GEOSEA V Proceedings Vol. II, Geol. Soc. Malaysia, Bulletin 20, August 1986; pp. 503–521

Petrochemistry of gem-bearing basalt in the Nong Bon area, Trat Province, Eastern Thailand

THEERAPONGS THANASUTHIPITAK[1] AND THANAWUT SIRINAWAN[2]
[1]Department of Geological Sciences
Chiang Mai University
Chiang Mai 50002, Thailand
[2]SEATRAD Centre
Tiger lane, Ipoh, Malaysia

Abstract: Basaltic rocks of Nong Bon area average 30 m thick. They are generally massive with few vesicular layers. Megacrysts of clinopyroxene, garnet, ilmenite and magnetite, and xenoliths of ultramafic rocks are common in these rocks. Petrographic studies so far indicate that some of the rocks are olivine nephelinites, porphyritic with phenocrysts of olivine, clinopyroxene and spinel. Geochemical data are also available for the basanitoid basalt.

On the basis of the data available, the origin of corundum found in the study area cannot be genetically related with the basanitoid basalts. It is suggested that pre-existing corundum was picked up from a depth just above the level of formation of the basanitoid basalts.

INTRODUCTION

Gem deposits of eastern Thailand, in Trat and Chanthaburi provinces, have been known for several decades. Gems produced in this part of the country account up to 90% of the total national production. The most important gem mineral is corundum, of ruby and sapphire varieties. Zircon and garnet are the other gem minerals produced in this area. These minerals are found in close association with soil or sediment derived from weathered basalt. It is, therefore, generally believed that basaltic rocks are the most likely source of these gems.

Three belts of basaltic rocks are recognized in this area (Figure 1):

1. The western belt, located just west of the town of Chanthaburi, yields gems of blue, green and yellow colour varieties.

2. The middle belt, located at the border between Chanthaburi and Trat Provinces, is the largest exposed belt and yields gems of blue and red colour varieties (blue sapphire and ruby).

3. The eastern belt, located approximately 4 km from the Thai-Kampuchean border, yields mainly red gem (ruby).

The basaltic rocks of Nong Bon, discussed in this paper, are part of this belt.

Megacrystic minerals generally found associated with corundum in the three belts include aluminous augite, spinel, ilmenite, zircon, garnet, olivine, sanidine(?), biotite and quartz.

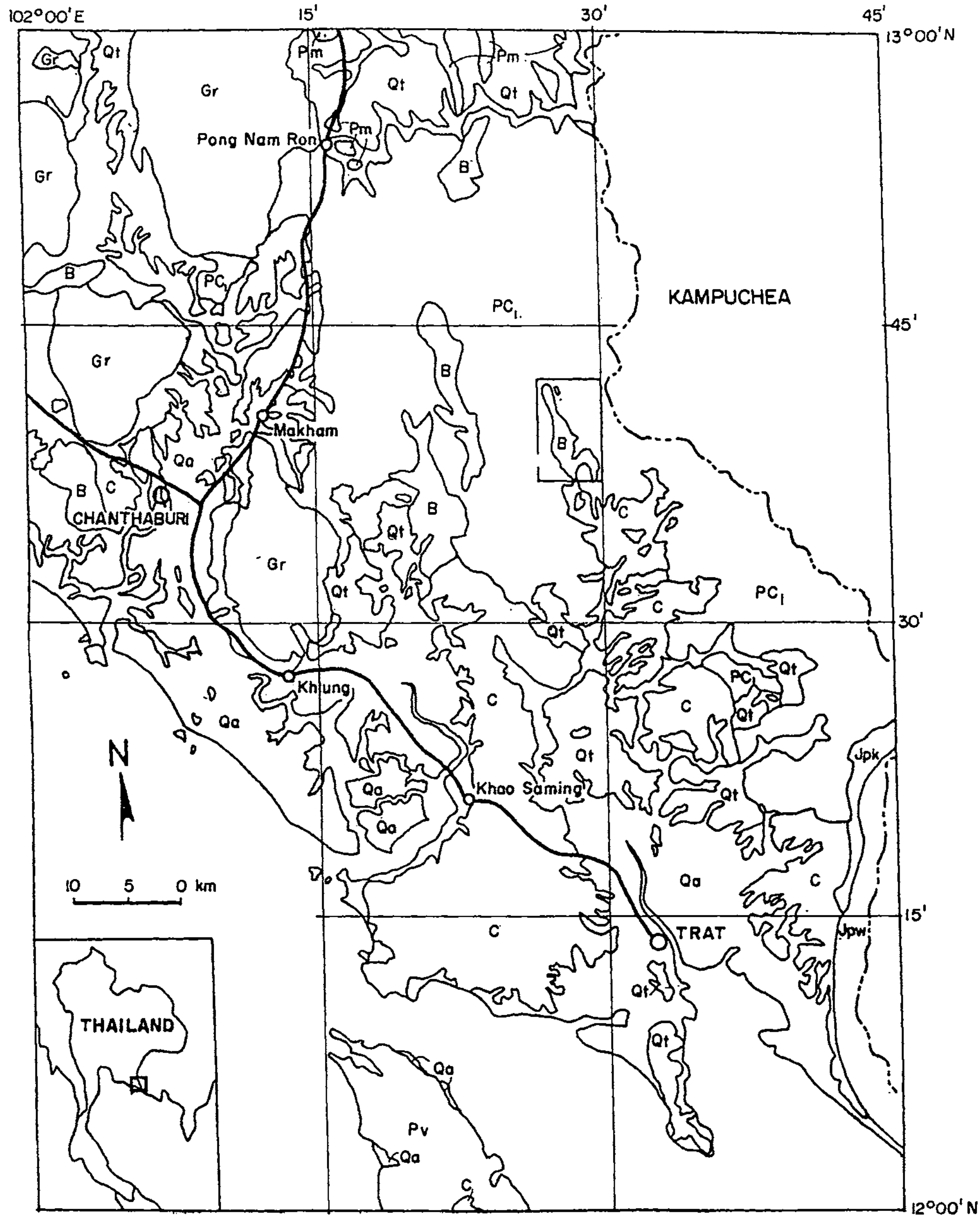

Fig. 1 Geologic map of Chanthaburi and Trat Provinces showing the study area (after Salyapongse and Jungyusuk, 1980) Qa = Quaternary alluvial; Qt = Quaternary terrace; Jpw = Jurassic Phra Wihan Formation; Jpk = Jurassic Phukradung Formation; Pm = Permian Sedimentary Sequence; PC_1 = Permo-Carboniferous graywacke; C = Carboniferous rocks; B = basalt; Gr = granite; Pv = Permian volcanics.

GEOLOGICAL SETTING

A map showing the distribution of various rock units found in the Chanthaburi and Trat area is shown in Figure 1. A brief description of each unit follows.

The oldest unit is a Carboniferous sequence consisting mainly of reddish-brown micaceous siltstone and medium-grained sandstone with fossils of brachiopods and bryozoa. The other rock types of the sequence include shale and interbedded chert, quartzite, dark gray limestone, and andesitic tuff. Overlying the Carboniferous rocks is massive gray to green, volcaniclastic graywacke of Permo-Carboniferous age, with a minor proportion of light gray chert, porcellanite and purplish to yellowish-white shale. This unit is the most extensive in terms of areal distribution, forming mountain ranges in the north-eastern part of the area, close to the Kampuchean border (Figure 1).

Permian rocks, although very limited in terms of distribution, are highly diverse. The lower portion of the sequence consists of well bedded, gray to green, volcaniclastic, micaceous sandstone interbedded with conglomerate, argillaceous conglomerate, and dark gray to yellow shale with chert nodules and limestone lenses containing fragments of volcanic rock and fusulinids. The middle portion is represented by massive to bedded maroon chert, maroon to green tuff, limestone breccia with fusulinids, agglomerate, diabasic lava, devitrified acid tuff, siliceous mudstone, yellowish-brown tuffaceous limestone with volcanic rock fragments. The upper portion of the sequence is mainly massive to thick-bedded limestone with fusulinid beds, as well as sandy mudstone, shale and maroon chert.

