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Fact or Fallacy: Rock Classification in Hong Kong as Carried Out By the Geotechnical Engineering Office of the Civil Engineering and Development Department Follows the Recommendations of the International Union of Geological Sciences and the British Geological Survey

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Introduction

In recent years, there have been comments in the local and regional literature that the Geotechnical Engineering Office of the Civil Engineering and Development Department (hereafter GEO) has not followed international standards and practice in naming rocks and this has supposedly led to confusion among geotechnical practitioners in the Hong Kong Special Administrative Region (hereafter Hong Kong) (Lai 2016; Lai 2017; Lai & Li, 2017). This communication aims to clarify a misunderstanding by showing that the GEO adheres closely with the fundamental principles of rock classification recommended by the International Union of Geological Sciences (IUGS) and the British Geological Survey (BGS), using as an example the recently published description and classification of the rocks of the Tuen Mun Formation (GEO Report No. 327; So and Sewell, 2017).

What international guidelines and recommendations are used by GEO to classify the rocks in Hong Kong?

Geoguide 3 (Guide to Rock and Soil Descriptions), first published in 1988 (GCO, 1988) and updated in 2017 (GEO, 2017), recommends a standard of good practice for the description of Hong Kong rocks and soils for engineering purposes. The scheme was based largely on the most widely used rock classifications available at the time. These were: Streckeisen (1974, 1980) for plutonic and volcanic rocks; Schmid (1981) and Fisher & Schmicke (1984) for pyroclastic rocks; and various publications for sedimentary rocks (Pettijohn, 1975; Blatt et al. 1980; Tucker 1982) and metamorphic rocks (Gillen, 1982; Fry, 1984). The standard for igneous rock classification outlined in Geoguide 3 is now largely incorporated within the IUGS publication and follows Le Maitre et al. (2002).

Although Geoguide 3 is suitable for describing most igneous rocks in Hong Kong, the schemes related to sedimentary and metamorphic rocks are considered of limited use because, for example, they cannot be easily applied to describing the complex lithologies of the Tuen

Mun Formation. Therefore, in a recent geological publication of GEO (GEO Report No. 327; So and Sewell, 2017), the latest recommendations given by the BGS and the IUGS for sedimentary and metamorphic rocks have been adopted (Gillespie & Styles, 1999; Hallsworth & Knox, 1999; Robertson, 1999; Brodie et al., 2007; Rosen et al., 2007; Schmid et al., 2007; Zharikov et al., 2007).

<u>How should rock classification be approached?</u>

A fundamental principle of rock classification is that "rocks should be named according to what they are, and not according to what they might have been" (Le Maitre et al., 2002). A rock should only be named according to Le Maitre et al. (2002) if it is "igneous or igneous-looking". With regard to metamorphic rocks, they should be named in the first instance based on directly observable features at the mesoscopic or microscopic scale (Schmid et al., 2007). Similarly, "sediment and sedimentary rock nomenclature is based as far as possible on actual, descriptive attributes, not interpretive attributes" (Hallsworth & Knox, 1999). In other words, rock classification should be carried out independently of any proposed geological model/interpretation and be based on clearly observable and measureable evidence, including minerals, rock fragments, composition, grain size, colour, textures, fabrics, structures and material strength. A simplified workflow on rock classification based on the latest recommendations given by the IUGS is given in Fig. 1.

<u>How are the IUGS and BGS recommendations applied by GEO to classify the rocks in Hong Kong? – A case example from the Tuen Mun Formation</u>

There has been a long-standing debate among geotechnical practitioners in Hong Kong on how to correctly classify rocks of the Tuen Mun Formation (Lai et al. 2004; Lai 2005; Chan et al. 2005; Chan & Kwong 2009; Lai 2010; Lai & Chan, 2011; Lai & Chan, 2012; Lai 2013; Lai 2016; Lai 2017; Lai & Li, 2017). This has prompted the GEO to publish guidelines on rock classification and nomenclature (GEO Report No. 327; So and Sewell, 2017). The approach outlined in GEO Report No. 327 is non-genetic and non-interpretive and adheres strictly to the IUGS and BGS recommendations on rock classification as outlined below:

