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Taneda, Sadakatsu
Faculty of Science, Kyushu University

https://doi.org/10.5109/1543648

出版情報：九州大學理學部紀要 : Series D, Geology. 17 (3), pp.311-330, 1966-09-15. Faculty of Science, Kyushu University
バージョン：
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Mem. Fac. Sci., Kyushu Univ., Ser. D, Geology, Vol. XVII, No. 3,
pp. 311–330, 16 text-figs., 4 tables, September 15, 1966

The Petrogenetic Significance of the Vapour Pressure in Magmas

By
Sadakatu TANEDA

In my previous papers, I pointed out that in the magma in which volatile matters is highly concentrated, the crystallization of "magnetite" (oxide minerals) is distinctly promoted to have an influence on the decrease of the FeO/MgO ratio of the ferro-magnesian silicate minerals (TANEDA, 1947; 1949; 1950). For example in the "hornblende-andesites" corresponding to the calc-alkalic rocks in this paper, the ferro-magnesian silicate minerals occurring in the groundmass are poorer in Fs (and Wo) contents and richer in En content than the phenocrysts, which show a reversal zonal structure at some times or usually. Here the plagioclase phenocryst, usually showing a prominent oscillatory zoning, is hardly different from the groundmass plagioclase in An content (TANEDA, 1941; 1943; 1947; 1952).

E. F. OSBORN, A. MUAN, R. F. FUDALI and others certified experimentally the similar influence of volatile matters for fractionating liquid corresponding to magma, and pointed out the differences in the FeO/Fe_2O_3-SiO_2 relation at the different oxygen partial pressures or fugacities (OSBORN, 1959; FUDALI et al., 1963; etc.).

*FeO/Fe_2O_3, FeO/Fe_2O_3-SiO_2, FeO/Fe_2O_3-H_2O** In this paper, I constructed the variation curves for FeO/Fe_2O_3 against SiO_2 for many rocks or rock series (plutonic and volcanic; alkalic and non-alkalic) from the Circum Japan Sea region and the Intra Pacific region, and for some typical rock averages given by DALY (1933), NOCKOLDS (1954), GREEN & POLDERVAART (1955), TOMITA (1935), KUNO (1954; 1960), YAGI (1959), TANEDA (1962), etc. (Figs. 1 & 2), and obtained such a conclusion as follows:

The FeO/Fe_2O_3 ratio in alkali rocks is comparatively low, and the trend of the variation curve for FeO/Fe_2O_3 for the acidity of rocks seems to correspond to OSBORN's crystallization course (FeO/Fe_2O_3-SiO_2 curve) in the system FeO-Fe_2O_3-MgO-SiO_2 at high oxygen partial pressure, while the ratio in non-alkalic rocks (tholeiitic and calc-alkalic rocks) is comparatively high, and the variation trend corresponds to his crystallization course at low oxygen partial pressure. Calc-alkalic rock magmas are assumed to be slightly higher in oxygen partial pressure than tholeiitic rock magmas.

Manuscript received May 31, 1966

* The FeO/Fe_2O_3 ratio and H_2O content of rocks might be rather different from those of their source magmas. It, however, seems to be true that the relative difference trends between different rock series in FeO/Fe_2O_3, H_2O, etc. are simlar to those between their source magmas.

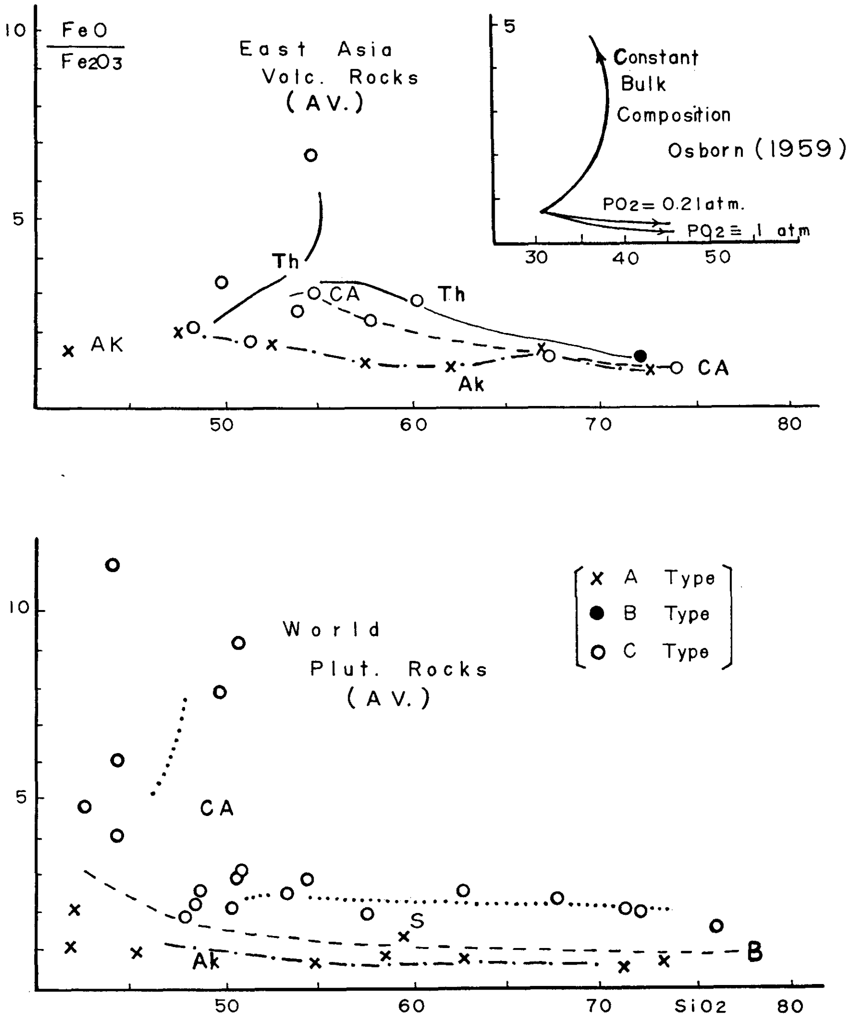

Fig. 1. The relationship between FeO/Fe_2O_3 and SiO_2 in volcanic and plutonic rocks.

East Asia Volc. Rocks (average)
- Ak: Alkaline rocks (The Circum Japan Sea region; Tomita, 1935).
- Th: Tholeiitic rocks ("Pigeonitic rock series" and tholeiites from Izu; Kuno, 1954; Iwasaki, 1935; Tsuya, 1937; Nagashima, 1953).
- CA: Calcalkaline rocks ("Hypersthenic rock series"; Kuno, 1954).

World Plutn. Rocks (average)
- AK: Alkaline rocks
- CA: Calcalkaline rocks (including S). Daly, 1933; Nockolds, 1954; Taneda, 1962; and others.

B (broken line): Boundary between alkaline rocks and non-alkaline (Th, CA) ones.

Full line, Dotted or broken line, and Chain line: The average trends of tholeiitic, calcalkaline and alkaline rocks respectively.

A, B and C Types refer to Table 1 (PF Type).

