Geol. Soc. Malaysia, Bulletin, 1980; pp. 79–86.

On the evolution of the nepheline to hypersthene normative alkali basaltic rocks of Kuantan, Pahang, Peninsular Malaysia.

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Abstract: The alkali basaltic rocks of Kuantan range from alkali olivine basalt to hawaiite. They are nepheline to hypersthene normative and straddle the critical plane of silica undersaturation of the basalt tetrahedron. The nepheline normative rocks have lower FeO*/(FeO* + MgO) and higher normative An/(An + Ab). With increasing FeO*/(FeO* + MgO), the normative nepheline decreases in amount and then gives way to hypersthene. Apparently, the nepheline normative alkali basalt magma has fractionated towards the hypersthene normative compositions which implies that the Kuantan alkali basalts have evolved under conditions where the 01-Di-Pl plane is not a thermal barrier. This is an uncommon type of differentiation and can be classified, following Miyashiro (1978), as straddle-B type. This evolutionary trend conforms well with the recent experimental results of Presnalt et. al (1978) that suggest that alkali basalt magmas can yield tholeiitic residual liquids by fractional crystallization under 4 to 12 kb pressure.

INTRODUCTION

Late Cenozoic basaltic lavas of Kuantan, Pahang, Peninsular Malaysia, comprise three distinct petrographically distinguishable groups, namely, alkali olivine basalt, limburgite and olivine nephelinite (Chakraborty, 1977). The first group constitutes the bulk of the lavas, and the present study is concerned only with the rocks of this group which compositionally range from alkali olivine basalt to hawaiite and are nepheline to hypersthene normative. The alkaline nature of the hypersthene normative varieties is evident from both chemical (e.g. alkali-silica relationship) and petrographic characteristics (such as groundmass olivine, absence of Ca-poor pyroxene, interstitial alkali feldspar). Also, they have positive values for the Poldervaart's (1964) expression Ab − 2En − 15Fs. Moreover they maintain petrographic and chemical continuity with the nepheline normative rocks. Thus these two normative types appear to have evolved from a single parent. The variation trend of the normative character of these rocks is very characteristic and is different from what may be expected from the commonly accepted fractionation models of the alkali basalt magmas. The main objective of this short article is to discuss the significance of this variation trend and its bearing on the evolution of these rocks.

PETROGRAPHY

The general petrographic uniformity of the members of the alkali olivine basalt group is noteworthy. They are fine grained and holocrystalline rocks containing microphenocrysts of euhedral to subhedral olivine, less abundant augite and rare plagioclase set in an intergranular to subophitic groundmass consisting of small plagioclase laths, augite, olivine and minor amounts of ubiquitous opaques. Augite microphenocrysts are usually zoned. Alkali feldspar and/or analcite frequently occur in small interstitial patches. Apatite is a common accessory mineral.

The composition of the modal plagioclase varies from An_{55} to about An_{40}. But the normative 100 An/(An + Ab) values of the fourteen chemically analyzed samples

* Total iron as FeO.