The next youngest unit found in the area is Mesozoic redbeds of the "Khorat Group".They occur at the southeastern part of the area, along the Kampuchean border. Only two formations of the Group are present: the Phukradung Formation and the Phra Wihan Formation, both of Jurassic age. The older Phukradung Formation consists of reddish-brown to purplish-red calcareous, micaceous siltstone, greenish-gray to yellowish-brown sandstone and, locally, basal conglomerate. The younger Phra Wihan Formation consists of thick-bedded white to yellowish-brown quartzitic sandstone, purplish-red siltstone and light gray claystone.

The youngest sediments found are Quaternary semi-consolidated gravel, sand, and silt, with local lateritic deposits, forming terraces, and unconsolidated alluvial flood plain, swamp, and beach sand deposits.

Three types of igneous rocks are present. The oldest are volcanic rocks of Permian age, consisting of intermediate to felsic differentiated shallow intrusions and lavas, with associated felsic tuff. Granitic rock of Triassic to Cretaceous age are found only in the western part of the area around Chanthaburi (Figure 1). The youngest igneous rocks are the basaltic rocks of Late Cenozoic age distributed in the three main belts mentioned earlier. Most of the basaltic rocks in this area are considered gem-bearing.

In the Nong Bon area (Fig. 2), the oldest rocks are grayish-green sandstones interbedded with dark gray shale and claystone of Permo-Carboniferous age, forming NW-SE trending ridges. The younger rocks are the Late Cenozoic basaltic rocks, apparently occurring as valley fills, at elevations not exceeding 263 m above mean sea level. The average thickness of the basaltic rocks is about 30 m. The basaltic rocks are generally fine-grained, locally

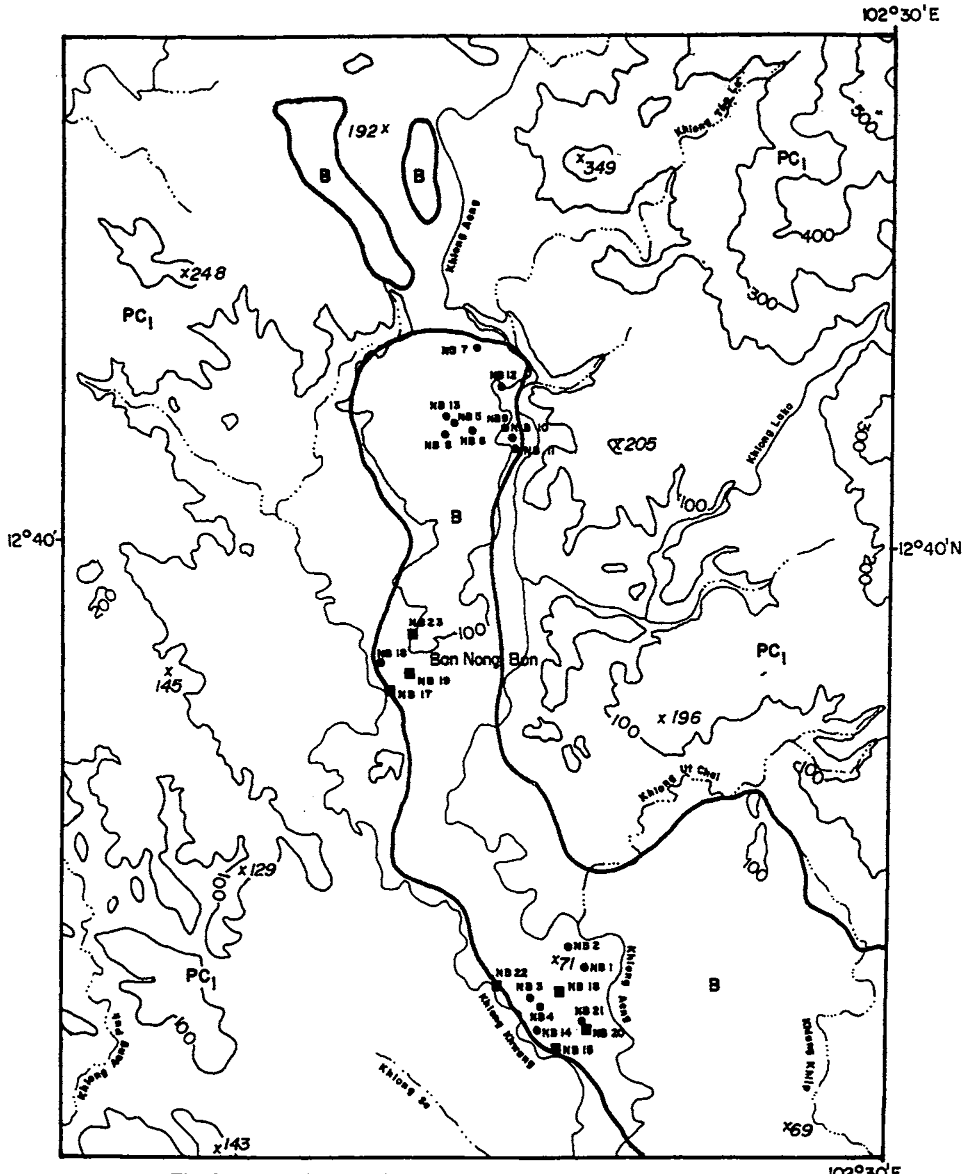

Fig. 2 Geologic map of the Nong Bon area showing sample locations.

vesicular, and show columnar jointing in places. Megacrysts, up to 6 cm across, of clinopyroxene, garnet, ilmenite, and magnetite are common. Clusters, averaging 2 cm across, of small garnet crystals are also found in the basaltic rocks, as are xenoliths of shale and ultramafic rocks. These basaltic rocks are the subject of the present study.

PETROCHEMISTRY

Petrographic Study

Petrographic study of some of the basaltic rocks from the Nong Bon area shows that they are porphyritic with phenocrysts of olivine, clinopyroxene and spinel. The groundmass is composed mainly of nepheline, clinopyroxene and Fe-Ti oxide minerals, with minor olivine and glass. Secondary minerals commonly found in the basalt are zeolites, serpentine, chlorite, Fe-Ti oxide minerals and calcite. On the basis of their mineralogy (mainly nepheline, clinopyroxene and Fe-Ti oxide minerals, with phenocrysts of olivine most common) the basaltic rocks of the Nong Bon area are classified as olivine nephelinite.

The average size of phenocrysts ranges from 0.1 to 0.2 mm. Some olivine phenocrysts show corroded outlines indicating resorption (Figure 3), and some are twinned (Figure 4). Clinopyroxene phenocrysts commonly show corroded outlines, and sieve texture (Figures 5). Similar features are also exhibited by larger crystals (megacrysts) of clinopyroxene

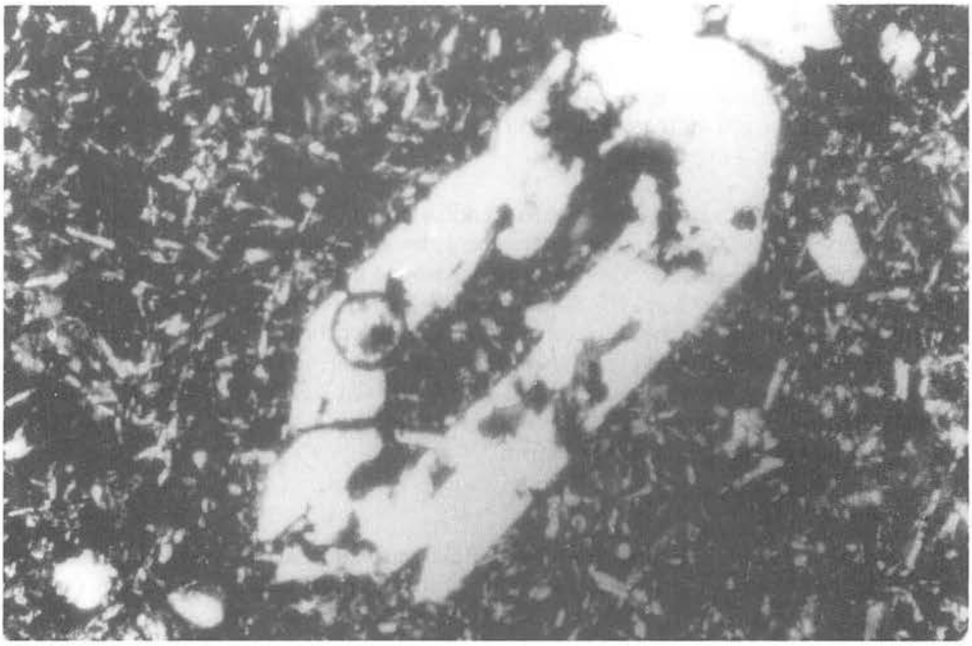

Fig. 3 Photomicrograph of Nong Bon basalt showing resorption of olivine phenocryst. Crossed nicols.