As stated above, for a rock to be classified as igneous, it has to be "igneous or igneous-looking" (Le Maitre et al., 2002) based on clearly observable and measureable evidence. The 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" (Point (2) of Chapter 2.1). On the other hand, the IUGS recommendations define plutonic rock as "igneous rock with phaneritic texture …. presumed to have formed by slow cooling" and volcanic rock as "igneous rock with aphanitic texture ….. presumed to have formed by relatively fast cooling. Such rocks often contain glass." (Points (3) and (4) of Chapter 2.1).

For igneous rocks that are considered to have a pyroclastic origin, (i.e. are formed by fragmentation as a result of explosive volcanic eruptions or processes, for example, air fall, flow and surge deposits, lahars, intrusion and extrusion breccias, tuff dykes and diatremes), the classification of pyroclastic rocks (Chapter 2.2) should be used. This classification is based on the size (ash, lapilli, blocks and bombs; Le Maitre et al. 2002) and composition (glass, crystal, lithic; GEO, 2017) of constituent juvenile pyroclasts.

The IUGS recommendations also state that the TAS (Total Alkali – Silica) classification should be used only if (1) the rock is considered to be volcanic, (2) a mineral mode cannot be determined, owing either to the presence of glass or to the fine-grained nature of the rock, and (3) a chemical analysis of the rock is available (Chapter 2.12). Therefore, there is no suggestion in the IUGS recommendations that geochemical analysis assumes primacy in the classification of pyroclastic rocks.

Many clast-bearing rocks in the Tuen Mun Formation have quartz-rich and feldspar-depleted matrices, and those containing marble clasts are also calcite-rich. The presence of quartz-rich matrices means that they cannot be labelled “andesitic” for the simple reason that andesite usually does not contain crystals of this mineral. Furthermore, geochemical analysis cannot be reliably applied to the fine-grained matrix of clast-bearing rocks because these rocks do not satisfy the primary principle that they were formed directly by cooling from magma (Le Maitre et al., 2002).

A considerable amount of work has been carried out by GEO (e.g., Tang, 2007) in unravelling the stratigraphy and provenance of the Tuen Mun Formation and this has been published in an international peer-reviewed journal (Sewell et al. 2017). To test whether whole rock geochemistry can be usefully applied, we have carried out our own independent geochemical analyses (Table 1) on the fine-grained matrix of marble clast-bearing rocks of the Tuen Mun Formation (Fig. 2), in which obvious clasts were avoided. The analyzed data are highly scattered on major element diagrams for igneous rocks and several have silica contents in excess of normal magmatic values (SiO_2>77 wt%; Figs. 3a & b). The results show clearly that the matrix of these rocks is non-igneous, given the fact that most known non-pyroclastic igneous rocks of the Tuen Mun Formation are of basaltic andesite or andesite composition. The presence of carbonate in the matrix also strongly affects the whole rock chemistry. Moreover, zircon geochemistry has demonstrated that the rocks of the Tuen Mun Formation have no relationship with the other rocks of Hong Kong (Sewell et al. 2017).

In GEO Report No. 327, rocks of the Tuen Mun Formation, except non-pyroclastic igneous rocks (e.g. lavas, dykes and sills), have been classified individually according to the pyroclastic, sedimentary or metamorphic rock classification schemes. In many cases, these rocks also display structures and textures which are clearly non-igneous, such as metamorphic foliation or graded bedding. It is reiterated that presupposing a geological model is inappropriate for a correct rock classification.

