DENDRITIC TITANAUGITE IN ULTRABASIC PICRITE BASALT FROM THE MINEOKA TECTONIC BELT, BOSO PENINSULA, CENTRAL JAPAN

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Introduction

Ultrabasic picrite basalt outcropped in the Mineoka tectonic belt, southern Boso Peninsula shows ferny or dendritic clinopyroxenes of typical quenched texture. In the slowly cooled inner parts of the outcrops, which are contiguous to the quenched parts, the slender prismatic or pinacoidal clinopyroxenes take the place of dendritic titanaugites.

Well-preserved dendritic quenched pyroxenes are rare in picrite basalts in Japan, while in some oceanic quenched basalts, dendritic or skeletal pyroxenes and olivines have been reported (BRYAN, 1972).

The mineral chemistry of these quenched dendritic and associated slender prismatic clinopyroxenes is described below with a brief discussion on their origin.

Occurrences

In Mineoka tectonic belt which extends from east to west in the southern Boso Peninsula, there are developed Paleogene Mineoka group which are mainly composed of alternation of sandstone and mudstone and basic to ultrabasic igneous rocks such as olivine tholeiitic pillow lavas, minor intrusion of picrite basalts and peridotite (dunite-harzburgerite series) intrusions. The minor intrusions of gabbro to diorite occur intimately associated with peridotite intrusions (KAWAI, 1957; KOIKE, 1957; KANEHIRA *et al.*, 1968). The present study was carried out on the specimens

collected from one of these picrite basalts.

The picrite basalt consists of partially serpentinized euhedral olivine phenocrysts ranging up to 5 mm and melanocratic compact groundmass (Plate 1-1). The olivine phenocrysts (Fo 89—91) show partly resorbed or skeletal form and cluster in part. Olivine microphenocrysts (Fo 86—90) less than 1 mm in length show in part long prismatic form which is regarded morphologically as quenched olivine (DREVER & JOHNSTON, 1957).

The groundmass is composed of ferny or dendritic titanaugite and glass of Al- and Si-rich compositions (Plate 1-2).

The dark brown to opaque titaniferous chrome spinels occur sporadically in partially serpentinized olivine phenocrysts, protruding from olivine to groundmass or among groundmass titanaugites (TAZAKI, 1975).

The ferny or dendritic titanaugite often grows up radially from nuclei of fine spinel grains. The ribs of these pyroxenes range from less than 8 μm in width and a few 100 μm long.

The modal analyses of the present picrite basalt give 58.8% olivine and 41.2% groundmass. The slowly cooled inner part has slender prismatic or pinacoidal augites. These clinopyroxenes range up to 0.5 mm in length, and 0.15 mm in width. The sector zoning or hour-glass structure are common and dendritic quenched clinopyroxenes diminish their amounts. They are almost colorless in thin section and extinction angle is 40 to 45°. Idiomorphic plagioclase occurs sporadically among these clinopyroxenes.

The average chemical analyses of the ultrabasic picrite basalt reported by SAMEJIMA

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Table 1. Chemical compositions of picrite basalts.

No.	1	2
SiO ₂	38.25	38.58
TiO ₂	1.14	0.89
Al ₂ O ₃	5.37	4.93
Fe ₂ O ₃	4.53	4.17
FeO	6.32	7.01
MnO	0.14	0.16
MgO	27.86	29.98
NiO	-	0.17
CaO	4.81	3.90
Na ₂ O	0.67	0.53
K ₂ O	0.35	0.19
P ₂ O ₅	0.06	0.15
Cr ₂ O ₃	-	0.29
H ₂ O ⁺	8.47	7.59
H ₂ O ⁻	1.58	1.44
Total	99.55	99.98

1. Tazaki (1975).

2. Average of four picrite basalts (Samejima, 1970).

(1970) and the analysis of the present sample listed in Table 1 show that they are high in MgO and relatively rich in Al₂O₃, TiO₂ and CaO. The chemistry of these rocks does not resemble to that of the so-called alpine-type peridotite but is akin to the members of alkaline ultrabasic rocks such as meimechites (EGOROV, 1970; SAMEJIMA, 1970).

