

**AN ACCURATE GEOLOGICAL MODEL IS AN ESSENTIAL REQUIREMENT FOR
GEOTECHNICAL ENGINEERING
--- A CASE STUDY ON THE GEOLOGY OF TUEN MUN TO TIN SHUI WAI AREA,
HONG KONG**

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ABSTRACT

In geotechnical engineering practice, an accurate geological model is an essential requirement for safe and economical geotechnical engineering design. After a review of geological investigation reports and geological publications in the Tuen Mun to Tin Shui Wai area, it can be seen that the current adopted rock classification is flawed. For instance, the tuff breccia has been misinterpreted as conglomerate; the marble clast-bearing andesite has been misidentified as siltstone with layered marble. Such misinterpretations may lead to the formation of an unreliable geological model. As there will be substantial development of mega-projects in the area, it is prudent to address the field work method and problematic rock classifications. Correction of these rock classifications would enable cost saving and shortening of development programme.

KEYWORDS

Tuen Mun Formation, andesite, plug, vent breccia.

INTRODUCTION

To gain a thorough understanding of pyroclastic rocks in the Tuen Mun to Tin Shui Wai area is a lengthy and oscillating process due to the complexity in the formation of this rock type. The study of the Tuen Mun Formation, especially the marble clast-bearing tuff breccia, can be divided into three stages:

Groping Stage.

From 1971 to mid-1989, Allen and Stephens (1971) divided the strata of Tuen Mun to Tin Shui Wai area into two formations. The Repulse Bay Formation in the south comprised mainly sedimentary rock and water-lain volcanic rock. The Lok Ma Chau Formation in the north composed meta-sedimentary and volcanic rock. Due to the insufficient borehole data and rock outcrops, tuff breccia has not been recognized for a long period. The geology of Tin Shui Wai still retained the Lok Ma Chau Formation name up to mid-1989, such as Geological

Map of San Tin of 1:20,000 scale (GCOa 1989) Geological Maps of Tin Shui Wai of 1:5,000 scale (GCOb 1989). Arthurton *et al* (GCO 1988) studied the strata in the area and defined the andesitic strata as Tuen Mun Formation which is fundamentally correct, but he misidentified the tuff breccia as conglomerate and assigned the strata as Tsing Shan Formation which is flawed (Figure 1).

Understanding Stage

From mid-1989 to 2000, after some 40 drillholes were sunk in the area by GCO, the marble clast-bearing tuff breccia of the Tin Shui Wai area was confirmed as volcanic in origin. This resulted in the renaming of the Lok Ma Chau Formation to Tuen Mun Formation (Darigo 1990), (Frost 1990) and (GEO 1994) Subsequently, Irfan (GCO1990) conducted a rock strength properties study; he also confirmed the volcanic origin. After further detailed study, the Tsing Shan Formation has been merged into Tuen Mun Formation as they both belong to the same rock type (GEO 2000) (Figure 2).

Re-examination Stage.

The updated geological result was included in “The Pre-Quaternary Geology of Hong Kong” and its related geological map. The preparation of the geological map was undertaken by Kirk et al (GEO 2000) whilst other geologists prepared the written report. Normally, report writing should refer to the updated geological map. Unfortunately, under the description of stratum, the author has quoted the outdated Tsing Shan Formation data (GCO 1988) (Figure 1), such as the rock in lower part of Tuen Mun Formation sedimentary rock predominates (Sewell et al 2000.p69); Also. Figure 3.5 of the report misinterprets the pyroclastic rock in the Tin Shui Wai area as Lok Ma Chau Formation. Both of these examples are contradictory with the accurate geological mapping represented in the 1:100,000 scale geological map of Hong Kong and the 1:20,000 scale Solid Geological Map of San Tin (GEO 1994). We regretted that we have not found these problems before publishing the report.

Up to 2003 a considerable borehole logs of Tin Shui Wai area has misidentified the pyroclastic rock as sedimentary rock. It has seriously affected the geotechnical engineering design in the study area. Those problems have been pointed out by the authors and other geologists in some published papers such as (Chan, J. et al 2005), (Chan & Kwong 2009), (Lai et al 2004) and (Li 2010). Nevertheless, the problems were not rectified. Subsequently, misinterpretations of rock classifications have also been carried over into other geological publications. For instance, in “Engineering Geological Practice in Hong Kong” the tuff breccia is misidentified as conglomerate (GEO 2007, Figs. 3.2.3, 5.5.1 and 6.2.7) (Figures 3 & 22) and the “Hong Kong Geology Guide Book” (GEO 2008 p52-59) misinterpreted the tuff breccia of Tsing Shan Monastery as comprising conglomerates and breccias which may have formed following the collapse of a volcano or by fluvial activity on the margin of a crater lake. Such errors seriously affect the geological model and subsequent geotechnical engineering design.

COMMON CHARACTERISTICS OF VOLCANIC PLUGS

In order to develop a thorough understanding of the Tuen Mun Formation volcanic rocks and plugs, detailed fieldwork and sample inspection has been conducted including re-mapping of five plugs, collection of 180 rock samples, identification of 105 thin sections and chemical analysis of 20 rock samples. Further to our local study, plugs and volcanoes in other parts of the world were also visited, such as Ship Rock and Smith Rock in America (Figures 6-7), the Pinatubo and Taal volcanoes in

Philippines, Changbaishan (Figure 8) and Tengchong in China, as well as volcanoes in Italy, Argentina, Chile, New Zealand and Iceland. Important characteristics of andesite plugs have been identified and concluded as follows:

- i The shape of plug is circular or elliptical in plan, and cylindrical in cross-section.
- ii The plug is composed of tuff breccia and lava or only one of them.
- iii Lithic clasts are cemented by lava forming an altered rim between the lithic clast and the lava.
- iv Autobreccia and vertical eruptive lava flow occur within the plug.
- v Forming vertical, irregular tabular joints parallel to the upstanding plug body or forming concentric circle joints.
- vi A chain of plugs controlled by a concealed fault forming a photolineament.

