



HOKKAIDO UNIVERSITY

Title	Phase Relations in the Chromium-Poor Part of the System Diopside-Anorthite-Forsterite-MgCr ₂ O ₄ in Air at 1 atm
Author(s)	Onuma, Kosuke
Citation	北海道大学理学部紀要, 20(2-3), 171-183
Issue Date	1983-02
Doc URL	https://hdl.handle.net/2115/36715
Type	departmental bulletin paper
File Information	20_2-3_p171-183.pdf



PHASE RELATIONS IN THE CHROMIUM-POOR PART OF
THE SYSTEM DIOPSIDE-ANORTHITE-FORSTERITE-MgCr₂O₄
IN AIR AT 1 ATM

by

Kosuke Onuma

(with 5 tables and 8 text-figures)

Abstract

The effect of chromium on the silicate system was studied at 1 atm by adding MgCr₂O₄ to the join diopside-anorthite-forsterite which is a thermal divide in the system CaO-MgO-Al₂O₃-SiO₂. When a small amount of MgCr₂O₄ (0.2 – 0.5 wt%) is added to the join, the liquidus surface for spinel expands at the expense of anorthite. Thus, the assemblage diopside + forsterite + anorthite + liquid at a ternary invariant point becomes unstable and the assemblages of diopside + anorthite + spinel + liquid and diopside + forsterite + spinel + liquids appear on the liquidus surface. The points at which these assemblages are present are not "invariant" point but "piercing" point, indicating that the join diopside-anorthite-forsterite with a small amount of chromium is not thermal divide, and that the residual liquid in the crystallization can move through the join diopside-anorthite-forsterite.

Introduction

Chromium-bearing silicate systems have a wide liquidus surface for spinel (Keith, 1954; Muan, 1975), indicating that the presence of very small amount of Cr gives considerable influence on the phase relation in the silicate system. For example, spinel is a liquidus phase for the composition containing 3 wt% of CaCrAlSiO₆ (1 wt% Cr₂O₃) in the join diopside-CaCrAlSiO₆ (Dickey et al., 1971). Irvine (1975) has pointed out the significance of Cr in the formulation of petrologic models. Thus, Cr should be taken into account in the discussion of petrogenetic models.

For this reason, the experimental study of the effect of Cr on the phase relation in the system CaO-MgO-Al₂O₃-SiO₂, which is an important model system in igneous petrology, has been performed. In this paper preliminary data of the join diopside-anorthite-forsterite at 1 atm, which is a thermal divide in the system CaO-MgO-Al₂O₃-SiO₂, are presented and their petrologic significance is briefly discussed.

Oxidation state of Cr (Cr²⁺, Cr³⁺ and Cr⁶⁺) is always problematical in experimental petrology as discussed by Schreiber (1978) and Ikeda and Yagi (1978), although several experimental studies were carried out in air (Keith, 1954; Dickey et al., 1971; Ikeda and Yagi, 1972, 1977; Onuma and Tohara, 1981) as well as present study. Cr redox state is affected by oxygen fugacity, temperature, and composition of melt (Schreiber and Haskin, 1976). However, fortunately the data of Cr redox state in the join diopside-anorthite-forsterite with 0.5 wt% Cr₂O₃ are available. Schreiber and Haskin (1976) demonstrated that at about 10^{-0.7} atm fO₂ (prevailing atmosphere of air) 90% of Cr are in Cr³⁺ state at

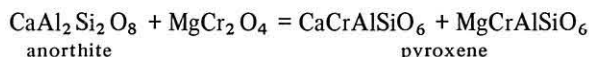
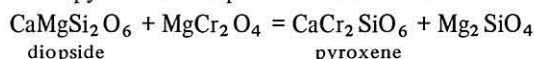
1500°C, and that the ratio of Cr^{3+} to total Cr increases with falling temperature. Since the present experiment was undertaken below 1500°C, more than 90% of Cr^{3+} may be expected. Of course it is needed to examine the effect of minor concentration of other redox state of Cr in establishing precise phase boundary in the silicate system. Nevertheless, the results obtained in the experiments in air provide some important information on the petrology, because terrestrial basalts have formed under the conditions that favor the presence of Cr^{3+} (Burns and Burns, 1975).