Analytical methods: Microprobe analysis was made using JEOL electron probe micro-

analyzer JXA5A with 40° take-off angle. Analytical conditions were as follows; 15 kV accelerating potential, 0.02 μ A specimen current, spot size about 2 μ m measured on ZrO₂. Other operating procedures were described in TAZAKI & HIRANO (1973). Oxide standards were used for Ti, Al, Fe, Mn, Mg, Cr and Ni, and albite, K-feldspar, and synthetic wollastonite for Na, K and Ca, respectively. Correction was made by empirical method of BENCE & ALBEE (1968) and alpha factors by NAKAMURA & KUSHIRO (1971).

Chemistry of clinopyroxenes

The microprobe analysis was carried out on the selected points of dendritic titanite, a long prismatic one and several augite grains. They exhibit rather wide variation in chemistry (Table 2). The iron content increases obviously towards rim or tips of the dendritic clinopyroxenes. Although total iron oxides were determined as ferrous oxide, about 20 % of total iron oxides might be ferric oxide estimated on the basis of $W+X+Y=2.000\pm 0.02$ in the pyroxene structure formula when $O=6.00$.

The values $\Sigma\text{Fe}\times 100/\text{mg}+\Sigma\text{Fe}+\text{Mn}$ of

Table 2. Selected microprobe analyses of the clinopyroxenes in ultrabasic picrite basalt.

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	G-2-9	1-B-1	1-A-1	G-3-14	G-2-6	G-3-12	G-2-7	G-2-10	7-A-14	1-F-1	7-A-9	1-D-2	7-A-10	1-E-1	1-C-1-2	1-D-1	7-A-11-3	1-J-1
SiO ₂	51.33	50.26	50.57	48.93	48.19	48.14	47.78	47.63	46.43	47.17	45.98	45.80	45.62	45.78	44.86	43.11	43.71	43.34
TiO ₂	1.03	1.39	1.13	1.51	1.92	2.22	1.99	2.19	3.08	2.91	2.94	3.08	3.68	3.67	3.11	4.27	3.74	3.93
Al ₂ O ₃	2.60	4.56	4.37	5.33	5.38	5.59	5.59	5.84	7.98	8.08	9.03	8.13	8.66	7.64	9.25	10.27	10.16	10.11
Fe ₂ O ₃ *	1.87	0.73	0.67	1.90	1.87	2.12	1.93	2.03	2.01	2.07	2.10	2.28	2.17	2.42	2.41	2.61	2.62	2.54
FeO	5.07	5.93	5.42	5.15	5.07	5.72	5.21	5.49	5.46	5.59	5.67	6.17	5.85	6.55	6.51	7.07	7.07	6.85
MnO	0.16	0.13	0.12	0.14	0.11	0.14	0.13	0.12	0.11	0.12	0.13	0.13	0.10	0.11	0.13	0.17	0.15	0.17
MgO	16.82	16.14	15.53	15.21	14.75	14.64	14.46	13.83	13.65	13.39	12.83	12.82	12.75	12.30	11.64	10.97	10.90	10.46
CaO	20.99	19.82	21.01	21.51	22.19	21.61	22.12	22.15	21.00	20.45	21.10	21.55	21.65	21.96	21.94	21.28	22.01	22.41
Na ₂ O	0.17	0.26	0.27	0.27	0.24	0.28	0.27	0.27	0.33	0.31	0.54	0.20	0.34	0.35	0.37	0.40	0.40	0.43
Cr ₂ O ₃	0.29	0.91	0.98	0.74	0.41	0.15	0.36	0.25	0.16	0.14	0.11	0.07	0.24	tr.	0.03	0.12	0.08	0.07
Total	100.33	100.13	100.07	100.69	100.13	100.61	99.84	99.80	100.21	100.23	100.43	100.23	101.06	100.78	100.25	100.27	100.84	100.31

