AN ALKALI OLIVINE BASALT AND ITS RELATED ROCKS FROM THE SETOGAWA GROUP, SHIZUOKA PREFECTURE

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Abstract An alkali olivine basalt sheet with a picrite substratum and camptonite vein has been found occurring among the dominant tholeiitic basalts in the Paleogene Setogawa Group in the northern part of Shizuoka City. Both tholeiitic and alkali olivine basalts are regarded as of the same geologic age, and this seems significant to the better understanding of the structural movement and volcanism of Southwest Japan prior to the Fossa Magna geosynclinal subsidence.

Zoned clinopyroxenes, amphiboles and chrome spinels, in samples from a successive section through the main sheets, have been studied using the electron microprobe. The overall fractionation trend of the clinopyroxenes shows a distinct salite-aegirine trend. To provide a basis for discussion of the zoned clinopyroxenes a new model involving differentiation within the composite lava flow is proposed.

On the basis of the composition of the mafic minerals it is inferred that the alkali suite was crystallized and differentiated rapidly under high oxygen fugacity with high initial H_2O content. It is argued that progressive melting of a mantle material could account for petrogenetic relationships between the alkali suite and the dominant tholeiitic basalt, whose pyroxenes show the typical augite-ferroaugite trend.

Introduction

The outer zone of Southwest Japan in the Akaishi Mountains is composed, from west to east, of the Sambagawa, the Chichibu, the Shimanto and the Setogawa terrains which have a general NE–SW trend. The Setogawa Group, a sedimentary sequence with occasional thin beds of volcanic rocks in the Setogawa terrain, yields Paleogene fossils at several localities (ISHII & MAKINO, 1946; OYAMA & MIZUNO, 1958).

The alkali suite, which is estimated to constitute less than 5 per cent of the volcanic rocks of the Setogawa Group, is dominated by alkali olivine basalt with minor amounts of camptonite and picrite. The Setogawa terrain is bounded to the east by the Ryusozan terrain composed mainly of alkali extrusive and intrusive rocks. Further to the east runs

the Itoigawa-Shizuoka Tectonic Line, which defines the western margin of the Fossa Magna where geosynclinal subsidence occurred during the Miocene. In connection with this episode submarine volcanism took place to constitute the Takakusayama-Ryusozan alkali rock province in the early Miocene. It contains a large amount of intermediate and acidic rocks such as mugearite and trachyte (TIBA, 1965, 1966).

ONO (1973) was probably the first to point out that both the Setogawa and the Ryusozan terrains might form a single petrographic alkali rock province. From this point of view stratigraphic and petrographic studies on the Setogawa volcanic rocks are of particular importance to reveal the tectonic movement of Southwest Japan preceding the Fossa Magna geosynclinal subsidence and volcanism.

Some explanations have been put forward so far as the petrogenesis of the Setogawa alkali suite is concerned. SAMESHIMA (1970)

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described the occurrence and petrochemistry of some alkali rocks from the Setogawa Group and its correlatives, *e.g.*, the Mineoka Group of the Boso and Miura Peninsulas, and concluded that the camptonite, corresponding in its chemical composition to that of the trachyandesitic basalt of the Circum Japan Sea alkali rock province, might be consanguineous with the picrite, which was regarded as an alkali ultramafic extrusive rock. With regard to the Takayama picrite in the Setogawa Group it was inferred from the morphology and composition of its olivine phenocryst that its initial magma might have been ultramafic

in nature (TAKASAWA, 1976).

Despite the widespread occurrence of various kind of alkali rocks in the Setogawa and the Mineoka Groups, occurrence in which mutual parentage can be discerned have never been reported. In this paper new field evidence to elucidate the genesis of the alkali olivine basalt, picrite and camptonite is presented. Their chemistry and mineralogy are described with the object of considering the petrogenesis and the course of differentiation of the alkali olivine basaltic magma in comparison with the dominant tholeiitic basalt.

Fig. 1 Distribution of mafic and ultramafic rocks in the Nakakouchigawa area with index map of the studied area. The heavy broken line refers to the Sasayama Tectonic Line by which the Setogawa terrain is bounded on the west.

Geological setting

The Setogawa Group, lying to the north of Shizuoka city, is composed of thick geosynclinal sequence of sandstone, shale and slate with subordinate mafic volcanics, chert, limestone and conglomerate including olistostrome. Serpentinized ultramafic rocks occur mostly as intrusives having N-S elongation and is confined near or along the Sasayama Tectonic Line, at which the Setogawa terrain is bounded on the west by the Shimanto terrain composed of the Mesozoic Mikura Formation.

Most of the Setogawa volcanic rocks consist of plagioclase phyric tholeiitic basalts, some of which occur as pillow lavas. They have suffered spilitic degradation to a great extent, are interbedded with isoclinally folded tuff and chert or limestone, and are repeatedly found subparallel to the general strike, north-east, of the Setogawa Group.

On the other hand, alkali rocks occur as small extrusive and intrusive bodies sporadically scattered in the area. Some of them are small diatreme or lens lying diagonal to

the general strike of the Setogawa Group, and others are found as separate large tectonic blocks composed of volcano-sedimentary sequence such as lava flow, tuff and chert, occurring in fault contact with the Setogawa sediments and/or serpentinite bodies. Thus their stratigraphic positions remain unknown. Direct contact of the alkali rocks with the tholeiitic ones is not observed, but fragments of both rocks occur as clasts in an olistostrome, apparently denying a significant break between the eruption of the tholeiitic basalt and that of the alkali olivine basalt. Three representative outcrops are seen along or in a serpentinite belt at point A, B and C in the Nakakouchi-gawa area (Fig. 1). An alkali olivine basalt overlying tuff and chert beds is well exposed in the form of a lava flow with pillow structure, about 20 meters thick, at point A. A sheared magnesite occur in fault contact with the top of this volcano-sedimentary unit. An alkali dolerite dike with a camptonite vein, about 3 meters in thickness, trends northwest facing the road at point B. It rests between argillaceous tuff bed and thick chert bed with undulatory

Fig. 2 Geological sketch map of alkali olivine basalt sheets of the Daido-jima region.

contact.