Phase Relations

Starting materials were prepared by crystallizing glasses at 900°C, which were made by melting the mixtures composed of CaCO_3 , MgO , Cr_2O_3 , Al_2O_3 , and SiO_2 at 1400–1450°C in a Pt90-Rh10 crucible in air. The color of glasses change from light green to dark green as Cr content increases, while the crystalline mixtures show slightly bluish gray, except those in diopside-forsterite join which are deep blue. The experiments were performed at 1 atm in air by the quenching method. Since Cr is mainly fixed in spinel, it was added to the system as a form of MgCr_2O_4 .

In the system clinopyroxene, anorthite, forsterite, and spinel are encountered. Although the compositions of these minerals have not analysed yet, judging from the X-ray diffraction patterns, the clinopyroxene is chromian diopside, the spinel is a solid solution between MgAl_2O_4 and MgCr_2O_4 , and anorthite and forsterite have nearly pure composition.

Chromian pyroxene components would be formed as follows:



The clinopyroxenes crystallized from the Al-bearing compositions are pale green in the temperature range 1350–1250°C, while those crystallized from the compositions in the diopside-forsterite join blue even at higher temperature, say around 1300°C. An interpretation of this sort of phenomena is given by Ikeda and Yagi (1977) and Ikeda (1981).

The join diopside-anorthite- MgCr_2O_4

The results of experiment are given in Tables 1, 2, and 3. Text-figs. 1, 2, and 3 show the phase relation in the sections with 5, 1, and 0.5 wt% MgCr_2O_4 . In the 5% MgCr_2O_4 section spinel is the first crystalline phase to appear throughout all the compositions studied. Clinopyroxene crystallizes next to spinel in the Di ($\text{CaMgSi}_2\text{O}_6$)-rich region of this section, while anorthite in the An($\text{CaAl}_2\text{Si}_2\text{O}_8$)-rich region. The assemblage clinopyroxene + anorthite + spinel + liquid is present at $1260 \pm 5^\circ\text{C}$ in all the compositions.

In the 1% MgCr_2O_4 section, the liquidus for clinopyroxene appears and crosses with that of spinel at $1360 \pm 5^\circ\text{C}$ and the clinopyroxene + spinel + liquid region is considerably decreased compared to that in the 5% MgCr_2O_4 section. The clinopyroxene + anorthite + spinel + liquid region is also decreased into the temperature interval of 5°C . The phase diagram of the 0.5% MgCr_2O_4 section was tentatively constructed from preliminary data. The liquidii for spinel and clinopyroxene cross with each other at $1300^\circ\text{C} \pm 5^\circ\text{C}$. The

Table 1 Runs in the 5 wt% MgCr₂O₄ section of the system diopside-anorthite-MgCr₂O₄

Composition (wt%)		Temp. (°C)	Time (h)	Phases Present
CaMgSi ₂ O ₆	CaAl ₂ Si ₂ O ₈			
75	30	1350	72	<i>sp + gl</i>
		1345	48	<i>cpx + sp + gl</i>
		1270	168	<i>cpx + sp + gl</i>
		1260	168	<i>cpx + sp + an + gl</i>
55	40	1300	72	<i>sp + gl</i>
		1280	168	<i>sp + gl</i>
		1260	168	<i>cpx + sp + gl</i>
		1250	168	<i>cpx + sp + an + gl</i>
		1220	336	<i>cpx + an + sp + gl</i>
35	60	1350	18	<i>sp + gl</i>
		1345	45	<i>an + sp + gl</i>
		1270	168	<i>an + sp + gl</i>
		1260	168	<i>cpx + an + sp + gl</i>
		1220	336	<i>cpx + an + sp + gl</i>
15	80	1360	16	<i>an + sp + gl</i>
		1355	45	<i>an + sp + gl</i>
		1280	168	<i>an + sp + gl</i>
		1260	168	<i>an + sp + gl</i>
		1250	168	<i>cpx + an + sp + gl</i>

