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Discussion on Description and Classification of Rocks of the Tuen Mun Formation

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Abstract

In geotechnical engineering practice, accurate geological data is an essential element for safe and economical design. Since the geology in Tuen Mun and Tin Shui Wai Areas is complex, a correct definition of rock classification and geological modeling are crucial to support subsequent building and infrastructure developments in the area. The currently adopted rock classification (Sewell, 2015) is fundamentally flawed which has created some incorrect rock characterization. According to detailed chemical analyses and accurate field observation data, a correct rock classification should be established for the industry to follow in order to advance the urban development.

Accurate Geological Data - The Basis of Urban Development

Over the past few decades, major urban and infrastructure development in the northwest area of the New Territories (shown in Figure 1) has taken place. The area is underlain by complex geology of the Tuen Mun Formation. Part of the West Rail, East Rail, and Express Rail alignments, and a proposed highway to the Hong Kong International Airport extending to Macau and Zhuhai, are located within the area that is underlain by the Tuen Mun Formation. It is therefore essential to affirm a correct geological model and rock classification for the underlying rock types. In terms of geotechnical engineering, it is important to determine the engineering properties of all rocks in which tunneling and foundation excavation will be conducted. Misinterpretation of the rock classification may create significant time delays and additional cost implications in the overall development. Since 2002, a variety of rock classification problems have been identified in over 1,500 borehole logs. If the misinterpretation of the Tuen Mun Formation rocks continues to proliferate within the industry, future development in the area may inevitably lead to undesirable technical problems and significant unnecessary remediation cost.

The Guidelines on Description and Classification of Rocks of the Tuen Mun Formation

In the Seminar dated 5 December 2015, Sewell (2015) proposed a guideline on a classification scheme which enables all rocks of the Tuen Mun Formation to be described accurately and consistently. However, there are some mistakes in the classification of volcanic rocks because the author did not exactly follow the recommendations from the Subcommission on the systematic classification of igneous rocks (Table 1) of the International Union of Geological Sciences (IUGS).

In specific, IUGS recommends that "The primary classification of igneous rocks should be based on their mineral content or mode. If a mineral mode is impossible to determine because of the fine grained nature of the rock, then other criteria may be used, e.g. chemical composition, as in the (Total Alkali Silica) TAS classification" (Le Maitre et al., 2002). Generally, the minerals of lava and the matrix of pyroclastic rocks of the Tuen Mun Formation are very fine-grained, impossible to be identified with the naked eye. The matrix composition of these rocks shown in photographs from page 27 to page 33 (Sewell 2015) have mostly not been further examined with the aid of chemical analyses, thus the confirmation of the matrix composition as carbonate or unknown is unreliable. In addition, the photograph locations have not been stated making it difficult to identify the matrix composition. Based on considerable chemical analysis data (Tables 2a & 2b), the dark grey, very fine grained matrix taken from Tin Shui Wai to Tuen Mun are similar to those in photographs shown from page 27 to page 33. Most of the matrix composition is andesitic or dacitic.

According to the origin, pyroclasts are divided into juvenile, cognate and accidental fragments. Accidental fragments are derived from the subvolcanic basement which may be of any composition such as sandstone, mudstone and marble. They are not epiclasts which are produced by weathering and erosion of volcanic rocks. In the proposed guideline where the origins of the "Tuffaceous marble breccia", "Tuffaceous breccia", "Marble breccia" and "Calcareous breccia" are discussed, the marble clasts are not considered as pyroclastic components. This resulted in the assignment of inappropriate rock names for these lithologies. One must acknowledge that pyroclasts do not necessarily have to be volcanic in composition if a direct relation to the volcanic eruption can be demonstrated. Here, the marble clasts can be considered as accidental fragments liberated from the subvolcanic basement during eruption. The guideline shows that both the "Marble breccia" and "Calcareous breccia" do not constitute any pyroclastic component. These "breccia" can be subsequently misjudged as non-volcanic, sedimentary rocks. Thus the conclusion is questionable.

The proposed guideline has not particularly studied the mode of occurrence and lithological facies in the field. Volcanic breccia may occur in various lithological facies. Tuff breccia mainly occur in the fallout and pyroclastic flow deposits which are cemented by compaction and hydrochemical cementation. If lithic clasts, including the marble clasts, occur in vent facies such as in the andesitic volcanic plug or dyke, they will be cemented by lava forming the lithic clasts or marble clasts-bearing andesite.

The Influence of the Proposed Guideline on the Geology and Geotechnical Engineering of Hong Kong

As the Guideline was prepared and recommended by the author to be the standard for all geologists, consultants and contractors in Hong Kong to follow, it should have been accurate and reliable but it is not. It is unfortunately that, except for the metamorphic rock, the guideline is flawed with mistakes but it has been adopted for a long time in Hong Kong. Some practicing geologists and professors have pointed out the problems repeatedly in many seminars or published articles such as Chan and Kwong (2009), Lai & Chan (2012), Lai (2013), and Professors Zhou and Chan (Li *et al* 2014).