At the point C near Daido-jima about 20 km northwest of the city center, three concordant sheets of basic rocks are almost continuously exposed through a height of some 20 meters along a gently inclined gorge where cross-section A-B was examined (Fig. 2). The lowest sheet of the three is a composite sheet about 8 meters thick, but any direct contact with the underlying sediments is hidden. The composite sheet can be divided into five units due to rock types. They are from the bottom up: *I. lower chilled portion* of coarse-grained basic rock (diabase) in fault contact with soil that might have been derived from the alteration of the underlying tuff. *II. picrite portion* about 2 meters in thickness, highly altered to dark green clayey matter. *III. coarse-grained basic rock (diabase) portion*, about 40 centimeters in thickness, clear-cut boundary with the picrite *II*, and having a gradual transition to *IV*. *IV. basaltic portion*, traversed by *V. a camptonite vein* with a thickness of 60 centimeters or less near the base. *III to V* altogether has a thickness of about 5 meters. Basaltic portion *IV* is followed abruptly by a vitric tuff layer with small amounts of basaltic fragments, and grading upward into vitric tuff containing shards and fragments of glass and odd chips of pyroxene and feldspar in a vitreous matrix (Plate 3). From this it may be inferred that the overlying tuff was deposited following the extrusion of the composite sheet.

Many carbonate-filled vesicles are preferentially observed near the top of the basaltic portion *V* (Plate 1). There is no evidence of interior chilling at the discontinuity and columnar joints crossing these units unbroken (Plate 2). The grain size of constituent minerals increases toward the center of the sheet. Textural and mineral variations within a cross-section of the sheet as a whole tend to be gradational with the exception of the camptonite vein. These facts may indicate that five units of the composite sheet are parts of a lava flow instead of multiple extrusion, though they involve coarse-grained basic portions exhibiting typical ophitic texture. Immediately above the vitric tuff lies

Fig. 3 Mineralogical variation in alkali olivine basalt sheets with a cross section. Horizontal dimension is modal vol. per cent of olivine, plagioclase, clinopyroxene and amphibole.

Zone I = lowermost chilled diabasic portion.

Zone II = picritic portion.

Zone III = diabasic portion.

Zone IV = basaltic portion.

Zone V = camptonite vein.

another sheet of lava with a mineralogy similar to the basalt of the underlying composite sheet. In this contact zone a brownish glass film, about 0.1 mm in thickness, is formed in the uppermost part of the tuff bed (Plate 4), while the overlying basalt exhibits a chilled contact phase. The contact relations, as mentioned above, indicate that the alternations form probably a volcanic unit successively erupted from a basaltic magma.

Petrography of the analyzed samples

For the present study a dozen samples

were collected from a serial section through the exposed part of the Daido-jima sheets. Optical and modal analyses, and chemical analyses of five bulk rocks and of main constituent minerals of nine samples are shown schematically with their mineral variation in Fig. 3. All of them highly altered, they usually retain original textures, and clinopyroxenes are perfectly fresh even in the most intensely altered rocks. The alteration is primarily an albitization of feldspar and a chloritization of olivine. The major mineral constituents are olivine, clinopyroxene, amphibole, biotite and feldspar. Apatite is a constant accessory. As opaque minerals pyrite, leucoxene and magnetite are abundant. Most of them may be secondary products. Alkali affinities are indicated by the presence of titanite, sodic pyroxene and amphiboles such as kaersutite, barkevikite and arfvedsonite and the absence of orthopyroxene.

The main rock types of the composite sheet are described below.

I). In the lower chilled portion a diabasic rock shows evident ophitic texture. Large subhedral grains of clinopyroxene, 1 to 2 mm in size, have a deep brown core and pale greenish rim, and are moulded on subhedral grains of feldspar. Small amounts of intergranular barkevikite, biotite, and opaque minerals occur.

II). The picrite consists mainly of olivine, plagioclase, clinopyroxene with lesser amount of amphibole and biotite. The matrix of the picrite involves small amounts of globular or irregular patches which are altered to chloritic materials. Square, prismatic or skeletal grains of chrome spinels are dispersed in the matrix.

III). The diabasic rocks show coarse grained, ophitic to subophitic texture evident to the naked eyes. Large ophitic clinopyroxenes exhibit sector zoning.

IV). The basaltic rocks are mostly intergranular to subophitic. Optically zoned pyroxene become coarser grained from the top to the bottom, up to 0.8 mm in size. Coarser specimens have slightly higher clinopyroxene/plagioclase ratio (see Fig. 3). Small a-

mounts of biotite and amphibole are present.

The chilled basalt from the uppermost portion of the composite sheet carries some phenocrysts of olivine (see Plate 5). Very minute grains of clinopyroxene occur as small prismatic crystals in the aphanitic matrix and are embedded in slender laths of plagioclase. While no fresh glass remains, minor patches of chlorite appear to have replaced glass. V). The camptonite vein consists of 29 per cent of plagioclase, 17 per cent of clinopyroxene, 4 per cent of amphibole and 2 per cent of biotite and accessory apatite in a chloritic matrix. Some clinopyroxene crystals, 1 to 3 mm in size, are stout prismatic or tabular, but more commonly they are subhedral, showing ophitic structure with subhedral plagioclase. Aegirine forms the outer rim on the clinopyroxene or occurs as anhedral crystals among feldspar.

Chemistry of the rocks

Chemical analyses of the major rock types of the composite sheet are given in Table 1. Most of the analyzed rocks are notably rich in alkali, due to prevailing spilitic alteration, i.e., albitization and chloritization. Normative nepheline appears in three analyses including the chilled basaltic portion (specimen 9 in Fig. 3), while no modal nepheline is observed. It may be attributable to the abundant alkali rich mafic minerals, but other factors may be also responsible. The presence of normative hypersthene (specimens 2 and 7) is probably attributed to the high ferric-ferrous ratio which results in the calculation of large amount of normative magnetite considerably in excess of the amount actually present in the rock.

Despite such modification by the later alteration, salient features of the original lava flow can be deduced from these analyses. The average TiO_2 content, 1.4 wt. per cent, of the three basaltic rocks is notably poorer than those of the Hawaiian alkali olivine basalt having 3.4 per cent TiO_2 (MACDONALD, 1968), the Takakusayama basaltic rocks having 2.6 per cent TiO_2 (TIBA, 1965), and the alkali olivine basalt from the point A of the studied area (Fig. 1) having 2.0 per cent

Table 1 Chemical compositions and C.I.P.W. norms of the alkali olivine basalts and its related rocks at point C in Fig. 1.