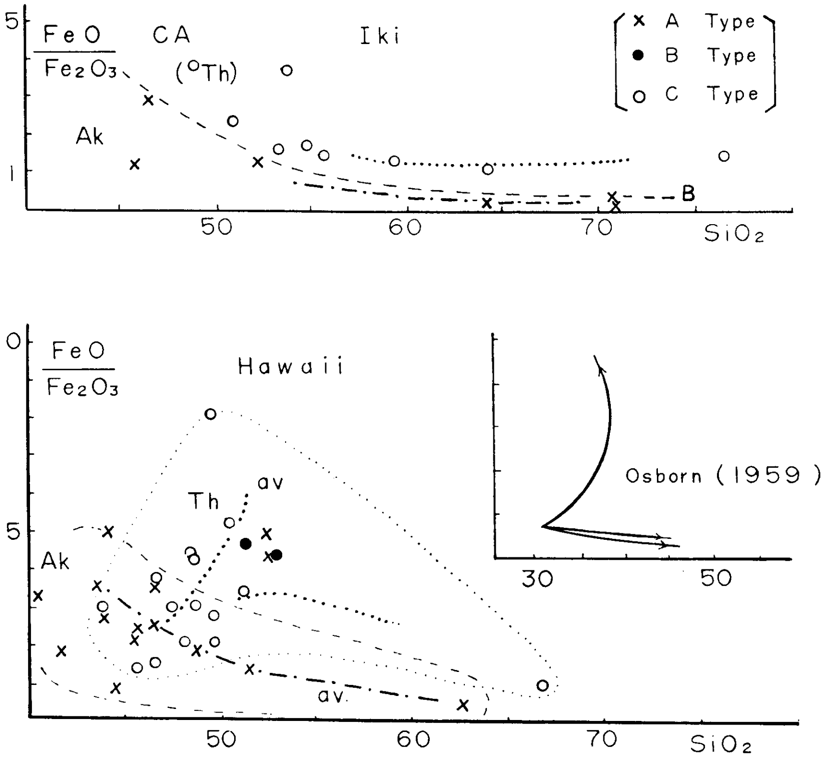

Fig. 2. The relationship between FeO/Fe$_2$O$_3$ and SiO$_2$ in volcanic rocks of Iki (Japan) and Hawaii.
AK: Alkaline rocks. Th: Tholeiite. CA: Calcalkaline rocks.
B (broken line): Boundary between AK and CA • Th. Dotted and Chain lines: The average trends.
A, B and C Types refer to Table 1.

Table 1. Classification of the Di-Hy-An-Ab-Or relations (PF Type)

A Type (×)**	(Ab+Or) and/or Di predominate Di/An>Hy/(Ab+Or) Di/Hy>An/(Ab+Or)
B Type (●)**	Di/An≒Hy/(Ab+Or)* Di/Hy≒An/(Ab+Or)
C Type (○)**	An and/or Hy predominate Di/An<Hy/(Ab+Or) Di/Hy<An/(Ab+Or)

* 100 Di/(Di+An)∼100 Hy/(Hy+Ab+Or)<10
100 Di/(Di+Hy)∼100 An/(An+Ab+Or)<10

** Figs. 1, 2, 7, 8, 13 and 14.

Table 2. PF Type of igneous rocks

PF Type	" Rock suite "
A Type	Almost all alkalic rocks A part of tholeiitic and calc-alkalic rocks
B Type	A part of alkalic, tholeiitic and calc-alkalic rocks
C Type	Almost all tholeiitic and calc-alkalic rocks A part of alkalic rocks

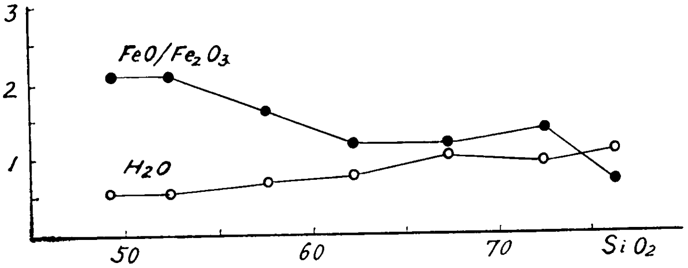

Fig. 3. Diagram showing the variation of FeO/Fe_2O_3 and $H_2O(+)$ in inverse proportion for the averages of Japanese volcanic rocks (TANEDA, 1962).

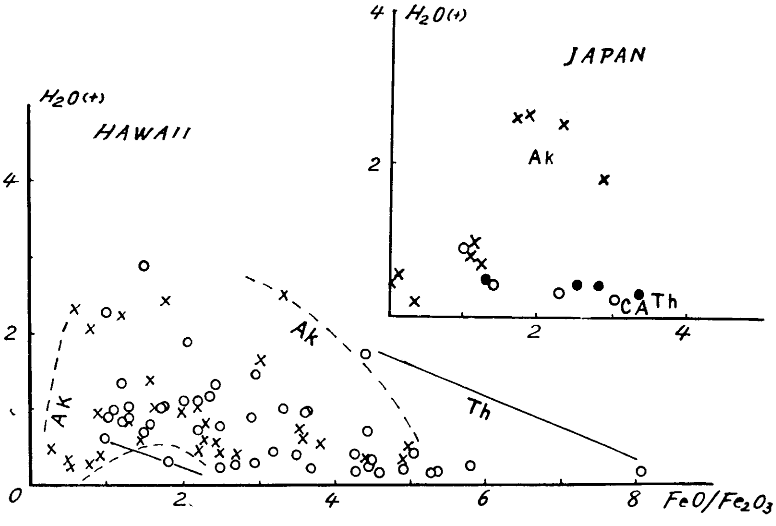

Fig. 4. The relationship between FeO/Fe_2O_3 and $H_2O(+)$ for the Japanese volcanic rocks and the Hawaiian volcanic rocks.

Japanese volcanic rocks: Ak (×) Alkaline rocks of the Circum Japan Sea region, Th (●) Tholeiitic rocks ("Pig. rock series" of KUNO), CA (○) Calcalkaline rocks ("Hyp. rock series" of KUNO).

Hawaiian volcanic rocks: Ak (×) Alkaline rocks, Th (○) Tholeiitic rocks (MACDONALD & KATSURA, 1964).

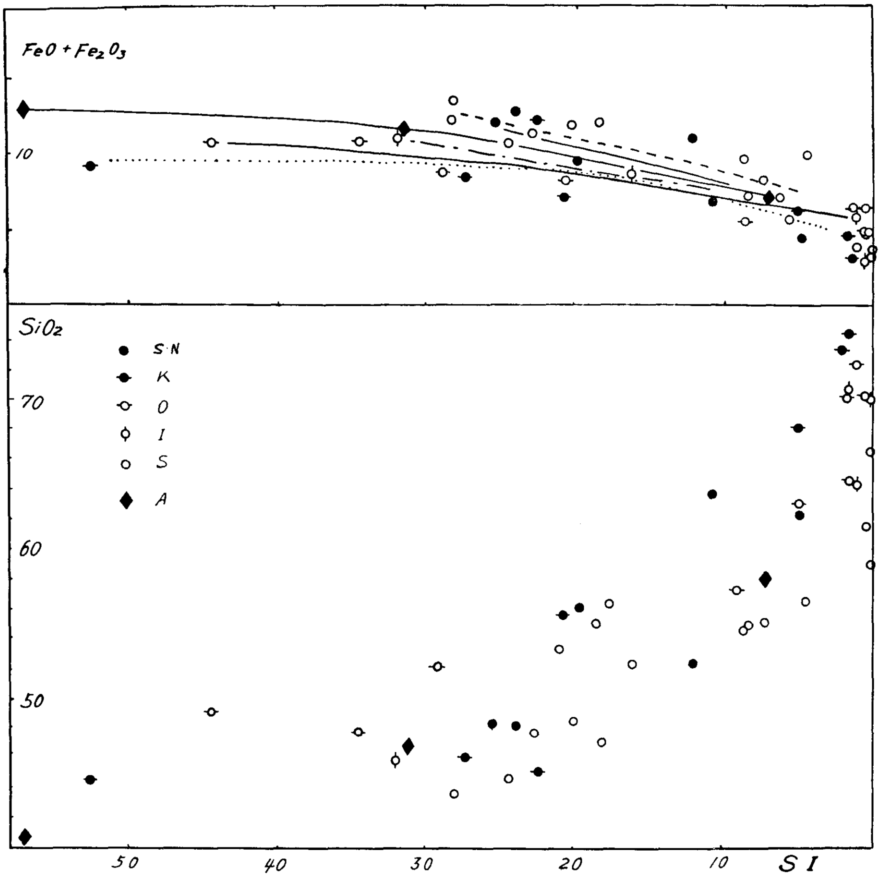

Fig. 5. Variation diagram for alkalic rocks.