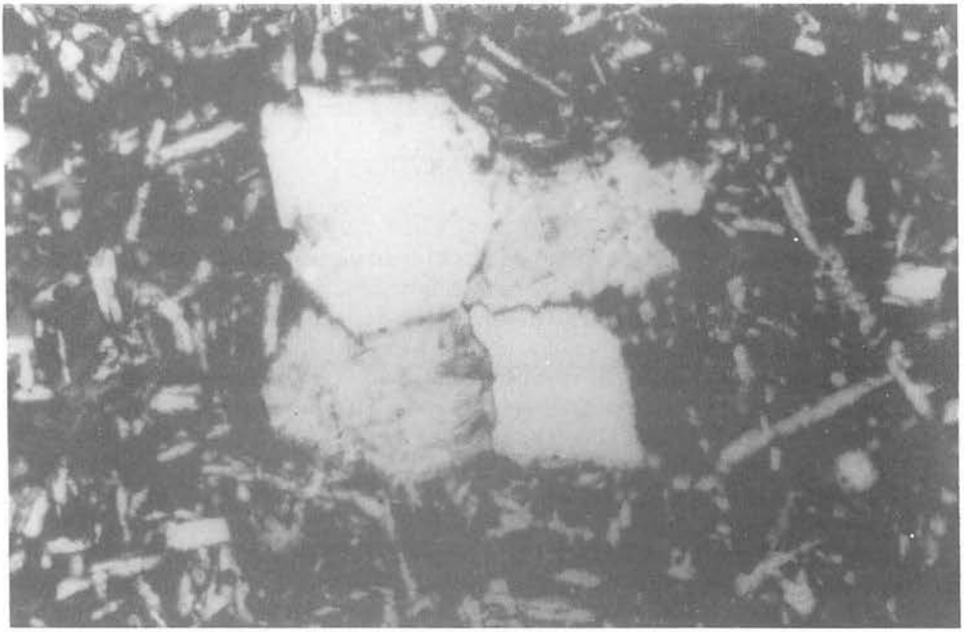

Fig. 4 Photomicrograph of Nong Bon basalt showing twinned olivine phenocryst. Crossed nicols.

(Figure 6). Replacement by amphibole is observed in some of the clinopyroxene megacrysts (Figure 7).

The groundmass is composed mainly of subhedral to anhedral nepheline, (Figure 8). Light pink, euhedral to anhedral clinopyroxene and euhedral to subhedral Fe-Ti oxide minerals are also common in the groundmass. Olivine in the groundmass is comparatively less common, and yellowish-brown glass is rare.

Ultramafic xenoliths are reddish-green to reddish-brown, showing xenomorphic-granular texture. They are composed mainly of garnet and clinopyroxene, with some olivine, spinel, orthopyroxene and plagioclase. Garnet commonly shows kelyphitic rims of chlorite and dark brown magnetite (Figures 9 and 10). Some garnet crystals are completely replaced by chlorite and magnetite. Clinopyroxenes are colourless or show pleochroism from light pink to light green. Resorbed and corroded clinopyroxenes occur in some thin sections. Spinel ranges in colour from green to brown (Figures 9 and 10). Spinel also occurs as inclusions in olivine crystals. The most common secondary mineral is chlorite, commonly found along grain boundaries and cracks (Figures 9 and 10).

Geochemistry

A total of 16 basaltic samples, from Nong Bon area were analysed for major, minor and trace elements. Various plots were made in order to determine geochemical characteristics

TABLE I

MAJOR AND MINOR ELEMENT CONTENT AND CIPW NORMATIVE MINERALS OF THE BASALTIC ROCKS OF NONG BON.

wt%	NB-1	NB-2	NB-3	NB-4	NB-5	NB-6	NB-7	NB-8	NB-9	NB-10	NB-11	NB-12	NB-13	NB-14	NB-16	NB-21
SiO_2	46.3	43.25	46.04	41.07	43.41	41.88	45.97	46.36	41.99	41.37	44.12	45.77	44.63	42.85	44.92	43.51
TiO_2	2.38	2.62	1.72	1.32	1.60	2.62	2.86	1.91	2.01	2.79	2.90	1.91	3.16	3.39	3.17	1.58
Al_2O_3	14.56	16.01	13.73	17.42	16.93	15.84	14.28	15.44	15.50	16.04	13.35	14.29	14.56	16.10	13.46	14.41
Fe_2O_3	2.00	0.95	3.76	3.47	2.74	3.94	5.14	2.81	5.36	2.67	3.35	6.34	3.07	2.35	3.06	4.06
FeO	10.67	11.50	9.32	9.84	10.69	8.69	7.96	9.99	8.51	10.18	10.20	7.09	10.33	10.24	10.17	9.09
MnO	0.20	0.21	0.23	0.23	0.18	0.23	0.24	0.22	0.27	0.22	0.20	0.15	0.20	0.21	0.19	0.21
MgO	7.70	7.48	6.56	6.64	7.25	7.78	6.51	7.57	6.57	7.57	7.48	6.71	8.06	6.82	7.10	7.14
CaO	9.28	9.72	9.98	10.39	9.41	10.80	10.06	9.52	10.54	9.84	9.81	9.80	8.65	9.38	9.22	9.80
Na_2O	3.58	4.04	4.62	4.48	4.56	2.50	3.46	3.82	4.66	4.23	4.36	4.19	4.10	4.16	4.16	4.06
K_2O	1.47	1.52	1.95	2.27	2.13	1.42	1.24	1.43	1.04	1.95	1.64	1.43	1.30	1.76	2.41	1.60
P_2O_5	1.22	1.14	1.54	1.55	1.36	1.20	1.59	1.23	1.67	1.30	1.32	1.53	1.27	1.54	1.23	1.39
Total	99.41	98.44	99.45	98.68	99.73	96.90	99.31	100.30	98.12	98.16	98.73	99.21	99.33	98.80	99.09	96.46

CIPW norm

wt%	NB-1	NB-2	NB-3	NB-4	NB-5	NB-6	NB-7	NB-8	NB-9	NB-10	NB-11	NB-12	NB-13	NB-14	NB-16	NB-21
Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Or	8.69	8.98	11.52	12.48	12.59	8.39	7.33	8.45	6.15	11.52	9.69	8.45	7.68	10.40	14.24	9.46
Ab	23.75	12.92	16.80	-	7.86	11.75	26.44	21.73	12.09	5.06	14.82	21.04	21.76	14.51	13.91	14.79
An	19.32	21.06	10.97	20.72	19.44	27.80	19.77	20.76	18.30	19.02	12.01	15.96	17.48	20.06	10.94	16.37
Ne	3.54	11.52	12.08	20.54	16.65	5.09	1.54	5.74	14.81	16.65	11.96	7.81	7.01	11.21	11.54	10.60
Di	15.28	16.06	23.42	17.05	15.05	14.59	16.16	15.06	18.99	17.35	22.87	18.66	13.92	13.36	21.83	19.04
Hy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ol	17.31	16.25	13.41	16.59	17.67	17.22	14.44	17.81	15.31	15.97	14.26	16.13	18.05	15.08	13.35	15.52
Mt	4.26	4.23	4.35	4.44	4.32	4.19	4.31	4.29	4.57	4.31	4.52	4.38	4.48	4.23	4.42	4.36
Il	4.52	4.98	3.27	2.51	3.04	4.98	5.43	3.63	3.82	6.30	5.51	3.63	6.00	6.44	6.02	3.00
Ap	2.83	2.64	3.57	3.59	3.15	2.78	3.68	2.85	3.87	3.01	3.06	3.54	2.94	3.57	2.85	3.22