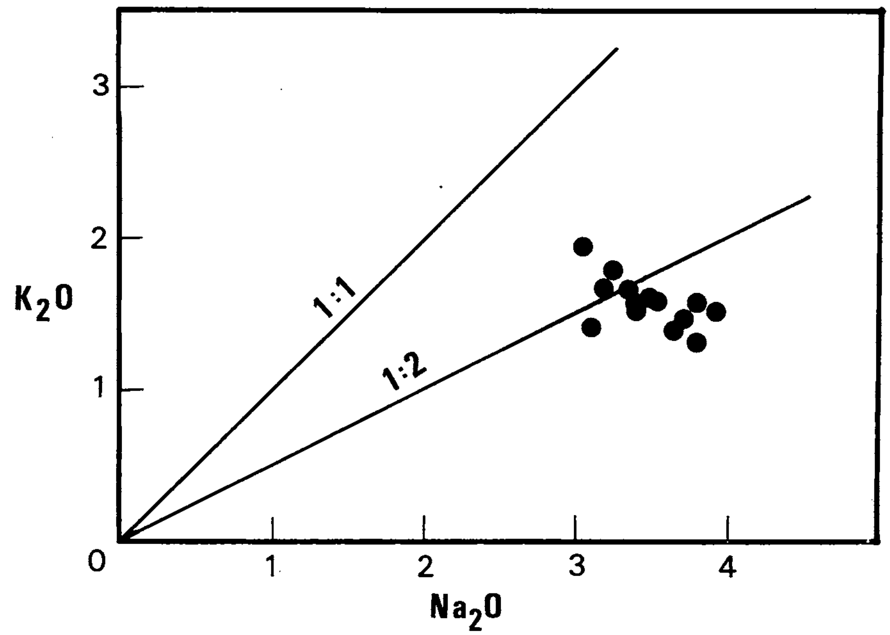

Fig. 1. K_2O versus Na_2O plots (wt. %) of the alkali basaltic rocks of Kuantan.

range from about 50 to 34 (see Table–2). The normative plagioclase is almost invariably more sodic than the corresponding modal plagioclase. The K_2O:Na_2O ratios of the analyzed rocks are in general less than 1:2 (Fig. 1). Thus the rocks range from alkali olivine basalt to hawaiite. More evolved differentiates like benmoreite or trachyte are absent suggesting that the high level differentiation was insignificant.

CHEMISTRY

A total of fourteen samples have been analyzed (by XRF) for major elements, and their CIPW norms have been computed on the basis of a constant Fe_2O_3/FeO ratio of 0.25. A few representative analyses are presented in Table-1 and the ranges of the individual oxides are summarized in Table-2. The noteworthy chemical features of these rocks are: (i) moderate to moderately high Na_2O content (3.05-3.93 %), (ii) moderate to moderately high K_2O (1.31-1.95 %) compared with Na_2O values, (iii) near constant total alkali content of about 5 % (4.89-5.45) with one exception of 4.49 %, and (iv) nearly constant TiO_2 values (1.82-1.96 %). All the analyzed rocks plot in the "within plate basalts" field on the discriminant function diagram of Pearce (1976).

The normative compositions of the analyzed rocks are projected on the Ne-Ol-Qz plane of the basalt tetrahedron (Fig. 2). They range from about 5 % nepheline normative to about 7 % hypersthene normative and thus straddle the critical plane of silica undersaturation (Di-Ol-Pl plane).

The chemical variations within these rocks are rather limited as indicated by the narrow variation range of individual oxides (Table 2). The most noticeable variations are shown by SiO_2 and FeO/MgO ratios. The spread of FeO*/(FeO* + MgO) (FM ratio) perhaps best reflects the extent of differentiation and may be regarded as a

TABLE 1

A FEW REPRESENTATIVE CHEMICAL ANALYSES OF THE ALKALI BASALTIC ROCKS OF KUANTAN

Oxide	1	2	3	4	5	6
SiO_2	47.43	47.61	48.67	48.33	50.98	50.71
TiO_2	1.82	1.91	1.91	1.91	1.92	1.85
Al_2O_3	13.94	14.08	14.14	13.94	14.48	14.39
FeO*	10.78	11.15	11.18	12.15	9.93	10.86
MnO	0.16	0.18	0.17	0.17	0.17	0.16
MgO	9.21	8.93	8.11	8.40	6.73	7.19
CaO	8.97	8.66	8.51	8.55	7.81	7.88
Na_2O	3.49	3.22	3.39	3.09	3.81	3.82
K_2O	1.61	1.67	1.58	1.40	1.57	1.31
P_2O_5	0.58	0.53	0.53	0.53	0.46	0.41
L.I.	1.61	1.64	1.33	1.12	1.77	1.07
Total	99.60	99.58	99.52	99.59	99.63	99.65
CIPW Norms						
Or	9.68	10.05	9.48	8.38	9.46	7.83
Ab	21.99	23.86	28.13	26.48	32.87	32.71
An	17.93	19.38	18.99	20.29	18.12	18.47
Ne	4.37	2.10	0.54	—	—	—
Di	19.04	16.91	16.58	15.63	14.92	15.00
Hy	—	—	—	3.48	7.28	6.34
Ol	18.82	19.35	17.95	17.15	9.54	11.87
Mt	3.25	3.37	3.36	3.64	2.99	3.26
Il	3.52	3.69	3.68	3.67	3.72	3.55
Ap	1.40	1.28	1.27	1.27	1.11	0.98

