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The gabbroic suite and associated hornfelses of Bukit Kemuning, Trengganu, Peninsular Malaysia

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Abstract: The small body of gabbroic rocks exposed on Bukit Kemuning includes an interesting and highly varied complex of hornfelsed xenoliths and contact rocks. Associated quartz diorite and granophyre are minor occurrences.

The Kemuning gabbro is an iron enriched variety which contains high modal proportions of hornblende and biotite. Olivine and orthopyroxene vary in composition from Fo 32 to Fo 14 and En 53 to En 37 respectively while clinopyroxene is augite or ferroaugite. The gabbro texture is typified by reaction rims and intergrowths produced by late magmatic reaction relationships.

The hornfelses associated with the gabbro are classified into four major groups: (A) Titaniferous basic granular hornfels; (B) Micro-gabbroid basic granular hornfels; (C) Calc-silicate hornfels and (D) Siliceous hornfels. Some of the hornfelses display strikingly unusual mineralogy and chemistry. All the hornfelses, with one exception, are derived from sedimentary parent material. Basic granular hornfelses are produced by the contact metamorphic action of the gabbroic magma on the original sedimentary material involving a significant metasomatic transfer of Ca, Fe, Mg, Ti and Mn into the sediments. Calc-silicate and siliceous hornfelses have suffered essentially isochemical contact metamorphism.

The subalkaline Kemuning gabbroic suite cannot be uniquely identified with either the tholeiite or calc-alkali magma series. The mixed magmatic character of this suite is due to contamination of the gabbroic magma by the hornfelsed xenoliths.

INTRODUCTION

Gabbroic bodies marginal to larger granitic masses are known to occur in the Malay Peninsula. Amongst the largest of these bodies are the Gombak Norite in Singapore Island and the Linden Hill Gabbro in south Johore. Further north in the state of Trengganu, gabbroic rocks are again exposed on Bukit Kemuning together with minor quartz diorite and granophyre. The Bukit Kemuning gabbroic body, which is amongst the smallest of the known occurrences, is unique in that it is associated with a varied and interesting suite of hornfelses. These hornfelses are classified on the basis of essential mineralogy as follows: (A) Titaniferous basic granular hornfels—by virtue of high content of Ti-bearing minerals (titanaugite and sphene); (B) Micro-gabbroid basic granular hornfels—approximate gabbroic mineralogy; (C) Calc-silicate hornfels—typical calc-silicate mineralogy; (D) Siliceous hornfels—high quartz content. The Kemuning gabbroic suite is interesting in itself as it exhibits mixed calc-alkaline and tholeiitic characteristics.

This paper is concerned with the petrography, mineralogy and major element geochemistry of the somewhat unique Kemuning gabbroic suite and its associated hornfelses. It is aimed at contributing towards a better understanding of the basic intrusive bodies within the Malay Peninsula and accounts for the origin of the hornfelsic rocks associated with the Kemuning gabbro some of which display highly abnormal mineralogical and chemical compositions.

Methods of study

More than 150 thin-sections were examined in detail during the course of this investigation. Modal analyses were made on this sections with a Swift automatic point counter. At least 3,000 points were counted.

Refractive indices of minerals measured using immersion oils and an Abbey refractometer, are accurate to about ± 0.001 (in sodium light). All index observations on orthopyroxene were made using the prismatic cleavage and determining N_γ. The N_β index of clinopyroxene was determined on either (100) or (001) parting plates. The orientation was checked by the method described by Slawson and Peck (1936). Optic angles were mostly determined by direct measurement between axed on a 4-axis universal stage, the error being considered less than $\pm 2°$. Orthopyroxene compositions were determined from 2V or N_γ when measured, using the curves of Hess (1960, p. 27). Clinopyroxene compositions have been obtained by plotting the values of N_β combined with 2V against the curves of Hess (1949) as modified by Muir (1951). Composition of plagioclase was determined with a 4-axis universal stage using correlation curves by Slemmons (1962). Accuracy is believed to be in the region of ± 2 percent An. Several separate grain measurements were averaged to give a single cited value. Olivine compositions were first estimated by correlating 2V with the curve in Deer, *et al.*, (1962, vol. 1, p. 22). More accurate determinations were subsequently made using the d_{130}, powder X-ray diffraction method of Yoder and Sahama (1957). The error for each measurement ranges from 3 to 4 mol. percent.

All major and minor element analyses of rock samples and a single mineral were carried out by a combination of X-ray fluorescence spectrometry, atomic absorption and flame emission spectrophotometry. Chemical analysis for Si, Ti, Al, Fe, Mn and P were done by X-ray fluorescence, as outlined by Hutchison (1975 a), using the fused borate button sample technique of Norrish and Hutton (1969). All K determinations were performed by flame emission while Na and Mg were analysed by atomic absorption. FeO was determined by titration using the modified technique of Lo Sun Jen (1973). CIPW norms were computed by the programme of Hutchison (1975 b). The chemically analysed mineral was concentrated by repeated runs through a Franz isodynamic separator and heavy liquids (bromoform and methylene iodide). Final hand picking produced an extract of very high purity.

GENERAL GEOLOGY

The Kemuning gabbroic stock occupies the western half of Bukit Kemuning which is situated approximately 22 km north of Kemaman town (Chukai), (see Figure 1).

The gabbroic body is marginal to a small body of granitic rocks which appear to be an eastern extension of the Jengai Granite of Rajah *et al.* (1977). Metasedimentary rocks border the Kemuning stock to the west (Figure 2). These regionally metamorphosed sediments form a ridge striking north-northwest and consist

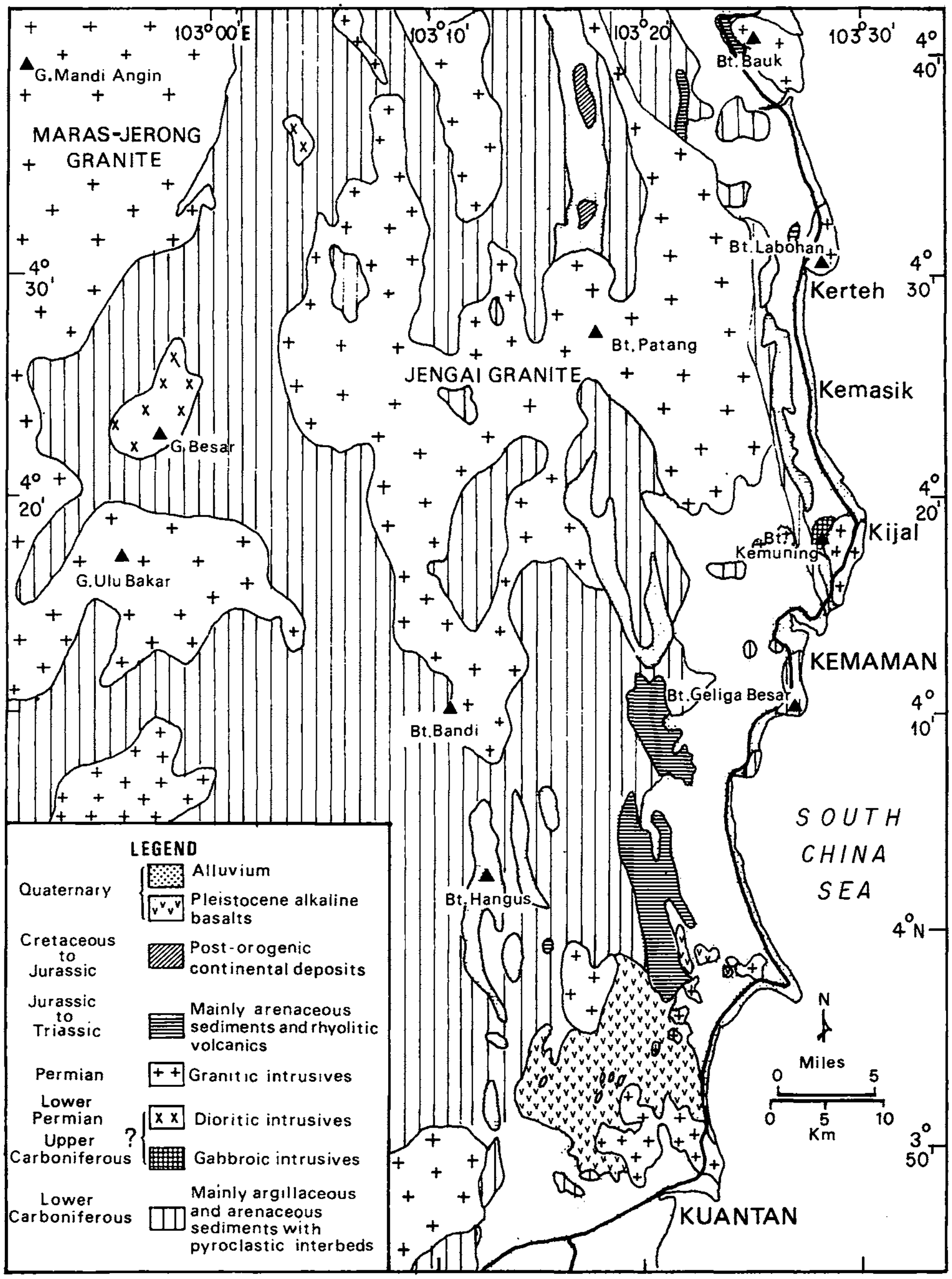


Fig. 1. Geological map of the Kemaman area of the Malay Peninsula, after Geological Survey of Malaysia (1973) and Kumar (1978), showing the location of the Kemuning gabbroic stock.