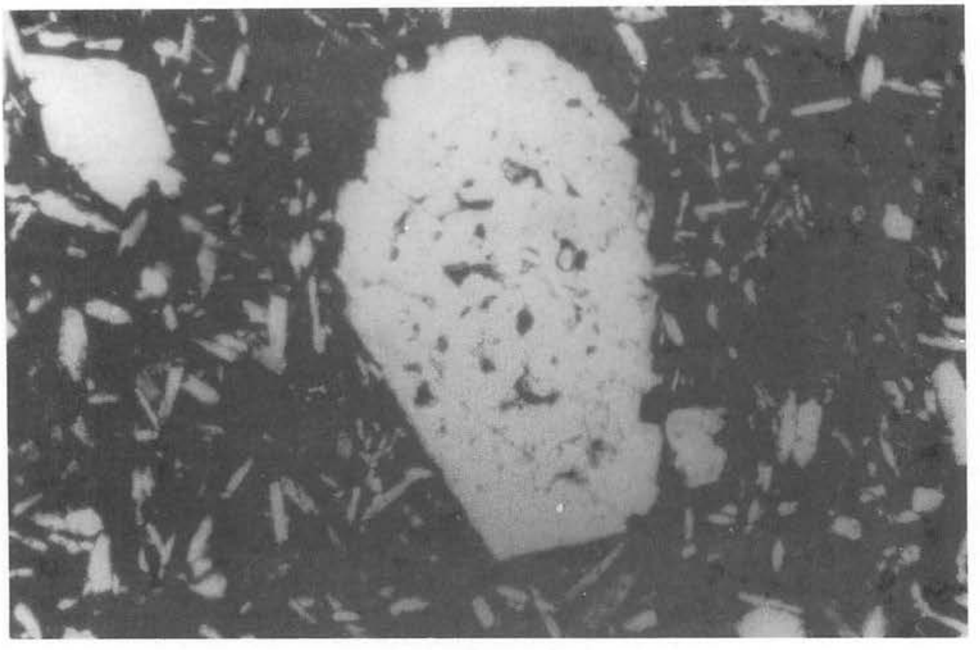

Fig. 5 Photomicrograph of Nong Bon basalt showing sieve texture in clinopyroxene phenocryst. Crossed nicols.

of the rock. Alkali-silica variation diagram (Figure 11) and AFM diagram (Figure 12) show that Nong Bon basalts are generally highly alkalic.

The major element contents of some of the Nong Bon basalts are given in Table 1. It shows that the rocks at Nong Bon have both basanite and nephelinite compositions, hence a term 'basanitoid basalt' (Barr & MacDonald, 1981) will be used in discussing the petrochemistry of the rocks of Nong Bon. The trace element content of the basaltic rocks of the Nong Bon are shown in Table 2.

Rare-earth element pattern of the basanitic basalts of Nong Bon (Figure 13) also shows corresponding pattern with rocks of alkalic series. The presence of Eu anomaly is probably due to its affiliation with clinopyroxene and garnet common in the Nong Bon basalts.

GENETIC CONSIDERATION

Basalt Petrogenesis

In discussing genesis of basanitoid basalts of Nong Bon the following points are considered: mantle soure materials, parental magma, mode of emplacement, and tectonic setting.

TABLE 2

TRACE ELEMENT CONTENT OF THE BASALTIC ROCKS OF NONG BON

ppm	NB-1	NB-2	NB-3	NB-4	NB-5	NB-6	NB-7	NB-8	NB-9	NB-10	NB-11	NB-12	NB-13	NB-14	NB-16	NB-21
Rb	28	43	31	18	30	37	18	19	37	48	49	25	28	36	60	31
Sr	1040	989	1112	1056	937	926	1136	852	1063	873	892	1208	914	1109	866	1040
Y	23	12	28	7	19	11	12	17	30	20	18	32	16	30	22	7
Zr	315	294	320	308	286	280	330	287	337	265	279	353	276	308	300	309
Nb	56	62	70	64	80	71	73	64	88	51	69	79	59	58	59	72
Ba	380	nd	529	656	729	nd	624	578	841	598	614	nd	622	351	663	525
La	65	50	102	90	55	623	108	77	74	76	77	93	76	66	71	80
Ce	104	112	133	136	114	105	142	91	120	14	98	133	92	89	80	96
Nd	30	37	34	42	41	43	38	46	39	32	56	48	33	33	47	18
Sm	11.38	7.54	10.26	13.81	9.63	10.36	12.	6.62	8.80	9.87	9.56	15.42	12.38	8.38	11.54	10.19
Eu	4.67	4.39	6.12	3.70	3.30	5.10	8.78	3.84	5.24	5.54	3.93	5.18	4.36	2.34	2.32	4.39
Dy	3.49	3.81	1.88	2.73	1.99	2.52	3.76	3.75	3.46	2.64	3.46	2.26	4.56	2.28	4.48	5.49
Yb	1.30	0.91	0.92	1.48	1.73	0.88	1.43	1.64	2.35	0.99	0.72	1.92	0.98	0.58	0.47	1.17
Lu	0.26	0.10	0.26	0.51	0.20	0.48	0.26	0.29	0.12	0.45	0.25	0.32	0.44	0.35	0.12	0.44
Hf	9.38	4.53	6.41	3.78	2.16	1.19	4.05	8.62	5.52	6.59	6.89	6.23	nd	5.05	8.89	4.65
Ta	2.99	1.28	2.74	2.84	3.06	2.79	3.78	0.92	2.84	4.63	4.16	4.85	3.90	2.12	1.46	1.80
Co	51	29	43	56	21	37	41	37	23	68	67	44	nd	53	40	28
Sc	18.1	16.7	13.1	14.9	13.7	14.8	15.3	12.4	11.6	14.4	14.5	14.5	16.9	11.8	19.3	12.3
V	223	257	289	232	280	235	216	244	375	273	264	240	295	231	268	190
Cr	133	85	144	87	66	39	77	64	38	102	88	119	29	52	101	110

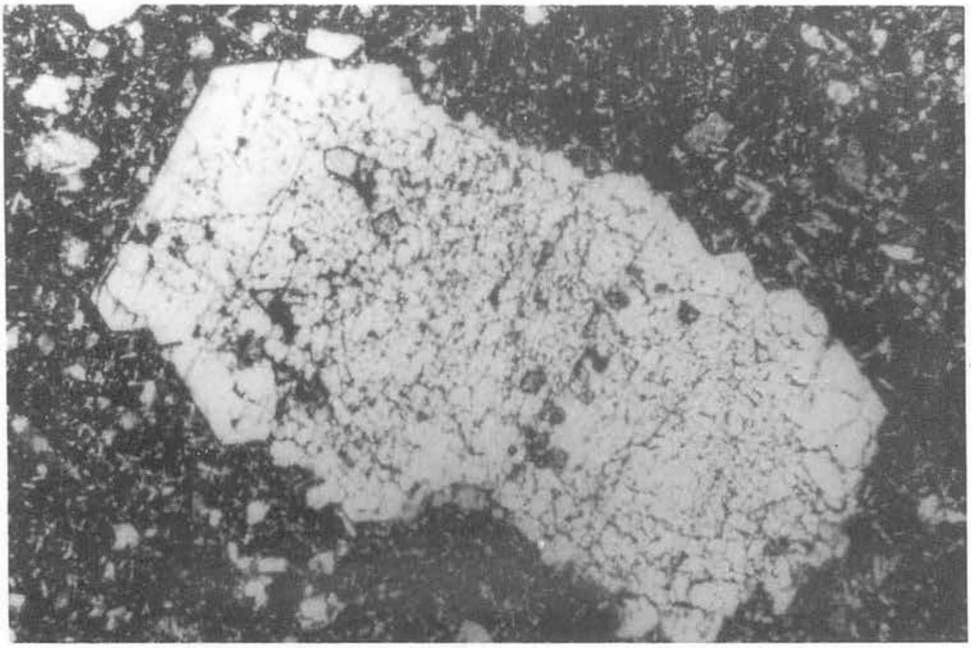

Fig. 6 Photomicrograph of corroded clinopyroxene megacryst in Nong Bon basalt, showing sieve texture. Crossed nicols.