S·N	San-in district and some islands in northern Kyushu, Japan (KOZU, 1911; KOZU & YOSHIKI, 1929; OTSUKI, 1910)
K	Kisshu-Meisen district, Korea (YAMANARI, 1925; TATEIWA, 1925)
O	Oki-dogo Is. Japan (KOZU, 1913, 1929; TOMITA, 1935)
I	Iki Is. (AOKI, 1959)
S	Saishuto ls, Korea (HARAGUCHI, 1931; S. NAKAMURA, 1925)
A	Averages of alkaline rocks (DALY, 1933; NOCKOLDS, 1954)

The FeO/Fe_2O_3-H_2O relations of representative rocks also support such an interpretation, because the rocks with high FeO/Fe_2O_3 are low in H_2O content, and the rocks with moderately low FeO/Fe_2O_3 are high in H_2O content, although the rocks with distinctly low FeO/Fe_2O_3 are also low in H_2O content (Figs. 3 & 4). It seems to be true that vapour pressures become effective through selective diffusion of hydrogen into the wall rocks ($H_2O \rightarrow H_2+\frac{1}{2}O_2$ (?)).

*Total FeO-S.I., SiO_2-S.I.** Variation curves for SiO_2 and $FeO+Fe_2O_3$ for the differentiation of the alkalic rock series of the Circum Japan Sea and Intra Pacific regions are shown in Fig. 5. When the variation curves are compared

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* S.I.=KUNO's Solidification Index.

Fig. 6-(1)

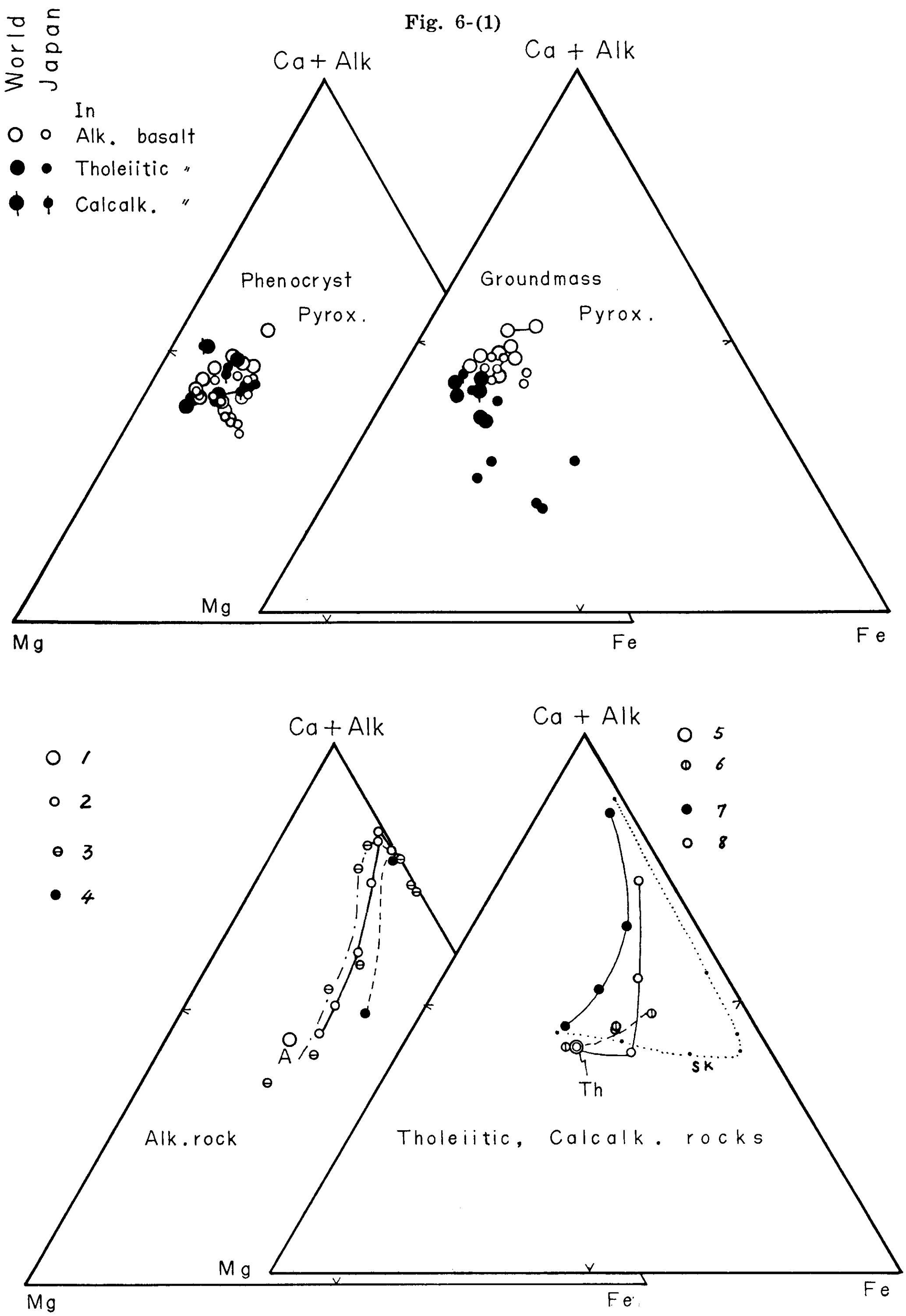
World
Japan
In
○ ○ Alk. basalt
● ● Tholeiitic ″
Calcalk. ″
Ca + Alk
Phenocryst
Pyrox.
Mg
Fe
Ca + Alk
Groundmass
Pyrox.
Mg
Fe
○ 1
○ 2
⊖ 3
● 4
Ca + Alk
A
Alk. rock
Mg
Fe
Ca + Alk
○ 5
⦶ 6
● 7
○ 8
SK
Th
Tholeiitic, Calcalk. rocks
Mg
Fe

Fig. 6-(2)

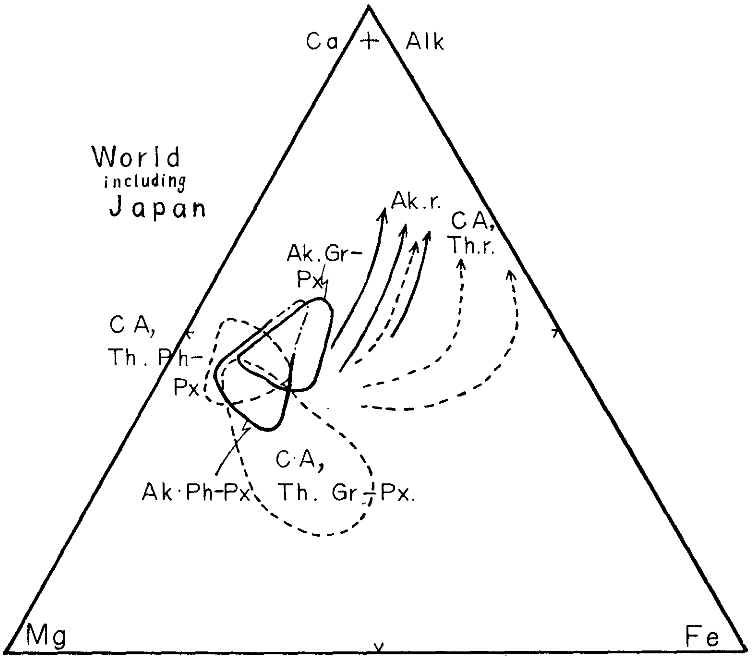

Fig. 6-(1), (2). Showing the relationships between the phenocryst and groundmass clinopyroxenes, and the fractionation trends of alkaline, tholeiitic and calcalkaline rock suites in the (Ca+Alk)–Mg–T·Fe diagram.

