

Field relation, petrochemistry and classification of the volcanic rocks from the eastern part of Tioman Island, Pahang

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Abstract: The volcanic rocks from eastern part of the Tioman Island can be divided into volcanic lava and pyroclastic types. Geochemically volcanic lavas can be classified as andesite, dacite and rhyolite. The proportion of quartz, K-feldspar and plagioclase of the three rock types are: rhyolite (Quartz: 60–65%, K-feldspar: 10–15%, Plagioclase: 10–15%), dacite (Quartz: 40–50%, K-feldspar: 25–30%, Plagioclase: 15–25%) and andesite (Quartz + K-feldspar: 15–25%, Plagioclase: 55–65%). Both rhyolite and dacite may have a common origin. On the other hand, the andesite samples show a slight concave upward REE pattern which may be the result of minerals such as garnet, clinopyroxene and amphibole having remained residual in their source. The presence of garnet constraints the mafic source to be within the lower crust (deeper than 25 km) or upper mantle.

Abstract: Batuan vulkanik dari bahagian timur Pulau Tioman boleh dibahagikan kepada jenis lava dan piroklastik. Secara geokimia lava vulkanik boleh dibahagikan kepada andesit, dacit dan riolit. Nisbah kuarza, K-feldspar dan plagioklas untuk tiga jenis batuan ialah: riolit (Kuarza: 60–65%, K-feldspar: 10–15%, Plagioklas: 10–15%), dacit (Kuarza: 40–50%, K-feldspar: 25–30%, Plagioklas: 15–25%) dan andesit (Kuarza + K-feldspar: 15–25%, Plagioklas: 55–65%). Kedua-dua riolit dan dacit mungkin berasal dari magma yang sama. Tetapi andesit menunjukkan corak plotan unsur nadir bumi yang mencadangkan mineral-mineral seperti garnet, klinopiroksin dan amfibol tertinggal dalam batuan puncanya. Kehadiran garnet mencadangkan punca mafik terletak di dalam kerak bawah (kedalaman lebih dari 25 km) atau mantel atas.

INTRODUCTION

Volcanic lavas and pyroclastics are volumetrically important in southeastern Johore. Two types of volcanic rocks that occur abundantly in this part of Peninsular Malaysia are felsic lavas and pyroclastic rocks. Tioman Island is the largest of all islands off the east coast of west Malaysia and ranks next in size to Langkawi Island and Pinang Island, the two largest ones on the west coast. The island is the most northerly of a chain of three islands, the other two to the southeast, being Pemanggil and Aur islands. The geology of the island has been described briefly by Scrivenor in his book *'The Geology of Malaya'* published in 1931. More detailed work on the geology of Pulau Tioman was given by Bean (1972). Later in 1974 Khoo published several short articles related to geomorphology and geology of the Tioman area.

TECTONIC SETTING

Tioman Island is underlain by igneous and metamorphic rocks (such as metavolcanics) (Bean, 1972; Khoo, 1974) (Fig. 1). The igneous rocks in the island consist of gabbro, diorite and granite, felsic volcanic and pyroclastic rocks. A granite sample from the Tioman Island was found to give a K-Ar age of 74 ± 2 Ma (Bignell and Snelling, 1972)

which may suggest that the rock is no younger than Late Cretaceous. Bean (1972) also showed that the host rocks (including volcanics) in the area are probably of Triassic age. Published geological map of Tioman Island by Bean (1972) shows that the granitic rocks in the island are of Jurassic age.

FIELD OCCURRENCE

Pyroclastic rocks

Rocks of volcanic origin of pyroclastics and interbedded flows, occupy an area of 20 km² in a narrow belt around the north, east and southeast coast of Tioman Island. Pyroclastic rocks exhibit a broad variation in both colour and texture. The main pyroclastic type is agglomerate containing various types of blocks up to 0.5 m in diameter (Figs. 2 and 3). The blocks sometimes flattened due to the magmatic movement (Fig. 4). Traces of flow structure can be recognized particularly around crystals or lithic fragments.

