description of the regional geological background; (2) How to Get There: location map and directions to the sites; (3) Outline of Geology: geological and related geomorphological features displayed at the sites; (4) Guide to Field Observations: key points of geological interest and a simple guide to observation methods; (5) Comments: elaboration on the geological and geomorphological phenomena, including problems with interpretation. A reference list is provided at the end of each chapter to assist readers who wish to explore the geological topics in greater depth. The language, photographs and figures are presented to facilitate an understanding of basic geological processes.

Geology is a science that requires continuous practice, and a continual improvement in understanding. New observations always lead to a deeper understanding, and to the refinement of earlier conclusions. The purpose of this field guide is to revitalise our understanding of the geology of Hong Kong, and to encourage and facilitate interested individuals to carry out further field observations and research. In this way, it is hoped that the understanding and interpretation of the geological phenomena in Hong Kong can be advanced.

Hong Kong Geology Guide Book

斜坡安全 人人受惠
SLOPE SAFETY FOR ALL

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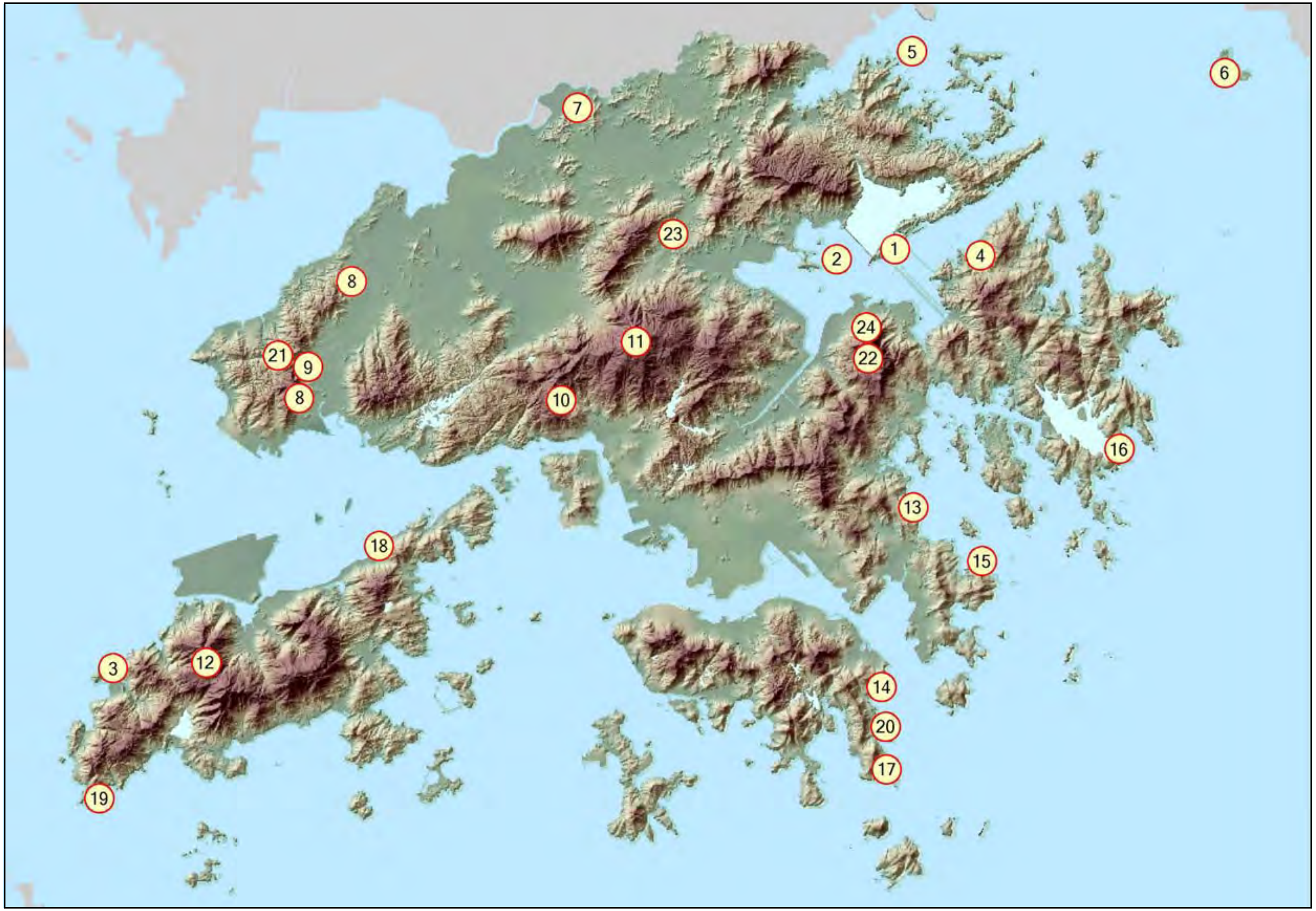


Location of 24 geological localities described in the field guide

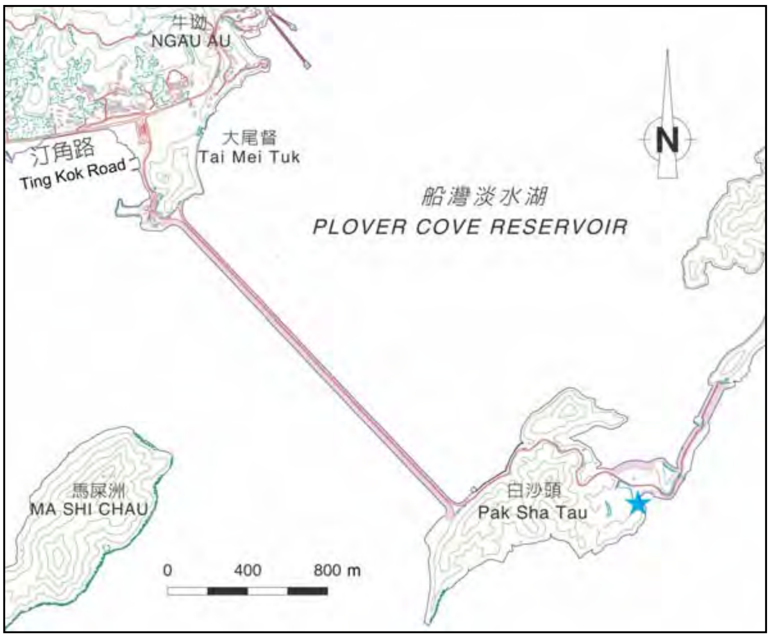
Chapter 1. Oldest Rocks Exposed in Hong Kong – The Bluff Head Formation

Introduction

Devonian sedimentary rocks are the oldest strata exposed in Hong Kong. These rocks, called the Bluff Head Formation, crop out mainly along the coast of Tolo Channel, in particular, along the northern shore from Pak Sha Tau Chau to Bluff Head. The sedimentary rocks include sandstones and siltstones, some of which are fossil-bearing, conglomeratic sandstone and conglomerate.

An impressive exposure of the Bluff Head Formation can be seen at Bluff Head, a headland at the northeastern end of the Tolo Channel. Over the long period since the deposition of these sediments, the rock layers have been tilted by earth movements so that they now stand sub-vertically. The Bluff Head Formation is also well-exposed near Pak Sha Tau Chau at the southwestern tip of the Plover Cove Reservoir.

Sub-vertical Devonian Strata near Bluff Head



Route from Tai Mei Tuk to Pak Sha Tau

<u>How to Get There</u>

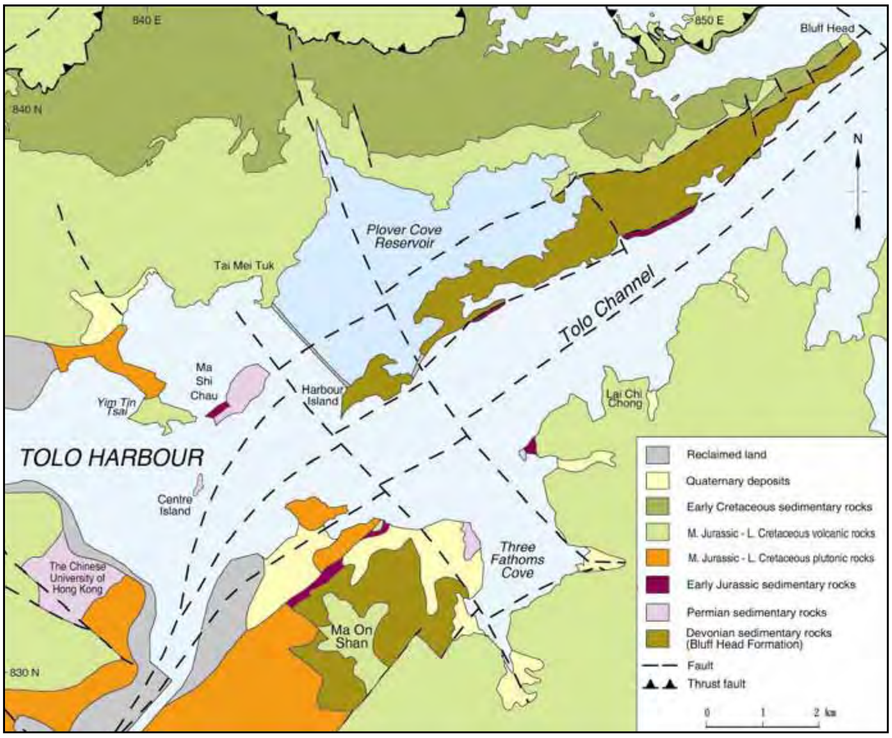
The optimum way to view the Bluff Head Formation is by hiring a boat, and cruising slowly along the northern shoreline of the Tolo Channel to Bluff Head. Depending upon the state of the tide, it is interesting to go ashore and observe the outcrops in detail.

Devonian rock at Pak Sha Tau. Note the almost vertical layers

Pak Sha Tau Chau can be reached by taking bus (No. 75K) from Tai Po Market KCR Station via Ting Kok Road to the Country Park entrance at Tai Mei Tuk, an area that is a popular destination for outdoor leisure activities, such as fishing, cycling and water sports.

“Rock Bridge” formed by weathering of Devonian sandstone

From Tai Mei Tuk, the geological localities at Pak Sha Tau Chau can be reached by walking along the main dam of the Plover Cove Reservoir (see the Route Plan). From the end of the dam, there is a footpath leading to Pak Sha Tau Pier, about 1.2 km away. The Devonian outcrop is visible on the western side of the pier, and can be reached by walking along the coast.



Geological Map of the Tolo Harbour area
(from HKGS 1:100,000-scale Geological Map HGM100)

Outline of the Geology

The Devonian rocks of the Bluff Head Formation crop out on the northern side of the Tolo Channel and on the southern side of Tolo Harbour. Along the northern coast they occur to the south of Plover Cove Reservoir, and along the southern coast they occur in the Ma On Shan area.

Devonian quartzitic conglomerate

The Bluff Head Formation is bounded, to the north and to the south, by faults. The Formation, which is over 800 m thick, has been sub-divided into upper and lower units. Coarse sandstones and conglomerates interbedded with siltstones make up the lower unit, which contains fossils of bivalves, ostracods and conchostracans that indicate a Lower to Middle Devonian age. The upper unit comprises sandstones, conglomeratic sandstones and conglomerates interbedded with grey siltstones that contain fossils of placoderms, ostracods, conchostracans and ferns indicating an Upper Devonian age.

The fossil assemblage suggests that the Bluff Head Formation may comprise a complete Devonian sedimentary sequence (Lee *et al.*, 1997). A standard Late Devonian index plant fossil (*Leptophloeum rhombicum*) (Dawson, 1861) has been recorded from Ma On Shan.

Devonian conglomeratic coarse sandstone
Note the indistinct cross-bedding

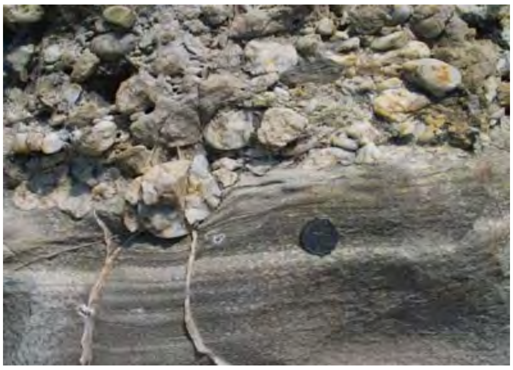
Guide to Field Observations

The Devonian rocks crop out along the coast near Pak Sha Tau Chau. Because the rocks are steeply inclined, they do not form convenient ledges so that space for walking around the outcrops is very limited. Consequently, extra care must be taken when visiting the outcrops. At low tide, it is possible to walk along the coast to the southwest corner of Pak Sha Tau, observing the extensive sedimentary sequence along the way.

Devonian conglomerate and conglomeratic sandstone at Pak Sha Tau Chau

1) Observe the variations in composition and grain size of the sedimentary rocks. Decide if the rock is a siltstone, sandstone or conglomerate, and whether it is a fine or coarse sandstone, or a quartz sandstone, or a siltstone containing rounded pebbles. Observe also the composition of the pebbles, their roundness, and whether they show any particular alignment.

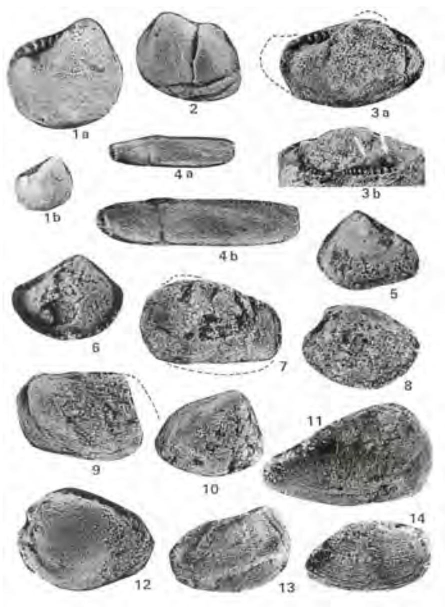
2) Try to study the general sedimentary sequence. Note that these rock layers are sub-vertical, or even overturned, in which case younger rocks may be underlying older rocks. Try to find evidence to determine if the rock layers have been overturned.



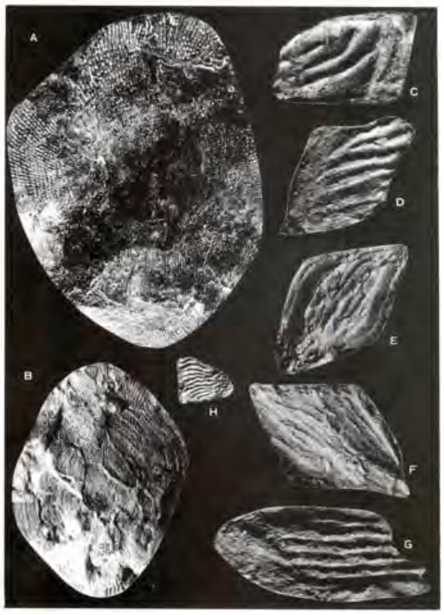
Conglomerate overlying horizontally bedded fine-grained sandstone/siltstone. Note that the sandstone/siltstone layers are deformed by the conglomerate

Joints in fine-grained sandstone controlling weathering patterns. Note the iron concentrated along joint planes

3) Try also to observe variations in the rock sequence that might indicate changes in the original depositional environment. For instance, a change from siltstone to sandstone, and then to conglomerate, may indicate an increase in water volume and current velocity with a resulting increase in capacity to transport coarser sediments. Alternatively, it may indicate a decline in relative water level.



Bivalve fossils from the Bluff Head Formation (after Lee *et al.*, 1997)



Fish scale fossils from the Bluff Head Formation (after Lee *et al.*, 1997)

4) Observe the sedimentary layering and any internal structures. The beds may contain two main types of structures, namely, flow structures or graded bedding.

Flow structures, such as current ripple marks and cross-bedding, result from the manner in which the sandy sediments are transported and laid down by water currents. Graded bedding develops when water currents that carry a large suspended sediment load containing a range of grain sizes are slowed. This results in the coarser, heavier particles being deposited first, followed by the finer, lighter particles. Thus, the beds show a gradual change in grain size from coarse at the base to fine at the top without any abrupt boundaries.

5) Observe the weathering characteristics of the different rock types. Consider the reasons for any observed differences in weathering patterns between the various grain sizes and rock structures.

6) Try to identify fossils in the finer-grained rocks, such as the well-graded siltstones. However, do not break or damage the rock surfaces, but leave the evidence for future generations to observe and enjoy.

Comments

Many different types of fossils have been discovered in the Devonian rocks along the Tolo Channel. Fossils provide evidence not only of the age of the sedimentary strata, but also offer reliable indications of the depositional environments that existed in Hong Kong during the Devonian period.

On the northern shore of the Tolo Channel, the Bluff Head Formation comprises mainly sandstones, siltstones and conglomerates. Although the lower and upper units of the succession show only limited variation in rock types, the fossil assemblages span the entire period from the Early to Late Devonian.

Fossils such as bivalves, ostracoda and estheria, within the lower unit of the Formation, indicate a deltaic, estuarine or nearshore shallow marine depositional environment in the Early to Middle Devonian. Fossils of primitive ferns in the upper unit indicate a marked change in the depositional environment from the earlier marine conditions to terrestrial (land) conditions in the Late Devonian.

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Bureau of Geology and Mineral Resources of Guangdong Province (BGMRGP) 1988. *Regional geology of Guangdong Province*. Geological Memoirs Series, v. 1, 941 p.

Lee, C.M., Chan, K.W. & Ho, K.H. 1997. *Palaeontology and stratigraphy of Hong Kong, Volume 1.* Science Press, Beijing, 206 p. plus 57 plates (In Chinese).

Lee, C.M., Chan, K.W. & Ho, K.H. 1998. *Palaeontology and stratigraphy of Hong Kong, Volume 2.* Science Press, Beijing, 242 p. plus 81 plates (In Chinese).

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

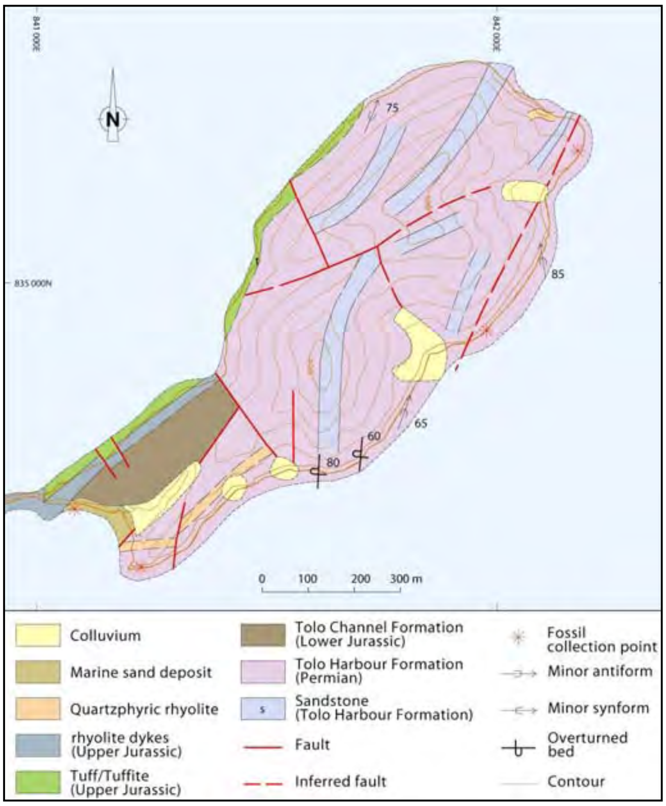
Williams, M.Y. 1943. The stratigraphy and palaeontology of Hong Kong and the New Territories. *Transactions of the Royal Society of Canada Third Series*, v. 37, sect. IV, pp.93-117.

Chapter 2 – Permian Sedimentary Rocks – Tolo Harbour Formation

Introduction

In addition to sandstones, pebbly sandstones and conglomerates of Devonian age exposed along the northwestern shoreline of the Tolo Channel, rocks visible on Ma Shi Chau are also representatives of Palaeozoic sedimentary strata that occur in Hong Kong. These rocks, called the Tolo Harbour Formation, are of Permian age. They are predominantly exposed around Tolo Harbour and adjacent areas, including Ma Shi Chau, Centre Island, The Chinese University of Hong Kong, and the western coast of Three Fathoms Cove (see the "Geological Map along the Tolo Channel" in Chapter 1). Ma Shi Chau is the type locality of the Tolo Harbour Formation. The rocks are well exposed on the island, comprising a sequence of rocks, including mudstone, siltstone and sandstone, that have been folded by earth movements.

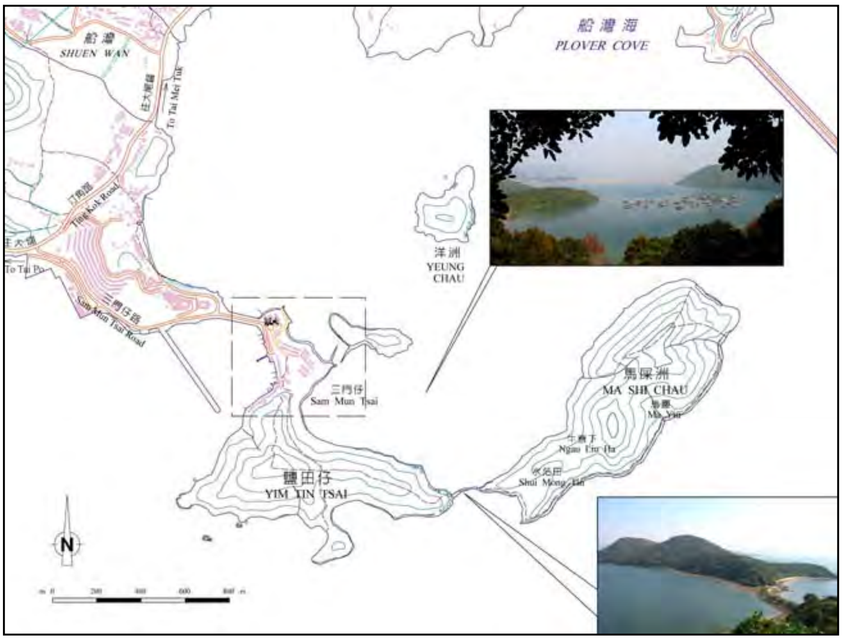
Ma Shi Chau hosts the largest exposure of Permian sedimentary rocks in Hong Kong, revealing a complex sequence of rocks that is disrupted by folding and faulting. Consequently, the island is an excellent place for examining the history of the rocks (stratigraphy), sedimentary rock types and textures, and various kinds of geological structures. The northwestern part of the island exposes dark siltstones and mudstones belonging to the Lower Jurassic Tolo Channel Formation, as well as sedimentary breccias, tuffs and tuffites of Middle Jurassic age.



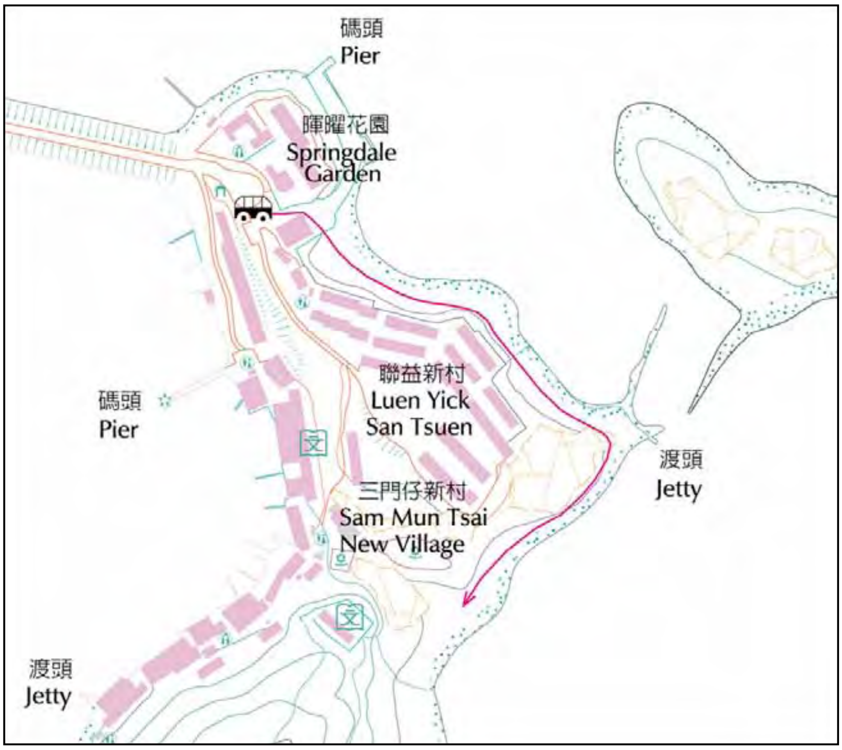
Outline Geology of Ma Shi Chau (GCO, 1986)

How to Get There

The Permian sedimentary rocks on Ma Shi Chau can be reached by taking bus no. 74K, or minibus no. 20K, from Tai Po Market KCR Station to Sam Mun Tsai. From



Transport to the Ma Shi Chau area



Route from the bus terminal to Sam Mun Tsai bay there it is a short (2 km) walk across the knoll at Yim Tin Tsai, and then along the sand ridge connecting Yim Tin Tsai and Ma Shi Chau. During low-tide, an alternative route can be taken to bypass the knoll. From Sam Mun Tsai, walk southeast from the bus terminal along the beach in front of Luen Yick San Tsuen, passing the bay to the east of Sam Mun Tsai New Village, to reach the sand ridge connecting Yim Tin Tsai and Ma Shi Chau.

Outline of the Geology

The Tolo Harbour Formation was named by Ruxton (1960), who was the first to identify fossils in the Formation. The Permian succession on the island, which has been estimated to be about 500 m thick, is sub-divided into two main rock groups (assemblages). The lower assemblage occurs on the southeastern part of the island, and mainly comprises thin layers of interbedded pale grey to light red, weak, calcareous siltstone and dark grey mudstone, siltstone and sandstone. Upwards, there is a gradual increase in sand content in the rocks, reaching a *c.* 0.5 m thick sandstone layer at the top. The upper assemblage occurs on the northern part of the island, mainly comprising siltstones, sandstones and conglomerates. The succession is well-bedded, with each layer up to almost 1 m thick. Poorly preserved fossils have been

Interbeds of [red] sandstone within [dark grey] siltstone in the Tolo Harbour Formation – note the sandy nodules along the bedding direction

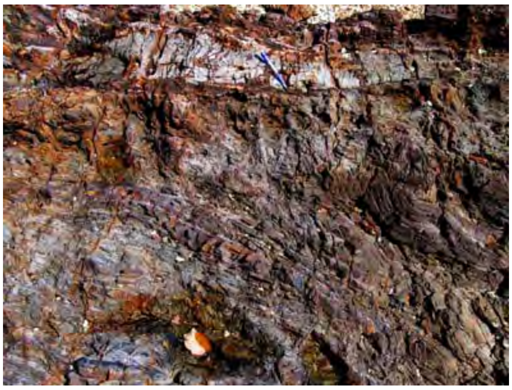
Small sandy lens within siltstone of the Tolo Harbour Formation

identified in both assemblages (Lee *et al.*, 1997). These comprise a variety of marine fauna such as molluscs, corals, bryozoans, brachiopods, crinoids, and some plant fossils.

Guide to Field Observations

Because the site is situated within the Ma Shi Chau Site of Special Scientific Interest, no rock or plant samples can be taken away. Even though fossils may be identified in a piece of rock, breaking the rock to collect specimens and the removal of fossils are prohibited. Please remember that, once fossils have been removed, they can never be replaced.

The optimum location for studying the Tolo Harbour Formation is along the southeastern coast of the island, which is not affected by tidal changes.



Slump fold within the Tolo Harbour Formation

Outcrop of sandstone from the upper rock assemblage, Tolo Harbour Formation

Differential weathering due to variations in rock type

Folds in the Tolo Harbour Formation

1) There is no clear break, or dividing line, between the upper and lower rock assemblages. Thus, careful observations need to be made along the route in order to determine to which of the two assemblages the rocks belong.

2) Pay particular attention to variations in thickness, form and lateral extent of the different rock layers. Many sandstone layers pinch-out and form lenticular bodies within the siltstones. The visitor may wish to consider how these features were formed.

3) Look out for sedimentary structures and their associated features. Local disturbance of the bedding may have been caused by slumping (collapse) or folding of the original bedding due to gravitational sliding of saturated sediment.

4) Observe how the strata have been deformed by subsequent earth movements. Fold structures are well-developed on Ma Shi Chau.

Fossils in rock outcrops

5) Visitors interested in fossils may wish to spend more time examining the rock faces. However, the use of geological hammers is prohibited, and the rocks cannot be split for examination. Commonly, only the thin edge, or only part, of a fossil is exposed, so they are often missed by inexperienced observers.

6) Observe the effects of weathering on the different rock types in the surrounding landscape. For instance, the more resistant quartz sandstones appear as prominent ridges, or form promontories along the coast, whereas the softer siltstones with sandstone interbeds, or the mudstones, have been selectively worn down by erosion.

Comments

Outcrops of Permian rocks in Hong Kong are scattered and discontinuous. In addition to Ma Shi Chau and the adjacent Centre Island, Permian rocks are also exposed to the northwest of the Chinese University of Hong Kong. The rock types there comprise sandstones and siltstones that are similar to those on Ma Shi Chau. Ripple marks and other water-flow structures have been identified in the sandstones, whereas evidence of the crawling and burrowing activities of organisms has been found in the siltstones. Based on the rock types and their fossil assemblages, the Permian rocks of Tolo Harbour and the surrounding area are generally thought to have been formed in a coastal delta or shallow sea environment. The rocks hardened from sands and silts that were laid down in an environment subject to current action forming ripple marks and other sedimentary structures. The structures suggest variations in sediment supply and current motion that are typical of a deltaic or shallow sea environment. Finally, both marine and terrestrial fossils have been found in the rocks, indicating that the biota were derived from the sea and land, respectively.

It is worth noting that Permian foraminifera (microfossils) were identified in drill core samples recovered from Tung Chung and northern Lantau (Lee *et al.*, 1998). The fossils were found in crystalline limestone/marble, suggesting a warm, continental shelf, shallow sea environment suitable for carbonate deposition. This environment is clearly different from that represented by rocks in the Tolo Harbour and surrounding areas.

References

Addison, R. 1986. *Geology of Sha Tin*. Hong Kong Geological Survey Memoir No.1, Geotechnical Control Office, Civil Engineering Services Department, Hong Kong, 85 p.

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Addison, R. & Purser, R.J. (1986). *Sha Tin. Hong Kong Geological Survey Sheet* 7, Solid and Superficial Geology, 1:20 000 Series HGM20, Geotechnical Control Office, Hong Kong.

Lai, K.W., Liu, K.B., Yeung, K.C., Leung, C.F., & Wai, C.C. 1982. A preliminary study on the geological structure of Ma Shi Chau, Hong Kong. *Geography Bulletin*, Education Department, Hong Kong, v. 16, pp 69-90.

Lee, C.M., Atherton, M.J., He, G.X., Chen, J.H. & Wu, S.Q. 1990. New collections for the Tolo Harbour Formation at Ma Shi Chau, New Territories, Hong Kong. Hong Kong Geological Society Newsletter, v. 8, pt. 3, pp 13-22.

Lee, C.M., Chan, K.W. & Ho, K.H. 1997. *Palaeontology and stratigraphy of Hong Kong, Volume 1.* Science Press, Beijing, 206 p. plus 57 plates (In Chinese).

Lee, C.M., Chan, K.W. & Ho, K.H. 1998. *Palaeontology and stratigraphy of Hong Kong, Volume 2.* Science Press, Beijing, 242 p. plus 81 plates (In Chinese).

Lam, K.C. 1973. Upper Palaeozoic fossils of the Tolo Harbour Formation, Ma Sze Chau, Hong Kong. *Bulletin of the Hong Kong Geographical Association*, v. 3, pp 21-27.

Nau, P.S. 1980. Geology of the Ma Shi Chau Island, New Territories, Hong Kong. *Annals of the Geographical, Geological & Archaeological Society*, University of Hong Kong, v. 9, pp 17-28.

Ruxton, B.P. 1960. The Geology of Hong Kong. *Quarterly Journal of Geological Society of London*, v. 115, pp 233-260.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

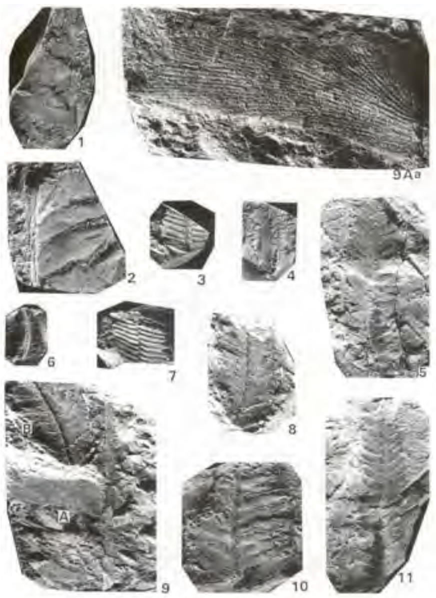
Kau San Tei, Tai O, Lantau Island

3. Early and Middle Jurassic Fluvial Deposits – Tai O Formation

Introduction

Although volcanic and intrusive rocks are widely distributed in Hong Kong, sedimentary rocks, particularly those of Mesozoic age, are restricted in their distribution. Mesozoic sedimentary rocks are mainly exposed in the less accessible upland areas or on islands in the northeast Territories, such as Pat Sin Leng, Wang Leng, and Wong Leng. However, there are more easily accessible exposures of Mesozoic sedimentary rocks at Kau San Tei, Tai O, on Lantau Island. A well-developed succession of red and grey siltstones, sandstones and conglomerates, grouped as the Tai O Formation, can be observed at this locality. Based on fossil evidence, the Formation has been dated as Early to Middle Jurassic age. Although the rocks were originally laid down in horizontal layers, the strata have subsequently been tilted by mountain-building forces so that the beds now dip to the south at between 40^{o} and 80^{o}.

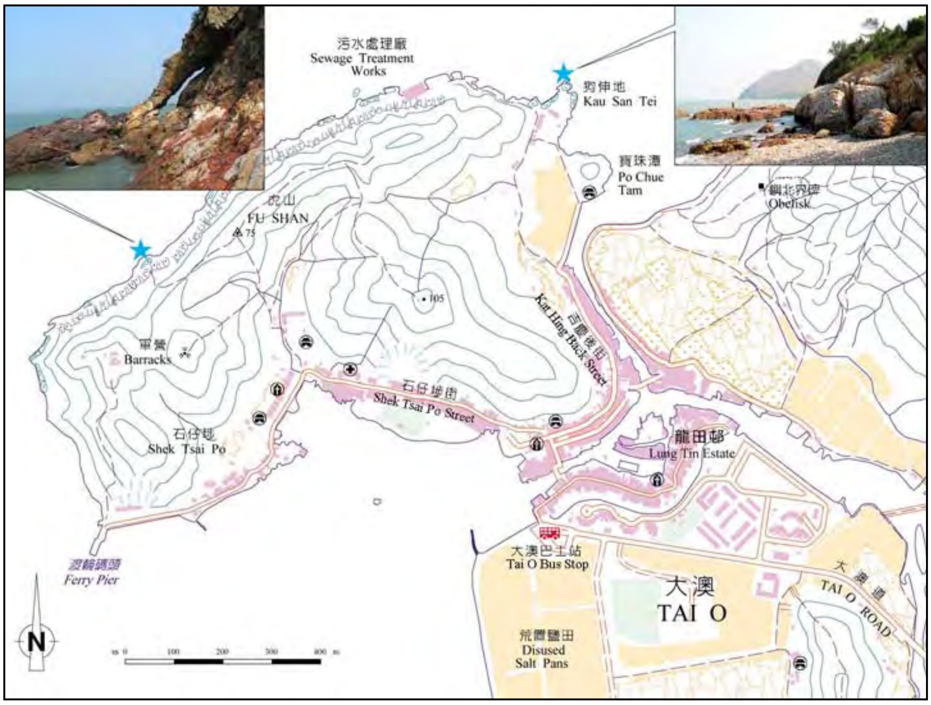
The Tai O district comprises a small island located in the northwestern part of the Lantau Island, and a strip of mudflats separating it from Lantau Island proper. In the past, the mudflats were developed to create fish ponds and salt pans. Today, the small village of Tai O is a very popular tourist destination. The residents are mostly fishermen who live in houses built on stilts along the seashore with every family owning a fishing boat.