Ak.r, Ak. } Alkaline (rocks)
CA, Th.r, CA, Th } Calcalkaline and tholeiitic (rocks)
Ph–Px Phenocryst clinopyroxene (in basic rocks).
Gr–Px Groundmass clinopyroxene (in basic rocks).
1(A) Parental alkali olivine basalt (average) (Kuno, 1960).
2 The Circum Japan Sea region (Tomita, 1935).
3 Oki-dogo, Japan (Kozu, 1913, 1929; Tomita, 1935).
4 Chohaku-san, Manchuria (Ogura, T.)
5(Th) Parental tholeiite (average) (Kuno, 1960).
6 Tholeiite (Do.).
7 Hypersthenic rock series (Kuno, 1954).
8 Pigeonitic rock series (Do.).
Sk Skaergaard intrusives (Wager & Deer, 1939).

with the curves for the tholeiitic and calc-alkalic rock series (Kuno, 1965)*, it is noticed that, in the alkalic rock series, the maximum concentration of $FeO+Fe_2O_3$, accompanied with the increase in SiO_2, is seen at the earliest stage of fractionation (Table 3). The maximum concentration of $FeO+Fe_2O_3$ thereof is comparatively low. Such phenomena as above mentioned also suggest

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* We find reason for agreeing with Kuno's interpretation for the difference between the pigeonitic rock series and hypersthenic rock series of Izu-Hakone, Japan.

that alkalic basic magma is higher than non-alkalic basic magmas in vapour pressure.

(Ca+Alk)-Mg-T·Fe relation in pyroxenes and host rocks From the relationships between the clinopyroxenes and the host rocks in the (Ca+Alk)-Mg-T·Fe diagram, as shown in Figs. 6-(1) & (2), it is assumed that the differentiation course for alkalic rocks correspond to the case where the crystallizations of pyroxene as well as iron oxide minerals rather predominated in the early stage of fractionation and that for tholeiitic · calc-alkalic rocks, the crystallization of feldspars (An-rich) rather predominated in the early stage.

"Pyroxene-Feldspar relation (PF relation)" "Pyroxene-Feldspar relation" means the relation in amount between normative pyroxenes (Di∼Hy) and normative feldspars (An∼Ab·Or). It is represented by the (Di+Hy)/(An+Ab·Or) ratio and the (Di+An)/(Hy+Ab·Or) ratio in the square diagram Di-Hy-An-Ab·Or ("PF diagram", Fig. 7). Generally speaking, the relations between Di, Hy, An and Ab·Or are divided into three types ("PF Types"), A, B and C. A Type: Ab·Or and/ or Di predominate, B type: Di/An≒Hy/An·Or, and C Type: An and/or Hy predominate. Almost all alkalic rocks and small number of tholeiitic and calc-alkalic rocks belong to A Type, while almost all tholeiitic and calc-alkalic rocks and a part of alkalic rocks belong to C Type. A few alkalic, tholeiitic and calc-alkalic rocks belong to B Type (Tables 1 & 2).

Table 3. Maximum values of $FeO+Fe_2O_3$ in differentiation series and stages of the maximum $FeO+Fe_2O_3$ concentration

	Maximum value of $FeO+Fe_2O_3$ (wt%) average	Stage of maximum concentration (S.I. value)	
Pigeonitic rock series	14	20 (Kuno, 1965)	Tholeiitic
Hypersthenic rock series	9	30±	Calc-alkalic
Iki Is., Japan	11	32<	Alkalic
Oki-dogo Is., Japan	9	40<, (Perhaps 45<)	″
Kissyu-Meisen, Korea	10	40<	″
Saishuto Is., Korea	13	30<	″

The mark < indicates that the extrapolated values should be higher than those given here.

Three Types are discriminated from each other by marks (○●×) in the PF diagram. In the PF diagram, therefore, we can show the (Di+Hy)/(An+Ab·Or) and (Di+An)/(Hy+Ab·Or) ratios as well as the PF Type by one point · one mark,—though one point · one mark does not always correspond to one rock.

In the PF diagram, most of the igneous rocks as well as the representative rock averages and the "parental magmas" given by several investigators, are plotted in a zone as shown in Figs. 7, 8, & 15, the area for alkali rocks being broader than that for tholeiitic · calc-alkalic rocks.

Table 4. Comparison of the bulk composiiions with the groundmass compositions (new calc.)

		H		A1	A2	F1	F2
		Hirano-yama, (gray)	Sendai (dark)	Kurofu, Asama	Kurofu, Asama	Futago, Futago	Okudai, Futago
Bulk composition of lavas	SiO_2	48.40	48.54	56.11	58.39	63.13	64.46
	TiO_2	—	—	0.75	0.71	0.72	0.71
	Al_2O_3	20.46	19.85	18.77	17.89	15.79	16.27
	Fe_2O_3	4.13	4.38	1.93	2.45	2.49	1.94
	FeO	5.36	4.80	5.67	5.33	3.12	2.14
	MnO	0.28	0.35	0.19	0.14	0.03	0.03
	MgO	6.49	7.08	3.91	3.30	2.64	2.46
	CaO	12.06	12.28	8.30	7.23	5.46	5.31
	Na_2O	1.70	1.26	3.12	3.04	3.76	4.11
	K_2O	0.91	0.96	0.85	0.71	1.96	2.12
	H_2O+	0.13	0.28	nd	0.36	0.63	0.57
	H_2O-				0.12		
	P_2O_5	—	—	0.11	0.15	0.60	0.50
	Total	99.92	99.78	99.78	99.82	100.32	100.62
	Anal.	Okada		Iwasaki	Tanaka	Kawano	Kawano
	Bib.	Taneda		Iwasaki	Tsuya	Kawano	Kawano
	PF-Type	C		C	C	B	B
Groundmass composition	SiO_2	48.5		57.7	62.1	68.9	68.7
	TiO_2	—		0.9	1.0	0.8	0.8
	Al_2O_3	20.2		18.5	16.1	14.1	14.6
	Fe_2O_3	4.2		1.7	1.5	1.8	1.6
	FeO	5.5		5.9	5.8	2.2	1.4
	MnO	0.3		0.2	0.2		
	MgO	0.6		3.1	3.4	1.6	1.8
	CaO	12.0		7.7	6.4	3.6	4.3
	Na_2O	1.7		3.1	2.4	3.5	3.5
	K_2O	0.9		1.1	0.9	2.6	2.7
	P_2O_5	—		0.1	0.2	0.8	0.7
	Total	99.9		100.1	100.0	99.9	100.0
	Calc.	Taneda		〃	〃	〃	〃
	PF Type	C		B(A)	C	C	C

H Olivine-bytownite basalt from Hirano-yama, Sendai City, Kagoshima Prefecture (Taneda, 1966).

