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Geochemistry of the Main rock forming minerals in the Perhentian Kecil Syenite, Besut, Terengganu

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ABSTRACT The Perhentian Kecil Syenite consists of variety of igneous rocks ranging in composition from syenitic to monzonitic and even gabbroic rocks. The essential minerals in Perhentian Kecil Syenite are K-feldspar, plagioclase, hornblende, pyroxene, quartz, biotite, sphene, epidote, apatite, zircon and magnetite. Composition of K-feldspar in Perhentian Kecil Syenite is near to pure orthoclase with An percentage less than 1%. Plagioclase composition range from oligoclase to andesine. Magnesio-hornblende is the main amphibole type and the crystals show an increase of TiO_2 and Al^{iv} and decrease in CaO from core to rim. The deduced magmatic crystallisation interval for the hornblende is in the range of 660 to 780 ^{o}C (± 70^{o}C). Composition of the sphene plot in igneous sphene field and is similar to those from the Victoria Range granitic rocks, South Island, New Zealand. Apatite can be divided into clear and clouded parts and the latter contain higher SiO_2, K_2O, Fe(tot) and BaO. Both CaO and P_2O_5 have a wider range in the clouded part compared to the clear part of apatite. Magnetite is the most common opaque mineral in the Perhentian Kecil Syenite.

ABSTRAK Syenit Perhentian Kecil terdiri dari berbagai batuan igneus berjulat dari syenit, monzonit dan gabro. Mineral utama yang terdapat dalam batuan Syenit Perhentian Kecil ialah K-feldspar, plagioklas, hornblend, piroksin, kuarza, biotit, sfen, epidot, apatit, zirkon and magnetit. Komposisi K-feldspar adalah menghampiri orthoklas tulin dengan peratusan An kurang dari 1%.Komposisi plagioklas pula menjulat dari oligoklas ke andesine. Jenis hornblend yang utama ialah magnesio-hornblende dan hablur-hablurnya menunjukkan kenaikan $TiO_2$and Al^{iv} dan penurunan CaO dari bahagian tengah ke bahagian tepi. Suhu penghabluran magmatik untuk hornblend ialah dari 660 ke 780°C (± 70°C). Sfen pula diplotkan didalam kawasan sfen igneus menyamai sfen yang terdapat di dalam batuan granitik Banjaran Victoria, New Zealand. Apatit pula boleh dibahagikan kepada apatit jernih dan berawan yang mana apatit berawan mengandungi lebih SiO_2, K_2O, Fe(tot) dan BaO. Jenis fasa opak yang utama ialah magnetit

(geochemistry, rock forming mineral, Syenite, Perhentian Island, Feldspar Alkali)

INTRODUCTION

The Perhentian Kecil Syenite forms a circular outcrop at the central part of Perhentian Kecil Island (Figure 1). Although the map indicates that it appears to intrude the surrounding granitic body, field evidence shows that the Perhentian granite is relatively younger than the Perhentian Kecil syenite. The pluton consists of a variety of igneous rocks ranging in composition from syenitic to monzonitic and even gabbroic rocks. The monzonitic rocks can be found at Tanjung Batu Nisan about 10 m from the contact between Perhentian Kecil Syenite and Perhentian granite. In terms of percentage the syenitic rocks encompasses almost 90% of the pluton. Epidote nodules and veins (thickness from 2 to 5 cm) can be seen throughout the pluton. The gabbroic rocks are found as boulders mainly at Kampung Pasir Hantu and Pasir Patani and they usually contain hornblende as a main mafic phase. The mineralogy of this rock is similar to appinitic rocks described elsewhere [1], [2].

Various types of structures can be found in the Perhentian Kecil syenite such as synplutonic dykes, hornblende rich enclaves and amphibolite blocks. The synplutonic dykes were found at Tanjung Batu Sireh and Tanjung Batu Peti. They usually show amphibolitic mineralogy suggesting a basic origin. They are also disrupted into several parts or sometimes necked along its length, which suggest that the dykes were intruded during the semi-solid state of the

Perhentian Kecil syenite magma. Hornblende-rich enclaves are invariably finer grained and darker coloured than their syenitic host. The enclaves were found at Teluk Aur and Tanjung Batu Peti. They usually show a sharp contact with their host. The enclave consists of hornblende, plagioclase, opaque phase, sphene and K-feldspar with size up to 30 cm across. The amphibolite blocks are found in Pasir Patani and Pasir Keranji. The blocks are larger than the hornblende rich enclaves and show a typical amphibolitic texture. The rock is usually medium grained equigranular and consists of acicular shaped amphibole crystals (up to 2 mm long).