Specimen	2	4	7	8	9
SiO ₂	38.92	43.76	41.27	46.06	44.54
TiO ₂	1.46	1.67	1.23	1.31	1.31
Al ₂ O ₃	10.85	15.77	13.94	15.15	13.25
Fe ₂ O ₃	6.17	4.40	5.12	3.27	1.48
FeO	8.05	7.62	6.37	6.75	10.99
MnO	0.26	0.16	0.19	0.19	0.22
MgO	18.24	7.01	14.26	7.04	8.57
CaO	5.28	8.45	6.07	6.95	7.09
Na ₂ O	0.58	3.53	1.98	5.79	4.77
K ₂ O	0.33	1.36	0.40	0.38	0.53
P ₂ O ₅	0.27	0.34	0.14	0.31	0.26
H ₂ O (+)	7.57	4.89	6.09	6.01	6.95
H ₂ O (-)	1.24	0.34	2.89	0.46	0.32
Total	99.22	99.30	99.95	99.67	100.28
Cr (ppm)	1521	---	---	---	381
Ni (ppm)	425	---	---	---	113
Or	2.23	7.79	2.23	2.23	3.34
Ab	4.72	24.19	16.78	35.27	27.80
An	24.20	23.37	28.08	14.47	13.08
Ne	---	3.09	---	7.31	6.82
C	0.61	---	---	---	---
Wo	---	7.09	0.46	7.67	8.48
En	25.10	---	11.60	---	---
Fs	4.22	---	1.98	---	---
Fo	14.20	12.23	16.66	12.30	14.97
Fa	2.65	6.01	3.06	6.22	13.35
Mt	9.03	6.48	7.42	4.63	2.08
Il	2.73	3.19	2.28	2.43	2.43
Ap	0.67	0.67	0.34	0.67	0.67
(Chr)	0.22	---	---	---	---

* The numbers in column correspond to those of the samples in Fig. 3.

2. Picrite, sample No. 74926001.

4. Diabase, sample No. 7492610.

7. Camptonite vein, sample No. 7640503 (Analyst: T. AGATA)

8. Basalt, sample No. 7492607C.

9. Basalt, the uppermost portion of the lowest sheet, sample No. 7532204.

TiO₂.

On the other hand the TiO₂ content, 1.5 per cent, of the picrite is high as compared

with some similar picrites of other localities from the Setogawa and the Mineoka Groups having nearly 0.9 per cent (SAMESHIMA, 1970). It reflects the presence of titanaugite, kaersutite and biotite.

The composition of the camptonite, having 41 per cent of SiO₂ and 14 per cent of MgO, is more akin to that of the picrite than the basalts, and is characterized by much lower Na₂O compared with the basalts, which is well represented in the calcic composition of its plagioclase.

Description of minerals

Olivine: Though completely replaced by chlorite, talc and other secondary minerals, euhedral or peri-euhedral pseudomorphs after olivine are readily recognized in a few samples. The chilled basalt has about 10 vol. per cent of olivine phenocryst, while the picrite has more than 40 per cent of euhedral olivine (see Plate 5, 6). Some small olivine grains are enclosed in the poikilitic augite of the picrite.

Clinopyroxene: Optics show considerable compositional variation even within a single crystal. In the picrite, 2V_r and refractive index β , for instance, is 54° and 1.722, respectively for a pinkish violet, moderately pleochroic sector, and 49° and 1.707 for a colorless sector. Selected microprobe analyses are shown in Table 2. The Mg/(Mg+Fe) ratio of the early pyroxene, the most magnesian observed in the specimens, varies 0.80 in the picrite (specimen 2), through 0.75 in the diabase (specimen 5), to 0.59 in the fine-grained basalt (specimen 10). Of all the basaltic rocks, coarser specimens have more magnesian early pyroxene and show wider range of Mg/(Mg+Fe) ratio.

Pyroxenes from the Setogawa volcanic rocks in terms of Ca, Mg and Fe are shown in Fig. 4. There are at least two series of volcanic rocks recognizable. "Cpx in alkali rocks" in the Figure refer to the plots of clinopyroxenes from the Daido-jima sheets. An overall trend would emerge, and it is distinctly separated from that of the clinopyroxenes in the spilite and the keratophyre, which may be tholeiitic in nature (unpublish-

Fig. 4 Plots of pyroxenes from the Setogawa volcanics in terms of Ca, Mg and Fe. Trends of clinopyroxene crystallization from (A) Shonking Sag laccolith (NASH & WILKINSON, 1970) and (B) Skaergaard intrusion (WAGER & BROWN, 1967) are also shown.

ed data, Ohashi). The dominant substitution is of Fe for Mg initially with a slight increase of Ca content and in the later stage a definite decrease in Ca. This trend is similar in appearance to the trend typical of strongly alkali mafic magma, viz, the salite-ferrosalite-aegirine trend, as shown in *e.g.*, the Shonking Sag laccolith (NASH & WILKINSON, 1970) and the Black Jack sill (WILKINSON, 1957).

Variation in the atomic proportion Ca: Mg: Fe for the pyroxenes analyzed from individual specimens is illustrated in Fig. 5. Composition of the pyroxenes from the basaltic portion forms a trend in the quadrilateral roughly parallel to the $\text{Ca}_{50}\text{Mg}_{50}$ – $\text{Ca}_{50}\text{Fe}_{50}$ line. The trend of the pyroxenes from the picrite and from the diabase, however, is at a high angle to the line with an apparent compositional gap between the Mg rich colorless sectors and the Ca and Fe rich pinkish violet sectors.

Plots of the Al and Ti contents against $\text{Mg}/(\text{Mg}+\text{Fe})$ of the pyroxenes in the individual specimens are shown in Fig. 6. In

the picrite and the diabase Al and Ti increase with Fe content, while in the basaltic rocks there is a reversal with increase in Fe leading to a decrease in Al with relatively constant Ti content. Similar relationships were reported in the zoned clinopyroxene from the Shiant sill (GIBB, 1973). Variation in the Na content of the pyroxenes over whole rocks is shown in Fig. 7, except that of aegirinic varieties. A slight increase in Na with Fe content is noticeable.

The clinopyroxene in the camptonite is extremely variable in composition (Table 2, 5). The $\text{Mg}/(\text{Mg}+\text{Fe})$ ratio, 0.72 of the early pyroxene, lies intermediately between that in the picrite and in the basalt, while Fe rich varieties are aegirinic. This variability may arise from a concentric zoning superimposed on sector zoning.

Feldspar: In all but the camptonite no calcic plagioclase survives, most being albite, of which refractive index α are less than 1.631 (An_5). Even in the camptonite, the feldspar, especially large individuals, are distinctly patchy. This patchiness is distinct by

Table 2 Representative microprobe analyses of clinopyroxenes to indicate the main compositional variation present in some of the samples. The full compositional range is not necessarily represented in each specimen.