The problems are as follows:

A considerable number of drillhole logs have misidentified the volcanic rocks as sedimentary rocks. After reviewing more than 10,000 drillholes from Tin Shui Wai, and from Hung Shui Kiu to Tuen Mun in which nearly 1,500 drillholes are questionable. The fine-grained andesitic lavas have been misjudged as siltstone, and tuff breccia misinterpreted as conglomerate. This has seriously affected the geotechnical engineering design and assessment, and affected the construction budget and prolonged the development programme.

The distribution area of the Tuen Mun Formation has been shown from Tuen Mun to south of Tin Shui Wai in the figure "Decades of debate" on page 4 of the proposed guidelines. The same figure is also shown in Fig 5.1 of "The Pre-Quaternary Geology of Hong Kong" (Sewell *et al* 2000). In the Figure 3.5 of the same report, it misinterpreted the Jurassic volcanic rocks in Tin Shui Wai area as Carboniferous sedimentary rocks.

The "Hong Kong Geology Guide Book" (GEO 2007) misidentified the vent breccia of Tsing Shan Monastery as conglomerate or breccia from page 55 to page 56. Meanwhile the origin of those rocks which were formed by fluvial flow or volcanic mudflow deposits was misinterpreted. The wrong geological model will have a major impact on the engineering projects concerning the design aspect since their engineering properties are quite different. Sedimentary and volcanic rocks have a major difference in strength properties and deformation modulus as well as the overall rockmass characteristics. For example, the uniaxial compressive strength of marble clasts bearing andesite ranges from 150MPa to 329MPa whereas for the calcareous conglomerate, the uniaxial compressive strength only ranges from 9.3MPa to 31.2MPa (Lai and Chan 2012).

The Geological Characteristics of the Tuen Mun Formation in Hong Kong

The Tuen Mun Formation is composed of andesite-dacite and related tuff, tuff breccia with minor tuffite forming volcanic plugs, stocks, dykes and sills of subvolcanic intrusion as well as effusive lava flow, fallout and eruptive-sedimentary deposits. These rocks outcrop along a NE-trending belt from Tuen Mun to Tin Shui Wai. This volcanic belt shows the earliest volcanic activity of the late Early Jurassic period in Hong Kong.

The complicated volcanic rocks and deep weathering of the Tuen Mun Formation resulted in difficulty of geological exploration. In some articles and a large quantity of investigation borehole logs these rocks were misjudged repeatedly after 2000. In order to develop a thorough understanding of the Tuen Mun Formation volcanic rocks the author carried out detailed fieldwork repeatedly from Tuen Mun to Tin Shui Wai areas more than 120 times in the past

15 years and collected over fifty two samples for detailed chemical analysis. (Tables 2a & 2b). It is found that the palaeovolcanoes and dykes occurred as two chains on both sides of the Tuen Mun valley trending NNE. The two chains are:-

West chain of palaeovolcanoes--Tsing Shan Monastery to Ling Tao Monastery. (Figures 3-10)

The area is characterized by a hilly terrain 100m by 200m wide, covered by a thick bed of vegetation. The rock types were classified as a largely epiclastic and voclanoclastic sequence of the lower part of the Tuen Mun Formation by Dr. Sewell *et al* (2000) and GEO (2007). Recently, through borehole investigation, results of the geochemical and petrographic analysis have confirmed that these rocks are predominantly volcanic in origin. A chain of ten palaeovolcanic plugs and parasitic plugs has been discovered and verified on site (Figure 2). The shape of these plugs appear circular or elliptical in plan view and subvertical cylindrical in cross-section. The typical one is the Tsing Shan Monastery Plug. The outcrop resembles a rain drop and stands out prominently in the landscape. It is some 120m long and 50m wide with a depth of more than 100m. The plug comprises of multiple eruptive lavas and vent breccia. The chemical composition of lava is mainly basaltic trachyandesite (rock samples TM1 and TM104, Table 2a) and subordinate dacite (sample TM106) and rhyolite (samples TM102 and TM107). The lava and gas flow direction are aligning upwards and parallel to the plug. The breccia within the plug were formed by the explosive eruption of magma which includes juvenile lava clast congealed in early stage, and lithic clast of Devonian quartzitic sandstone and Carboniferous marble clasts of possible Devonian age. The lithic clasts are usually angular, some clasts forming a shuttle shape. Contact metamorphism often occurs between the marble clasts and lava forming a reaction rim. Multiple eruptions of lava veins and vent breccia are distinct in the Por Lor Shan Plug. The sequence of an initial violent eruption of vent breccia, followed by a quiescent upwelling of lava dyke.

Surrounding the Tsing Shan Monastery and Por Lor Shan plugs are the crystal ash tuff of fallout deposits which were fallen from the eruption cloud. The tuff outcrops occur on both sides of the plug. Boreholes DH2 and DH3 reveal that the tuff is interbedded with the tuff breccia of fallout facies and basaltic andesite of effusive facies. These rocks formed cyclic deposits with a gentle dip varying from 25º to 50º. The thickness of the tuff is up to 10m. The clasts within the tuff breccia are angular to subangular with poor sorting. Approximately 50m west of the plug the andesite is widespread. The boreholes in the area reveal that the deeper part is also interbedded with tuff and tuff breccia. The elongated axis of lithic clast is parallel to the gently inclined bedding. The rocks have experienced erosion for over millions of years and a thickness speculatively of about hundreds of meters have been removed. The sandstone was only found in localized areas, such as in a ridge near Shan King Estate. A 0.6m thick lenticular shape conglomerate was found in an intercalate bed within the tuff breccia near Por Lor Shan.