Volcanic lava and its relationship with the granitic rocks: Field description from Tanjung Beruntum

The volcanic lavas are fine grained dark coloured rocks and do not contain any enclaves. The contacts between

the volcanic and granitic rocks are well exposed at Tanjung Beruntum (Azman and Anuar, 2001). The area is a small coastal outcrop exposed at the middle of Pasir Panjang beach. This area is dominated by felsic volcanics intruded by granitic veins and dykes. The volcanic rocks are fine grained and darker than the granitic rocks (Fig. 5). The granitic rocks enclosed various sizes of angular volcanic enclaves (10 cm–0.5 m) (Figs. 6, 7). The volcanic blocks are distributed in a random manner throughout the granitic host. Contacts between the volcanic enclaves and their granitic host are frequently sharp.

In extreme cases felsic volcanics form a banded structure in the granitic rock (Fig. 8). The width of the felsic volcanic bands ranges from 10 to 15 cm and can be up to 1 m long. In extreme cases the volcanic bands form a “schlieren like” structure in the granitic rock. It clearly

indicates that the volcanic magma has stretched their shape into thin narrow wisps in the granitic magma. This relationship shows that the granitic magma was injected into the consolidating volcanic host. The granite magma may have partially crystallised when intruding into the volcanic magma. This is evident from the porphyritic nature of the lobe (Fig. 8).

PETROLOGY AND GEOCHEMISTRY

Nomenclature

For classification purposes, the Tioman volcanics have been classified using total alkali ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) vs SiO_2 (Fig. 9) (Le Maitre *et al.*, 1989). This classification is superior compared to classification based on modal