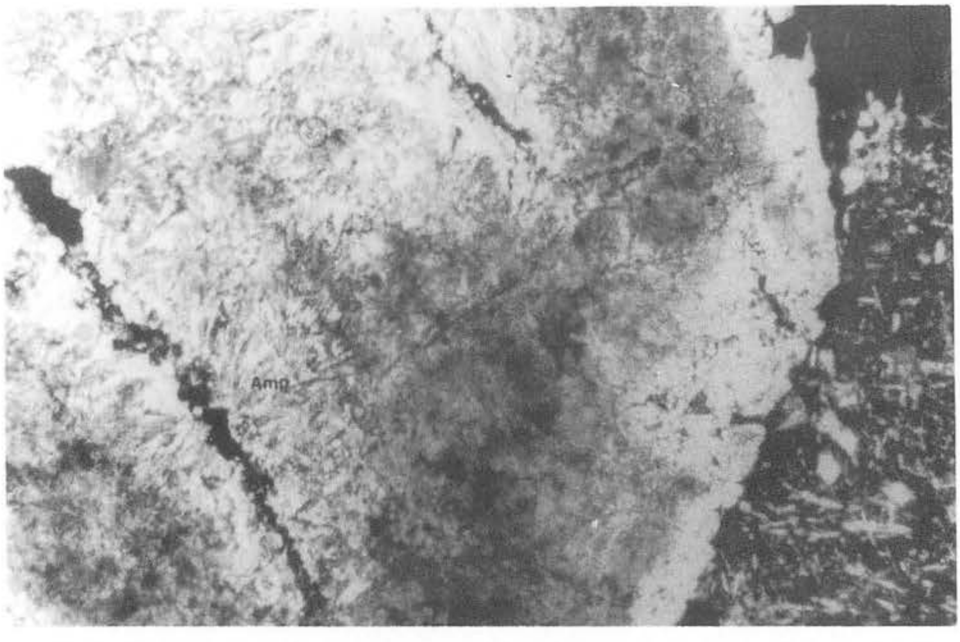

Fig. 7 Photomicrograph showing replacement of clinopyroxene megacryst by amphibole (Amp) in Nong Bon basalt. Crossed nicols.

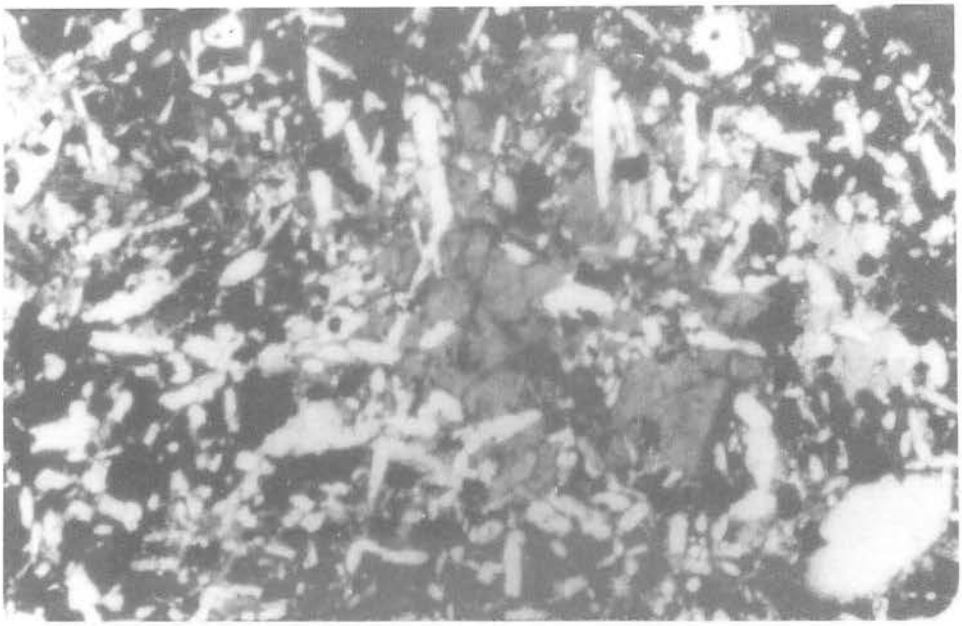

Fig.8 Photomicrograph of Nong Bon basalt showing nepheline (dark grey) and clinopyroxene laths (light colour). Crossed nicols.

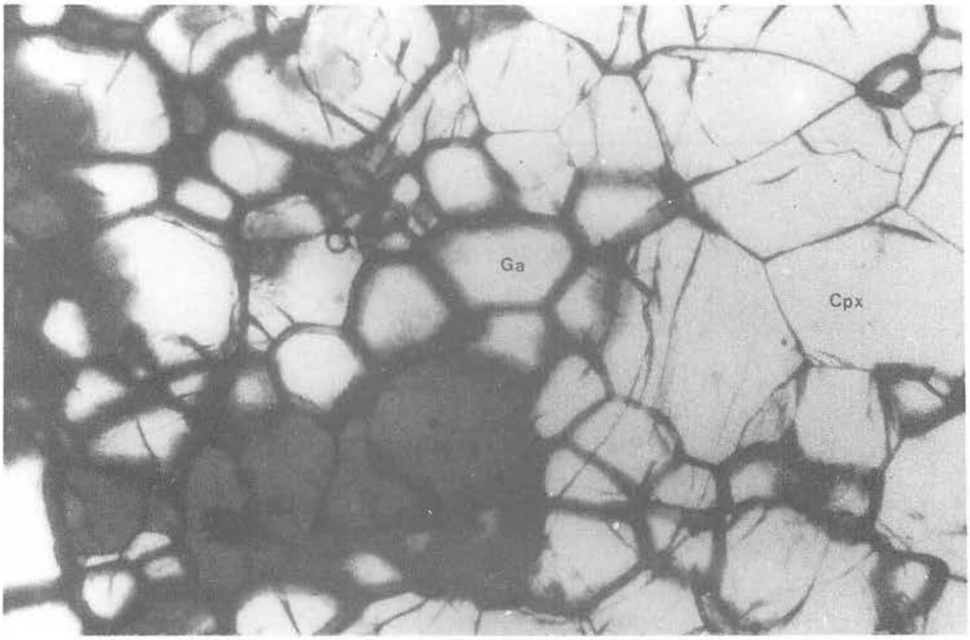

Fig. 9 Photomicrograph of xenolith in Nong Bon basalt, consisting of clinopyroxene (Cpx), garnet (Ga) and brown spinel (Sp). Uncrossed nicols.

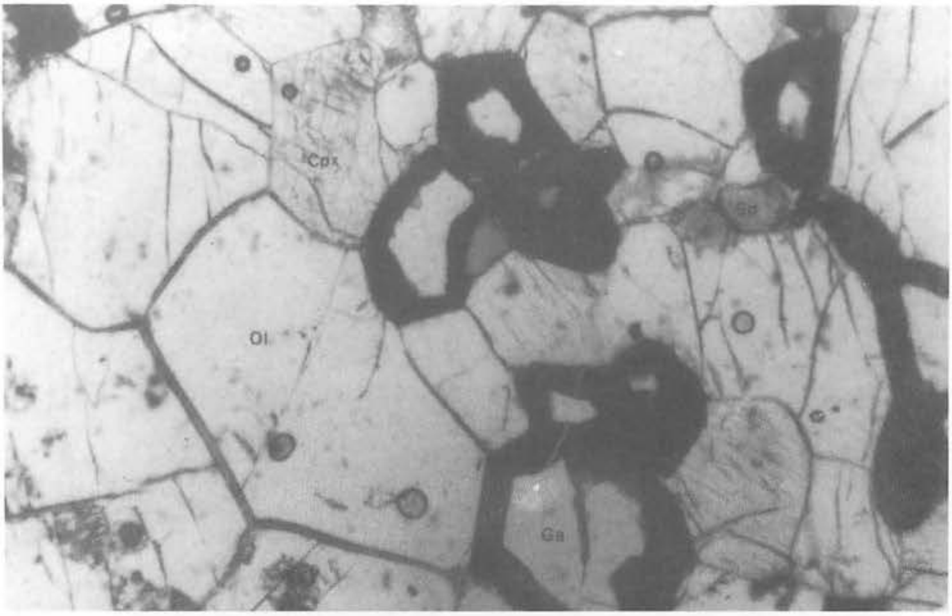

Fig. 10 Photomicrograph of xenolith in Nong Bon basalt, consisting of clinopyroxene (Cpx), garnet (Ga), olivine (Ol) and green spinel (Sp). Uncrossed nicols.