Fossil plants from the Tai O Formation
(from Lee e*t al*, 1997)

How to Get There

Transport to Tai O is very convenient: the island can be accessed directly from the Tung Chung New Town via bus route no. 11, or from Mei Wo via bus route no. 1. The site of geological interest at Kau San Tei is only 1 km from the bus terminal at Tai O. The access path is flat and well maintained, and makes an easy walk. An interesting eroded sea arch in the sandstone of the Tai O Formation can be seen by walking westward along the Shek Tsai Po Street, turning north at the ferry pier, and then walking along the beach.



Access map to Kau San Tei, Tai O

Outline of Geology

The Early to Middle Jurassic Tai O Formation is exposed only along the northwest margin of Lantau Island, where it forms a 50 to 600 m-wide strip that runs parallel to the shoreline. To the southeast, the formation is overlain in continuity by the Middle Jurassic Tsuen Wan Volcanic Group (southwestern part) and with the Late Jurassic Lantau Volcanic Group (northwestern part). The Formation is composed of greyish fine sandstone with siltstone, sandy siltstone and shale. Based on detailed geological studies, the Tai O Formation was laid down as river (fluvial) deposits, composed mainly of sandstones that were deposited in the river channel, and sandy siltstones deposited on the adjacent floodplain (Jones, 1996). These two types of sedimentary rock make up 95% of the Formation. It is worth noting that angular quartz granules are present in many of the sandstone units, indicating that the sediments were derived from siliceous sources.

<u>Guide to Field Observations</u>

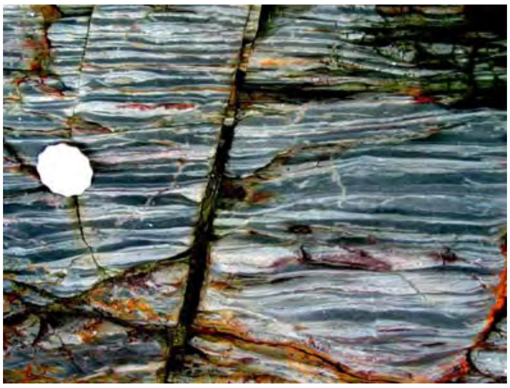
As the terrain is fairly rugged, care should be taken to ensure personal safety when inspecting the outcrops along the seashore. Because the field appearance of sedimentary and igneous rocks differ in many respects, the following key features should be noted:

1) Bedding identification, including its type, characteristics and lateral continuity: The development of bedding (layering) in rocks is determined by the composition and supply of sediments deposited in different water current conditions. Structures within the beds are important for reconstructing the depositional setting of the original rocks. For example, massive (thick) bedding is formed by rapid deposition of water-born sediments. Cross bedding (curved layers) is formed by flowing water or wave action. Thin, horizontal bedding is generally formed under low energy conditions, such as in a lake, lagoon, *etc*. When observing these rocks in the field, take care not to confuse bedding with joint planes or structural lineations that show preferred orientation, or with the colour variations that develop on the weathered rock surfaces.

2) Grain size variation and change of sediment composition: Gradational changes in grain size in a rock do not only reflect the characteristics of water current regimes, but also provide direct evidence of depositional conditions. For example, the change from pebbles to coarse sandstone, through to fine sandstone, and to siltstone, may indicate that the sedimentary environment has steadily evolved from that of a river channel to a river flood plain. The composition and shape of the sediments can indicate the characteristics of the source area and the distance travelled from the source, as well as the changing water conditions. Details of these features are important for understanding the depositional setting.

3) Sedimentary structures, such as ripple marks, flute casts or groove casts, pillow structures, or sand vein/dykes, *etc*. (Tsang & Xia, 1986): These structures all develop during deposition of the sediments, or by the later rock forming processes, so they are useful for interpreting the sedimentary environment and sedimentation processes.

4) It is important to record the characteristics of the rock bedding, and then to interpret the effects of later structural modification on this succession of sedimentary strata.



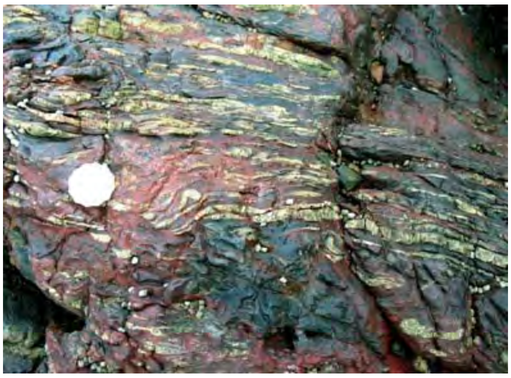
Siltstone deposited on a floodplain – the undulating surface of the floodplain is indicated by the slightly irregular fine laminae

Siltstone deposited on a floodplain – iron staining developed during weathering has formed banding that can facilitate interpretation of local minor structures

The contact relationship between finely bedded river channel sandstone and siltstone

Horizontal bedding within a channel sandstone

Cross bedding and disturbed bedding



Sandstone lens (light colour) interbedded with siltstones

Sediments infilling a groove – transported mudstone fragments deposited in the eroded groove during a flood

Sedimentary dykes within sandy siltstone – before the sediments were lithified, the weight of the siltstone caused the underlying pebbly sand to liquefy and inject upwards into the siltstone

Folds in interbedded siltstone (dark colour) and sandstone (light colour)

Differential weathering in the interbedded silstone and sandstone – laminae or lenses of quartz sandstone are more resistance to weathering than the siltstone, so they protrude above the weathered rock surface

Comments

Previously, the Tai O Formation was mistakenly assigned to the Carboniferous Mai Po Member of the Lok Ma Chau Formation, San Tin Group. In 1996, a geological survey team from the Civil Engineering and Development Department, the Polytechnic University, and the Nanjing Institute of Geology and Paleontology of the Chinese Academy of Sciences recovered numerous fossil plants from the siltstone and fine sandstone sequences along the seashore at Kau San Tei, Tai O (Lee *et al.*, 1997). The assemblage of fossil plants was dominated by cycads, gingko, and Gymnosperms (conifers), as well as some Pteridophyta (ferns). The characteristics of the flora were correlated with those of the "Xiangxi Flora" from the Southern China, evidence that helped to establish the late Early to early Middle Jurassic age of the Tai O Formation.

There are three sedimentary rock units recognised in the Mesozoic (Jurassic-Cretaceous) of Hong Kong, namely, the Early Jurassic Tolo Channel Formation, the late Early to early Middle Jurassic Tai O Formation, and the Late Jurassic-Cretaceous Lai Chi Chong Formation. Each of these formations is characterised by different depositional features that record how the physical environments of Hong Kong changed throughout geological time.

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Bennett, J.D. 1984b. *Review of Hong Kong Stratigraphy*. GCO Publication No. 5/84, Geotechnical Control Office, Hong Kong, 62 p.

Bennett, J.D. 1984c. *Review of Tectonic History, Structure and Metamorphism of Hong Kong*. GCO Publication No. 6/84, Geotechnical Control Office, Hong Kong, 63 p.

Jones, N.S. 1996. *The geology and sedimentology of Upper Palaeozoic and Mesozoic sedimentary successions in Hong Kong*. British Geological Survey Technical Report WH/96/130R, British Geological Survey, U.K., 48 p.

Langford, R.L., James, J.W.C., Shaw, R., Campbell, S.D.G., Kirk, P.A. & Sewell, R.J. 1995. *Geology of Lantau District*. Hong Kong Geological Survey Memoir No. 6, Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 173 p.

Lee, C.M., Chan, K.W. & Ho, K.H. 1997. *Palaeontology and stratigraphy of Hong Kong, Volume 1*. Science Press, Beijing, 206 p. plus 57 plates (In Chinese).

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Strange, P.J., Shaw, R. & Addison, R. 1990. *Geology of Sai Kung and Clear Water Bay.* Hong Kong Geological Survey Memoir No. 4, Geotechnical Control Office, Civil Engineering Services Department, Hong Kong, 111 p.

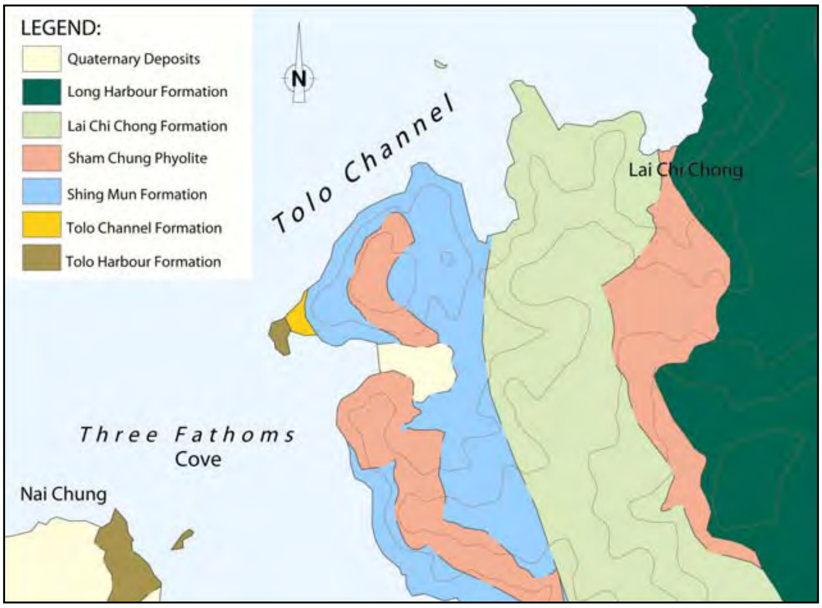
Tsang, Y.F. & Xia, W.C. (eds.) 1986. *Sedimentology*. Geological Publication Press, Beijing, 274 p.

4. Volcaniclastic Rocks - Lai Chi Chong Formation

Introduction

Well-bedded rock strata are exposed at Lai Chi Chong on the southeastern coast of Tolo Channel in the eastern New Territories. The volcaniclastic (volcanic and sedimentary rock) characteristics of these rocks were first identified by Allen & Stephens (1971) during preparation of the 1:50,000 scale geological map of Hong Kong. They assigned these rocks to a special unit within the Jurassic Repulse Bay Formation, and correlated them with similar stratified rocks at Ma On Shan, Ma Liu Shui and West Lantau. Following further examination of the rocks at Lai Chi Chong, Strange *et al.* (1990) proposed the name Lai Chi Chong Formation for these volcanic-related sedimentary rocks and assigned them to the Early Cretaceous.

The Lai Chi Chong Formation initially included rocks exposed over the area between the east coast of Three Fathoms Cove and Lai Chi Chong. However, later studies revealed that the rock types and geological structures are very complex. In addition to the Mesozoic volcanic-rich sedimentary rocks, tuff, rhyolite and Palaeozoic sedimentary rocks were also identified in this area. After detailed research involving U-Pb isotope dating, Campbell & Sewell (1998) proposed that the Lai Chi Chong Formation should only include rocks in the vicinity of Lai Chi Chong Pier, which form a 130 to 180 m-wide outcrop along the coast (Sewell *et al.*, 2000).



Simplified Geological Map of the Lai Chi Chong area
(from HKGS 1:100,000 HGM1000)

The Lai Chi Chong Formation is an assemblage of volcanic-related rocks comprising tuffite, tuffaceous sandstone, siltstone and mudstone. The formation is representative of the volcaniclastic rocks that occur in Hong Kong. A variety of interesting sedimentary structures and post-depositional fold features are developed in these rocks, and they also contain fossil plant fragments and tree-trunk remains, making them ideal for research on Early Cretaceous volcaniclastic rocks in Hong Kong.

<u>How to Get There</u>

The most convenient route to Lai Chi Chong is by ferry from Ma Liu Shui Pier in Sha Tin. There are two scheduled daily ferry sailings to Lai Chi Chong Pier on weekdays, and three on weekends. It is also possible to reach Lai Chi Chong overland. Although the land route is relatively harder, the natural scenery is more beautiful. The overland route begins either in Sai Kung, taking bus route no. 94 to Wong Shek Pier via Tai Mong Tsai Road, or from Diamond Hill MTR Station, taking bus route no. 96R to Wong Shek Pier via Sai Kung. At Pak Tam Chung, transfer to New Territories green minibus route no. 7 to Ko Tong, and alight at Pak Sha O station in Hoi Ha Road. From there, a footpath of approximately 3.5 km length leads to Lai Chi Chong. The footpath is well paved, with plenty of shade and beautiful views. Near Nam Shan Tung, the path passes through a saddle (rising to about 70 m in elevation from Pak Sha O), before turning northwest and descending towards Lai Chi Chong Pier. This is an extremely enjoyable hiking route.

Transport routes from Pak Sai O to Lai Chi Chong

Footpath from Pak Sha O to Lai Chi Chong

Lai Chi Chong Pier

Outline of the Geology

The Lai Chi Chong Formation crops out mainly on the beach west of Lai Chi Chong Pier. Although these strata are exposed for less than 200 m, the lithologies are very complex. In addition to tuffite, tuffaceous sandstone, siltstone, mudstone and tuff-breccia, there are also layers of coarse ash crystal tuff, eutaxitic fine ash tuff, and flow-banded porphyritic rhyolite that are more directly related to volcanic activity.

The Lai Chi Chong Formation is characteristically well-bedded. Sedimentary structures abound, such as current bedding, graded bedding, convolute bedding, subaqueous slumps, *etc*., which were formed during deposition of the beds. Structural disturbance due to fault movements, such as folds, faults and changes in bedding orientations, can also be clearly identified in the outcrops. The great variety of rock types and sedimentary structures within such a small area makes this site ideal for research studies on volcaniclastic rocks.

Well-bedded Lai Chi Chong Formation

Differential weathering of various rock types typeshologies

Discordance of strata due to fault movement (1)

Discordance of strata due to fault movement (2)

Folded strata of the Lai Chi Chong Formation

Interbedded mudstone (pale grey) and sandstone (greyish yellow)

Syn-depositonal conglomerate/breccia formed by subaquatic slump

Syn-depositional fold and fault formed by subaquatic slump

Guide to Field Observations

The optimum time to observe the volcaniclastic rocks on the beach at Lai Chi Chong is during low tide when the sea has retreated to reveal a wide area of exposed rock. However, even at high tide, many sedimentary features in the rock outcrops can still be observed along the coast to the west of Lai Chi Chong Pier.

1) Use a hand lens to distinguish the different rock types, such as sandstone, siltstone and mudstone. Some rocks consist of very fine sediment that has been altered by silica-rich fluids, making field identification difficult. If possible, a rock sample can be taken for detailed thin-section study.

Sandstone and gravelly sandstone with current bedding

Current and graded bedding. Note: In places, the upper part of the bed may be disturbed into chaotic and discontinuous red bands

2) The top and bottom of a bed can usually be determined by looking at the grain-size variations and the sedimentary structures. For example, normal graded bedding comprises coarse (heavier) grains at the base, and fine (lighter) grains at the top.

3) Note carefully the joint patterns and weathered surfaces of the different rock types. Observe the differences between rock types picked out by differential weathering.

4) Try to identify the different sedimentary structures, and to distinguish between structures formed during deposition, and those that have affected the strata after deposition.

5) Identify any intrusive veins in the strata, and determine what might have controlled these intrusions.

Comments

The Lai Chi Chong Formation contains a wide diversity of rock types with complex origin, including tuffite, tuffaceous sedimentary rocks, non-volcanic sedimentary rocks, and primary volcanic rocks. In view of the complexity of the Lai Chi Chong Formation, Workman (1991b) suggested that the term "volcaniclastic" be used to resolve difficulties in field identification between rocks of volcanic and non-volcanic origin. Correspondingly, the rocks at Lai Chi Chong are named as volcanic conglomerate/breccia, volcanic sandstone/siltstone, *etc*. The following description is quoted from Workman, as a reference for who are interested in further study.

[Quotation: "…a pyroclastic fragment is 'a fragment produced directly from volcanic process'. …Reworking or recycling of unconsolidated pyroclastic debris by water or wind does not transform pyroclasts into epiclastic fragments. An epiclastic volcanic fragment is produced by weathering and erosion of volcanic rocks. Reworked pyroclastic fragment are derived from the remobilization of loose materials. A rock resulting from processes would still be pyroclastic, i.e. a tuff" – Workman (1991b), p.30]

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Atherton, M.J. & Burnett, A.D. 1986. *Hong Kong Rocks*. Published by the Urban Council, Hong Kong, 145 p.

Campbell, S.D.G. & Sewell, R.J. 1998. A proposed revision of the volcanic stratigraphy and related plutonic classification of Hong Kong. *Hong Kong Geologist*, v. 4, pp 1–11.

Campbell, S.D.G. & Shaw, R. 2002. The Lai Chi Chong Section: A Photographic Feature. *Hong Kong Geologist*, v. 8, pp 31–41.

Dale, M.J. & Nash, J.M. 1984. The occurrence of silicified wood in the Repulse Bay Formation sediments at Lai Chi Chong, New Territories, Hong Kong. *Geological Society of Hong Kong Newsletter*, v. 2, pp 1–4.

Lai, K.W., Campbell, S.D.G. & Shaw, R. 1996. *Geology of the northeastern New Territories.* Hong Kong Geological Survey Memoir No. 5, Geotechnical Engineering Office, Civil Engineering Department, Hong Kong, 143 p.

Nau, P.S. 1986. Discussion on the age of the rock sequence on the coast north of Lai Chi Chong, New Territories, Hong Kong. *Geological Society of Hong Kong*

Newsletter, v. 4, pp 1–4.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Strange, P.J., Shaw, R. & Addison, R. 1990. *Geology of Sai Kung and Clear Water Bay.* Hong Kong Geological Survey Memoir No. 4, Geotechnical Control Office, Civil Engineering Services Department, Hong Kong, 111 p.

Wai, C.C. 1986. A note on the discovery of fossil wood found in the Repulse Bay Formation sediments at Cheung Sheung, Sai Kung, New Territories. *Geological Society of Hong Kong Newsletter,* v. 4, pp 5–7.

Williams, M.Y. 1943. The stratigraphy and palaeontology of Hong Kong and the New Territories. *Transactions of the Royal Society of Canada Third Series*, v. 37, sect. IV, pp.93-117.

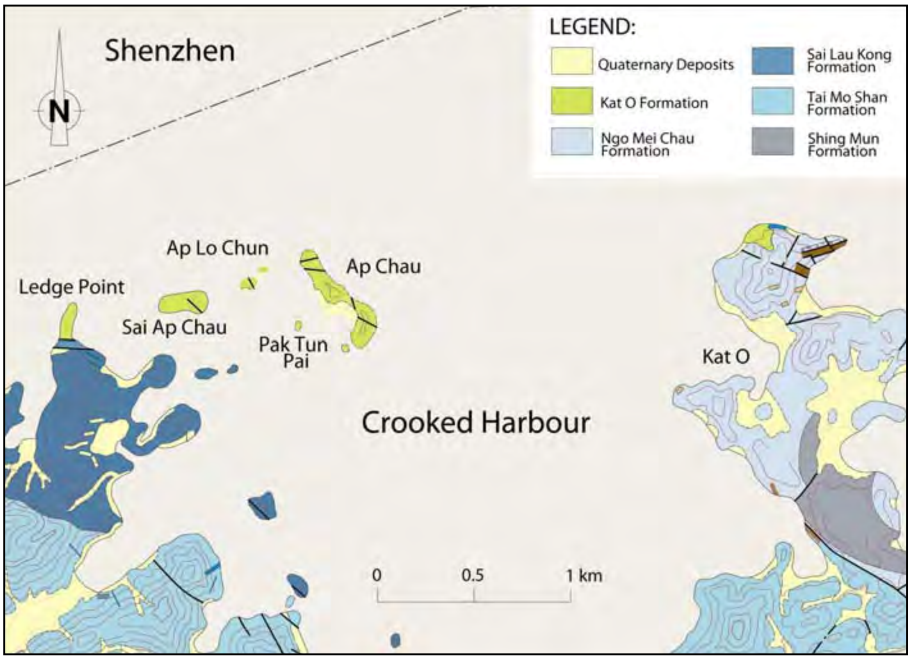
Workman, D.R. 1991a. Field guide to the geology of the shoreline west of Lai Chi Chong, Tolo Channel. *Geological Society of Hong Kong Newsletter*, v. 9, no. 3, pp 20-29.

Workman, D.R. 1991b. Appendix - Discussion on the naming of rocks that may be partly of pyroclastic origin. *Geological Society of Hong Kong Newsletter,* v. 9, no. 1, pp 30-33.

5. Cretaceous "Red Beds" – Kat O Formation

Introduction

Ap Chau (also called Robinson Island) is a small island of 0.03 km^2 close to Sha Tau Kok in the northeastern of Hong Kong. A few indigenous residents remain on the island, relying on fishing and the sale of dried seafood for a living. In addition to Ap Chau, other nearby rocky islands include Sai Ap Chau, Ap Lo Chun, Pak Tun Pai, and Ledge Point. The Kat O Formation, comprising calcareous breccia, conglomerate, and gravelly coarse-grained sandstone, crops out sporadically on these islands, but is best exposed on Ap Chau.



Geology of Ap Chau (GCO, 1991; GEO, 1992)

How to Get There

The most convenient way to visit Ap Chau is by taking a ferry from Sha Tau Kok Pier. However, a Closed Area Permit is required for this route. Alternatively, it is possible to hire a private charter boat to leave from Ma Liu Shui or Tai Mei Tuk. By taking either of these latter routes, the Devonian stratigraphy along the Tolo Channel, and the Pat Sin Leng Formation near Wong Chuk Kok Tsui (Bluff Head), and Double Island, can also be visited along the way.

Outline of the Geology

Exposures of the Kat O Formation are relatively limited. The stratigraphy is locally well-developed, comprising beds of calcareous breccia, conglomerate and coarse-grained sandstone. Analyses of the sediments and their depositional characteristics concluded that the rocks accumulated as talus on hillsides, or at the toe of a fault scarp. There is evidence of some minor reworking under a semi-arid climate. The reddish colour of the rocks results from the oxidation of iron, which suggests that the rocks were formed under semi-arid to arid conditions. Local variations in the layering and structures of the gravels and sands suggest that they might have been deposited, at least in part, during periodic floods. The large particle size of the rocks, including gravels and coarse sand, indicates that the sediments were derived from nearby sources.

“Duck’s eye” on Ap Chau – a typical sea-arch

Close-up of the sea-arch

Angular volcanic clasts in breccia

Scour bedding in gravelly coarse-grained sandstone

Guide to Field Observations

There are many excellent rock outcrops on Ap Chau, which can easily be accessed by good footpaths, taking care to avoid the activities of the local residents. A well-developed sea-arch at the northwestern tip of the island, known as the “Duck’s eye” (Ap Chau means “Island of the Duck” in Chinese) provides excellent rock exposures. The sedimentary rocks at the “Duck’s eye” comprise mainly calcareous breccia/conglomerate, and gravelly coarse-grained sandstone. Although the rock appears to be loose, the material is actually quite well-cemented and strong.

(1) Examine the rocks to determine if the particles are sorted (*i.e.* if they are of a similar particle size), and if there are any bedding or other sedimentary structures visible. Try to determine the lateral continuity of the bedding, and consider how this might relate to the depositional environment.

(2) Observe the shape and composition of the gravels and coarser fragments. Consider their characteristics in relation to possible source rocks, and to the distance travelled from their source.

(3) Consider the characteristics of weathering and erosion on the rock outcrops. Interpret the natural processes that lead to the formation of the sea arch known locally as the “Duck’s eye”.

(4) Identify the normal high tide level, and try to delineate the extent of the wave-cut rock platform that surrounds the island.

Comments

Following the cessation of volcanic (magmatic) activity in Hong Kong, the environment became exceptionally dry and hot in the late Early Cretaceous. Substantial diurnal (day-night) temperature variations favoured mechanical weathering of the rocks. Intense seasonal rainstorms eroded the resulting gravels and finer grained sediments, transporting the materials to alluvial plains where they were deposited. Three stratigraphical units are recognised in Hong Kong from this period, namely the Pat Sin Ling, Port Island and Kai O formations.

Formation	Rock Type	Depositional Environment
Kat O Formation	Calcareous breccia or conglomerate, gravelly coarse-grained sandstone	Talus deposited on hillsides or along a fault scarp near the margin of a basin
Port Island Formation	Conglomerate, sandstone, siltstone and silty mudstone	Alluvial plain near hillslope/flood plain
Pat Sin Leng Formation	Conglomerate, gravelly sandstone and siltstone	Alluvial plain

The Pat Sin Leng Formation was the first sedimentary unit to be deposited after volcanic (magmatic) activity in Hong Kong ceased at around 140 million years ago. Consequently, in its lower part, the Formation comprises mainly tuffaceous clasts, suggesting that the sediments were derived from the erosion of existing volcanic materials. Overlying the Pat Sin Leng Formation, without any evidence of a break in deposition, is the Port Island Formation, a sequence of conglomerates, sandstones, siltstones and silty mudstones. The coarser Kat O Formation is a sequence of poorly-sorted conglomerates interbedded with gravelly coarse-grained sandstones. The gravels are angular, and are cemented by calcareous materials. These sediments appear to have been deposited as talus on hillsides or along the bases of fault scarps. It is probable that the Kat O and Port Island formations were formed at the same time, but in different sedimentary environments. Because all three formations have a strong reddish colour, they are known as “Cretaceous Red Beds”.

Pat Sin Leng Formation siltstone and volcanic conglomerate

Port Island Formation sandstone (lower part of the photograph) and thickly-bedded volcanic conglomerate

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Atherton, M.J. & Burnett, A.D. 1986. *Hong Kong Rocks*. Published by the Urban Council, Hong Kong, 145 p.

Bennett, J.D. 1984b. *Review of Hong Kong Stratigraphy*. GCO Publication No. 5/84, Geotechnical Control Office, Hong Kong, 62 p.

Lai, K.W., Campbell, S.D.G. & Shaw, R. 1996. *Geology of the northeastern New Territories.* Hong Kong Geological Survey Memoir No. 5, Geotechnical Engineering Office, Civil Engineering Department, Hong Kong, 143 p.

Lai, K.W. & Shaw, R. 1991. *Sheung Shui, Hong Kong Geological Survey Sheet 3*, Solid and Superficial Geology, 1:20 000 Series HGM20, Geotechnical Control Office, Hong Kong Government.

Lai, K.W. & Shaw, R. 1992. *Kat O Chau (Crooked Island, Hong Kong Geological Survey Sheet 4*, Solid and Superficial Geology, 1:20 000 Series HGM20, Geotechnical Engineering Office, Hong Kong Government.

Ruxton, B.P. 1960. The Geology of Hong Kong. *Quarterly Journal of Geological Society of London*, v. 115, pp 233-260.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

East Ping Chau, Eastern New Territories

Chapter 6 – The Youngest Sedimentary Rocks in Hong Kong – Ping Chau Formation

Introduction

Aerial view of Ping Chau

Ping Chau (also called "East Ping Chau") is a small island, measuring approximately 600 m long and 200 m wide, located in Mirs Bay in the northeast New Territories. The island is formed of thinly bedded siltstone, dolomitic siltstone, mudstone and chert layers.

Williams (1943) named these sedimentary rocks the Ping Chau Formation, and assigned an Early Jurassic age. Subsequent scholars, including Allen & Stephens (1971), also considered that the rocks were of Jurassic age. A large assemblage of fossils, representing various genera, is well-preserved in the strata. Detailed studies of the fossils, rock types, geological structures, and depositional setting, have now shown that the Ping Chau Formation is a product of Palaeogene (*i.e.* Early Tertiary) sedimentation.

The Ping Chau Formation rocks are the youngest in Hong Kong. All sediments in Hong Kong younger than the Early Tertiary are unconsolidated. Thus, the Ping Chau Formation represents the final product of rock forming processes in Hong Kong.

Thinly bedded siltstone and mudstone, Ping Chau

How to Get There

A limited public ferry service operates from Ma Liu Shui to Ping Chau on Saturdays and Sundays. The journey time is about one hour and 40 minutes. However, on windy days when the sea is rough, the journey may take 2 to 3 hours. Alternatively, a motor boat or cruiser can be hired for a day trip out to Mirs Bay.

Ma Liu Shui Public Ferry Schedule

From Ma Liu Shui pier to Ping Chau:	Saturdays 9:00 *a.m.* and 3:30 *p.m.* Sundays 9:00 *a.m.*
From Ping Chau to Ma Liu Shui pier:	Saturdays and Sundays: 5:15 *p.m.*

Horizontal layers within thinly bedded siltstone and mudstone

Protruding of more resistant chert layer on outcrop

Outline of the Geology

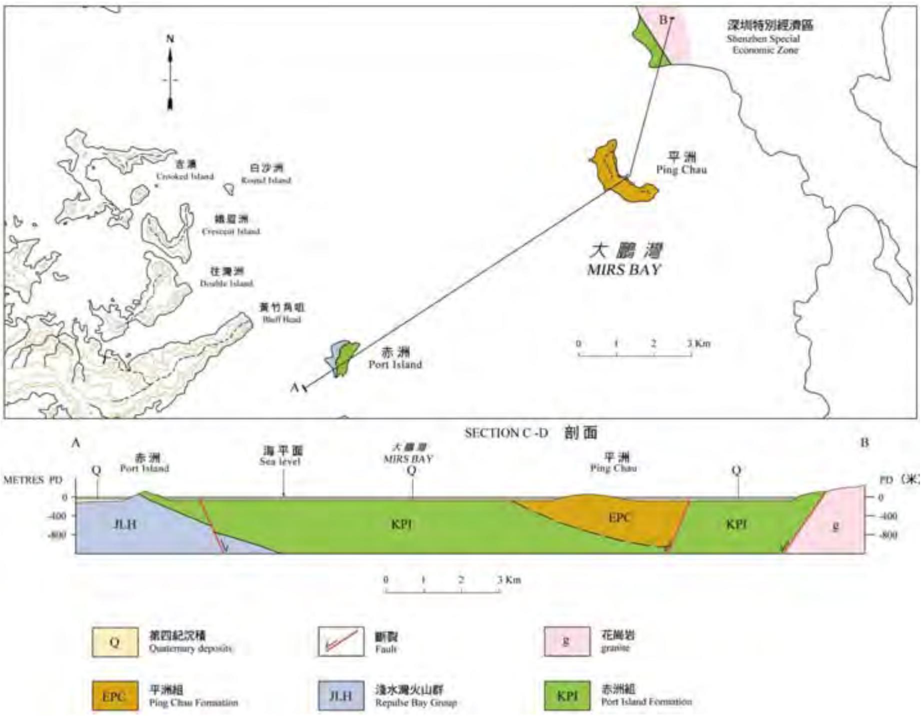
The Ping Chau Formation comprises predominantly dark grey, thinly bedded siltstone, and dolomitic siltstone, intercalated with mudstone. There is a 0.5 m to 1.2 m thick chert layer on Ping Chau. Beds are generally laterally continuous, with each bed varying from 2 to 6 cm thick, and comprising numerous thin (<0.1 cm) laminae. Under the microscope, the laminae consist of interbeds of silt or mud, deposited mostly from solution. These laminae are excellent indicators of the depositional environment.

Geochemical analyses and microscopic examination have revealed that the Ping Chau Formation contains many minerals, such as quartz, feldspar, dolomite, zeolite, aegirine, pyrite, calcite, apatite, illite, bitumen and carbonaceous material.

The dolomitic siltstone, particularly zeolite- and aegirine-bearing siltstone, indicates that the rocks were formed in a subtropical, brackish water lake under arid conditions. Different types of sediment were deposited as the salinity of the lake water and the source of the sediments varied seasonally. During wet seasons, lake water levels rose

Insect and plant fossils from the Ping Chau Formation (from Lee *et al*, 1997)

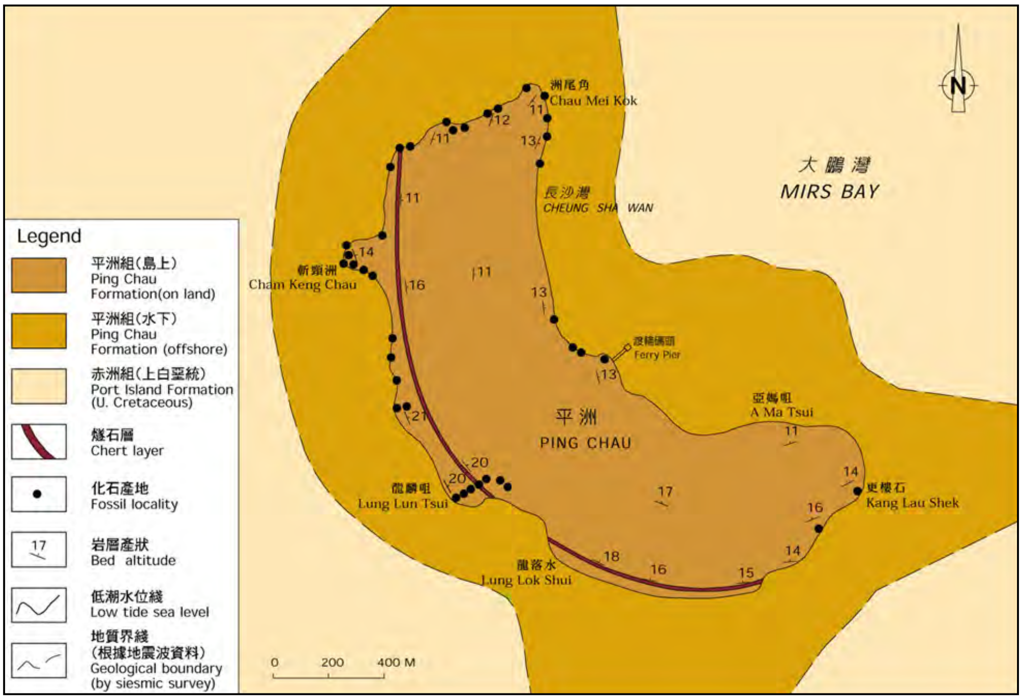
and the salinity was reduced. Waters entering the lake carried more silty and muddy material. When these materials were deposited, they formed one type of lamina. During dry seasons, lake levels fell and the salinity of lake water rose, while silt and mud input was reduced. In these conditions, chemical sedimentation dominated, forming another type of lamina. Thus, seasonal laminations were built up from alternating chemical and sedimentary layers.



Structure geology of Ping Chau area (from Lai, 1991)

Plant, pollen and insect fossils found in the Ping Chau Formation comprise a Late Cretaceous to Tertiary assemblage. While some organisms could have appeared as early as the Late Cretaceous, until their extinction in the Tertiary, some of the plant fossils are Tertiary index fossils (*i.e.* they are confined to the Tertiary). Hence, these index fossils enable the Ping Chau Formation to be assigned an Early Tertiary age.

The Ping Chau Formation is estimated to be greater than 450 m thick. Seismic surveys clearly show that the rocks underlie the surrounding seabed. Mapping the regional geology has shown that sediments of the Ping Chau Formation were deposited without interruption on the red sediments of the Cretaceous Port Island Formation. Together with the underlying Port Island Formation, the Ping Chau Formation forms a gently inclined, open basin in Mirs Bay.



Distribution of rock type and red attitude in the Ping Chau Formation

Guide to Field Observations

Owing to excellent coastal exposures that are devoid of vegetation cover, the sedimentary rocks of Ping Chau can be easily examined. Access to rock outcrops is easy along the many footpaths that cross the island, and it is possible to observe the rock strata along the coastal platform at low tide.

Study of the rock outcrops, particularly at the northern and southern ends of Ping Chau, provides an opportunity to understand shallow freshwater lake-type sedimentation processes. At the northern end of the island, the rock layers are inclined towards the southeast, whereas at the southern end, they tilt towards northwest. Thus, the island is arcuate in shape. The dip angle of the rock layers varies from 11^o to 21^o (see figure above).

Convolute bedding in the Ping Chau Formation

Angular fragment and calcite cement infilled along a tensional fault

Careful observation will enable identification of sedimentary structures, such as low-angle inclined bedding and convolute structures. Other structures, such as mud cracks, ripple marks, rain prints, hieroglyphs/scolite, should also be searched for as additional evidence of the depositional environment.

In general, fossils can be found in the well-sorted and fine-grained sedimentary rocks, such as the siltstone and mudstone. Patience is required for fossil hunting. However, please do not destroy the natural environment by haphazardly splitting rocks searching for fossils.

Comments

The Yanshanian mountain-building period, which had a major influence in the coastal region in southeast China, concluded in the Late Cretaceous. The subsequent Himalayan mountain-building period, during the Tertiary period, mainly affected the western part of China. Consequently, the coastal area of southern China has remained fairly stable since the Late Cretaceous. Although some local earth movement has occurred along faults, it is thought that the post-Cretaceous sedimentary sequence in the coastal area of southern China, to which the Ping Chau Formation belongs, has retained much of its original character throughout the Tertiary.

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Kemp, S.J., Styles, M.T. & Merriman, R.J. 1997. *Mineralogy of Tertiary sedimentary rocks from Ping Chau, Hong Kong.* British Geological Survey Technical Report, Mineralogy & Petrology Series, Report No. WG/97/27C, British Geological Survey, U.K., 16 p.