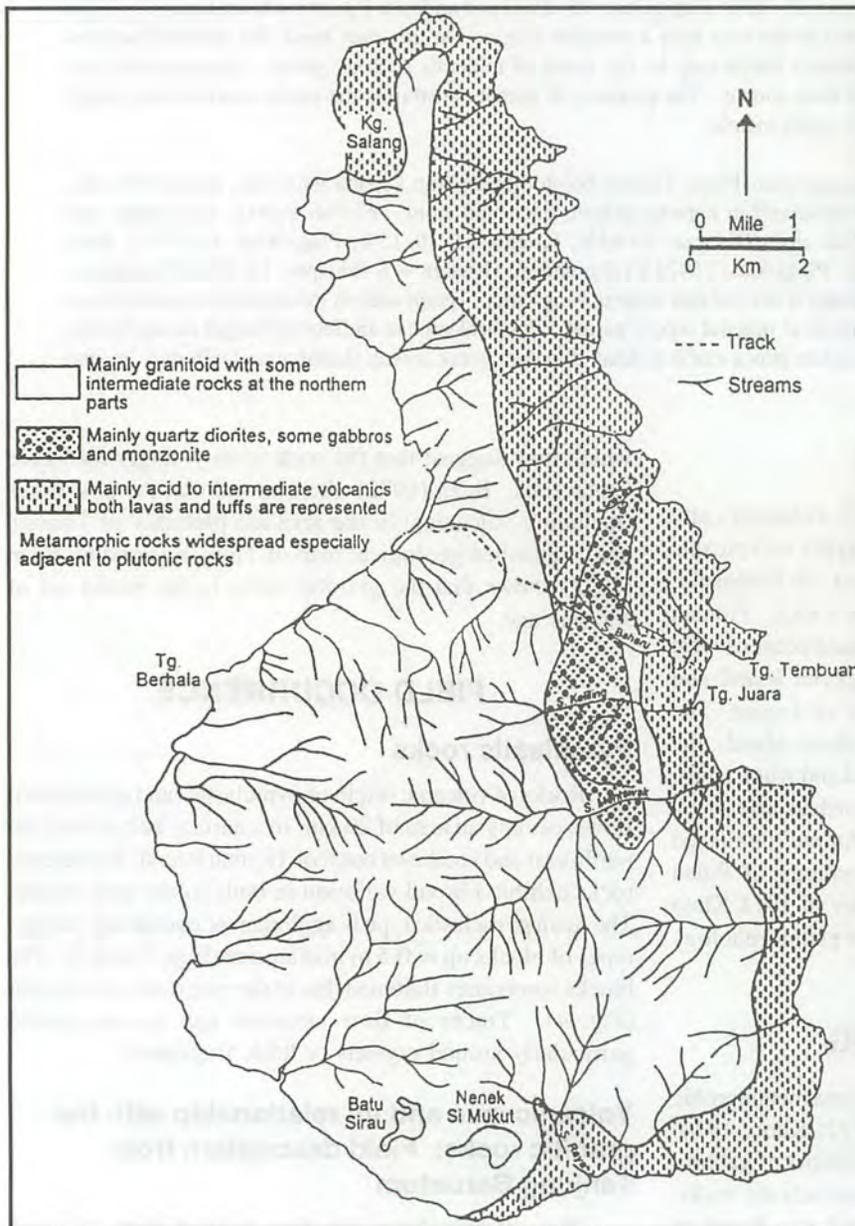


Figure 1. Geological map of the Tioman Island, Pahang.



Figure 2. The main pyroclastic type is agglomerate containing various types of block up to 0.5 m in diameter. North of Pantai Juara.



Figure 3. Angular andesitic block in the granitic host. North of Pantai Juara.



Figure 4. The blocks are sometimes flattened due to the magmatic movement. North of Pantai Juara.

composition, as a portion of the rocks are composed of fine-grained material. In this diagram, the volcanic rocks from Tioman Island can be divided into three types namely rhyolite, dacite and andesite. The andesite straddle between four fields i.e. basalt trachy-andesite, basaltic-andesite, trachy-andesite and andesite. Nearly 90% of the volcanic rocks occurring in the Tioman Island are dacite and rhyolite and it is difficult to differentiate between these two rocks in the field. Andesite is more identifiable in the field because it contains euhedral lath shaped plagioclase as the main phenocrystic phase.

Petrography

In general, all the three rock types are hypocrystalline and porphyritic. They consist of various types of phenocrysts, embedded in quartz-feldspar microcrystalline to cryptocrystalline and occasionally devitrified groundmass. The groundmass consists of fine grained matrix of quartz, feldspar, mica and glassy material. The proportion of quartz, K-feldspar and plagioclase of the three rock types are: rhyolite (Quartz: 60–65%, K-feldspar: 10–15%, Plagioclase: 10–15%), dacite (Quartz: 40–50%, K-feldspar: 25–30%, Plagioclase: 15–25%) and andesite (Quartz + K-feldspar: 15–25%, Plagioclase: 55–65%). Biotite is the main mafic phase in the rhyolite and dacite whereas hornblende is dominant in andesite. Texturally both dacite and rhyolite are indistinguishable in the field.

Both are fine grained and black to green black in colour sometimes showing porphyritic texture. The main textural difference between dacite/ rhyolite and andesite is that the later always have porphyritic or glomeroporphyritic textures with plagioclase as the main phenocryst phase.

Geochemistry

24 samples of the volcanic rocks were analysed for major elements and 15 of these samples were analysed for trace elements (Table 1). Four samples, two rhyolite and one each of andesite and dacite were analysed for their Rare Earth Element (REE) content (Table 2). Harker diagrams for the selected major and trace elements are given in Figure 10. The range of SiO_2 for each rock type is: rhyolite (71.03–77.28), dacite (63.04–68.98), and andesite (54.76–58.35). The SiO_2 content shows some overlap between trachyte and dacite but a distinct composition field for both rhyolite and andesite. Harker diagrams show that the TiO_2 , Al_2O_3 , $\text{Fe}(\text{tot})$, MgO and Na_2O decrease in concentration with increasing SiO_2 . However, in detail, the andesite particularly shows somewhat different behaviour with SiO_2 compared to the rest of the rock types. Thus the MgO and Na_2O in andesite increase with SiO_2 in contrast to the general trend. The andesite also has high large ion lithophile elements (Ba and Sr) and total alkali ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) compared to the other volcanic rocks.