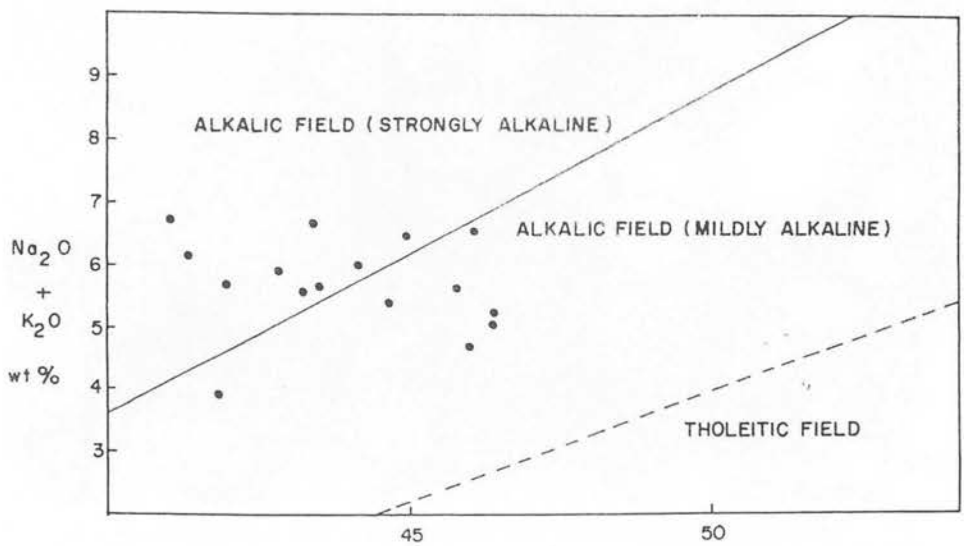

Fig. 11 Plots of Nong Bon basalts in alkali-silica variation diagram. Field boundary between tholeiitic and alkalic rocks is taken from Macdonald and Katsura (1964), while the one between strongly and mildly alkaline is from Saggerson and Williams (1964).

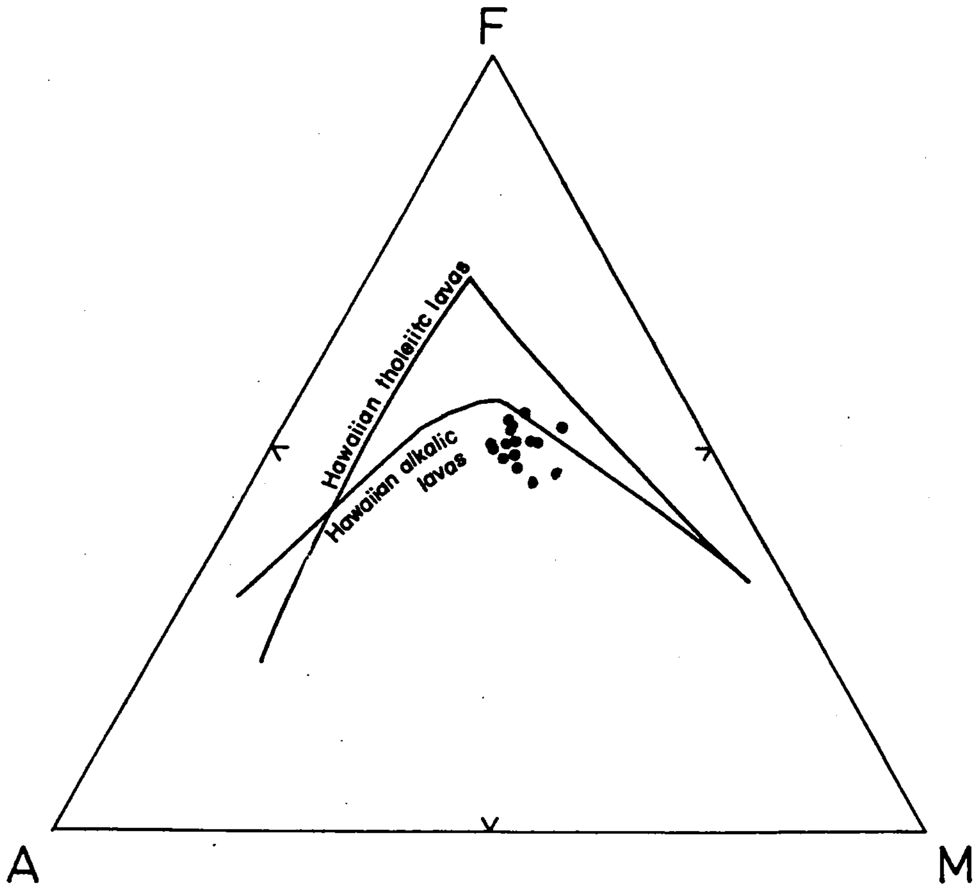

Fig. 12 Plots of Nong Bon basalts in AFM diagram. Both Hawaiian tholeiitic and alkalic lavas trends are from Macdonald and Katsura (1964).

1. *Mantle source materials.* Model mantle calculated by Griffin and Murthy (1969) was used for the determination of possible composition of source materials for the basaltic rocks of Nong Bon. When the ratios K/Rb (455 ± 190), Rb/Sr (0.034 ± 0.014), K/Sr (14 ± 4), and K/Ba (25 ± 8) o f the rocks of Nong Bon are compared with those of 'the model, it is noted that possible parental mantle material of the basanitoid basalts is "garnet peridotite + 0.2% phlogopite".

2. *Parental magma.* It is generally believed that basalt crystallized from either: (a) Primary magma, originated from partial melting of mantle material (pyrolite). The composition of primary magma depends largely on the original composition of the mantle material, degree of partial melting, temperature and pressure conditions (during melting), and volatile content (during melting); or (b) Derivative magma, derived from primary magma as a result of change in temperature and pressure conditions, development of crystal fractionation, and/ or reaction with wall rocks.