Cpx.	(lowermost diabase)		(picrite)		(diabase)		(basalt)	
	1 (c)	1 (r)	2 (l)	2 (p)	5 (l)	5 (p)	6 (c)	6 (r)
SiO ₂	43.2	47.3	48.4	42.7	48.4	43.1	46.3	44.7
TiO ₂	3.69	3.05	2.07	3.78	1.54	3.63	2.88	1.88
Al ₂ O ₃	8.03	6.24	4.50	9.32	4.33	9.47	7.23	4.77
Cr ₂ O ₃	0.03	0.05	0.08	0.20	---	0.01	0.00	0.01
FeO *	9.80	10.6	6.99	8.07	8.67	9.59	10.8	14.2
MnO	0.19	0.23	0.16	0.13	0.11	0.14	0.24	0.28
MgO	11.3	11.2	15.6	11.3	14.2	11.7	11.0	9.40
CaO	22.3	22.3	22.5	22.5	22.9	22.5	23.0	23.6
Na ₂ O	0.60	0.67	0.35	0.49	0.39	0.49	0.79	0.90
Total	99.2	101.6	98.7	98.4	100.6	100.6	102.2	99.7
100 (Mg/Mg+Fe)	67.4	65.4	77.7	71.4	74.6	68.4	64.6	54.2
Ca	48.8	48.4	48.0	50.4	46.3	48.7	49.1	49.4
Mg	34.5	33.7	40.4	35.4	40.0	35.1	32.9	27.4
Fe	16.7	17.9	11.6	14.2	13.7	16.2	18.0	23.2

Cpx	(camptonite)		(basalt)		(uppermost basalt)		(basalt **)	
	7 (l)	7 (p)	8 (c)	8 (r)	9 (l)	9 (2)	11 (c)	11 (aeg.)
SiO ₂	45.2	44.2	42.5	43.3	42.2	44.9	41.7	51.2
TiO ₂	2.84	4.01	4.19	4.46	3.41	2.95	4.37	1.47
Al ₂ O ₃	7.86	7.90	8.60	6.95	12.4	5.89	8.78	0.87
Cr ₂ O ₃	0.08	0.01	n.d.	0.05	0.09	0.03	0.07	0.07
FeO *	8.35	10.7	11.0	13.9	10.2	11.3	11.8	27.7
MnO	0.09	0.17	0.20	0.26	0.08	0.22	0.22	0.47
MgO	11.7	10.1	10.5	8.55	9.38	10.2	9.09	0.75
CaO	23.0	22.5	23.1	22.3	22.8	21.9	21.5	7.81
Na ₂ O	0.42	0.65	0.66	0.87	0.45	0.75	0.75	9.55
Total	99.5	100.2	100.7	100.6	101.0	98.1	98.3	99.9
100 (Mg/Mg+Fe)	71.3	62.7	63.0	52.3	62.1	61.7	57.9	4.6
Ca	50.2	50.1	50.0	49.5	52.0	48.7	49.6	25.6
Mg	35.5	31.1	31.5	26.4	29.8	31.7	29.2	3.4
Fe	14.3	18.6	18.5	24.0	18.2	19.6	21.2	70.9

** Clinopyroxenes of a basalt from another sheet of lava, situated at the horizon about 5 meters higher than the composite sheet.

c=core, r=rim, l=colorless sector, p=pinkish violet sector, aeg.=aegirine.

included green chlorite flakes bounding irregular areas of albite to the andesine host (up to $\text{An}_{50}\text{Ab}_{49}\text{Or}_1$).

Amphibole: Occurring in a subordinate amount in all samples, it shows a wide mineralogical variation which ranges from kaersutite in the picrite, through hastingsite or barkevikite in the mafic rocks, to arfvedsonite in the camptonite (Table 3). Slightly zoned kaersutite occur usually as thin growth on pyroxene, but sometimes as isolated crystals in the picrite. They have relatively high $\text{Mg}/(\text{Mg}+\text{Fe})$ ratio, ranging from 0.64 to 0.61, and high TiO_2 and Al_2O_3 contents. In the diabasic portion the occurrence of brown barkevikite or hastingsite with a greenish rim is very similar to that of kaersutite in the picrite. They often have narrow incomplete biotite fringes. In the basaltic portion small grains of peri-euhedral barkevikite or hastingsite occur selectively in or near vesicles. The composition of amphiboles from mafic rock is titaniferous and low in $\text{Mg}/(\text{Mg}+\text{Fe})$ ratio

ranging from 0.34 to 0.48. Dark blackish green amphibole is sometimes intergrown with aegirine in the camptonite vein. Discontinuous zoning from brown barkevikite to dark green amphibole is also observed. Seemingly the irregular boundary between these two amphiboles resulted partly from the latter replacing the former. Chemical analyses [7-(2)] identifies the mineral as an arfvedsonite. The $\text{K}/(\text{K}+\text{Na})$ ratio of the arfvedsonite, 0.095, is nearly the same as that of the kaersutite, and higher than that of amphiboles in the mafic rocks, ranging from 0.063 to 0.092.

Biotite: Biotite occurs as small individual crystals or parallel growth with other mafic minerals. Biotite is 2 to 3 vol. per cent in the picrite and the diabase, but only less than 1 per cent in the basalts. Refractive index γ ranges from 1.640 in the picrite, through 1.645 in the basalt, to 1.649 in the lower chilled diabase.

Chrome spinel: A small amount of euhedral

Fig. 5 Analyses of clinopyroxenes from the individual specimens expressed in terms of the atomic ratio $\text{Ca}:\text{Mg}:\text{Fe}$.

p=clinopyroxenes of pinkish violet sector.

l=clinopyroxenes of colorless sector.

Fig. 6 Al and Ti contents against $Mg/(Mg+Fe)$ ratio of the clinopyroxenes from the individual specimens. They are expressed in terms of atomic number per 6 oxygens. In basaltic rocks clinopyroxenes in finer specimens are slightly higher in Al content. The clinopyroxene in the uppermost (*) and lowermost (**) specimens respectively show unique quench patterns.

(*)=The clinopyroxenes in the uppermost are purple brown in color and $10\ \mu\text{m}$ or less in size. They have relatively narrow range of the $Mg/(Mg+Fe)$ with considerably high and variable amount of Al_2O_3 , 12.4 to 5.9 wt. per cent. This variability might be due to either local small-scale variation in melts composition or a disequilibrium crystal-liquid partitioning (EVANS & MOORE, 1968).