A_1 Augite-bearing hypersthene andesite (Bulk composition: Iwasaki, I., 1936).

A_2 Olivine-bearing two-pyroxene andesite (Bulk composition: Tsuya, H., 1933).

F_1 Two pyroxene-bearing hornblende-andesine andesite (Bulk composition: Kawano, Y., 1937).

F_2 Biotite-hornblende-andesine dacite (Bulk composition: Kawano, Y., 1937).

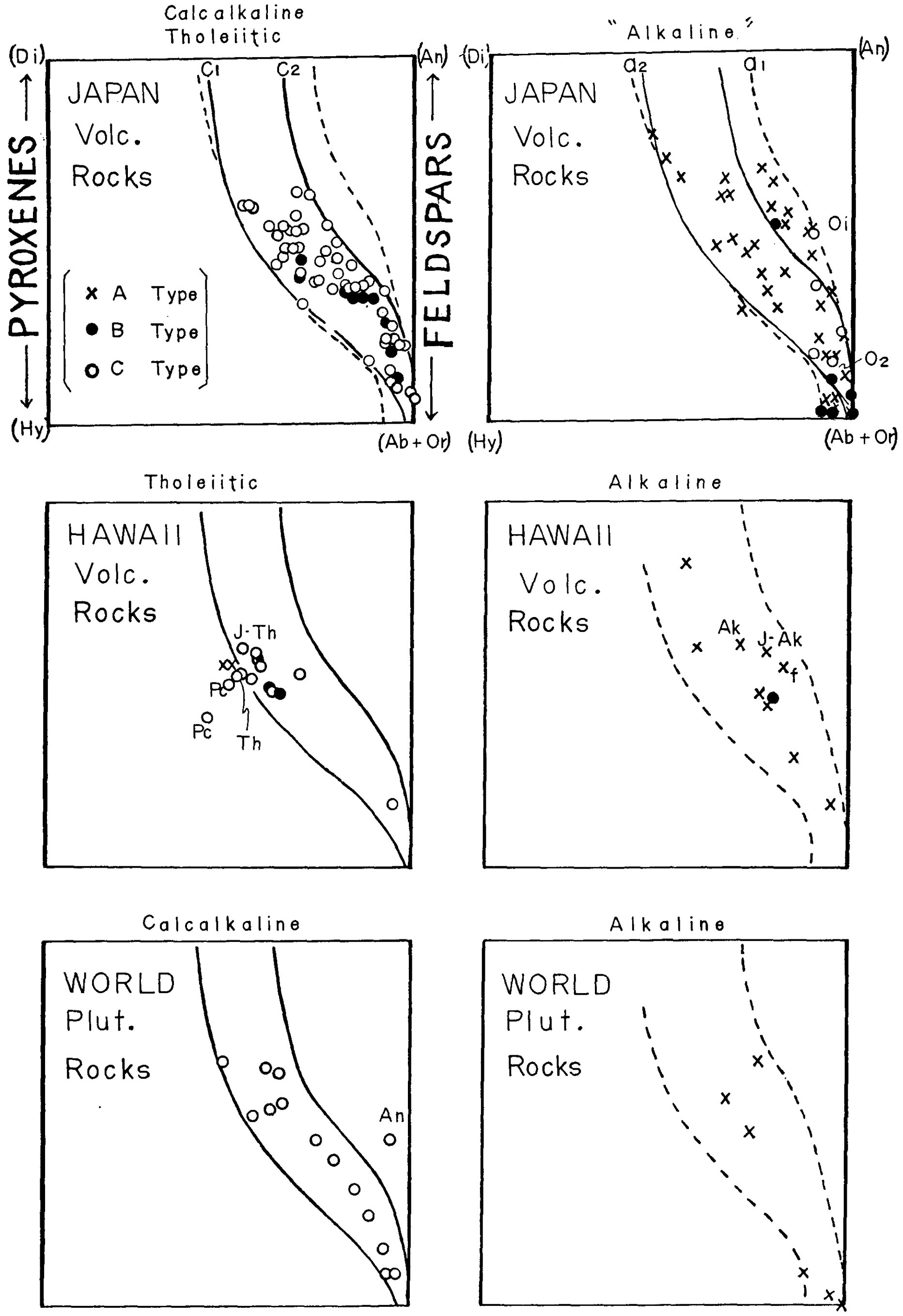
Calcalkaline
Tholeiitic
(Di)
(An)
(Hy)
(Ab+Or)
PYROXENES
FELDSPARS
JAPAN
Volc.
Rocks
C1
C2
× A Type
● B Type
○ C Type
"Alkaline"
a2
a1
O1
O2
Tholeiitic
HAWAII
Volc.
Rocks
J-Th
Pc
Th
Alkaline
Ak
J-Ak
f
Calcalkaline
WORLD
Plut.
Rocks
An
Alkaline

Fig. 7.

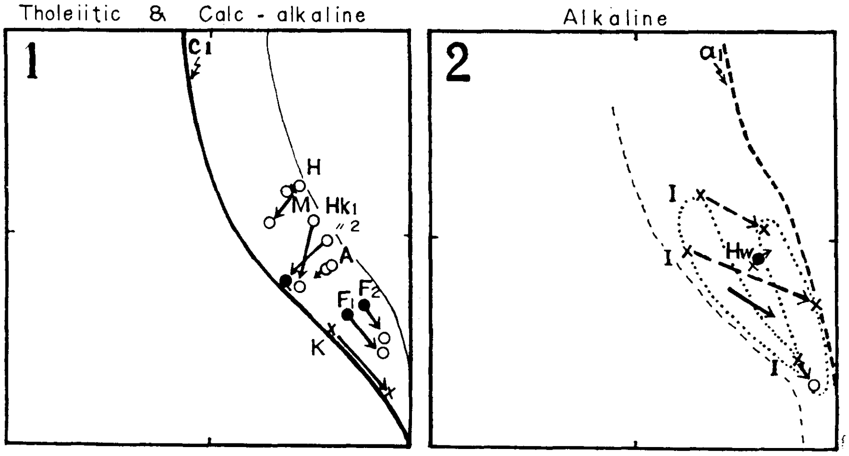

Fig. 8. Comparison of groundmass compositions with bulk compositions of alkaline and tholeiitic-calcalkaline rocks. Marks refer to Fig. 7.

A	Kurofu, Asama Volcano (Table 2)
Hk_1, Hk_2	Hakone Volcano (KUNO, 1936; 1950)
F_1, F_2	Futago Volcano (Table 2)
H	Hirano-yama, Sendai-City, Kagoshima Prefecture (Table 2)
K	Komaga-take Volcano (KOZU & SETO, 1931)
I	Iki Is. (AOKI, 1959)
Hw	Waiane Volcano, Hawaii (MACDONALD & KATSURA, 1964)
M	Mitaki, Sendai-City (KAWANO & AOKI, 1959)

Tholeiitic·calc-alkalic rocks of C Type are dotted over the whole area of zone, while those of A Type are confined to the pyroxene-rich side (narrow area by Line c_1 in Fig. 7). On the contrary as regards alkalic rocks, it is noticed that A Type occupies the whole area of zone, while C Type is confined to the feldspar-rich side (near Line a_1 in Fig. 7).

Moreover throughout the alkalic, tholeiitic and calc-alkalic basic rocks, the A Type rock (bulk) is richer in Pyroxenes than the groundmass, while the C Type rock (bulk) is richer in Feldspars than the groundmass (Fig. 8).