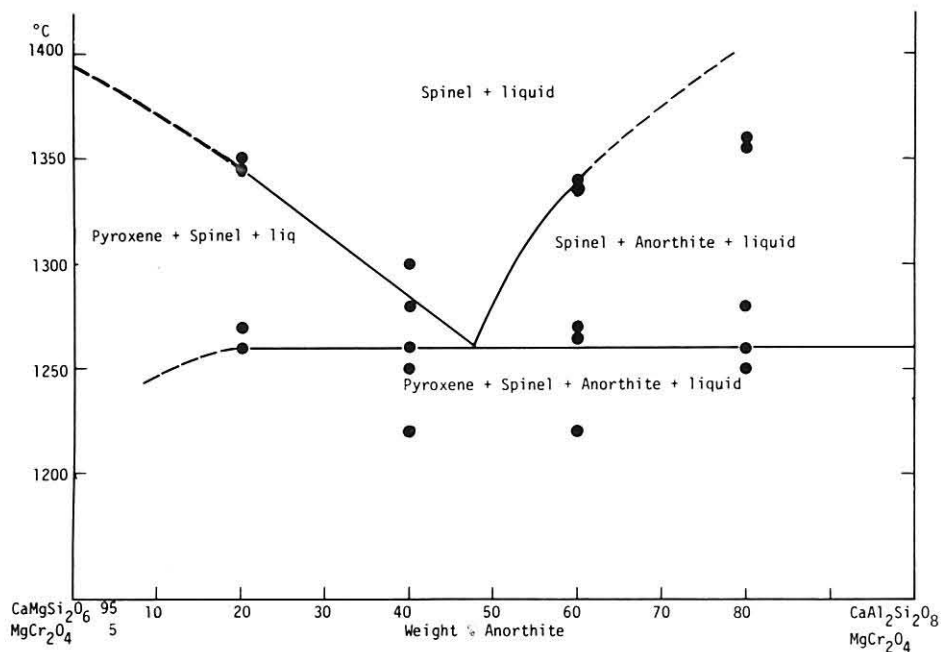
**Text-fig. 1** Phase relations in the 5 wt% MgCr₂O₄ section of the Di-An-MgCr₂O₄ system.

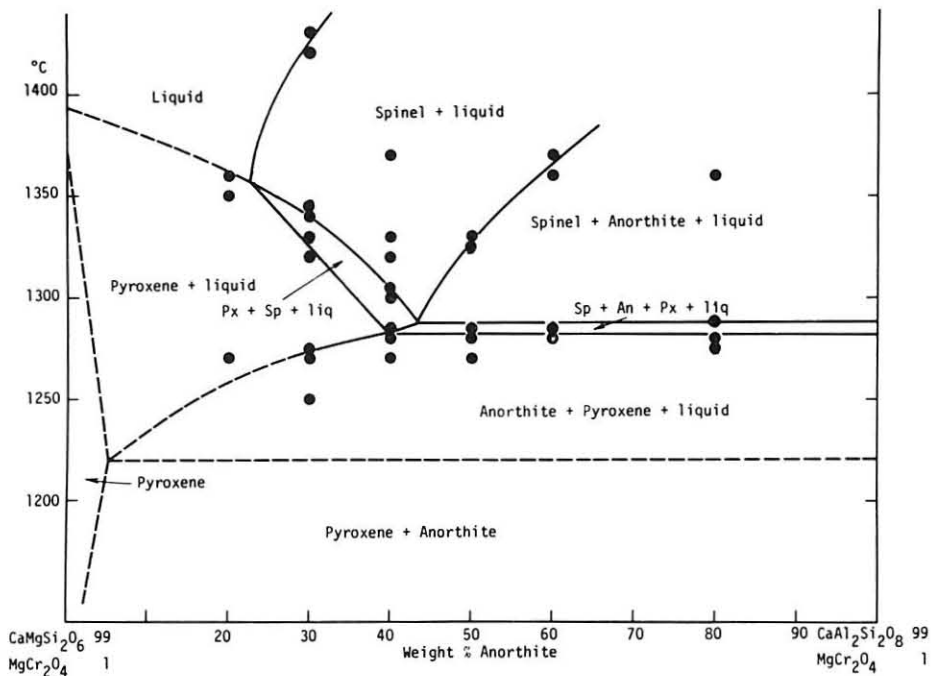
Table 2 Runs in the 1 wt% MgCr_2O_4 section of the system diopside-anorthite- MgCr_2O_4