(**)=The clinopyroxenes in the lowermost diabase have very narrow range of $Mg/(Mg+Fe)$ ratio with Al rich deep brown core, having 8 wt. per cent of Al_2O_3 . This zoning pattern is similar to that of the fine grained basalts.

chrome spinel occurs mostly as an inclusion of olivine pseudomorph and clinopyroxene. Selected analyses are shown in Table 4. The chrome spinels show considerable compositional variation from chromian spinel (9) in the chilled basalt to the chromian titanomagnetite (7) in the camptonite.

The chrome spinel richest in Mg, Al and Cr, found as inclusions in olivine phenocryst in the chilled basalt (9), is similar in composition to the early spinel in the abyssal basalt from the Parece Vela Basin (RIDLEY, *et al.*, 1974). In view of the occurrence and the composition, this spinel is believed to represent more closely the composition of the chrome spinel that precipitated from the liquid.

Fig. 7 Variation in the Na content of the clinopyroxenes with $Mg/(Mg+Fe)$ ratio for all samples.

Amph.	2	4	7-(1)	7-(2)	9	11
SiO ₂	39.0	41.0	40.0	47.8	39.9	40.4
TiO ₂	6.02	3.62	4.16	1.30	4.42	4.08
Al ₂ O ₃	12.7	9.29	11.7	2.88	10.9	9.70
Cr ₂ O ₃	0.15	---	---	---	---	0.07
FeO *	12.1	23.8	23.7	33.2	18.5	21.9
MnO	0.15	0.51	0.33	0.85	0.28	0.47
MgO	11.7	6.76	7.08	0.79	9.78	7.26
CaO	11.7	9.14	9.33	1.88	10.8	10.7
K ₂ O	0.50	0.63	0.37	1.35	0.38	0.54
Na ₂ O	3.18	4.10	2.89	8.50	3.72	3.57
H ₂ O **	2.00	2.00	2.00	2.00	2.00	2.00
Total	99.1	100.9	101.6	100.6	100.7	100.7

Table 3- Selected microprobe analyses of amphiboles.

* Total iron as FeO

** H₂O normalized to 2.0 wt. per cent. Atomic proportions are calculated on the basis of 24 (O, OH).

2. kaersutite in the picrite.

4. barkevikite in the diabase.

7-1. barkevikite in the camptonite vein.

7-2. arfvedsonite in the camptonite vein.

9. hastingsitic hornblende in the chilled basalt.

11. barkevikite in the basalt.

Numbers of ions on the basis of 24 (O, OH)

Si	5.86	6.34	6.10	7.64	6.06	6.23
Al	2.14	1.66	1.90	0.36	1.94	1.76
Al	0.10	0.03	0.21	0.18	0.01	---
Ti	0.68	0.42	0.48	0.16	0.50	0.47
Cr	0.00	---	---	---	---	0.01
Fe	1.52	3.08	3.02	4.44	2.35	2.83
Mn	0.19	0.07	0.04	0.12	0.04	0.06
Mg	2.62	1.56	1.61	0.19	2.21	1.67
Ca	1.89	1.52	1.53	0.32	1.76	1.77
K	0.10	0.13	0.07	0.28	0.07	0.11
Na	0.93	1.23	0.86	2.64	1.09	1.07
(OH)	2.03	2.06	2.04	2.13	2.03	2.06

Mg/Mg + Fe	0.63	0.34	0.35	0.04	0.49	0.37

before olivine. The spinel (7) in the augite of the camptonite invariably is more titaniferous and ferriferous. The spinel (2) in the picrite is rather titaniferous and ferriferous and akin to those in the camptonite and in the picrite basalt from the Mineoka Tectonic Belt (TAZAKI, 1975). As a whole the chrome spinels show considerable rise in Ti, Fe and Mn as Cr, Al and Mg fall.

Discussion

1) Emplacement and Differentiation of the alkali rock

The composite basaltic sheet of Daidojima is essentially a single extrusive body, except the picrite unit. It is almost impos-

sible to infer that the picrite unit containing more than 40 vol. per cent of olivine was formed in situ by the gravitative settling of olivine, because the uppermost chilled basalt has only about 10 per cent of olivine phenocryst.

A model for the emplacement and differentiation of the composite lava sheet is now proposed. (1) Substantial amount of gravity settling of olivine formed an olivine sludge at the bottom of the basaltic magma chamber. (2) After successive emplacement of magma the olivine sludge was scoured, and concentrated toward the center of the melt during emplacement (BHATACHARJI & SMITH, 1964). (3) The melt would extrude and

Sp.	2	6	7	9
SiO ₂	0.12	0.02	0.35	0.02
TiO ₂	2.99	1.72	10.0	0.79
Al ₂ O ₃	21.3	28.9	8.67	33.5
Cr ₂ O ₃	22.7	27.5	10.4	27.7
Fe ₂ O ₃ *	17.6	12.6	28.7	9.36
FeO	25.3	18.3	38.6	15.8
MnO	0.45	0.29	3.54	0.09
MgO	7.43	13.2	0.15	14.8
CaO	0.17	0.00	0.28	0.03
NiO	0.09	0.05	0.02	0.03
Total	98.2	102.6	100.7	102.1
100(Mg/Mg+Fe ⁺⁺)	34.3	56.2	0.7	62.6
100(Al/Al+Cr)	58.3	61.1	55.5	64.3
100(Fe ⁺⁺⁺ /Al+Cr+Fe ⁺⁺⁺)	23.5	14.5	53.9	10.3
(Mn,Ca)Fe ₂ O ₄	1.8	0.7	10.8	0.2
NiFe ₂ O ₄	0.2	0.1	0.1	0.1
Fe ₂ TiO ₄	7.4	3.8	27.1	1.7
Fe ₂ SiO ₄	0.4	0.1	1.3	0.1
FeFe ₂ O ₄	19.6	13.1	27.8	9.8
MgAl ₂ O ₄	21.2	35.4	0.4	40.8
FeAl ₂ O ₄	20.0	14.8	17.9	15.9
MgCr ₂ O ₄	15.1	22.6	0.4	22.7
FeCr ₂ O ₄	14.3	9.4	14.3	8.8

Table 4 Selected microprobe analyses and molecular norms of spinels in the alkali olivine basalts and its related rocks from the Setogawa terrain.