REGIONAL GEOLOGY OF TUEN MUN TO TIN SHUI WAI AREA

The Tuen Mun Formation occurs in the NW New Territories between two NNE trending faults from Tuen Mun passing through Tin Shui Wai towards Shenzhen. The granite occurs in the west whereas the Carboniferous sedimentary rock outcrops in the east. They are composed of basaltic andesite, dacite lava, tuff breccia and tuff with minor tuffaceous sandstone. The Ar-Ar dating of andesite indicates ages of 181 ± 3 Ma and 182 ± 3.5 Ma respectively which are of Middle Jurassic age. Since most plugs in the world belong to the Cenozoic Era, this would make the Mesozoic plugs some of the oldest in the world. These rocks have been subject to weathering for a long period. Several hundred metres of volcanic rock have been eroded with only the bottom and root parts of the volcanoes remaining. Based on the volcanic facies, they can be divided into:

- i Explosive facies – violent explosion with accumulated tuff breccia and lapilli tuff surrounding the crater.
- ii Effusive facies – gentle volcanic eruption mainly forming lava flow in the valley and plain.
- iii Vent facies – including plug and dyke formed by tuff breccia and/or lava vein.
- iv Airfall facies – pyroclastic fragments fallen from eruption cloud forming stratovolcanic deposits.
- v Eruptive-sedimentary facies – minor tuffaceous sandstone occurring in the crater lake.

CHARACTERISTICS OF PYROCLASTIC ROCK AND PLUGS OF TUEN MUN FORMATION

The Tuen Mun Formation occurs in the Tuen Mun valley. It contains a total of nine plugs ranging from 20m to 120m in diameter extending NNW from Tsing Shan Monastery to north Por Lo Shan. The misidentification of these rocks is due to lacking study on the mode of occurrence of rock body; no chemical analysis on the cement material of tuff breccia and failing to differentiate the layered conglomerate and vent-shaped volcanic plug.



Figure 1 Misinterpretation of a layer of Tsing Shan Formation conglomerate shown in the 1:20,000 scale geological map (GCO 1988)

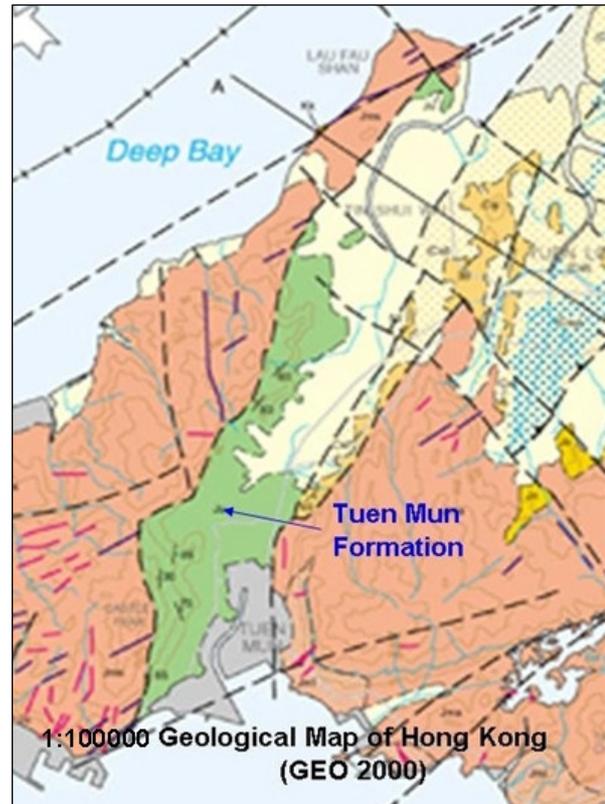


Figure 2 The Tsing Shan Formation was deleted in the 1:100,000 scale geological map (GEO 2000)

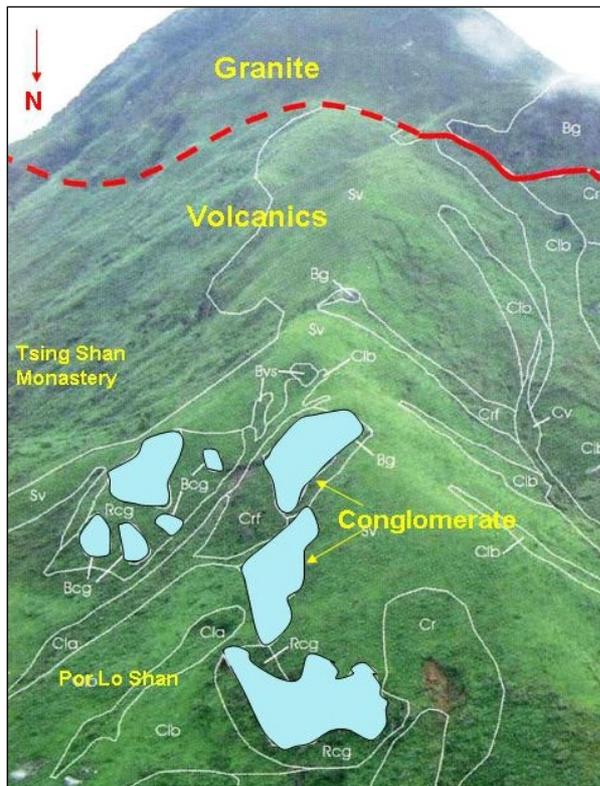


Figure 3 In “Engineering geological practice in Hong Kong” (GEO 2007 Fig.3.2.3) the vent breccia is misinterpreted as conglomerate.