Conclusion

The repeated criticism that GEO is not following IUGS recommendations and guidelines in the description and classification of rocks of Hong Kong is not supported by facts as noted in the sections above. The arguments concerning rock classification and nomenclature of the Tuen Mun Formation are unjustified. While we welcome discussion on various interpretive geological models for better understanding of the geology of Hong Kong, unfounded querying of GEO’s approach to rock classification and nomenclature can cause unnecessary confusion among geotechnical practitioners. The GEO will continue to discuss its objective and well-researched scientific findings with the geological community through internationally peer-reviewed publications and seek to promulgate guidelines and standards with the local industry for the fruitful and beneficial development of geotechnical practice in Hong Kong.

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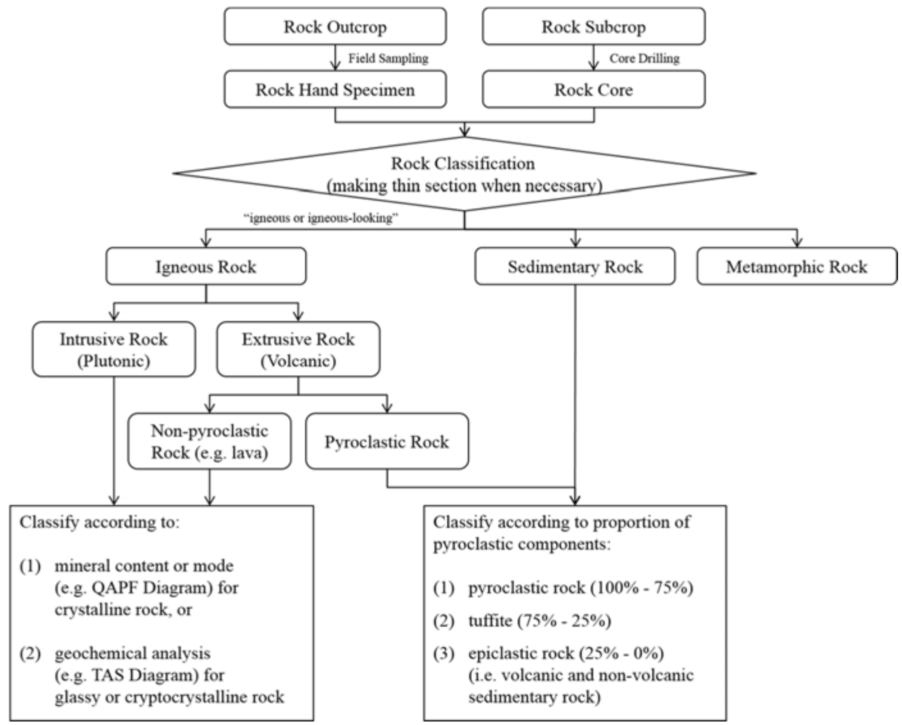

Figure 1. Flow chart of rock classification as recommended by the IUGS and British Geological Survey. Rock classification should be based on clearly observable and measureable evidence, including minerals, rock fragments, composition, grain size, colour, textures, fabrics, structures and material strength. Rocks should be named according to what they are, and not according to what they might have been (based on Le Maitre et al., 2002).