Structure formula on the basis of O=6																		
Si	1.885	1.848	1.861	1.801	1.788	1.780	1.780	1.778	1.721	1.742	1.704	1.708	1.686	1.705	1.679	1.622	1.636	1.632
Al ^{IV}	0.113	0.152	0.139	0.199	0.212	0.220	0.220	0.221	0.279	0.258	0.296	0.292	0.314	0.103	0.321	0.378	0.364	0.368
Al	-	0.045	0.051	0.032	0.023	0.024	0.025	0.036	0.070	0.093	0.098	0.065	0.063	0.040	0.087	0.077	0.084	0.081
Ti	0.002	0.038	0.031	0.042	0.053	0.062	0.056	0.061	0.086	0.081	0.082	0.086	0.102	0.103	0.087	0.121	0.105	0.111
Fe ²⁺	0.156	0.182	0.167	0.159	0.157	0.177	0.162	0.171	0.169	0.173	0.176	0.193	0.181	0.204	0.204	0.223	0.221	0.216
Mn	0.005	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.004	0.004	0.005	0.005	0.005
Mg	0.921	0.885	0.852	0.835	0.816	0.807	0.803	0.769	0.754	0.737	0.709	0.712	0.703	0.683	0.650	0.615	0.608	0.587
Ca	0.826	0.781	0.828	0.848	0.882	0.856	0.883	0.886	0.843	0.809	0.837	0.861	0.857	0.876	0.880	0.858	0.883	0.904
Na	0.012	0.019	0.019	0.019	0.017	0.020	0.020	0.020	0.024	0.022	0.039	0.014	0.024	0.025	0.027	0.029	0.029	0.031
Fe ³⁺	0.052	0.020	0.019	0.053	0.052	0.059	0.054	0.057	0.056	0.058	0.058	0.064	0.060	0.068	0.068	0.074	0.074	0.072
Cr	0.008	0.027	0.028	0.022	0.012	0.004	0.011	0.007	0.005	0.004	0.003	0.002	0.007	-	0.001	0.004	0.002	0.002
Total	4.007	4.001	3.999	4.014	4.016	4.013	4.018	4.010	4.002	3.981	4.007	4.001	4.000	4.003	4.008	4.006	4.011	4.009

Ca**	42.5	41.0	43.9	44.8	46.0	44.7	46.2	46.7	44.8	44.4	46.0	46.1	46.1	46.6	48.1	46.8	48.4	49.7
Mg	49.2	48.9	46.9	46.4	45.3	45.4	44.8	43.6	45.1	45.0	43.2	42.4	42.9	41.1	39.5	39.0	37.8	36.8
Fe ²⁺	8.3	10.1	9.2	8.8	8.7	10.0	9.0	9.7	10.1	10.6	10.7	11.5	11.0	12.3	12.4	14.2	13.7	13.5

The columns no.1 to no.8 are the slender prismatic or pinacoidal augites.

*Fe₂O₃ are calculated from total iron oxides to satisfy WXY = 2.00±0.002.

The columns no.9 to no.18 are the dendritic titanites.

** The numbers of (Ca-Ti) ions are taken as Ca.

Fig. 1. Variation of the analyzed clinopyroxenes in terms of major elements Ca, Mg and Fe.

The numbers of (Ca-Ti) are taken as Ca to eliminate the effect of $\text{CaTiAl}_2\text{O}_6$ component. Large solid circle, dendritic titanaugites; Small solid circle, long prismatic rib of dendritic titanaugite; Open circle, slender prismatic or pinacoidal augites including sector-zoned ones.

the titanaugites vary from 23.0 to 32.0, while those of augite range from 17.0 to 26.3.