East chain of palaeovolcanoes--Tuen Mun Hospital to Tin Shui Wai (Figure 11-25).

This chain is situated in a plain covered by superficial deposits between 200m to 400m wide. The depth is more than 140m below the ground surface. The volcanic plugs and dykes occur intermittently, trending NNE. The rocks are composed of andesite to dacite which are similar to that of the west chain. The volcanic plug shows several characteristics:

(i) the lava dykes and vent breccia occurred closely together forming a circle or oval shape;
(ii) the contact between the lava and the lithic clasts have been altered to skarns and epidotes;
(iii) the lava and air flow textures are subvertically parallel to the plugs.

These phenomena can be observed at Maywood Court of Tin Shui Wai and Tsz Tin Tsuen. The diameter of the inferred plugs ranges from 80m to 200m. There is a large quantity of vent breccia in the east chain such as at Lam Tei, Tao Yuen Wai, Hung Shui Kiu and Tin Shui Wai. Three dykes, 0.8m to 1.5m wide, containing vent breccia occur at Yick Yuen Tsuen. The breccia mainly comprise skarnizated marbles and lava clasts

CONCLUSIONS

The Tuen Mun Formation rocks have been studied by Hong Kong geologists for a long period. Through decades of hard work, there has been a paradigm shift from ignorance to knowledge, i.e. the change from misinterpreted sedimentary rock to volcanic rock. Finally, two chains of palaeovolcanoes have been studied and verified. The experience of reviewing the aphanitic rocks in this area reinforces the importance of chemical analysis. Accompanied by detailed and accurate field observation, a correct geological model can be established. These study results should be of benefit to future urban development.

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Table 1. Classification and Nomenclature of Pyroclastic and Mixed Pyroclastic Rocks

<table>
<tr><th>Average clast size in mm</th><th>* Pyroclastic Lava (Mixed pyroclastic - lava)</th><th>Pyroclastic</th><th>Tuffites (mixed pyroclastic - epiclastic)</th><th>Epiclastic (volcanic and/or non - volcanic)</th></tr>
<tr><td rowspan="5">64
2
1/16
1/256</td><td>agglomerate lava</td><td>agglomerate, pyroclastic breccia</td><td rowspan="2">tuffaceous conglomerate, tuffaceous breccia</td><td rowspan="2">conglomerate, breccia</td></tr>
<tr><td>breccia lava</td><td>lapillistone</td></tr>
<tr><td rowspan="3">tuff lava</td><td rowspan="3">coarse
(ash tuff)
fine</td><td>tuffaceous sandstone</td><td>sandstone</td></tr>
<tr><td>tuffaceous siltstone</td><td>siltstone</td></tr>
<tr><td>tuffaceous mudstone, shale</td><td>mudstone, shale</td></tr>
<tr><td>Amount of pyroclastic material</td><td>90% to 10%</td><td>100% to 75%</td><td>75% to 25%</td><td>25% to 0%</td></tr>
<tr><td>* Type of cementation</td><td>lava cementation</td><td>compaction and hydrochemical cementation</td><td>compaction and hydrochemical cementation</td><td>compaction and hydrochemical cementation</td></tr>
</table>

Source: After Le Maitre *et al*., (2002) and Schmid (1981, Table 2). *After Li *et al* (1984)

Table 2a Whole Rock Major Element Concentration of the Tuen Mun Formation Rocks (Wt%)