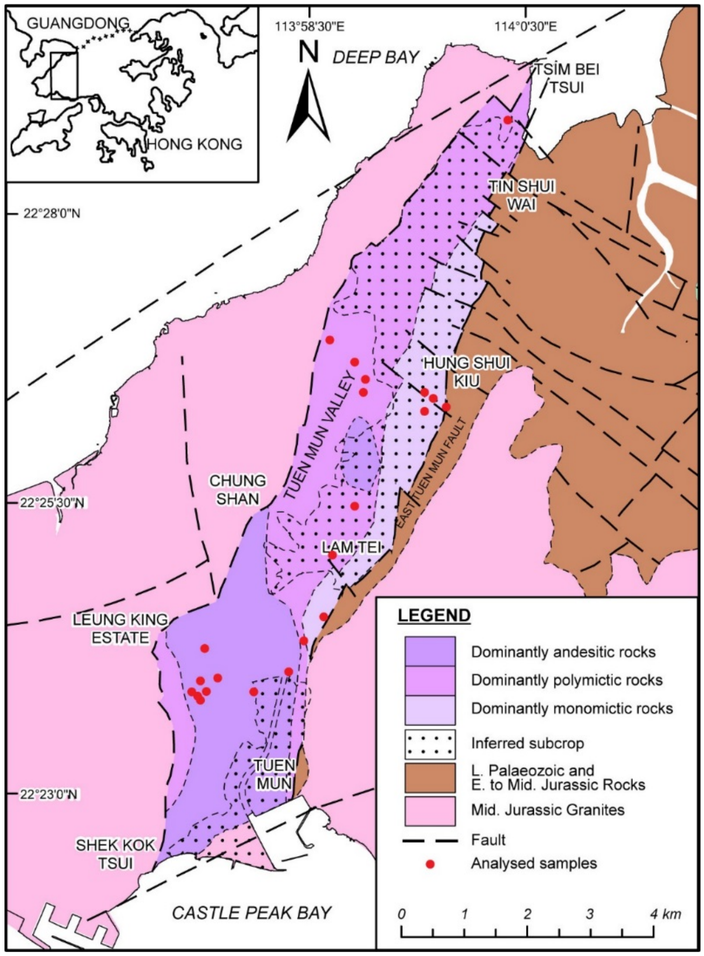

Figure 2. Summary geological map showing the distribution of the Tuen Mun Formation and location of analysed samples.

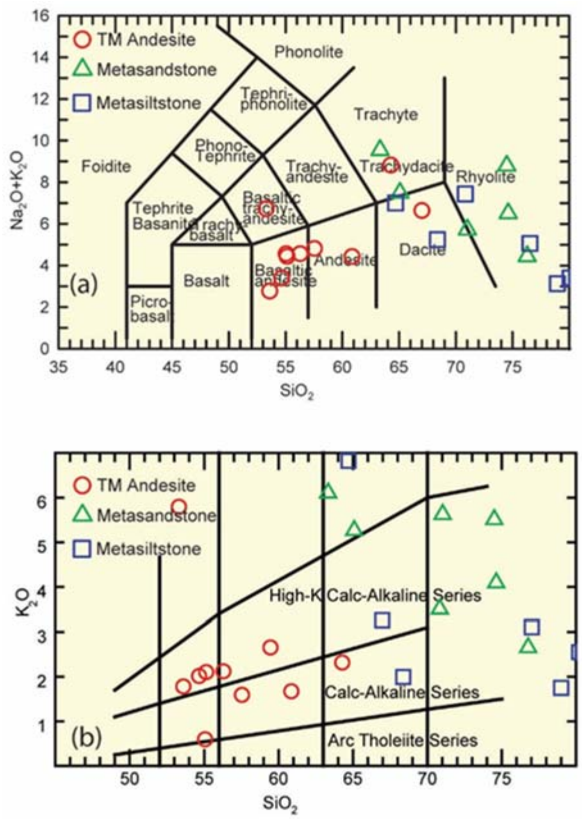

Figure 3. Major and trace element analyses for the matrix of clast-bearing rocks in Tuen Mun Valley compared with andesite lava from outcrops in Tuen Mun. (a) Total Alkali versus Silica (TAS); (b) K_2O versus Silica (after Peccerillo & Taylor, 1976). (Note: All analyses are plotted on a "loss-free" basis)