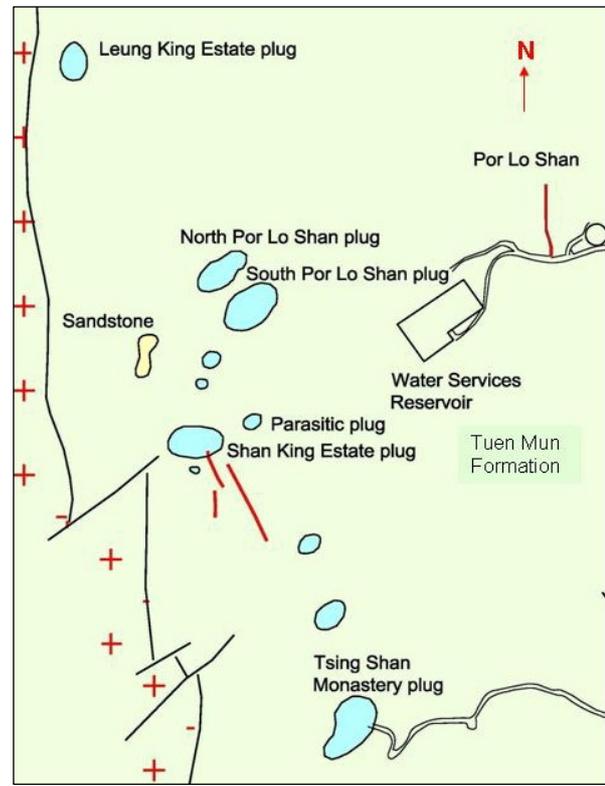


Figure 4 A series of volcanic plugs shown in the same area as in Figs. 1 & 3 from Tsing Shan to Por Lo Shan (Lai 2005, 2009).

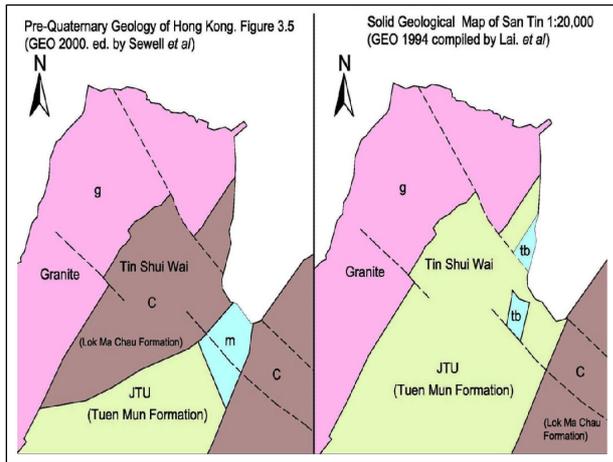


Figure 5 The geological map in the Fig.3.5 of <Pre-Quaternary geology of Hong Kong> (GEO 2000) applied obsolete data resulting in the difference from the map of 1994 (GEO)

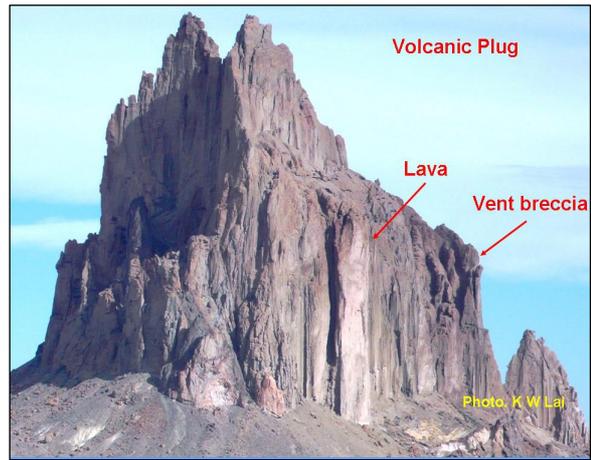


Figure 6 Volcanic plug of Ship Rock comprises vertical lava vein and tuff breccia, New Mexico, USA



Figure 7 Volcanic plug of Ship Rock is composed of vent breccia and lava

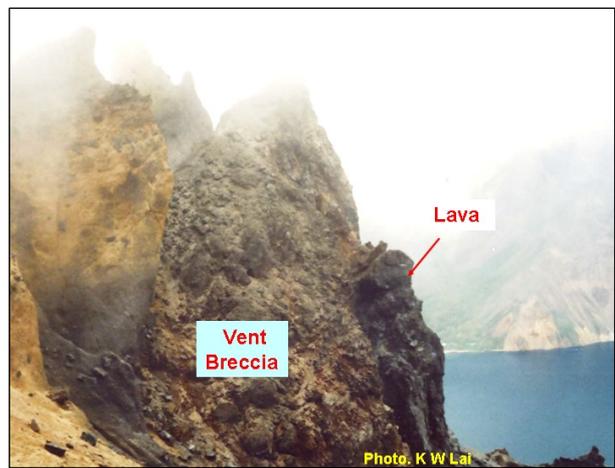


Figure 8 Vent breccia and lava occur in the Tianchi Crater, Changbaishan, Jilin Province, China