Figure 5. Photograph showing a contact between granitic and volcanic rocks at Tanjung Beruntum.



Figure 6. Photograph showing a various shapes and sizes of volcanic blocks (black) in the granitic rocks at Tanjung Beruntum.

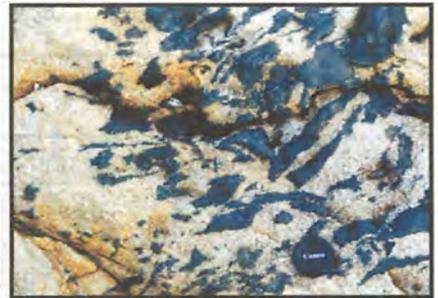


Figure 7. Photograph showing a various shapes and sizes of volcanic blocks (black) in the granitic rocks at Tanjung Beruntum.



Figure 8. Banded structure in the granitic rock resulting from "drawn out" of the volcanic blocks in the granitic magmas at south of Pantai Juara.

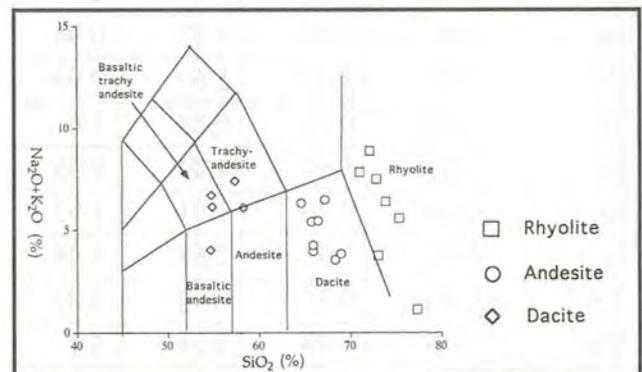


Figure 9. TAS Diagram diagram of the volcanic rocks from Tioman Island.

Table 1. Representative chemical composition of major and trace elements for the volcanic rocks from the eastern part of Tioman Island.

Rock Type Sample N	Riolit TB21	Riolit TS34	Riolit TT1	Riolit TT17	Riolit TM1	Riolit TS35	Dasit PM1	Dasit TD1	Dasit TB26	Dasit TR6	Andesit TR7	Andesit TB25A	Andesit TT2
Major element in wt%													
SiO ₂	72.11	75.38	77.28	73.92	73.07	71.03	65.72	64.65	68.36	67.26	58.35	54.87	54.76
TiO ₂	0.25	0.39	0.22	0.2	0.49	0.33	0.65	0.68	0.28	0.73	1.2	1.3	1.67
Al ₂ O ₃	14.73	12.81	11.49	14.31	13.16	15.18	19.31	17.07	14.21	17.42	17.01	18.99	19
Fe(tot)	1.83	2.53	4.07	2.6	4.54	2.06	4.47	5.68	5.14	3.85	7.03	9.48	11.4
MnO	0.04	0.06	0.23	0.04	0.14	0.06	0.11	0.1	0.24	0.09	0.1	0.19	0.25
CaO	1.68	2.06	5.26	1.8	3.17	1.96	1.77	2.87	5.94	2.85	6.05	6.06	7.82
K ₂ O	7.45	3.57	0.24	3.96	0.98	5.96	3.6	3.27	2.36	2.82	2.83	3	0.98
P ₂ O ₅	0.05	0.09	0.04	0.05	0.11	0.08	0.04	0.25	0.05	0.2	0.78	0.48	0.7
MgO	0.69	0.45	0.26	0.21	0.8	0.41	1.15	1.14	1.52	0.49	2.9	2.26	2.06
Na ₂ O	1.43	2	0.86	2.43	2.76	1.9	1.81	3.05	1.18	3.68	3.25	3.1	3
LOI	0.63	0.52	1.38	0.82	0.74	0.65	0.99	0.96	0.73	0.8	0.5	0.7	0.41
Total	100.89	99.86	101.33	100.34	99.96	99.62	99.62	99.72	100.01	100.19	100	100.43	102.05
Trace element in ppm													
Ba	208	291	120	484	1347	473	701	744	134	400	976	649	1013
Ce	88	64	15	156	443	116	223	251	22	116	365	190	312
La	46	47	36	26	25	18	31	43	49	37	40	39	23
Nb	82	79	81	73	78	77	80	82	81	83	82	81	82
Ni	3	2	2	3	12	4	21	2	4	5	30	2	2
Pb	6	17	18	17	20	53	26	19	0	21	5	0	0
Rb	211	123	6	104	38	158	163	111	73	113	58	129	26
Sr	217	315	301	127	259	415	1012	316	283	316	1595	316	791
Th	173	163	107	130	94	139	131	72	103	116	73	0	0
V	22	40	15	15	74	33	68	53	28	58	126	132	179
Y	83	57	58	28	22	41	55	41	68	46	9	35	29
Zr	376	313	309	124	153	272	269	288	349	249	304	172	196
Zn	10	56	142	42	150	81	62	101	155	87	60	83	158
Cr	116	108	101	215	155	82	173	85	126	129	101	65	77
As	15	10	18	20	10	20	8	13	12	5	23	8	8
Cu	12	18	16	19	27	24	18	36	8	17	7	6	3
Ga	22	19	17	21	16	19	21	19	19	21	20	19	17
Hf	10	8	8	7	5	9	9	9	10	7	11	7	7
Co	2	1	7	13	23	0	9	13	14	2	16	30	27