Lai, K.W. 1991. Stratigraphy of the Ping Chau Formation, Hong Kong. *Geological Society of Hong Kong Newsletter*, v. 9, no. 2, pp 3–23.

Lai, K.W. 1997. Early Tertiary Depositional Basins of Hong Kong. *Proceedings of the 30th International Geological Congress,* International Science Publishers, Netherlands, 8, pp 107 - 120.

Lee, C.M., Atherton M.J., Wu S.Q., He, G.X., Chen J.H. & Nau, P.S. 1991a. Discovery of Angiosperm fossils from Hong Kong with discussion on the age of the Ping Chau Formation. *Geological Society of Hong Kong Newsletter*, v. 9, no. 1, pp 50 – 60.

Lee, C.M., Chan, K.W. & Ho, K.H. 1998. *Palaeontology and stratigraphy of Hong Kong, Volume 2.* Science Press, Beijing, 242 p. plus 81 plates (In Chinese).

Lee, C.M., Chen J.H., He, G.X., Atherton M.J. & Lai, K.W. 1991b. On the age of the Ping Chau Formation. *Geological Society of Hong Kong Newsletter*, v. 9, no. 1, pp 34 - 49.

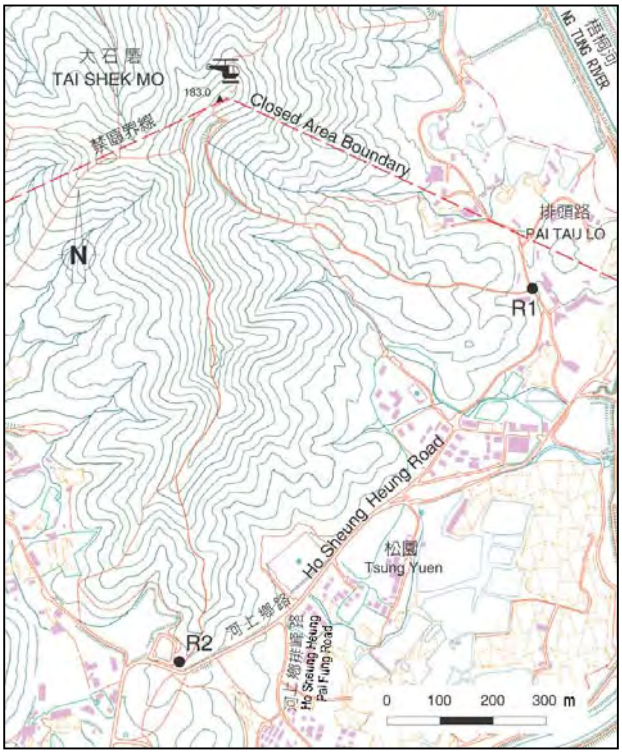
Williams, M.Y. 1943. The stratigraphy and palaeontology of Hong Kong and the New Territories. *Transactions of the Royal Society of Canada*, Third Series, v. 37, sect. IV, pp 93–117.

7. Metasedimentary Rocks – Lok Ma Chau Formation

Introduction

The Carboniferous rocks of Hong Kong are represented by the San Tin Group. They comprise the carbonate rocks (*i.e.* marble) of the Yuen Long Formation, Lower San Tin Group, and the overlying non-carbonate sedimentary rocks of the Lok Ma Chau Formation, Upper San Tin Group. Although the Yuen Long Formation is known to exhibit a uniform change upwards into the Lok Ma Chau Formation, the nature of the top of the Upper San Tin Group is not known.

The carbonate rocks of the Yuen Long Formation are not exposed at the surface in Hong Kong. Consequently, they have been proved entirely by drillholes. In contrast, the Lok Ma Chau Formation is exposed over a relatively large area in the northern part of the New Territories. Two members of the Lok Ma Chau Formation can be distinguished, the lower Mai Po Member and the upper Tai Shek Mo Member.



Map of the route to Tai Shek Mo

The outcrops of the Lok Ma Chau Formation are mainly confined to the area between Lok Ma Chau and Man Kam To, where they form a series of low hills. Outcrops to the west of Lo Wu are located within the Closed Frontier Area, so they are not easily accessible for field inspection. The Formation is most easily seen between Chau Tau, Lok Ma Chau and Tai Shek Mo, Ho Sheung Heung, especially along the ridge extending southwards from the summit of Tai Shek Mo. These Palaeozoic metasedimentary rocks are particularly well exposed in this area, and they are easily accessible by public transport.

How to Get There

Tai Shek Mo is a hill located to the northwest of Ho Sheung Heung, Lo Wu, in the northern New Territories. The highest peak in the area is only 183 m high. Tai Shek Mo can be accessed from several directions. By private car, turn onto Ho Sheung Heung Road from Chau Tau, Castle Peak Road, and then drive northwards along the Ho Sheung Heung Road until an uphill road is encountered (point R1 on the Route Map). The summit of the Tai Shek Mo can be reached by driving northwestwards along this road. Alternatively, take Green Mini Bus Route no. 51K from Sheung Shui KCR Station, and then alight from the mini bus at Ho Sheung Heung Road. Walk northwards along the Ho Sheung Heung Road until a walking trail appears just before the Ho Sheung Heung Pai Fung Road. (point R2 on the Route Map). Walk northward along the trail to the peak of Tai Shek Mo. Please note that the area north of the peak is within the boundary of the Closed Frontier Area, so do not enter without permission.

Vehicle access to Tai Shek Mo Hill (R1)

Access to Tai Shek Mo Hill by the northward walking trail (R2)

Outline of the Geology

The hills between Lo Wu, Tai Shek Mo and Pak Shek Au to Lok Ma Chau in the northern New Territories are underlain by rocks of the Carboniferous Lok Ma Chau Formation. The Tai Shek Mo Member, which forms the upper part of the Formation, comprises mainly metasandstones intercalated with metaconglomerate and phyllite. These rock types form the hill of Tai Shek Mo. The Mai Po Member, which forms the lower part of the Lok Ma Chau Formation, comprises mainly metasiltstone, phyllite intercalated with metasandstone, and graphite. These rocks are exposed only at the foot of Tai Shek Mo. The outcrop of the Lok Ma Chau Formation in Hong Kong is bounded to the north by the Shenzhen River. To the south, the Formation is in abrupt contact with the Jurassic Tai Mo Shan Formation, of the Tsuen Wan Volcanic Group. Here, the Lok Ma Chau Formation is thrust over the Tai Mo Shan Formation. This major thrust fault was named the San Tin Fault by Sewell *et al.* (2000). The rocks on both sides of the fault have been altered (metamorphosed). Thus, the rock layers have been distorted toward a certain direction and, in some cases, they have been intensely deformed (mylonitised). Mudstone and carbonaceous mudstone have been altered to phyllite and graphite respectively.

Metasandstone outcrop

Metaconglomerate outcrop

Schistose fine sandstone outcrop

Siltstone outcrop

Sandstone laminations and lens in siltstone. Note that the sandstone has been altered to quartzite

Conformable thick quartzite beds (lower) and thin siltstone beds (upper)

Phyllite outcrop

Late stage quartz veins

<u>Guide to Field Observations</u>

The safest way to inspect the Lok Ma Chau Formation rocks is to walk along the ridge crest, because the slopes are steep and dangerous. Fortunately, the outcrops are more continuous along the ridge than on the side slopes.

1) Try to identify the different rock types, *i.e.* look for sandstone, siltstone and conglomerate along the ridge. Also, try to distinguish between the Tai Shek Mo Member and the Mai Po Member in the field.

2) Observe and measure the rock fabrics. It is important to differentiate between the metamorphic fabric (schistosity) and the bedding planes in the rocks.

3) Observe the various degrees of metamorphism, and look for changes in the appearance of the rocks caused by metamorphism.

4) Search for late stage quartz veins. Compare the relationship between the direction of the quartz veins and the direction of the rock bedding or schistosity.

5) Inspect the relative resistance to weathering of the various rock types, and note how these differences affect the landforms in the area.

Outcrops along the main ridge

Comments

In addition to extensive exposures in the northern New Territories, the Carboniferous sedimentary rocks of the San Tin Group are also present below Yuen Long and Tin Shui Wai, and along the eastern side of the Tuen Mun Valley. The San Tin Group carbonate rocks occur offshore on the northern side of Lantau Island. There, they are entirely covered by Quaternary superficial deposits, having been proven by drillholes. The carbonate rocks (now metamorphosed to marble) of the Yuen Long Formation are soluble, resulting in the formation of solution cavities that have had important consequences for designing and constructing building foundations in the area.

The graphite bearing siltstone and graphitic schist exposed on The Brothers islands to the north of Lantau Island belong to the Mai Po Member of the Lok Ma Chau Formation. Detailed studies have concluded that the Lok Ma Chau Formation was deposited in a prograding delta (Lai *et al.*, 1988). A prograding delta is one that extends progressively seaward from a river mouth. Sandstone, conglomeratic sandstone, and conglomerate are typical deltaic sediments. In contrast, evidence suggests that the fine sandstone, siltstone and carbonaceous layers of the Mai Po Member were deposited in a near-shore tidal flat or on the alluvial plain of a delta.

References

Allen, P. M. & Stephens, E. A. 1969. *Interim report on the Geological Survey of Hong Kong*. Overseas Division, Institute of Geological Sciences, London, 133 p.

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Atherton, M.J. & Burnett, A.D. 1986. *Hong Kong Rocks*. Published by the Urban Council, Hong Kong, 145 p.

Bennett, J.D. 1984b. *Review of Hong Kong Stratigraphy*. GCO Publication No. 5/84, Geotechnical Control Office, Hong Kong, 62 p.

Chan, M.C. 1987. Petrography of the Lower Carboniferous San Tin Group, Hong Kong. *Geological Society of Hong Kong Newsletter*, v. 5, no. 2, pp 9 - 15.

Davis, S.G. 1952. *The geology of Hong Kong.* Government Printer, Hong Kong. 231 p. plus 14 plates & 3 maps.

Fletcher, C.J.N., Campbell, S.D.G., Busby, J.P., Carruthers, R.M. & Lai, K.W. 1997. Regional tectonic setting of Hong Kong: implications of new gravity models. *Journal of the Geological Society*, v. 154, pp 1021–1030.

Frost, D.V. 1992. *Geology of Yuen Long, Hong Kong Geological Survey Sheet Report*

No.1, Geotechnical Engineering Office, Civil Engineering Department, Hong Kong, 69 p.

Geotechnical Control Office 1988. *Geotechnical Area Studies Programme, North New Territories, GASP Report V*, Civil Engineering Services Department, Hong Kong Government, 134 p.

Ha, T.H.C., Ng, S.K.C. & Li, Q.W. 1981. Discovery of carbonate rocks in the Yuen Long area, Hong Kong. *Hong Kong Baptist College Academic Journal*, v. 8, pp 129–131.

Lai, K.W. 1977. Major geotectonic features of Hong Kong. *Hong Kong Baptist College Academic Journal*, v. 4, pp 241–286.

Lai, K.W., Campbell, S.D.G. & Shaw, R. 1996. *Geology of the northeastern New Territories.* Hong Kong Geological Survey Memoir No. 5, Geotechnical Engineering Office, Civil Engineering Department, Hong Kong, 143 p.

Lai, K.W. & Hansen, A. 1987. Report of a field trip to the Northwestern New Territories. *Geological Society of Hong Kong Newsletter*, v. 5, no. 2, pp 16 - 18.

Lai, K.W. & Mui, M. 1984. The stratigraphy of the Lok Ma Chau Formation in Hong Kong. *Hong Kong Baptist College Academic Journal*, v. 11, pp 177–185.

Langford, R.L., Lai, K.W., Arthurton, R.S. & Shaw R. 1989. *Geology of the Western New Territories. Hong Kong Geological Survey Memoir No.3*, Geotechnical Control Office, Civil Engineering Services Department Hong Kong, 140 p.

Lee, C.M. 1985. Explanatory Notes by C.M. Lee on his stratigraphic column in Table 1. *Geological Society of Hong Kong Newsletter*, v. 3, pp 8 - 9.

Ruxton, B.P. 1960. The Geology of Hong Kong. *Quarterly Journal of Geological Society of London*, v. 115, pp 233-260.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

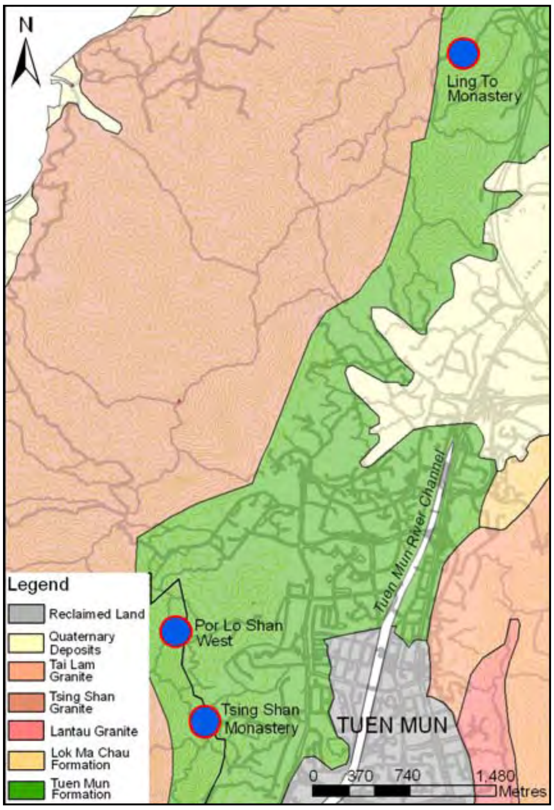
Williams, M.Y. 1943. The stratigraphy and palaeontology of Hong Kong and the New Territories. *Transactions of the Royal Society of Canada*, Third Series, v. 37, sect. IV, pp 93–117.

Tsing Shan Monastery, Tuen Mun, Western New Territories – Ling Tao Monastery, Northwestern New Territories

8. Volcanic Breccia and Conglomerate – Lower Part of the Tuen Mun Formation

<u>Introduction</u>

Although the Tuen Mun Formation is largely the product of volcanic-related processes, the characteristics of the rocks differ markedly from those exposed elsewhere in Hong Kong. Outcrops of the Tuen Mun Formation are confined to the north-south trending Tuen Mun Valley. In the west, the Jurassic Tsing Shan Granite is in fault contact with the Tuen Mun Formation. In the east, the Formation is also partly faulted against the Carboniferous Lok Ma Chau Formation of the San Tin Group and the Jurassic Tai Lam Granite. The Pre-Quaternary Geology of Hong Kong (Sewell *et al.* 2000) described two subdivisions of the Tuen Mun Formation. The lower part, previously named the Tsing Shan Formation, comprises a largely volcanic-sedimentary sequence. The upper part mainly comprises andesitic lavas with some inter-bedded lapilli-bearing ash crystal tuffs. Thus, the lower part of the depositional sequence predominantly consists of re-sedimented granular volcanic material, suggesting a period of erosion, whereas the upper part predominantly consists of primary volcanic material derived directly from volcanic eruptions.



Distribution of the Tuen Mun Formation

The outcrops at Tuen Mun, Ho Tin Tsuen, and the Tuen Mun North Salt Water Service Reservoir consist mainly of andesite and andesitic breccia, which are typical of the upper, primary volcanic, subdivision of Tuen Mun Formation (see Chapter 9). Rocks outcropping at Tsing Shan Monastery, West Por Lo Shan, and Ling Tao Monastery in the northwestern New Territories, belong to the lower, re-sedimented, subdivision of the Formation. There are many similarities between the rocks at these three locations.

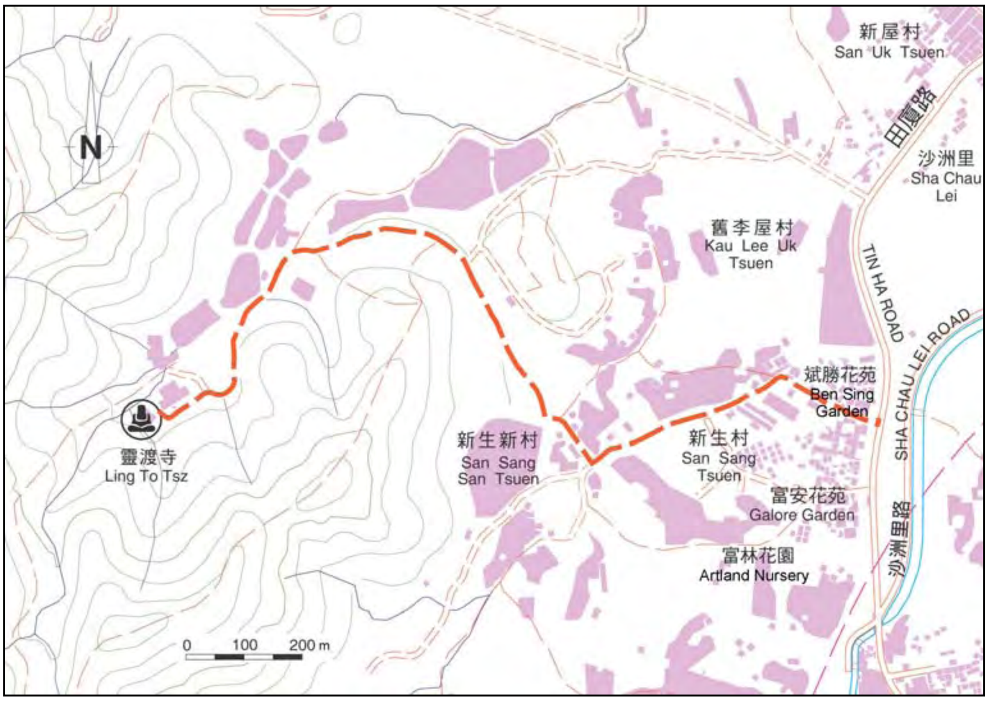
They largely consist of conglomerate, breccia and fine-grained sedimentary rocks, such as sandstone and siltstone, that suggest the reworking of volcanic-related material.

However, some debate surrounds the interpretation of the origin of these rocks. An alternative view holds that the rocks exposed at these localities, in particular the fine-grained rocks exposed at West Por Lo Shan and Ling Tao Monastery, are related to primary magmatic activity rather than to re-sedimentation of volcanic materials. Instead of having a sedimentary origin, the fine-grained rocks are considered to be equivalent to andesite lava, whereas the conglomerates and breccias are primary fragmental volcanic deposits set within an andesitic lava matrix. Because these rocks have limited exposure, and have been affected to varying degrees by metamorphism, weathering, and other forms of alteration, further detailed field and desk studies are required to confirm this view of the origin of these interesting rocks.

<u>How to Get There</u>

1) Ling Tao Monastery

Because Ling Tao Monastery is located in an undeveloped area between Tsing Shan and Tin Shui Wai, the roads connecting the small villages are un-named, and there are no public transport services.

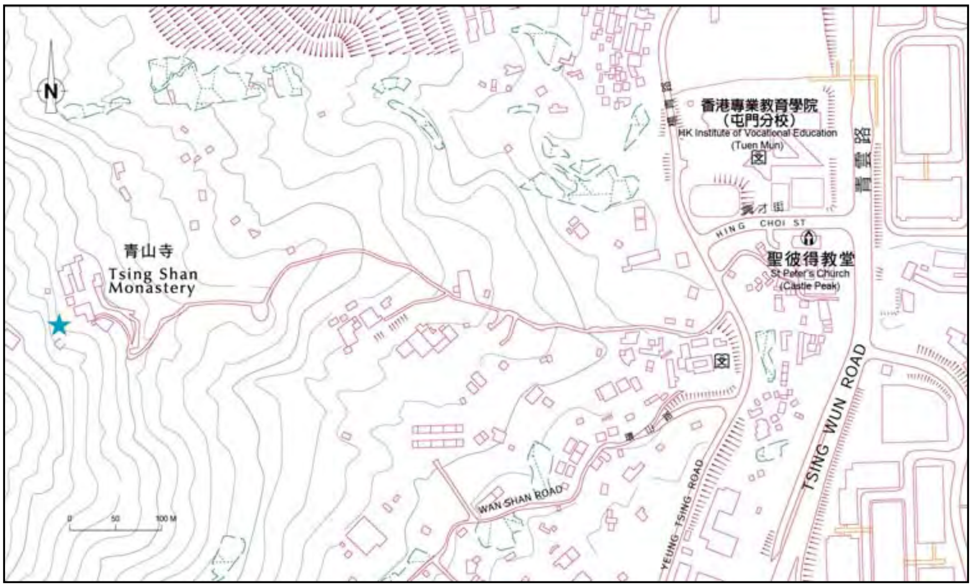


Route map to Ling Tao Monastery

Ling Tao Monastery is best reached from Tin Shui Wai by heading southwards along Tin Ha Road as far as the west branching road near San Sang Tsuen (between Ben Shing Fa Yuen and San Sang Tsuen). Head west along this road, then follow the path shown on the route map. Local taxi drivers will usually know the way to Ling Tao Monastery.

2) Tsing Shan Monastery

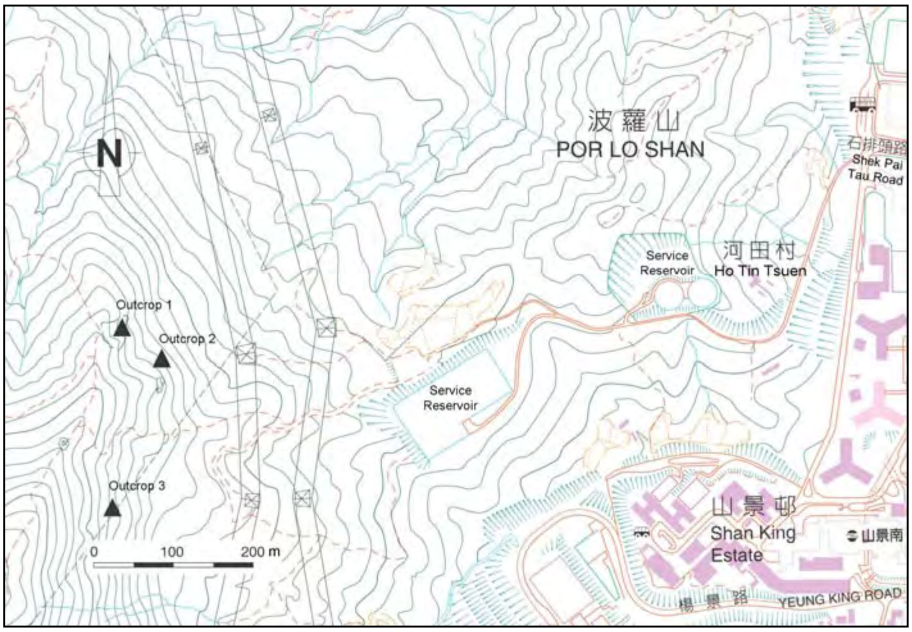
Tsing Shan Monastery is located mid-way up the slopes of Tsing Shan, not far from Tuen Mun Town Centre. However, there is no direct connection by public transport. For a field trip to Tsing Shan Monastery using private transport, depart from Yeung Tsing Road at west Tuen Mun, then turn west into a rising driveway. Follow this road up to Tsing Shan Monastery. Alternatively, various public bus routes, and the KCR light rail, may be taken to the Hong Kong Institute of Vocational Education (Tuen Mun), followed by an uphill walk to the Monastery. The public bus options include: route no. 57M (Tuen Mun Shan King Estate – North Lai King), route no. 66X (Tai Hing – Olympic Station), route no. 257B (Tuen Mun Shan King Estate – Tsim Sha Tsui) and route no. 258D (Leung King Estate – Lam Tin MTR Station).



Route map to Tsing Shan Monastery

3) West Por Lo Shan

West Por Lo Shan is not an official place name, but is adopted here for convenience. The area is located mid-way up the slopes of Tsing Shan, about 700 m north of the Tsing Shan Monastery. Geological field observation points at west Por Lo Shan are located near the andesite outcrop at the Tuen Mun North Salt Water Service Reservoir. Walk westwards along the reservoir driveway to a small open area at the end, then climb up a footpath to the mid-slopes of Tsing Shan. There are two outcrops, north and south, which have similar rock types and bedding. If time is limited, a visit to the southern outcrop (outcrop 3 in the figure) is recommended.



Route map to west Por Lo Shan

Outline of the Geology

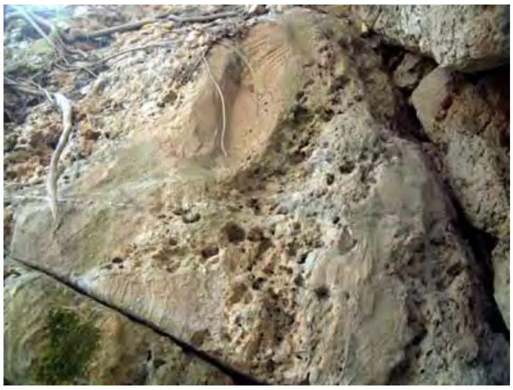
The rocks at Tsing Shan Monastery consist of a variety of conglomerates and breccias. The clasts are very poorly sorted and mostly angular to subangular, but in some locations they are slightly rounded. These rocks may have formed following the collapse of a volcanic edifice, or by fluvial activity on the margin of a crater lake. Layers of seemingly flow-banded rocks can be observed in some places. The layers are about 30-40 cm thick and are discontinuous. These layers are probably andesitic,

Breccia/Conglomerate in Tsing Shan

Conglomerate in Tsing Shan Monastery

and may have been formed by small-scale, localised magmatic flow through the conglomerate layer. This phenomenon is most pronounced at Ling Tao Monastery.


Breccia at Tsing Shan Monastery


Fine-grained banded strata between breccia/conglomerate

At Ling Tao Monastery, interbedded coarse- and fine-grained rocks can be seen in some places. The appearance of bedded conglomerate and breccias suggests that they could have been deposited by gravity flows in close proximity to a volcanic vent or caldera. Interestingly, the rocks contain both angular and rounded clasts. This can be explained by the fact that, following an eruption, volcanic materials were reworked under gravity, possibly assisted by rainwater. Angular, gravel-sized fragments in the flow became rounded as they were transported downslope. Gravitational collapse of the volcanic edifice could have provided a new supply of angular materials. The fine-grained rocks are andesite, possibly emplaced by volcanic activity. Relatively minor, imtermittent eruptions from a nearby volcano may have produced thin andesite lavas that flowed downslope over the transported fragmental deposits. In this way, a sequence of interbedded conglomerate/breccias and andesite could have been laid down.


Breccia/Conglomerate near Ling Tao Monastery


Conglomerate near Ling Tao Monastery

Complex composition of gravel in conglomerate near Ling Tao Monastery

Contact relationship between conglomerate and andesite near Ling Tao Monastery

The characteristics of the outcrop at west Por Lo Shan are very similar to those at Ling Tao Monastery and Tsing Shan Monastery. Because these outcrops stand out prominently in the landscape, one interpretation holds that they are volcanic plugs. It is noteworthy that two rock types exist at outcrop 3. The lower part of the slope consists mainly of conglomerate containing rounded clasts of an homogeneous composition, set within a pale greyish-white coarse ash crystal tuff matrix. In contrast, the upper part of the slope comprises a conglomerate/breccia that contains mainly angular to sub-angular clasts. The latter rock type is more prominent in the landscape. The rock types at outcrops 1 and 2 are similar to the latter one.

Outcrop 3 at west Por Lo Shan: A possible volcanic plug?

Complex composition of conglomerate at west Por Lo Shan

The characteristics of the rock outcrops at Ling Tao Monastery, west Por Lo Shan and Tsing Shan Monastery indicate that they belong to the lower part of Tuen Mun Formation, the volcanic-sedimentary sequence (*i.e.* formerly the Tsing Shan Formation). This fact is generally agreed.

The interpretation of a re-sedimentation (sedimentary) origin of the conglomerate and breccias of the lower part of the Tuen Mun Formation has been challenged. Because these outcrops stand out prominently in the landscape at west Por Lo Shan, one interpretation holds that they are volcanic plugs.

The origins of the rocks of the lower part of Tuen Mun Formations are the subject of debate. There are generally two interpretations and the key points of debate are:

1) The conglomerate and breccia are primary volcanic rocks formed as volcanic plugs (volcanic vents). In this case, the conglomerate and breccias would have formed by magma entraining, carrying and fusing rock fragments during extrusion. The fine-grained rocks in the sequence are presumably andesite.

2) The conglomerate and breccias are secondary volcanic deposits formed by reworking of volcanic-related materials. In this case, the conglomerate and breccias would have formed on the flanks of a volcano, largely by sedimentary processes such as fluvial flow or a volcanic mudflow, possibly incorporating hot ash flows. Since then, these strata have been orientated vertically by deformation associated with faulting.

Conglomerate with coarse ash crystal tuff, west Por Lo Shan

Relationships between fine-grained strata and conglomerate

Guide to Field Observations

When carrying out field observations at the three localities of Tsing Shan Monastery, west Por Lo Shan and Ling Tao Monastery, diagnostic evidence can be searched for at the outcrops to determine if the exposed rocks are primary volcanic rocks or secondary volcanic rocks deposited on the flanks of a volcano. Particular attention should be paid to the following features:

1) The bedding orientation of the strata, its pattern and distribution.

2) The composition and relative proportions of the contained rock fragments.

3) The size and shape (rounding) of the contained rock fragments.

4) The orientation of the contained rock fragments.

5) The composition of the matrix cementing the rock fragments.

6) The relationship between the contained rock fragments and the matrix.

7) The composition and structure of the fine-grained strata, and their contact relationships with adjacent strata.

8) The characteristics of the weathered rock materials, including their relative resistance to weathering.

9) The distribution and characteristics of joints in the strata.

Comments

Slopes on the eastern side of Tsing Shan are relatively steep, with angles of about 28°-30°. Jurassic age Tsing Shan Granite is exposed from the top of Tsing Shan to the mid-slopes. The Tuen Mun Formation crops out in a north-south strip that occupies the lower eastern slopes of Tsing Shan and the Tuen Mun Valley. The western margin of the Tuen Mun Formation is in fault contact with Tsing Shan Granite. Therefore, in addition to the complexity of rock types in the district, there is also evidence for structural disturbance on major faults. Several questions can be considered. For example, what are the relationships between the rocks that crop out at Tsing Shan Monastery, west Por Lo Shan and Ling Tao Monastery? Do they belong to the same group of rocks? Do conglomerates and breccias exposed at the above three locations share the same origin as similar rocks in the Tuen Mun Valley, especially those observed in drillholes around Tin Shui Wai that contain marble fragments? Do the upstanding outcrops of vertical strata at west Por Lo Shan represent the remnants of a volcanic plug, or were these strata originally laid down on the flanks of a volcano and have since been orientated vertically by deformation associated with movement on the Tsing Shan Fault?

Rock cores with marble clasts, Tuen Mun Valley

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Bennett, J.D. 1984c. *Review of Tectonic History, Structure and Metamorphism of Hong Kong*. GCO Publication No. 6/84, Geotechnical Control Office, Hong Kong, 63 p.

Campbell, S.D.G.. & Sewell R.J. 1997. Structural control and tectonic setting of Mesozoic volcanism in Hong Kong. *Journal of the Geological Society*, London, v. 154, pp 1039-1052.

Campbell, S.D.G. & Sewell, R.J. 1998. A proposed revision of the volcanic stratigraphy and related plutonic classification of Hong Kong. *Hong Kong Geologist*, v. 4, pp 1–11.

Darigo, N.J. 1990. Marble-bearing Jurassic volcanics of the western New Territories, Hong Kong.) *Karst geology in Hong Kong*, Geological Society of Hong Kong Bulletin No. 4, pp 61 - 72.

Davis, D.W., Sewell, R.J. & Campbell, S.D.G. 1997. U–Pb dating of Mesozoic igneous rocks from Hong Kong. *Journal of the Geological Society*, v. 154, pp 1067–1076.

Fisher, R.V. & Schminke, H.U. 1984. *Pyroclastic rocks*. Springer Verlag, New York, 472 p.

Lai, K.W. 2004. The characteristics of marble-bearing volcanic rock and its influence on foundation design in Hong Kong. In: Yueng, A.T. (Ed.) *Proceedings of the Conference on Foundation Practice in Hong Kong*, pp E1 – E10.

Langford, R.L., Lai, K.W., Arthurton, R.S. & Shaw, R. 1989. *Geology of the Western New Territories*. Hong Kong Geological Survey Memoir No. 3, Geotechnical Control Office, Civil Engineering Services Department, Hong Kong Government, 140 p.

Ruxton, B.P. 1960. The Geology of Hong Kong. *Quarterly Journal of Geological Society of London*, v. 115, pp 233-260.

Sewell, R.J. & Campbell, S.D.G. 1997. Geochemistry of coeval Mesozoic plutonic and volcanic suites in Hong Kong. *Journal of the Geological Society*, Vol. 154, pp 1053–1066.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Workman, D.R. 1983. Field description of pyroclastic rocks. *Geological Society of Hong Kong Newsletter*, v. 1, no. 2, pp 3 – 6.

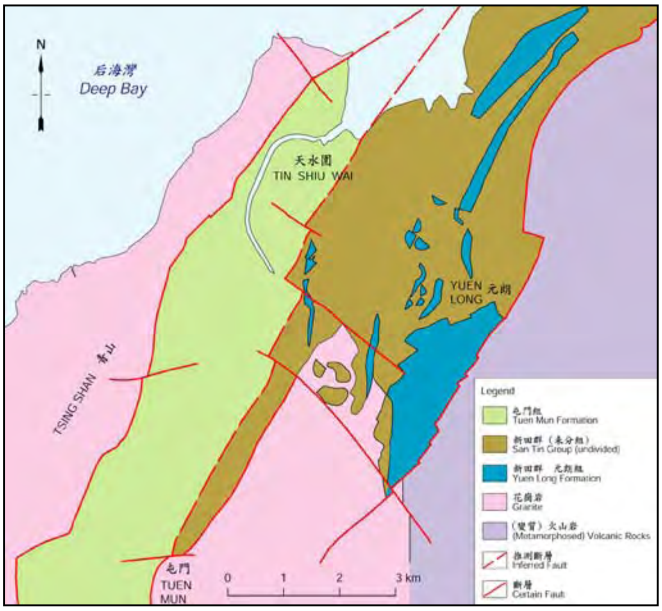
Chapter 9. Andesite Breccia – Upper Member of the Tuen Mun Formation

<u>Introduction</u>

The area between Tuen Mun and Tin Shui Wai is a northeast-trending low-lying valley, known as the Tuen Mun Valley. Rocks preserved in this area are part of an ancient volcanic province, and represent the earliest volcanic activity recorded in the geological history of Hong Kong. Several cycles of eruption have been identified.

In the Tuen Mun Valley, the magmas are dominantly intermediate (andesitic), whereas most other magmas found in Hong Kong are acidic (felsic). Because andesitic magmas have a lower viscosity, and thus flow more easily than acidic magmas, the effusive styles characteristically included near-surface intrusions and lava flows, rather than the explosive eruptions typically associated with felsic magmas.

Fluvial and other sedimentation continued during the quiet periods that occurred between the cycles of volcanic eruption. Consequently, a large variation in rock types is found in the Tuen Mun Valley. These rock assemblages are grouped together as the Tuen Mun Formation. The Formation is fault-bounded, and is restricted to the Tuen Mun Valley.



Distribution of the Tuen Mun Formation (simplified from Sewell *et al.*, 2000)

Andesite and andesitic breccia exposed near the Tuen Mun North Salt Water Service Reservoir are the most important rock types occurring in the Tuen Mun Formation.

How to Get There

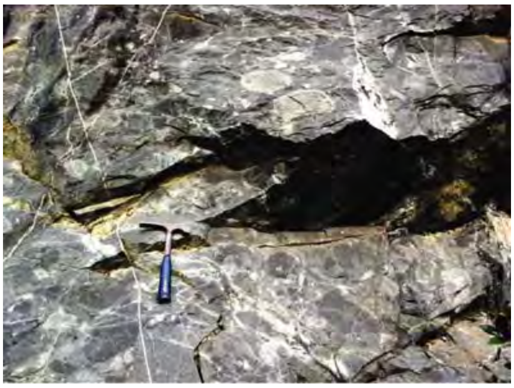
The rock outcrops near Tuen Mun North Salt Water Service Reservoir are the most convenient exposures to visit. From the bus terminal at Shek Pai Tau Road in the Shan King Estate, locate the path from the western side of the road to Ho Tin Tsuen. Follow this path for about 500 m to reach a gate to the Tuen Mun North Salt Water Service Reservoir. An outcrop of andesitic breccia is located on the hillslope near the gate of the Service Reservoir. Similar outcrops of andesitic breccia can be seen on the cut-slope near the western end of Shek Pai Tau Road. Compare the different outcrops of andesite.