The contacts between Perhentian Kecil syenite and Perhentian granite are sharp and can be found at Pasir Karang, Pasir Patani, Tanjung Batu Nisan and along Tanjung Batu Peti to Tanjung Sireh. The relationship of the contacts suggests that the Perhentian granite is younger than Perhentian Kecil syenite. Evidence supporting the younger age of the Perhentian granite are listed below [3]:

1. occurrence of a syenitic blocks in the granitic rock,
2. cross cutting relation of the contact between the rocks,
3. offshoot of microgranite vein from granite to syenite,
4. occurrence of microgranite and porphyritic rocks in the Perhentian granite at the contact, which suggests that the granitic magma quickly chilled against cooled syenitic rocks.

The Perhentian Kecil Syenite is characterised by the rocks with SiO_2 from 46.8 to 65.9% and can be classified as 'I' type [4]. The rocks are metaluminous with the ACNK value of 0.63 - 0.97. They also have high Ba and Sr values and total REE content (224-450 ppm) compared to other Eastern Belt igneous rocks. This suggests that the syenitic magma was formed by hydrous melting of lower crust probably as a result of underplating by, or intrusion of mantle derived basaltic magmas [5]. The strong enrichment of large ion lithophile elements (Sr and Ba) is probably related to transfer of enriched (hydrous?) fluids from the mantle into the lower crust, and possibly initiated melting to form the syenites [5]. The aim of this paper is to present the petrography and geochemistry some of the major and accessory mineral phases of the Perhentian Kecil Syenite.

PETROGRAPHY

The essential minerals in Perhentian Kecil syenite are K-feldspar, plagioclase, hornblende, pyroxene, quartz, biotite, sphene, epidote, apatite, zircon and magnetite. Large alkali feldspars, up to 3 cm across often give the rock a distinctly porphyritic appearance in hand specimen. It is subhedral to anhedral and sometimes highly sericitised. Plagioclase is subhedral to anhedral and ranges in size between 1 to 2 mm across. It usually shows albite, carlsbad-albite and pericline twinning.

Biotite is subhedral to anhedral and occurs as elongate crystals or aggregates associated with hornblende and sphene. Hornblende is euhedral to anhedral. The most common pleochroic scheme is X = light yellowish green, Y = Z = dark green. It sometimes poikilitically encloses K- feldspar, apatite, sphene, zircon and anhedral quartz crystals. Prehnite is lens shaped or interleave in biotite crystals and sometimes occurs as radiating crystals in the biotite. The long axis of the lens is parallel to the biotite cleavage. It is colourless in thin section and shows characteristic wavy extincion and sometimes show well developed cleavage. The cleavage appears to branch outwards from the middle of the lens, usually known as 'bow tie' texture.

Euhedral to subhedral sphene is the most common accessory mineral and is preferentially associated with hornblende and biotite or as individual crystals. It is sometimes cracked probably as a result of thermal shock during magma ascent. Apatite occurs as inclusions in hornblende, biotite, plagioclase, quartz and microcline. It occurs in two habits i.e small prismatic to acicular crystals and euhedral to anhedral squat shaped crystals. The apatite crystal commonly has clouded core. Epidote is greenish yellow and occurs as anhedral crystals. It occurs in veins, as inclusions in biotite and in the sericitised parts of plagioclase.