Fig. 7. PF diagram showing the relationships in amount, between Pyroxene (Di~Hy) and Feldspar (An~Ab, Or), and between (Di+An)and (Hy+A b·Or) in the volcanic and plutonic rocks.

A Type	$Di/An > Hy/(Ab+Or)$, $Di/Hy > An/(Ab+Or)$
B Type	$Di/An \fallingdotseq Hy/(Ab+Or)$, $Di/Hy \fallingdotseq An/(Ab+Or)$
C Type	$Di/An < Hy/(Ab+Or)$, $Di/Hy < An/(Ab+Or)$
Ak	Alkaline basalt average
J-Ak	Japanese alkaline basalt average
Th	Tholeiite average
J-Th	Japanese tholeiite average
Pc	Picrite
f	Feldspar-rich alkaline basalt
An	Anorthosite
O_1, O_2	Alkaline rocks from Oki Island

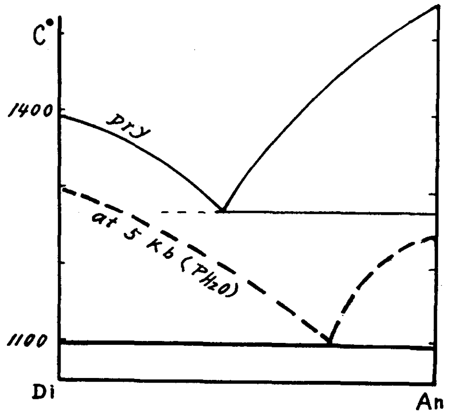

Fig. 9.

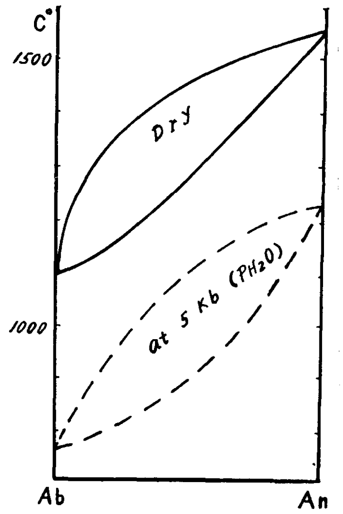

Fig. 10.

Fig. 9. Binary equilibrium diagram diopside-anorthite. anhydrous (full line) and 5 Kilobars P_{H_2O} (broken line) (YODER, 1953(54)).

Fig. 10. Binary equilibrium diagram anorthite-albite. anhydrous (full line) and 5 Kilobars P_{H_2O} (broken line) (BOWEN, 1928; YODER, STEWART & SMITH, 1957).

These facts suggest that the crystallization of pyroxenes predominates in the alkalic basic magmas, though the crystallization of feldspar (An-rich) predominates in the tholeiitic · calc-alkalic basic magmas (Ref. Table 2).

"The system Pyroxene-Feldspar" On the basis of experimental knowledge of the effect of vapour pressure (P_{H_2O}) on the systems Di-An (YODER, 1953(54)), An-Ab (YODER, STEWART & SMITH, 1956(57)), and En-Ab (YODER, 1963(64)), together with the data of the systems En-Sa, Di-Sa, Di-Ab and En-Ab (SCHAIRER, 1954; SCHAIRER & YODER (1961); YODER & TILLEY (1962), and ANDERSON (1915)); and considering the difference between alkalic and non-alkalic rocks in the PF relation and PF Type, the (Ca+Alk)-Mg-T·Fe and FeO/Fe_2O_3-SiO_2 relations above mentioned, as well as the T. FeO-MgO-Alk, Fe_2O_3-FeO-MgO, and An-Ab-Or (norm) relations (Figs. 12 & 13), the schematic phase diagram for "the system pyroxene-feldspar" is assumed as shown, for convenience, in Fig. 14, where the "cotectic-like line" at dry condition (high temperature) corresponds to Line c_1 in Fig. 7, and the "cotectic-like line" at the highest vapour pressure (the lowest temperature) to Line a_1. The boundary surface between pyroxene field and feldspar field declines from Line c_1 (pyroxene side, lower in vapour pressure and higher in temperature) to Line a_1 (feldspar side, higher in vapour pressure and lower in temperature).

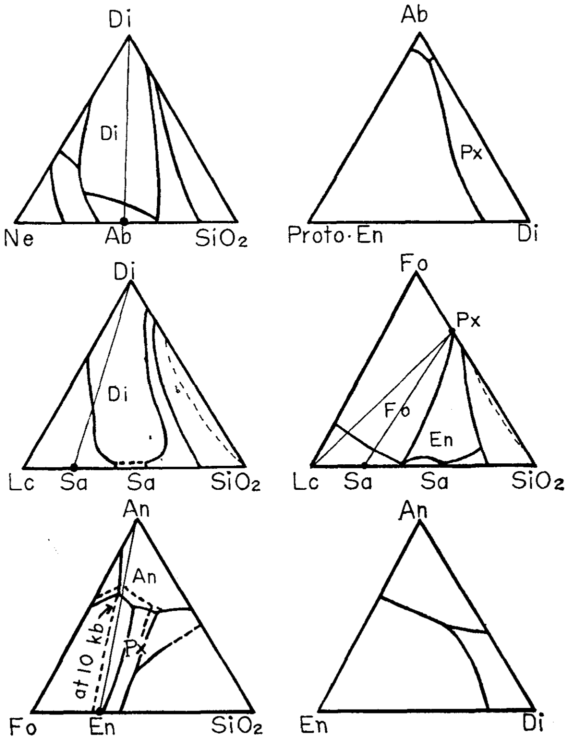

Fig. 11. Some ternary diagrams, usuable for the construction of the provisional phase diagram for "the system pyroxene-feldspar."

Di-Ne-SiO_2 (SCHAIRER & YODER, 1960).
Ab-Proto En-Di (SCHAIRER & BOWEN, 1938).
Di-Lc-SiO_2 (ANDERSON, 1915; TILLEY & YODER, 1962).
Fo-Lc-SiO_2 (SCHAIRER & MORIMOTO, 1958(59)).
An-Fo-SiO_2 (SCHAIRER, 1954).
An-En-Di (HYTONEN & SCHAIRER, 1959(60)).

Conclusion; genetical interpretation

(1) It seems to be true that the rocks of A Type (PF type) are derived by some way where crystallization starts and/or predominates in the pyroxene field* of "the system pyroxene-feldspar" ((Di~Hy)-(An~Ab·Or)), and the rocks of C Type are formed largely in the feldspar field in the same system.

(2) Generally speaking, alkalic rock magmas are produced and crystallized at, or being accompanied with, high vapour pressure (over "1 k bars P_{H_2O} approx.**"), while tholeiitic · calc-alkalic rock magmas at low vapour pressure (less than "1 k bars P_{H_2O} approx.**"). Therefore almost all tholeiitic · calc-alkalic rocks belong to C Type, and most of alkalic rocks to A Type (Figs. 14 & 15).

(3) The basic magmas (represented by E in a binary diagram of Fig. 15) involv-

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* or primary phase area.