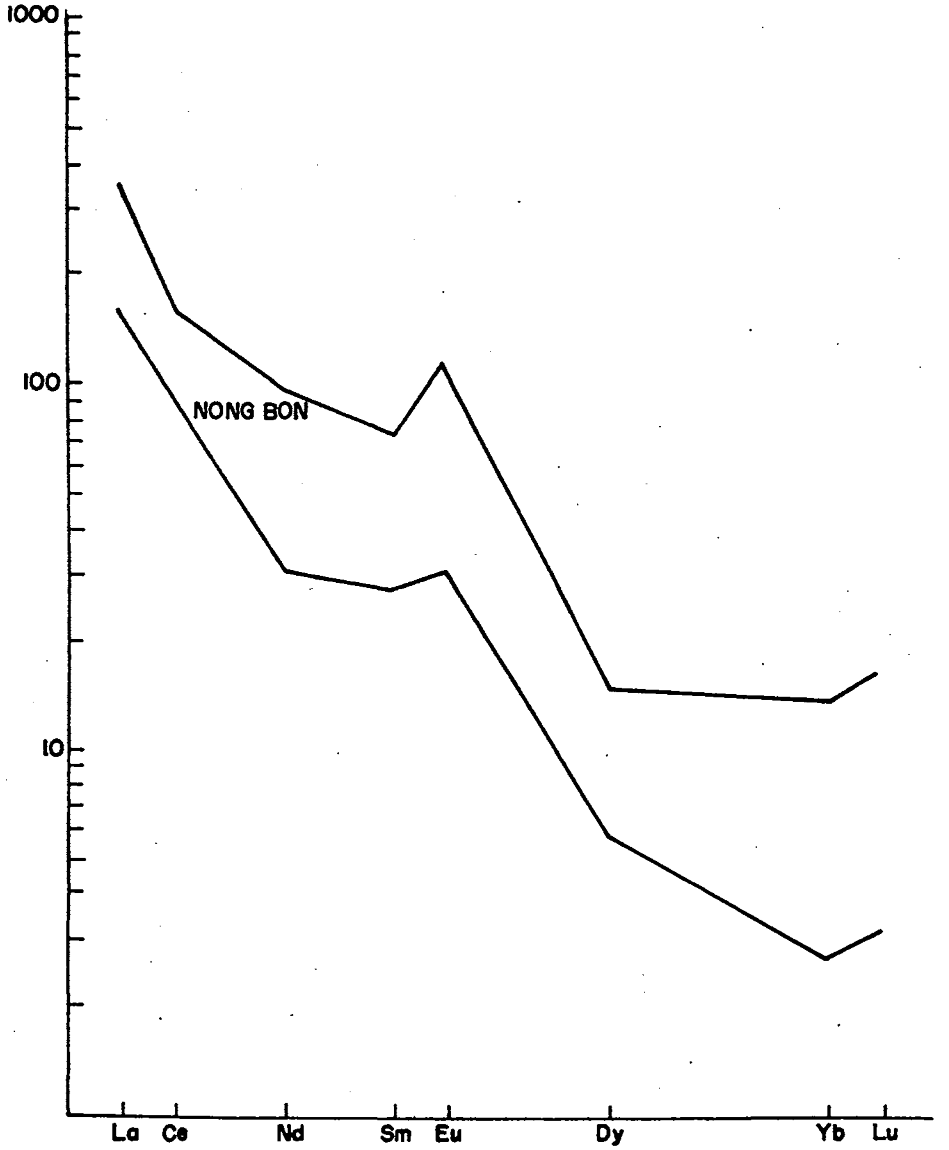

Fig. 13 Diagram showing rare-earth element pattern of Nong Bon basalts.

Considering the Mg-value (100 Mg/Mg + Fe^{2+}) and Cr-content of the basanitoid basalt of Nong Bon which are less than 66 and 300 ppm respectively, it is likely that the rocks crystallized from derivative magma (Green, 1971; Ringwood, 1975; Irving and Green, 1976; Frey and others, 1978).

The presence of xenoliths of ultramafic rocks and megacrysts of high pressure minerals such as clinopyroxene and garnet in the basanitoid basalts of Nong Bon suggest that the

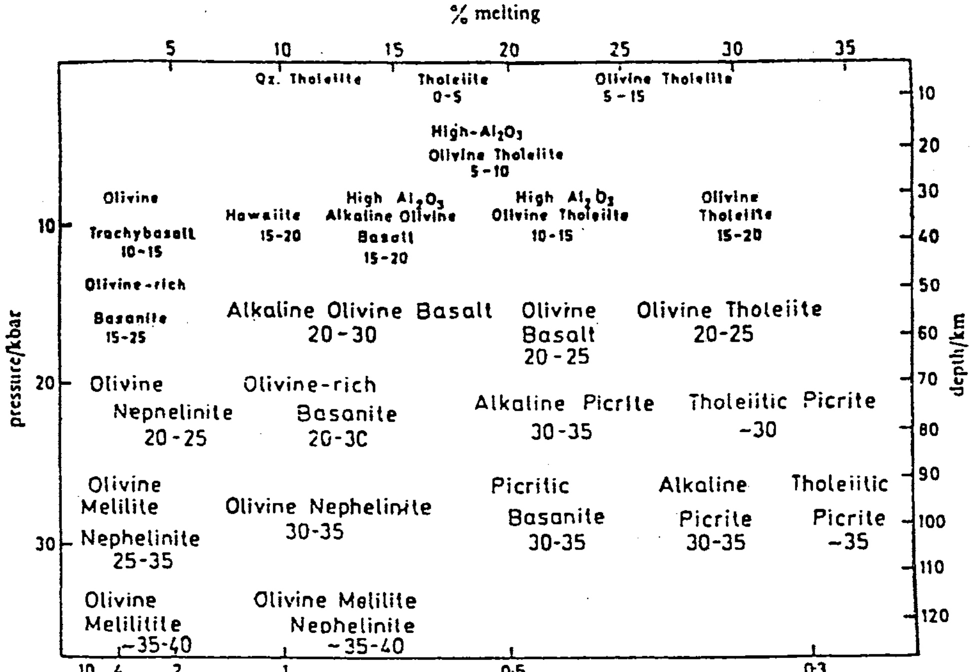

Fig. 14 Petrogenetic grid for mantle-derived basaltic magmas (after Green, 1971). The numbers placed with each type refer to the normative olivine content.

basalts crystallized from magma of direct mantle derivation (Green, 1971). Green's (1971) model for derivation of basalt types (Figure 14) and Bultitude and Green's (1971) experimental study were hence followed. From Figure 14 it is probable that the basanitoid basalts crystallized from a derivative parental magma which in turn, derived from a primary magma originated from 5-10% partial melting of pyrolite containing 0.1% H_2O at 20-25 kilobar (70 to 90 km depth).

3. *Mode of emplacement*. The presence of the xenoliths and megacrysts also suggests that the derivative parental magma of the basanitoid basalts rose rapidly to the surface. The rocks then crystallized directly from the magma without influences of differentiation and/or assimilation.

4. *Tectonic setting*. Plots of Nong Bon basanitoid basalts in a ternary Ti-Zi-Y diagram (Figure 15) of Pearce and Cann (1973) show that most of them lie close to the within-plate basalts field. The Y/Nb ratio of the basanitoid basalts, which is less than 1.0, is also in accordance with that of within-plate basalts. The within-plate tectonic setting of the Nong Bon basalt is also indicated by the plots of discriminant functions F_1 against F_2 for the basanitoid basalts (Figure 16).

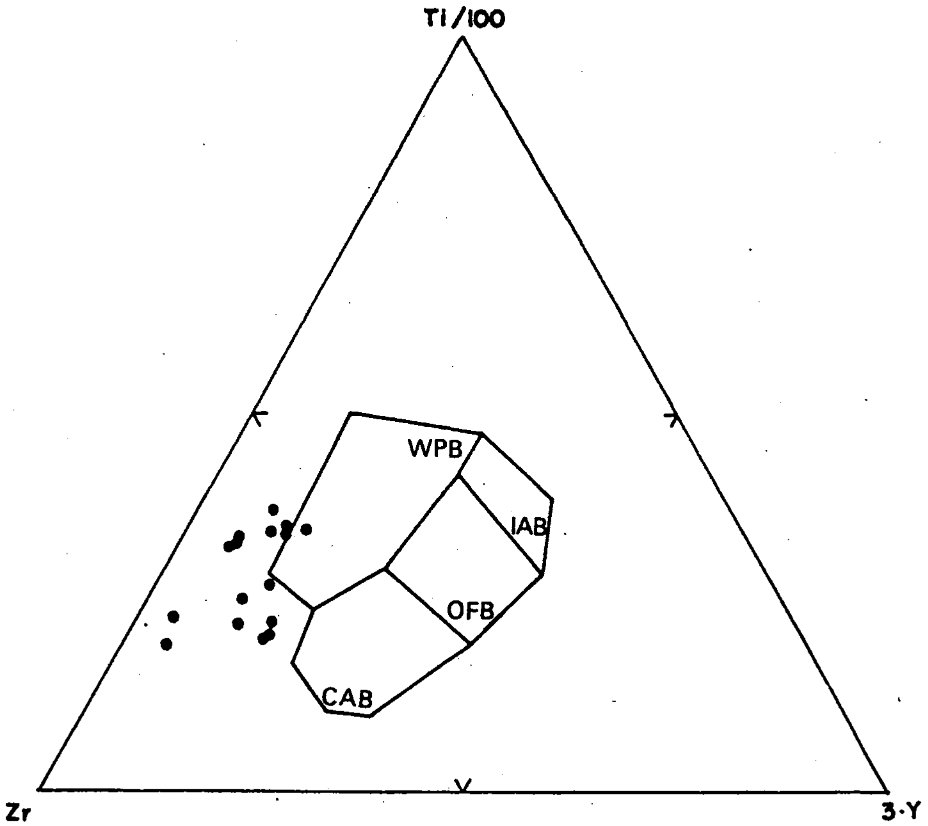

Fig. 15 Ti-Zr-Y ternary diagram with plots of basaltic rocks of Nong Bon. Field boundaries of the four different settings for basic volcanic rocks are after Pearce and Cann (1973).

On the basis of the foregoing discussion, it is concluded that the basanitoid basalts of Nong Bon crystallized from derivative magma whose parental primary magma originated from "garnet peridotite + 0.2% phlogopite" mantle material containing 0.1% H_2O, melted at a pressure condition of 20 to 25 kilobar with 5-10% partial melting. The derivative magma reached the surface, in within-plate tectonic setting, through rapid ascending hence no influences of the processes of differentiation or assimilation.