Access to Ho Tin Tsuen Service Reservoir

Outline of the Geology

The rocks exposed near the Tuen Mun North Salt Water Service Reservoir are mainly andesitic breccias of the Tuen Mun Formation. Rocks of the Formation include near surface intrusions, lava flows, and tuff breccia, as well as sedimentary breccias and sandstones. On the HKGS 1:20,000-scale geological map sheet No. 5 (GEO, 1988), the rocks in the Tuen Mun Valley were divided into two formations: (1) the lower Tsing Shan Formation, located in western part of the Tuen Mun Valley, comprising mainly sandstone, siltstone, and mudstone interbedded with conglomerate and tuff; and (2) the upper Tuen Mun Formation, located in the eastern part of the Tuen Mun Valley, comprising mainly andesites interbedded with tuff and tuffite. Later, in the "Pre-Quaternary Geology of Hong Kong", Sewell *et al.* (2000) combined the two

Brecciated andesite near Tuen Mun North Service Reservoir



Brecciated andesite near Tuen Mun North Service Reservoir

formations as the Tuen Mun Formation, but with two parts. The lower part includes mainly volcanic-related sedimentary rocks that are equivalent to the original Tsing Shan Formation, whereas the upper part consists of andesite lava interbedded with lapilli ash crystal tuff, which corresponds to the original Tuen Mun Formation.

Outcrops near the Tuen Mun North Salt Water Service Reservoir, comprising mainly andesite and andesitic breccia, are typical of the upper part of the Tuen Mun Formation, whereas the conglomerate and breccia cropping out near Ling Tao Monastery and Po Lo Shan West are thought to represent the lower part of the Tuen Mun Formation.

Andesitic clasts in brecciated andesite

Lithic clasts in brecciated andesit

The andesitic breccia was most probably formed during multiple phases of intrusion, an earlier andesite magma being fragmented and incorporated within later intrusions of andesitic magma. Evidence of an intrusive origin is demonstrated by the inclusion of fragments of the surrounding host (country) rock within the breccia. However, two alternative explanations have been proposed. One possibility is that an andesitic lava flow was covered by a fluvial conglomerate, or flowed over semi-consolidated conglomerate. Another possibility is that the andesitic breccia represents a near-surface intrusion. Overall, however, the characteristics of the rocks suggest an extrusive, rather than an intrusive, origin.

Importantly, the rocks are altered. Alteration is common in mafic to intermediate rocks such as andesite. In the presence of carbonate- and sulphur-rich hydrothermal fluids, minerals in the andesite may be altered to calcite, chlorite, epidote and serpentine. As a result, the hydrothermally-altered andesite exhibits a greenish colour.

Altered andesite

Guide to Field Observations

This site is relatively small, providing an opportunity to carry out relatively detailed observations. Moreover, it is possible to carry out systematic measurements of the size and composition of the clasts, and then to compare these with the composition of the breccia groundmass.

The following questions should be asked while examining and measuring the exposures:

1) Are the contained clasts arranged in a particular pattern, or are they concentrated in certain areas?

2) How rounded are the clasts? Are there any clasts that show a jig-saw pattern fit?

3) What rock types are the clasts, and what are the proportions of the different types of rock clasts?

4) Are there any systematic changes in size and distribution of the clasts, either horizontally or vertically? If there are, what are the controlling factors?

5) What are the differences between volcanic breccias and sedimentary breccias?

Try to compare the outcrops near the Service Reservoir with those near the Bus Terminal in Shek Pai Road. The outcrops near the bus terminal are andesite lava that contains very few brecciated clasts and shows only weak alteration. This location may represent the main body of the magma intrusion. On the other hand, outcrops near the Service Reservoir formed relatively near to the margin of intrusion, so may have been more easily fragmented and incorporated in the adjacent country rocks.

Discussion

The Tuen Mun Formation has been provisionally dated by ^{40}Ar-^{39}Ar (Argon-Argon) methods at approximately 182 million years old. Thus, the rocks of the Tuen Mun Formation are older than most other volcanic rocks in Hong Kong, which have yielded dates of between about 165 million years and 140 million years old. Following cessation of the magmatic activity represented by the Tuen Mun Formation, there is estimated to have been a gap of about 20 million years before further magmatic activity commenced. During this hiatus, the sources of magma underwent a significant change. Rocks of the Tuen Mun Formation are intermediate andesitic, whereas the younger igneous rocks, whether intrusive or extrusive, are all granitic or rhyolitic. Therefore, the Tuen Mun Formation is unique in Hong Kong, characterised by magma sources and associated volcanic activity that are generally quite different from those of the younger magmatic episodes in Hong Kong.

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Atherton, M.J. & Burnett, A.D. 1986. *Hong Kong Rocks*. Published by the Urban Council, Hong Kong, 145 p.

Campbell, S.D.G.. & Sewell R.J. 1997. Structural control and tectonic setting of Mesozoic volcanism in Hong Kong. *Journal of the Geological Society*, London, v. 154, pp 1039-1052.

Campbell, S.D.G. & Sewell, R.J. 1998. A proposed revision of the volcanic stratigraphy and related plutonic classification of Hong Kong. *Hong Kong Geologist*, v. 4, pp 1–11.

Davis, D.W., Sewell, R.J. & Campbell, S.D.G. 1997. U–Pb dating of Mesozoic igneous rocks from Hong Kong. *Journal of the Geological Society*, v. 154, pp 1067–1076.

Fisher, R.V. & Schminke, H.U. 1984. *Pyroclastic rocks*. Springer Verlag, New York, 472 p.

Frost, D.V. 1992. *Geology of Yuen Long*. Hong Kong Geological Survey Sheet Report No. 1, Geotechnical Engineering Office, Civil Enginering Department, Hong Kong Government, 69 p.

Langford, R.L., 1991. Discussion on marble clasts in coarse ash crystal tuff at Au Tau, New Territories, Hong Kong. *Geological Society of Hong Kong Newsletter*, v. 9, no. 2, p. 52.

Langford, R.L., Lai, K.W., Arthurton, R.S. & Shaw, R. 1989. *Geology of the Western New Territories*. Hong Kong Geological Survey Memoir No. 3, Geotechnical Control Office, Civil Engineering Services Department, Hong Kong Government, 140 p.

Ruxton, B.P. 1960. The Geology of Hong Kong. *Quarterly Journal of Geological Society of London*, v. 115, pp 233-260.

Sewell, R.J. & Campbell, S.D.G. 1997. Geochemistry of coeval Mesozoic plutonic and volcanic suites in Hong Kong. *Journal of the Geological Society*, Vol. 154, pp 1053–1066.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Wong, K.M. 1991. Marble clasts in coarse ash crystal tuff at Au Tau, New Territories, Hong Kong. *Geological Society of Hong Kong Newsletter*, v. 9, no. 1, pp 16 - 19.

Chapter 10 – Agglomeratic Tuff – Shek Lung Kung Member of the Shing Mun Formation

Background

Agglomeratic tuff and volcanic breccia are generally formed by the accumulation of coarse volcanic fragments (ejecta). These originate either, directly from explosive activity (agglomeratic tuff), or, indirectly by gravitational collapse of a pre-existing accumulation of material close to an eruption vent (volcanic breccia). Magma rising through the earth's crust may break-off and entrain fragments of the surrounding rocks. These fragments are then erupted along with the magma at the surface. During an explosive eruption, the larger rock fragments are deposited subaerially close to the volcanic vent, forming agglomeratic tuff. Following an eruption, material deposited near the source vent may become unstable, leading to collapse of the volcanic edifice and the formation of thick volcanic breccia layers. Therefore, the occurrence of agglomeratic tuff and volcanic breccia, suggests proximity to an original source vent. Finer material erupted from the vent is carried higher and further within an ash cloud and may be deposited many kilometres away from the vent.

Directions to Shek Lung Kung

Volcanic rocks, including volcanic breccia, are widely distributed in Hong Kong. However, agglomeratic tuff is less common. There are well-developed agglomeratic tuff and volcanic breccia outcrops at Sheung Fa Shan and Shek Long Kung, northwest of Tsuen Wan. Rock types in this area differ from those at Tai Mo Shan. The coarse fragmental nature of agglomeratic tuff and volcanic breccia is clearly seen on weathered or fresh rock surfaces. Clasts vary considerably in size, some of which may reach up to several metres across. Also, the composition and distribution of the clasts are very variable. Analyses of the composition of the agglomeratic tuffs and volcanic breccias provide valuable information about the type of volcanic activity that affected the area.

How to Get There

The most convenient way to reach Shek Lung Kung is to walk along the Country Park road connecting Tai Mo Shan Country Park and Lin Fa Shan. It is the only path connecting Lin Fa Shan (440 m) to Shek Lung Kung (474 m). The distance from the Tai Mo Shan Country Park entrance to Lin Fa Shan is about 4 km. The path provides easy, gentle walking, with an overall variation in elevation of less than 40 m. Although the path is paved, private cars are prohibited.

Outline of the Geology

Agglomeratic tuff has been mapped in the area of Shek Lung Kung, northwest of Tsuen Wan, and was shown on Allen & Stephens's (1971) geological map. It was designated as a separate mappable unit within the Repulse Bay Formation. On the subsequent 1:20,000 scale HKGS Map Sheet 6 (GCO, 1988), this rare rock type was named the Shek Lung Kung Member of the Late Jurassic Shing Mun Formation, which is part of the Repulse Bay Volcanic Group. The volcanic sequence in the Shek Lung Kung area is estimated to be about 200 m thick.

Outcrop of agglomeratic tuff at Shek Lung Kung (1)

Outcrops of agglomeratic tuff are much less common in Hong Kong than volcanic breccia and tuff-breccia. The agglomeratic tuff typically contains more than 80% clasts, which mainly comprise angular to subangular fragments of tuff that range in size from tens of centimetres to several metres across. This type of rock is most likely to have been deposited near a volcanic vent during an eruption. The fragmental content of the more widespread volcanic breccias and tuff-breccias in the area is generally less than 70%, and typically varies from 30% to 50%. Clasts in the breccias generally comprise tuff, with some quartzite or chert debris, are angular to subangular, and range in size from a few centimetres to several tens of centimetres. The clasts are enclosed in a matrix of fine ash, coarse crystal ash, and vitric ash. In some locations, the clasts are aligned, suggesting that the rock may have been formed by volcanic flow processes, possibly generated by gravitational collapse of the volcanic edifice.

Outcrop of agglomeratic tuff (2)

Close-up of agglomeratic tuff

Weathered surface of agglomeratic tuff

Volcanic breccia

Volcanic breccia showing aligned fabric

Close-up of unweathered tuff-breccia – note the scattered clasts within crystal ash. Due to the small grain size, vitric ash cannot be distinguished

Close-up of tuff-breccia

Quartzite clasts within agglomeratic tuff

Guide to Field Observations

1) Observe the differing characteristics of the clasts. For example, the composition, size, and shape of the clasts, their relative proportion, and the nature of the surrounding matrix.

2) Try to identify the geographical distribution of agglomeratic tuff, to determine whether it was formed by deposition near, or far from, a volcanic vent. Also, look for evidence that volcanic breccia and tuff-breccia might have been formed by volcanic flow processes. These observations will help to provide an understanding of the mechanisms that formed these different types of volcanic rocks.

3) Measure the long-axis orientation of any aligned clasts, which might indicate a possible source direction.

4) Map the distribution of agglomeratic tuffs, volcanic breccias and tuff-breccias, and try to identify the possible location of the original volcanic vent.

Comments

The Repulse Bay Formation, first defined by Williams *et al*. (1945), is the thickest and most extensive volcanic unit in Hong Kong. Langford (1995) sub-divided the Formation into two units. The upper unit was named the Repulse Bay Volcanic Group, and the lower unit was named the Tsuen Wan Volcanic Group. The stratigraphical sequence of the Tsuen Wan Volcanic Group comprises the Yin Tin Tsai, Shing Mun, Tai Mo Shan and Sai Lau Kong formations. The Shek Lung Kung Member is a lithological unit within the Shing Mun Formation. Stratigraphical nomenclature in Hong Kong evolved in association with advances in the understanding of volcanic processes. Therefore, to avoid any confusion when reviewing the literature, it is important to understand the concepts of stratigraphical terms such as “Member” and “Formation” (Sewell *et al*., 2000).

The Shek Lung Kung Member, as described from Lantau Island by Langford *et al*. (1995), mainly comprises ash to lapilli-ash crystal vitric tuff. Based on the description given by Langford *et al*. (1989), it is possible that the Shek Lung Kung Member formed close to a volcanic vent, either by accumulation of eruption debris near the volcanic vent (agglomeratic tuff), or by collapse of a volcanic edifice (volcanic breccia). The ash to lapilli-ash crystal or vitric tuff of the Shek Lung Kung Member described by Langford *et al*. (1995) was probably the product of more distal primary volcanic activity.

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Fisher, R.V. & Schminke, H.U. 1984. *Pyroclastic rocks*. Springer Verlag, New York, 472 p.

Langford, R.L., Lai, K.W., Arthurton, R.S. & Shaw, R. 1989. *Geology of the Western New Territories*. Hong Kong Geological Survey Memoir No. 3, Geotechnical Control Office, Civil Engineering Services Department, Hong Kong Government, 140 p.

Langford, R.L., James, J.W.C., Shaw, R., Campbell, S.D.G., Kirk, P.A. & Sewell, R.J. 1995. *Geology of Lantau District.* Hong Kong Geological Survey Memoir No. 6, Geotechnical Engineering Office, Hong Kong Government, 173 p.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Williams, M.Y., Brock, R.W., Schofield, S.J. & Phemister, T.C. 1945. The physiography and igneous geology of Hong Kong and the New Territories. *Transactions of the Royal Society of Canada*, Vol. 39, pp 91–119.

Tai Mo Shan, New Territories

11. Welded Crystal Tuff – Tai Mo Shan Formation

Introduction

Tai Mo Shan, located to the north of Tsuen Wan, is the highest mountain in Hong Kong, at an elevation of 957 m. The massif is the type locality of the Tai Mo Shan Formation, a constituent of the Tsuen Wan Volcanic Group, the most widespread assemblage of volcanic rocks in the New Territories. Rocks of the Group extend westward from Tai Mo Shan to the Castle Peak – Yuen Long Expressways and the Tai Lam Tunnel area, eastwards to the Tolo Channel, northwards to Fanling and Sheung Shui, and southwestwards to Tsing Yi and northeast Lantau Island.

The lower slopes of Tai Mo Shan support a dense cover of shrubs and trees, particularly in the stream channels, whereas the upper slopes mainly have a cover of grass and scattered low shrubs. In general, weathering of these rocks does not produce a thick weathered mantle with a weak matrix, but tends to produce very large, isolated, sub-angular to sub-rounded, joint-bounded corestones that litter the landscape. Following exhumation of these corestones, they tilt and topple to varying degrees so can now be seen in various orientations. Boulders are sometimes concentrated in contorted linear piles along the steep stream courses that descend the flanks of Tai Mo Shan. Bedrock outcrops are largely confined to the crests of ridgelines and the ends of spurs, forming tors, below which sheets of boulder debris cover the slopes. The numerous boulders provide ample opportunity to examine the rocks of the Tai Mo Shan Formation.

The summit of Tai Mo Shan. Note the distribution of the vegetation

How to Get There

Tai Mo Shan can be reached by taking Route Twisk to the Tai Mo Shan Country Park near Tsuen Kam Au, and then turning eastwards onto Tai Mo Shan Road. Although it is more convenient to travel by private car, these must be parked at the gate shown on the map. It is necessary to walk the remaining one kilometre to the summit area, near the radar station.

Alternatively, Bus No. 51 departs from the Nina Tower, Tsuen Wan for Kam Tin Town Centre passing through Tsuen Kam Au along the Route Twisk. There is also a bus stop close to the Tsuen Wan MTR station. Alight from the bus near the Tai Mo Shan Country Park Management Centre in Tsuen Kam Au, and then cross the road and walk up along the Tai Mo Shan Road. It is also possible to take green mini bus No. 85, which departs from Shiu Wo Street, Tsuen Wan to Chuen Lung, and then walk to Tsuen Kam Au.

Transport to Tai Mo Shan

Outline of the Geology

Rocks of the Tai Mo Shan Formation are best exposed on the upper slopes of Tai Mo Shan. The Formation comprises a massive sequence, at least 600 m thick (Sewell *et al.*, 2000), of slightly-welded coarse-ash crystal tuff. Crystals are mainly of feldspar and quartz, with minor biotite mica. Fragments of tuff and quartzite are common within the tuffs. The Tai Mo Shan Formation overlies volcanic rocks of the Shing Mun Formation without a visible break in deposition. The Shing Mun Formation can be distinguished from the overlying Tai Mo Shan Formation because it contains a larger variety of rock types, including tuff breccia and tuffite.

Close up of the tuff with aligned pumice fragments

Block-bearing coarse ash crystal tuff

Coarse ash crystal tuff, Tai Mo Shan Formation

Tuff with aligned pumice fragments

The tuffs in the upper part of the succession, near the summit of Tai Mo Shan, contain abundant fragments of deformed devitrified pumice (former froth-like rhyolitic glass). These tuffs are similar in their appearance to volcanic rocks distributed along the southeastern coast of China, which have been called "plastic pumice" by geologists from the Nanjing Institute of Geology and Mineral Resources. The tuff probably originated as a pumice-rich hot ash flow, most likely during a very large-scale volcanic eruption. Pumice fragments were probably deformed, while they were still in a plastic or semi-plastic state, during compaction of the volcanic ash layers. This resulted in a diverse range of internal structures upon solidification, similar to the streaked appearance of welded tuffs containing fiamme (flame structures). However, it is believed that the pumice fragments were not sufficiently hot that they welded together.

Outcrop of block-bearing coarse ash crystal tuff

Differential weathering of rock fragments in a coarse ash crystal tuff

Fragments of other rock types, of various sizes, contained within the tuffs tend to be more resistant to weathering than the coarse ash crystal groundmass that encloses them. Consequently, the weathered surfaces of the boulders commonly have a very irregular appearance, with the rock fragments standing prominently above the surface of the boulders. In some cases, these fragments appear to have a more resistant outer shell that has been breached by weathering, exposing the more easily weathered centre. This process of differential weathering creates a raised rim that protrudes from the surface of the boulder, and surrounds a depressed central core.

<u>Guide to Field Observations</u>

It is recommended that observations begin from near the summit of Tai Mo Shan, and that the path along the ridge to the south-east of Sze Lok Yuen is then followed.

1) Try to identify the various components of the rock, particularly the larger crystals, and their relative proportions.

2) Carefully look for any structures within the rock, a pumice-rich, unwelded tuff with some preferred orientation of the elongate devitrified pumice fragments. Consider the origins of the tuff. Compare any similarities and differences between the fiamme and structures that occur in welded tuffs.

3) Distinguish boulders from rock outcrops. Make sure that any measurements are

taken on rock outcrops, and not on boulders that may have moved and rotated.

4) Look for any slight differences in the nature of the rocks along the path, and think about what type of volcanic activity they each might represent.

Comments

The Tai Mo Shan Formation is the most widespread volcanic formation in Hong Kong, occurring around Tai Mo Shan, in the northern New Territories, and in the western New Territories. Coarse ash crystals tuffs in the Sai Kung area, originally mapped as the Tai Mo Shan Formation (GCO, 1986, 1989) (SHEETS 7 & 8), have been shown by geochemical analyses, U-Pb (Uranium-Lead) isotope dating, and petrological studies, to be the the product of younger volcanic activity (Sewell *et al.*, 2000), so are now assigned to the Long Harbour Formation.

The Tsuen Wan Volcanic Group is a product of the second phase of intensive volcanic activity in Hong Kong, which followed the earliest phase of volcanic activity in Hong Kong that formed the Tuen Mun Formation. In contrast to the rather quiescent andesite lava flows that deposited the rocks of the Tuen Mun Formation, the volcanic activity that produced the Tsuen Wan Volcanic Group was more explosive and on a much larger scale. The different eruption modes and magma types gave rise to rocks that contain abundant rock fragments, pumice-rich layers, and breccias, or even agglomerates (such as at Shek Lung Kung, Tsuen Wan). All four formations of the Tsuen Wan Volcanic Group, which are from oldest to youngest, the Yim Tin Tsai Formation, the Shing Mun Formation, the Tai Mo Shan Formation, and the Sai Lau Kong Formation, exhibit these rock characteristics. Thus, the Tsuen Wan Volcanic Group represents the product of the most voluminous period of rhyolitic volcanism in the geological history of Hong Kong.

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Davis, D.W., Sewell, R.J. & Campbell, S.D.G. 1997. U–Pb dating of Mesozoic igneous rocks from Hong Kong. *Journal of the Geological Society*, v. 154, pp 1067–1076.

Campbell, S.D.G.. & Sewell R.J. 1997. Structural control and tectonic setting of Mesozoic volcanism in Hong Kong. *Journal of the Geological Society*, London, v. 154, pp 1039-1052.

Campbell, S.D.G. & Sewell, R.J. 1998. A proposed revision of the volcanic stratigraphy and related plutonic classification of Hong Kong. *Hong Kong Geologist*, v. 4, pp 1–11.

Fisher, R.V. & Schminke, H.U. 1984. *Pyroclastic rocks*. Springer Verlag, New York, 472 p.

Langford, R.L., James, J.W.C., Shaw, R., Campbell, S.D.G., Kirk, P.A. & Sewell, R.J. 1995. *Geology of Lantau District.* Hong Kong Geological Survey Memoir No. 6, Geotechnical Engineering Office, Hong Kong Government, 173 p.

Ruxton, B.P. 1960. The Geology of Hong Kong. *Quarterly Journal of Geological Society of London*, v. 115, pp 233-260.

Sewell, R.J. & Campbell, S.D.G. 1997. Geochemistry of coeval Mesozoic plutonic and volcanic suites in Hong Kong. *Journal of the Geological Society*, Vol. 154, pp 1053–1066.

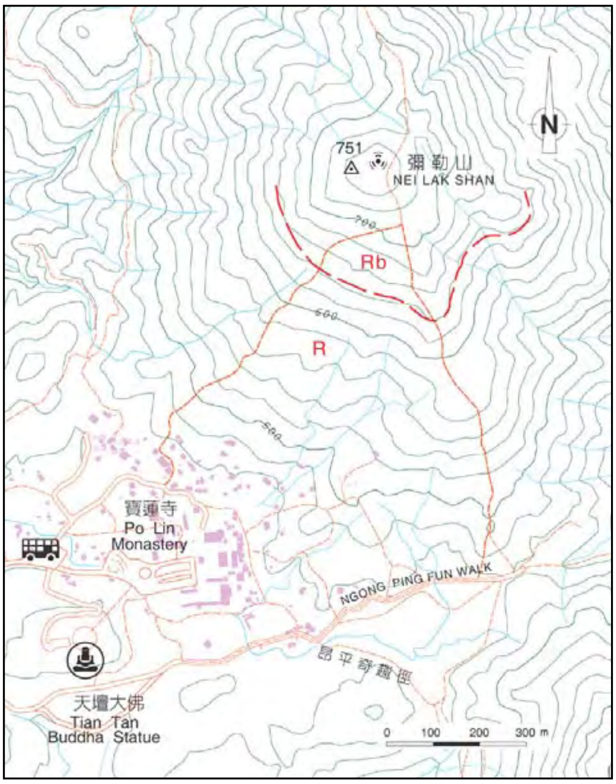
Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Workman, D.R. 1983. Field description of pyroclastic rocks. *Geological Society of Hong Kong Newsletter*, v. 1, no. 2, pp 3 – 6.

12. Slightly-welded Rhyolitic Tuff and Tuff Breccia – Lantau Volcanic Group Undifferentiated

Introduction

The highest peaks of Hong Kong are predominantly underlain by volcanic rocks. Volcanic rocks of the Lantau Volcanic Group underlie the upland areas in central and western Lantau Island. These rocks are believed to have formed in a bowl-shaped volcanic depression known as a caldera. Flows of hot volcanic ash and lava filled the caldera, where they were ponded to form a molten "ash lake", before cooling to form rock. This volcanic succession is not only very thick, but has a relatively gentle dip at 20° to 30° toward the north or northwest (Sewell *et al.*, 2000), possibly due to subsequent collapse of the caldera.



Route from Po Lin Monastery to Nei Lak Shan

The southern slope of Nei Lak Shan, northwest of Po Lin Monastery at Ngong Ping, is an excellent location for examining the characteristic rock types of the Lantau Volcanic Group (*i.e.* the slightly-welded tuffs and slightly-welded tuff breccias). This locality not only provides good exposures of the rocks, but also has convenient transport links.

How to Get There

Because the roads in the upland areas of south Lantau Island are very narrow, vehicle access is restricted and permits are required. Fortunately, Po Lin Monastery at Ngong Ping is a popular tourist destination so the location is well served by public transport. Bus services include Route no. 2 from Mui Wo to Ngong Ping, Route no. 21 from Tai O to Ngong Ping, and Route no. 23 from Tung Chung to Ngong Ping. In addition, there is the Ngong Ping 360 Cable Car from Tung Chung.

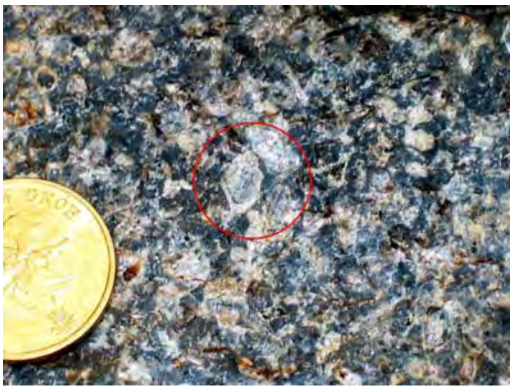
Nei Lak Shan reaches an elevation of 751 m but, because the bus terminal at the Po Lin Monastery is at an elevation of *c.* 460 m, the summit of Nei Lak Shan is only a relatively short 300 m climb. There are two possible routes to the summit. One, slightly shorter, route is along the footpath from behind Po Lin Monastery. The initial 70-80 metres of the path is overgrown, making walking a little difficult. A second, slightly longer but gentler and more popular, route follows the path along the southeast ridge of Nei Lak Shan.

<u>Outline of the Geology</u>

The summits around Ngong Ping are underlain by porphyritic rhyolite lava, welded and unwelded rhyolitic tuff, and tuffaceous sedimentary rocks of the Lantau Volcanic Group (Sewell *et al.*, 2000). Two main types of tuff within the Group are represented on Nei Lak Shan: 1) slightly-welded tuffs with parallel flow bands. These rocks,

Boulders of tuff with parallel flow-bands, mid-slopes of Nei Lak Shan

Close-up of tuff with parallel flow-bands



Feldspar crystal developed by slow cooling in slightly-welded tuff

Weathered surface of slightly-welded coarse ash crystal tuff which crop out on the lower part of the slope (as indicated with "R" on the map), comprise abundant coarse crystal fragments, mainly of quartz (18%) and feldspar (15%). 2) slightly-welded tuff breccia. These rocks, which are present near the summit of Nei Lak Shan (as indicated with "Rb" on the map), seldom have parallel fiamme (welding bands) and only rarely have flow structures. They consist of up to 15% angular rock fragments, with sizes mostly in the range of 30-60 mm up to a maximum of about 300 mm. The abundance of tuff breccia suggests that the rocks at the summit of Nei Lak Shan may have been formed close to a volcanic vent.

Boulder of slightly-welded tuff breccia near the summit: Note the size and shape of gravel

Close-up of slightly-welded tuff breccia

Gravel in slightly-welded tuff breccia composed of coarse ash crystal tuff

Tuff with irregular flow bands

Guide to Field Observations

The uphill footpath presents good opportunities for observing the rocks. Although boulders dominate sections of the path, good outcrops of rock are found near the summit.

1) Examine the structure and composition of the rock in detail. Look at properties such as the composition, proportion and size of the phenocrysts (large crystals) or crystal fragments, the presence of rock fragments, the presence of fiamme (welding bands) and/or flow structures. Based on these characteristics, try to name the rock.

2) Different types of volcanic activity are reflected by the rock characteristics. For example, tuffs with abundant crystal fragments may indicate volcanic ash flows that had temperature gradients suitable for the generation and preservation of crystals. Thinly bedded strata may indicate pulses of eruption, or the accumulation of hot ash within a caldera. Coarse angular tuff deposits may suggest proximity to a volcanic vent.

3) Observe how the characteristics of the rocks change along the route. It is important to look out for subtle changes in rock characteristics. Small changes may reflect differences in the mode of emplacement, or the environment of deposition, of the volcanic material. The rocks may sometimes appear as a thick, single unit, so small changes may provide important clues, but may be difficult to detect in a thick, apparently homogenous unit.

4) Carefully measure the orientation of the fiamme (welding bands) or flow structures. These data can provide information about the flow direction, and thus about the possible former location of volcanic vents.

Description

The Lantau Volcanic Group includes two formations, the Lai Chi Chong Formation, which is exposed on the southeast coast of the Tolo Channel in the eastern New Territories, and the Lantau Volcanic Group (undifferentiated), which crops out widely in the central and eastern portions of Lantau Island (Sewell *et al.*, 2000). The Lai Chi Chong Formation consists largely of interbedded volcanic sedimentary rocks, such as tuffaceous sandstone, mudstone, *etc*.

Special attention should be paid to the distribution of Lantau Volcanic Group (undifferentiated), which is bounded in the west by volcanic rocks of the Shing Mun Formation, and in the south by volcanic rocks of the Yim Tin Tsai Formation, both of which belong to the earlier Tsuen Wan Volcanic Group. In the east, the Lantau Volcanic Group is in contact with the older Lantau Granite. Many of these boundaries are represented by faults, which suggest the presence of a bounding caldera ring fault. Magmatic intrusions, forming dykes and plutons, occurred both during and after the formation of the Lantau Volcanic Group (undifferentiated). Intrusions include the East Lantau Dyke swarm, the Tong Fuk Quartz Monzonite, and the Fan Lau Granite that surrounds the caldera. Overall, the district has experienced multiple stages of volcanic eruption and magmatic intrusion, and a complex history of caldera development. Knowledge of the age, distribution, and contact relationships of the volcanic and intrusive rocks will aid the reconstruction of the history of magmatic evolution in the district.

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Davis, D.W., Sewell, R.J. & Campbell, S.D.G. 1997. U–Pb dating of Mesozoic igneous rocks from Hong Kong. *Journal of the Geological Society*, v. 154, pp 1067–1076.

Campbell, S.D.G.. & Sewell R.J. 1997. Structural control and tectonic setting of Mesozoic volcanism in Hong Kong. *Journal of the Geological Society*, London, v. 154, pp 1039-1052.

Campbell, S.D.G. & Sewell, R.J. 1998. A proposed revision of the volcanic stratigraphy and related plutonic classification of Hong Kong. *Hong Kong Geologist*, v. 4, pp 1–11.

Fisher, R.V. & Schminke, H.U. 1984. *Pyroclastic rocks*. Springer Verlag, New York, 472 p.

Langford, R.L., James, J.W.C., Shaw, R., Campbell, S.D.G., Kirk, P.A. & Sewell, R.J. 1995. *Geology of Lantau District.* Hong Kong Geological Survey Memoir No. 6, Geotechnical Engineering Office, Hong Kong Government, 173 p.

Ruxton, B.P. 1960. The Geology of Hong Kong. *Quarterly Journal of Geological Society of London*, v. 115, pp 233-260.

Sewell, R.J. & Campbell, S.D.G. 1997. Geochemistry of coeval Mesozoic plutonic and volcanic suites in Hong Kong. *Journal of the Geological Society*, Vol. 154, pp 1053–1066.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Workman, D.R. 1983. Field description of pyroclastic rocks. *Geological Society of*

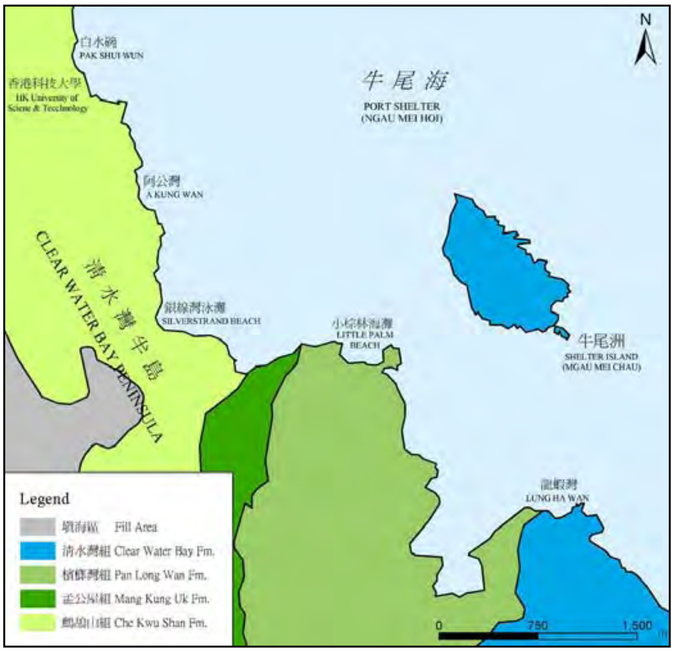
Hong Kong Newsletter, v. 1, no. 2, pp 3 – 6.

Chapter 13. Eutaxitic Tuff and Tuff-Breccia – Che Kwu Shan Formation

Introduction

The term volcanic rock is used for any rock that is formed by extrusive magmatic activity, that is when hot magma reaches the earth's surface in or around volcanoes. The characteristics of volcanic rocks are determined by magma composition and eruption processes. Rocks formed during different phases of an eruption, or at different locations on a volcano, may vary significantly in their structures and textures.

The Clear Water Bay Peninsula is underlain predominantly by rocks of the Repulse Bay Volcanic Group. Within this Group, the Che Kwu Shan Formation is the most extensively exposed formation in the area. The Formation comprises mainly welded crystal-bearing fine ash vitric tuff and tuff breccia. In addition to the type locality of Che Kwu Shan, the formation also crops out around the Hong Kong University of Science and Technology (HKUST), near Pak Shui Wun, and to the east of Silverstrand Beach. Coastal areas provide the best exposures of the Formation, as well as displaying illustrative volcanic rock landforms.



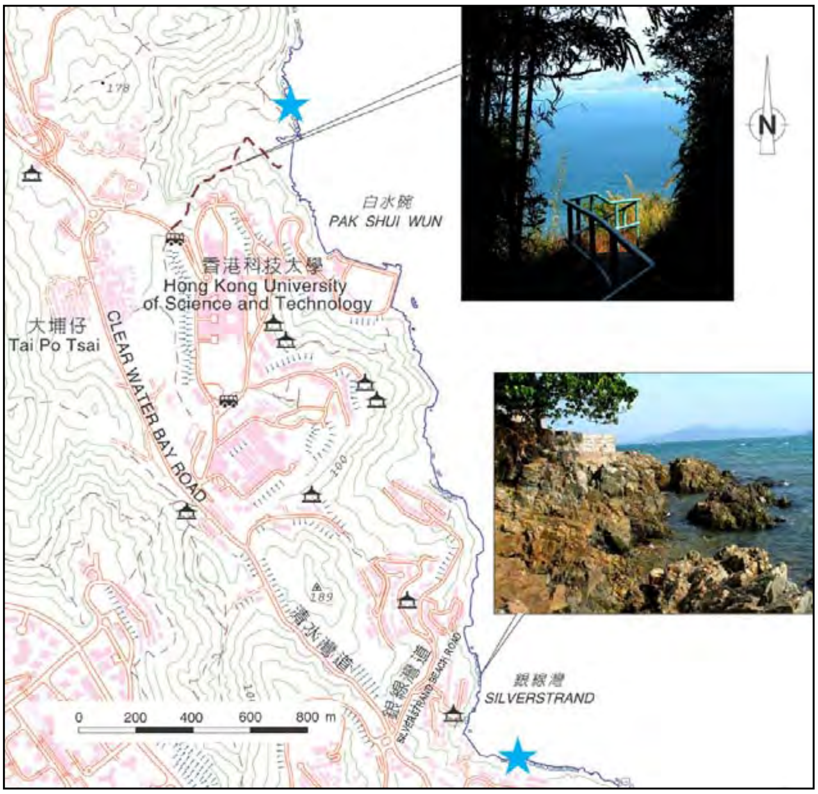
Geological map of the Clear Water Bay Peninsula
(from HKGS 1:100,000 HGM100)

How to Get There

The most convenient access to the volcanic rocks in the area is along the southeastern section of Silverstrand Beach. Silverstrand Beach is well-served by public transport. The bus routes include, No. 91 (Diamond Hill MTR Station to Sai Kung), No. 91M

(Diamond Hill MTR Station to Hang Hau), No. 298 (Lam Tin MTR Station to HKUST) or No. 792 (Tseung Kwan O to Sai Kung). Alight at the bus stop near the junction of Clear Water Bay Road and Silverstrand Beach Road, and then walk about 1 km to Silverstrand Beach. At the beach, walk eastwards for about 150 m to the Chek Kwu Shan Formation outcrop.

Travelling by private car, turn into Silverstrand Beach Road from the Clear Water Bay Road.