	Sample Number	Location	Coordinate		Rock Name	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL
			E	N													
1	TM-1	TST BH3 2.8m	1387	2807	Basaltic trachyandesite	52.360	0.745	17.621	7.315	0.078	3.224	9.971	3.420	3.531	0.509	1.100	99.873
2	TM-8	Shan Shek Wan Area 19			Dacite	68.560	0.056	19.499	1.410	0.048	0.339	1.578	4.538	2.812	0.019	1.571	100.430
3	TM-9	Por Lor Shan			Basaltic andesite	55.010	0.915	17.219	8.721	0.138	3.742	6.933	2.897	1.770	0.217	1.787	99.349
4	TM-10	Ling Dao Monartery	1607	3351	Dacite	65.945	0.783	10.578	6.044	0.170	1.012	9.472	2.340	3.803	0.107	0.733	100.986
5	TM-15	Tsing Shan Au			Andesite	60.327	0.682	16.391	6.969	0.151	1.929	2.307	0.148	6.395	0.215	3.856	99.370
6	TM-16	Por Lor Shan			Basaltic andesite	55.830	1.006	17.352	9.198	0.139	4.171	6.272	2.686	2.396	0.217	0.686	99.955
7	TM-17	Leung King Estate	1388	2952	Rhyolitic tuff	74.091	0.321	13.924	2.750	0.072	0.543	0.783	2.083	4.540	0.082	1.733	100.920
8	TM-31	300m NW of TSM			Andesite	59.275	0.719	15.202	9.163	0.168	2.640	3.007	2.967	3.456	0.245	2.162	99.003
9	TM-36	Wog Leung King Estate			Dacite	66.320	0.538	16.381	4.055	0.086	1.253	2.144	4.865	3.152	0.184	0.785	99.763
10	TM-37	Leung King Estate	1395	2985	Trachyandesite	66.963	0.521	15.521	4.324	0.075	1.023	2.109	4.283	3.976	0.157	0.899	99.850
11	TM-53	Sog Shan Plug			Rhyolitic tuff	76.863	0.603	10.657	3.170	0.047	1.572	2.053	2.927	1.384	0.112	0.793	100.181
12	TM-56	Shan King Plug			Dacite	71.462	0.642	13.680	4.613	0.096	1.290	0.054	0.156	4.880	0.052	1.906	98.831
13	TM-57	Shan King Parasitic Plug			Andesite	61.708	0.833	18.303	6.775	0.085	2.030	0.865	0.939	4.893	0.117	2.433	98.981
14	TM-58	Shan King Parasitic Plug			Dacite	67.036	0.457	17.083	3.568	0.050	1.626	0.939	1.197	4.949	0.091	2.257	99.253
15	TM-59	South Por Lor Shan	1372	2863	Rhyolitic tuff	77.357	0.135	12.200	1.658	0.031	0.378	1.017	2.327	3.727	0.009	0.867	99.705
16	TM-61	South Por Lor Shan	1371	2860	Basaltic andesite	53.283	1.047	17.838	10.582	0.147	3.602	6.654	2.662	2.152	0.247	1.765	99.979
17	TM62	Shan King Parasitic Plug			Dacite	63.159	0.161	18.230	2.155	0.045	3.742	0.933	2.316	7.955	0.041	1.037	99.774
18	TM-64	South Por Lor Shan	1366	2850	Andesite	60.777	0.673	17.587	6.501	0.089	2.951	5.009	2.960	2.179	0.266	0.799	99.792
19	TM-65	Tuen Mun Sea Water SR	1425	2889	Basaltic andesite	52.309	1.104	18.355	9.312	0.167	4.431	7.791	2.502	1.616	0.262	1.796	99.645
20	TM-65B	Tuen Mun Sea Water SR	1425	2889	Basaltic andesite	52.279	1.096	18.710	9.722	0.144	2.978	8.153	2.441	2.571	0.223	1.396	99.713
21	TM-66	Wog Shan King Estate			Dacite	69.683	0.474	14.651	3.450	0.062	1.013	1.665	4.479	2.792	0.107	0.917	99.294
22	TM-68	South Por Lor Shan	1364	2852	Dacite	70.315	0.662	14.492	4.587	0.063	1.583	1.185	0.688	3.788	0.100	3.130	100.592
23	TM-70	South Por Lor Shan	1364	2849	Trachyandesite	58.489	0.857	20.679	7.549	0.060	2.311	0.465	0.080	6.350	0.144	2.329	99.312
24	TM-71	South Por Lor Shan	1366	2850	Trachyandesite Dyke	68.965	0.205	15.879	2.176	0.037	2.324	1.215	2.841	6.664	0.018	0.532	100.855
25	TM-72	Ling Dao Monastery			Rhyolitic tuff	72.212	0.567	10.390	4.012	0.078	1.602	3.052	4.312	2.208	0.092	0.269	98.793
26	TM-73	Shan King Estate	1375	2885	Basaltic andesite	56.290	0.760	19.190	8.920	0.170	3.950	1.110	0.420	3.960	0.100	4.830	99.690
27	TM-74	Shan King Parasitic Plug			Dacite	65.785	0.541	16.223	4.288	0.077	0.827	3.432	3.310	4.395	0.186	0.886	99.950
28	TM-76	Wog Shan King Plug			Dacite	62.920	0.240	15.543	3.283	0.117	3.245	3.116	4.397	6.772	0.078	0.333	100.044
29	TM-77	East Por Lor Shan	1371	2862	Rhyolitic tuff	72.800	0.310	13.790	1.940	0.050	0.700	1.740	3.120	4.540	0.090	0.750	99.810
30	TM-80	S Por Lor Shan Plug			Rhyolitic tuff	76.557	0.140	10.420	1.806	0.052	1.387	1.632	3.637	2.641	0.048	0.659	98.979
	Source:	Samples No 1-24 (Earth Sciences Department, Hong Kong University), No. 25-30 (Guangzhou Institute of Geochemistry)															
	Notes:	TSW--Tin Shui Wai, TSM--Tsing Shan Monastery, Tuen Mun Sea Water SR--Tuen Mun Sea Water Service Reservoir															

Table 2b Whole Rock Major Element Concentration of the Tuen Mun Formation Rocks (Wt%)