Genesis of Corundum

Although intact crystals of corundum in the solid rocks have not been observed in this study, field observations show that corundum is always found in the terrain covered with basaltic rocks, in the residual soil weathered from the basaltic rocks. It is logical, therefore, to state that corundum is closely related with the basaltic rocks. However, experimental petrologic studies showed that melting of pyrolite never yield corundum (O 'Hara, 1968 and Green, 1971). This suggests that it is not likely for corundum to crystallize in or with the basaltic rocks.

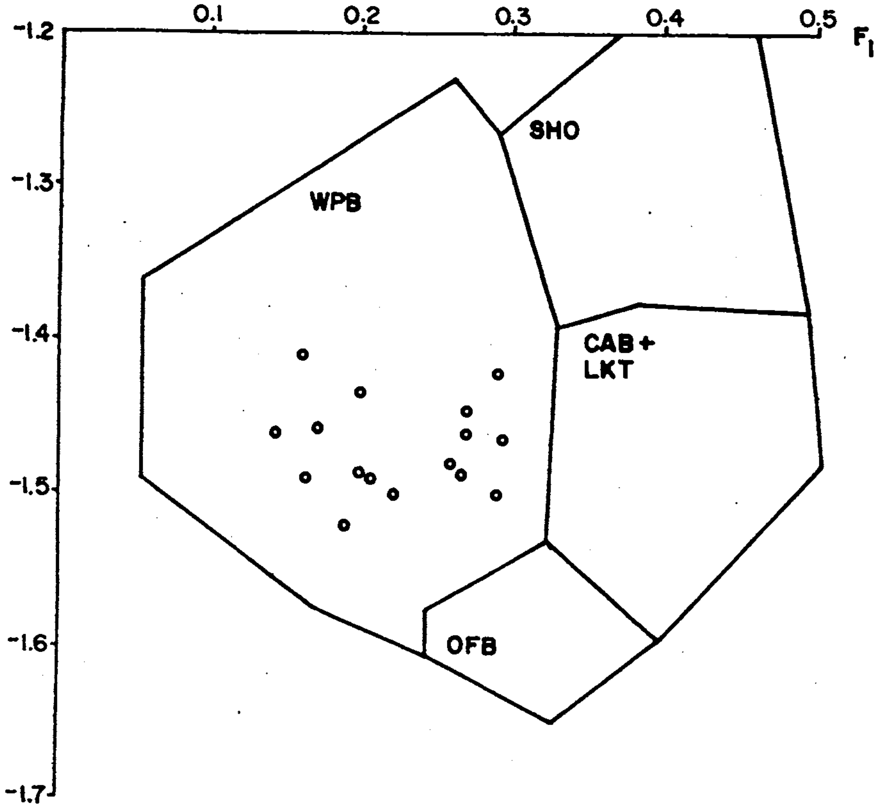

Fig. 16 Plots of discriminant functions F_1 against F_2 for samples of Nong Bon basaltic rocks. Field boundaries of ocean floor basalt (OFB), low-potassium tholeiite (LKT), calc-alkali basalt (CAB), shoshonite (SHO), and within-plate basalt (WPB) are from Pearce (1976).

Presnall and others (1978) studied the melting behaviour of synthetic diopside-anorthite-forsterite at various pressure and temperature conditions. The results are shown in Figure 17. First appearance of corundum in equilibrium with melt is at 7 kbar. The stability field of corundum increases with increasing pressure, while anorthite's field decreases. At 20 kbar anorthite disappears. This suggests that corundum should crystallize and is stable with melt at pressure not lower than 20 kbar. It is also noted, in Figure 17, that at lower pressure conditions the melt at piercing points has higher MgO content than that at higher pressure. This phenomenon is contradicted by the melting behaviour of mantle rocks whose melts contain higher MgO at higher pressure. Therefore the mantle material suitable for producing corundum must have a composition similar to the synthetic system studied by Presnall and others (1978) i.e. a suitable "depleted" mantle. This depleted mantle, partially melted at 20 kbar or higher, could yield corundum in equilibrium with pyroxene, spinel and melt. Subsequent rapid ascending of derivative magma of the basanitiod basalts from lower level could then pick up the corondum, pyroxene and spinel and bring them to the surface as megacrysts.

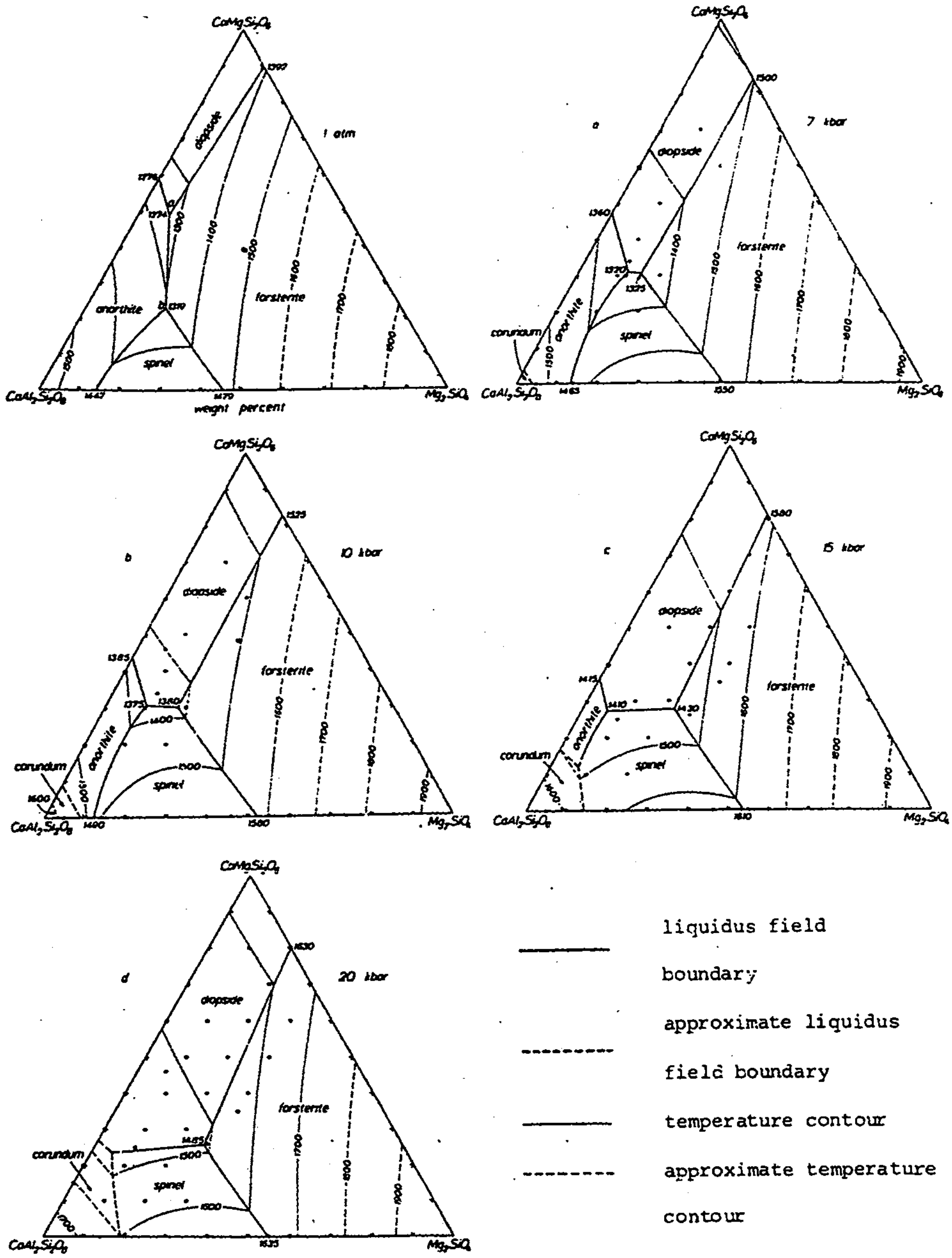

Fig. 17 Ternary diagram showing equilibrium of solid crystal phases and melt in the system diopside-anorthite-forsterite at various pressures (After Presnall and others, 1978).

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Manuscript received 8th February 1985
Revised manuscript received 17th September 1985