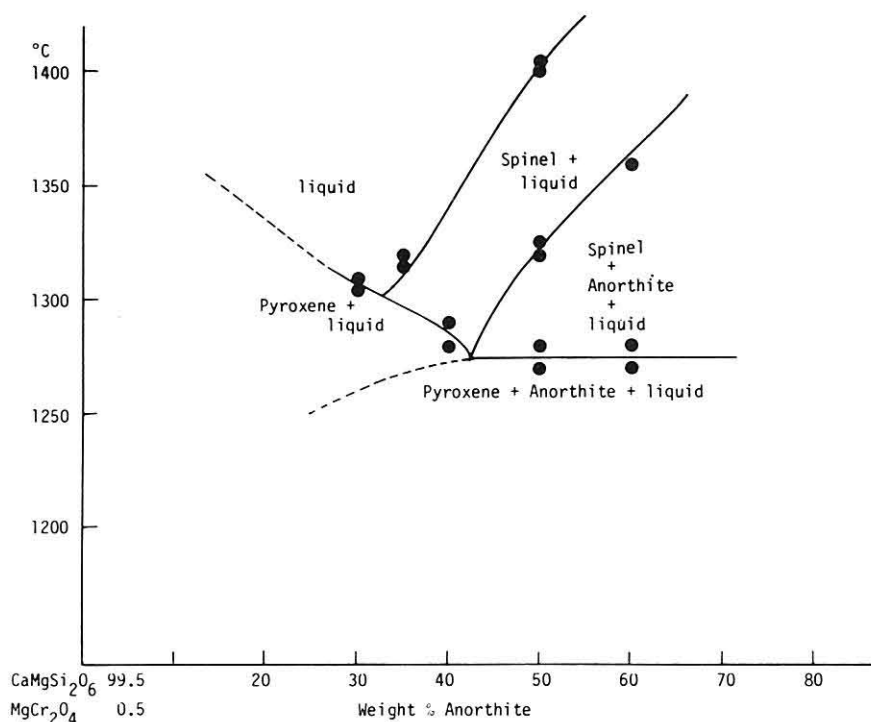
Composition (wt%)		Temp. (°C)	Time (h)	Phases Present
CaMgSi ₂ O ₆	CaAl ₂ Si ₂ O ₈			
79	20	1360	16	<i>gl</i>
		1350	18	<i>cpx + gl</i>
		1270	168	<i>cpx + gl</i>
69	30	1430	16	<i>gl</i>
		1420	16	<i>sp + gl</i>
		1345	18	<i>sp + gl</i>
		1340	18	<i>cpx + sp + gl</i>
		1330	18	<i>cpx + sp + gl</i>
		1320	18	<i>cpx + gl</i>
		1270	168	<i>cpx + gl</i>
		1270	258	<i>cpx + an + gl</i>
		1250	258	<i>cpx + an + gl</i>
59	40	1370	18	<i>sp + gl</i>
		1305	20	<i>sp + gl</i>
		1300	24	<i>cpx + sp + gl</i>
		1285	45	<i>cpx + sp + gl</i>
		1280	70	<i>cpx + gl</i>
49	50	1270	168	<i>cpx + (an) + gl</i>
		1325	24	<i>sp + gl</i>
		1320	20	<i>an + sp + gl</i>
		1285	72	<i>an + sp + gl</i>
		1280	258	<i>cpx + an + gl</i>
39	60	1250	258	<i>cpx + an + gl</i>
		1270	3	<i>sp + gl</i>
		1360	18	<i>an + sp + gl</i>
		1285	48	<i>an + sp + gl</i>
19	80	1280	72	<i>cpx + an + gl</i>
		1350	72	<i>sp + an + gl</i>
		1285	72	<i>an + sp + gl</i>
		1280	48	<i>cpx + an + sp + gl</i>
		1275	72	<i>cpx + an + gl</i>

assemblages clinopyroxene + spinel + liquid and clinopyroxene + anorthite + spinel + liquid do not have temperature interval within the experimental error, indicating that the spinel is consumed by the reaction with liquid to form clinopyroxene. The temperature at which clinopyroxene, anorthite, and spinel coexist with liquid decreases with increasing Cr content of the system throughout the three sections. It is also noticed that clinopyroxene + anorthite + spinel + liquid region becomes narrow with a decrease in MgCr_2O_4 component, and finally may be converged to a line. The temperatures at which the spinel disappears and clinopyroxene appears are almost constant throughout all the compositions in the 0.5% MgCr_2O_4 section. This means that, although the system diopside-anorthite- MgCr_2O_4 is pseudoternary, the assemblage clinopyroxene + anorthite + spinel + liquid can be treated like an invariant point (peritectic point) in the portion extremely poor in Cr. Therefore, when some other component (Mg_2SiO_4) is added to this system, this assemblage may behave like an "univariant" curve in quaternary system.