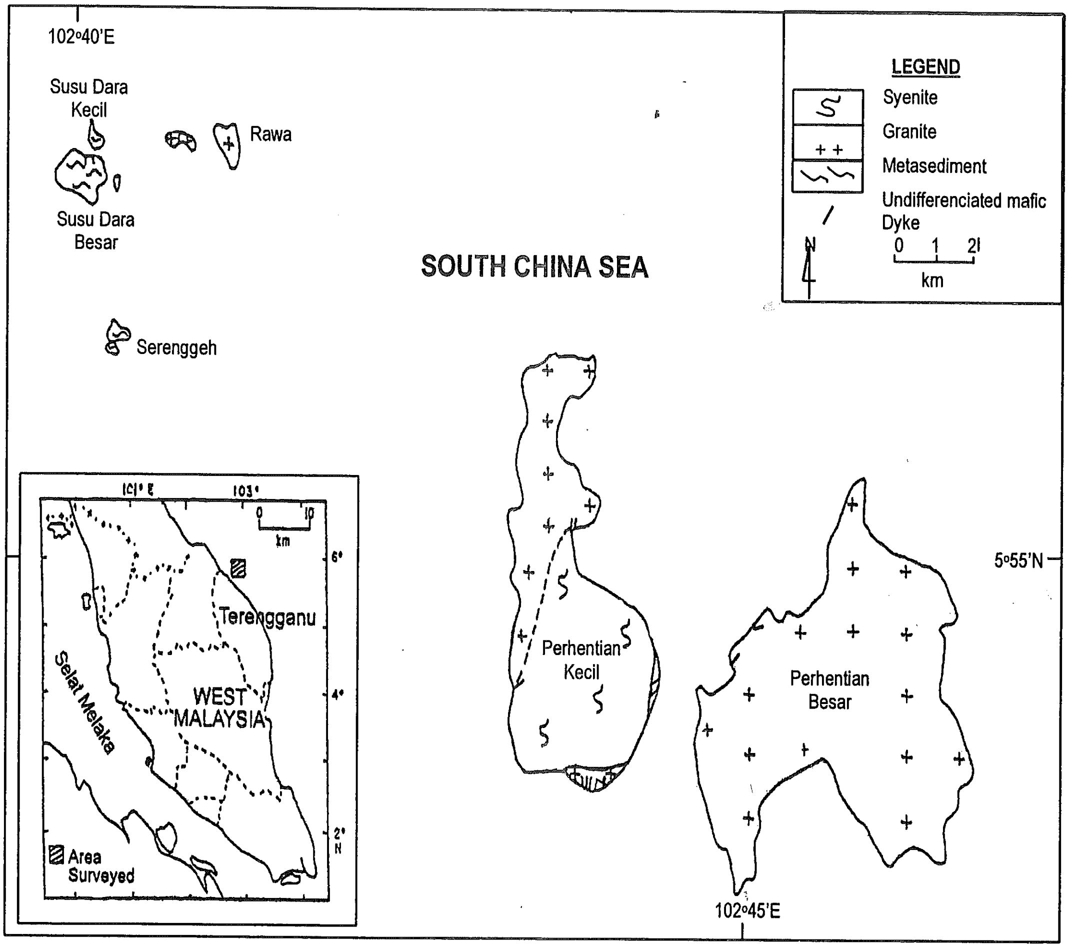

Figure 1. Geological map of Perhentian island and surrounding area

MINERAL CHEMISTRY

Analytical procedure

The composition of the plagioclase, K-feldspar, hornblende, apatite and sphene have been determine using an electron microprobe located at the University of Manchester. All samples used were highly polished thin section coated with 20 nm carbon film. The instrument (modified Cambridge Geoscan) was operated under the following conditions: 3 nA specimen current on cobalt metal with count time of 40 liveseconds.

Plagioclase and K-feldspar

The elemental content of plagioclase and K-feldspar in the Perhentian Kecil Syenite is given in (Table 1). The K-feldspar and plagioclase data are plotted on an An-Ab-Or diagram (Figure 2). The K-feldspar has very low An content (0.44 to 0.86%), and plot very near to the Or apex. This suggests that the composition of K-feldspar is nearly pure orthoclase. It also has higher large ion lithophile element content compared to the co-existing plagioclase. Thus the barium content in the K feldspar ranged from 0.5 to 0.63% compared to plagioclase which only recorded the highest value of 0.15% Ba. In terms of geochemical analyses, the plagioclase can be classified as oligoclase to andesine ($An_{27.2-37.3}$).

Table 1. Analytical results of K feldspar and Plagioclase from the Perhentian Kecil Syenite. Note: Samples 12 and 34: K-feldspar ; others are plagioclase.

Sample No.	20	21	22	29	36	37	38	39	40	41	12	34
Locations	Rim	Rim	Core	Rim	Rim	Core	Rim	Core	Rim	Half		
SiO_2	59.74	60.10	58.97	59.95	60.06	59.19	58.53	59.27	60.55	60.68	64.58	63.52
TiO_2	0.00	0.00	0.00	0.08	0.00	0.05	0.00	0.10	0.00	0.04	0.05	0.00
Cr_2O_3	0.00	0.14	0.02	0.00	0.53	0.16	0.11	0.00	0.03	0.07	0.07	0.08
Al_2O_3	24.66	24.96	25.49	24.88	24.64	24.74	24.77	25.32	23.71	23.65	18.18	17.88
FeO	0.17	0.09	0.25	0.36	0.33	0.22	0.29	0.41	0.17	0.20	0.14	0.06
MnO	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na_2O	7.49	7.48	6.87	7.30	7.99	7.26	7.25	7.75	8.02	8.08	0.59	0.62
K_2O	0.39	0.93	0.39	0.27	0.30	0.17	0.26	0.37	0.21	0.28	15.53	15.35
CaO	6.85	6.66	7.76	7.17	6.45	7.30	7.06	5.84	5.94	5.72	0.17	0.09
P_2O_5	0.00	0.06	0.05	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.25	0.00
BaO	0.00	0.15	0.01	0.01	0.12	0.03	0.00	0.04	0.01	0.11	0.50	0.63
Total	**99.28**	**100.01**	**99.84**	**100.01**	**100.42**	**99.16**	**98.27**	**99.18**	**98.62**	**98.84**	**100.07**	**98.24**
Structural formula on the basis of 8 Oxygen												
Si	2.69	2.68	2.65	2.67	2.69	2.67	2.67	2.67	2.74	2.74	2.99	3.00
Al	1.31	1.31	1.35	1.33	1.30	1.32	1.33	1.34	1.26	1.26	0.99	1.00
Fe	0.00	0.00	0.00	0.13	0.01	0.00	0.01	0.02	0.00	0.00	0.01	0.00
Na	0.65	0.65	0.60	0.64	0.69	0.64	0.64	0.68	0.70	0.71	0.05	0.06
K	0.02	0.02	0.02	0.02	0.14	0.01	0.02	0.02	0.01	0.02	0.92	0.93
Ca	0.33	0.32	0.37	0.35	0.31	0.35	0.34	0.28	0.29	0.28	0.01	0.00
Total	**5.00**	**4.98**	**4.99**	**5.14**	**5.14**	**4.99**	**5.01**	**5.01**	**5.00**	**5.01**	**4.97**	**4.99**
(Ca+Na+K)	1.00	0.99	0.99	1.00	1.14	1.00	1.00	0.98	1.00	1.01	0.98	0.99
%An	32.90	32.30	37.30	34.70	27.20	35.00	34.20	28.60	28.80	27.80	0.86	0.44