* Calculated from total iron assuming ideal spinel formula and TiO₂ substitutes as in ulvöspinel.

chill there as basaltic margins. The olivine sludge, when spreading laterally, would be affected by gravity and move down to form the picrite along the base of the sheet, 0.5 meter above the lower contact. Both gravity and flow concentration worked together to produce the discontinuity at the top of the picrite unit, essentially coinciding with the interface between crystal mush and overlying liquid. Similar model was summarized as flowage differentiation by SIMKIN (1967) and BHATTACHARJI (1967), and applied to a dorelite-picrite composite sill of the Shiant Isles (GIBB, 1973). However the composite sheet studied is not a sill but a thin lava flow, its cooling rate being much faster than that of a sill. The examination of pyroxenes

from all the three sheets revealing their more or less identical nature, the composite sheet is indicated to be essentially a lava and belong to the lava group of other two sheets.

2) Crystallization of Clinopyroxene

The crystallization of the clinopyroxene of the Daido-jima composite sheets can now be discussed within the framework of the proposed genetic model. The olivine sludge, which was subsequently intruded to form the picrite, consisted of an accumulate of olivine crystals with an interstitial liquid of the same composition as the overlying basaltic melt in which the olivine was crystallizing and sinking. The liquid phase of both the olivine sludge and the basaltic melt would not have followed identical fractionation paths because

of the difference in the behavior of specific crystallization in the magma chamber, including the relative proportions of olivine crystals and liquid, in cooling rate and possibly in the temperature of crystallization. The liquid of the olivine sludge is assumed to become more magnesian than that of the basaltic melt. Whatever the exact mechanism, when the olivine sludge was emplaced, equilibration of the two liquid may have started across the picrite-mafic rock interface, but was not completed because of the relatively rapid cooling. The result could account for the difference in the compositions of the early pyroxene that are significantly more magnesian in the picrite and in the diabase than those in the basaltic rocks. Regarding slight variation within the basaltic portions, coarser specimens have more magnesian early pyroxene (Fig. 5) and higher clinopyroxene/plagioclase ratio. These may be explicable in terms of local magmatic fractionation in situ, where some sinking of clinopyroxene took place regardless of rapid cooling. The composition of the early pyroxene depends largely on the composition of the melt, and the subsequent trend is obviously controlled by conditions under which fractional crystallization took place.

3) Effect of Quenching

Zoning of pyroxene in specimens from

layered tholeiitic intrusions such as Skaergaard (WAGER, 1963) is usually minor, and the zoning trend follows the overall crystallization trends. Individual specimens of volcanic rocks commonly show very strong zoning in pyroxenes, in some case following a normal plutonic trend and in others a quench trend (*e.g.*, SMITH & LINDLEY, 1971; HEWINS, 1974). This implies that, under certain conditions, kinetic factors, as well as the chemical composition of the host magma, may be significant in determining the chemical composition of phase precipitated (WASS, 1973).

As shown in Fig. 5, an unusual zoning of clinopyroxenes from rock to rock is revealed. In the diabasic and picritic rocks, deep colored sectors contain higher Ti, Al and Fe (Table 5) and lower Si and Mg than the colorless sectors of clinopyroxenes, while in the basaltic rocks individual crystals are zoned from Mg and Al rich core to Fe rich and Al poor rim.

Many authors (*e.g.*, BENGE *et al.*, 1971; BOYD & SMITH, 1971) consider that the reversal of zoning pattern on Al contents occurs below a certain Mg/(Mg+Fe) value that coincide with the onset of plagioclase crystallization. Although similar reversal is seemingly shown in the extrusive composite sheet, rapid cooling is presumed to be the alternative cause of the pattern. In the basaltic portions, the

Cpx.		TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO*	Na ₂ O
2 (picrite)	a	2.07	4.50	0.08	6.99	0.35
	b	2.05	4.27	0.02	7.35	0.37
	c	3.76	9.49	0.36	7.75	0.45
	d	3.78	9.32	0.20	8.07	0.49
5 (diabase)	a	1.54	4.51	0.01	8.14	0.39
	b	1.46	4.67	0.00	8.35	0.37
	c	2.85	7.59	0.02	8.95	0.45
	d	2.29	6.36	0.01	10.3	0.68
7 (camptonite)	a	2.84	7.86	0.08	8.35	0.42
	b	2.92	7.11	0.06	8.98	0.50
	c	3.84	7.59	0.06	9.73	0.61
	d	4.35	9.11	0.02	11.7	0.79
	e	1.49	0.86	0.03	27.5	8.58

Table 5 Representative partial analyses of different sectors and zones in each of a single clinopyroxene grain from three specimens. There is, as in the case of Ca:Mg:Fe, a compositional gap in Al₂O₃, TiO₂ and Na₂O between pinkish violet sector and colorless sector.

* Total iron as FeO

a=core of colorless sector.

b=rim of colorless sector.

c=core of pinkish violet sector.

d=rim of pinkish violet sector.

e=aegirine, greenish fringe of pinkish violet sector.

plagioclase crystallization which result in impoverishment of the liquid in Al is almost simultaneous with the clinopyroxene crystallization in these quench liquids. It would account for Al content decreasing with Fe content. In the diabasic and picritic portions, on the contrary, the Al content increases with Fe, in the sector zoned clinopyroxenes (Table 5). The favorable condition for the formation of the sector zoning may also be achieved in quenching one that caused appreciable supersaturation in clinopyroxene followed by sudden nucleation and rapid growth (FERGUSON, 1973; NAKAMURA & COOMBS, 1973) at relatively low pressure (LEUNG, 1974). Even the coarsest clinopyroxenes, representing the slowest cooling parts, show sector zoning in the diabasic rocks. Because of this, kinetic factors (quenching effect) instead of onset of plagioclase crystallization could cause the reversal of the zoning pattern on Al contents.

4) *Nature of the initial liquid*

Petrographic and chemical evidence indicates that the initial liquid was essentially an alkali olivine basaltic one. The TiO_2 content of the bulk rock is rather low, nevertheless the clinopyroxene contains greater amount of Al and Ti. GUPTA *et al.* (1973) concluded that silica concentration is the most important factor in controlling the solubility of Al and Ti, and increased silica concentration decreases Al and Ti contents in diopsidic pyroxenes. The high Ca content of the clinopyroxenes may be also due to the lower Si activity of the magma (LARSEN, 1976; GIBB, 1973) and the subsequent trend toward aegirine rather than hedenbergite might be due to crystallization under conditions of relatively high oxygen fugacity (RONSBO *et al.*, 1977). Water vapor pressure is one of the main controlling factors of oxygen fugacity, and a hydrous alkali magma is likely to cool under a fairly constant high to moderate P_{O_2} (BARBERI *et al.*, 1971). It is possible to assume that the crystallization switched from pyroxene to amphibole even in the picrite, probably as a result of rising $P_{\text{H}_2\text{O}}$ in the trapped liquid.