Access to Silverstrand Bay and HKUST

The Che Kwu Shan Formation is also well exposed on the coast at Pak Shui Wan near the HKUST. From near the bus terminus at the gates of HKUST, a well-established footpath leads directly to the seashore at Pak Shui Wan.

Outline of the Geology

Rocks of the Repulse Bay Volcanic Group are divided into two sub-groups, the lower "trachytic sub-group" and the upper "rhyolitic sub-group". The "trachytic sub-group" is characterised by well-developed welding structures, whereas the "rhyolitic sub-group" is dominated by coarse ash crystal tuff.

Welded tuff, eastern side of Silverstrand Beach

Unweathered welded tuff

Weathered surface of welded tuff

Fresh surface of volcanic lava. Note the tiny vesicles nd finae quartz crystals

Tuff breccia, Pak Shui Wun

Mafic veins in tuff breccia, Pak Shui Wun

The Che Kwu Shan Formation is the dominant component of the lower "trachytic sub-group". Rocks of the Formation are characterised by a streaked appearance that results from the flattening and welding of the many included pumiceous rock fragments (fiamme) within the tuff. This structure is termed eutaxitic foliation. The Formation is similar in appearance to the Ap Lei Chau Formation. However, whole-rock geochemical analyses have confirmed that rocks of the Che Kwu Shan Formation are generally composed of less than 70% SiO_2, whereas rocks of the Ap Lei Chau Formation contain more than 75% SiO_2. The groundmass of the welded tuff comprises mainly quartz and feldspar crystal fragments set within a fine ash vitric matrix. Upon weathering, the pumiceous rock fragments may be removed, resulting in the array of voids that can be seen in many outcrops. Interbeds of lava occur locally in the Che Kwu Shan Formation.

Guide to Field Observations

1) Summarise the main characteristics of volcanic rocks in the area. This is the type locality of the Che Kwu Shan Formation, from which the name of the formation is derived, and all the rocks exposed in this area are representative of the Che Kwu Shan Formation.

2) Determine the composition of the rocks. Try to determine the size, mineralogy, and relative percentages of the different types of crystal fragments.

3) Observe the structures of the rocks. Try to distinguish between welded tuff structures (eutaxitic foliation) and breccia, and consider their modes of occurrence.

4) Note the included rock fragments. Determine if they are flattened, indicating flow-banding, and what the structures reveal about the characteristics of the volcanic processes.

5) Note the variation in rock types, and observe if there are any interbeds of lava and tuff. What can the occurrence of lava reveal about changes in the nature of the volcanic activity?

Comments

During the geological survey for the 1:20,000-scale geological map of Sai Kung and Clear Water Bay, Strange *et al.* (1990) developed a detailed classification of the Repulse Bay Volcanic Group. The Group was sub-divided into eight formations. Volcanic rocks exposed in the northern part of the Clear Water Bay Peninsula, near Silverstrand Bay, were designated the "Silverstrand Formation", which is characterised by a well-developed welded appearance (eutaxitic foliation). Both the "Silverstrand Formation" and the Ap Lei Chau Formation exhibit eutaxitic foliation, so they were considered to be similar. Subsequent geochemical analyses showed that the "Silverstrand Formation" has a lower SiO_2 content, so the "Silverstrand Formation" was named the Che Kwu Shan Formation (Sewell *et al.*, 2000). Now, the Che Kwu Shan Formation is the major component of the "trachytic" sub-group of the Repulse Bay Volcanic Group. Special attention should be paid to understanding the evolution of stratigraphic nomenclature in Hong Kong in order to avoid confusion.

References

Addison, R. & So, A.C.T. 1989. Textural features, field characteristics and geochemistry of aphanitic volcanic rocks of Eastern Hong Kong Island. *Geological Society of Hong Kong Newsletter*, v. 7, no. 4, pp 20 - 31.

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Campbell, S.D.G.. & Sewell R.J. 1997. Structural control and tectonic setting of Mesozoic volcanism in Hong Kong. *Journal of the Geological Society*, London, v. 154, pp 1039-1052.

Fisher, R.V. & Schminke, H.U. 1984. *Pyroclastic rocks*. Springer Verlag, New York, 472 p.

Lau, P.N.Y. & Kirk, P.A. 2001. Recognition of structural features in Sai Kung District, Eastern Hong Kong. Interpreted from a shaded relief map. *Hong Kong Geologist*, v. 7, pp 23 – 30.

Ruxton, B.P. 1960. The Geology of Hong Kong. *Quarterly Journal of Geological Society of London*, v. 115, pp 233-260.

Sewell, R.J. & Campbell, S.D.G. 1997. Geochemistry of coeval Mesozoic plutonic and volcanic suites in Hong Kong. *Journal of the Geological Society*, Vol. 154, pp 1053–1066.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Smith, R.L. 1979. Ash-flow magmatism. *Geological Society of America Special Paper No. 180*, pp 5 – 27.

Strange, P.J. 1992. Discussion on the geological age of the Repulse Bay Formation, Hong Kong. *Geological Society of Hong Kong Newsletter*, v. 10, no. 1, p. 26.

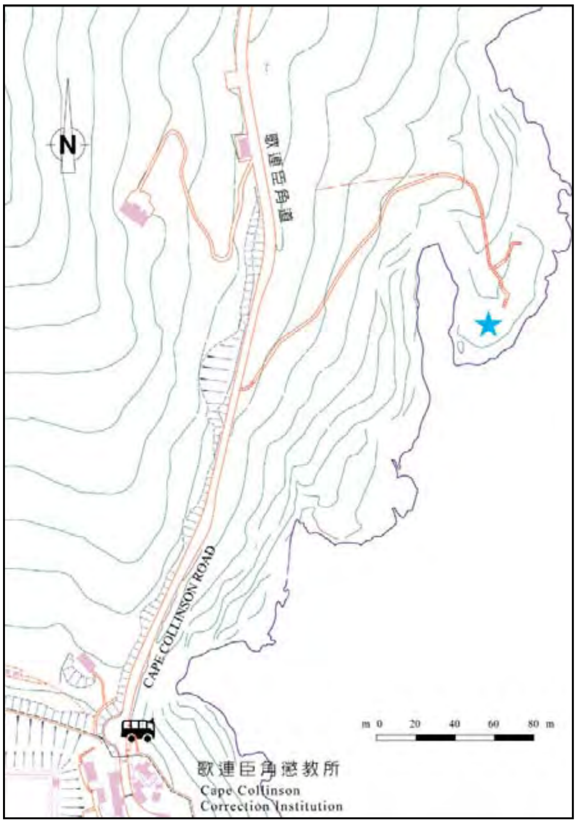
Strange, P.J., Shaw, R. & Addison, R. 1990. *Geology of Sai Kung and Clear Water Bay*. Hong Kong Geological Survey Memoir No. 4, Geotechnical Control Office, Civil Engineering Services Department, Hong Kong, 111 p.

Workman, D.R. 1983. Field description of pyroclastic rocks. *Geological Society of Hong Kong Newsletter*, v. 1, no. 2, pp 3 – 6.

Chapter 14 – Tuff-breccia and Rhyolitic Crystal Tuff – Che Kwu Shan Formation (II)

Introduction

The Che Kwu Shan Formation, part of the Repulse Bay Volcanic Group, was considered to have been deposited by a hot rhyolitic volcanic ash flow (Sewell *et al.*, 2000). In addition to a streaked appearance that resulted from welding of the very hot crystal ash particles, the Formation also comprises a large volume of tuff-breccia. Along the eastern side of Hong Kong Island, tuff-breccia and rhyolitic crystal tuff are common in coastal outcrops to the east of Cape Collinson Road, Siu Sai Wan. These various rock types were previously assigned to the Shing Mun Formation by Strange & Shaw (1986). However, based on U-Pb isotope age dating, major and trace element geochemistry, petrographic properties and stratigraphic relationships, Campbell & Sewell (1997) later defined the Che Kwu Shan Formation, which mainly crops out in the vicinity of the Clear Water Bay peninsula. However, the outcrops near the Cape Collinson Correctional Institution appear to differ in several respects from those at Silverstrand Bay, Clear Water Bay peninsula, which have been assigned to the same Formation. The differences may be due to variations in depositional processes during volcanic eruption.



Geological reconnaissance map of Cape Collinson

How to Get There

The rocks of the Che Kwu Shan Formation are well-exposed along the coast to the north of the Cape Collinson Correctional Institution. However, the rock cliffs are very steep and subject to strong wave action along the exposed coastline. Direct access to the coast is difficult because of the dense vegetation that covers the hillslopes above. An easier and safer way of reaching the outcrops is along a footpath that begins at Cape Collinson Road, to the north of the Correctional Institution. Please note that the footpath starts in the woodland behind the fence along Cape Collinson Road, so may be difficult to find. Also, the first few tens of metres of the path are difficult to follow. However, once the footpath has been located, it is relatively easy to follow along a paved track to the coastal outcrops.

The start of the footpath can be reached by taking green minibus no.18M from Chai Wan MTR Station, which terminates at Cape Collinson Correctional Institution.

Footpath to the coastal rock outcrops

Outline of the Geology

The Che Kwu Shan Formation near the Cape Collinson Correctional Institution comprises mainly dark grey to black rhyolitic crystal tuff, with a weak streaked appearance, and grey tuff-breccia. The former was generated by welding of very hot crystal ash particles. The clasts within the tuff-breccia are composed mainly of angular to subangular crystal tuff, and vary in size from a few centimetres up to about 8 cm. The tuff-breccia was probably formed by a flow of block and ash that resulted from the collapse of a growing lava dome. In contrast, the rhyolitic crystal tuff probably formed by a volcanic ash flow.

Tuff-breccia (1)

Tuff-breccia (2)

There are many late stage dark-coloured mafic (basic) dykes intruding the rocks in this area. These dykes are greyish green, with a fine-grained texture. Mafic dykes are distinguished from felsic (acidic) dykes by their darker colour, and by the fact that they exhibit evidence of more mobile flow. The dykes appear to have been intruded along discontinuities that existed in the volcanic rocks.

Tuff-breccia (3)

Rhyolitic crystal ash tuff

Late-stage mafic dykes within tuff breccia,
Che Kwu Shan Formation)

Contact between late-stage mafic dykes
and tuff-breccia

Guide to Field Observations

1) Observe the details of these rocks. Look for features such as the composition of the matrix, the type of crystals within the matrix, and the composition of the angular clasts within the rock.

2) Compare and contrast the nature of the clasts, and that of their surrounding matrix. Try to determine their modes of formation.

3) Try to summarise the characteristics of the volcanic rocks in this district, and compare them with what you know about volcanic rocks in other areas of Hong Kong, particularly with the rock types within the Che Kwu Shan Formation on the Clear Water Bay peninsula.

4) Observe the characteristics of the late stage mafic dyke intrusions, particularly their size and orientation, as well as their contact relationships with the surrounding rocks.

5) Observe the joint patterns and weathering features in the different volcanic rocks.

Comments

The rocks assigned to the Che Kwu Shan Formation on the coast near Cape Collinson, Siu Sai Wan, appear to be different in several respects to those that crop out on the Clear Water Bay peninsula. Although they are all products of volcanic eruption, the streaked appearance appears to be weaker at Siu Sai Wan, and there is a greater abundance of tuff-breccia than on the Clear Water Bay peninsula. This difference is probably due to variations in the depositional processes that occurred during the volcanic eruptions. The clasts within the tuff-breccias are angular to subangular. This suggests that either, the rocks were formed at low temperature so that they were not deformed plastically, or that the fragments were deposited close to source and so not rounded during turbulent transport. The streaked appearance of the rhyolite crystal tuffs suggests that they were formed under higher temperatures when the fabrics were deformed plastically. The details of the two rock types reflect their different modes of formation.

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Campbell, S.D.G.. & Sewell R.J. 1997. Structural control and tectonic setting of Mesozoic volcanism in Hong Kong. *Journal of the Geological Society*, London, v. 154, pp 1039-1052.

Davis, S.G. 1952. *The geology of Hong Kong.* Government Printer, Hong Kong. 231 p. plus 14 plates & 3 maps.

Fisher, R.V. & Schminke, H.U. 1984. *Pyroclastic rocks*. Springer Verlag, New York, 472 p.

Ruxton, B.P. 1960. The Geology of Hong Kong. *Quarterly Journal of Geological Society of London*, v. 115, pp 233-260.

Sewell, R.J. & Campbell, S.D.G. 1997. Geochemistry of coeval Mesozoic plutonic and volcanic suites in Hong Kong. *Journal of the Geological Society*, Vol. 154, pp 1053–1066.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Strange, P.J. & Shaw, R. 1986. *Geology of Hong Kong Island and Kowloon.* Hong Kong Geological Survey Memoir No. 2, Geotechnical Control Office, Hong Kong, 134 p.

Workman, D.R. 1983. Field description of pyroclastic rocks. *Geological Society of Hong Kong Newsletter*, v. 1, no. 2, pp 3 – 6.

Lung Ha Wan, Sai Kung, Eastern New Territories

15. Rhyolitic Lava and Fine Vitric Tuff – Pan Long Wan Formation and Clear Water Bay Formation

Introduction

Among the seven formations that make up the Repulse Bay Volcanic Group, the Pan Long Wan Formation is the only one that is composed predominantly of lava. The Formation is restricted in its outcrop to the Clear Water Bay Peninsula, where it is exposed between Pan Long Wan to Lung Ha Wan in the north, and Clear Water Bay in the south.

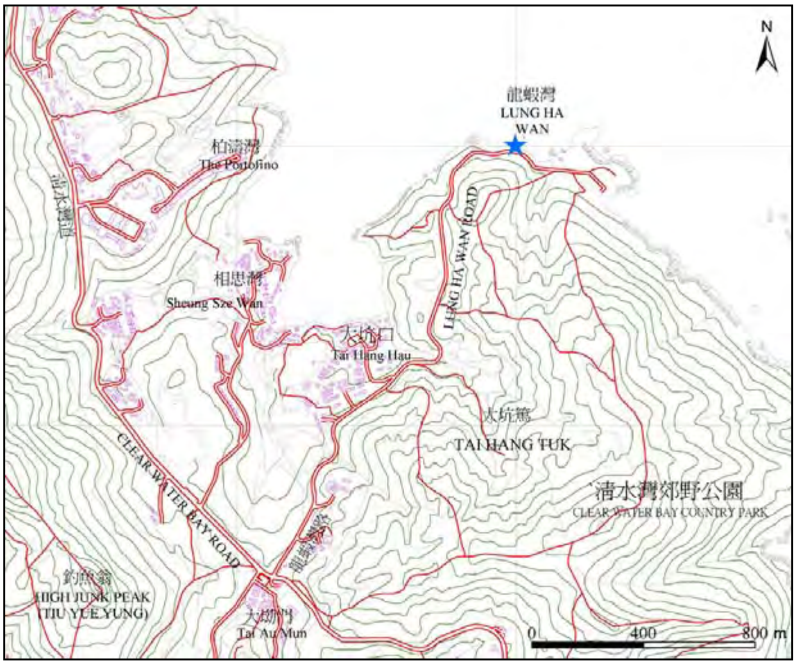
The Clear Water Bay Formation is part of the Kau Sai Chau Volcanic Group, which is the youngest volcanic group in Hong Kong. This Formation displays characteristics that are typical of the final stage of Mesozoic volcanic activity in Hong Kong.

Lung Ha Wan is an ideal location for geological observations because, in addition to extensive outcrops of the Pan Long Wan Formation, fine ash vitric tuff of the Clear Water Bay Formation can also be inspected nearby.

How to Get There

Lung Ha Wan can be reached by New Territories Green Minibus Route 103 from Kwun Tong Ferry Station to Clear Water Bay, or by New Territories Bus Route 91 from Diamond Hill MTR Station to Clear Water Bay. Alight at Tai Au Mun, and then walk approximately 2.5 km along Lung Ha Wan Road to Lung Ha Wan.

By car, follow the Clear Water Bay Road southeastwards, then turn north onto Lung Ha Wan Road at Tai Au Mun. Lung Ha Wan is located at the end of the Lung Ha Wan Road.



Access to Lung Ha Wan

Outline of the Geology

The Pan Long Wan Formation is restricted to the area between Little Palm Beach and Lung Ha Wan on the Clear Water Bay Peninsula, and the area around Tai Miu Wan at the southeastern end of the peninsula. The rocks are dominated by trachydacite and rhyolitic lava, with intermittent fine ash tuff and minor tuffaceous sandstone and mudstone.

Trachydacite lava outcrop, Pan Long Wan Formation

Polished surface of the trachydacite lava outcrop, Pan Long Wan Formation

The Clear Water Bay Formation, which has a total thickness of over 400 m, crops out in a large area to the east and north of Sai Kung, New Territories. In the Port Shelter area, it is exposed only between Lung Ha Wan and Clear Water Bay, on Sharp Island, and on Shelter Island. The Formation is dominated by fine ash vitric tuff with less common tuffaceous siltstone, mudstone and rhyolitic lava. Abundant feldspar crystals are present in the fine ash vitric tuff. This Formation overlies the Pan Long Wan Formation without any obvious interruption in the depositional sequence.

Flow banded trachydacite lava, Pan Long Wan Formation

Fresh outcrop of fine ash vitric tuff, Clear Water Bay Formation

Stratified trachydacite lava, Pan Long Wan Formation

Slightly weathered fine ash vitric tuff, Clear Water Bay Formation

Guide to Field Observations

Rocks exposed on the coast at the end of Lung Ha Wan Road belong to the Clear

Water Bay Formation, Kau Sai Chau Volcanic Group. The Pan Long Wan Formation is exposed only at the western end of Lung Ha Wan, which can be accessed by following the sign "Ancient Rock Carving" at the junction of the path.

1) Carefully examine the tuff, and try to identify which minerals form the large crystals in the rock, the degree of crystallisation, and the composition of the groundmass/matrix.

2) Compare the characteristics of the tuff and the lava, and consider their different origins.

3) Summarise the characteristics of the rock types from the two formations. Note that they are of different age, and they each reflect different types of volcanic processes.

4) Inspect the rocks cropping out along a section of Lung Ha Wan Road, and try to identify the contact relationship between the Clear Water Bay Formation and the Pan Long Wan Formation.

5) Consider the pattern joints in the rocks, and describe the degree of weathering in the different types of volcanic rocks.

Junction of the path to the coastal outcrop of the Pan Long Wan Formation

Comments

The volcanic stratigraphy of Hong Kong has recently been extensively revised, mostly as a result of absolute dating of the volcanic rocks. A summary of these changes is presented in the Pre-Quaternary Geology of Hong Kong (Sewell *et al.*, 2000). For example, the Clear Water Bay Formation exposed at Lung Ha Wan was originally classified as High Island Formation by Strange *et al.*, (1990). Also, the rocks of the Pan Long Wan Formation were previously designated as an undifferentiated member of the Clear Water Bay Formation, composed mainly of trachydacite and rhyolitic lava (Strange *et al.*, 1990). At that time, it was believed that the Clear Water Bay Formation overlay the older Mang Kung Uk Formation. However, based on the results of U-Pb isotope dating (Sewell *et al.*, 2000), the Clear Water Bay Formation was assigned to the Kau Sai Chau Volcanic Group, which is the youngest Mesozoic volcanic group in Hong Kong. The previously undifferentiated member of the Clear Water Bay Formation was then assigned to a new formation, the Pan Long Wan Formation. This Formation, together with the Mang Kung Uk Formation, are included within the Repulse Bay Volcanic Group, which is older than the Kau Sai Chau Volcanic Group.

References

Addison, R. & So, A.C.T. 1989. Textural features, field characteristics and geochemistry of aphanitic volcanic rocks of Eastern Hong Kong Island. *Geological Society of Hong Kong Newsletter,* v. 7, no. 4, pp 20 - 31.

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Campbell, S.D.G.. & Sewell R.J. 1997. Structural control and tectonic setting of Mesozoic volcanism in Hong Kong. *Journal of the Geological Society*, London, v. 154, pp 1039-1052.

Fisher, R.V. & Schminke, H.U. 1984. *Pyroclastic rocks*. Springer Verlag, New York, 472 p.

Lau, P.N.Y. & Kirk, P.A. 2001. Recognition of structural features in Sai Kung District, Eastern Hong Kong. Interpreted from a shaded relief map. *Hong Kong Geologist*, v. 7, pp 23 – 30.

Ruxton, B.P. 1960. The Geology of Hong Kong. *Quarterly Journal of Geological Society of London*, v. 115, pp 233-260.

Sewell, R.J. & Campbell, S.D.G. 1997. Geochemistry of coeval Mesozoic plutonic and volcanic suites in Hong Kong. *Journal of the Geological Society,* Vol. 154, pp 1053–1066.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Smith, R.L. 1979. Ash-flow magmatism. *Geological Society of America Special Paper No. 180*, pp 5 – 27.

Strange, P.J. 1992. Discussion on the geological age of the Repulse Bay Formation, Hong Kong. *Geological Society of Hong Kong Newsletter*, v. 10, no. 1, p. 26.

Strange, P.J., Shaw, R. & Addison, R. 1990. *Geology of Sai Kung and Clear Water Bay.* Hong Kong Geological Survey Memoir No. 4, Geotechnical Control Office, Civil Engineering Services Department, Hong Kong, 111 p.

Workman, D.R. 1983. Field description of pyroclastic rocks. *Geological Society of Hong Kong Newsletter*, v. 1, no. 2, pp 3 – 6.

16. Columnar Jointed Tuff – High Island Formation

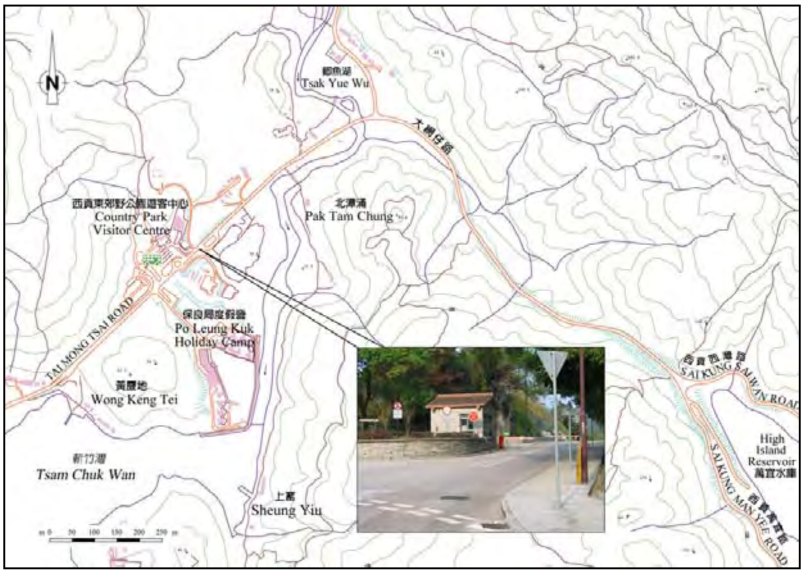
Introduction

The geological landscape in the area between High Island Reservoir and the Ninepin Group of islands in the eastern New Territories is particularly spectacular, the outcrops of volcanic rocks comprising rows of giant hexagonal or polygonal columns separated by uniform vertical or sub-vertical joints.

How to Get There

High Island Reservoir provides a relatively convenient location for examining the spectacular outcrops of columnar-jointed tuff. High Island Reservoir is located in the Sai Kung East Country Park. Access is on foot from the Country Park Visitor's Centre at Pak Tam Chung, which is on the route of public bus no. 94 from Sai Kung to Wong Shek Pier, and no. 96R from Diamond Hill MTR Station to Wong Shek Pier (services only on weekends and public holidays). Alight by the car park in front of Country Park Visitor's Centre, then walk southeast along the Tai Mong Tsai Road for about 1.5 km to the shelter at the High Island Reservoir. At this point, Tai Mong Tsai Road branches. The left branch is Sai Kung Sai Wan Road, which runs along the north side of the reservoir, and the right branch is Sai Kung Man Yee Road, which runs along the south side of the reservoir. Take the right branch, and walk southeast for about 9 km, crossing the West Dam, until the East Dam of High Island Reservoir is reached. The columnar jointed rock is visible at the far side of the dam. To reach the Ninepin Group of islands, it is necessary to hire a boat because there are no public ferry services available.

The East Dam of High Island Reservoir from Po Pin Chau



Access to the East Dam of High Island Reservoir

Outline of the Geology

The columnar jointed volcanic rock exposed in the area from High Island Reservoir to the Ninepin Group of islands comprises rhyolitic to dacitic ash flow deposits. The rock is relatively homogenous, containing abundant large crystals of potassium feldspar (K-feldspar) and quartz. These rocks belong to the Early Cretaceous High Island Formation of the Kau Sai Chau Volcanic Group. The Formation is estimated to have a minimum thickness of 400 m.

Collapsed rhyolitic-dacitic volcanic rock column at north Ninepin Island

The spectacular columns of volcanic rock formed about 140 million years ago as a result of catastrophic volcanic eruption. Voluminous ash flows were produced during the eruption, covering the surrounding ground to a great thickness. Multiple ash flows were probably generated during the eruption that built up successive layers of tuff. Upon cessation of the eruption, the tuff cooled relatively slowly, gradually consolidating to form rock. Hexagonal columns developed in the tuff as a result of contraction during cooling. The cooling joints within the tuff can extend vertically for up to 30 metres, leading to the development of spectacular scenery.

The wide distribution of the tuff surrounding the High Island Reservoir and beyond suggests that it formed within a complex, fault-bounded caldera.

Landscape near the East Dam of High Island Reservoir

Guide to Field Observations

Columnar jointed volcanic tuffs are well-exposed at the East Dam of High Island Reservoir. The rock slopes at the site, which were excavated during construction of the dam, provide extremely good cross-sections through the columns. The rock slopes can be accessed easily and safely, making them ideal for detailed observations.

Tightly interlocked columnar joints

Scarp in thick layer of welded tuff

1) At the base of many of the rock slopes are scattered blocks of columnar-jointed tuff. Note the almost regular hexagonal shape of these blocks, which vary from about 0.8 to 2.0 metres across. The interlocking columns fit together like the pieces of a jig-saw.

2) In some places, continuous, subhorizontal cracks can be seen extending into the rock face. These cracks may be gently inclined to the east or southeast. They could possibly represent the boundary between different pulses of ash flow produced during the volcanic eruption although, because the rocks form a single, continuous cooling unit, they are more likely to be stress release joints within the rock mass.

3) Carefully examine the rock type and the characteristics of the columnar jointing. Abundant large crystals of potassium feldspar and quartz can be seen by the naked eye in the fresh rock. The potassium feldspar crystals are pink in colour and are well-shaped, with sizes in the range of 1.5 to 2.0 mm. Quartz crystals are a glassy grey, spherical in shape, and about 1.0 mm in size. Potassium feldspar crystals usually weather to a pink colour, or may even become white, making them difficult to distinguish in hand specimen. Sometimes, only quartz crystals are visible in the weathered rock.

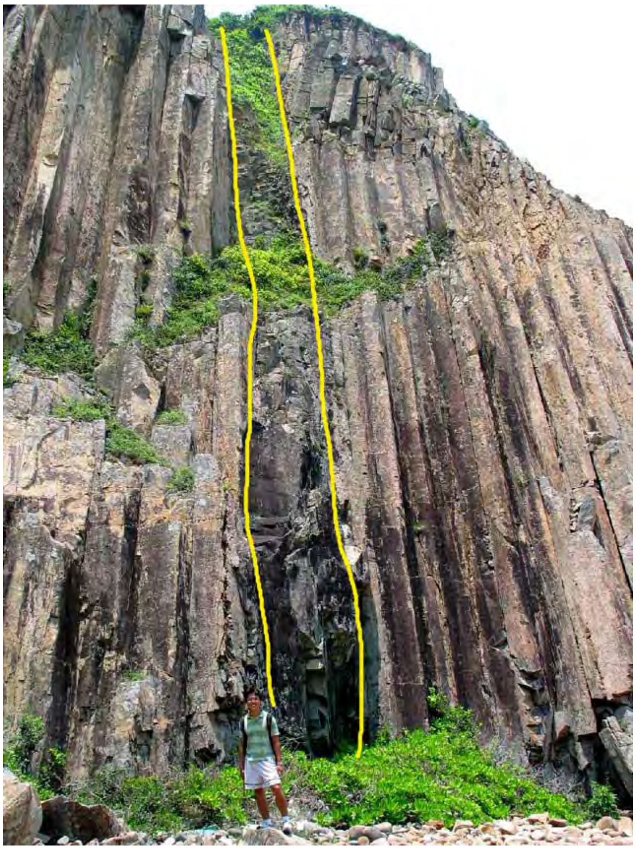
4) Gentle S-shaped flexures of the columns can be seen in some places. This may be due to gravitational settling of the mass of cooling ash when it was still in a plastic state. The original slip direction can be determined from the direction of the bending.

Pink potassium feldspar and dark grey quartz phenocrysts in fresh rhyolitic tuff

Banding in rhyolitic tuff

5) Mafic dykes are common in the area. These are later intrusions of magma that probably exploited tension cracks within the tuff. Toppling failure of the columns can be seen near the top of some of the rock faces, with the columns leaning out of the face. This mechanism is important from a slope engineering perspective.

6) Further examples of spectacular scenery formed in columnar-jointed rocks can be seen by climbing over the mountain to Po Pin Chau, Pak Lap Tsai, or by visiting the coast around Pak Lap Wan.



Dark coloured basic dyke intruded along joint in columnar tuff

Comments

The development of columnar joints in volcanic rocks is not an uncommon phenomenon in other areas of the world. Indeed, they are a feature of many national parks. However, in most cases, the cooling columns formed in basaltic lava flows, which are relatively fluid and pond easily. The development of columnar joints in volcanic ash, particularly of rhyolitic composition, is less common. Also, rarely are columns seen developed to the size and extent of those that are exposed at High Island Reservoir.

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Campbell, S.D.G., Parry, S. & Liu, Y.s. 1999. Hong Kong's Classic Geology No. 1: Deformation and slope failure modes in columnar jointed tuffs of the High Island Formation, Hong Kong. *Hong Kong Geologist*, v. 5, pp 37 – 40.

Davis, S.G. 1952. *The geology of Hong Kong.* Government Printer, Hong Kong. 231 p.

plus 14 plates & 3 maps.

Fisher, R.V. & Schminke, H.U. 1984. *Pyroclastic rocks*. Springer Verlag, New York, 472 p.

Ruxton, B.P. 1960. The Geology of Hong Kong. *Quarterly Journal of Geological Society of London*, v. 115, pp 233-260.

Smith, R.L. 1979. Ash-flow magmatism. *Geological Society of America Special Paper No. 180*, pp 5 – 27.

Strange, P.J., Shaw, R. & Addison, R. 1990. *Geology of Sai Kung and Clear Water Bay.* Hong Kong Geological Survey Memoir No. 4, Geotechnical Control Office, Hong Kong, 111 p.

Tam, S.W. & Chan, Y.M. 1983. Late Jurassic ash-flow tuffs in the eastern part of Hong Kong, South China. *Asian Geographer*, v. 2, no. 1, pp 47 – 69.

Tam, S.W. 1970. *Landform in Sai Kung Peninsula and adjacent islands*. Unpublished MA Thesis, Hong Kong University, 240 p.

Chapter 17. Dykes and Coastal Environment – Hok Tsui Rhyolite

Introduction

Cape D’Aguilar (Hok Tsui) is located at the southern tip of the Shek O – Cape D’Aguilar Peninsula, southeastern Hong Kong Island. The Cape D’Aguilar area has been designated as a Marine Reserve by the Hong Kong Government. Consequently, the appropriate permission must be obtained before entering the area, and visitors must strictly follow the Marine Reserve regulations.

Both intrusive (granite) and extrusive (tuff) rocks are present at the Cape D’Aguilar Marine Reserve. In addition, a range of interesting coastal landforms has developed through a combination of wave action upon the distinctive underlying geology. Therefore, the Cape D’Aguilar Marine Reserve area provides an ideal location for studying both geology and geomorphology.

Access to Cape D’Aguilar

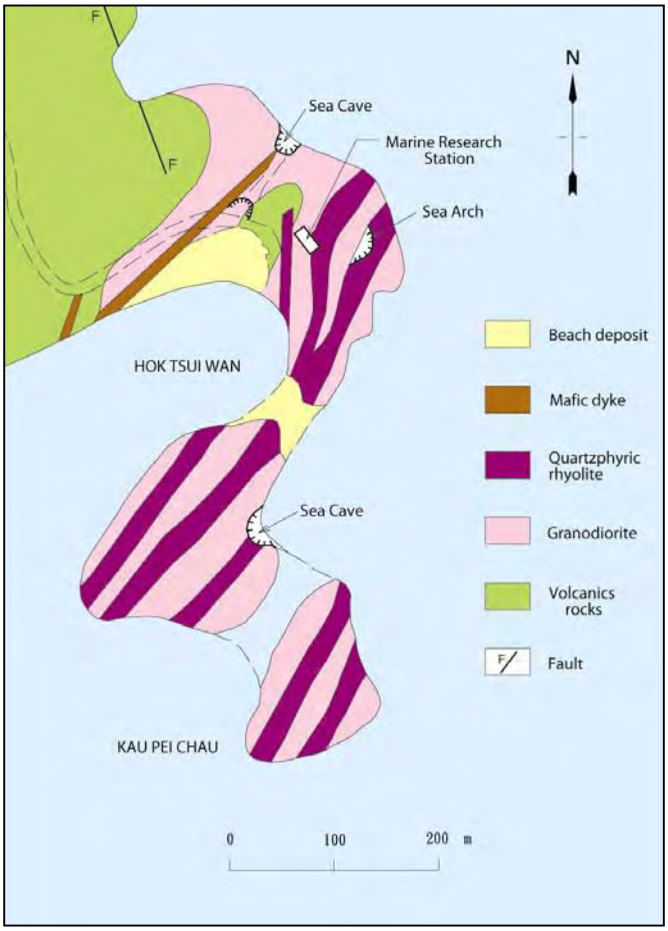
How to Get There

The Cape D’Aguilar Marine Reserve cannot be reached directly by public transport. Access is by bus No. 9 between Shau Kei Wan and Shek O, or by bus No. 309 between Exchange Square, Central, and Shek O, and alighting at Windy Gap on the hill above Shek O. From there it is a 3.5 km walk southeastwards along the road to Cape D’Aguilar.

Outline of the Geology

The geology of the Cape D’Aguilar peninsula is relatively complex. Granite at Windy Gap changes southwards to quartz monzonite. These two rock types were emplaced as separate igneous intrusions during the Cretaceous Period. Extrusive coarse ash –

lapilli crystal tuff of the Jurassic Yim Tin Tsai Formation crops out at the southern tip of the peninsula. This is intruded by Jurassic granodiorite. A key geological feature of the Cape D'Aguilar peninsula is that the granodiorite body is traversed by numerous quartzphyric rhyolite dykes and mafic (basic) dykes. The north-northeast-trending quartzphyric rhyolite dykes cut through, and have ripped off, blocks of the host granodiorite. Wave action along this exposed section of coastline has eroded the complex rock pattern to produce an interesting range of coastal landforms, such as cliffs, headlands, sea caves, and sea arches.



Geological map of the Cape D'Aguilar area

Guide to Field Observations

The Cape D'Aguilar Marine Reserve provides an ideal location for studying both geology and geomophology. However, visitors should strictly observe the Marine Reserve regulations while carrying out field observations in the area. Hammering the rocks, or collecting rock samples, is not allowed. Please endeavour to protect the natural environment within the Reserve.

1) Eroded into the cliff, to the west of Swire Institute of Marine Science, Hong Kong University, is a large sea cave that makes an excellent starting point. The roof of this sea cave has been breached, so that it is now a blowhole. A blowhole is narrow chamber in a sea cliff with an opening at the top. At certain stages of the tide, incoming waves funnel under pressure into the cave so that sea water and spray are pushed upwards and then forced out through the relatively narrow opening in the roof. Closely examine the geology and try to determine if there is any difference in rock types on opposite sides of the cave. Read the geological map and try to determine how the cave was formed.

Blow hole with sea water rushing in

Blow hole on the hillside

Distinctive dark lamprophyre dyke

Lamprophyre cutting quartzphyric rhyolite

2) Walk westwards along the footpath to the northwestern shore of Cape D'Aguilar Bay. There, you will see a mafic dyke cutting across the granodiorite. Carefully observe the contact relationships between the dyke and the country rock. The mafic dyke has a specific relationship with the blowhole, try to determine what that is. There are many mafic dykes and veins in the area, some of which are only several tens of centimetres in thickness.

Mafic dyke with xenoliths of quartzphyric rhyolite

Mafic dyke showing vesicles and flow structures

3) Observe the variations in rock types exposed in the coastal outcrops. Their colour, grain size, mineral composition, textures, joint patterns and weathering characteristics differ quite markedly.