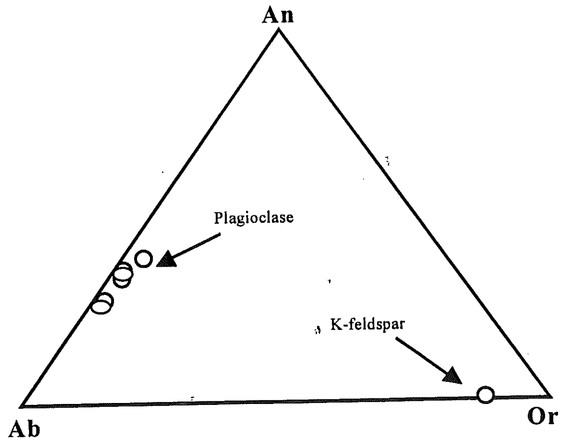

Figure 2. An-Ab-Or diagram for plagioclase and K-feldspar from Perhentian Kecil Syenite

Hornblende

The elemental content of hornblende are given in (Table 2). A plot of Mg/(Mg+Fe_{tot}) vs Si [6], [7] shows that, the main type of hornblende found in the Perhentian Kecil syenite are magnesio-hornblende and some are ferro- hornblende and actin- hornblende (Figure 3). The hornblende show an increase of TiO_2 and Al^{iv} and decrease in CaO from core to rim. Contents of other elements are typically: 14.73 to 19.35 % Fetot, 10.6 to 12.3 % CaO and 0.22 to 1.21 % K_2O. The thermal stability of the amphiboles from the Perhentian Kecil Syenite was estimated in a plot of the T-sensitive cations Ti and Al^{4+} [8] (Figure 4). The largely empirical T scale is based on the correlation of Al^{4+} vs Ti [9], which is largely independent of pressure [10]. Generally, there is a positive correlation of Ti and Al^{4+} cations with temperature. The deduced magmatic crystallisation interval for the hornblende is in the range of 660 to 780 ^{o}C (± $70^{o}C$).