	Sample Number	Location	Coordinate		Rock Name	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL
			E	N													
31	TM-81	S Por Lor Shan Plug	1372	2882		68.770	0.530	14.160	3.890	0.070	1.560	3.040	2.990	3.730	0.110	0.910	99.770
32	TM-82	Tin Tan St BH2 42m TSW			Rhyolitic tuff	74.663	0.528	10.717	4.525	0.068	1.355	3.267	1.984	1.722	0.125	0.680	99.633
33	TM-83	Tin Tan St BH3 23m TSW			Rhyoletic Tuff	73.933	0.553	12.140	3.130	0.031	0.765	2.252	3.534	2.586	0.106	0.410	99.441
34	TM-85	Tin Tan St TSW			Rhyoletic Tuff	74.387	0.621	11.366	3.943	0.114	1.221	3.074	2.773	1.527	0.131	0.526	99.682
35	TM-86	BH83 Tin Shui Wai 113m			Dacite	72.959	0.616	10.424	6.881	0.060	2.929	0.544	0.101	2.476	0.082	2.402	99.473
36	TM-87	N Por Lor Shan Plug			Rhyoletic Tuff	78.285	0.205	10.152	1.447	0.062	0.838	4.469	1.475	2.524	0.082	0.333	99.872
37	TM-90	N Por Lor Shan Plug			Rhyoletic Tuff	71.751	0.247	13.781	2.192	0.034	1.408	1.917	2.658	5.126	0.065	0.615	99.794
38	TM-102	TST BH4 16.4m	1387	2807	Rhyoletic Tuff	70.050	0.340	14.390	2.300	0.060	0.970	2.950	1.980	4.460	0.090	2.130	99.710
39	TM-103	TST BH7 13.6m	1386	2809	Rhyoletic Tuff	70.750	0.300	13.100	1.910	0.050	0.880	3.230	1.530	5.240	0.080	2.650	99.710
40	TM-104	TST BH3 2.5m	1388	2808	Baslltic trachyandesite	52.000	0.830	18.610	7.580	0.050	3.350	7.760	4.080	3.760	0.480	1.000	99.480
41	TM-106	TST BH7 14m	1386	2806	Dacite	69.260	0.300	13.770	1.920	0.050	0.880	3.420	1.730	5.400	0.080	2.940	99.730
42	TM-107	TST BH7 16m	1386	2809	Rhyoletic Tuff	69.530	0.300	13.620	1.870	0.050	0.950	3.360	2.820	4.680	0.090	2.450	99.720
43	TM-114	S Por Lor Shan			Dacite	70.773	0.612	14.251	4.538	0.043	1.174	0.092	0.209	4.758	0.089	2.332	98.872
44	TM-115	S Por Lor Shan	1365	2880	Andesite	62.896	0.739	18.267	5.748	0.055	1.515	0.142	0.431	6.162	0.087	2.742	98.783
45	TM-117	N Por Lor Shan	1361	2885	Rhyoletic Tuff	78.493	0.205	10.319	1.892	0.045	0.952	2.360	1.837	3.406	0.072	0.477	100.057
46	TM-118	S Por Lor Shan	1366	2880	Rhyoletic Tuff	78.919	0.146	9.961	1.500	0.037	1.404	2.938	2.546	2.360	0.040	0.542	100.393
47	TM-119	S Por Lor Shan	1368	2880	Dacite	69.197	0.502	11.392	3.998	0.168	1.313	4.500	3.062	3.954	0.119	0.771	98.974
48	TM-120	S Por Lor Shan	1368	2874	Rhyoletic Tuff	73.766	0.264	12.861	2.045	0.046	0.481	2.239	1.894	4.563	0.068	0.976	99.203
49	TM-121	NE parastic Plug	1367	2865	Dacite	66.896	0.606	15.236	5.204	0.099	1.227	2.719	3.188	2.968	0.131	1.161	99.434
50	TM-122	S Shan King Plug	1359	2859	Dacite	64.272	0.265	15.782	3.478	0.099	3.113	1.227	4.043	5.798	0.085	0.643	98.805
51	TM-123	NW Shan King Plug	1358	2863	Rhyoletic Tuff	77.152	0.118	12.235	1.336	0.019	0.214	0.168	2.102	4.972	0.031	1.003	99.350
52	TM-124	Tsing Shan TP2	1372	2772	Andesite	56.885	0.822	20.879	7.893	0.087	2.428	0.357	0.205	5.645	0.114	3.815	99.130
53	HK856	Tuen Mun Sea Water SR	1427	2889	Basaltic andesite	54.390	1.010	17.190	8.500	0.150	3.870	7.260	2.360	2.050	0.210	0.670	99.330
54	HK3778	Tsui Lam Garden	1517	2910	Trachyandesite	53.460	1.480	18.450	9.390	0.110	1.300	4.540	4.570	4.940	0.790	---	100.470
55	HK10246	Leung King Estate	1407	2932	Basaltic andesite	53.130	1.020	17.630	9.200	0.170	4.610	8.790	1.340	1.960	0.270	2.000	100.120
56	HK10247	Tuen Mun Water SR	1400	2880	Basaltic andesite	52.020	0.890	17.550	9.060	0.290	3.560	11.620	0.960	1.730	0.270	2.060	100.010
57	HK10378	Shan King Estate	1388	2852	Basaltic andesite	55.970	1.010	16.790	9.500	0.160	4.390	5.500	3.130	1.550	0.220	1.920	100.140
58	HK10379	Shan King Estate	1388	2858	Basaltic andesite	53.990	0.950	18.320	8.950	0.150	3.930	7.940	2.280	2.060	0.240	1.460	100.270
59	HK10380	Shan King Estate	1396	2854	Trachyandesite	51.600	1.120	19.140	10.550	0.170	4.720	3.810	0.900	5.610	0.240	1.910	99.770
60	HK10382	Shan King Estate	1409	2864	Basaltic andesite	53.440	1.020	18.000	9.420	0.160	4.360	6.920	3.850	0.580	0.250	1.820	99.820
61	HK10417	Choi fai Garden	1599	2984	Dacite	65.990	0.600	16.180	4.980	0.070	0.820	3.520	3.420	3.210	0.250	1.230	100.270
62	HK10421	Tai Hing Garden	1541	2896	Trachydacite	63.490	0.730	18.730	3.170	0.070	1.060	2.880	6.420	2.290	0.250	0.900	99.990
63	HK10444	Kin Wing Street	1484	2861	Andesite	59.960	0.870	16.570	7.970	0.140	2.260	6.950	2.710	1.650	0.240	0.880	99.320