Table 1a Sample Description and Locality Details

Sample	Field No.	Locality	East	North	Rock Type
HK12111	35262/DH48A	Tuen Mun North	815622	829471	Tuffaceous Metasandstone
HK12113	35261/DH33	Tuen Mun North	816087	830810	Tuffaceous Metasandstone
HK12760	40758/NDH38	Ha Tseun	816057	834231	Tuffaceous Metasandstone
HK12763	40758/NDH39	Ha Tseun	816441	833864	Tuffaceous Metasandstone
HK12772	40758/NDH42	Ha Tseun	816611	833562	Tuffaceous Metasandstone
HK12778	40758/NDH45	Ha Tseun	816581	833396	Tuffaceous Metasandstone
HK12791	40758/NDH60	Lam Tei	816430	831560	Tuffaceous Metasandstone
HK11107	KW/BG/258	Mong Tseng Wai	818840	837590	Tuffaceous Metasandstone
HK13081	62268/A1	Hung Shui Kiu	817691	833274	Calcareous Metasiltstone
HK13084	62268/A18	Hung Shui Kiu	817813	833168	Calcareous Metasiltstone
HK13085	62268/A29	Hung Shiu Kiu	817751	833045	Calcareous Metasiltstone
HK13089	62268/A46	Hung Shui Kiu	817964	833081	Calcareous Metasiltstone
HK10417	3409/897D	Tuen Mun	815993	829838	Tuffaceous Metasiltstone
HK856	RS/ED/77	Tuen Mun	814270	828889	Metaandesite
HK10246	14676/27D	Leung King	814065	829320	Metaandesite
HK10247	2041/39D	Leung King	814000	828800	Metaandesite
HK10378	725/253D	Shan King	813875	828524	Metaandesite
HK10379	725/254D	Shan King	813897	828577	Metaandesite
HK10380	725/255D	Shan King Estate	813960	828536	Metaandesite
HK10382	725/257D	Shan King Esate	814086	828643	Metaandesite
HK10421	6930/905D	San Hui	815407	828963	Metaandesite
HK10444	3425/1048D	Shan King	814840	828609	Metaandesite

Table 1b. Whole-rock major and trace element data for rocks of the Tuen Mun Formation (major elements in wt%; trace elements in ppm)