4) Observe the contact relationships between the different rock types and, from these, try to determine their sequence of formation. Based on the observed cross-cutting relationships of dykes and veins, it is possible to work out their relative age of emplacement. In this area, younger quartzphyric rhyolite dykes (a light, flesh coloured rock) can be seen cutting through older granodiorite (grey to dark grey coloured rock). Both sets of dykes are cut by later (younger) mafic veins.

Examine the granodiorite, and record the differences between granodiorite and granite

Sand particles and gravel reflect different wave energies

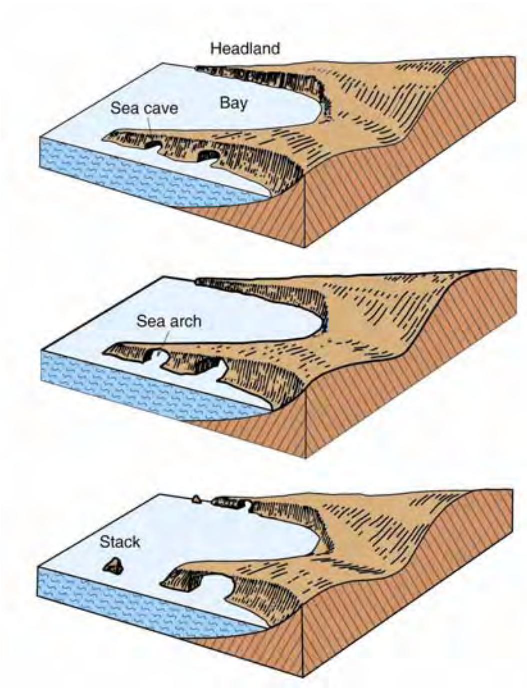
5) Walk along the coast of Cape D'Aguilar Bay from northwest to southeast and carefully observe the beach. Note the appearance of the bedrock, scoured by the abrasive action of wave borne sediments. Consider the various conditions in which the sandy beach and rocky beach have been formed.

6) From the high ground on the southern side of the area, observe the beautiful coastal scenery. The rocky platform between Cape D’Aguilar and Kau Pei Chau is the remains of a headland eroded and breached by the sea. Several sea caves and sea arches have developed in this area. In fact, the two rocky islands off the coast are features known as sea stacks, columns of rock that have been left behind after a sea arch collapsed and the debris was washed away. Some historical narratives suggested that, many years ago, it was possible at low tide to walk across a tombolo (a connecting sand bar) that linked the mainland peninsula with the island located immediately offshore, to the south of Cape D’Aguilar Bay. Should this have previously been the case then, perhaps due to changing wave and current conditions, the small sand bar has now been almost completely eroded away.

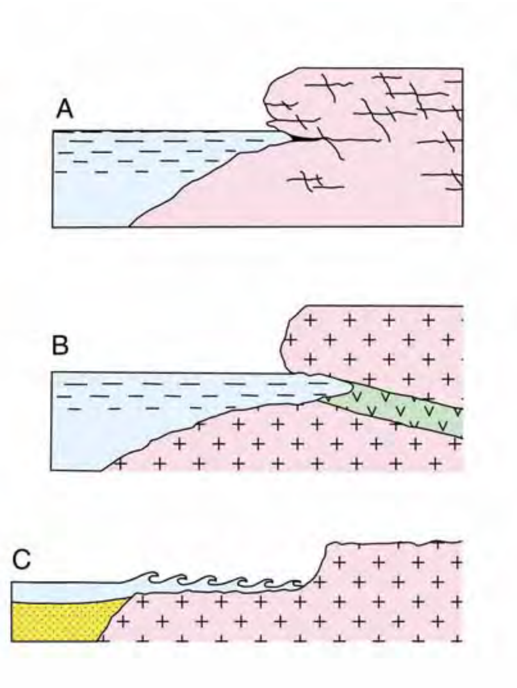
Erosion concentrated along joints

Sea arch (1)

Sea arch (2)



Evolution of a headland, and the formation of caves, arches and stacks



Rock type and structures control the coastal morphology
(A) Waves erode joints;
(B) Waves erode less resistant dyke;
(C) Waves and tidal effects form the wave cut platform

Comments

The two main rock types exposed at Cape D'Aguilar are examples of rocks with an identical magmatic composition, but with different modes of formation. Granodiorite is an acidic intrusive rock, and tuff is an acidic extrusive rock. Dark coloured veins that cut through these two rocks are mainly mafic (basic) in composition. These dyke rocks were previously termed basalt. However, because of their composition and their mode of occurrence, they are more appropriately termed "mafic dykes".

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Bennett, J.D. 1984. *Review of superficial deposits and weathering in Hong Kong*. Geotechnical Control Office, Hong Kong, 51 p.

Campbell, S.D.G. & Sewell, R.J. 1998. A proposed revision of the volcanic stratigraphy and related plutonic classification of Hong Kong. *Hong Kong Geologist*, v. 4, pp 1–11.

Fyfe, J.A., Shaw, R., Campbell, S.D.G., Lai, K.W. & Kirk, P.A. 2000. *The Quaternary geology of Hong Kong.* Geotechnical Engineering Office, Hong Kong SAR Government, 208 p. plus 6 maps

Ruxton, B.P. & Berry, L. 1957. The weathering of granite and associated erosional features in Hong Kong. *Bulletin of the Geological Society of America*, Vol. 68, pp 1263-1292.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

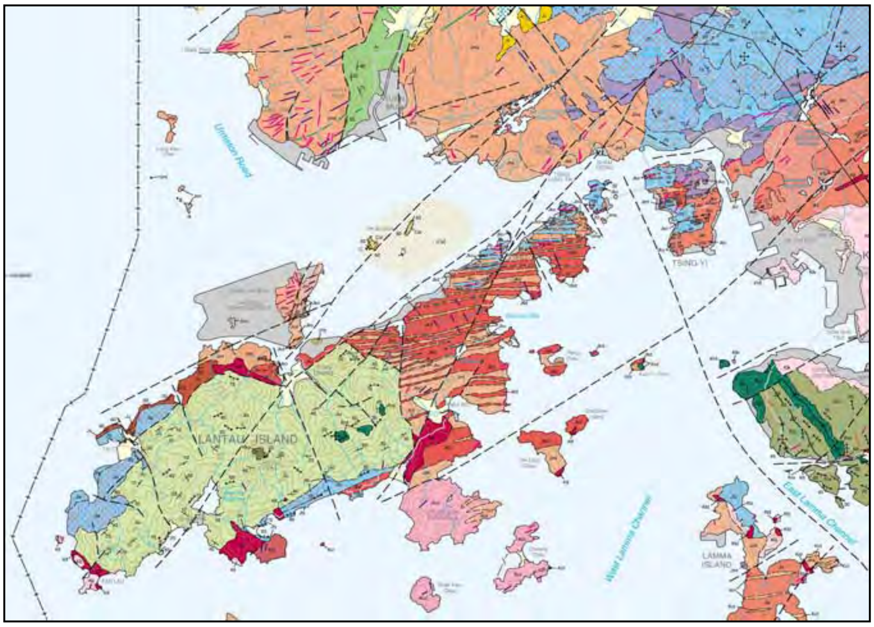
Strange, P.J. & Shaw, R. 1986. *Geology of Hong Kong Island and Kowloon.* Hong Kong Geological Survey Memoir No. 2, Geotechnical Control Office, Hong Kong, 134 p.

Strange, P.J. & Shaw, R. 1987. *Hong Kong South and Lamma Island. Hong Kong Geological Survey Sheet 15*, Solid and Superficial Geology. 1:20 000 Series HGM20, Geotechnical Control Office, Hong Kong.

Chapter 18 – Lantau Dyke Swarm – East Lantau Rhyolite

Introduction

The Lantau Dyke Swarm is a special geological feature comprising numerous east-north-east-trending rhyolitic dykes that intrude older granitic or volcanic country rock in the area between northeast Lantau and Tsing Yi.



Geological Map of northeast Lantau and Tsing Yi
(from 1:100,000 HGM100)

How to Get There

An illustrative cross-section through part of the Lantau Dyke Swarm is visible in a large cut-slope situated on the northern side of North Lantau Expressway at Sham Shui Kok. Access to the rock slope is gained from a dual-lane service road that parallels the south side of the Expressway.

Access from the North Lantau Expressway to
Sham Shui Kok

Travelling west by vehicle from the Tsing Ma Bridge, take the Disneyland, Penny’s Bay exit. Follow the service road, parallel to the Expressway, for about 2.5 km then turn left through a subway beneath the Expressway, and turn immediately right. After about 60 m the road passes a knoll. The cut slope is located on the side of the knoll that faces the Expressway.

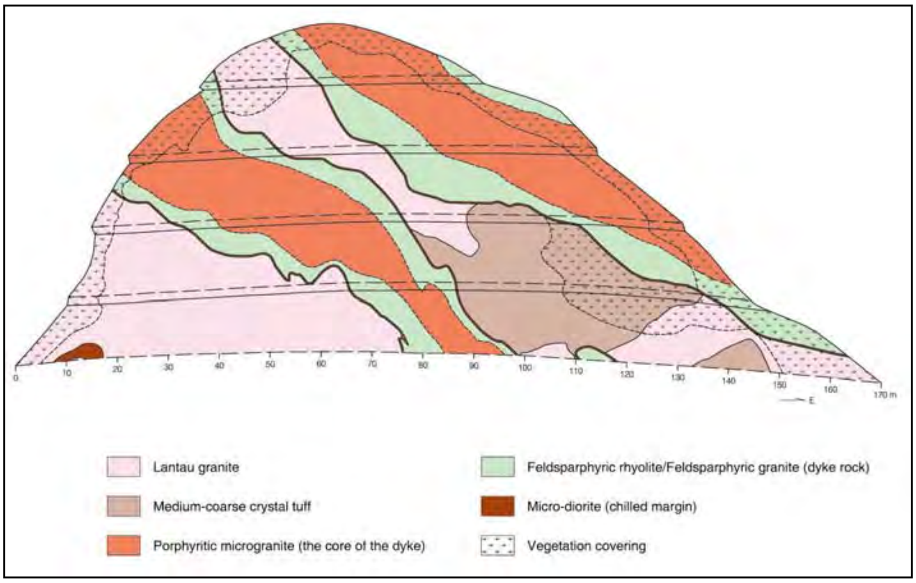
Driving from Tung Chung, start from Tat Tung Road near Exit “D” of Tung Chung MTR Station. Travel northeastwards along Cheung Tung Road until an access road parallel to the expressway is reached. Turn right here, and pass through the subway to reach the slope.

Route to the rock cut slope at Sham Shui Kok, Lantau

Outline of the Geology

The rock cut-slope at Sham Shui Kok is situated on the northern side of the North Lantau Expressway, with the slope facing southeast, parallel to the Expressway. The slope is 170 m long and 45 m high. Four berms subdivide the slope into five batters.

This cut-slope presents a representative cross-section through the northwestern part of the Lantau Dyke Swarm, allowing dykes and their cross-cutting relationships to be observed. The slope face consists of the Lantau Granite and coarse ash crystal tuff (the so-called country rocks), which crops out only at the eastern end of the cut-slope.



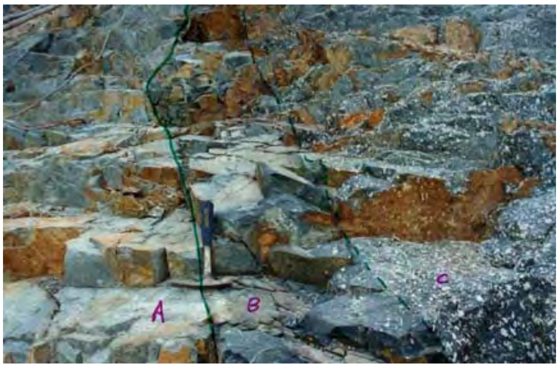
Geological map of Sham Shui Kok (from Li et al., 2000)

Two parallel rhyolite dykes cut across the slope, and systematic variations can be observed within the dykes. Within one particular dyke, the different rock types and textural variations show a symmetrical distribution. From the margins to the interior of the largest dyke, the following changes in rock types and textures can be observed: basaltic andesite (chilled margin); feldsparphyric rhyolite (main rock type I); porphyritic very fine-grained granite (main rock type II), and very fine-grained granite (core of the dyke). Changes in rock types and textures within the dyke can be observed over an interval of less than 20 m.

<u>Guide to Field Observations</u>

The cut slope at Sham Shui Kok is an excellent locality for geological field observations. It is recommended that an initial examination is first made, from west to east along the lowest berm, to observe the full range of geological features. These include changes in textures, properties of the surrounding rock, and contact relationships.

1) Changes from west to east observable from the lowest berm include the following:



Geological map of Sham Shui Kok
(from Li et al., 2000)

i) Country rock (I) – the Lantau Granite: The granite exposed at the western end of the berm is one of the two major rock types of the area into which the dykes have been intruded. The Lantau Granite is medium-grained with large (2-5 mm across) crystals of feldspar that are set within a medium-grained matrix. Results of U-Pb isotope dating showed that the Lantau Granite is about 161.5 million years old, making it one of the oldest plutons in Hong Kong.

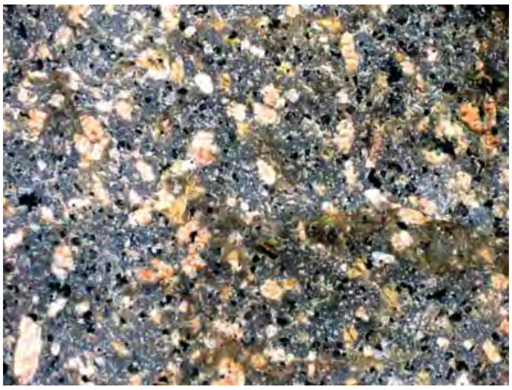
ii) Dyke chilled margin – Basaltic andesite: Eastwards, a 30-50 cm thick zone of dark greyish green rock can be identified cutting across the Lantau Granite. This rock exhibits a sharp contact with granite on its western side, whereas in the east, although the contact with granite is abrupt, it demonstrates a slightly more transitional textural change. The dark greyish green dyke rock cooled relatively quickly when it came into contact with the cold country rock during intrusion, so it is fine-grained. This phenomenon is known as a chilled margin. Thus, the contact with the cold surrounding host rock is sharp, whereas away from the margins, towards the inner part of the dyke, the dyke rock is coarser grained and changes in textural features are more transitional.

Main Rock Type (I) – Well-formed crystals in feldsparphyric rhyolite

Main Rock Type (II) – Porphyritic microgranite

iii) Main rock type (I) – Feldsparphyric rhyolite: A major dyke rock in this area is feldsparphyric rhyolite. This rock is characterised by a high proportion of large (0.8-1.0 cm, up to 2.0 cm across) feldspar crystals, and smaller quartz crystals (0.2-0.4 cm) within a greenish grey fine-grained groundmass. The feldspars occur as well-formed crystals. Inclusions of a pre-existing rock-type (basaltic andesite) can be identified within the feldsparphyric rhyolite, fragments that were probably torn off from the margins of the intrusion and entrained in the rising magma.

iv) Main rock type (II) – Porphyritic microgranite: Careful observation from the feldsparphyric rhyolite towards the middle of dyke will show that the rock type changes in such a way that the finer matrix crystals become visible, the feldspar crystals become smaller (commonly <5 cm across), dark crystals appear, and the rock colour turns to greyish red.



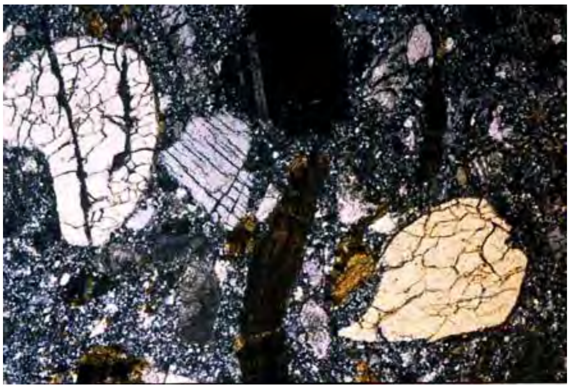
Main Rock Type (II) – Porphyritic microgranite

Microgranite Dyke Core

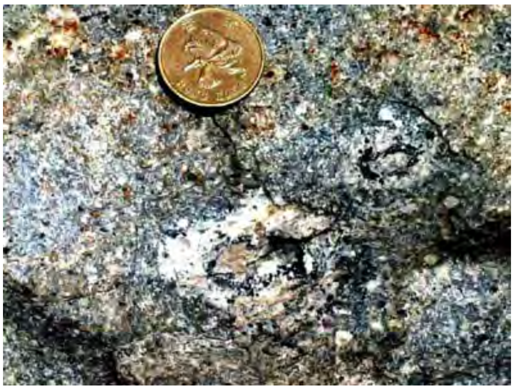
v) Microgranite Dyke Core – Towards the centre of the dyke, the larger crystals are reduced in size to become invisible in the core of the dyke, turning the texture of the rock into a pale-red, even-grained very fine-grained granite. Because of the symmetrical distribution of rock types within the intrusion, a reverse sequence of textural changes is encountered eastwards, ending with a chilled margin at the eastern margin of the dyke.

vi) Country rock (II) – Coarse ash crystal tuff: Volcanic rocks are exposed on the western side of the chilled margin. Although the rock appears to be a crystalline intrusive rock with abundant quartz, feldspar and biotite, the extrusive nature of the rock is demonstrated by the concentric alteration zones around the entrained rock fragments.

vii) Part of another rhyolite dyke is exposed at the eastern end of the slope. This feldsparphyric rhyolite dyke displays a chilled margin.



Microscope view of coarse ash crystal tuff: Cracks in phenocrysts formed by reduced pressure



Altered entrained clast in coarse ash crystal tuff: Concentric structures due to recrystallisation

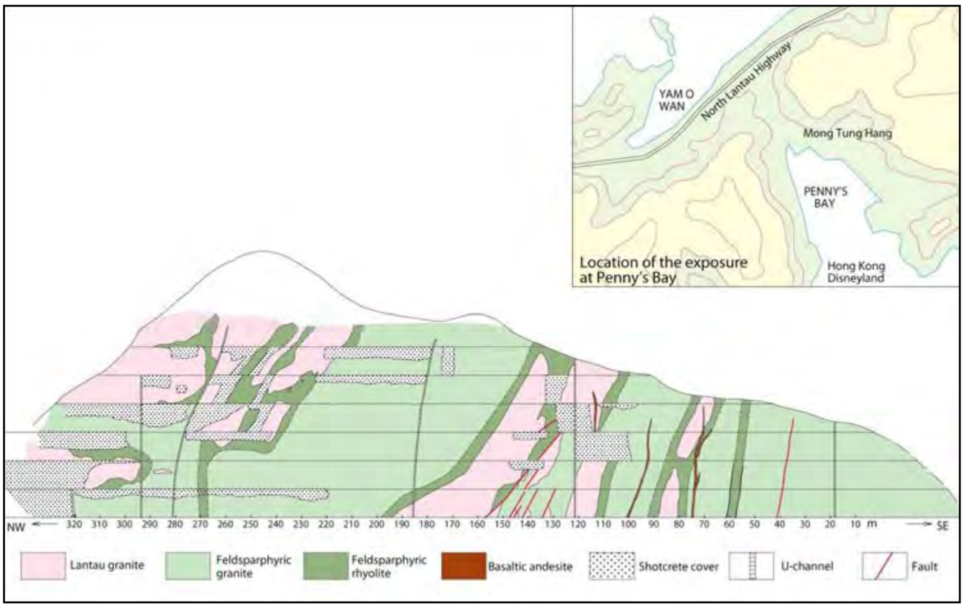
2) Rock types and textures exposed on the cut slope are typical of those found in the dyke swarm in this district. Therefore, this exposure provides an opportunity to examine and appreciate the properties of dyke rocks and intrusive processes.

3) Cross-cutting relationships can also be studied by paying careful attention to contact zones between the different rock types.

4) Try to prepare a simple geological map of the cut slope, including measurements of the width and orientation of the different rock types within the dykes. Record the occurrence of any other structures, and examine variations in rock weathering in different sections of the cut-slope.

Comments

The main geological feature in the area between northeastern Lantau and Tsing Yi is the Lantau Dyke Swarm. Based on an interpretation of several geological sections in the district, three phases of dyke intrusion have been identified. Phases I and II were rhyolitic dyke intrusions, whereas Phase III comprised intermediate to mafic intrusions, mainly basaltic andesite. It is possible that the Phases I, II and III dyke intrusions were the result of differentiation from the same magma source. Typical exposures of dykes intruded in Phase I can be seen at Sham Shui Kok, whereas dykes of Phase II are well-developed at Penny’s Bay.



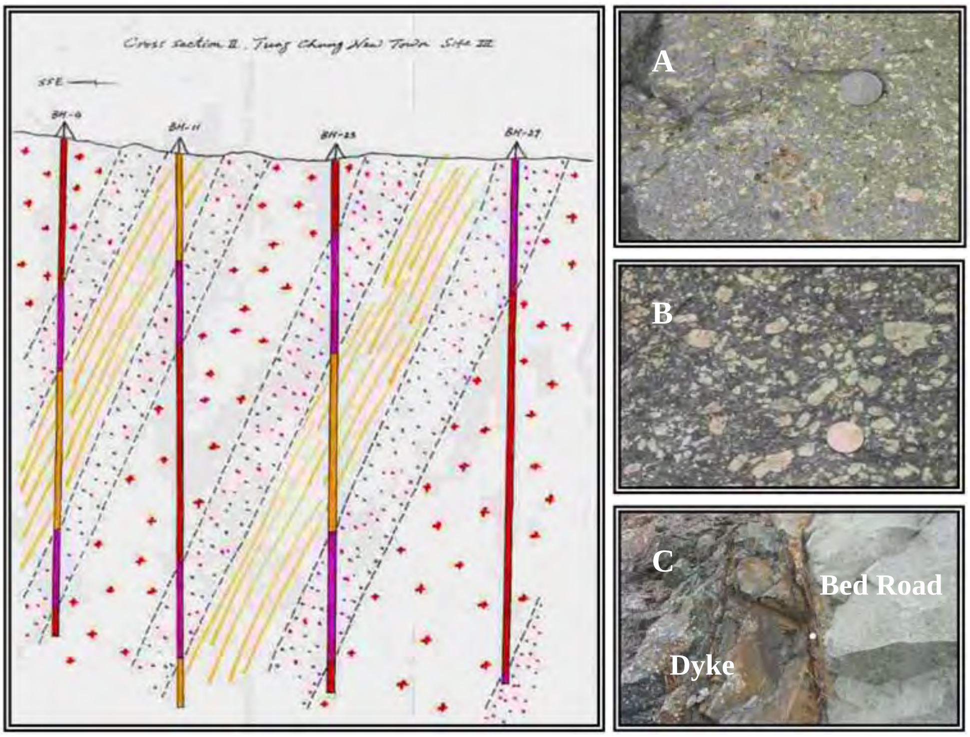
Sketch of Phase II dykes at Penny's Bay (Width of the chilled margin in feldsparphyric rhyolite dykes can reach about 5m)

The characteristics of the Phase I dykes are (1) that they vary from less than one metre to tens of metres wide; (2) there is no obvious basaltic andesite chilled margin; (3) there is no clear zonation within the dykes; and (4) the rock type is relatively uniform, being dominated by porphyritic medium- to coarse-grained granite, with feldsparphyric rhyolite mainly forming the chilled margins of the dykes. In contrast, the Phase II dykes are larger scale, with dykes ranging from tens of metres to one hundred metres.

Basaltic andesite dyke near Siu Ho Wan water treatment plant, Lantau

Phase III dykes are narrower, with widths mostly less than 1 m. Generally, it is easy to distinguish Phase III dykes from the earlier dykes based on rock type and colour (dark grey to greyish green). Basaltic andesite dykes occur in many parts of Hong Kong, but further work is required to determine if these dykes belong to Phase III.

Since there are considerable variations in texture and rock type within the dykes, rock cores recovered from engineering drillholes commonly show unexpectedly abrupt changes. With an improved understanding of the geological characteristics of the dyke swarm, variations found in drillhole cores can be more satisfactorily understood and explained.



Cross-section at Tung Chung works site, Lantau A – Core of dyke (porphyritic fine-grained granite, B – outer part of dyke (feldsparphyric rhyolite), C – chilled margin of dyke (microandesite) immediately adjacent to country rock

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Davis, S.G. 1952. *The geology of Hong Kong.* Government Printer, Hong Kong. 231 p. plus 14 plates & 3 maps.

Langford, R.L. 1994. *Geology of Chek Lap Kok.* Hong Kong Geological Survey Sheet Report No. 2, Geotechnical Engineering Office, Hong Kong Government, 61 p.

Langford, R.L., James, J.W.C., Shaw, R., Campbell, S.D.G., Kirk, P.A. & Sewell, R.J. 1995. *Geology of Lantau District.* Hong Kong Geological Survey Memoir No. 6, Geotechnical Engineering Office, Hong Kong Government, 173 p.

Li, X.C., Sewell, R.J. & Fletcher, C.J.N. 2000. *The dykes of northeastern Lantau Island.* Geological Report, GR 6/2000, Geotechnical Engineering Office, Civil Engineering Department, The government of the Hong Kong SAR, 61 p.

Ruxton, B.P. 1960. The Geology of Hong Kong. *Quarterly Journal of Geological Society of London*, v. 115, pp 233-260.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Sewell, R.J. & James, J.W.C. 1995. *Geology of North Lantau Island and Ma Wan.* Hong Kong Geological Survey Sheet Report No. 4, Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 46 p.

Sewell, R.J. & Kirk, P.A. 2002. *Geology of Tung Chung and Northshore Lantau Island and Ma Wan.* Hong Kong Geological Survey Sheet Report No. 6, Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 90 p.

Fan Lau, Lantau Island

19. Tong Fuk Quartz Monzonite and Fan Lau Granite

Introduction

The Mesozoic intrusive rocks of Hong Kong have been classified into four suites that represent four main phases of intrusive magmatism. These four suites can be correlated with four major volcanic groups. Although the Tong Fuk Quartz Monzonite and Fan Lau Granite are different rock types, they both belong to the youngest Lion Rock Suite. The Tong Fuk Quartz Monzonite occurs intermittently around the northern and southern margins of the main outcrop of the Upper Jurassic Lantau Volcanic Group (mainly on the southern margin), and was probably intruded along ring faults associated with the Lantau caldera. In contrast, the Fan Lau Granite is exposed only on the Fan Lau peninsula, so can be regarded as a relatively minor body.

Granitic rocks are the second most common rock type in Hong Kong, with volcanic rocks covering a larger area. In addition, granite weathers more deeply than the volcanic rocks. Consequently, outcrops of fresh granite are generally much less common than those of volcanic rock. However, there are excellent exposures of the Tong Fuk Quartz Monzonite and the Fan Lau Granite on the Fan Lau peninsula.

Access to Fan Lau, Lantau Island

How to Get There

Buses from Tung Chung or Mui Wo to Ngong Ping or Tai O cross the Shek Pik Dam. Fan Lau can be reached by alighting at Shek Pik, and then walking along a foot path, the first 5 km along a catchwater, which is wide and flat, and so walking is easy. The second part of the path is along a mountain trail for about 1.5 km. The trail is rough, but safe to walk, and magnificent cliff and beach scenery can be viewed along the way.

Junction of the catchwater and the trail to the Fan Lau Peninsula

The trail to Fan Lau is well-constructed and safe

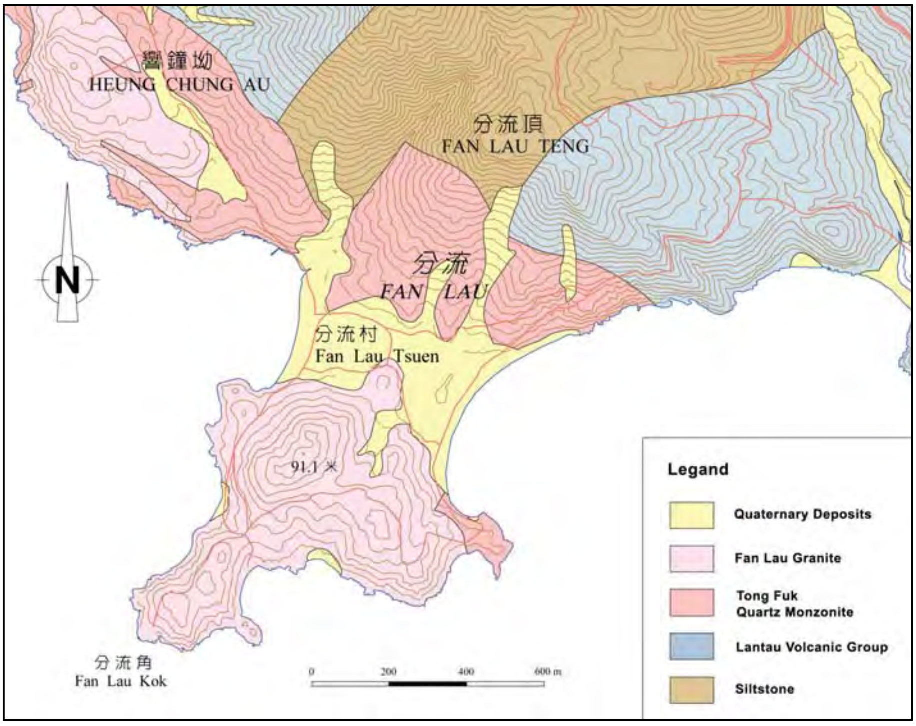
Outline of the Geology

Fan Lau is an ideal location for studying granitic rocks because the Tong Fuk Quartz Monzonite and Fan Lau Granite are both well-exposed along the coast and the outcrops are relatively fresh. The granitic bedrock of the Fan Lau peninsula is covered in part by Quaternary superficial deposits, mainly colluvium.

Fresh Tong Fuk Quartz Monzonite

Prominent phenocrysts of feldspar in slightly weathered Tong Fuk Quartz Monzonite

The Tong Fuk Quartz Monzonite is characterised by the occurrence of very large crystals (megacrysts) of alkali feldspar (up to 15 mm long) surrounded by a finer crystalline matrix. Subordinate smaller crystals (1-3 mm) of plagioclase feldspar also occur. Features termed ‘double enclaves’ have been identified in the rock. These are fragments of older Lantau Granite that are enclosed by younger Luk Keng Quartz Monzonite, which are in turn contained within the youngest Tong Fuk Quartz Monzonite (Sewell *et al.*, 2000). Enclaves provide valuable evidence of the relative ages of various intrusive phases. Results of Uranium-Lead (U-Pb) isotope dating indicate that the Tong Fuk Quartz Monzonite was emplaced around 140 million years ago.



Geological map of the Fan Lau Peninsula (GEO, 1995)

Contact relationships between the different rock units usually provide the most direct evidence of the sequence of emplacement. The Fan Lau Granite has intruded into the Tong Fuk Quartz Monzonite, and is, therefore, younger. The Granite contains abundant large crystals of quartz and alkali feldspar enclosed in a finer matrix comprising quartz, alkali feldspar (microperthite), plagioclase feldspar (albite), and biotite mica. Fan Lau Granite can be distinguished from the Tong Fuk Quartz Monzonite in two ways. Firstly, the Fan Lau Granite generally contains more biotite, and secondly, small, mafic mineral-rich aggregates resulting from magmatic differentiation are generally more common in the Fan Lau Granite.

Joint pattern in Tong Fuk Quartz Monzonite

Joint sets in Fan Lau Granite

Mineral aggregates formed by magmatic differentiation, Fan Lau Granite

Rock structures formed by magmatic differentiation, Fan Lau Granite

Pegmatite in Fan Lau Granite

Quartz veins in Fan Lau Granite

Guide to Field Observations

Fan Lau Granite dominates the Fan Lau peninsula, whereas the Tong Fuk Quartz Monzonite underlies the northern part of the peninsula and crops out in a small area on the southern end. Selection of the optimum sites for field observations can be carried out by reference to the generalised geological map.

Detailed examination of the igneous rocks of the Fan Lau peninsula is best done along the coast, which is generally free of vegetation. In addition to numerous boulders of fresh rock, there are many exposures of fresh bedrock. Because the topography is rugged, care should be taken while walking along the coast.

Important things to look at when inspecting the intrusive igneous rocks:

1) The mineral composition of the rocks

2) Structures within the rock

3) Characteristics of, and contact relationships with, adjacent rock bodies

4) The weathering characteristics of the rocks

Comments

Allen & Stephens (1971) distinguished four granitic intrusive phases in Hong Kong. Subsequently, on the 1:20,000-scale geological map (GEO, 1995), the granitic rocks were classified on the basis of composition (*i.e.* alkali feldspar, plagioclase and quartz content) and grain size. Although this classification, and the associated nomenclature, is simpler to follow, it does not provide a clear indication of the relative ages of the intrusive units, or of their sequence of emplacement.

More recently, refinements have been made to the classification and nomenclature of the intrusive rocks based on age dating, and on chemical analyses of the composition of the various intrusive bodies. In particular, advances have been made with regard to understanding the emplacement sequence of the intrusive units. Thus, the intrusive rocks are now classified into four suites on the 1:100,000-scale geological map and in the associated geological memoir (Sewell *et al.*, 2000). The four suites are, from oldest to youngest, the Lamma Suite, the Kwai Chung Suite, the Cheung Chau Suite and the Lion Rock Suite. A total of twenty-five intrusive units (plutons and dykes) have been identified within these four suites. The Fan Lau Granite and the Tong Fuk Quartz Monozonite belong to the youngest, Lion Rock Suite.

References

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Davis, D.W., Sewell, R.J. & Campbell, S.D.G. 1997. U–Pb dating of Mesozoic igneous rocks from Hong Kong. *Journal of the Geological Society*, Vol. 154, pp 1067–1076.

Gamon, T.I & Finn, R.P. 1984. The structure of the Hong Kong Granite – A preliminary appraisal. *Geological Society of Hong Kong Newsletter*, v. 2, no. 2, pp 5 – 9.

Langford, R.L. & James, J.W.C. 1995. *Shek Pik. Hong Kong Geological Survey Sheet 13*, Solid and Superficial Geology. 1:20 000 Series HGM20. Geotechnical Engineering Office, Hong Kong.

Langford, R.L., James, J.W.C., Shaw, R., Campbell, S.D.G., Kirk, P.A. & Sewell, R.J. 1995. *Geology of Lantau District.* Hong Kong Geological Survey Memoir No. 6, Geotechnical Engineering Office, Hong Kong Government, 173 p.

Ruxton, B.P. 1960. The Geology of Hong Kong. *Quarterly Journal of Geological Society of London*, v. 115, pp 233-260.

Sewell, R.J. 1992. Mesozoic granites of Hong Kong: tectonic implications. *Geological Society of Hong Kong Newsletter*, v. 10, no. 3, pp 8 - 14.

Sewell, R.J. & Campbell, S.D.G. 1997. Geochemistry of coeval Mesozoic plutonic and volcanic suites in Hong Kong. *Journal of the Geological Society*, Vol. 154, pp 1053–1066.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Strange, P.J. 1987. Petrological aspects of the Hong Kong quartz syenites. *Geological Society of Hong Kong Newsletter*, v. 5, no. 2, pp 3 - 8.

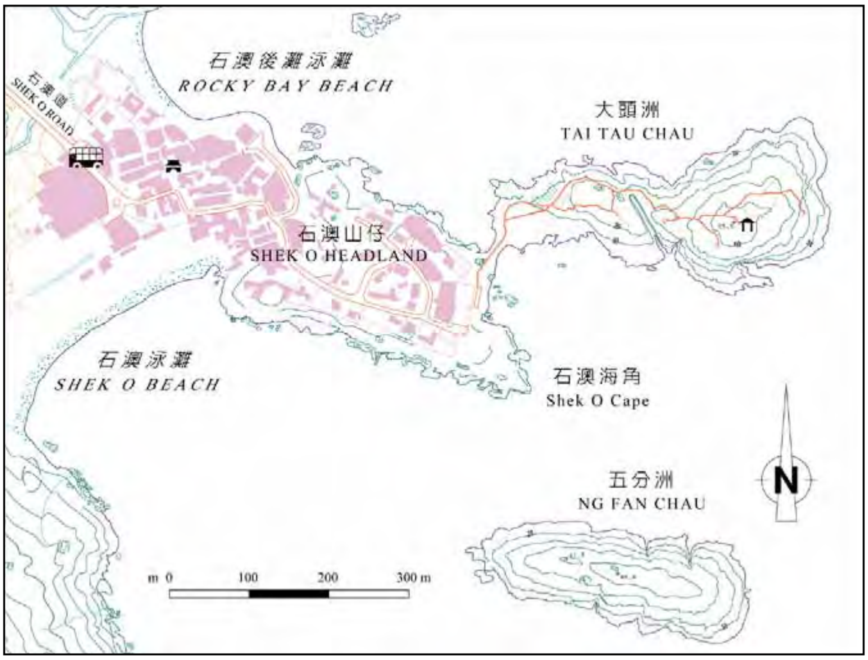
Hong Kong Island, Shek O Headland, Tai Tau Chau

20. Cretaceous Po Toi Granite

Introduction

The Po Toi Granite crops out mainly on Po Toi Island, from where it is named, in the area around the Stanley peninsula, and at Shek O in southeastern Hong Kong Island. Po Toi Granite comprises both megacrystic coarse-grained granite, and equigranular fine-grained biotite granite. Although the granite has not yet been accurately dated, the geochemistry and field relationships suggest that it belongs to the youngest suite of granites in Hong Kong, the Lion Rock Suite.