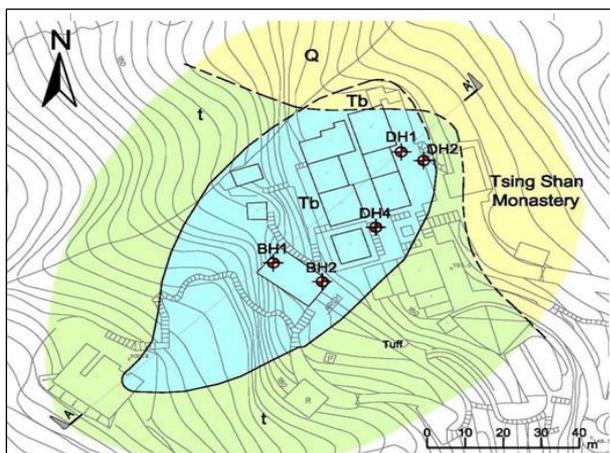


Figure 9 Volcanic plug of Tsing Shan Monastery was surrounded by crystal tuff

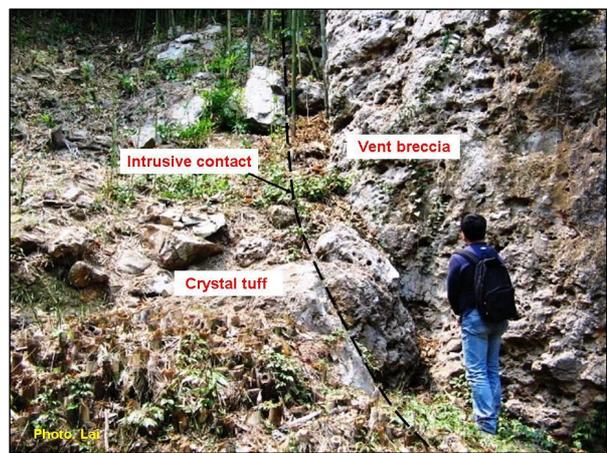


Figure 10 The vent breccia intruded the crystal tuff, Tsing Shan Monastery

Tsing Shan Monastery Plug.

Recently the temple has been refurbished and 11 boreholes were sunk. After studying the borehole data and re-mapping the area, the temple is situated in a 120m long and 50m wide rain drop shaped plug. It is composed of andesine lava and vent breccia/tuff breccia. The main minerals are plagioclase and hornblende with minor biotite, augite, quartz and sphene as well as secondary minerals of epidote, chlorite and sericite. Most rocks are aphanitic texture, occasionally the prism plagioclase is up to 3mm long. Lithic clasts contain tuff and andesite of an early eruptive stage, sandstone, siltstone and marble of country rock. They are subangular to subrounded, 10mm to 300mm across and cemented by lava. The results of chemical analysis of lava in the plug indicated that two samples are basaltic trachyandesite and three samples are dacite. Contact metamorphism took place between the lava and lithic clast. The ferromagnesian clast formed chloritization or epidotization, the marble clast formed skarnization. The lava flow structure has been misinterpreted as evidence of bedding or banded strata. Surrounding the plug is crystal ash tuff as confirmed by thin section identification. The relation between the plug and tuff is an intrusive contact (Figures 9 - 12).

Shan King Estate Plug.

This plug is located at 600m west of Shan King Estate. It is elliptical in shape and cylindrical in cross-section, up to 80m long and 50m wide forming a 50m high steep cliff. It is a good exposure composed of tuff breccia and lava vein. The tuff breccia represents the violent eruption whereas the lava vein indicates the quiescent eruption. The lithic clast is cemented by andesite lava with an altered rim between their contacts. The plug is associated with two parasitic plugs and some dykes in nearby area. The lava flow structure and very fine degassing pipes are parallel to the vertical plug. The vertical cracks produced an irregular columnar or tabular jointing (Figure 18). The plug has been misinterpreted as conglomerate and breccia strata which were 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 (Hong Kong Geology Guide book, GEO 2008 p59).

Shan King Estate Parasitic Plug.

Also referred to as the smaller plug. This plug forms a 50m diameter, 20m high sub-circle, located 80m west of Shan King Estate and 40m apart from Shan King Estate Plug. The plug is composed of lava and tuff breccia. The lithic clast is greyish white subrounded to rounded, up to 800mm across and is cemented by lava. Chemical analysis indicated that the lava is mainly basaltic andesite and the lithic clast is rhyolitic ash tuff congealed in early stage. Tuff breccia occurs in the core of the plug. A special feature is that the plug reveals a concentric circle joint pattern (Figure 16-17).

South Por Lo Shan Plug.

Two plugs are situated 550m southwest of Por Lo Shan. The south one is sub-elliptical in shape and is 85m long, 50m wide and approximately 55m high. This plug comprises lava and tuff breccia of multiple eruptive stages. (Figures 19-21). The chemical analysis result indicates the lava is mainly andesitic dacite while the lithic clasts have sandstone, siltstone marble and andesite congealed in early stage. When the lithic clast contacts the hot magma, the margin of marble may alter to skarn, tremolite or silicified marble. When subject to ductile deformation, the lithic clast may be flattened or elongated. The chemical analysis also shows the country rock in the eastern part of the plug is rhyolitic ash tuff.

North Por Lo Shan Plug.