Table 2. Analytical results of hornblende from the Perhentian Kecil Syenite

Sample No.	1	2	7	8	11	12	13	14	15	18	19	30	31
Locations	Core	Rim	Core	Rim	Core	Rim	Core	Half	Rim	Core	Rim	Core	Rim
SiO_2	42.39	44.87	44.43	44.69	45.01	51.99	45.64	47.27	46.17	45.67	48.71	44.56	44.02
TiO_2	1.10	0.95	1.09	0.80	1.08	0.00	0.88	0.70	0.58	0.64	0.46	1.06	1.33
Cr_2O_3	0.00	0.20	0.00	0.07	0.08	0.00	0.06	0.04	0.10	0.00	0.12	0.00	0.05
Al_2O_3	8.93	7.65	7.68	7.81	7.99	2.77	7.43	0.46	7.39	7.22	5.55	8.01	8.03
FeO	16.93	16.73	15.34	17.71	15.68	14.96	17.32	14.83	16.09	15.39	14.73	16.24	16.27
MnO	0.00	0.08	0.06	0.00	0.00	0.00	0.00	0.06	0.00	0.20	0.00	0.00	0.00
MgO	11.93	11.92	12.22	10.95	12.29	14.34	12.20	13.30	12.54	13.07	14.03	12.16	11.87
Na_2O	1.85	2.06	2.05	1.78	1.89	0.94	1.58	1.74	1.69	2.00	1.46	2.11	1.86
K_2O	1.17	1.20	1.19	1.11	1.20	0.22	0.92	0.94	1.15	0.98	0.83	1.20	1.22
CaO	10.57	11.82	11.80	11.81	11.94	12.34	11.39	12.13	12.06	12.07	12.11	11.91	11.45
P_2O_5	0.06	0.07	0.09	0.07	0.06	0.02	0.19	0.03	0.05	0.00	0.00	0.07	0.00
BaO	0.13	0.15	0.00	0.14	0.08	0.21	0.04	0.07	0.00	0.30	0.00	0.31	0.50
Total	**95.06**	**97.70**	**95.94**	**96.94**	**97.29**	**97.79**	**97.65**	**91.55**	**97.81**	**97.54**	**98.00**	**98.24**	**96.59**
Structural formula on the basis of 23 Oxygen													
Si	6.58	6.80	6.80	6.84	6.80	7.62	6.9	7.1	6.9	6.86	7.18	6.73	6.74
Ti	0.13	0.11	0.13	0.09	0.12	0	0.1	0.08	0.07	0.072	0.05	0.12	0.15
Cr	0.00	0.02	0.00	0.01	0.01	0	0	0.01	0.01	0	0.014	0	0
Al	1.63	0.37	1.39	1.41	1.42	0.48	1.32	1.14	1.31	1.28	0.96	1.426	1.45
Al^{iv}	1.42	1.20	1.20	1.16	1.20	0.38	1.1	0.9	1.1	1.14	0.82	1.27	1.26
Al^{vi}	0.21	0.00	0.19	0.25	0.22	0.1	0.22	0.24	0.21	0.14	0.14	0.16	0.19
Fe	2.20	2.12	1.97	2.27	1.98	1.83	2.2	1.85	2.02	1.93	1.82	2.05	2.08
Mn	0.00	0.01	0.01	0.00	0.00	0	0	0.01	0	0.025	0	0	0
Mg	2.76	2.64	2.80	2.50	2.77	3.13	2.7	2.96	2.81	2.93	3.08	2.74	2.71
Na	0.56	0.61	0.61	0.53	0.56	0.27	0.46	0.5	0.49	0.58	0.42	0.62	0.55
K	0.23	0.23	0.23	0.22	0.23	0.041	0.18	0.19	0.22	0.187	0.16	0.23	0.24
Ca	1.76	1.92	1.94	1.94	1.93	1.94	1.84	1.94	1.94	1.94	1.91	1.93	1.88
P	0.00	0.01	0.01	0.01	0.01	0	0.03	0	0	0	0	0	0
Ba	0.00	0.00	0.00	0.01	0.01	0.013	0	0	0	0.018	0	0.02	0
Total	**15.85**	**15.67**	**15.89**	**15.83**	**15.84**	**15.3**	**15.7**	**15.8**	**15.8**	**15.8**	**15.6**	**15.9**	**15.8**
(Mg+Fe)	4.96	4.76	4.77	4.77	4.75	4.96	4.9	4.81	4.83	4.86	4.90	4.79	4.79
Mg/(Mg+Fe)	0.56	0.55	0.59	0.52	0.58	0.63	0.55	0.62	0.58	0.60	0.63	0.57	0.57

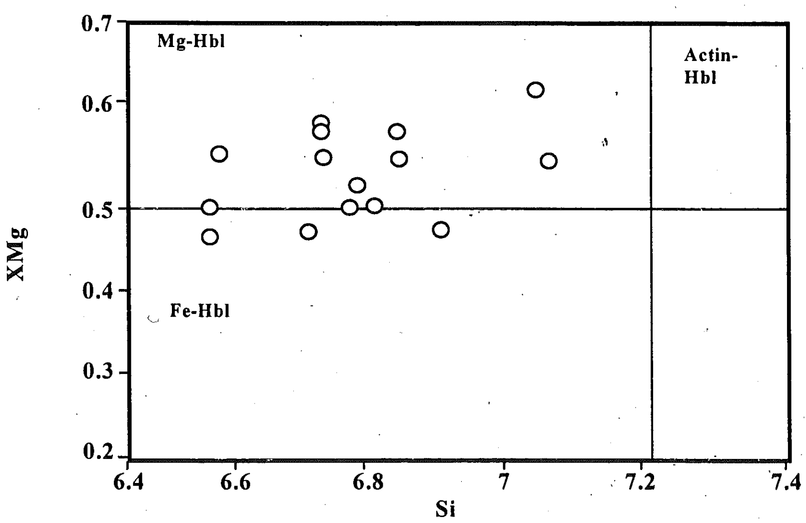

Figure 3. $Mg/(Mg+Fe^{tot})$ vs Si (pfu.) diagram for the hornblende from Perhentian Kecil Syenite. The hornblende plot mainly in the magnesio-hornblende field.