The difficulties of access to Po Toi Island and dense residential development on the Stanley peninsula make both areas unsuitable for observing the Po Toi Granite. Coastal outcrops around the Shek O headland and adjacent to Tai Tau Chau are more accessible for studying Po Toi Granite, as not only does this locality have convenient transport, but the granite outcrops are superb.



Access to the Shek O headland

How to Get There

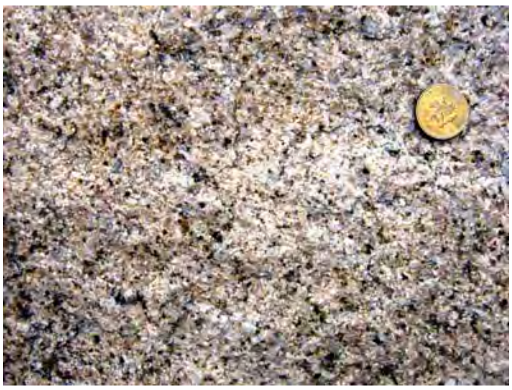
The type locality on Po Toi Island can be visited by public ferry. Services depart from Aberdeen at 9:00 am every Tuesday, Thursday and Saturday, and return immediately. An afternoon ferry service is only available on Sundays or Public Holidays.

Three bus routes serve the Shek O headland and Tai Tau Chau. These are, bus no. 9 from Shau Kei Wan, bus no. 309 from Exchange Square, Central, and bus no. 319 from Siu Sai Wan Island Resort. There is also a minibus service to Shek O headland from Po Man Street in Shau Kei Wan.

Alight from the bus at Shek O headland, then walk eastwards to Shek O Wan. A rock bridge connects Shek O Wan to Tai Tau Chau. All of the area, including Ng Fan Chau, and the slope on the southwestern end of Shek O Beach, is underlain by Po Toi Granite.

Outline of the Geology

The Po Toi Granite forms an elliptical pluton in southeastern Hong Kong Island, with the main exposures on the Stanley and Shek O – D’Aguilar peninsulas, as well as on Po Toi Island. Granite in the southeast of Po Toi Island comprises mainly uneven (inequigranular) coarse-grained textures with large crystals of feldspar surrounded by a coarse-grained matrix, whereas in the northwestern part it consists of even (equigranular) medium to fine-grained textures.



Equigranular medium-grained granite, Shek O headland

Surface of weathered granite, Shek O

Po Toi Granite is exposed mainly in the central region of the Shek O – D'Aguilar peninsulas. Along the northern margin, the granite is in contact with fine ash tuff of the Ap Lei Chau Formation of Repulse Bay Volcanic Group, whereas along the southern margin it is in intrusive contact with D'Aguilar Quartz Monzonite of the Lion Rock Suite. On the Shek O – D'Aguilar peninsulas, the Po Toi Granite consists mainly of equigranular medium-grained or fine-grained granite. Fine-grained granite dykes intruding medium-grained granite can also be seen in this area. The most important geomorphological characteristic of the Po Toi Granite is the development of large scale sheeting joints. These appear as large expanses of smooth, convex rock slopes, which are most obvious on Po Toi Island, but can also be seen along the east coast of Stanley peninsula, and on the slopes to the southwest of Shek O Beach.

Rock slope formed along sheeting joints, Po Toi Island

Medium- to coarse-grained granite (mid-upper part) intruded by fine-grained granite (lower part)

Contact relationship between fine-grained and medium-grained granite

Quartz vein in granite pluton faulted into three sections

Pegmatite vein formed in the pluton by late stage hydrothermal fluids

Granite sheeting joints, Shek O Wan

Lithified beach rock at high water mark

Abundant quartz gravel and shell fragments in beach rock

Huge vertical cracks at Ng Fan Chau, giving rise to the island's name

Vertical cracks at Tai Tau Chau

<u>Observation Guide</u>

1) Note the variation in the grain size within the granite, and identify the different minerals and their relative proportions. Note the shape of the constituent minerals, and consider suitable rock names.

2) Identify any minor intrusions within the medium-grained granite body, including dykes or quartz veins.

3) Consider the characteristics of the slopes formed by sheeting joints, and decide what positive or negative effects these might have on slope stability.

4) Locate the three huge vertical cracks on Ng Fan Chau, and consider how they might have formed. There is a similar structure on Tai Tau Chau that should also be observed.

5) Note any differences in the geomorphology of the areas underlain by granite and those underlain by volcanic rocks. Consider what factors might influence these differences.

<u>Comments</u>

The 1:20,000-scale geological maps are used extensively for city planning in Hong Kong, as well as for a range of different engineering applications. However, users should be aware that the intrusive rocks in these maps are classified mainly on the basis of their grain size and their general felsic mineral (quartz, K-feldspar, plagioclase) composition (Langford *et al.*, 1995). Names such as fine-grained granite, medium-grained quartz syenite, and coarse-grained granite, were typically used. In contrast, on the recently published 1:100,000-scale geological map (Sewell *et al.*, 2000), the intrusive rocks were re-classified as individual intrusive units (*i.e.* plutons) based on their contact relationships, mineral content, geochemistry, and absolute age. Each pluton was named after the locality where the optimum development crops out. Plutons were then grouped into different suites based on their intrusive sequence, age, geochemistry and mineralogy. Four main pluton suites have been identified in Hong Kong. Finally, the intrusive history can be integrated with the volcanic stratigraphy to construct a model of the overall geological history of the territory.

<u>References</u>

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Davis, D.W., Sewell, R.J. & Campbell, S.D.G. 1997. U–Pb dating of Mesozoic igneous rocks from Hong Kong. *Journal of the Geological Society*, Vol. 154, pp 1067–1076.

Finn, R.P. & Gamon, T.I. 1989. An interpretation of the cooling history of different phases of the granite of Hong Kong from their discontinuity patterns. *Geological Society of Hong Kong Newsletter,* v. 7, no. 3, pp 23 - 28.

Gamon, T.I & Finn, R.P. 1984. The structure of the Hong Kong Granite – A preliminary appraisal. *Geological Society of Hong Kong Newsletter*, v. 2, no. 2, pp 5 – 9.

Sewell, R.J. 1992. Mesozoic granites of Hong Kong: tectonic implications. *Geological Society of Hong Kong Newsletter*, v. 10, no. 3, pp 8 - 14.

Sewell, R.J. & Campbell, S.D.G. 1997. Geochemistry of coeval Mesozoic plutonic and volcanic suites in Hong Kong. *Journal of the Geological Society*, Vol. 154, pp 1053–1066.

Sewell, R.J., Campbell, S.D.G. & Davis, D.W. 2001. New high precision U–Pb zircon ages for Mesozoic intrusive rocks from the southern Hong Kong SAR. *Hong Kong Geologist*, v. 7, pp 1 – 8.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Sewell, R.J. & Langford, R.L. 1991. Second Hutton Symposium on the Origin of Granites and Related Rocks. Excursion C2 - Granites of Hong Kong. 30 September - 2 October 1991. *Geological Society of Hong Kong Newsletter*, v. 9, no. 3, pp 3-28.

Strange, P.J. 1985. Towards a simpler classification of the Hong Kong granites. In: *Geological Aspects of Site Investigation: Geological Society of Hong Kong, Bulletin no. 2*, (Edited by I. McFeat-Smith), pp 99 - 103.

Strange, P.J. 1986. High level beach rock on Hong Kong Island. *Geological Society of Hong Kong Newsletter,* v. 4, no. 2, pp 13-16.

Strange, P.J. 1990. The classification of granitic rocks in Hong Kong and their sequence of emplacement in Sha Tin, Kowloon and Hong Kong Island. *Geological Society of Hong Kong Newsletter*, v. 8, no. 1, pp 18-27.

Strange, P.J. & Shaw, R. 1986. *Geology of Hong Kong Island and Kowloon.* Hong Kong Geological Survey Memoir No. 2, Geotechnical Control Office, Hong Kong, 134 p.

Chapter 21. The Power of Weathering – Erosion Topography in Tsing Shan

Introduction

From a geological development point of view, high mountains are all gradually weathered and eroded and become lower in elevation. Because the force of gravity is constantly trying to reduce mountains to a state of equilibrium, it is impossible to resist the effects of erosion. The base level of erosion is sea level. Therefore, although erosion may progress slowly, it never ceases entirely. When certain special conditions permit, however, the rate of erosion may increase dramatically. Landslides, slope failures, debris flows and rock falls are all expressions of accelerated erosion.

Weathering and erosion geomorphology in Tsing Shan

Erosion occurs when weathered rocks are subject to natural wastage, and are transported by flowing water or winds (or ice in fact). There are three main types of weathering: physical weathering, chemical weathering and biological weathering. Physical weathering occurs when rocks are gradually broken up (from larger pieces to smaller pieces) under repeated cooling and heating or frost wedging. Chemical weathering is the chemical changes of rocks (from stronger to weaker) caused by the effects of groundwater, temperature and other factors. For example, feldspar minerals will become kaolin or other clay minerals under chemical weathering. Biological weathering is changes

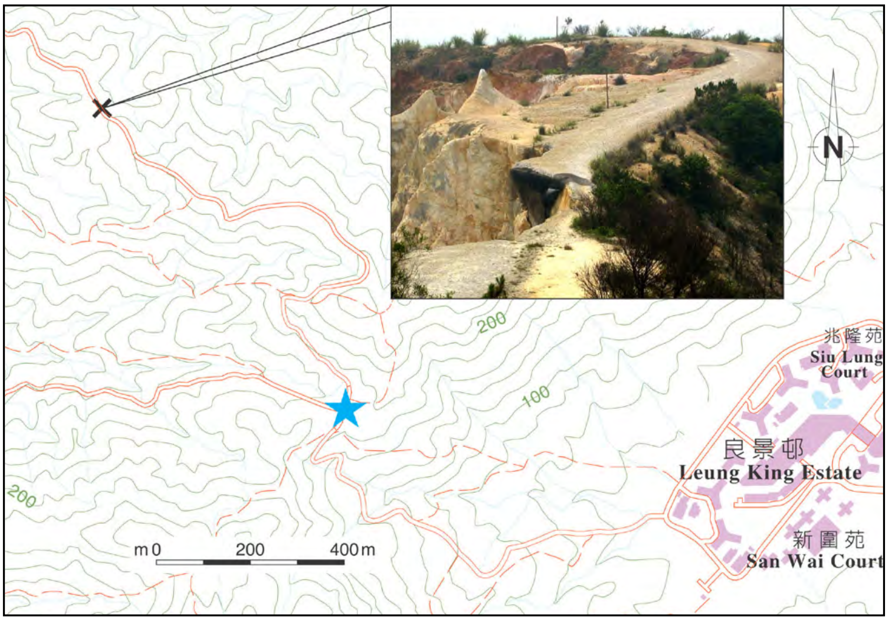
Deeply eroded gullies in Tsing Shan

in the properties and appearance of rocks (weakening) due to the actions of living organisms. Bacterial breakdown and absorption by roots are some examples. The action of water currents and strong winds plays an important role in weathering. They provide favourable conditions and media for weathering, and are main transportation agents of weathered materials.

Due to strong compression and faulting over geological time, the granite in Castle Peak in the western New Territories is strongly deformed and metamorphosed (schistose). As a result, the rate of weathering has accelerated causing the development of a special erosional morphology in the area. You can get a strong sense of the power of weathering and erosion while observing this bare land of weathered soil and the erosion gullies that incise deeply into the hillslopes.

How to Get There

At the western side of Leung King Estate in Tuen Mun, there is a road leading to Castle Peak (Tsing Shan). This road climbs from Leung King Estate to the peak at an elevation of 185 m and is about 1.5 km in length. It is possible to drive a car up to the peak. From there, you can view the Leung King Estate in the east, and the bare weathered land of Tsing Shan in the west. Continue to drive along the road in a northwest direction to view many erosional gullies. Farther along, the road is cut by deep gullies providing a good section with which to examine the weathered granite.



Route plan to geological observation spots of the weathering and erosion morphology in Tsing Shan

Outline of the Geology

Tsing Shan Granite is present on the western side of the Tuen Mun Valley from Lung Kwu Chau in the west to Tsim Bei Tsui in the north. The intrusion of Tsing Shan Granite is bounded by the Deep Bay Fault to the west. The eastern margin of the Tsing Shan Granite is in fault contact (Tuen Mun Fault) with the Tuen Mun Formation. Tsing Shan Granite comprises mainly equigranular to inequigranular two-mica granite. Feldspars and quartz generally form larger crystals (phenocrysts) set in a finer groundmass. Black mica (biotite) is the main mafic mineral, and there is some minor interstitial white mica (muscovite) between quartz and feldspar crystals. Based on U-Pb isotope age dating, the Tsing Shan Granite belongs to the Lamma Suite, which is stratigraphically the oldest granite suite.

Bounded between the Deep Bay Fault and Tsing Shan Fault, the Tsing Shan Granite is strongly sheared and metamorphosed (schistose). The degree of deformation is higher in the northern part of the pluton than in the southern part. This could possibly be due to additional compression related to the San Tin thrust fault in the north.

The sheared and metamorphosed character of the Tsing Shan Granite has significantly weakened the rocks making them more susceptible to weathering. Hong Kong is located in a sub-tropical zone with high, and sometimes intense, rainfall. This favours weathering and erosion of the steep terrain, and therefore, Tsing Shan, has formed a special erosional morphology.

Guide to Field Observations

The erosional morphology can be examined both at outcrop scale and in hand specimens. In outcrop scale, take note of the appearance, slope gradient, slope aspect and vegetation cover of the hillside. For instance in Tsing Shan, if the degree of weathering is similar, the south-easterly facing slopes (mainly from the upper part of the slope to the crest) are generally covered by sparse vegetation, and are subject to severe erosion. This could possibly be related to the direction of rainfall.

At hand specimen scale, observe the metamorphism and weathering effects on the rocks. The joints, deformation layering, faults, minor folds and intrusive veins are all directly controlling the rate of weathering. At the same time, note the correlation between the thickness of weathering profile and the morphology. On a rounded hill, the weathering profile is generally thicker. With an increase in slope gradient, the remains of weathering profiles become thinner. Deep and steeply incised erosion gullies are often found at the margin of a thick weathering profile. These erosion gullies gradually retreat uphill and eventually cut through the ridgeline. This is similar to that observed at the peak of Tsing Shan where the road is cut by erosion gullies.

Sheared granite in Tsing Shan

Corestones in weathered granite

Gullies in thick weathering profile

Gullies cutting across the road

Foliation in granite promotes the rate of weathering

Relict quartz veins in weathered granite

Comments

The Tsing Shan Granite is deeply weathered with the development of numerous erosion gullies. This is unusual when compared to other granitic terrains in Hong Kong where spheroidal/onion-skin weathering and the development of corestones are characteristic weathering features. In the Tsing Shan area, chemical weathering is dominant. The minerals in the rocks are altered and therefore their resistance to erosion has been greatly reduced. An area of deep weathering, closely related to the structural history of the granite has developed. The granite is sheared and deformed (schistose), causing weakening of the rock and an increased potential for weathering. The seasonal heavy rainfall is the major cause of formation of erosion gullies. Moreover, the rate of erosion appears to be rapid. The road leading to the peak, which was constructed in 1992 – 93, has been cut through by erosion gullies in less than 10 years.

References

Fyfe, J.A., Shaw, R., Campbell, S.D.G., Lai, K.W. & Kirk, P.A. 2000. *The Quaternary geology of Hong Kong.* Geotechnical Engineering Office, Hong Kong SAR Government, 209 p. plus 6 maps.

Harris, R. 1984. Rotten relics rule resudual regoliths, Hong Kong. *Geological Society of Hong Kong Newsletter*, v. 2, no. 1, pp 1 - 7.

Langford, R.L., Lai, K.W., Arthurton, R.S. & Shaw, R. 1989. *Geology of the Western New Territories: 1:20 000 Sheets 2, 5 and 6*. Hong Kong Geological Survey Memoir No. 3, Geotechnical Control Office, Civil Engineering Services Department, Hong Kong, 140 p.

Ng, S.L. & Lam, K.C. 2002. Hong Kong's Classic Geology No. 3: Rain erosion, piping, rilling and gullying. *Hong Kong Geologist*, v. 18, pp 42 – 44.

Ruxton, B.P. & Berry, L. 1957. The weathering of granite and associated erosional features in Hong Kong. *Bulletin of the Geological Society of America*, Vol. 68, pp 1263-1292.

Ruxton, B.P. & Peart, M.R. 1990. Polygonal hill ridges on weathered granite in Hong Kong. *Geological Society of Hong Kong Newsletter*, v. 8, no. 2, pp 2 - 15.

Sewell, R.J. & Campbell, S.D.G. 1997. Geochemistry of coeval Mesozoic plutonic and volcanic suites in Hong Kong. *Journal of the Geological Society*, Vol. 154, pp 1053–1066.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Shaw, R. 1995. Granite weathering and deep weathering profiles. *Hong Kong Geologist*, v. 1 (Autumn), pp 88 - 92.

Shaw, R. 1997. Variations in sub-tropical weathering profiles over the Kowloon Granite, Hong Kong. *Journal of the Geological Society, London,* v. 154, Part 6, pp 1077-1085.

Chapter 22 – Stone Bushland

Introduction

The "Stone Bushland" at Shek Lung Tsai, Ma On Shan, is a natural deposit. It stands proud as a greyish natural monument in contrast with the surrounding green vegetated hillslope. Strangely-shaped stones which look like monsters, dinosaurs, tortoises, and lizards, *etc.*, are common within this 0.07 km^2 bare zone.

"Stone Bushland" in Hong Kong

How to Get There

Shek Lung Tsai, is situated south of the abandoned Ma On Shan iron ore mine at an elevation of 443 to 457 m. It can be accessed by walking from the mine southeast along the Ma On Shan Country Trail (please refer to Chapter 24 – Industrial Iron Ore Mining in Hong Kong). The trail is well-suited for hiking. Beginning from the mine at an elevation of 310 m, a pavilion (*c.* 401 m) will be reached after walking at a normal

Ma On Shan Country Trail

pace for about half an hour. Pyramid Hill (Tai Kam Chung) is situated to the east of the pavilion, while the “Stone Bushland” is situated about 800 m to the west.

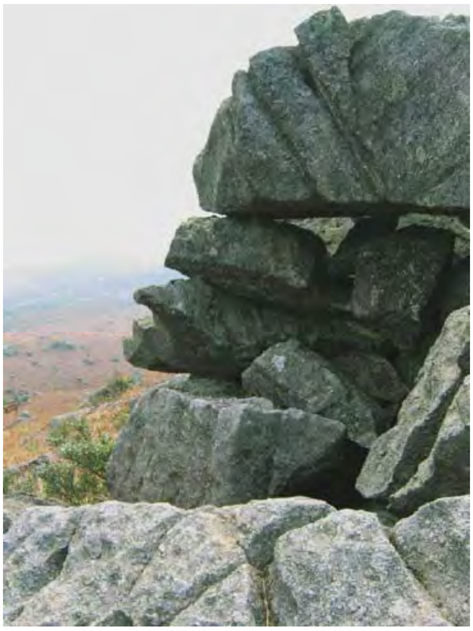
Map of Shek Lung Tsai

<u>Outline of the Geology</u>

The rock type of the “Stone Bushland” belongs to the Mount Davis Formation of the Repulse Bay Volcanic Group, which mainly comprises lapilli-bearing coarse ash crystal tuff or lapilli tuff. The rock has an uneven texture with abundant angular volcanic fragments and erodes easily. From the size and shape of the stones, it is considered that they were probably eroded locally and transported only a short distance.

Lapilli-bearing coarse ash crystal tuff

A saddle along the northwesterly-trending ridge connecting Shek Lung Tsai and Luk Chau Shan may represent the intersection of a northeast-trending fault. Farther north, the possible fault cuts across the eastern side of the Ma On Shan Mine. This fault appears to separate the "Stone Bushland" and the underlying volcanic rocks from granite to the northwest. Contact relationships between the two rock types are difficult to trace in the field due to discontinuous outcrops and thick vegetation cover. However, there are good outcrops of porphyritic fine-grained and medium-grained granite near Luk Chau Shan. In view of the local variation in rock type, it appears that the "Stone Bushland" only developed on the area underlain by volcanic rock.



Stacked stones

Guide to Field Observations

Shek Lung Tsai is an excellent location for studying geology and geomorphology of the region as well as being a good place for hiking and recreation. It is worth carrying out detailed observations to explore how the stones may have formed.

Stacked stones covering a valley

Erosion flutes on the stone surface

1) Identify the different stone rock types. There are abundant angular and subangular rock fragments of various sizes within the coarse ash crystal tuff. This suggests that the rocks were formed by explosive volcanic eruption.

2) Observe the different weathering characteristics of the rocks to identify which parts have been strongly weathered, and which parts are more resistant to erosion.

3) Determine which of the stones are essentially relict, and which have been transported from the hillslopes. Additionally, consider how the "Stone Bushland" may have formed.

Erosion flutes formed by erosion of unevenly distributed lapilli in the rock mass

"Hiker" – look like a hiker with a backpack

"Robot Monster" – with a protruding "hungry" tongue

"Loose Box Rock" – it looks like a loose box in a shippen

4) Go to the middle of the "Stone Bushland" and observe the relationships between giant stones, and the original overlying hillslope.

5) Try getting a strange feeling by viewing the stones at different angles.

"Lizard viewing the sea" (I)

"Lizard viewing the sea" (II)

“Broken tortoise head” should be viewed at a particularly location where the body and the head of the “stone tortoise” can connect with each other

“Little sky pool” – it provides water for birds and animals in the “Stone Bushland”

Comments

From field observation, the “Stone Bushland” covers one or two southwest trending valleys, to a depth of at least 30 m. The base of the Bushland is hard to see, even from the openings within the stacked stones. From an analysis of the topography, the landform appears to have changed from an area with valleys into one of open hillslopes since deposition of the stones in the “Stone Bushland”. The composition of the stones, and the giant stone at the peak of Shek Lung Tsai, are the same. The “Stone Bushland” has been interpreted to have formed from a talus mass wasting deposit. Accordingly, it has been postulated that Shek Lung Tsai was once situated near a high cliff. Due to processes of weathering and erosion over time, coupled with mountain building activities, the original rock mass probably collapsed towards the southwest and subsequently infilled valleys on the downhill side of the cliff to produce the area of “Stone Bushland” which is devoid of vegetation.

References

Addison, R. 1986. *Geology of Sha Tin.* Hong Kong Geological Survey Memoir No. 1, Geotechnical Control Office, Hong Kong, 85 p.

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Bennett, J.D. 1984. *Review of superficial deposits and weathering in Hong Kong.* Geotechnical Control Office, Hong Kong, 51 p.

Fisher, R.V. & Schminke, H.U. 1984. *Pyroclastic rocks*. Springer Verlag, New York, 472 p.

Fyfe, J.A., Shaw, R., Campbell, S.D.G., Lai, K.W. & Kirk, P.A. 2000. *The Quaternary geology of Hong Kong.* Geotechnical Engineering Office, Hong Kong SAR Government, 209 p. plus 6 maps.

Lai, K.W. 1982. Discussion on the colluvium of Hong Kong. *Hong Kong Baptist College Academic Journal,* v. 9, pp 139-158.

Lai, K.W. Campbell, S.D.G. & Shaw, R. 1996. *Geology of the North East New Territories, 1:20 000 Sheets 3 and 4*. Hong Kong Geological Survey Memoir No. 5, Geotechnical Engineering Office, Civil Engineering Services Department, Hong Kong, 144 p.

Lai, K.W. & Taylor, B.W. 1984. The classification of colluvium in Hong Kong. In: W.W.-S Yim (editor) *Geology of Superficial Deposits in Hong Kong*. Geological Society of Hong Kong, Bulletin No.1, pp 75-85.

Langford, R.L., Lai, K.W., Arthurton, R.S. & Shaw, R. 1989. *Geology of the Western New Territories: 1:20 000 Sheets 2, 5 and 6*. Hong Kong Geological Survey Memoir No. 3, Geotechnical Control Office, Civil Engineering Services Department, Hong Kong, 140 p.

Sewell, R.J. 1996. *Geology of Ma On Shan*. Hong Kong Geological Survey Sheet Report No.5, Geotechnical Engineering Office, Civil Engineering Department, Hong Kong, 45 p.

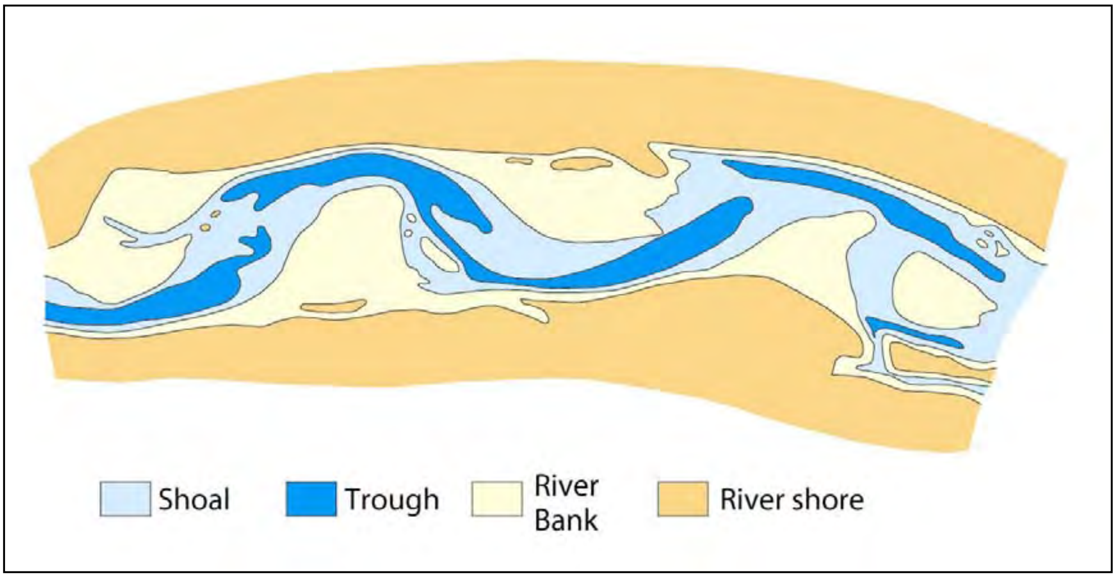
Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. 2000. *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong SAR, 181 p.

Lam Tsuen Valley, Tai Po, New Territories

23. Quaternary River Terrace Deposits

Introduction

A river terrace represents the former level of a river bed on the valley floor. A river may erode its bed more energetically due to lowering of sea level or the effects of regional earth movements. The basal erosion surface cuts into the former river bed or floodplain to reach a new level of equilibrium, where it can deposit sediments and construct a new lower floodplain or river bed. The former relict floodplain or river bed is no longer affected by flood water and consequently its forms a river terrace. A number of terraces with different levels will be formed by continuous river incision. Erosion and sedimentation may occur in different parts of a curved river channel. Generally scattered and non-continuous troughs develop along the main channel – the troughs are the locations of strongest basal erosion of a river. A shoal is the area where erosion takes place in the dry season and deposition takes place in wet season. A river bank is an area of sedimentation on both sides of the river channel. Continuous basal erosion will cause a change from river bank to terraces. The present-day river channel is just an instance of equilibrium during the perpetual evolution of a river channel.

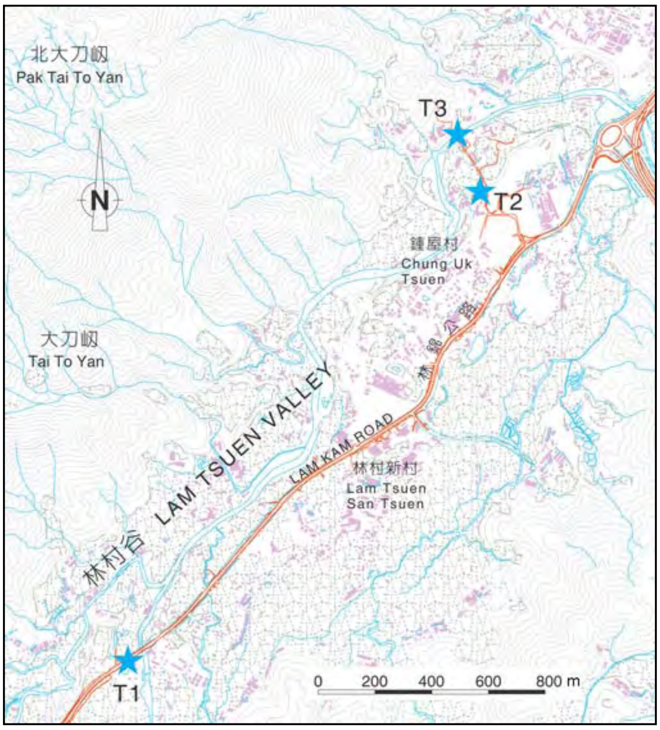


Subdivision of a river channel

Except for the Shenzhen River, there are essentially no perennial rivers in Hong Kong with constant water flow. Most stream courses are seasonal. However, ancient alluvial deposits can still be identified and mapped out in Hong Kong. For example, relict river terrace deposits can be found in the Lam Tsuen Valley at Tai Po in the New Territories. The best locations for observation of the river terraces are all along the Lam Kam Road or the area to the north of that road. River terraces can be recognised and the characteristics of their formation can be inspected in these locations.

<u>How to Get There</u>

The relict river terraces in the Lam Tsuen Valley are best viewed from a bus along Lam Kam Road. Bus routes along Lam Kam Road include routes 64K and 64P departing from Tai Po Market KCR station for Yuen Long West, and route 65K from Tai Po Market Station to Sheung Tsuen. Red and green minibus routes 25K departing from Tai Wo KCR station for Kam Tin also pass through Lam Kam Road.

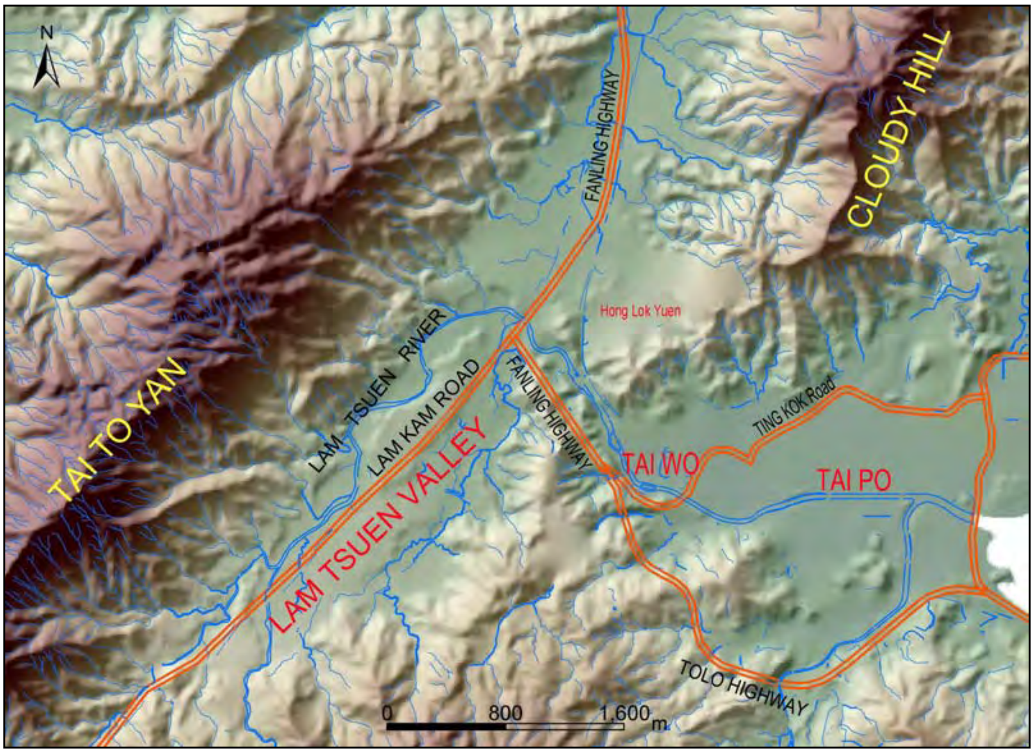


Transport map in the Lam Tsuen valley area

Outline of the Geology

The Lam Tsuen Valley is a river valley lying between the mountains of Tai To Yan and Tai Mo Shan. The hills in the Lam Tsuen Valley and its vicinity are underlain by Middle Jurassic volcanic and intrusive rocks of the Shing Mun Formation and the Tai Po Granodiorite, respectively. These units are thought to be roughly the same age. The granodiorite is restricted in outcrop to the southeastern part of the Lam Tsuen Valley.

Originally, the Lam Tsuen River flowed to the north to enter the Shenzhen River. However, the Lam Tsuen River was later captured by the Tolo Harbour drainage system and now drains eastwards into Tolo Harbour. The gradient of Tai To Yan is steep, with numerous streams flowing into the Lam Tsuen River. The mountain ridge extending from Tai Mo Shan has a more gentle gradient, but the catchment area is much larger than that of the Tai To Yan. Most of the streams to the north of Tai Mo Shan enter the Lam Tsuen River. In the past, the Lam Tsuen River formed a rather large 1.3 km–wide valley which extended for about 5.5 km in a northeasterly direction.



Topography of the Lam Tsuen Valley area

Locally, two river terraces are preserved in the Lam Tsuen Valley. The lower level terrace (Terrace I) was formed in the late Pleistocene, while the higher level terrace (Terrace II) was formed even earlier in the middle to late Pleistocene. The terraces are composed of boulders, pebbles, sands and clay. Today, the low lying river valley in Lam Tsuen has become a densely-populated developed area. As more roads and buildings are built to accommodate population growth in the future, there will be fewer locations available to observe the valley geomorphology.

Guide to Field Observations

It is important to obtain an overview of the river valley area before carrying out a detailed inspection. Carefully observe the orientation and morphology of the valley as a whole, changes in topography, and characteristics of the river channel. The best perspective is gained by viewing the valley from a high point in order to see as much of the landscape as possible. The terrace closest to the present river valley is Terrace I. Terrace II is the terrace higher than Terrace I. It might be possible to identify an even older, higher terrace. Note that the top of a single terrace will decrease in altitude downstream. When that terrace is not well preserved, it will appear intermittently downstream as isolated terraces. Careful judgment is required to determine if these isolated terraces can be matched to a single level.

Distant view of the Lam Tsuen Valley – The fields in the foreground belong to Terrace I and the two houses on the far left hand side are built on Terrace II

The high landform in the middle of the photo is a relict Terrace II feature (looking toward northwest from location T1 as marked on the Transport Map)

The materials that make up a river terrace can usually be observed in the terrace scarp. The two levels of terraces in the Lam Tsuen Valley are left by erosion of the river sediments. These terraces formed by incision into the old floodplain so that the

(Looking southwestward toward Lam Tsuen Valley from a hill located to the north of location T3 as marked on the Transport Map)- The barren field by the river is on Terrace I and the houses in the distance are on Terrace II

Close up view of Terrace I near a river at Location T3 as marked on the Transport map

materials of the terraces are composed of river pebbles, sand and clay. Sometimes, beds of pebbles and sand can be differentiated. Note that the roundness of the pebbles and boulders in the terrace material is equally as good as that in the present river valley. Occasionally, sand and clay are interbedded with pebbles, or may occur as lenses within the pebble layer. This feature suggests that the sediments were deposited in an ancient floodplain.