* Total iron as FeO. L.I. = Loss on ignition

TABLE 2

COMPOSITIONAL RANGE OF THE ALKALI BASALTIC ROCKS OF KUANTAN

SiO_2	46.42–51.01
TiO_2	1.82– 1.96
Al_2O_3	13.77–14.57
FeO*	9.93–12.15
MnO	0.15– 0.20
MgO	6.68– 9.92
CaO	7.81– 9.01
Na_2O	3.05– 3.93
K_2O	1.31– 1.95
P_2O_5	0.41– 0.79
$\frac{100\ FeO^*}{FeO^* + MgO}$	51.89–60.26
$\frac{100\ An}{An + Ab}$	34.64–50.11

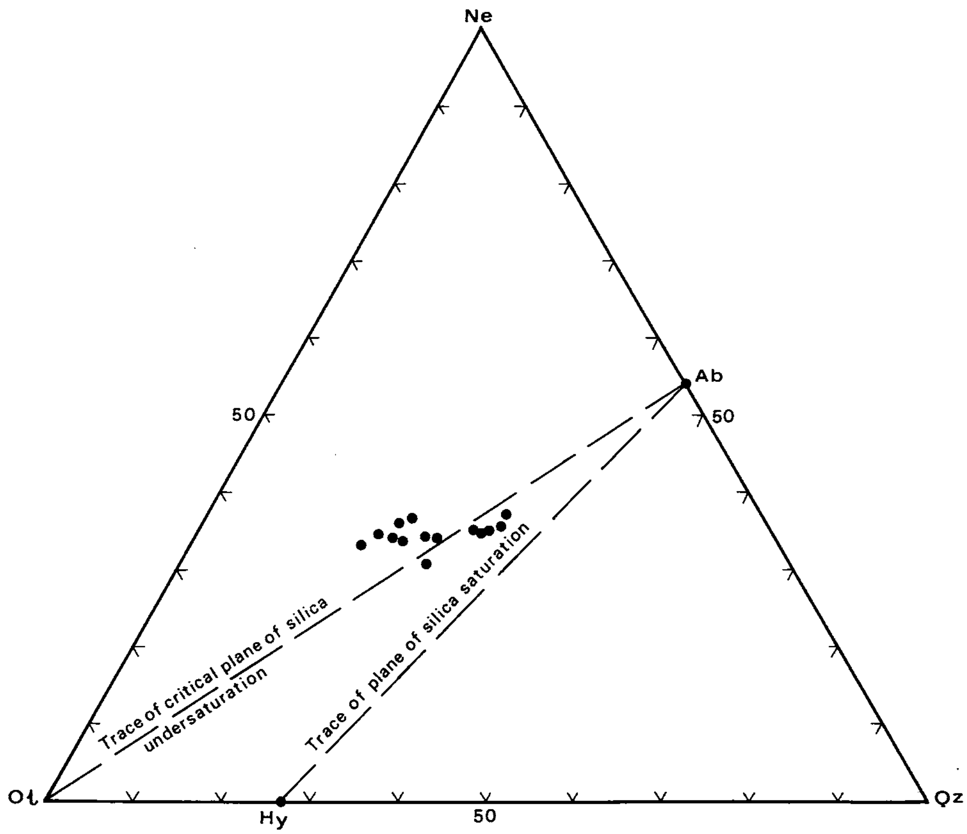

Fig. 2. Normative mineralogy of the alkali basaltic rocks of Kuantan projected from diopside onto the ne-ol-qz plane of the basalt tetrahedron.

qualitative fractionation index. There is a significant increase of SiO_2 with increasing FM, while Al_2O_3 and CaO show slight increase and decrease respectively (Fig. 3). The normative An % also decreases with increasing FM (Fig. 3). The normative An % also decreases with increasing FM (Fig. 3). In general, the hypersthene normative rocks have lower normative An %. The AFM variation of the analyzed rocks is shown in Figure 4. Because of the limited extent of differentiation (rocks further evolved than hawaiite are absent), the spread of the plots is not very pronounced. But yet a slight iron enrichment trend is apparent within this restricted spread.