The plug is composed of multiple eruptive tuff breccia and andesite -dacite lava. It forms a 95m long, 45m wide and 20m high ellipse which is 50m apart from the South Por Lo Shan Plug. The lithic clasts contain marble, sandstone and lava of early stage which were cemented by andesite. The plug intruded the ash crystal tuff forming a steep cliff. Vertical eruptive lava flow structure is evident. This plug has been misinterpreted as conglomerate (Figures 22-23) in “Engineering geological practice in Hong Kong” (GEO 2007, p140 and Figure 6.2.7.).

Stratovolcanic deposits at Ling To Monastery.

Interbedded tuff breccias, tuff, and fine-grained lava with localized tuffite form cyclic deposits. A large rock outcrop reveals five eruptive cycles with inclined bedding (Figures 24-26). The rocks contain the angular, subrounded and shuttle shaped lithic clasts. The lava vein and lava spatter show flow structure. The shuttle shaped clast and lava spatter suggest that those rocks are airfall deposits on the flanks of a nearby crater comprising parts of a stratovolcano. Some colluvial boulders with stratovolcanic strata can be seen from Por Lo Shan to Ling To Monastery but they are difficult to be found in the in-situ outcrop.

PROBLEMS IN TUEN MUN – TIN SHUI WAI SITE INVESTIGATION BOREHOLE LOGGING

More than 1000 borehole logs from the Tuen Mun to Tin Shui Wai area were reviewed in 2003 of which, 60% borehole logs are believed to have problems in rock identification. The major problems were misclassifying the marble clast-bearing pyroclastic rock as layered marble interbedded with siltstone. This rock formation adjoins the marble strata of Yuen Long Formation, which contains sink hole and karst features which can seriously affect the safety of foundations. Therefore, within marble area, it is necessary to drill at least 20m into sound marble rock during site investigation. On the contrary, if the volcanic rock is encountered, the requirement is to sink borehole to at least 5m into grad III or better rock..

Due to the misidentification of rock type, a total of 9,809m drillcores of 553 boreholes are believed to have exceeded the drilling requirement. These would have made a substantial cost and time implication in the development areas. Also, since the marble clasts were cemented by lava, the marble clast would be dissolved and the lava will remain which only forms the honeycomb structure, unlike the sink holes in carboniferous marble which were formed as a result of the complete dissolution of marble. The engineering geological properties of both layered marble and marble clast-bearing tuff breccia are very different.

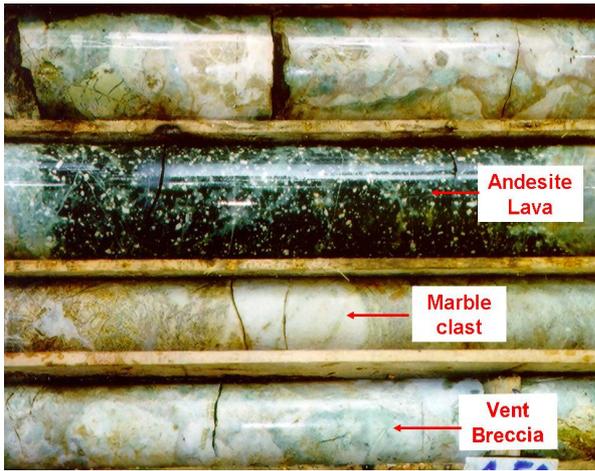


Figure 11 Rock cores of vent breccia and andesite lava, Tsing Shan Monastery

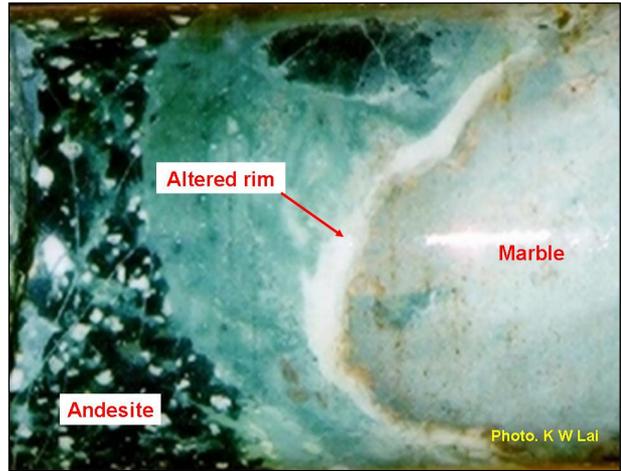


Figure 12 Altered rim between andesite and marble clast from core sample at Tsing Shan Monastery