Source: Samples No 31-52 (Guangzhou Institute of Geochemistry), No.52-63 (Nottingham University, UK, published by GEO, 1997)

Notes: TSW--Tin Shui Wai, TSM--Tsing Shan Monastery, Tuen Mun Sea Water SR--Tuen Mun Sea Water Service Reservoir.

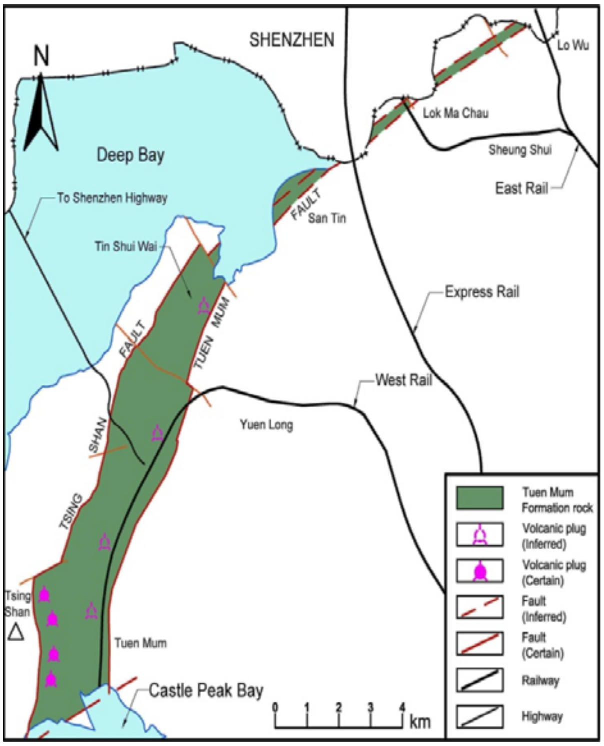


Figure 1. Location of Tuen Mum Formation

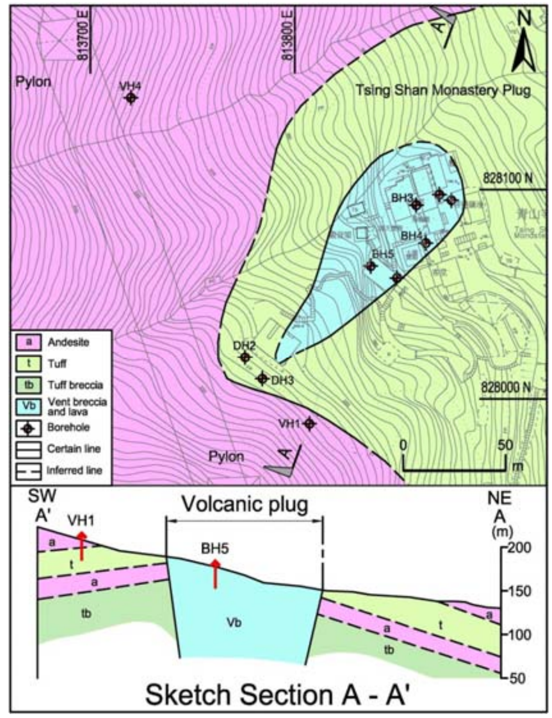


Figure 3. Tsing Shan Monastery Plugs

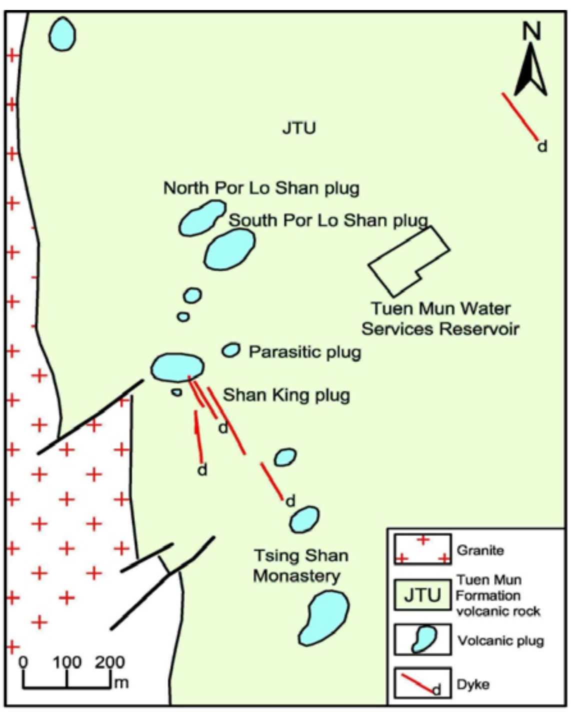


Figure 2. Volcanic plugs occurred from Tsing Shan Monastery to Por Lor Shan

Figure 4. Andesite and marble clasts bearing vent breccia in the Tsing Shan Monastery plug

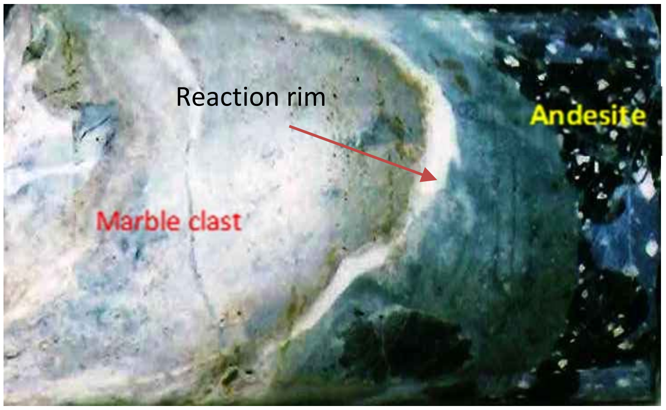


Figure 5. A reaction rim occurs between andesite and marble clast

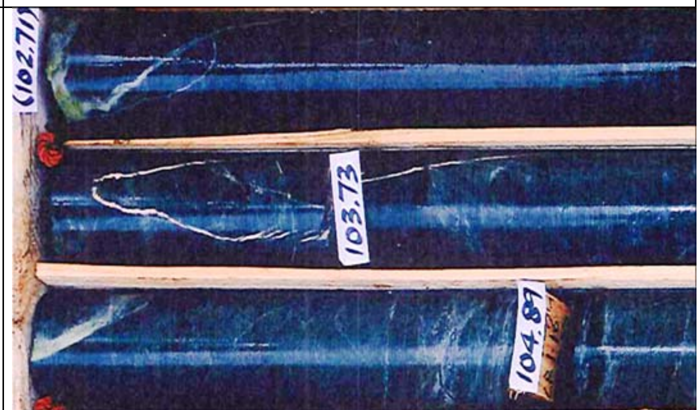


Figure 6. Basaltic andesite in a 120m deep borehole of Tuen Mun Sea Water Service Reservoir