PETROGENESIS

The single most important evolutionary feature of petrogenetic significance is the development of the compositional range astride the critical plane of silica undersaturation displaying a characteristic relationship of the normative character with FM ratio as shown in Figure-5 where the normative percentage of nepheline/hypersthene is plotted against the FM ratio. It is apparent that the rocks with lowFM are characterized by normative nepheline which gives way to hypersthene as FM increases. Significantly, in the nepheline normative part of the diagram (Fig. 5),

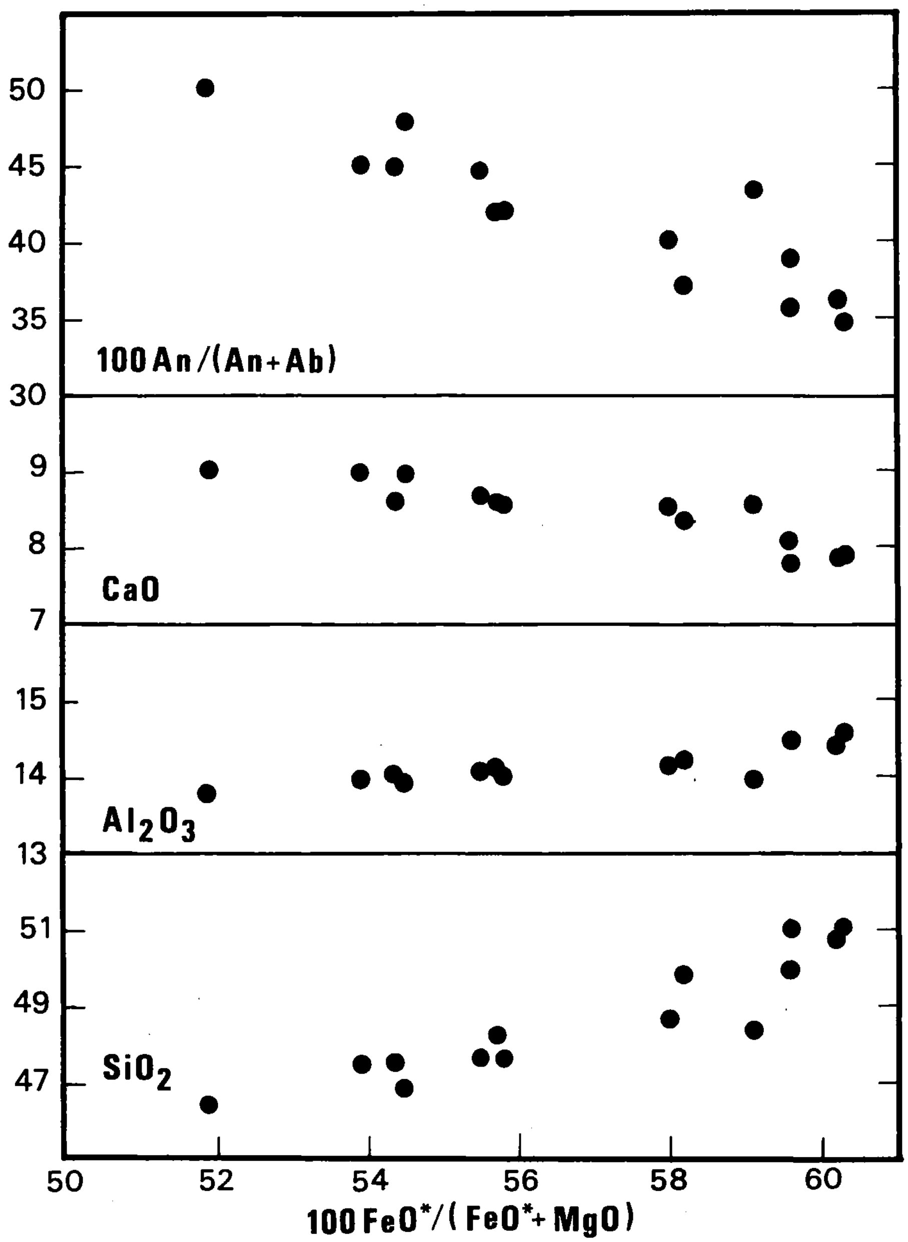

Fig. 3. Variation of SiO_2, Al_2O_3, CaO and normative An/An + Ab against FeO*/(FeO* + MgO) for alkali basaltic rocks of Kuantan.

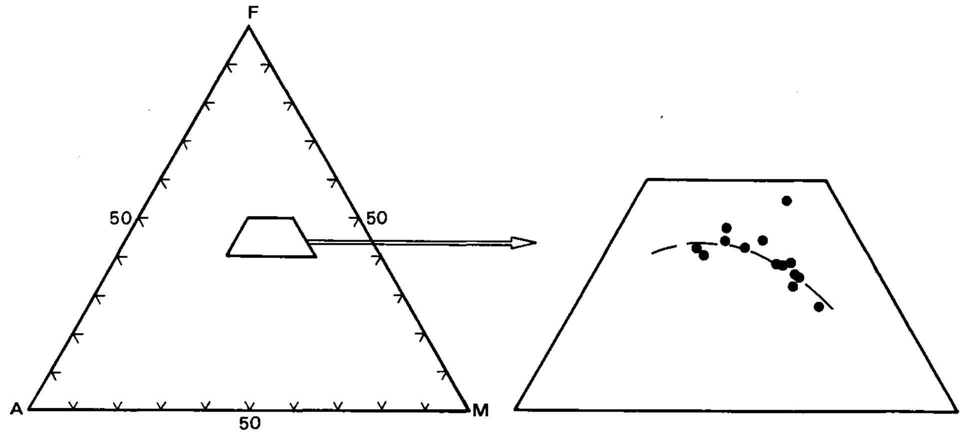

Fig. 4. AFM variation diagram for the alkali basaltic rocks of Kuantan.

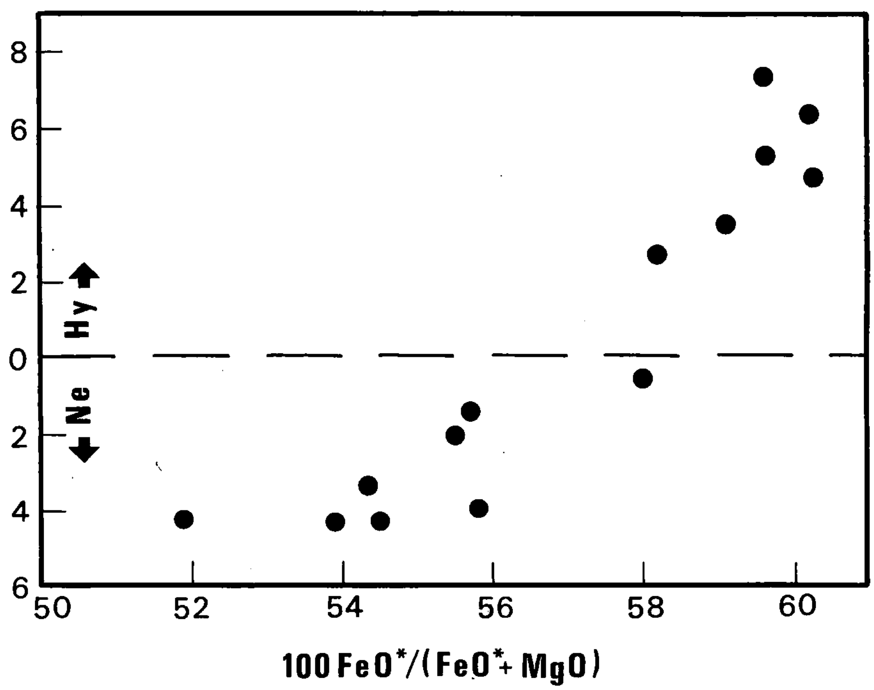

Fig. 5. Plots of normative nepheline/hypersthene versus FeO*/(FeO* + MgO) for the alkali basaltic rocks of Kuantan.