Table 3 Runs in the 0.5 wt% MgCr₂O₄ section of the system diopside-anorthite-MgCr₂O₄

Composition (wt%)		Temp. (°C)	Time (h)	Phases Present
CaMgSi ₂ O ₆	CaAl ₂ Si ₂ O ₈			
69.5	30.0	1310	18	<i>gl</i>
		1305	18	<i>cpx + gl</i>
64.5	35.0	1320	18	<i>gl</i>
		1315	18	<i>tr. sp + gl</i>
59.5	40.0	1330	18	<i>sp + gl</i>
		1315	5	<i>sp + gl</i>
		1290	48	<i>sp + gl</i>
49.5	50.0	1280	48	<i>cpx + gl</i>
		1405	45	<i>gl</i>
		1400	18	<i>sp + gl</i>
		1325	20	<i>sp + gl</i>
		1320	18	<i>an + sp + gl</i>
39.5	60.0	1280	72	<i>an + sp + gl</i>
		1270	72	<i>cpx + an + gl</i>
		1360	5	<i>an + sp + gl</i>
		1280	48	<i>an + sp + gl</i>
		1270	72	<i>cpx + an + gl</i>

**Text-fig. 2** Phase relations in the 1 wt% MgCr₂O₄ section of the Di-An-MgCr₂O₄ system.



Text-fig. 3 Phase relations in the 0.5 wt% MgCr_2O_4 section of the $\text{Di-An-MgCr}_2\text{O}_4$ system.

Liquidus phase relations in the system diopside-anorthite-forsterite- MgCr_2O_4

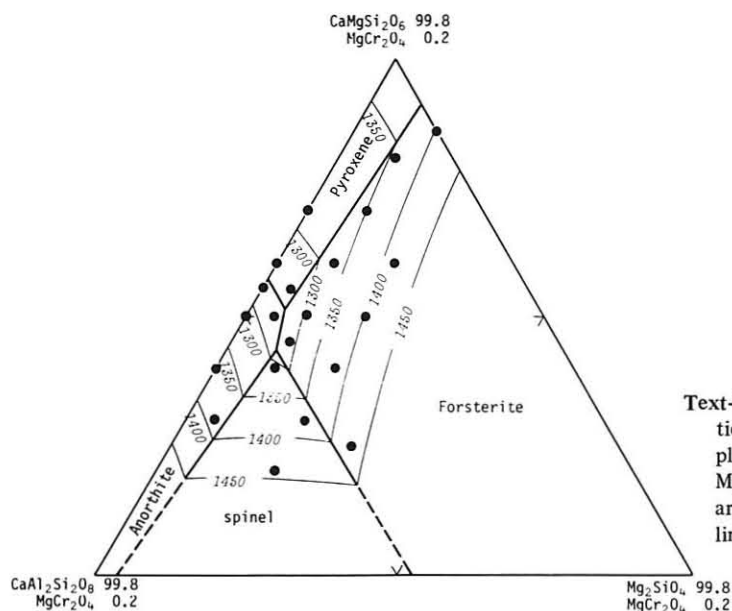
The liquidus diagrams of the 0.2 and 0.5 wt% MgCr_2O_4 (0.16 and 0.40 wt% Cr_2O_3) planes are shown in Text-figs. 4 and 5, respectively. The results of quenching experiments are given in Tables 4 and 5.

On the 0.2% plane (Text-fig. 4), clinopyroxene, anorthite, forsterite, and spinel are encountered as primary phase. There are two points showing four phase assemblage: one, at $1265 \pm 5^\circ\text{C}$, shows the liquid coexisting with clinopyroxene, anorthite and forsterite, and the other, at $1270 \pm 5^\circ\text{C}$, the liquid coexisting with anorthite, forsterite, and spinel. The former point is treated as an "eutectic point" in the ternary system, because the compositions around this point crystallize into the assemblage clinopyroxene + forsterite + anorthite at a same temperature $1265^\circ \pm 5^\circ\text{C}$ within the experimental error. While the latter point behaves like "piercing point", through which an "univariant curve" anorthite + forsterite + spinel + liquid of the quaternary system passes. Along this "univariant curve" the spinel reacts with liquid to form clinopyroxene.