Table 2. REE analyses of the volcanic rocks from the eastern part Tioman Island.

Rock Type	Rhyolite	Andesite	Rhyolite	Dacite
Sample no	TS35	TR7	TT17	TB26
La	25.07	54.57	39.22	40.45
Ce	48.55	113.6	67.63	85.2
Pr	4.98	11.08	7.16	9.1
Nd	20.22	47.64	28.66	38.65
Sm	3.48	7.59	5.51	8.74
Eu	0.85	2.28	1.12	0.94
Gd	3.77	5.67	5.6	9.94
Tb	0.54	0.71	0.88	1.6
Dy	3.32	3.59	4.84	9.36
Ho	0.66	0.76	1.01	1.93
Er	1.97	1.92	2.68	5.46
Tm	0.31	0.25	0.42	0.82
Yb	2.18	1.49	3.04	5.7
Lu	0.37	0.24	0.51	1
Y	17.32	16.13	25.13	49.32

The REE data for a andesite, dacite and rhyolite is given in Table 2. The rhyolite has low total REE (133–193) contents compared to the andesite (267) and dacite (268). All samples are generally enriched in light rare earth elements (LREE) and depleted in heavy rare earth elements (HREE) (Fig. 11). The plot shows that the rhyolite and dacite samples, especially the most felsic ones are characterized by high HREE compared to those from the andesite sample. The overall abundance of REE shows a systematic decrease with SiO₂, implying the profile is controlled by fractionation of REE rich accessory phases (allanite, apatite, sphene and/or zircon). All the profiles except andesite has Eu anomaly, which suggests the importance of plagioclase fractionation. The dacitic sample has the most prominent Eu anomaly. The absence of Eu anomaly in the andesitic rock indicates the plagioclase fractionation is not a necessary requirement in the development of this andesitic intrusion (Liggett, 1990). Furthermore, the slight concave upward anomaly shown by the andesite sample may be the result of minerals such as garnet, clinopyroxene and amphibole having remained residual in their source (Williamson *et al.*, 1992).