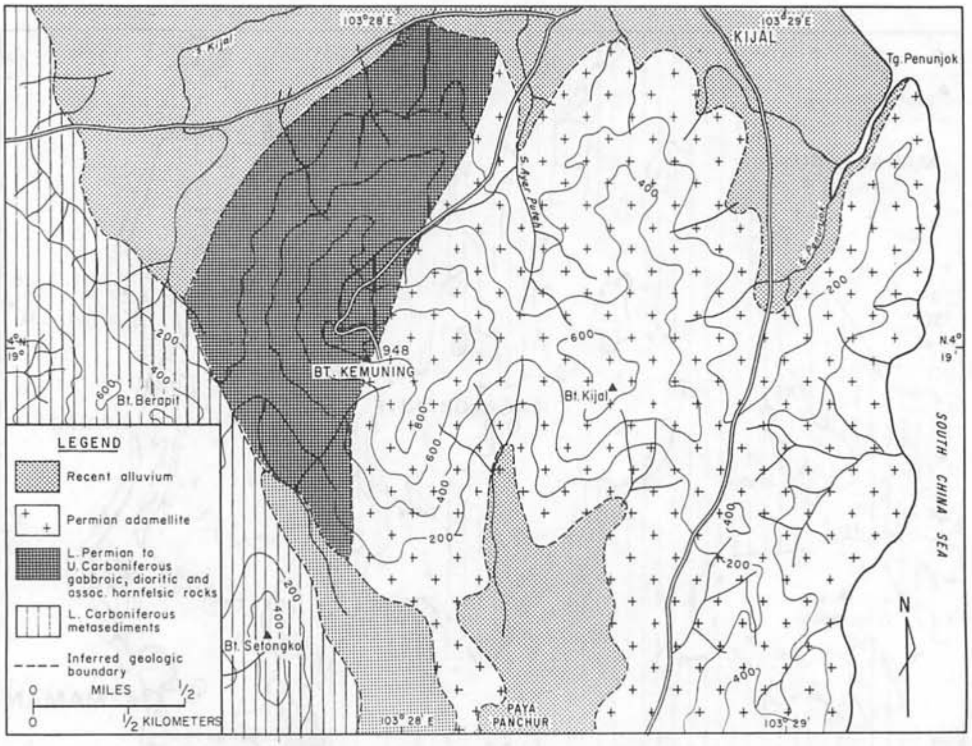


Fig. 2. The Bukit Kemuning area showing the outcrop of the Kemuning gabbroic stock in relation to the adjacent adamellite and metasediments.

essentially of phyllites, slates and schists interbedded with sandstone and quartzite. Fossil plant remains discovered by Goh (1973) give these metasediments a Lower Carboniferous age.

Definitely intrusive into the metasediments are gabbroic rocks of the Kemuning stock. Hornfelsed xenoliths of the metasediments are ubiquitous in the gabbroic rocks particularly along the western margin of the stock close to the gabbro-metasediments contact. In certain exposures large masses of hornfels, which are unlikely to be xenoliths, clearly overlie the gabbro and are intruded by tongues of the latter indicating that the gabbroic stock is only slightly unroofed by erosion. Most of the hornfelses examined and described in this paper are definite xenoliths.

As indicated above, and discussed later, most of the hornfelses are considered to be of sedimentary parentage despite the apparent igneous appearance of rocks belonging to groups (A) and (B). A hornfels of undoubted igneous parentage has also been sampled. This rock is believed to represent a hornfelsed fragment of the acid volcanics which are known to occur as interbedded pyroclastics and flows within the Lower Carboniferous metasediments.

The granitic body which includes the eastern half of Bukit Kemuning is composed mainly of a medium grained hornblende and biotite bearing adamellite. Granodiorite and weakly porphyritic varieties are local variations. Medium to fine grained dark coloured xenoliths of igneous parentage are abundant in the granitic rocks along the coast. Aplite dykes and veins are common throughout the granitic mass. The Bukit Kemuning adamellite has not been radiometrically dated. By correlation with radiometrically dated granites to the west (Bukit Bandi, approximately 51 km west of Kemaman) and north of the Kemuning area (an unnamed pluton approximately 20 km north of Bukit Kemuning), the Kemuning adamellites are probably of Permian (250 Ma) age.

The exact age relationship between the Kemuning gabbroic stock and the adjacent adamellite is not evident in the field. However, a pre-granite age is strongly indicated by the occurrence of acidic dykes within the gabbro which appear related to the Permian adamellite. Gabbroic stocks in the southern Malay Peninsula are similarly believed to pre-date their associated granites (Kumar, 1980 b). This temporal sequence of basic plutons being emplaced earlier than their associated granites is in fact typical of batholithic associations throughout the world. A lower limit for the age of the Kemuning gabbro is clearly defined by the Lower Carboniferous metasediments into which the gabbroic stock intrudes. It would appear that the age of the Kemuning stock may be confined to the Permo-Carboniferous.

PETROGRAPHY AND MINERALOGY OF THE GABBROIC SUITE

Gabbroic Rocks

The Kemuning gabbro is a medium grained ophitic rock without recognisable cumulate textures. High modal proportions of hornblende and biotite are characteristic, and together they commonly exceed pyroxene in amount and may constitute more than 20% of the rock. In addition titanomagnetite-ilmenite and apatite are persistent accessories which may individually exceed 5% in mode. Few samples are olivine bearing while in others quartz is almost always present. Varying proportions of clinopyroxene and orthopyroxene result in petrographic varieties which range from gabbro through gabbro-norite to norite.

Plagioclase composition varies from An 72 to An 50 throughout the suite. The most common type being labradorite of composition approximately An 65. The mineral forms strongly zoned subhedral laths. Moderately developed planar alignment of the plagioclase laths may sometimes be observed.

The iron enriched character of mafic minerals is perhaps the most interesting feature of the gabbroids of this stock. Olivine and orthopyroxene range in composition from Fo 32 to Fo 14 and En 53 to En 37 respectively. Clinopyroxene is either augite or ferroaugite (see Figure 3). In consideration of the co-existing plagioclase composition which is labradorite, the Kemuning gabbro may be better termed 'ferrogabbro' (Wager and Deer, 1939). Clinopyroxene is subophitic or granular and occurs as clusters of several individual grains. Orthopyroxene however is distinctly poikilitic and forms large interstitial plates with common inclusions of plagioclase, opaques, clinopyroxene and apatite. In addition, inclusions of fine subrounded grains of resorbed olivine may

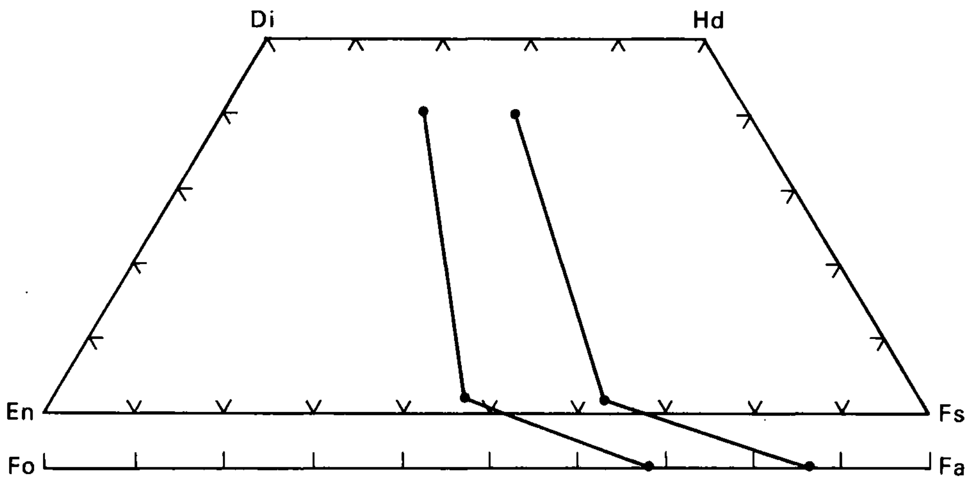


Fig. 3. Variation in composition of coexisting clinopyroxene, orthopyroxene and olivine in gabbroic rocks from the Kemuning stock. The tie-lines represent samples BK-23 and MI2M from left to right.

also be found. Inverted pigeonite is not texturally recognised in Kemuning gabbro even in the most ferriferous compositions. On the contrary exsolution lamellae are either absent or very poorly developed as in ferrohypersthene.