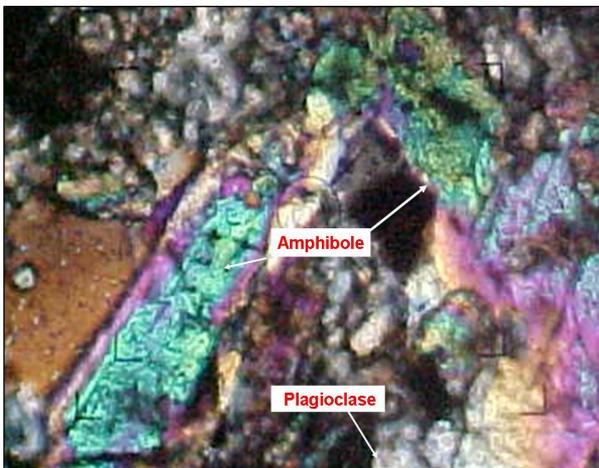


Figure 13 Andesite in thin section under the polarization microscope

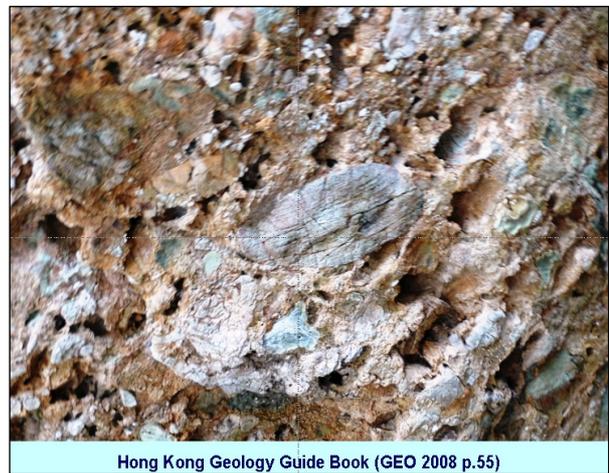


Figure 14 Vent breccia cemented by andesite within a plug which is not conglomerate

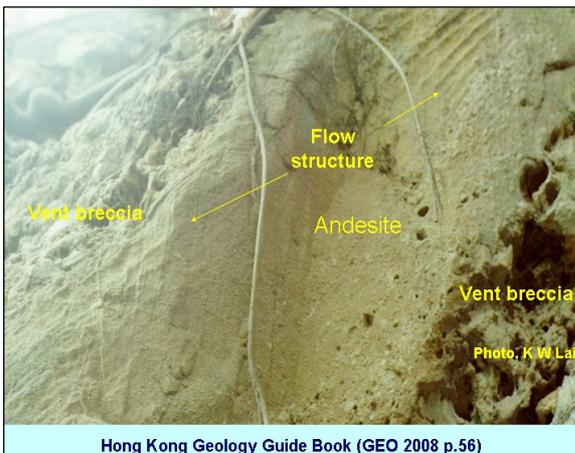


Figure 15 Vent breccia with lava flow in a plug were misjudged as fine-grained banded strata between breccia/conglomerate

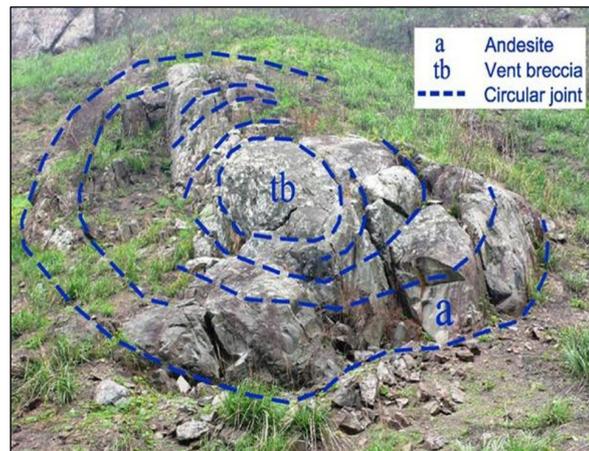


Figure 16 Concentric circular joints in a parasitic plug, Shan King Estate



Figure 17 Subrounded tuff clasts cemented by lava within the core of a parasitic plug, Shan King Estate