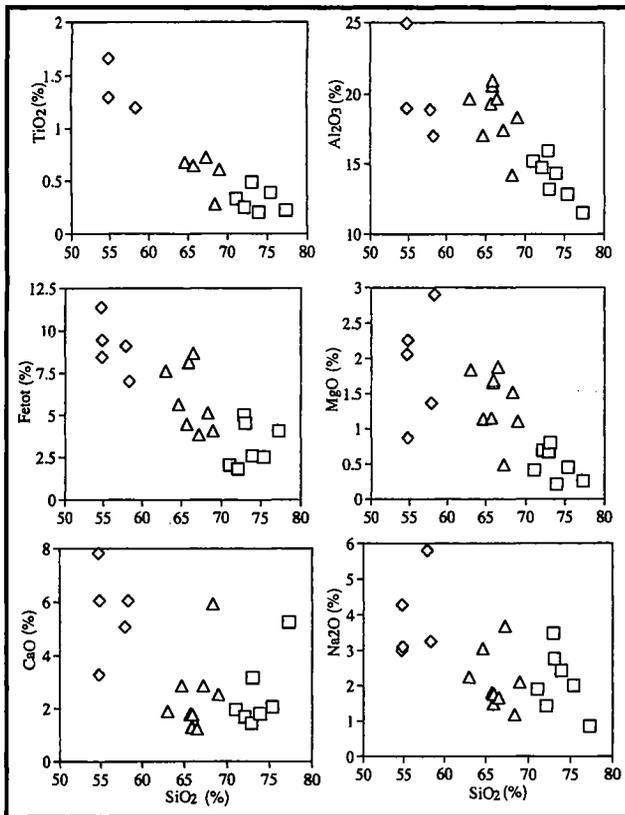


Figure 10. Major Harker diagrams of the volcanic rock from Tioman Island. Symbols as in Figure 9.

CONCLUDING REMARKS

Based on the geochemical analyses three types of volcanic rocks were identified in the eastern part of the Tioman Island: namely rhyolite, dacite and andesite. Nearly 90% of the volcanic rocks occur in the Tioman Island is dacite and rhyolite and it is difficult to differentiate between these two rocks in the field. Andesite is more identifiable in the field because it contains euhedral lath shape plagioclase as the main phenocrystic phase. The range of SiO_2 for each rock type is as follows: rhyolite (71.03–77.28), dacite (63.04–68.98), and andesite (54.76–58.35). REE data suggest that both rhyolite and dacite may have a common origin. On the other hand, the andesite samples show a slight concave upward REE pattern which may be the result of minerals such as garnet, clinopyroxene and amphibole having remained residual in their source. The presence of garnet constrains the mafic source to be within the lower crust (deeper than 25 km) or upper mantle

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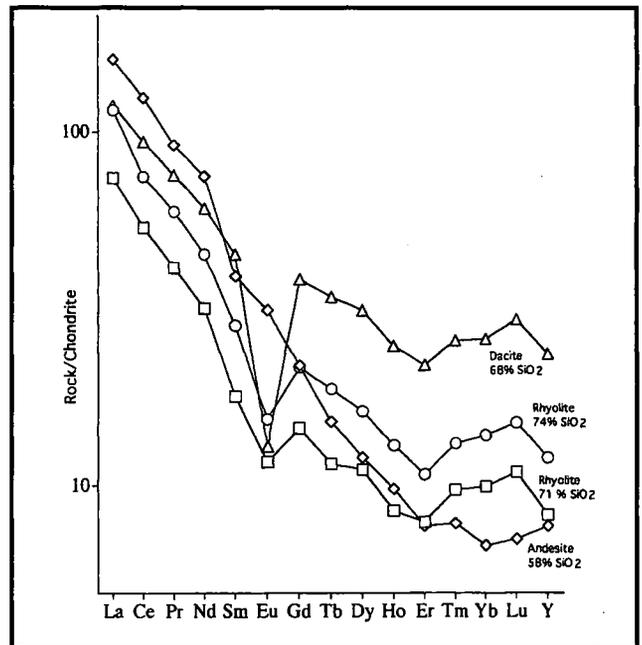


Figure 11. REE profile for the volcanic rock from Tioman Island. Chondrite values used in normalizing REE are taken from Wakita *et al.* (1971).

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