Early magmatic opaque minerals and apatite are most often idiomorphic though occasionally they may be irregular in shape. They may occur as inclusions in all other phases, though mainly confined to the zoned margins of plagioclase. Opaque minerals are titaniferous magnetite and ilmenite. Rare fine grains may show lamella intergrowths of the two oxides. Apatite granules may measure up to 2 mm in length.

Late magmatic reaction relationships produce conspicuous reaction rims and intergrowths which typify the gabbro texture. Reaction rims follow the sequence of Bowen's discontinuous reaction series. Olivine commonly shows mutliple or single rims of orthopyroxene, clinopyroxene and hornblende (Plate 1). Hornblende replaces clinopyroxene along grain boundaries and in some cases along cleavage and parting planes (Plate 2). Replacement of subophitic clinopyroxene may leave few small relict areas with only minor alteration of the textures of enclosed minerals. Symplectitic intergrowth of orthopyroxene and opaque oxides (Plate 3) occasionally observed in these rocks may be explained by the subsolidus oxidation of olivine (Yoder and Tilley, 1962, p. 425; Goode, 1974). Alternatively, orthopyroxene-magnetite symplectites may be due to olivine resorption (Kuno, 1950, p. 970). Biotite is almost invariably associated with opaque minerals usually forming extensive mantles around them. Thin films of translucent hematite of brilliant red colour may also surround the opaques. Strikingly similar textural relations have been reported from the Piedmont gabbros of the southern Appalachians, U.S.A (Hermes, 1968; McSween and Nystrom, 1979; Medlin, *et al.*, 1972; Butler and Ragland, 1969).

Uralitization is a common phenomenon, sometimes so severe as to leave no trace of the original pyroxene.

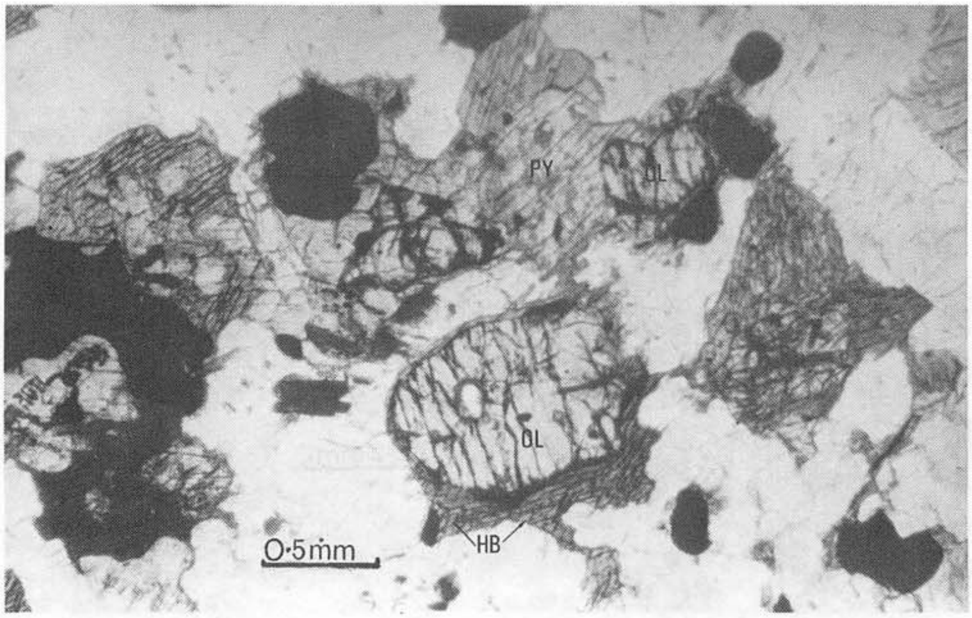


Plate 1. Photomicrograph in plane light showing rims of hornblende and pyroxene around olivine. Kemuning gabbro-norite. (HB-hornblende, PY-pyroxene, OL-olivine).

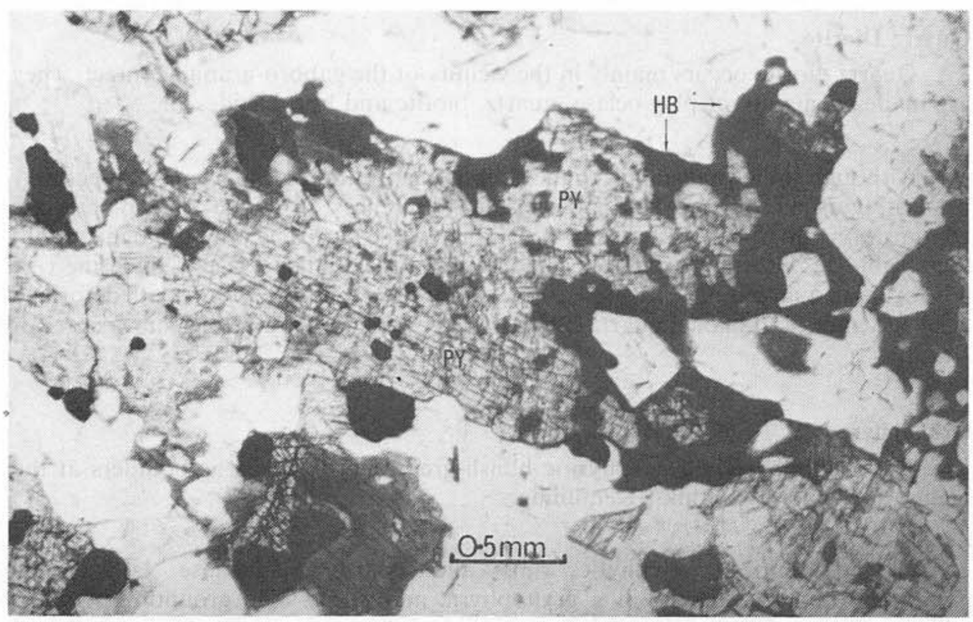


Plate 2. Photomicrograph in plane light showing rim replacement of pyroxene by hornblende. Kemuning gabbro-norite. (PY-pyroxene, HB-hornblende).

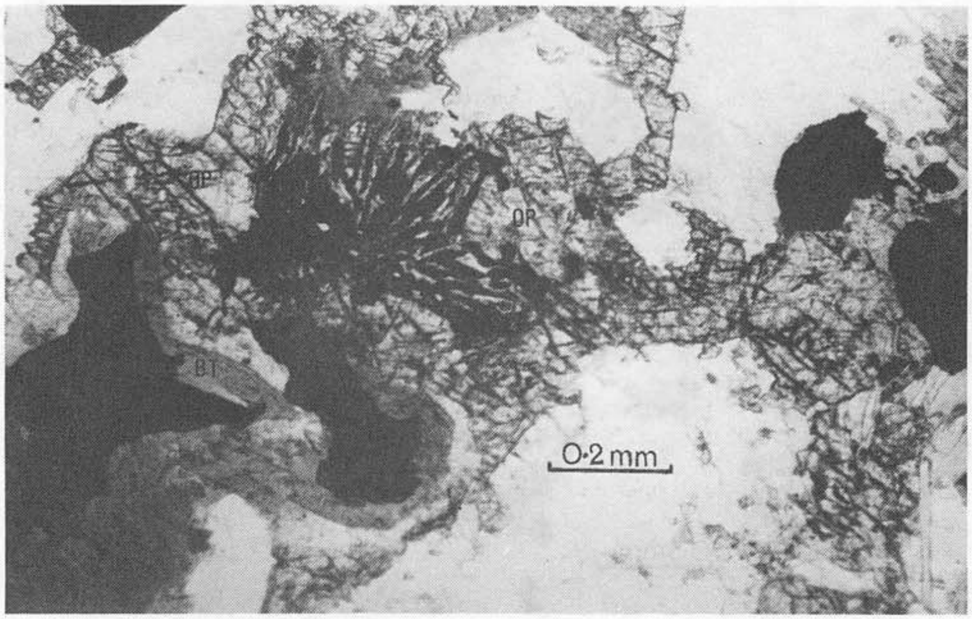


Plate 3. Photomicrograph in plane light showing vermicular intergrowth of opaque mineral in orthopyroxene. The associated opaques are rimmed by biotite. Kemuning gabbro. (OP-orthopyroxene, BT-biotite)

Quartz Diorite

Quartz diorite occurs mainly in the vicinity of the gabbro-granite contact. They are made up mainly of plagioclase, quartz, biotite and hornblende.