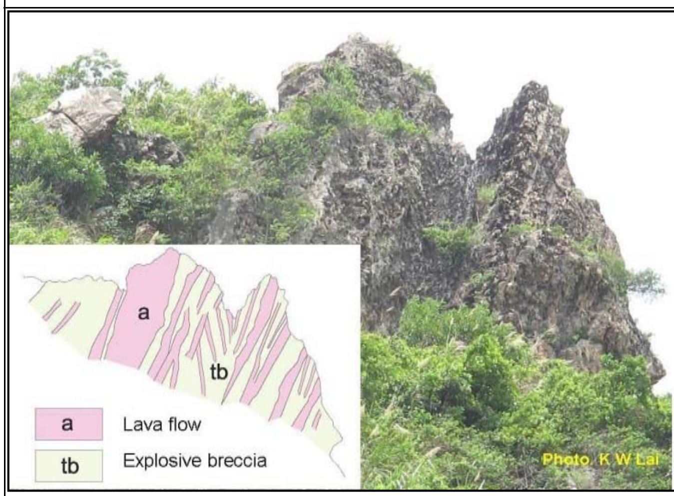


Figure 7. Lava dykes and vent breccia in the Por Lor Shan Plug

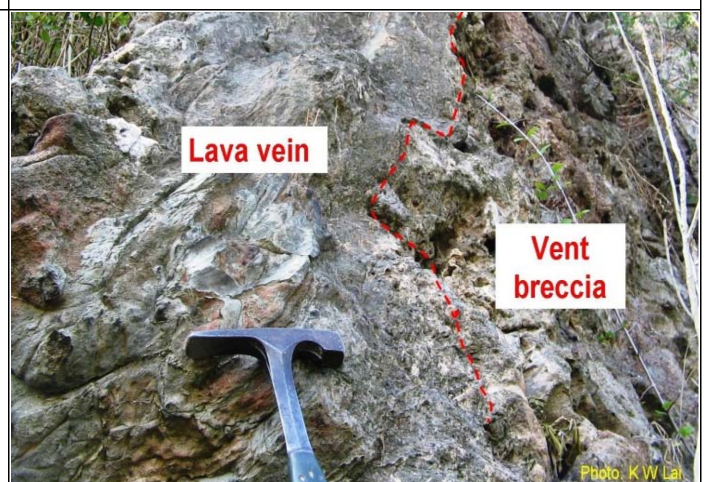


Figure 8. A lava dyke intrudes the vent breccia in the Por Lor Shan Plug

Figure 9. Tuff breccia of fallout facies showing gentle dip bedding

Figure 10. An Andesite dyke intrudes the Tuff breccia

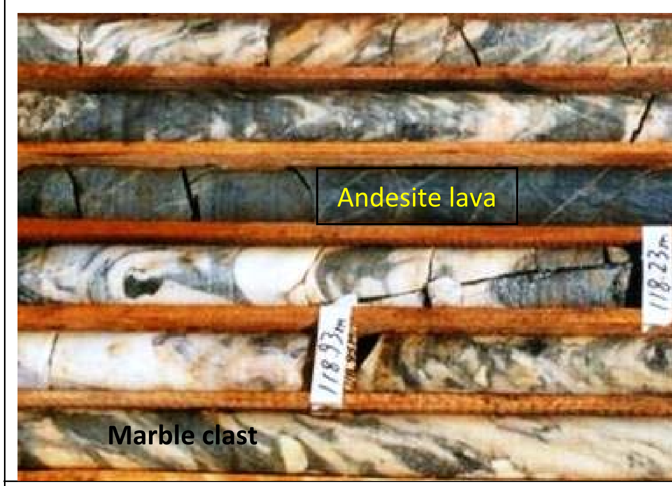
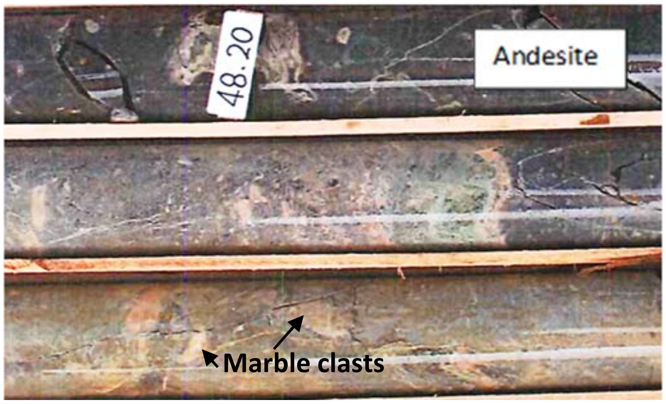


Figure 11. Mylonitic marble clasts (white) bearing andesite (black), Tin Shui Wai