** perhaps a little below 1 k bars.

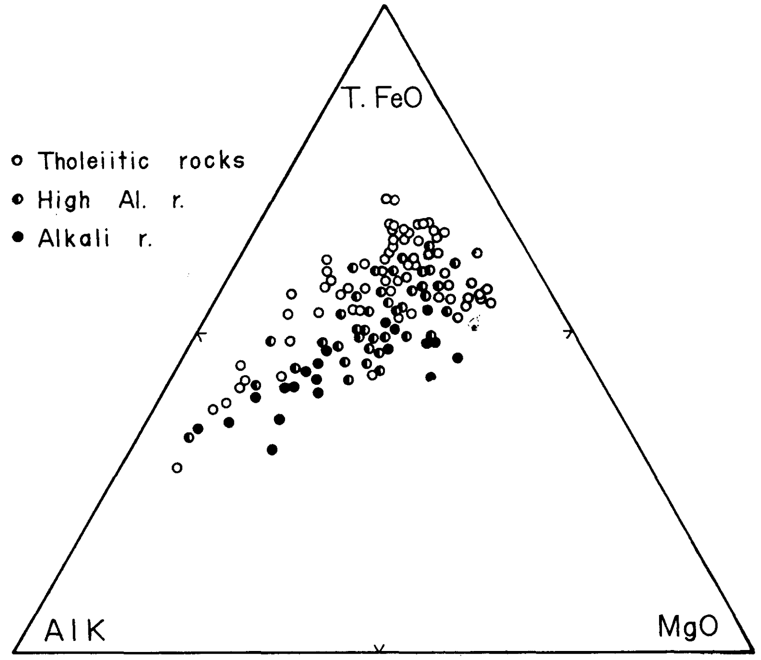

Fig. 12. The Total FeO-MgO-Alk diagram for Japanese volcanic rocks. After TANEDA, 1965.

ing alkalic, and tholeiitic · calc-alkalic, are produced by partial or almost complete melting of gabbroic rocks (an lower pressure equivalent of eclogite and amphibolite) under various vapour pressures, though some of alkalic rock magmas can be, and may be, produced also by partial melting of mantle peridotite. Tholeiitic and calc-alkalic rocks, almost all of which belong to C Type, can not be produced by partial melting of peridotite, because the melts from peridotite belong to the A Type field through the stage of consolidation, unless excessive overheat accompanied with the release of vapour pressure takes place.

(4) Considering the physico-chemical condition for basalt(gabbro-)-eclogite transition, and the geothermal gradient according to some different authors, it is provisionally concluded that the basic magmas as above mentioned, are formed at various depths depending upon largely vapour pressure, ranging from 40 to 70 Km approximately. Under the higher vapour pressure the alkalic magmas are produced at shallower depth than the tholeiitic magmas which are produced under the lower vapour pressure (Fig. 16). Taking in account the amount of water in basic rocks and chondrites, and the solubility of water in mafic magma (HAMILTON et al., 1964) ; it seems to be possible that vapour pressure increases in some places of the crust and upper mantle under a certain condition.

The granitic-rhyolitic magmas formed by the partial~complete melting of granitic rocks (WYLLIE and TUTTLE, 1964) can be, under high vapour pressure, generated at shallow depths, even in the granitic crust (Fig. 16).

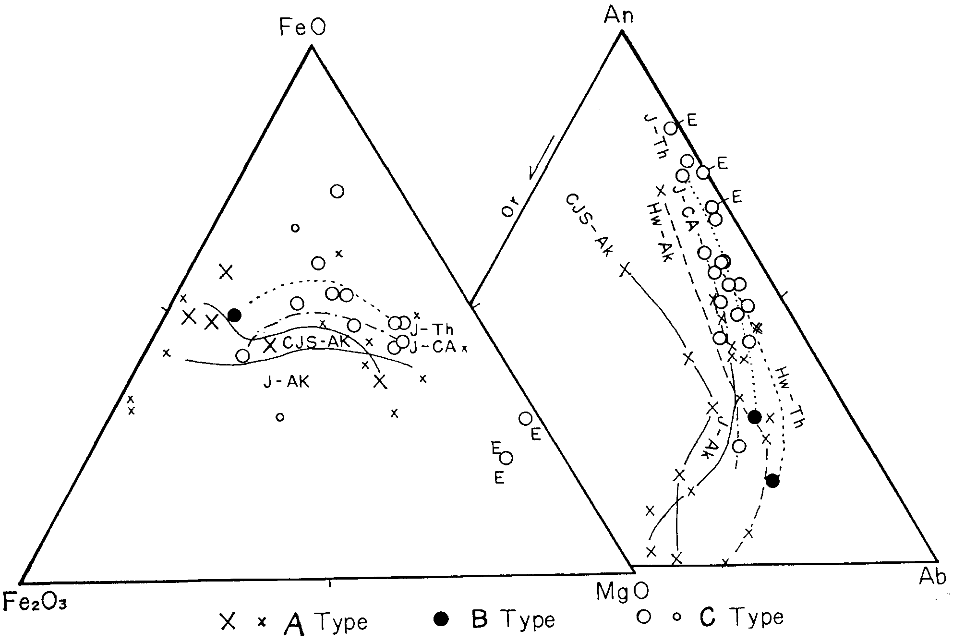

Fig. 13.

Left: The relationship between alkaline and non-alkaline volcanic rocks in the FeO-Fe_2O_3-MgO relation

Right: Normative feldspars.

J-Th	Japanese tholeiitic rocks
J-CA	Japanese calcalkaline rocks
CJS-Ak	Alkaline rocks in the Circum Japan Sea region
J-Ak	Japanese alkaline rocks
Hw-Ak	Hawaiian alkaline rocks
Hw-Th	Hawaiian tholeiitic rocks
E	Eclogite

A, B and C Types refer to Table 1.

The major source of error in estimating the depth of magma production may be the geothermal gradient extrapolated by the present author, according to the gradient curves of GUTERNBERG, Vening MEINESZ et al. The transition between basalt (gabbro) and eclogite · amphibolite should be also reinvestigated.

Appendix

Such an idea mentioned in this paper does not always assert that it is impossible that non-alkalic rocks are formed by any processes as assimilation and crystal concentration or subtraction, from some magmas produced by partial melting of peridotite. Moreover the effects of SO_3, NH_3, HCl, CO_2, etc. in addition to H_2O on the melting of the source rocks should be discussed in future.