Although somewhat similar to the gabbro in appearance, the two rock types may be distinguished on the basis of certain differences in mode and plagioclase composition. Quartz is an abundant constituent while pyroxene is minimal in amount (See Table 1). Orthopyroxene may be entirely absent. Plagioclase is andesine (An 36–An 38) in quartz diorite as opposed to labradorite in gabbro. Biotite with deformed cleavage traces and biaxial quartz ($2V < 10°$) are common, indicating some degree of strain.

Granophyre

The granophyre is a porphyritic bluish-grey rock observed as boulders at the highest most point on Bukit Kemuning.

Olivine centred kelyphytic rims and coarse plagioclase laths form glomeroporphyritic clusters in a granophyric mesostasis. The groundmass which makes up about 70% of the rock comprises an intricate intergrowth of quartz and feldspar.

TABLE I

PETROGRAPHICAL AND MINERALOGICAL DATA FOR SOME REPRESENTATIVE ROCKS FROM THE KEMUNING GABBROIC STOCK.

Specimen	BK-23*	KE31C*	M8N*	M12M*	31K	M121*	M8M*	BK-9*
Olivine	4.4	—	—	0.8	0.8	—	—	—
Plagioclase	50.2	59.6	54.7	52.7	74.8	47.7	50.8	62.5
Clinopyroxene	8.2	3.3	10.0	8.6	2.1	1.9	1.3	3.5
Orthopyroxene	12.0	12.1	6.1	12.6	<0.5	0.6	0.5	—
Amphibole+	14.3	16.0	10.4	2.9	15.6	22.9	9.2	8.6
Biotite	3.8	3.7	10.6	8.7	0.9	14.7	11.3	9.4
Quartz	—	1.4	0.8	4.7	3.4	7.6	24.5	14.0
Opaque minerals	5.3	3.7	4.6	4.2	1.4	2.5	2.2	1.4
Apatite	1.8	<0.5	3.0	1.6	1.0	2.1	<0.5	0.7
% Fo in olivine	3.2	—	—	14	—	—	—	—
% An in plagioclase	72	68–65	—	55–50	52	—	—	37
Clinopyroxene N_β	1.698	—	—	1.712	—	—	—	—
$2V_z$	49	—	—	51	48	—	—	—
Orthopyroxene N_γ	1.722	—	—	1.742	—	—	—	—
$2V_x$	53	43	50	64	45	—	—	—

*Chemical analysis and brief description appear in Table 4.

+Includes uralite after pyroxene.

31K—Anorthositic gabbro, probably due to contamination by xenoliths. Loc. Bt. Kemuning.

Fayalitic olivine is rimmed by concentric margins of minute amphibole and biotite flakes. The biotite rich outer margins are associated with abundant opaque granules. Euhedral plagioclase prisms of the glomeroporphyritic clusters are andesine in composition. Plagioclase margins in contact with the groundmass are entirely uncorroded.

CRYSTALLISATION SEQUENCE

In the absence of megascopic layering, diagnostic textures and cryptic variation of the minerals are used to infer the order of crystallisation of minerals and rocks. The progressive sequence of Fe enrichment in coexisting ferromagnesian minerals presumably represents increasing differentiation.

The compositional variation of coexisting clinopyroxene, orthopyroxene and olivine from two samples of the Kemuning gabbroic suite is illustrated in Figure 3. The Fe enriched mineralogy of the Kemuning gabbro is readily apparent. There is a definite systematic variation in composition of these ferromagnesian minerals. In addition, coexisting plagioclase demonstrates a consistent decrease in calcium content from An 72 to An 50 in sympathy with the decreasing Mg content of the ferromagnesian minerals.

Limited petrographic criteria, due essentially to the absence of obvious cumulates, coupled with late magmatic mineral reactions allow only an approximation of the crystallisation sequence of the Kemuning gabbroic suite. The following stages of crystallisation are inferred:

(i) Early—crystallisation of olivine, plagioclase, titanomagnetite, ilmenite and apatite.

(ii) Intermediate—continued crystallisation of early magmatic phases with olivine-liquid reaction, crystallisation of clinopyroxene followed by orthopyroxene.

(iii) Late—reaction and crystallisation of hydrous minerals and quartz. A late volatile phase appears to have been active as evidenced by extensive uralitization, sericitization and late stage residual deposits of granophyre and abundant quartz veins.

PETROGRAPHY AND MINERALOGY OF THE HORNFELSES

Titaniferous Basic Granular Hornfels

Titaniferous hornfelses are extremely interesting rocks with strikingly peculiar mineralogy and texture. They are either massive or banded. The massive variety shows coarse amphibole porphyroblasts up to 3 cm in length while banded rocks possess fine alternate light and dark coloured bands which vary in thickness (commonly < 3 mm) and frequency from sample to sample.

The banded variety will be described first. It is seen in thin-section to comprise between 80–95% of an uncommon, vividly pleochroic titanaugite. This metamorphic titanaugite and similar species from other areas are chemically distinct from titanaugite of igneous paragenesis by their exceptionally high alumina and low silica contents, as pointed out by Kumar (1980 a). The mineral is almost always fine grained and forms granoblastic aggregates (Plate 4-A) segregated into layers which alternate with felsic bands. Some samples are virtually monomineralic where the layering is barely visible as the felsic bands become very narrow and discontinuous.

Amphibole, sphene and biotite occur in variable amounts in these rocks. Like the titanaugite, they are also strongly coloured and pleochroic. Sphene occurs either as fine euhedral grains segregated into distinct bands or rare coarse anhedral grains associated in patches with hornblende. Hornblende forms fairly large sieve textured porphyroblasts in all stages of development which include numerous pyroxene and apatite granules.

Leucocratic layers are usually a cloudy cryptocrystalline mass of altered plagioclase which finger into the adjacent pyroxene rich bands. Rare garnet and calcite may be associated with these felsic layers. Advanced alteration of plagioclase appears to be characteristic of these titanaugite rich rocks.

Massive titaniferous hornfels appears, at first sight, to be distinct from the banded variety. However, several features reveal that the two rocks are related. The overall texture of the massive hornfels may be described as poikiloblastic granular.

Clinopyroxene is the main constituent. Two varieties are readily recognised. The more abundant pyroxene is a light greenish, faintly pleochroic diopside. Titanaugite identical to the species in the banded rocks is also present though very subordinate in amount. The pyroxenes together comprise almost 40% of the rock. They occur as small equidimensional, drop-like inclusions in coarse poikiloblastic plagioclase (An 31 to An 34). The included pyroxenes often form train-like aggregates. This feature, if exaggerated, would tend towards the texture of the banded titaniferous hornfels with pyroxene rich bands alternating between interstitial plagioclase rich layers. Interestingly, plagioclase immediately adjacent to the included pyroxene is always zoned.

Hornblende forms coarse subhedral or anhedral porphyroblasts in the massive variety. Less developed sieve plates with numerous partially replaced pyroxene inclusions are also present. It is clear that hornblende forms at the expense of plagioclase and pyroxene (Plate 4-D). Unreacted areas of plagioclase occur as inclusions within the hornblende porphyroblasts. These inclusions are in optical continuity with the surrounding plagioclase. It is also significant that plagioclase immediately enclosing hornblende is conspicuously devoid of pyroxene inclusions.

Sphene is common and variable in grain size and shape (Plate 4-C). The mineral is usually poikiloblastic with inclusions of pyroxene granules. Rare twinned sphene crystals are noted. Textural relations suggest that sphene is contemporaneous with hornblende.

Micro-Gabbroid Basic Granular Hornfels

Hornfelses of this group are characterised by mineralogical assemblages which approach or are similar to the main gabbroic rocks. The chief constituents are usually plagioclase, pyroxene, biotite and opaques. Quartz, amphibole, and orthoclase may be significant components. Olivine is on occasion also a significant constituent. Fine grained small xenolithic patches often encountered in the gabbro (Plate 4-E) are included in this group.

Although mineralogically quite similar, the micro-gabbroid hornfelses and enclosing gabbro are texturally very distinct. The hornfelses show typical granoblastic texture. Grain size rarely exceeds one mm. Furthermore, there is an almost invariable tendency for the various minerals to segregate into distinct layers producing a banded structure (Plate 4-B). Samples which exhibit an entirely random distribution of minerals are extremely rare.