Atomic proportion of Ca, Mg and Fe^{2+} are plotted in Fig. 1, where the numbers of (Ca-Ti) are taken as Ca to eliminate the effect of $\text{CaTiAl}_2\text{O}_6$ component. The chemical compositions of the analyzed clinopyroxenes spread over from augite to salite in the pyroxene quadrilateral. The dendritic titanaugite are rather iron-rich, as $\text{Ca}_{45-50}\text{Mg}_{37-46}\text{Fe}_{11-15}$. The slender prismatic or pinacoidal augites of the inner part are $\text{Ca}_{41-47}\text{Mg}_{43-50}\text{Fe}_{8-12}$. Differences in chemical composition between different sectors are observed. The acute sectors extending parallel to crystallographic C-axis are low in Al and Ti than the contiguous obtuse sectors (Table 3; Fig. 2).

The present dendritic titanaugites are high in the Al_2O_3 content attaining 10%, whereas the augites contain less than 6% Al_2O_3 .

The total Al versus Ti relations in Fig. 3 show that Al increases with the increase of Ti content. Most plots fall between the straight lines $\text{Ti}/\text{Al}=1/4$ and $\text{Ti}/\text{Al}=1/8$.

As discussed by many authors, entering of Al and Ti into clinopyroxenes may occur in the coupling substitution of $\text{R}^{2+} + 2\text{Si} \rightleftharpoons \text{Ti}^{4+} + 2\text{Al}^{\text{IV}}$ and $\text{R}^{2+} + \text{Si} \rightleftharpoons \text{Al}^{\text{IV}} + \text{Al}^{\text{VI}}$. In the magma of alkaline affinity, these two substitutions may play an important role in entering of Al and Ti. In the present dendritic titanaugites, coupled substitution $\text{R}^{2+} + \text{Si} \rightleftharpoons \text{Fe}^{3+} + \text{Al}^{\text{IV}}$ may also occur because the amount of Fe^{3+} seems

Table 3. Microprobe analyses of the sector zoned clinopyroxene

No.	1-1	1-2	1-3	1-4	4-1	4-2	4-3
SiO_2	51.35	50.40	47.73	47.15	48.91	46.82	50.86
TiO_2	0.94	1.20	1.87	2.08	1.84	2.08	0.97
Al_2O_3	2.42	2.87	5.52	5.85	5.10	5.55	2.73
Fe_2O_3^*	1.94	1.83	1.94	2.04	1.95	1.97	2.00
FeO	5.23	4.95	5.26	5.51	5.27	5.34	5.42
MnO	0.17	0.14	0.13	0.14	0.15	0.14	0.17
MgO	17.25	17.18	14.83	14.25	14.30	14.32	16.57
CaO	20.34	20.65	21.56	21.79	21.91	21.59	20.30
Na_2O	0.19	0.17	0.26	0.28	0.29	0.33	0.23
Cr_2O_3	0.21	0.52	0.56	0.27	0.36	0.43	0.17
Total	100.04	99.91	99.66	99.36	100.08	98.57	99.42
Structure formula on the basis of O=6							
Si	1.890	1.862	1.781	1.768	1.813	1.770	1.886
Al	0.105	0.123	0.219	0.232	0.187	0.230	0.144
Al	-	-	0.024	0.027	0.036	0.017	0.005
Ti	0.005	0.015	0.053	0.059	0.051	0.059	0.027
Fe^{2+}	0.021	0.018	0.053	0.059	0.051	0.059	0.027
Fe^{2+}	0.161	0.153	0.164	0.178	0.163	0.169	0.168
Mn	0.005	0.004	0.004	0.005	0.005	0.005	0.005
Mg	0.946	0.946	0.825	0.797	0.790	0.807	0.916
Ca	0.802	0.817	0.862	0.876	0.870	0.875	0.807
Na	0.014	0.012	0.019	0.020	0.021	0.024	0.017
Fe^{3+}	0.053	0.051	0.054	0.058	0.054	0.056	0.056
Cr	0.006	0.015	0.017	0.008	0.011	0.013	0.005
Total	4.008	4.016	4.022	4.023	4.001	4.025	4.006
Ca**	41.2	41.6	45.0	45.6	46.2	45.5	41.9
Mg	50.2	50.2	45.9	44.5	44.6	45.0	49.1
Fe^{2+}	8.6	8.1	9.1	9.9	9.2	9.4	9.0

The numbers in column correspond to the analyzed points in Fig. 2. * Fe_2O_3 are calculated from total iron oxides to satisfy $\text{WXY} = 2.000 \pm 0.02$. **The numbers of (Ca-Ti) ions are taken as Ca.