Figure 18 Vertical joints and lava flow structure of the Shan King Estate Plug

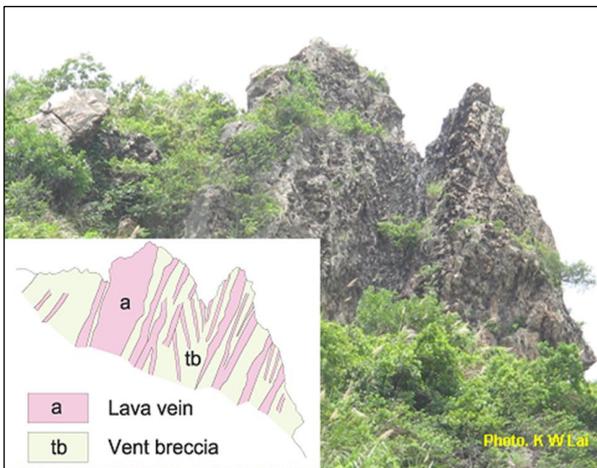


Figure 19 South Por Lo Shan Plug composed of vent breccia and lava veins

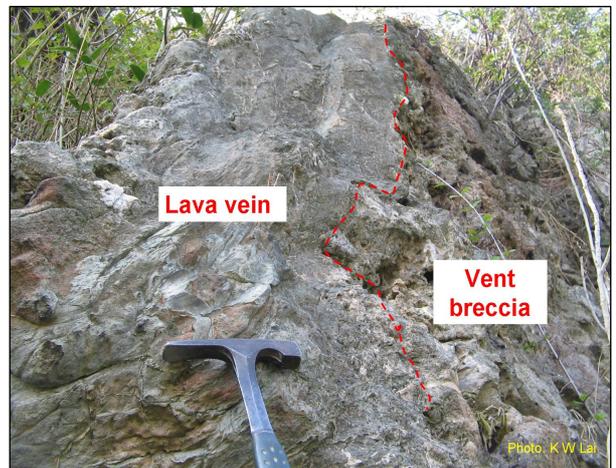


Figure 20 Intrusion of lava vein into the tuff breccia in South Por Lo Shan Plug



Figure 21 Lava flow structure in south Por Lo Shan Plug

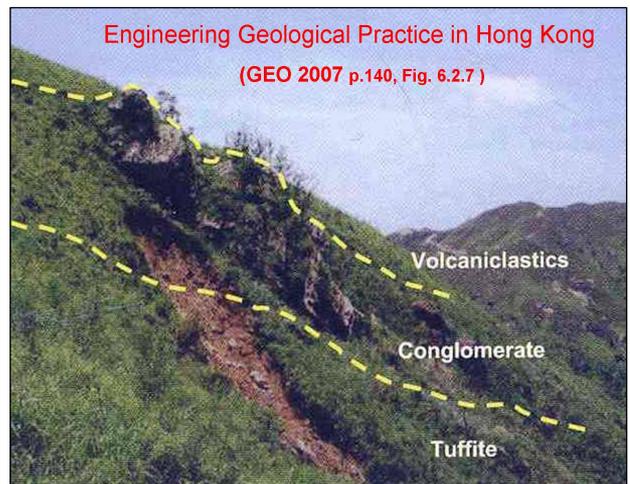


Figure 22 Tuff breccia and lava vein were misidentified as conglomerate in North Por Lo Shan

CHEMICAL COMPOSITION OF TUEN MUN FORMATION VOLCANIC ROCKS

Hong Kong Geological Survey has conducted 11 chemical analyses on the rocks of Tuen Mun Formation (Langford 1989 and Sewell 1997). These analyses were carried out on samples collected from outside of craters; no samples were collected from plugs. Due to the aphanitic texture, the rock is very difficult to be identified with naked eyes.

In accordance with the recommendation of International Union of Geological Sciences, 19 rock samples were collected from different volcanic facies including: plug, dyke, airfall and effusive facies. All chemical results were plotted in the TAS (total alkali-silica) diagram to classify different rock types (Figure 27). With respect to the determination of accurate chemical composition, only clean rock samples which were free of metamorphism, weathering, hydrothermal alteration and mixed lithic clast could be used for chemical analysis. Laboratories in Hong Kong, Guangzhou and England were used to conduct the analysis.

The results of the chemical analyses indicate the pattern of volcanic eruption. The tuff breccia in the plug indicates the violent eruption, whereas the andesite lava is widespread in the valley and plain representing the quiescent eruption. The crystal ash tuff and tuff breccia were found in the airfall facies surrounding the crater forming the stratovolcanic volcanoes. The primary magma is probably the basalt rising from the mantle which becomes more silica rich by contamination of the basalt with crustal rock of higher silica content forming andesite to dacite.

GEOMECHANICAL BEHAVIOR OF TUEN MUN FORMATION

It is easy to misidentify the tuff breccia as conglomerate due to their similarities in superficial appearance. Nevertheless, the two rock types are very different in terms of geomechanical characteristics. Some geomechanics classification was conducted on the Tuen Mun Formation by Irfan (GCO 1990) and Chan and Kwong (2009) in which the uniaxial compressive strength and the elastic modulus of both rocks were very different and they would therefore have different load deformation behavior. The uniaxial compressive strength of both rock types are tabulated in Table 1 for reference. The marble clast-bearing tuff breccia acquired a UCS about 5 to 10 times stronger than that of sedimentary rock, and 2 to 3 times stronger than that of marble. The UCS of siltstone is approximately 30 MPa which is about 3 to 6 times smaller than that of fine ash tuff. The errors made in rock identification could therefore result in a major impact in the engineering design as these rocks have different geomechanical behavior. It is therefore strongly suggested to classify the rock types carefully with reference to geomechanical characterization as well.

Table 1: Uniaxial Compression Test Results for Intact Rock Samples

Marble clast - bearing tuff breccia (MPa)	Calcareous conglomerate (MPa)	Clayey Conglomerate (MPa)	Fine ash crystal Tuff (MPa)	Marble (MPa)
a. 150 – 296 ¹	9.3 – 31.2 ³	4.0 -27.4 ⁴	c. 111 - 194 ²	d. 65 - 138 ¹
b. 195 - 329 ²				
Origin: a. Tin Shui Wai b. Tsing Shan Temple c. Tuen Mun d. Yuen Long				
Source of Origin: ¹ GCO (1990), ² Chan and Kwong (2009), ³ Fugro Rock Mechanics Lab. ⁴ FIGG Rock Mechanics Lab.				
Only intact rock samples were tested				

CONCLUSIONS

Over the past 40 years, many geologists have spent much of their precious time to conduct detailed field mapping and survey in Tuen Mun, Yuen Long and Tin Shui Wai areas. The knowledge of volcanic rock has gradually expanded to reach a comprehensive level of understanding. A change in rock type from stratified conglomerate to cylindrical shape tuff breccia has been identified. Finally, a chain of palaeovolcanic plugs has been exposed and verified. The experience of reviewing the rock types in this area highlights the importance of carrying out detailed field mapping to accurately observe the mode of occurrence of such rocks and conducting chemical analysis for aphanitic rocks determine their chemical composition as recommended by IUGS, since identification by naked eye alone is extremely difficult.