Plagioclase is usually An 49 to An 57 though rare specimens may contain sodic bytownite (An 72–An 74). Monoclinic and orthorhombic pyroxene occur together. Orthopyroxene ($2V_x \simeq 70 - 78$) is generally more abundant than augite ($2V_z \simeq 50 - 53$). Besides forming bands and train-like aggregates, fine subrounded granules of orthopyroxene may coalease producing large sieve plates (Plate 4-F). Such sieve plates are optically continuous. Magnesian olivine ($2V_x 84 \pm 1$) is usually granular. In a single strongly banded sample, olivine forms idiomorphic grains associated with other ferromagnesian minerals in rare coarse grained bands which alternate with fine grained

DESCRIPTION OF PLATE 4

Photomicrographs of hornfelses associated with the Kemuning gabbroic stock. A, B, D, F and H in plane light. C, E and G under crossed polars. (PL—plagioclase; PY—pyroxene; SP—sphene; HB—hornblende; PHH—potasian hastingsitic hornblende).

A—Granoblastic aggregate of pleochroic metamorphic titanaugite with some apatite granules. Banded titaniferous basic granular hornfels.

B—Banded micro-gabbroid basic granular hornfels showing alternating pyroxene rich and plagioclase rich bands.

C—Euhedral and anhedral sphene sieved by pyroxene granules in association with hornblende. All the minerals are included in coarse poikiloblastic plagioclase. Massive titaniferous basic granular hornfels.

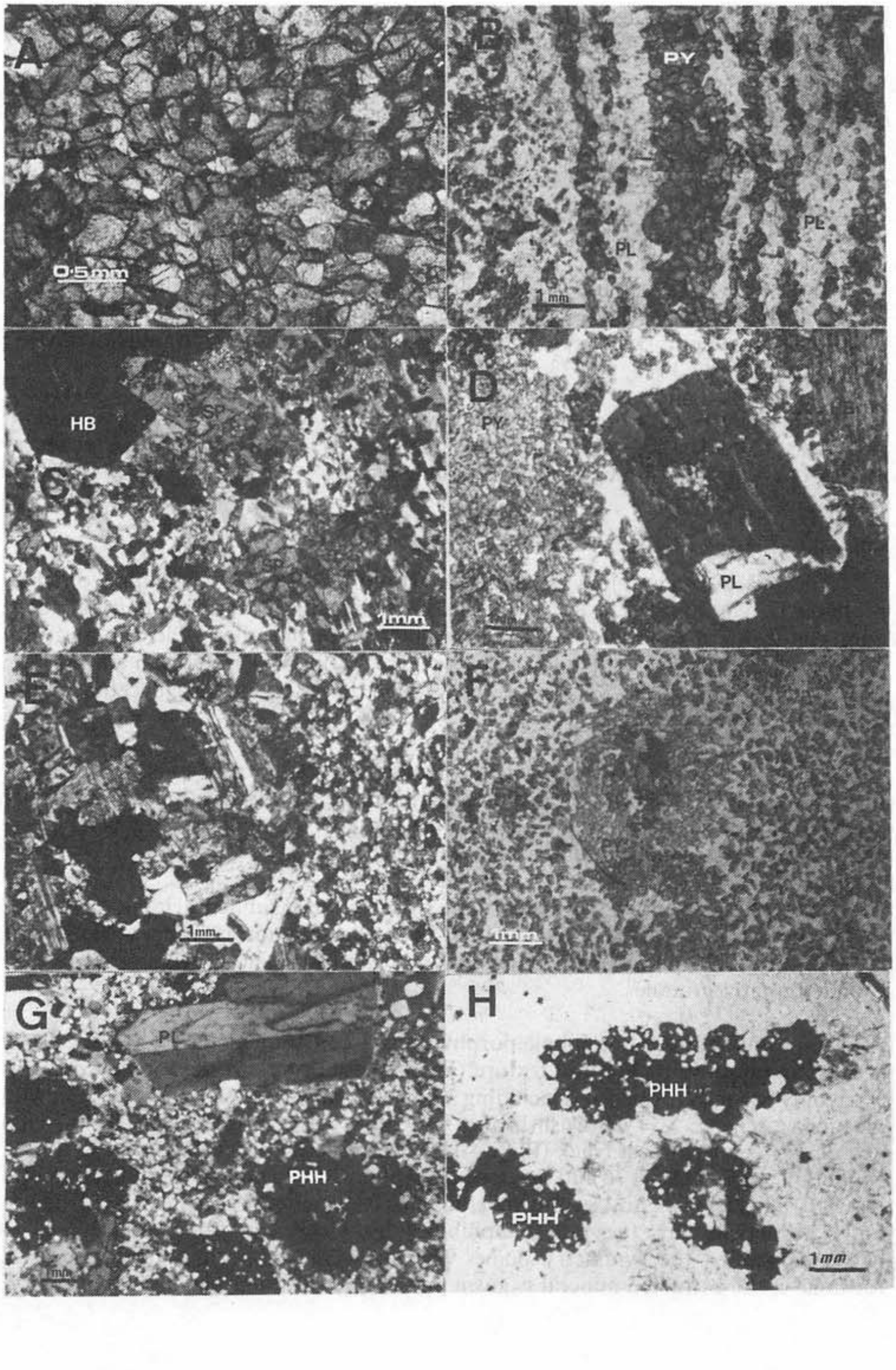
D—Hornblende porphyroblast forming at the expense of plagioclase and clinopyroxene. Note that plagioclase immediately surrounding hornblende is virtually devoid of pyroxene inclusions. The plagioclase is a single optically continuous porphyroblast. Massive titaniferous basic granular hornfels.

E—Photomicrograph showing contact between a small xenolith of micro-gabbroid hornfels, (to the right), and normal gabbro. Contaminated gabbro.

F—Fine subrounded granules of hypersthene coalease producing large optically continuous sieve plates. Micro-gabbroid basic granular hornfels.

G—Overall texture of siliceous hornfels of igneous parentage showing plagioclase and potasian hastingsitic hornblende porphyroblasts in a granoblastic mesostasis of quartz and feldspar.

H—Pleochroic sieve textured porphyroblasts of potasian hastingsitic hornblende in a granoblastic matrix of quartz and feldspar. Siliceous hornfels of igneous parentage.


A
0.5mm
B
PY
PL
PL
1mm
HB
SP
SP
1mm
D
PY
PL
E
1mm
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PL
PHH
H
PHH
PHH
1mm

bands. Opaques may range in mode from less than 1% to almost 15%. Typically the opaques segregate into mafic bands together with other coloured minerals.

Calc- Silicate Hornfels

The hornfelses of this group are white or whitish-grey in colour. Some specimens are clearly banded. They are usually fine to very fine in grain size. Often, the calc-silicate hornfelses occur as thin layers within other hornfelsic types. As such, they probably represent hornfelsed, rare calcareous interbeds of the original sediments.

Diopside is the most important component. Other minerals include plagioclase, quartz, scapolite, garnet, sphene, calcite and rarely biotite. In scapolite bearing rocks, diopside forms idiomorphic grains ($2V_z 66$, $Z \wedge c$ 48) included in large anhedral masses of mizzonite (Me 70 ± 5, $\delta 0.023 \pm 0.002$).

Feebly birefringent grossularite usually occurs as very fine grains in a random granoblastic association with diopside. Occasionally it may form large anhedral masses concentrated in megascopically visible bands.

Siliceous Hornfels

Siliceous hornfelses may be subdivided into two groups depending on their probable parental material. Rocks of obvious sedimentary origin contain abundant quartz with lesser amounts of sillimanite, biotite, turbid alkali feldspar and rare epidote. The parent rock types of these hornfelses probably varied from almost pure sandstone to argillaceous sandstone and siltstone. The original argillaceous matrix sometimes persists unreconstituted.

The other type of siliceous hornfels is strongly suggestive of an igneous parentage. It is bluish-grey in colour with a spotted appearance. In thin-section it is distinctly porphyroblastic with a recrystallised granoblastic matrix of quartz and feldspar (Plate 4-G). The matrix makes up about 60% of the rock.

Relict plagioclase phenocrysts forming strongly zoned subhedral laths, reveal that this hornfels was originally a volcanic rock. The relict plagioclase ranges in size from 5.0 to 3.0 mm and is andesine in composition with albitised margins which are sieved by rounded quartz granules.