Fig. 2. Sector-zoned augites.

Dots with numbers show the analyzed points. Bar is 100 μm long. (1), (4) ... sample number; 1, 2, 3, ... analyzed points.

to increase with Ti content (TIBA, 1966).

Calculation of tentative pyroxene components by KUSHIRO's (1962) method suggests that the amount of the $\text{CaTiAl}_2\text{O}_6$ component reaches about 10%, while the $\text{CaAl}_2\text{SiO}_6$ component exceeds the $\text{CaTiAl}_2\text{O}_6$ component and the former reaches about 20% in the case of the most Al-rich augite.

Fig. 3. Ti versus Al relations of analyzed clinopyroxenes.

The symbols are the same as in Fig. 1.

Fig. 4. Ti versus Al relations of Ti-rich clinopyroxenes of various occurrences.

Solid triangles, the groundmass titanaugites in alkaline basalts from various localities in Japan (AOKI, 1964); Solid square, titansalites from the alkaline rocks of Takakusayama (TIBA, 1966); Cross, sector-zoned titaniferous clinopyroxenes in the alkali basalt from the Southern Highlands, New South Wales (WASS, 1973); Open square, titanaugites in dolerite from Morotu, Sakhalin (YAGI, 1953).

The total Al versus Ti relations of titanaugites from various occurrences are shown in Fig. 4.

The groundmass titanaugites in alkaline basalts from various localities in Japan (AOKI, 1964) and titansalites from the alkaline rocks of Takakusayama (TIBA, 1966) fall in the region between the straight lines $Ti/Al=1/2$ and $Ti/Al=1/4$. One titanaugite in dolerite from Morotu, Sakhalin, is also plotted in the same region, whereas the other is located above $1/2$ line (YAGI, 1953).

Most of these clinopyroxenes are lower in Al than the present dendritic titanaugites,

Fig. 5. Variation of Cr and Ti contents in analyzed clinopyroxenes in relation to $\Sigma Fe \times 100 / Mg + \Sigma Fe + Mn$.

Circles, Ti content. Symbols are the same as in Fig. 1. Square, Cr content. Open, solid and small solid represent the slender prismatic or pinacoidal augite including sector-zoned clinopyroxenes, the dendritic titanaugites, and a long prismatic rib of dendritic titanaugite, respectively.

while, the sector-zoned titaniferous clinopyroxenes in an alkaline basalt from the Southern Highland, New South Wales contain more than 10% Al_2O_3 in deeply colored sectors (WASS, 1973).

The variations of Ti and Cr contents in relation to $\Sigma Fe \times 100 / Mg + \Sigma Fe + Mn$ are represented in Fig. 5. The Ti content increases proportionally from augite to dendritic titanaugite with the increase of $\Sigma Fe \times 100 / Mg + \Sigma Fe + Mn$ value. The Cr content is, however, higher in augite and very low in dendritic titanaugite. The $\Sigma Fe \times 100 / Mg + \Sigma Fe + Mn$ value increases, in general, through the fractional crystallization of basic magmas, whereas Cr is enriched in clinopyroxenes of early crystallization. Variation of $\Sigma Fe \times 100 / Mg + \Sigma Fe + Mn$ in the present clinopyroxenes is, however, produced in a process of quenching crystallization from one liquid. Therefore, the present variation of $\Sigma Fe \times 100 / Mg + \Sigma Fe + Mn$ suggests the local or domain crystallization in the magma.