Figure 12. Mylonitic marble clast cemented by andesite (dark grey), Tin Shui Wai



Figures 12. Andesite and altered marble clasts, Tsz Tin Tsuen

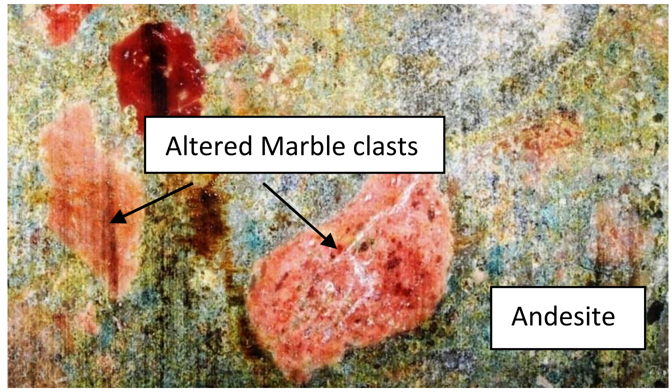


Figure 13. Contact metamorphism occurs between andesite and marble clasts, Tsz Tin

Figure 14. Andesite under the polarization microscope, Tsz Tin Tsuen

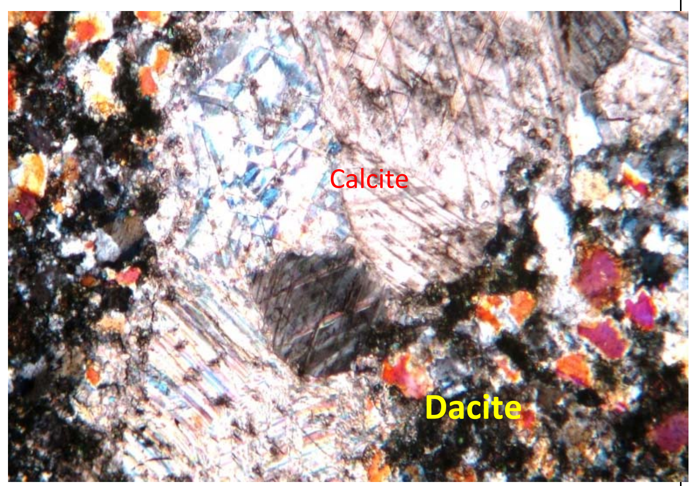


Figure 15, Calcite margin of marble clasts is altered by dacite lava