Somewhat curious amphibole porphyroblasts constitute 25% of the rock. They are striking both in colour and texture. The mineral occurs as sieve textured grains often only partially formed and including abundant quartz. It is strongly coloured with pleochroic scheme X = yellowish brown, Y = green with a faint yellowish tint, and Z = dark green to almost black (Plate 4-H). Other optical properties are, $2V_x$ 40–43, extinction angle, $X \wedge c = 76$ and the optic axial plane is perpendicular to the symmetry plane (010). According to Deer, *et al.*, (1963), Arfvedsonite, riebeckite, some crossites and katophorite are the only amphiboles in which the optic axial plane is perpendicular to the symmetry plane. The chemical composition and structural formula of the extracted mineral is given in Table 2. Although the measured optical

TABLE 2
CHEMICAL ANALYSIS OF POTASIAN HASTINGSITIC HORNBLENDE FROM SILICEOUS HORNFELS (sample M8H)

Oxide	Wt. %	Number of ions on the basis of 23 (O)	
SiO_2	39.85	Si	6.416
TiO_2	1.34	Ti	0.163
Al_2O_3	8.22	Al	1.560
Fe_2O_3	7.70	Fe^{3+}	0.933
FeO	23.57	Fe^{2+}	3.173
MnO	0.90	Mn	0.123
MgO	2.59	Mg	0.621
CaO	10.25	Ca	1.769
Na_2O	1.70	Na	0.530
K_2O	1.49	K	0.306
Total	97.61	$A_{0.605}$ B_2 $C_{4.99}$ T_8 O_{22} $(OH, F, Cl)_2$ $Mg/Mg + Fe^2 = 0.164$	

properties correspond most closely with those of katophorite, the mineral is classified as a potasian hastingsitic hornblende based on the chemical contents of a standard amphibole calculated to 23 (O) after Leake (1978).

ORIGIN OF THE BASIC GRANULAR HORNFELSES

While the origin of calc-silicate and siliceous hornfelses is fairly obvious, the basic granular hornfelses pose a problem in that they may originate in more than one way.

Basic hornfels inclusions and contact rocks associated with gabbroic intrusives, which are very similar to the Kemuning hornfelses, have been described from other localities and are, apparently, not uncommon. In these published accounts, the origin of the basic hornfelses have been discussed mainly along two lines of thought as outlined below:

(a) The basic hornfelses represent the chilled margins of the gabbroic intrusion or an earlier basalt which has been contact metamorphosed by a later surge of basic magma (e.g. McSween and Nystrom, 1979; MacGregor, 1931; Richey and Thomas , 1930).

(b) The basic hornfelses are derived through metamorphism and metasomatism of sediments (Grout, 1930; Read, 1935; Sadashivaiah, 1950; Wells, 1951).

The basic hornfelses of Bukit Kemuning are commonly banded, a feature unusual in chilled margins, and they are often intercalated with obviously sedimentary types. These basic hornfelses, therefore, appear unlikely to be of original igneous parentage and as such hypothesis (a) is discarded. On the other hand, the structure of the banded rocks and the details of crystal habit, which indicate that diffusion processes were active, favour the second hypothesis. Furthermore, previous descriptions of texturally and mineralogically similar hornfelses, such as the titanaugite-rich rocks, in their proper field setting (e.g. Sadashivaiah, 1950; Tilley and Harwood, 1931) provide strong evidence of a similar sedimentary origin for the Kemuning examples.

The chemical composition of ten hornfelses representative of the four petrographic types is given in Table 3. The chemistry of the hornfelses substantiates the proposed modes of origin. The siliceous hornfels of igneous parentage has a composition closely comparable with that of rhyodacite (compare Nockolds, 1954), while the siliceous hornfels of sedimentary parentage and the calc-silicate hornfelses have compositions which may be correlated with that of argillaceous sandstones and calcareous mudstones or marls respectively. As such, these hornfelses have suffered essentially isochemical contact metamorphism. The basic granular hornfelses, however, possess chemical compositions which cannot be equated with that of any known sediments implying that metasomatism was particularly significant. The metasediments flanking the gabbro, which are the inferred source of the hornfelsed xenoliths, are essentially argillaceous in composition. It is, as such, not unreasonable to propose that the basic granular hornfelses were originally argillaceous metasedimentary inclusions which have attained their present composition by a significant influx of material from the enclosing gabbro magma. It is also very likely that the titaniferous basic granular hornfels was derived from argillaceous metasediments which contained a significant calcareous component as similar rocks in other areas are always found in association with calcareous sediments which have been contact metamorphosed by gabbroic magma (Kumar, 1980 a). The substantial CaO content of the titaniferous basic granular hornfels from Bukit Kemuning supports this suggestion.

Detailed chemical aspects of the transformation of these originally sedimentary xenoliths cannot be fully evaluated here as there is no available data on the chemistry of the source metasediments. Assuming that the basic granular hornfelses were derived from mainly argillaceous sediments than it is apparent that they could have attained their present composition only by an influx of Ca, Fe, Mg, Ti and Mn from the Kemuning gabbroic melt. In explaining the origin of basic hornfels inclusions in the Insch olivine-norite and the Duluth gabbro, Sadashivaiah (1950) has postulated a transfer of these same elements from the enclosing gabbroic magmas into the argillaceous parent material of their inclusions. The process is clearly an example of the basification of sediments by gabbroic magma. At Bukit Kemuning basification of original metasediments has resulted in micro-gabbroid hornfelses, with overall compositions approaching that of the enclosing gabbro, and titaniferous basic granular hornfelses which illustrate, in particular, the enrichment in titanium.

GEOCHEMISTRY AND PETROGENESIS OF THE GABBROIC SUITE

Chemical Characteristics

Sixteen representative samples from the Kemuning gabbroic suite were chemically analysed. Chemical data and corresponding CIPW norms are presented in Table 4. Only analyses of unaltered samples have been considered in the interpretation of chemical characteristics.

TABLE 3
CHEMICAL COMPOSITION OF HORNFELSES ASSOCIATED WITH THE KEMUNING GABBROIC STOCK

	M9H	M5A	KE19B	KE9A	KE31M	BK-22	KE10	KE22C	KE28F	M8H
SiO_2	48.22	51.29	49.60	40.45	39.82	41.88	48.84	47.34	76.01	67.90
TiO_2	0.79	0.99	0.85	3.22	3.08	3.58	0.43	0.75	0.65	0.48
Al_2O_3	14.18	17.71	16.00	13.69	12.50	12.98	8.56	17.26	14.47	13.97
Fe_2O_3	1.60	2.75	0.63	3.69	4.14	1.98	0.35	1.34	4.60*	1.38
FeO	7.90	7.75	9.47	5.22	6.93	9.24	4.64	5.10	—	4.27
MnO	0.18	0.27	0.22	0.18	0.22	0.17	0.12	0.10	0.05	0.13
MgO	13.10	6.00	8.99	7.71	8.39	7.13	2.70	4.10	0.48	0.26
CaO	11.45	7.68	11.09	21.58	21.33	16.00	33.53	19.30	0.27	2.81
Na_2O	1.54	1.85	1.75	1.20	0.58	1.60	0.15	1.58	0.82	3.88
K_2O	0.20	1.45	0.12	0.64	0.35	1.48	0.25	1.50	2.05	3.59
P_2O_5	0.01	0.10	0.11	0.62	0.74	0.97	0.20	0.22	0.00	0.08
L.O.I.	0.99	1.45	1.20	1.92	2.49	2.24	0.96	0.96	0.51	0.64
Total	100.16	99.29	100.03	100.12	100.57	99.25	100.73	99.55	99.91	99.39

M9H, M5A, KE19B—micro-gabbroid basic granular hornfels.
KE9A, KE31M, BK-22 – titaniferous basic granular hornfels.
KE10, KE22C – calc-silicate hornfels.
KE28F – siliceous hornfels of sedimentary parentage.
M8H—siliceous hornfels of igneous parentage.
*—total iron expressed as Fe_2O_3.