It has been shown experimentally that the

composition of a primary magma is dependent on a variety of parameter such as the depth and extent of melting and the activity of H_2O . GREEN (1973) suggests a model mantle material, pyrolite with 0.2% H_2O yielding 6% olivine rich basanite, also yields olivine-rich tholeiitic magma by 30% melting at shallower depth. So far as genetic relationships of the hydrous alkali olivine basalt to the dominant and almost anhydrous tholeiitic one is concerned, the available data are inconclusive on account of a lack of stratigraphic evidence. A plausible mechanism is as follows. The sequential eruption of alkalic and transitional tholeiitic lavas could suggest that melting in the mantle beneath the region was a progressive event associated with mantle diapir. Because of this point of view, melting of voluminous water-undersaturated tholeiitic magma is considered to be preceded by hydrous alkali magma.

Mineralogical data are of prime importance in discussing the connection between them. Although tholeiitic basalts have quite another pyroxene trend, namely augite-ferroaugite trend, chemical composition of chrome spinel from a tholeiitic basalt (unpublished data) is similar to that in the chilled alkali olivine basalt. No Ca-poor pyroxene can be detected even in coarse specimens of both of the rock types. Early pyroxene, with the $\text{Mg}/(\text{Mg}+\text{Fe})$ ratio up to 0.83 in the tholeiitic basalt is slightly more magnesian than that in the alkali suite.

5) *The camptonite vein*

Its boundary to the basaltic host is not gradual transition and the separation of a camptonitic fraction is concluded to have occurred prior to the extrusion of the composite sheet. Evidence leading to the conclusion that the camptonite has originated as a late stage segregation from the olivine sludge, is gleaned from the chemical compositions in which the former shows some resemblance to the latter, particularly as regards those of the bulk rocks, early pyroxenes and spinels. A mechanism of filter-press action (VINCENT, 1953) is adequate to explain the separation of magmatic residua from the already crystallized parts bringing forth more alkalic

and siliceous rocks with higher volatile contents. The last residuum consists of aegirine, arfvedsonite and late sodic feldspar which fringe the earlier separated clinopyroxene, brown hornblende and andesine in the camptonite. The fine scale concentric zoning superimposed on the sector of clinopyroxene in the camptonite may have taken place as the result of the rapid crystallization and temperature oscillations owing to repeated boiling in volatile rich camptonitic melts (COOPER, 1979).

As already mentioned, the picrite contains small globular or irregular patches which are completely altered to chloritic materials. These patches may also occur as late stage segregation (RAMSAY, 1955). It is reasonable to assume that the olivine sludge will be fully saturated with dissolved volatile. During ascent the conflicting pressure will decrease, reducing the volatile solubility, causing vesiculation. The vapor phase may escape and proceed in advance of the magma opening up the joint along which the camptonite is subsequently intruded.

The mineralogical feature of dominant tholeiitic basalts and their differentiates will be described and discussed in a separate paper.

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Reference

- BARBERI, F., BIZOUARD, H. and VARET, J., 1971 : Nature of the clinopyroxene and iron enrichment in alkalic and transitional basaltic magmas. *Contr. Mineral. Petrol.*, **33**, 93—107.
- BENCE, F., PAPIKE, J. J. and LINDSLEY, D. H., 1971 : Crystallization histories of clinopyroxenes in two porphyritic rocks from Oceanus Procellarum. *Proc. Second Lunar Sci. Conf.*, **1**, 559—574.
- BHATTACHARJI, S. and SMITH, C. H., 1964 : Flowage differentiation. *Science*, **145**, 150—153.
- , 1967 : Scale model experiments on flowage differentiation in sills. In Wyllie, P. J. (editor) *Ultramafic and related rocks*. 69—70. New York: John Wiley & Sons.
- BOYD, F. R. and SMITH, D., 1971 : Compositional zoning in pyroxenes from lunar rock 12021, Oceanus Procellarum. *Jour. Petrol.*, **12**, 439—464.
- COOPER, A. F., 1979 : Petrology of ocellar lamprophyre from Western Otago, New Zealand. *Jour. Petrol.*, **20**, 139—163.
- EVANS, B. W. and MOORE, J. G., 1968 : Mineralogy as a function of depth in the prehistoric Makaopuhi tholeiitic lava lake, Hawaii. *Contr. Mineral. Petrol.*, **17**, 85—115.
- FERGUSON, A. K., 1973 : On hour-glass sector zoning in clinopyroxene. *Mineral. Mag.*, **39**, 321—325.
- GIBB, F. G. F., 1973 : The zoned clinopyroxenes of the Shiant Isles sill, Scotland. *Jour. Petrol.*, **14**, 203—230.
- GREEN, D. H., 1973 : Conditions of melting of basanite magma from garnet peridotite. *Earth Planet. Sci. Letters*, **17**, 456—465.
- GUPTA, A. K., ONUMA, K., YAGI, K. and LIDIAK, E. G., 1973 : Effect of silica concentration on the diopsidic pyroxenes in the system diopside-CaTiAl₂O₆-SiO₂. *Contr. Mineral. Petrol.*, **41**, 333—444.
- HEWINS, R. H., 1974 : Pyroxene crystallization trends and contrasting augite zoning in the Sudbury Nickel Irruptive. *Amer. Mineral.*, **59**, 120—126.
- ISHII, M. and MAKINO, T., 1964 : On the Dis-cocyclina found from the Setogawa Series (In Japanese). *Jour. Geol. Soc. Japan*, **52**, 1—2.