A depression along the Lam Kam Road at T1 leading to Ma Po Mei and Tai Yeung Che. The depression was excavated on Terrace II

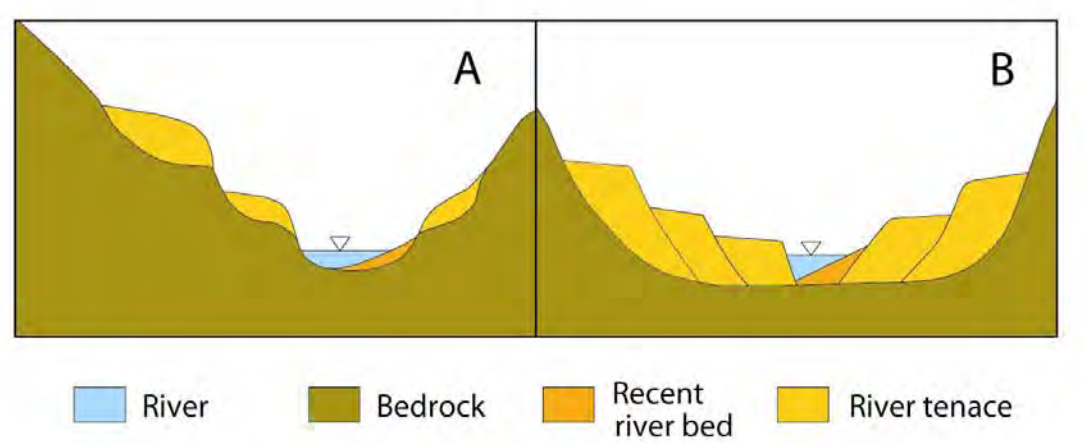
A relict Terrace II at The Duke of Edinburgh Training Camp near Hang Ha Po, Lam Tsuen, Tai Po (Location T2 as marked on the Transport map)

Boulders in the Lam Tsuen River terrace

Sand, pebbles and boulders in the Lam Tsuen River terrace

Comments

The classification of the river terraces is from young to old. The youngest terrace is named as Terrace I, and the next older one as Terrace II, and so on. Several types of river terrace are present. The bedrock erosion terrace is formed first by erosion of the bedrock to a platform, followed by deposition of sediments on the platform. Deposition layers erosional terraces are formed by the continuous river incision of the floodplain sediments. The development of corresponding terraces on both sides of the river is not symmetrical, and sometimes the corresponding terrace on the other side of one terrace may not develop at all. As the river is always changing its course, erosion may occur on both sides of the river bank so that some terraces may not be preserved at all.



Types of terrace: A - Bedrock erosion terrace : B - Deposition layers erosion terrace

References

Addison, R. 1986. *Geology of Sha Tin.* Hong Kong Geological Survey Memoir No. 1, Geotechnical Control Office, Hong Kong, 85 p.

Allen, P. M. & Stephens, E. A. 1971. *Report on the Geological Survey of Hong Kong*. Government Printer, 107 p. plus 2 maps.

Bennett, J.D. 1984. *Review of superficial deposits and weathering in Hong Kong.* Geotechnical Control Office, Hong Kong, 51 p.

Fisher, R.V. & Schminke, H.U. 1984. *Pyroclastic rocks*. Springer Verlag, New York, 472 p.

Fyfe, J.A. 1992b. Towards a Quaternary stratigraphy for Hong Kong. *Geological Society of Hong Kong Newsletter*, v. 10, no. 2, pp 5-10.

Fyfe, J.A., Shaw, R., Campbell, S.D.G., Lai, K.W. & Kirk, P.A. 2000. *The Quaternary geology of Hong Kong.* Geotechnical Engineering Office, Hong Kong SAR Government, 209 p. plus 6 maps.

Lai, K.W. 1982. Discussion on the colluvium of Hong Kong. *Hong Kong Baptist College Academic Journal,* v. 9, pp 139-158.

Lai, K.W. 1997. Quaternary evolution of the onshore superficial deposits of Hong Kong. *Proceedings of the Fourth Conference on the evolution of the East Asian Environment*, pp 178 - 188.

Lai, K.W. 1998. Middle Pleistocene alluvial and debris flow deposits of Hong Kong. *Guangdong Geology*, v. 13, no. 1, pp 71 - 78.

Lai, K.W. & Taylor, B.W. 1984. The classification of colluvium in Hong Kong. In: W.W.-S Yim (editor) *Geology of Superficial Deposits in Hong Kong*. Geological Society of Hong Kong, Bulletin No.1, pp 75-85.

Langford, R.L., Lai, K.W., Arthurton, R.S. & Shaw, R. 1989. *Geology of the Western New Territories: 1:20 000 Sheets 2, 5 and 6*. Hong Kong Geological Survey Memoir No. 3, Geotechnical Control Office, Civil Engineering Services Department, Hong Kong, 140 p.

Neller, R.J. 1996. Alluvial floodplains and upward-fining stratigraphic sequences. *Hong Kong Geologist*, v. 2 (Spring), pp 37 – 40.

Peart, M.R. 1997. The meanders and floodplain at Kam Hing Wai near Kam Tin. *Hong Kong Geologist*, v. 3 (Spring), pp 25 – 31.

Ruxton, B.P. & Berry, L. 1957. The weathering of granite and associated erosional features in Hong Kong. *Bulletin of the Geological Society of America*, Vol. 68, pp 1263-1292.

Tang, L.K. 2000. *Mapping of superficial deposits in the Lam Tsuen valley (Pak Ngau Shek to Wai Tau Tsuen), Hong Kong SAR.* Practice Report No. 7/2000, Geotechnical Engineering Office, 20 p.

Yim, W.W.S. 1992. Discussion on "Towards a Quaternary stratigraphy for Hong Kong" by J.A. Fyfe. *Geological Society of Hong Kong Newsletter*, v. 10, no. 3, pp 19 - 22.

Sha Tin, Ma On Shan, East New Territories

24. Industrial Iron Ore Mining in Hong Kong

<u>Introduction</u>

Ma On Shan, 702 m high, is located about 10 km northeast of Sha Tin Town Centre. Iron ore was mined from the area between 1906 and 1976, reaching its climax in the 1960s and 1970s when annual ore production exceeded 400,000 tons. During the 70 years that the Ma On Shan mine was in operation, over 3 millions tons of iron ore was produced. Economic conditions during the early 1970s led to the termination of mining operations in March 1976, and the mine was totally abandoned. Evidence of the past large-scale mining activities, including open mining pits, mining and transport benches, mine tunnels, and ore piles, can still be seen today.

The iron ore deposit at Ma On Shan formed within a contact zone between the original limestone bedrock and intruding granite. Percolation of hot mineral-rich fluids from the granite magma altered the limestone bedrock by a process known as metasomatism, which involves silicification to produce a rock called skarn. The resulting iron ore deposit is classified as a typical "post-magmatic skarn mineral deposit". Skarn-related rocks in the mining area are complex, comprising a very diverse range of minerals.

Blasthole drilling in the mining tunnel

Today, the underground tunnels and mining chambers are closed for safety reasons. However, a brief glimpse of the scale of the former mining operation can be seen at the surface entrances to the 110 m and 240 m tunnels (adits). The mine transport platform and open mining pit can be also visited. Remnants of the mineralised and silicified rocks that hosted the iron ore still lie scattered about at various locations, especially in the open mining pit and on the transport platform.

How to Get There

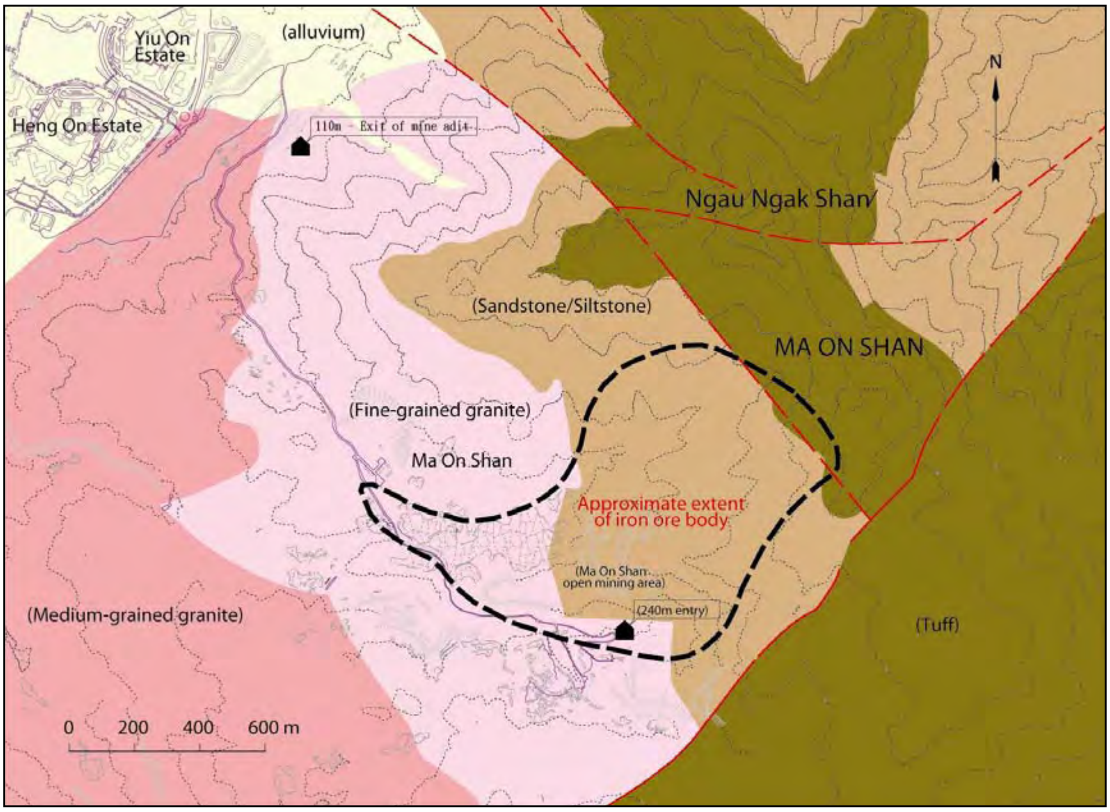
The old Ma On Shan mine is located to the southeast of the Ma On Shan Country Park Management Centre, near Ma On Shan Tsuen. Although there is a minibus service between Ma On Shan Hang On Estate and Ma On Shan Tsuen, the service is infrequent. From the roundabout east of Ma On Shan Heng On Estate, follow the road uphill towards the Ma On Shan Country Trail. This is the only road to the Ma On Shan mine. The abandoned open pit mining platform is about 2 km beyond the Ma On Shan Country Park Management Centre. Vehicles can only be driven to an area of flat land indicated as “car park” on the Access map. From the left hand side of the “car park”, a footpath leads uphill to a knoll and the abandoned open pit mining platform.

Access from Ma On Shan Town to the Ma On Shan mine

Outline of the Geology

The formation of the Ma On Shan iron ore body is closely related to the formation of skarn. Skarn is a type of altered (metamorphic) rock formed when felsic (acidic) magma, such as granite, comes into contact with rocks rich in calcium carbonate, such as marble, limestone, or dolomite. Hydrothermal fluids containing iron, magnesium, silicon and aluminium selectively transform the minerals in the existing rock into a diverse range of new minerals, including magnetite. This process is known as metasomatism, and the rock hosting the new minerals is known as skarn. The form and extent of the ore body is directly related to the nature of the intrusion and the characteristics of the contact zone between granite and marble (see Appendix I).

Volcanic rocks of the Shing Mun Formation, Repulse Bay Volcanic Group, form the peak area of Ma On Shan. These rocks overlie sedimentary rocks of the Ma On Shan Formation, which were intruded by granite. Siltstone in the Ma On Shan Formation was metamorphosed to hornfels at the granite contact, and limestone (marble) was metamorphosed to skarn. The resulting Ma On Shan iron ore body consists mainly of magnetite and haematite. Limonite and goethite were later formed by weathering of the original iron ore and iron-bearing minerals, and these provided important additional sources of ore for iron-smelting.



Geological map of the Ma On Shan area (GCO, 1986)

Magnetite ore (24x21x24 cm)

Honeycomb shaped limonite ore
(40x30x70 cm)

Guide to Field Observations

The underground workings have all been sealed for safety reasons. However, remains of the former mining operations can still be viewed in the open pits, platforms and benches. Only a small section of the open mining platform is preserved and accessible owing to partial burial by landslides from the adjacent slopes, dense vegetation growth, or general decay.

Open mining platform, Ma On Shan with Sha Tin visible in the distance

1) Small pieces of iron ore can usually be found scattered around in the streams, valleys, or level areas surrounding the mine. Iron ore, which is greyish black and very dense (heavy) when fresh, weathers to a brown or rusty colour and becomes more porous and lighter. A small magnet is useful to assist with detecting the iron ore.

2) Scattered fragments of iron ore and skarn can be seen on the way up to the open mining platform. Rocks with a greenish colour are mostly skarn or metasomatised rocks. Piles of skarn can be seen around the entrance to the 240 m mining adit.

3) The large scale of the former mining operation can best be appreciated from the

open mining platform, which is located at the uppermost Level Six or Level Seven of the mining pit (see the figure in "Appendix I"). The rocks are mainly granite and silicified granite, some of which are slightly mineralised. Directly in front of, and below, the platform is the old mining pit.

4) Several large landslide scars can be seen on the slopes surrounding the mining pit. These were mostly triggered by excavation of the mining pit at the base of the natural slopes. Consequently, they are one example of how economic activities can have an adverse impact on the natural environment.

5) The entrance to the 240 m level mining adit is located in the valley below the mining platform, and the portal of the 110 m level tunnel is located on the slope above the roundabout to the east of Ma On Shan Heng On Estate. An estimate can be made of the scope of the mining operation based on the scale of construction surrounding the tunnel portal. The tunnels and adits have not been maintained for over 40 years, so they are potentially very unsafe. Consequently, the entrances have been sealed, so please do not try to enter them.

Comments

The skarn at Ma On Shan is one of the most mineralogically complex rock types found in Hong Kong. Major minerals include actinolite, chlorite, epidote, wollastonite, diopside and garnet. Minor fluorite, rhodochrosite, galena, periclase and serpentine are also present. The characteristics of the major minerals found at Ma On Shan are referenced in "Appendix II".

References

Addison, R. & Purser, R.J. 1986. *Sha Tin. Hong Kong Geological Survey Sheet 7*. Solid and Superficial Geology. 1:20 000 Series HGM20. Geotechnical Control Office, Hong Kong.

Davis, S.G. 1961. Mineralogy of the Ma On Shan iron mine, Hong Kong. *Economic Geology*, v. 56, no. 3, pp 592 - 602.

Davis, S.G. 1964. Mineralogy of the Ma On Shan iron mine, New Territories, Hong Kong. In: *Economic Geology of Hong Kong*, Edited by S.G. Davis, Hong Kong University Press, pp 42 - 51.

Hu, Z.X., Chen, J.H., Wang, X.D., Wang, Y. & Lai, K.W. 1997. The discovery of *Leptophloeum rhombicum* Dawson from Ma On Shan, Hong Kong. *Hong Kong*

Geologist, v. 3, pp 14–18.

Knapp, J.H. 1961. Mining in Hong Kong. In: *Land Use and Mineral Deposits in Hong Kong, Southern China and South-east Asia*, Edited by S.G. Davis, Hong Kong University Press, pp 155 – 162.

Strange, P.J. & Woods, N.W. 1991. The geology and exploitation of the Ma On Shan magnetite deposit. *Geological Society of Hong Kong Newsletter*, v. 9, no. 1, pp 3-15.

Shibata, T. 1964. Development plan of Ma On Shan Iron Mine, New Territories, Hong Kong. In: *Economic Geology of Hong Kong*, Edited by S.G. Davis, Hong Kong University Press, pp 52 - 57.

Shibata, T. 1973. Development plan of lower deposit in Ma On Shan Iron Mine. Report to Nittetsu Mining Co., Ltd.

Weld, C.M. 1908. Notes on an iron-ore deposit near Hong Kong, China. *Economic Geology*, v. 3, no. 4, pp 236 - 277.

Appendix I

Outline History and Geology of the Ma On Shan Iron Mine

History of the Ma On Shan Iron Mine

The first licence for exploration and mining of the iron ore body at Ma On Shan was issued in 1906 to The Hong Kong Ironing Mining Company. Open-pit mining commenced shortly thereafter. Later, in 1931, the New Territories Iron Mining Company was granted a 50-year Crown Lease by the Hong Kong Government for exploration and mining. At that time, the mine employed about 1500 workers, the extracted ore being transported by sea to Japan. In 1949, the mining rights were transferred to the The Mutual Mining and Trade Company. By 1950, over 150 thousand tons of iron ore were being supplied annually to the Associated Steel Company in Japan.

In 1953, the Nittetsu Mining Company of Japan signed a contract with The Mutual Mining and Trade Company to jointly develop the Ma On Shan mine. Further exploration within and around the open pit mining area confirmed the existence of major ore reserves below ground. Consequently, the Nittetsu Mining Company expanded the operation by developing the mine underground, involving the design and excavation of many adits, tunnels and shafts. In 1954, the company invested US$500,000 to construct an ore dressing plant, with the dressed ore being transported to Japan. Open-pit mining operations ceased in 1959, and all mining activities were transferred below ground.

Global demand for steel declined in the mid 1970s. At that time, a new supplier of high-grade iron ore to Asian countries commenced large-scale operations. Consequently, the mine could not secure further supply contracts from Japan, and ore extraction stopped at the mine in March 1976. Following expiration of the 50-year lease in March 1981, the mine was finally abandoned, so ending 70-years of mining history at Ma On Shan.

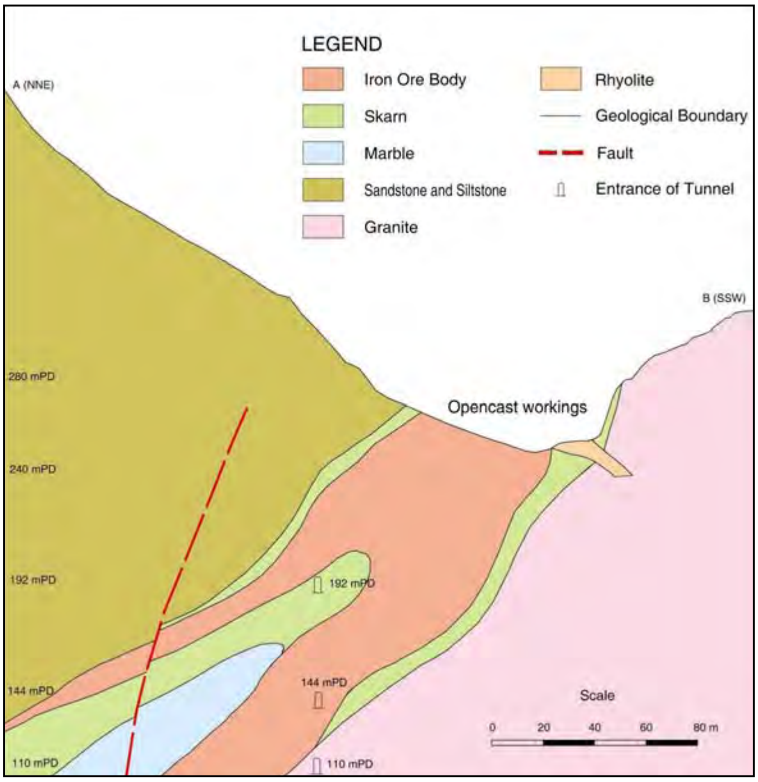
Geology of the Ma On Shan Ore Deposit

Because of its location in the contact zone between granite, sedimentary and volcanic rocks, the structure of the Ma On Shan iron ore body is relatively complex. The ore body is located within the metamorphic contact zone between a granite intrusion and the calcium carbonate-rich country rock. The altered rock at the contact zone is known as skarn.

The iron ore body is a product of a type of metamorphism that involves major chemical changes to the rocks (metasomatism) caused by the percolation of hot mineral-rich hydrothermal fluids. This type of deposit is classified as a "post-magmatic skarn mineral deposit", because it was formed by metasomatism following the intrusion of granitic magma into carbonate-bearing country rock. Metasomatism appears to have occurred selectively and repeatedly, leading to concentration of iron ore within the skarn, which also hosts a complex and variable mineral assemblage. Major minerals include actinolite, chlorite, epidote, wollastonite, diopside and garnet. Minor minerals include fluorite, rhodochrosite, galena, periclase and serpentine.

<u>Characteristics of the Ma On Shan iron ore body</u>

The Ma On Shan iron ore body is lenticular-shaped and is generally located along the marginal contact with the marble country rock. It crops out at an elevation of about 300 m, at which level it is around 100 m wide, dipping to north at between 35° and 55° over a distance of about 50 m. The ore body reaches its maximum width of around



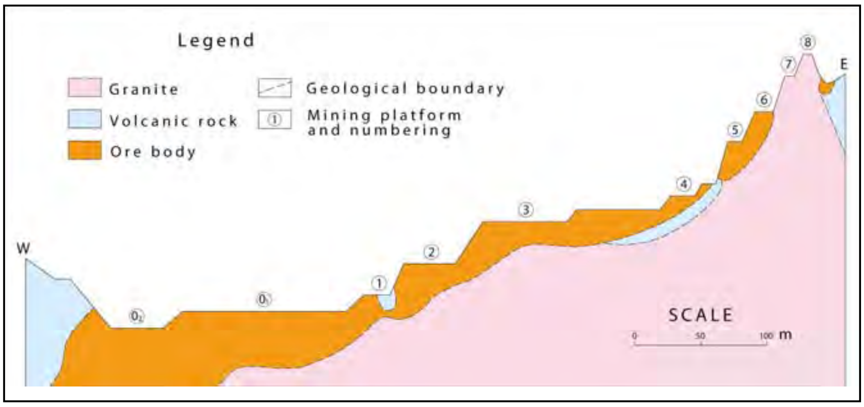
Geological cross-section through the Ma On Shan mine

500 m in a NE-SW orientation at an elevation of 240 m, and from 200 m to 160 m elevation the ore body narrows. Mineralisation is too weak to be of any economic value at about 110 m elevation.

Mineralogically, the ore is mainly magnetite and haematite. Pure magnetite is a dark, iron-grey, fine-grained aggregate, with strong magnetism, and haematite is iron-black to steel-grey, with a metallic to semi-metallic lustre. In addition to being deposited by mineral-rich hydrothermal fluids, haematite can be also formed by oxidation (weathering) of magnetite. Moreover, the weathering of iron and iron-bearing minerals creates secondary minerals, such as limonite and goethite, that are also important sources of iron for smelting. Limonite is yellow to brownish yellow, with an earthy, dusky appearance and a non-metallic lustre. The mineral aggregate is usually occurs in lumpy, kidney, tubercular and stalactitic shapes. Goethite is usually dark brown in colour, with a semi-metallic lustre, and occurs as needle-like or cylindrical crystals. The mineral aggregate is kidney-like or stalactitic. Magnetite and haematite are locally abundant in the skarn at Ma On Shan, where they occur as lumpy and granular aggregates within the orebody. They also occur as small intrusive veins, or as disseminated crystals, within the country rock. Small mineral veins are also commonly found within the quartzite.

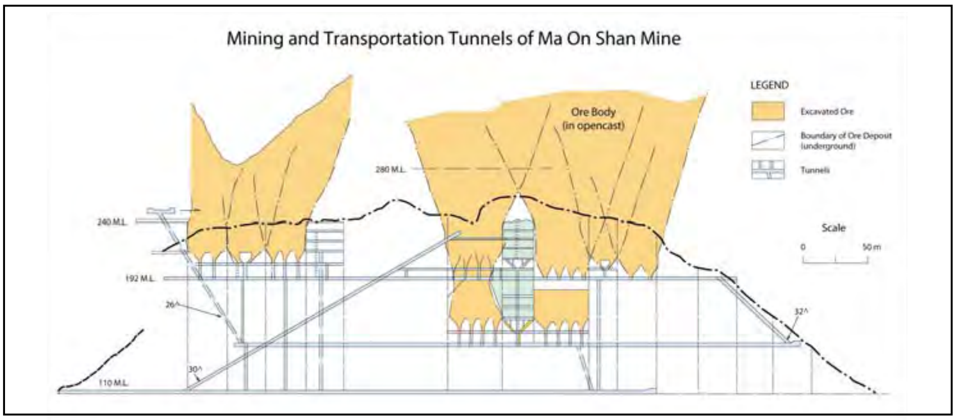
The Ma On Shan open-pit mine

Mining at Ma On Shan commenced in 1906 at 300 m elevation where the ore body cropped out at the surface. Between 1906 and 1959, the majority of iron ore production was from this open pit excavation, the pit being extended downwards from the 300 m level to about 240 m elevation. Ten mining and transport platforms, oriented NW-SE, were formed at different levels during the lifetime of the open pit.



Section across the open-pit mining platform

The open pit was 500 m long in an E-W direction, and had a width of about 300 m, with the access road in the WNW face.



Section across the open-pit mining platform

Underground mining at Ma On Shan

Underground mining at Ma On Shan began in March 1953. The total length of mining tunnels excavated in that first year was 335 m, but by the end of the third year this had increased to 3,139 m. Following closure of the open pit operation in 1959, the rate of construction of underground mining tunnels accelerated.

Portal of the 110m main ore haulage tunnel

Underground mining was mainly carried out by the "Sub-level Stoping" method. This involved excavation of the ore, from top to bottom, within a series of blocks. Tunnels were used to divide the ore body into three excavation levels, the 240-192 m level, the 192-152 m level, and the 152-110 m level. Every level was sub-divided into secondary extraction working levels for top to bottom excavation, the main and secondary levels arranged in 20 m x 10 m extraction zones. Each secondary level was generally 7-8 m high. Vertical, or inclined, shafts were excavated between adjacent levels to convey the extracted ore down to the main

Portal of the 110m main ore haulage tunnel haulage drive at the 110 m level. The underground mine was designed to ensure the maximum use of gravity to move the ore between levels. Finally, a mine railway was used to transport the ore along the haulage tunnel to the dressing plant outside. The dressed ore was then loaded onto ships bound for Japan.

The ore dressing plant

The ore dressing plant was installed to reduce the cost of transporting undressed ore, with a large proportion of waste rock, overseas. Construction of the ore dressing plant commenced in mid-March 1954 and was completed by the 1st November in that year. From that date, all ore extracted from the mine was dressed prior to transportation.

Processing the ore at the dressing plant increased the pure-iron content from the 32% of the original ore to above 56%. In the month following completion of the dressing plant, 2,800 tons of dressed ore was produced. The highest monthly production of dressed ore reached nearly 11,000 tons. A total of 1.68 million tons of dressed ore was produced between 1960 and 1973.

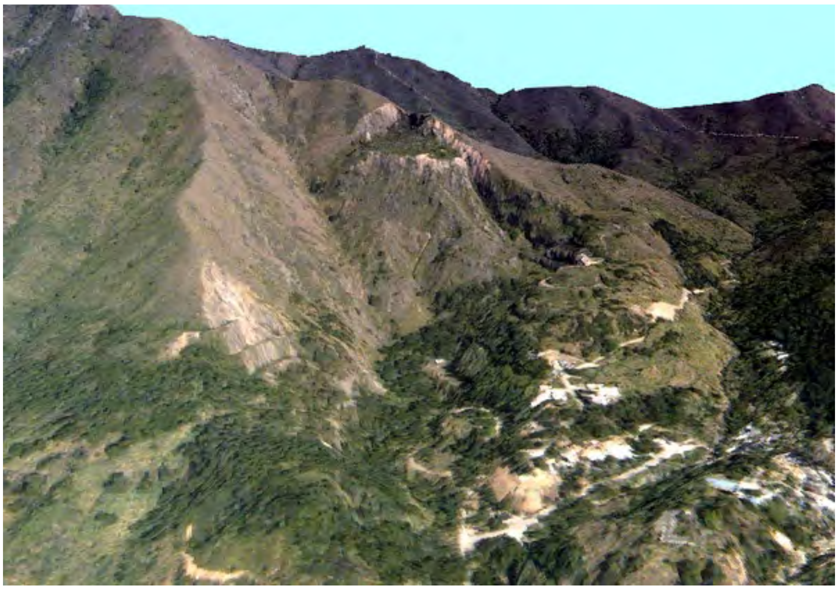
The main mine haulage tunnel

In order to efficiently transport ore out of the mine to the new dressing plant, a 2,200 m long haulage tunnel was excavated at the 110 m level. Excavation of the tunnel commenced in June 1961, and work was completed in August 1963. Following completion of the 110 m haulage tunnel, ore production increased rapidly. In 1964, annual ore production rose to 250,000 tons, and the following year it rose to 270,000 tons. By the early 1970s, annual ore production had reached a maximum of 400,000 tons. Because the tunnel was constructed in granite, there have been relatively few collapses. However, the haulage tunnel is periodically subject to serious flooding, so unauthorised entry is now forbidden.

Overview of mine production at Ma On Shan

Prior to 1949, annual production of iron ore at the Ma On Shan mine was below 1,000 tons, but by 1950, annual ore production had increased rapidly to 169,000 tons. During the early 1960s, ore from the 240 m level near the top of the ore body, was almost exhausted. Consequently, from 1963 onwards, extraction was carried out mainly between the 240 m level and the 192 m level. By the early 1970s, extraction had reached the 144 m level, with an annual production of over 400,000 tons. From

1949 to the closure of the mine in 1976, over 3 million tons of iron ore were produced from the mine. A general estimate of iron ore remaining underground at the mine is about 4 million tons.



Aerial view of the Ma On Shan open-pit mine
(a 3D-model produced from aerial photographs).
Note: That part of the mining platform buried by landslide debris can be clearly seen

Portal of the 240 m tunnel

Abandoned mining tunnel in a dangerous condition

Current condition of Ma On Shan mining area

Open-pit mining area After cessation of the surface workings in 1959, the abandoned open pit mine slowly revegetated, and is now covered with shrubs and trees. Berms between the mining and transportation platform collapsed in places, covering the platforms in debris. The upper platform and the landslide scars can still be viewed by climbing up a steep footpath.

Abandoned ore pile

Mining tunnels Due to a complete absence of maintenance since the mine closed in 1981, the supporting structures have decayed and the mining tunnels are in an extremely dangerous condition. Consequently, all the entrances have now been sealed. In places, the tunnel roof has collapsed, and rock debris has blocked the passageways. The tunnels are knee-deep in water in places, and there is no serviceable lighting, ventilation, or fire prevention equipment. As a result, it is not safe to enter the mining tunnels at Ma On Shan.

Environmental impacts of the mining operations

The Ma On Shan iron mine is an example of how the natural environment can be affected by economic activities. Following extension of the open pit operation in 1953, the surrounding hill slopes became unstable. Combined with the sub-tropical climate of Hong Kong, characterised by deep weathering of the rocks and high summer rainfalls, a series of large-scale landslides were triggered on these slopes in 1957, 1958 and 1959. The scars of these large landslides can still be seen clearly on the slopes of Ma On Shan. Although open-pit mining ceased completely in 1959, when ore extraction was transferred underground, the visual effects on the landscape were irreversible. Also, although the underground mining operation had very little visual impact on the natural landscape, there remains the possibility of ground subsidence due to collapse of un-maintained and un-backfilled tunnels.

Large piles of rock waste from mining excavations and ore dressing operations have been left near the mine. Weathering and leaching of sulphides and other chemicals in the waste ore may contaminate the surrounding soil and adversely affect the natural vegetation.

Appendix II

Table of characteristics of the common minerals found at Ma On Shan

Mineral	Origin and Occurrence	Hardness	Colour
Actinolite	Found within iron-bearing ore deposits associated with contact metamorphism of carbonate rocks	5.5-6	Various shades of green. Darker green with increasing iron content
Amphibole (Group)	The general name for a group of minerals. An important rock-forming mineral	5-6	Dark colours. Can be green, or brown to black
Andradite	Product of contact metasomatism. An important constituent of skarn deposits	7	Commonly brown. Also yellow, green or black
Biotite (Mica)	Dark coloured, platey, rock-forming mineral in igneous rocks	2.5-3	Black or dark brown
Calcite	Found in various geological settings. The major constituent of carbonate rocks	3	Colourless or white. Impurities produce other colours
Chalcedony	Cryptocrystalline (no visible crystals) mineral. Can form in a low or high temperature hydrothermal deposit	7	Variety of colours. Can be red, green, yellow, brown, black, *etc*. Material used for arts and crafts
Chlorite	Common in metamorphic rocks or hydrothermally altered rocks	2-2.5	Dark to light green
Diopside	A common constituent of skarn. Associated with metasomatism	5-6	Light green to light greyish green
Epidote	Common in contact metamorphosed ore deposits. Late stage metasomatic alteration product of skarn minerals. Also common in altered volcanic rocks	6.5	Green or yellowish green
Feldspar (Group)	The general name for a group of minerals. Feldspar is a widely distributed rock-forming mineral, important for rock classification	7	Grey or greyish white

Mineral	Origin and Occurrence	Hardness	Colour
Fluorite	Found in hydrothermal veins	4	Purple, blue, yellow, green, *etc*.
Galena	Found in various hydrothermal ore deposits. Common paragenesis (origin) with sphalerite and silver	2-3	Lead grey
Garnet	A typical high temperature, metamorphic mineral	6.5-7.5	Blood red, yellowish brown, yellowish green, black, *etc*.
Goethite	Secondary mineral formed by oxidation of iron-bearing minerals. Seldom formed below the surface	5-5.5	Dark brown
Haematite	Formed below the surface by hydrothermal alteration, or at the surface by condensation of colloidal solutions. A major raw material for iron smelting	5.5-6	Iron black to steel grey
Hornblende (Amphibole)	A major rock-forming mineral in igneous rocks	5.5-6	Dark green or dark brown to black
Kaolinite	An important clay mineral, characteristically formed by weathering of feldspar, mica, *etc*. Also formed by hydrothermal metasomatism	1	White when pure, but usually stained by impurities
Limonite	Formed by oxidation and decomposition of primary iron-bearing minerals	<5.5	Yellowish brown to dark brown
Malachite	Secondary mineral formed by oxidation of primary copper-bearing minerals	3.5-4	Bright green or green
Mica (Group)	General name for a group of minerals. Very common rock-forming mineral in igneous, sedimentary and metamorphic rocks	2-3	Green or brown to black

Mineral	Origin and Occurrence	Hardness	Colour
Molybdenite	Found mainly in high- to mid-temperature hydrothermal ore deposits, or in contact metasomatic ore deposits	1	Lead grey
Montmorillonite	Weathering product of aluminium-silicate minerals, such as feldspars. Primarily from volcanic rocks	1	White, sometimes pink to light green
Muscovite (Mica)	Light coloured, platey, rock-forming mineral in igneous and metamorphic rocks. Found in granite, pegmatite, greisen, and mica schist	2.5-3	Colourless in thin sheets. Yellow, green or brown when thicker
Opal	Formed mainly from volcanic hot-spring activity, or by precipitation from silicic solutions after leaching	5-5.5	Most commonly opalescent (irridescent). Impurities create other colours
Periclase	Typical hydrothermal alteration mineral. Readily hydrated to brucite	5.5	Greyish white, light yellow, or brown to black
Phlogopite (Mica)	Primarily a product of contact metasomatism	2.5-3	Yellowish brown, reddish brown or colourless
Plagioclase	General name for a series of major rock forming feldspar minerals. Almost 70% of all feldspars are plagioclase	6-6.5	Usually white or dark grey
Potash Feldspar	A major rock-forming mineral. Includes polymorphs of potassium aluminosilicate (*i.e.* sanidine, orthoclase and microcline)	6-7	Mainly a pinkish colour
Pyrite	Formed in a variety of geological settings, such as hydrothermal ore deposits, epiclastic deposits, concretions in coal, *etc.*	6-6.5	Light brass (yellow) colour

Mineral	Origin and Occurrence	Hardness	Colour
Pyroxene	An important rock-forming mineral in igneous rocks	5-7	Dark coloured, usually green or brown, to black
Quartz	An important rock-forming mineral. Also common in hydrothermal mineral veins. The most abundant mineral in the Earth's crust	7	Various colours. Commonly transparent, grey or white
Rhodochrosite	Common in hydrothermal and contact metasomatic ore deposits. Also found in manganese ores	3.5-4.5	Rose colour. Readily oxidised to brownish black
Sericite (Mica)	Product of mid- to low temperature hydrothermal alteration. Also occurs in dynamically metamorphosed rocks	2.5-3	Yellowish green or greyish white
Serpentinite	Formed by the hydrothermal metasomatism of olivine and pyroxene in ultrabasic rocks or dolomite	2.5-3.5	Greyish white, light green to yellowish green, or dark green
Tourmaline	Occurs primarily in granite, pegmatite, greisen and quartz veins	7-7.5	Commonly black or brown, but can be red and bluish green
Tremolite	Occurs mainly in contact metamorphosed limestone and dolomite	5.5-6	White to light grey
Vesuvianite (Idocrase)	Typical contact metamorphism mineral. Most common in the contact zone between granitic intrusions and carbonate rock	6.5	Yellowish green or brown
Wolframite	Formed mainly in high temperature hydrothermal ore deposits in granitic areas	4.5-5.5	Reddish brown to black
Wollastonite	Formed mainly in the contact metamorphic zone between granitic intrusions and limestone	4.5-5	White, pale grey or greyish red

Moh's Hardness Scale: *(From soft to hard)* (1) Talc: (2) Gypsum: (3) Calcite: (4) Fluorite: (5) Apatite: (6) Orthoclase: (7) Quartz: (8) Topaz: (9) Corundum: (10) Diamond