TABLE 4

CHEMICAL ANALYSES AND **CIPW** NORMS OF REPRESENTATIVE ROCKS FROM THE KEMUNING STOCK

	KE31D	BK-5	BK-3	KE31C	M8N	BK-23	M12M	M13C	M12I	KE22A	KE28A	BK-8	M12E	BK-9	M8M	KE18A
SiO_2	48.55	48.16	45.79	45.62	45.34	43.51	48.47	48.52	50.85	49.70	49.46	48.26	51.63	55.69	59.40	67.77
TiO_2	1.55	4.38	4.46	4.27	3.18	3.41	2.40	2.26	2.60	2.11	3.02	5.15	1.71	1.53	1.17	0.46
Al_2O_3	15.19	14.44	17.14	16.79	14.78	14.88	14.03	15.41	15.16	17.73	15.33	12.98	15.77	17.50	14.86	14.67
Fe_2O_3	1.52	0.50	2.03	1.86	2.02	1.64	1.64	1.81	1.63	1.91	1.20	2.00	1.48	1.56	2.33	4.65*
FeO	11.51	12.54	11.16	11.31	13.31	15.06	14.57	11.36	10.91	8.81	12.52	12.41	10.43	6.68	8.74	—
MnO	0.23	0.24	0.22	0.21	0.24	0.28	0.26	0.23	0.22	0.18	0.24	0.25	0.18	0.15	0.22	0.07
MgO	7.39	5.43	5.55	5.51	4.96	6.46	3.45	3.43	4.11	3.91	5.49	5.03	4.39	2.22	1.53	0.51
CaO	10.11	9.63	9.84	9.69	9.33	9.09	8.45	9.05	7.81	8.61	7.18	8.29	6.68	7.86	5.59	2.68
Na_2O	1.86	1.81	2.43	2.43	2.67	2.16	2.62	2.86	2.56	2.56	1.73	1.75	1.87	3.02	2.67	3.83
K_2O	0.71	0.65	0.64	0.66	0.81	0.60	1.01	1.24	1.85	0.86	1.13	2.06	3.06	1.59	1.26	3.90
P_2O_5	0.39	0.35	0.43	0.46	1.61	0.40	0.97	0.92	1.14	0.80	0.42	0.23	0.58	0.58	0.39	0.10
L.O.I.	1.41	1.68	1.27	1.40	1.55	1.80	1.62	1.90	2.02	2.73	1.79	1.87	1.51	1.58	1.72	0.52
Total	100.42	99.81	100.96	100.21	99.80	99.29	99.49	98.99	100.86	99.91	99.51	100.28	99.29	99.96	99.88	99.16

Table 4 (*contd.*)

CIPW NORM																	
Q		—	3.75	—	—	—	—	1.51	0.82	4.03	5.11	5.33	3.60	3.66	10.96	20.60	22.55
Or		4.24	3.91	3.79	3.95	4.87	3.64	6.10	7.54	11.05	5.23	6.83	12.37	18.49	9.55	7.58	23.46
Ab		15.89	15.60	20.62	20.80	22.97	18.74	22.64	24.91	21.90	22.28	14.98	15.04	16.18	25.97	23.01	32.99
An		31.30	29.91	34.07	33.34	26.39	29.88	24.04	26.30	24.68	35.33	31.44	21.82	26.18	29.97	25.30	11.52
Mt		2.23	0.74	2.95	2.73	2.98	2.44	2.43	2.70	2.39	2.85	1.78	2.95	2.19	2.30	3.44	0.96
Il		2.97	8.48	8.50	8.21	6.14	6.64	4.66	4.42	4.99	4.12	5.87	9.94	3.32	2.95	2.26	0.89
Ap		0.93	0.85	1.02	1.10	3.88	0.97	2.35	2.24	2.73	1.95	1.02	0.55	1.36	1.40	0.94	0.24
Di	Mg	7.53	6.77	5.69	5.62	3.69	5.32	3.26	4.40	2.58	1.33	0.87	7.99	1.49	2.05	0.08	0.25
	Fe	6.33	6.90	4.25	4.49	4.68	6.11	7.24	7.21	3.25	1.36	0.97	7.28	1.83	2.82	0.22	0.92
Hy	En	13.04	10.64	7.71	7.64	7.32	3.61	7.27	6.76	9.15	9.40	13.59	9.02	10.49	4.67	3.85	1.18
	Fs	12.57	12.45	6.61	7.00	10.64	4.75	18.54	12.70	13.24	11.05	17.35	9.43	14.81	7.37	12.72	5.05
Ol	Fo	1.44	—	2.47	2.55	2.48	7.31	—	—	—	—	—	—	—	—	—	—
	Fa	1.53	—	2.33	2.57	3.97	10.61	—	—	—	—	—	—	—	—	—	—
D.I.		20.13	23.27	24.41	24.75	27.84	22.38	30.24	33.28	36.98	32.61	27.13	31.01	38.33	46.47	51.20	78.99
Normative Plag.		An 65	An 64	An 61	An 60	An 52	An 60	An 50	An 50	An 52	An 60	An 66	An 58	An 60	An 52	An 51	An 25

KE31D—Medium grained, hornblende gabbro-norite. Loc. Bukit Kemuning, Kemaman.
BK-5—Medium grained, hornblende, biotite quartz gabbro. Loc. Bt. Kemuning, Kemaman.
BK-3—Medium grained, hornblende gabbro-norite. Loc. Bt. Kemuning, Kemaman.
KE31C[a]—Medium grained, hornblende norite. Loc. Bt. Kemuning, Kemaman.
M8N[a]—Medium grained, biotite, hornblende, gabbro-norite. Loc. Bt. Kemuning, Kemaman.
BK-23[a]—Medium grained hornblende, biotite, olivine, gabbro-norite. Loc. Bt. Kemuning, Kemaman.
M12M[a]—Medium grained, biotite gabbro-norite. Loc. Bt. Kemuning, Kemaman.
M13C—Medium grained, biotite, hornblende, quartz, gabbro-norite. Loc. Bt. Kemuning, Kemaman.
M121[a]—Medium grained, uralitized gabbro-norite. Loc. Bt. Kemuning, Kemaman.
KE22A—Severely uralitized gabbroid. Loc. Bt. Kemuning, Kemaman.
KE28A—Medium grained biotite gabbro-norite. Contains small xenoliths. Loc. Bt. Kemuning, Kemaman.
BK-8—Medium grained biotite gabbro. Contaminated by xenoliths. Loc. Bt. Kemuning, Kemaman.
M12E—Highly contaminated gabbroid. Loc. Bt. Kemuning, Kemaman.
BK-9[a]—Medium grained, quartz diorite. Loc. Bt. Kemuning, Kemaman.
M8M[a]—Medium grained, quartz diorite. Loc. Bt. Kemuning, Kemaman.
KE18A—Granophyre. Loc. Bt. Kemuning, Kemaman.
a—modal data in Table 1.
*—total iron expressed as Fe_2O_3.

The Kemuning gabbros have high contents of FeO, TiO_2, Na_2O, K_2O and P_2O_5. The chemistry of these rocks clearly reflects the mineralogy of the suite. In particular the high Fe/Mg ratios of the Kemuning rocks are readily attributable to their iron enriched mineralogy. Total iron content of these basic rocks range from 13 to 17 percent (expressed as FeO) and accordingly they may be termed as iron rich gabbros or ferrogabbros. High values for TiO_2, P_2O_5 and total alkalis reflect the modal abundance of titanomagnetite/ilmenite, apatite, and hornblende and biotite respectively.

Classification Of The Magma Series

In the alkali-silica diagram (Figure 4), following the dividing line of Irving and Baragar (1971), the Kemuning suite appears to be in part alkaline in character. It has, however, been pointed out by Irving and Baragar (1971) that the alkali-silica diagram has definite limitations and should be used with care. In this respect the nature of the constituent pyroxenes becomes particularly important. Rocks of the alkaline series generally contain augite, commonly a titaniferous variety, while Ca-poor pyroxene is rare. Significant modal orthopyroxene in the Kemuning gabbros indicates a subalkaline affinity.

From the AFM variation diagram (Figure 5) it would appear that the Kemuning suite belongs to the tholeiite series as it shows an iron enrichment trend closely similar

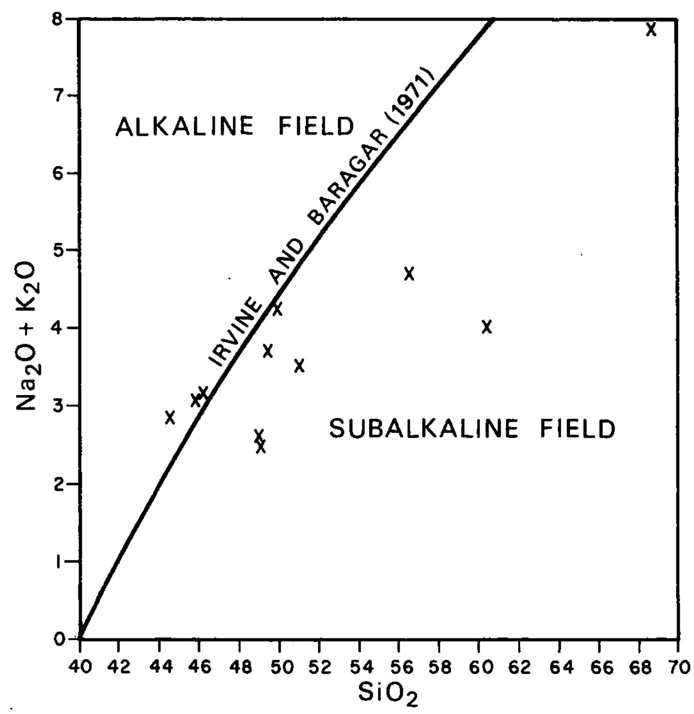

Fig. 4. Alkali-silica plots in weight percent for samples from the Kemuning gabbroic stock. The dividing line between the alkaline and subalkaline fields is reproduced from Irving and Baragar (1971).