- LARSEN, L. M., 1976 : Clinopyroxenes and coexisting mafic minerals from the alkaline Ilimaussaq Intrusion, South Greenland. *Jour. Petrol.*, **17**, 258—290.
- LEUNG, L. M. 1974 : Sector-zoned titanaugites: Morphology, crystal chemistry and growth. *Amer. Mineral.*, **59**, 127—138.
- NAKAMURA, Y. and COOMBS, D. S., 1973 : Clinopyroxenes in the Tawhiroko tholeiitic dolerite at Moeraki, north-eastern Otago, New Zealand. *Contr. Mineral. Petrol.*, **42**, 213—228.
- NASH, W. P. and WILKINSON, J. F. G., 1970 : Shonking Sag laccolith, Montana. I. Mafic minerals and estimates of temperature, pressure, oxygen fugacity and silica activity. *Contr. Mineral. Petrol.*, **25**, 241—269.
- ONO, S., 1973 : Slaty cleavages in the Paleogene Setogawa Group in central Japan. *Jour. Fac. Sci., Univ. Tokyo, Sec. II*, **18**, 431—454.
- OYAMA, K. and MIZUNO, A., 1958 : On the new forms of Paleogene molluscs from Japan. *Bull. Geol. Surv. Japan*, **9**, 1—27.
- RAMSAY, J. G., 1955 : A camptonitic dike suite at Monar, Ross-shire and Inverness-shire. *Geol. Mag.*, **92**, 297—309.
- RIDLEY, W. I., RHODES, J. M., REID, A. M., JAKES, P., SHIH, C. and BASS, M. N., 1974 : Basalts from Leg. 6 of the Deep-Sea Drilling Project. *Jour. Petrol.*, **15**, 140—159.
- RØNSBO, J. G., PEDERSEN, A. K. and ENGELL, J., 1977 : Titanaegirine from early Tertiary ash layers in northern Denmark. *Lithos*, **10**, 193—204.
- SAMESHIMA, T., 1970 : Miocene ultrabasites in the Setogawa zone, central Japan. *Ph. D. Thesis, Nagoya Univ.* (Manuscript)
- SIMKIN, T., 1967 : Flow differentiation in the picritic sills of North Skye. In Wyllie, P. J. (editor) *Ultramafic and related rocks*, 64—69. New York: John Wiley and Sons.
- SMITH, D. and LINDSLEY, D. H., 1971 : Stable and metastable augite crystallization trends in a single basalt flow. *Amer. Mineral.*, **56**, 225—233.
- TAKASAWA, K., 1976 : Olivine from the Takayama picrite in the Setogawa Group, Shizuoka Prefecture, central Japan (in Japanese with English abstract). *Jour. Geol. Soc. Japan*, **82**, 765—771.
- TAZAKI, K., 1975 : Chromian spinels in picrite basalt from Mineoka Tectonic Belt, Boso Peninsula, central Japan (in Japanese with English abstract). *Jour. Geol. Soc. Japan*, **81**, 399—406.
- TIBA, T., 1965 : On alkaline rocks of the Takakusayama district, Shizuoka (in Japanese with English abstract). *Jour. Japan, Assoc. Min. Petrol. Econ. Geol.*, **54**, 23—31.
- , 1966 : Petrology of the alkaline rocks of the Takakusayama district, Japan. *Sci. Rep. Tohoku Univ.*, [3], **9**, 541—610.
- VINCENT, E. A., 1953 : Hornblende-lamprophyre dykes of basaltic parentage from the Skaergaard area, East Greenland. *Quart. Jour. Geol. Soc.*, **cix**, 21—47.
- WAGER, L. R., 1963 : The mechanism of adcumulus growth in the layered series of the Skaergaard intrusion. *Mineral. Soc. Amer., Spec. Paper*, **1**, 1—9.
- and BROWN, G. M., 1967 : Layered igneous rocks. Edingurg: Oliver and Boyd.
- WASS, S. Y., 1973 : The origin and petrogenetic significance of hour-glass zoning in titaniferous clinopyroxenes. *Mineral. Mag.*, **39**, 133—144.
- WILKINSON, J. F. G., 1957 : The clinopyroxenes of a differentiated teschenite sill near Gunnedah, New South Wales. *Geol. Mag.*, **94**, 123—134.

静岡市北方, 瀬戸川層群中のアルカリ・かんらん石玄武岩と関係岩類

大 橋 不 三 男

(要 旨)

古第三系, 瀬戸川層群に産する火山岩類としてはソレイト玄武岩類が卓越するが, ピクライト底層とカンプトナイト細脈を含むアルカリ・かんらん石玄武岩の岩体が見つかった. 両玄武岩類はほとんど同時代の噴出であると考えられ, このことはフォッサ・マグナ地向斜の沈降に先立つ西南日本の構造運動と火山活動を理解するうえで重要である.

一連の溶岩より系統的に採集したサンプル中の累帯する単斜輝石, 角閃石およびクロム・スピネルを EPMA により分析した. 単斜輝石は全体としてアルカリ・かんらん石玄武岩に典型的なサーラ輝石—エジル輝石への分化を示す. 累帯する単斜輝石について論じつつ 1 枚の複

合溶岩流内での分別作用についてモデルを提案した.

苦鉄質鉍物類の化学組成から推定すると, これらのアルカリ岩類は水含有量の高いマグマから, 比較的酸素のフガシティーの高い条件下で急激に結晶が晶出し, 分化したものである. 瀬戸川層群中には, 単斜輝石が普通輝石—鉄質普通輝石の分化を示すソレイル質玄武岩が卓越するが, 当アルカリ岩類との成因関係をマントル物質の累進溶融によって説明しうることも論じた.

(地 名)

Takakusayama	高草山	Sasayama	笹山
Ryusozan	竜爪山	Nakakouchi-gawa	中河内川
Takayama	高山	Daido-jima	大道島

Explanation of plate

1. An alkali olivine basalt sheet showing characteristic mottled appearance near the top of the sheet. Note that many carbonate-filled vesicles are observed preferentially in a horizon beneath a fountain pen.
2. An inclined basalt (B)-picrite (P) composite sheet. At the top of the picrite zone a discontinuity is visible and bring the picrite into abrupt contact with a coarse-grained basic rock showing ophitic texture (diabase, D) which contains significantly less olivine than the picrite.
3. Photomicrograph of a transitional zone of basalt(B) to tuff(T) upwards. Very fine-grained basaltic rock, directly overlaid by vitric tuff, forms upper chilled portion of the Daido-jima composite sheet. The arrow indicates the upward direction of volcano-sedimentary unit.
4. Photomicrograph of the upper margin of a tuff bed (T), where it is in contact with basaltic flow (lack in this photo), and brownish glass (G) is formed in the uppermost part of the bed. Contact relation, tuff to basalt upwards, is pyro-metamorphic one.
5. Photomicrograph showing the chilled basaltic rock, the uppermost portion of the composite sheet of Daido-jima. Olivine phenocryst (pseudomorph, Ol), ranging 0.6 to 0.1 mm in size, with minor inclusions of chrome spinel are observed in an aphanitic matrix.
6. Photomicrograph showing the Daido-jima picritic rock. Many euhedral to peri-euhedral olivine grains (Ol), 2 to 0.1 mm in size, are completely altered to talc, chlorite and serpentine. A titanagite (Cpx) showing ophitic texture with euhedral grains of olivine.