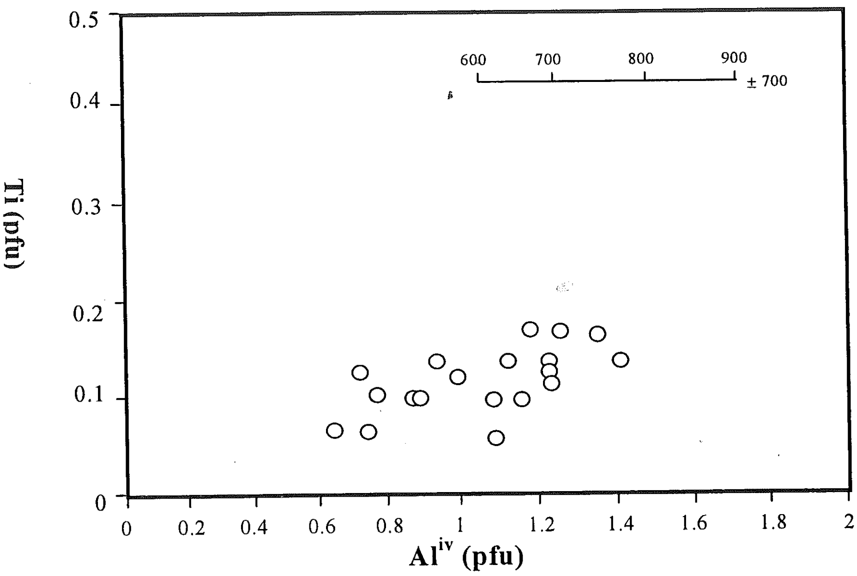

Figure 4. Ti vs Al^{4+} diagram for the hornblende from Perhentian Kecil Syenite

Sphene

Analyses of sphene is given in (Table 3). It contains 25.7 - 27.4% CaO and 0.63 - 2.4% BaO. Both elements are relatively lower compared to other sphene from calc alkaline granites [11]. On a Al-Ti-Fe diagram which discriminates between igneous and secondary sphene in the Victoria Range granitic rocks, South island New Zealand, the Perhentian sphene fall into the igneous field of this diagram (Figure 5) [12].

Table 3. Analytical results of sphene from the Perhentian Kecil Syenite

Sample No.	3AUR	4AUR	16AUR	17AUR	22AUR	23AUR	24AUR	25AUR	26AUR	27AUR	18TBN	19TBN	20TBN
SiO_2	29.353	30.393	29.968	29.82	29.72	29.852	29.638	29.201	29.405	29.072	29.807	30.053	29.258
TiO_2	35.161	35.426	36.064	36.68	35.735	34.237	36.183	34.929	35.908	35.164	33.164	34.589	34.51
Cr_2O_3	0	0.135	0.135	0	0.123	0.032	0	0	0	0	0	0	0
Al_2O_3	1.365	1.663	1.357	1.31	1.42	2.577	1.359	1.87	1.662	2.208	2.208	1.851	1.562
FeO	1.1811	1.55	1.424	1.57	1.554	1.664	1.519	1.985	1.591	2.132	2.132	2.071	1.857
MnO	0	0	0	0.038	0	0	0	0	0	0	0	0	0
MgO	0	0.074	0.087	0	0.014	0.06	0.171	0.084	0.112	0.082	0.082	0.043	0.035
Na_2O	0.05	0.181	0.27	0.071	0.225	0.1	0.125	0.182	0.191	0.233	0.233	0.197	0.091
K_2O	0.06	0.026	0.072	0.078	0.011	0.057	0.016	0.028	0	0.013	0.013	0.063	0.059
CaO	26.456	27.43	27.145	27.437	27.056	27.269	27.384	26.28	27.156	26.782	26.782	27.071	25.676
P_2O_5	0.027	0.105	0.057	0.054	0.224	0.084	0.06	0	0	0.054	0.054	0.096	0.01
BaO	2.0105	2.369	1.602	0.856	2.017	1.296	0.651	1.243	0.625	1.35	1.35	0.832	1.781
Total	**96.294**	**99.352**	**98.181**	**97.914**	**98.099**	**97.228**	**96.106**	**95.802**	**96.650**	**95.825**	95.825	**96.866**	**94.839**
Structural formula on the basis of 4 Oxygen													
Si	0.8	0.807	0.8	0.797	0.798	0.8	0.796	0.802	0.795	0.799	0.815	0.81	0.814
Ti	0.7	0.707	0.72	0.737	0.722	0.7	0.731	0.722	0.73	0.724	0.682	0.7	0.722
Cr	0	0.003	0.003	0	0.003	0.001	0	0	0	0	0	0	0
Al	0.044	0.052	0.043	0.041	0.045	0.082	0.043	0.06	0.053	0.052	0.071	0.059	0.051
Fe	0.041	0.034	0.032	0.035	0.035	0.037	0.034	0.046	0.036	0.039	0.049	0.047	0.043
Mn	0	0	0	0.001	0	0	0	0	0	0	0	0	0
Mg	0	0.003	0.003	0	0.001	0.002	0.01	0.003	0.0045	0.005	0.003	0.002	0.001
Na	0.003	0.009	0.014	0.004	0.012	0.005	0.01	0.0097	0.01	0.008	0.012	0.01	0.0049
K	0.002	0.001	0.003	0.003	0.0004	0.002	0.001	0.0009	0	0.001	0.004	0.002	0.002
Ca	0.776	0.78	0.784	0.785	0.779	0.786	0.788	0.773	0.79	0.786	0.785	0.782	0.765
P	0.001	0.002	0.001	0.0013	0.01	0.002	0.0014	0	0	0	0.0013	0.002	0.0002
Ba	0.023	0.025	0.017	0.009	0.212	0.014	0.01	0.013	0.007	0.014	0.014	0.009	0.019
Total	**2.39**	**2.42**	**2.42**	**2.41**	**2.62**	**2.42**	**2.42**	**2.43**	**2.43**	**2.43**	**2.44**	**2.42**	**2.42**