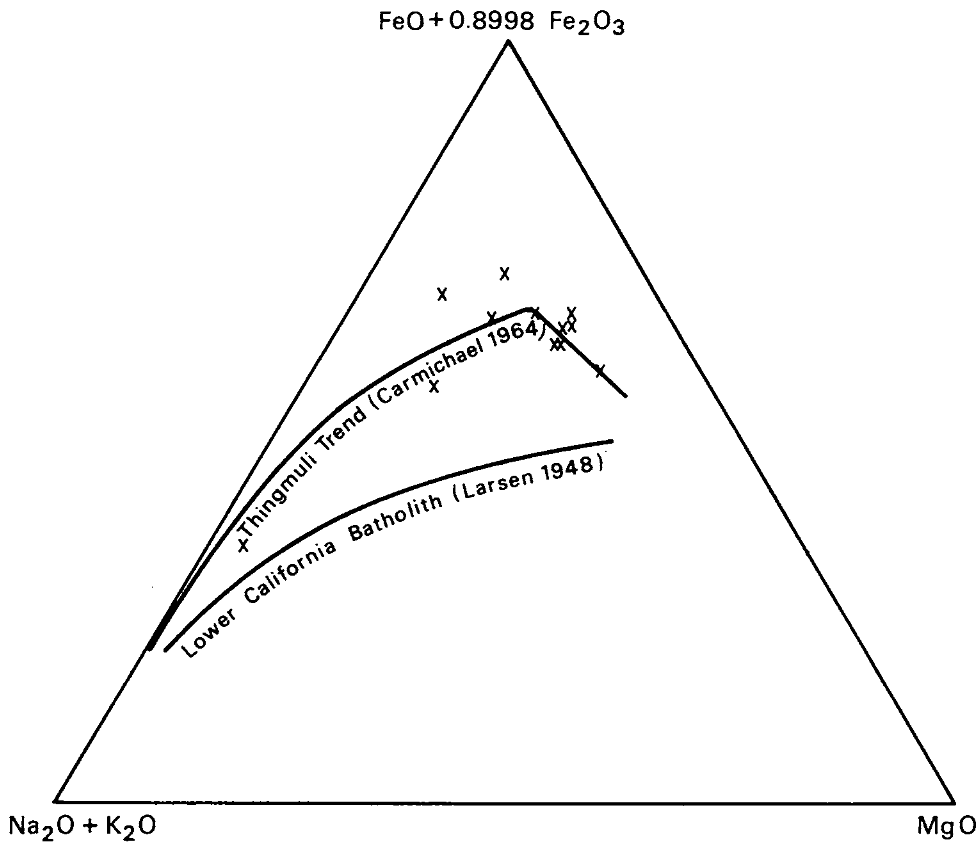

Fig. 5. AFM variation diagram for samples from the Kemuning gabbroic stock. Weight percent. The Thingmuli tholeiite trend (Carmichael, 1964) and the calc-alkaline Lower California batholith trend (Larsen, 1948) are reproduced.

to the trends recorded from other tholeiite suites (e.g. Carmichael, 1964). The AFM variation of the Kemuning suite is distinctly opposed to the non-iron enrichment trend typical of the calc-alkali series (e.g. Larsen, 1948). Judging from the trends of some typical intrusions, for example, the Dillsburg and Palisade sills (Hess, 1960), most of the analysed Kemuning gabbros are probably representatives of the middle stages of fractionation corresponding to the culmination of iron enrichment in the differentiating magma.

Other diagrams which have been used to distinguish between tholeiitic and calc-alkaline suites such as Miyashiro's (1974) plots of SiO_2 and FeO(total) against FeO (total)/MgO (Figure 6) also indicate tholeiitic trends for the Kemuning suite.

The iron enriched mineralogy of the Kemuning gabbroic suite is typical of the tholeiite series where olivine crystallisation extends to very fayalitic compositions. In contrast, olivine in most calc-alkaline gabbros stop crystallising early. Similarly,

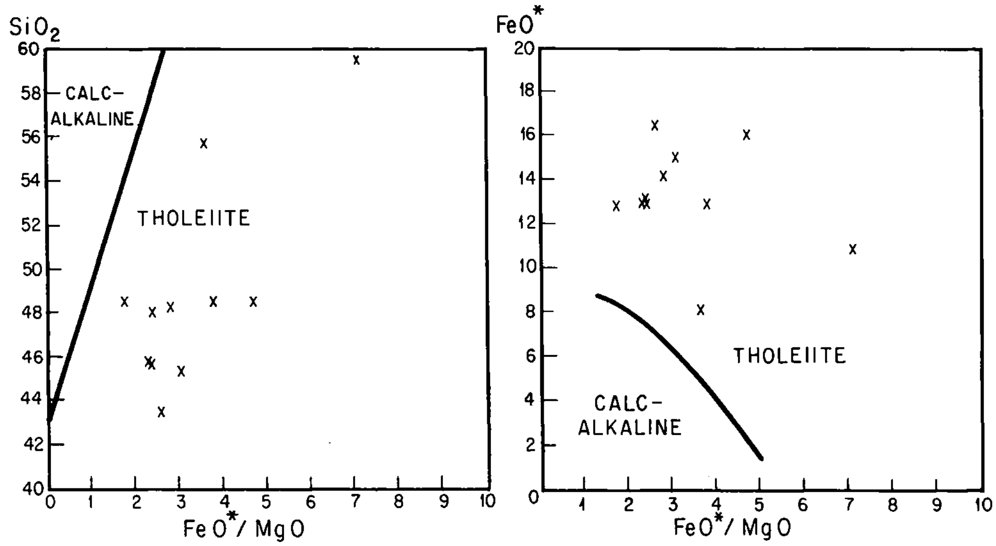

Fig. 6. Miyashiro's (1974) diagrams for making a calc-alkaline, tholeiite distinction using plots of SiO_2 and FeO (total) against FeO (total)/MgO ratio. X—gabbroic rocks from the Kemuning stock.

pyroxene never become very iron rich being replaced by hornblende and biotite at relatively magnesian compositions (Best and Mercy, 1967).

The iron enriched character of the Kemuning gabbroic suite as expressed in the chemistry and mineralogy of the rock types appears to indicate an overall tholeiitic affinity for this suite. However, the Kemuning suite differs from typical tholeiites in containing abundant hydrous minerals. Furthermore, inverted pigeonite which is characteristic of tholeiitic intrusives is entirely lacking. Also the orthopyroxenes in the Kemuning gabbros show lesser abundance of exsolved augite lamellae parallel to (100) than that in typical tholeiitic gabbros. In all these respects, the Kemuning gabbros share the mineralogical characteristics of calc-alkaline basic intrusives.

This dual magmatic character is most likely to be due to the contaminating effects of the presently hornfelsed metasedimentary inclusions on an initial tholeiitic or calc-alkaline magma. The actual mechanism of the contamination process and the problem of classifying the magma type parental to the Kemuning gabbroic suite cannot be conclusively resolved with the available data. Further work pertaining to these problems will undoubtedly prove most interesting.

SUMMARY

The Kemuning gabbro is characterised by an iron enriched mineralogy coupled with abundant hydrous minerals and late magmatic reaction relationships. The hornfelses associated with the gabbro are, with one exception, entirely of sedimentary parentage having acquired their present texture and composition as a result of the metasomatic and/or thermal metamorphic action of the gabbroic magma. Calc-silicate and siliceous hornfelses have experienced non-additive contact metamorphism whereas basic granular hornfelses have been chemically modified by a significant metasomatic transfer of material from the gabbroic magma into the originally sedimentary xenoliths and contact rocks. In this respect, Ca, Fe, Mg, Ti and Mn must have been particularly active.

The geochemical and mineralogical character of the Kemuning gabbroic suite does not allow it to be uniquely identified with either the calc-alkali or tholeiite magma series. The typically tholeiitic iron enriched chemistry and mineralogy of this suite contrast with a typically calc-alkaline abundance of hydrous minerals. The mixed magmatic character of the Kemuning gabbroic suite is attributable to the contamination of the gabbroic melt by the hornfelsed xenoliths.

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