The rock character (or diversity) should depend on the chemical compositions

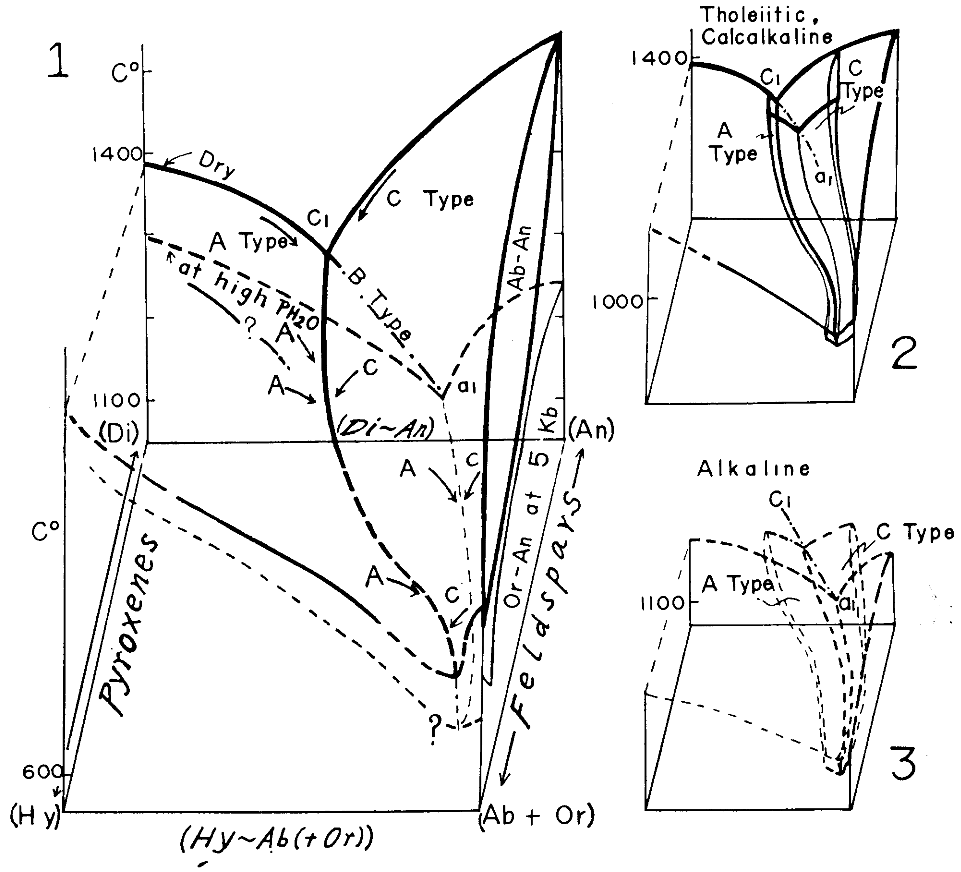

Fig. 14. Schematic diagram showing the genetical relations between three PF types (A, B and C). (Conf. Figs. 7–10).

c_1 "Cotectic-like line" at low vapour pressure.

a_1 "Cotectic-like line" at high vapour pressure (corresponding to 5 K bars approx. in the Di-An system).

In this diagram the vapour pressure relation between "Alkaline rocks" and "Tholeiitic · Calcalkaline rocks" is also shown. Alkaline rocks crystallize at the higher vapour pressures and tholeiitic · Calcalkaline rocks at the lower vapour pressures.

(including available water and other volatile substances) of the parental source rocks from which magmas are produced by partial~complete melting under various vapour pressures, and on the physico-chemical condition through the process of magma production and consolidation, including assimilation or contamination.

Acknowledgements I appreciate the contribution made by many investigators, and the kind discussion on the present study given by some members of the Volcanological Society of Japan; Prof. H. KUNO, Dr. S. ARAMAKI, Dr. I. KUSHIRO, etc. gave a partial discussion or advice. The study was partly supported by a grant from the Japanese Government Fund for Scientific Research.

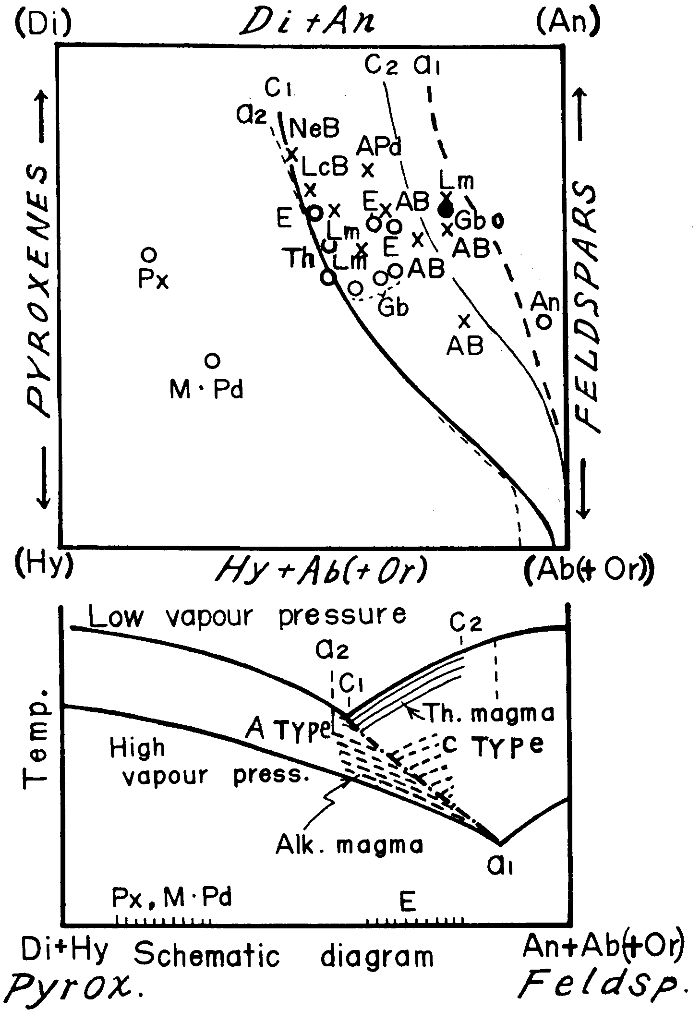

Fig. 15. The Pyroxene (Di~Hy)-Feldspar (An~Ab·Or) relation of ultrabasic~basic rocks and their genetical interpretation. (Cf. Fig. 14).

A	Alkaline	AB	Alkali basalt
An	Anorthosite		
E	Eclogite (equivalents)		
Gb	Gabbro		
Gbo	Olivine gabbro		
LcB	Leucite basalt		
Lm	Limburgite		
M-Pd	Mantle peridotite (KUSHIRO and KUNO, 1963) (equivalents)		
NeB	Nepheline basalt		
Px	Pyroxenite		

a_1, a_2, c_1, c_2 refer to Figs. 7, 8.

Marks (open circle, solid circle and cross) refer to Fig. 1 and Table 1.

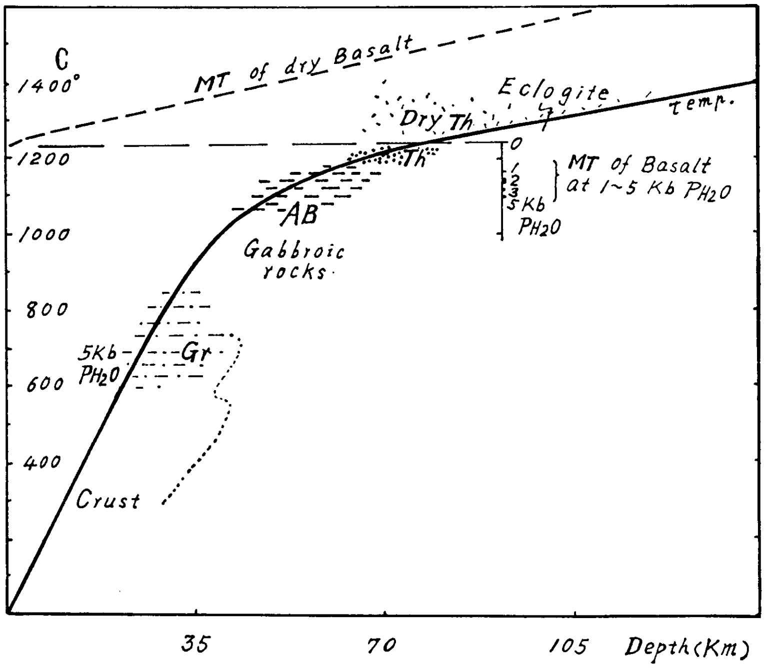

Fig. 16. Schematic diagram shawing the relation between depth, temperature and vapour pressure of magmas.

AB Alkaline basalt magmas } produced by partial~complete
Th Tholeiite magmas } melting of gabbroic rocks.
Gr Granite magmas: produced by melting of granitic crust.
Temp. General temperature distribution through the crust and upper mantle, estimated by the present author, according to the geothermal gradient of Gutenberg, Vening Meinesz et al.
MT of basalt at 1~5 kb P_{H_2O} melting temperature of basalt under hydrous condition, after YODER and TILLEY.

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