KUSHIRO (1960) and LE BAS (1962), in their discussion on the genetical significance of the amounts of Al, Si and Ti in igneous clinopyroxenes, showed that the concentrations of Al and Ti in igneous clinopyroxenes are mainly dependent on the degree of saturation of Si in the host magmas.

Fig. 6. Variation of SiO_2 and Al_2O_3 in analyzed clinopyroxenes.

The symbols are the same as in Fig. 1. The broken lines separate the three fields of non-alkaline, normal alkaline and per-alkaline from upper left to lower right (LE BAS, 1962).

The Al_2O_3 versus SiO_2 relations in Fig. 6 show that augites fall in both non-alkaline and alkaline fields, whereas, the dendritic titanaugites fall in per-alkaline field defined by LE BAS (1962). The detailed microprobe analyses of clinopyroxenes revealed that the definition of LE BAS (1962) is not always applicable to elucidate the host magma (BARBERI *et al.*, 1971; GIBB, 1973). TIBA (1966) has also reached the same conclusion by her detailed chemical analyses of the alkaline clinopyroxenes from Takakusayama, Central Japan.

The present results show that the chemistry of igneous clinopyroxenes were controlled by not only the chemistry of the host magma but also the crystallization process.

Discussion

Chemical variation of dendritic titanaugite

The Ti-rich clinopyroxenes crystallized from ultrabasic picrite basalt show a wide range of chemical composition from diopsidic augite to aluminous titanaugite. These variations are equivalent to the pyroxenes formed through the fractional crystallization of alkaline basalt magmas (YAGI, 1953; WILKINSON, 1957; AOKI, 1964; TIBA, 1966; YAGI & ONUMA, 1967; FERGUSON, 1973; WASS, 1973).

Successive crystallization of the present clinopyroxenes might have taken place under the following process. During the quenching process of crystal mush or melt of ultrabasic

picrite basalt composition with abundant olivine crystals, crystallization of Ti-rich clinopyroxenes proceeded by the reaction between the crystals and surrounding melt. The melt in contact with crystal surface was rapidly enriched in the low-melting constituents such as Fe, Mn, Al and Ti etc. From these melt, the pyroxenes of rather low liquidus temperature have continuously crystallized at the contact surface under the condition of rapid falling of the temperature (LOFGREN, 1971, 1974). It seems reasonable that the reaction between crystals and ambient melt had occurred in a restricted domain, and intra-liquid equilibrium could not be reached.

The latent heat produced by crystallization of quenched crystals might have interrupted the falling of temperature of melt, so that the actual temperature of melt might have fluctuated. These resulted in a wide chemical variation of quenched titanaugites. During the quenching process, plagioclase could not be produced from the melt because of their sluggish rate of crystallization, or because of the crystallization occurred in the field of pyroxene.

Distribution of Ti and Cr between clinopyroxenes and chrome spinel.

As shown in Fig. 5, the amounts of Ti and Cr ions in the Ti-rich clinopyroxenes vary inversely from diopsidic augite to aluminous titanaugites. Distribution of these two elements between clinopyroxene and chrome spinel is intimately related to the oxygen fugacity and activity of Al_2O_3 in the melt.

The distribution coefficient, D of a specific element is expressed as $D = C_{\text{mineral}}/C_{\text{melt}}$ where the concentrations of the element in the mineral phase and the melt are represented as C_{mineral} and C_{melt} respectively.

The chromian spinels coexisting with dendritic titanaugite contain 30 to 48% Cr_2O_3 and 2 to 3% TiO_2 (TAZAKI, 1975). Average chemical composition of groundmass gives 2.8% TiO_2 . Distribution of Ti between chromian spinels among groundmass and melt is roughly estimated as $1.1 \geq D \geq 0.5$, whereas the distribution of Ti between titanaugites and melt is estimated as $1.5 \geq D \geq 1.0$. Thus, Ti is slightly enriched in quenched titanaugite

than chromian spinels.