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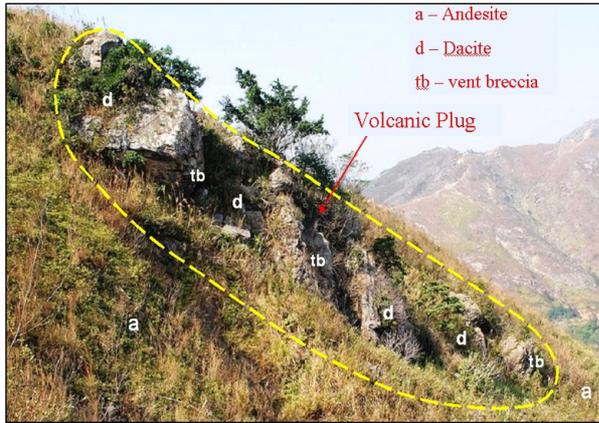


Figure 23 Tuff breccia and lava vein forming a volcanic plug in North Por Lo Shan

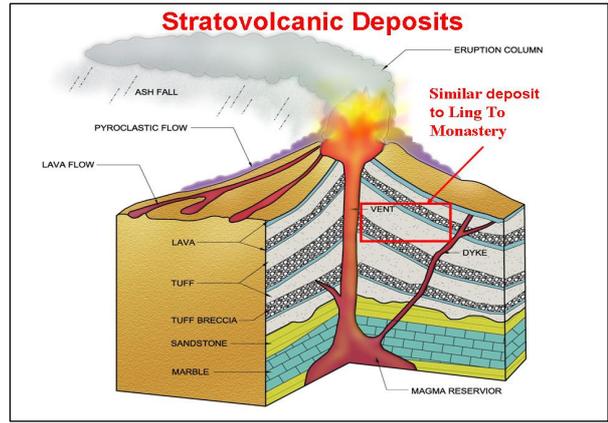


Figure 24 Sketch showing volcanic plug and stratovolcanic deposits

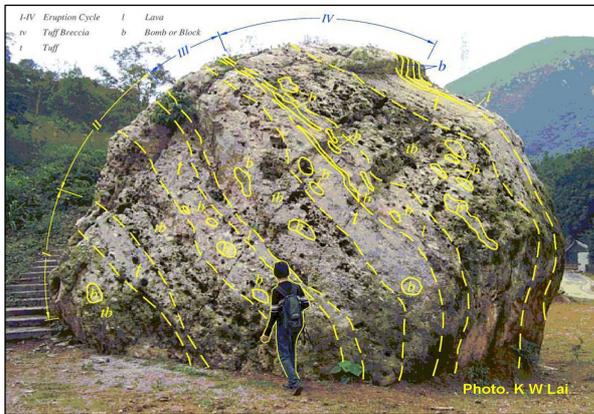


Figure 25 Stratovolcanic deposits at Ling To Monastery

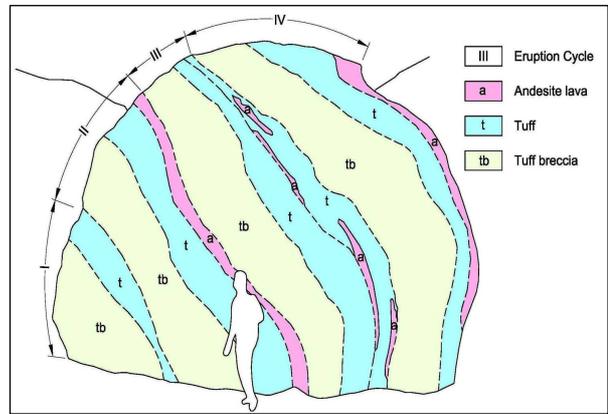


Figure 26 Sketch of the stratovolcanic deposit of Ling To Monastery

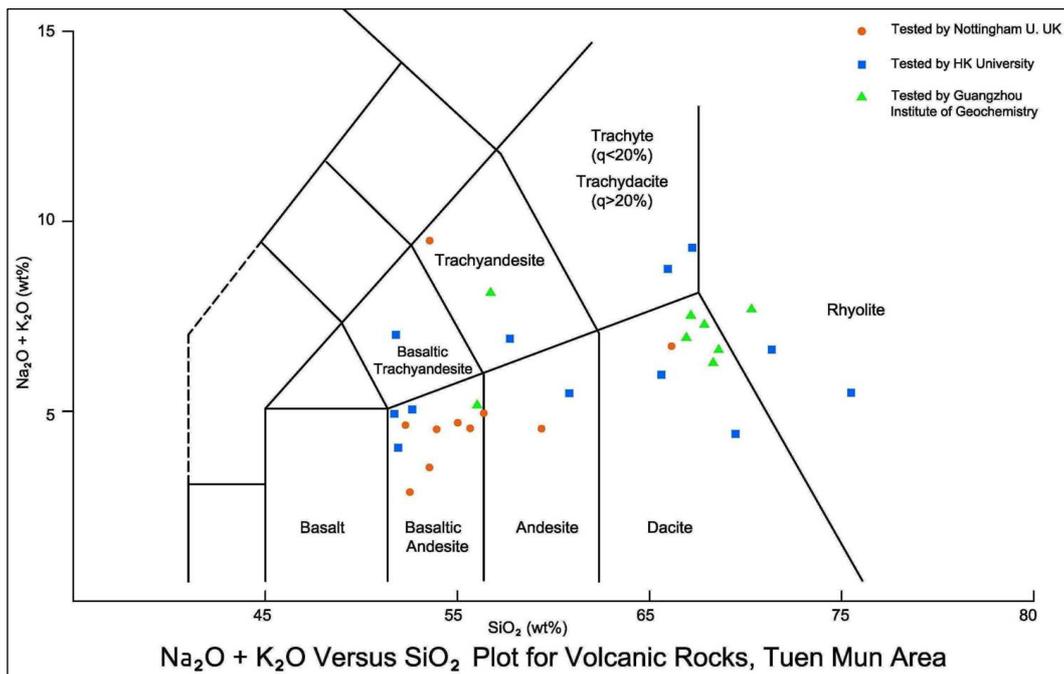


Figure 27 Chemical composition of volcanic rocks in the Tuen Mun Formation

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