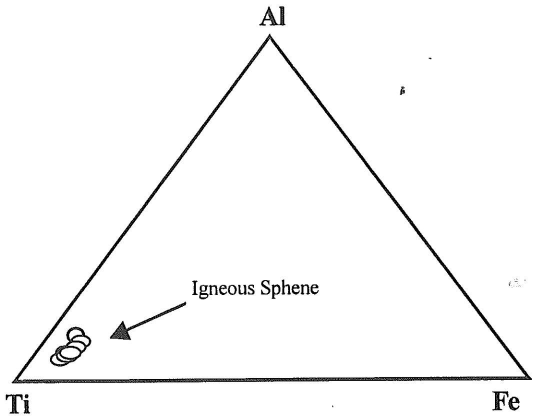

Figure 5. Al-Ti-Fe diagram for the sphene from Perhentian Kecil Syenite. Field of igneous sphene after Tulloch (1979)

Apatite

Analyses of apatite in the Perhentian Kecil Syenite is given in (Table 4). The results have been divided into clear and clouded parts of the apatite. Microprobe analysis shows that the clouded parts have higher SiO_2, K_2O, Fe(tot) and BaO and both CaO and P_2O_5 have a wider range in the clouded parts compared to the clear parts of apatite [13]. They contain 41.56 to 43.24% P_2O_5 and 53.37 to 55.81 % CaO. Interestingly, the apatites contain no MnO compared to apatite analyses given by Deer et al. [14] which contain considerable amount of MnO (0.01 to 5.32%). This suggests that the replacemant of Ca by Mn is not an important mechanism in the apatite from the Perhentian Kecil Syenite.

Table 4. Analytical results of apatite from the Perhentian Kecil Syenite

Sample No.	32	33	23	28	29	1	2	5	8	9	10	11	17	18	21
Location	Clear	Clouded		Clear	Clear	Clear	Clear	Clouded	Clouded	Clouded	Clear	Clouded	Clear	Clouded	Clouded
SiO_2	0.64	0.88	0.67	0.29	0.37	0.57	0.45	0.40	0.47	0.53	0.25	0.93	0.15	0.44	0.21
TiO_2	0.00	0.00	0.00	0.34	0.10	0.00	0.00	0.08	0.00	0.00	0.07	0.00	0.02	0.00	0.00
Cr_2O_3	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00
Al_2O_3	0.11	0.03	0.08	0.00	0.01	0.00	0.13	0.14	0.23	0.09	0.01	0.10	0.02	0.06	0.13
FeO	0.15	0.47	0.66	0.34	0.26	0.38	0.66	0.35	0.08	0.18	0.12	0.65	0.01	0.25	0.02
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.51	0.00	0.07	0.08	0.04	0.00	0.12	0.07	0.00	0.15	0.05	0.02	0.00	0.01	0.11
Na_2O	0.12	0.13	0.10	0.19	0.10	0.08	0.13	0.19	0.03	0.28	0.05	0.18	0.04	0.07	0.22
K_2O	0.05	0.12	0.06	0.08	0.07	0.09	0.11	0.15	0.05	0.09	0.03	0.11	0.07	0.07	0.05
CaO	54.29	53.37	53.72	54.96	54.53	53.92	54.08	53.40	54.64	54.49	55.11	53.81	55.42	54.13	55.10
P_2O_5	42.49	42.56	41.97	42.69	43.01	42.36	42.15	42.15	42.79	42.49	43.40	42.11	43.51	42.83	43.24
BaO	0.10	0.00	0.24	0.00	0.00	0.09	0.00	0.00	0.04	0.07	0.00	0.00	0.00	0.33	0.19
Total	**98.46**	**97.56**	**97.56**	**98.95**	**98.49**	**97.50**	**97.84**	**96.92**	**98.33**	**98.38**	**99.08**	**97.90**	**99.28**	**98.18**	**99.27**
Structural formula on the basis of 12.5 Oxygen															
Si	0.05	0.07	0.06	0.02	0.03	0.05	0.04	0.03	0.04	0.04	0.02	0.08	0.01	0.04	0.02
Ti	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.01
Fe	0.01	0.03	0.05	0.02	0.02	0.03	0.05	0.03	0.01	0.01	0.01	0.05	0.00	0.02	0.00
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg	0.01	0.00	0.01	0.01	0.00	0.00	0.02	0.01	0.00	0.02	0.01	0.00	0.00	0.00	0.00
Na	0.02	0.02	0.02	0.03	0.02	0.01	0.02	0.03	0.00	0.05	0.01	0.03	0.01	0.00	0.04
K	0.01	0.01	0.06	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.01
Ca	4.86	4.86	4.84	4.90	4.85	4.86	4.87	4.83	4.88	4.87	4.87	4.83	4.89	4.85	4.87
P	3.01	2.99	2.99	3.01	3.02	3.02	3.00	3.02	3.02	3.00	3.03	2.98	3.04	3.03	3.02
Ba	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Total	**7.98**	**7.99**	**8.04**	**8.01**	**7.95**	**8.01**	**8.02**	**7.98**	**7.96**	**8.01**	**7.95**	**7.98**	**7.96**	**7.96**	**7.97**