As stated above, the slender prismatic or pinacoidal augites coexisting with calcic plagioclases are low in Ti and Al in comparison with dendritic titanaugites. These facts suggest that the crystallization of the present dendritic titanaugites had occurred in the melt of high Al activity (VERHOOGEN, 1962), and the concentration of Al in clinopyroxenes is also dependent on whether there is the coprecipitating aluminosilicate phase or not.

YAGI & ONUMA (1967) found that the maximum solubility of TiO_2 in the limited binary solid solution of $\text{CaTiAl}_2\text{O}_6$ -diopside is about 4 wt%. Of the present dendritic titanaugites, several, grains contain more than 4% TiO_2 . Furthermore, titanaugites which contain more than 4% TiO_2 were reported by many authors (HOLZNER, 1934; KUNITZ, 1936; SAHAMA & MEYER, 1958; TIBA, 1966; WASS, 1973; LEUNG, 1974). It may be concluded at present that the solubility of TiO_2 in terrestrial titanaugites ranges up to 6%.

Melting temperature and oxygen fugacity

Preliminary melting experiments of the ultrabasic picrite basalt at atmospheric pressure by the present writer reveals that the dendritic titanaugites melt completely at $\log f_{\text{O}_2} = -11$ to -10.5 , and 1190 to 1200 °C, which is about 50 °C lower than that of iron-free diopside synthesized from $\text{Di}_{70}\text{Tp}_{30}$ composition (YAGI & ONUMA, 1967). At the same temperature, dusty iron oxides are exsolved from residual olivine grains under $\log f_{\text{O}_2} > -7.5$, whereas olivine becomes more fayalite-rich and coexisting chromian spinel becomes more Cr-rich than that of natural occurrences under $\log f_{\text{O}_2} < -10.5$.

According to the experiments by HILL & ROEDER (1974), the lower the oxygen fugacity, the higher the Cr content in the chromites at constant temperature. They also reported that the higher the f_{O_2} , the lower the ferrous iron content of the system, and the more forsteritic the olivine. These experimental results suggest that the oxygen fugacity for the crystallization of dendritic titanaugites ranges $-10.5 < \log f_{\text{O}_2} < -7.5$, and the temperature between 1100 and 1200 °C.

LOFGREN (1971, 1974) revealed in his

crystallization experiments of plagioclase and pyroxenes that the degree of super-cooling was one of the major causes for the crystal form. The crystal morphology changes from tabular to skeletal and dendritic with increasing ΔT (degree of super-cooling).

The fact that ultrabasic picrite basalts in the studied district are small bodies in comparison with the olivine tholeiitic basalt flow might be responsible for an increase of ΔT , which have resulted in the formation of the dendritic titanaugites.

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(*in Japanese with English abstract)

房総半島，嶺岡構造帯に産する超塩基性ピクライト玄武岩の樹枝状 *titanaugite*

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(要 旨)

嶺岡構造帯には小規模な超塩基性ピクライト玄武岩が点在する。このような岩体のひとつに、石基部が主として羊歯状ないし樹枝状の急冷 *titanaugite* とガラスからなるものがある。この急冷部と漸移する部分では、sector zoning の著しい短柱状の *augite* が多くなり、樹枝状の *titanaugite* は減少する。

EPMA 分析によると、これらの輝石は、化学成分の

変化の幅がひろく、1~4%の TiO_2 、3~10%の Al_2O_3 を含有する。

単一のマグマから、ほぼ同時に晶出した単斜輝石に著しい成分変化が生じたのは、急冷過程で早期に晶出した結晶と、これを取りまく液相との間のある局限された領域で、準安定な平衡が成立し、液相間の平衡が回復しないまま、結晶が成長したためであろう。

Explanation of Plates

Plate I. Photomicrographs of picrite basalt.

1: Picrite basalt (Open polar).

Most of the crystal grains are olivines. Large phenocrysts are partially serpentinized.

Black part is groundmass comprising dendritic *titanaugite* and glass.

2: Dendritic *titanaugites* (Open polar).