the amount of normative nepheline increases with decreasing FM, whereas in the hypersthene normative part the FM bears a positive correlation with hypersthene. Since the rocks having the lowest FM represent the immediate parental composition, it is obvious that the differentiation of a nepheline normative magma has yielded the hypersthene normative derivatives in Kuantan—an uncommon but petrogenetically intriguing trend. Miyashiro (1978) has recently drawn attention to similar differentiation trends in a few other areas and has classified them as straddle-B type.

The parental alkali basalt magma of Kuantan (low FM) lies on the silica poor side of the critical plane of silica undersaturation (Fig. 2). Since this plane is a low pressure thermal divide (Yoder and Tilley, 1962), fractional crystallization of such magma under low pressure can yield only nepheline normative derivatives. The straddle-B type differentiation trend, therefore, could not have evolved by simple fractionation at shallow level. Consequently, the alkali basaltic rocks of Kuantan must have evolved, at least partly, under conditions where the Di-Ol-Pl plane does not act as a thermal barrier.

According to Green and Ringwood (1967) and O'Hara (1965, 1968), the Di-Ol-Pl thermal divide breaks down at about 8-10 kb. Under such conditions it is possible for magmas to form with compositions close to but astride the critical plane of silica undersaturation. If subsequent low-pressure fractionations occur, then the magmas on either side of the divide would follow differentiation paths away from it producing more evolved nepheline and hypersthene normative residual liquids. This model, however, is not applicable for the Kuantan rocks, since in such an event the amount of nepheline should have increased with increasing FM within the nepheline normative part of the nepheline/hypersthene versus FM diagram (Fig. 5).

Green and Ringwood (1967) have shown from experimental studies that the orthopyroxene is the liquidus phase for common basaltic rocks at pressure between 13 and 18 kb implying that the primary phase field of orthopyroxene penetrates even the alkali basalt volume at such pressures. Thus, orthopyroxene fractionation from hypersthene normative basaltic magma may yield nepheline normative derivative liquids producing an association of hypersthene to nepheline normative basaltic rocks. The relationship of the normative character with the FM for an association so derived would, however, be the reverse of the straddle-B type trend.

The fractionation of basaltic magmas under various pressures has been studied and discussed by a number of workers. But very few attempts have been directed to explore the possibility and the mechanism of deriving hypersthene normative liquids from nepheline normative parents. Although amphibole fractionation provides a suitable mechanism, there is no obvious petrographic evidence in favour of it in Kuantan. In this connection, the recent experimental study of Presnall et al. (1978) on the liquidus phase relationships of the join Di-Fo-An in the system CaO-MgO-Al_2O_3-SiO_2 at various pressures up to 20 kb is very significant. This study suggests that the join Di-Fo-An represents a thermal divide only up to 3 kb. At about 3-5 kb, according to them, the isobaric univariant line along which forsterite, diopside, anorthite and liquid are in equilibrium, penetrates the join Di-Fo-An with temperature decreasing from the silica-poor to silica-rich side of the join. This implies that the fractionation of these three phases from alkali basalt magma would give rise to tholeiitic liquids. In the pressure range of 5 to 12 kb, two univariant lines, Di-Fo-Sp-Liquid and Di-An-Sp-Liquid, penetrate the Di-Fo-An join and temperatures along these two lines also decrease from the alkalic to tholeiitic side. The experimental results of Presnall et al. (1978), if valid for the natural systems, suggest that the fractional crystallization of nepheline normative alkali basaltic magma can produce hypersthene normative residual liquids within a pressure range of 4 to 12 kb, and thus provide a satisfactory explanation for the evolution of the straddle-B type differentiation trend as observed in Kuantan.

ACKNOWLEDGEMENT

Thanks are due to Mr. Koh Tai Cheong for his help with the chemical analyses and to Mr. Roslin bin Ismail for drawing the figures.

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