Opaque phase

Analyses of opaque phase in the Perhentian Kecil Syenite is given in (Table 5). Samples 5 and 6 occur as inclusions in hornblende. Magnetite is the most common opaque mineral in the syenite ([14], Table 53 in p. 563). In general there is no significant difference between these samples compared to other opaque phases. All analyses have more than 90% Fe(tot) except sample 33 which has 84% Fe(tot). Apart from the sample 33, all other samples have small amounts of Al_2O_3 (0.14 – 0.24%). This small amount of Al can substitute for Fe^{3+} and generally similar small proportions of Ca, Mn and Mg replace Fe^{2+}.

Table 5. Analytical results of opaque phases from the Perhentian Kecil Syenite

Sample No.	5	6	33	34	35
Location	In Hbl	In Hbl			
SiO_2	0.34	0.25	2.37	0.29	0.24
TiO_2	0.38	0.34	0.12	0.22	0.06
Cr_2O_3	0.24	0.33	0.34	0.17	0.19
Al_2O_3	0.26	0.25	4.05	0.24	0.14
FeO	90.98	90.79	84.22	90.45	90.99
MnO	0.00	0.00	0.00	0.00	0.00
MgO	0.14	0.05	0.54	0.17	0.03
Na_2O	0.48	0.36	0.50	0.62	0.65
K_2O	0.10	0.07	0.09	0.03	0.02
CaO	0.00	0.11	0.24	0.06	0.00
P_2O_5	0.00	0.00	0.02	0.00	0.01
BaO	0.00	0.00	0.00	0.00	0.00
Total	**92.916**	**92.551**	**92.491**	**92.256**	**92.312**
Structural formula on the basis of 5 Oxygen					
Si	0.02	0.02	0.14	0.02	0.02
Ti	0.02	0.02	0.01	0.01	0.00
Cr	0.01	0.02	0.02	0.01	0.01
Al	0.02	0.02	0.29	0.02	0.01
Fe	4.92	4.93	4.20	4.95	4.97
Mn	0.00	0.00	0.00	0.00	0.00
Mg	0.01	0.01	0.05	0.02	0.00
Na	0.06	0.05	0.06	0.08	0.08
K	0.01	0.01	0.01	0.00	0.00
Ca	0.00	0.01	0.02	0.00	0.00
P	0.00	0.00	0.00	0.00	0.00
Ba	0.00	0.00	0.00	0.00	0.00
Total	**5.07**	**5.06**	**4.78**	**5.11**	**5.10**

CONCLUSIONS

Composition of K-fedspar in the Perhentian Kecil Syenite is near to the pure orthoclase with An percentage less than 1%. The plagioclase can be classified as oligoclase - andesine (An percent ranging from 27.2 to 37.3). The main amphibole type of the Perhentian Kecil Syenite are magnesio-hornblende with subordinate ferro and actin- hornblende. The hornblende show an increase of TiO_2 and Al^{iv} and decrease in CaO from core to rim. The deduced magmatic crystallisation interval for the hornblende in the Perhentian Kecil Syenite ranged from 660 to 780 ^oC ($\pm$ 70^{o}C). Composition of the sphene plots in igneous sphene field, similar to those from the Victoria Range granitic rocks, South Island New Zealand [13]. Apatite can be divided into clear and clouded parts. Chemically, the clouded parts contain higher SiO_2, K_2O, Fe(tot) and BaO and both CaO and P_2O_5 have a wider range in the clouded parts compared to the clear parts of apatite [14]. Magnetite is the most common opaque mineral in the Perhentian Kecil Syenite.

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