Sample	HK13081	HK13084	HK13085	HK13089	HK10417	HK856	HK10246	HK10247	HK12111	HK12113	HK12760	HK12763	HK12772	HK12778	HK12791	HK11107	HK10378	HK10379	HK10380	HK10382	HK10421	HK10444
SiO_2	75.69	78.67	62.33	75.09	65.99	54.39	53.13	52.02	66.55	70.57	62.52	74.5	64.12	68.5	72.96	73.98	55.97	53.99	51.6	53.44	63.49	59.96
TiO_2	0.52	0.61	0.77	0.69	0.6	1.01	1.02	0.89	1	0.61	0.8	0.53	0.89	0.46	0.26	0.18	1.01	0.95	1.12	1.02	0.73	0.87
Al_2O_3	8.43	9.41	19.1	10.93	16.18	17.19	17.63	17.55	14.02	11.46	16.13	9.87	15.15	16.59	13.66	13.4	16.79	18.32	19.14	18	18.73	16.57
Fe_2O_3	3.23	3.07	6.63	3.55	4.98	9.04	9.2	9.06	6.41	3.27	5.86	4.3	5.58	3.94	1.78	1.69	9.5	8.95	10.55	9.42	3.17	7.97
MnO	0.09	0.02	0.02	0.04	0.07	0.15	0.17	0.29	0.08	0.02	0.03	0.04	0.03	0.04	0.03	0.07	0.16	0.15	0.17	0.16	0.07	0.14
MgO	0.89	0.64	0.99	0.92	0.82	3.87	4.61	3.56	1.27	2.19	1.89	1.4	1.35	0.98	1.58	0.2	4.39	3.93	4.72	4.36	1.06	2.26
CaO	4.06	1.58	0.32	2.16	3.52	7.26	8.79	11.62	3.43	4.41	2.54	3.02	4.36	0.67	1.2	1.18	5.5	7.94	3.81	6.92	2.88	6.95
Na_2O	1.36	0.92	0.17	1.92	3.42	2.36	1.34	0.96	3.16	3.84	3.39	1.74	2.19	0.09	2.36	3.26	3.13	2.28	0.9	3.85	6.42	2.71
K_2O	1.7	2.46	6.57	3.05	3.21	2.05	1.96	1.73	1.94	3.49	6.02	2.6	5.19	5.42	4	5.47	1.55	2.06	5.61	0.58	2.29	1.65
P_2O_5	0.09	0.12	0.1	0.12	0.25	0.21	0.27	0.27	0.11	0.1	0.12	0.09	0.22	0.15	0.13	0.05	0.22	0.24	0.24	0.25	0.25	0.24
LOI	2.96	1.51	2.65	0.61	1.23	2.88	2	2.06	1.03	0.22	0.44	1.3	0.62	2.5	1.29	0.21	1.92	1.46	1.91	1.82	0.9	0.88
Total	99.04	99.05	99.63	99.1	100.27	100.41	100.12	100.01	99.06	100.19	99.75	99.86	99.75	99.38	99.24	99.69	100.14	100.27	99.77	99.82	99.99	100.2
Cr	52	34	67	60	24	29	27	31	40	63	130	29	56	25	4	9	34	31	5	34	16	22
Ni	7	7	23	12	7	13	11	10	12	16	22	9	5	0	0	6	11	16	8	10	13	10
Co	8	6	13	7	11	23	17	22	10	11	14	12	10	5	3	4	21	25	10	30	6	20
Sc	3	2	3	1	0	0	0	0	1	0	0	1	1	3	1	3	0	0	0	0	0	0
V	49	56	101	63	0	147	0	0	119	50	90	68	120	45	24	13	0	0	0	0	0	0
Cu	0	10	5	35	15	7	1	7	49	0	2	21	48	13	0	7	40	1	2	1	1	1
Pb	11	9	8	13	30	18	12	15	20	12	31	13	32	5	16	22	12	7	26	10	19	8
Zn	37	40	65	45	27	123	77	104	58	31	70	47	42	44	90	32	105	76	73	90	37	77
Sn	0	0	2	2	0	1	0	0	0	2	3	0	0	3	3	3	0	0	0	0	0	0
W	6	9	7	3	3	2	4	3	0	0	0	0	26	16	4	0	7	2	3	3	3	3
Mo	1	1	1	1	3	0	1	1	1	1	1	12	3	1	0	1	7	2	4	1	1	1
S	101	178	0	70	221	0	47	127	229	47	76	1920	251	146	15	177	156	42	298	51	55	68
Rb	62	94	240	134	158	108	80	71	115	116	249	152	178	307	215	3	78	87	227	32	125	65
Ba	539	638	1054	978	789	447	457	490	494	465	626	244	1208	633	1045	197	483	458	896	261	278	371
Sr	219	154	66	306	663	515	621	500	328	248	201	121	471	58	305	398	608	323	420	745	381	585
Ga	9	11	24	12	16	17	17	19	16	12	19	12	15	17	14	143	17	16	17	20	14	17
Nb	9	10	16	12	13	8	8	8	12	13	15	10	11	13	14	16	10	7	16	7	10	8
Zr	288	326	191	291	202	173	147	160	286	272	198	228	185	191	156	17	155	147	208	133	167	154
Y	22	23	31	26	28	29	32	31	27	23	33	20	26	23	80	138	35	28	37	34	36	31
Th	8	10	16	11	18	6	2	12	13	14	16	11	15	19	29	51	8	8	23	4	16	6
U	2	2	3	3	6	0	2	2	3	3	3	2	4	3	5	29	3	2	6	1	5	2
La	36	29	38	30	35	18	20	14	36	33	43	34	30	39	42	4	29	14	45	17	17	27
Ce	49	44	73	54	60	42	39	53	68	48	68	51	44	59	60	39	60	52	88	26	47	38
Nd	21	21	33	27	0	33	0	0	26	22	35	26	23	25	28	76	0	0	0	0	0	0

Major and trace elements by XRF at the University of Leicester, U.K. (Loss on ignition (LOI) at 1000°C, Fe as total Fe_2O_3). Analyst: N.G. Marsh