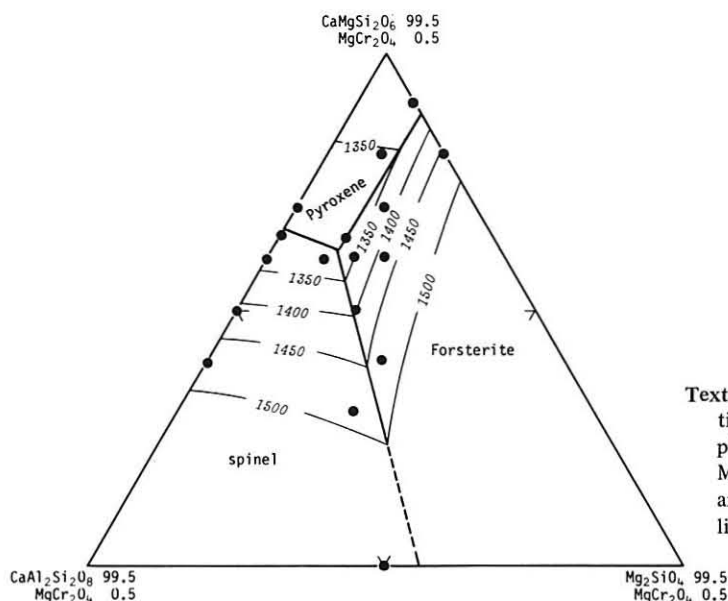
Text-fig. 5 shows the liquidus diagram of 0.5 wt% MgCr_2O_4 plane. On the liquidus diagram clinopyroxene, forsterite and spinel are present, but anorthite absent. The primary fields for clinopyroxene, spinel and forsterite cross with each other at $1305^\circ \pm 5^\circ\text{C}$. This point, however, behaves like piercing point, and an "univariant curve" clinopyroxene +

Table 4 Runs on the 0.2 wt% MgCr₂O₄ plane of the system diopside-anorthite-forsterite-MgCr₂O₄

Composition (wt%)			Temp. (°C)	Time (h)	Phases Present
CaMgSi ₂ O ₆	CaAl ₂ Si ₂ O ₈	Mg ₂ SiO ₄			
84.8	0	15.0	1390	18	<i>fo + gl</i>
79.8	10.0	10.0	1355	18	<i>gl</i>
			1350	18	<i>fo + gl</i>
69.8	20.0	10.0	1340	22	<i>gl</i>
			1335	18	<i>fo + gl</i>
			1330	22	<i>cpx + fo + gl</i>
69.8	30.0	0	1330	22	<i>gl</i>
			1325	22	<i>cpx + gl</i>
59.8	20.0	20.0	1425	40	<i>gl</i>
			1420	18	<i>fo + gl</i>
59.8	30.0	10.0	1325	22	<i>gl</i>
			1320	18	<i>fo + gl</i>
59.8	40.0	0	1275	18	<i>gl</i>
			1270	18	<i>cpx + gl</i>
			1260	72	<i>an + cpx + gl</i>
54.8	40.0	5.0	1280	48	<i>gl</i>
			1275	48	<i>cpx + gl</i>
			1260	72	<i>an + cpx + gl</i>
54.8	45.0	0	1280	48	<i>gl</i>
			1275	48	<i>an + gl</i>
			1260	72	
49.8	30.0	20.0	1395	18	<i>gl</i>
			1390	18	<i>fo + gl</i>
49.8	40.0	10.0	1295	18	<i>gl</i>
			1290	40	<i>fo + gl</i>
			1270	72	<i>fo + gl</i>
			1265	72	<i>cpx + an + fo + gl</i>
49.8	45.0	5.0	1275	18	<i>gl</i>
			1270	18	<i>an + gl</i>
49.8	50.0	0	1320	22	<i>gl</i>
			1315	22	<i>an + gl</i>
			1270	72	<i>an + gl</i>
			1260	72	<i>cpx + an + gl</i>
44.8	45.0	10.0	1275	18	<i>gl</i>
			1270	18	<i>fo + gl</i>
39.8	40.0	20.0	1375	18	<i>gl</i>
			1370	18	<i>fo + gl</i>
39.8	50.0	10.0	1315	22	<i>gl</i>
			1310	22	<i>sp + gl</i>
			1270	72	<i>sp + gl</i>
			1265	72	<i>cpx + an + fo + gl</i>
39.8	60.0	0	1380	18	<i>gl</i>
			1375	18	<i>an + gl</i>
			1270	72	<i>an + gl</i>
			1260	72	<i>cpx + an + gl</i>
29.8	50.0	20.0	1365	22	<i>gl</i>
			1360	22	<i>sp + gl</i>
			1325	18	<i>sp + gl</i>
			1320	72	<i>fo + sp + gl</i>
29.8	65.0	5.0	1390	18	<i>gl</i>
			1380	18	<i>an + gl</i>
24.8	45.0	30.0	1420	3	<i>gl</i>
			1410	4	<i>fo + gl</i>
			1400	18	<i>fo + gl</i>
			1380	18	<i>sp + fo + gl</i>
19.8	60.0	20.0	1420	3	<i>sp + gl</i>
			1310	72	<i>sp + gl</i>
			1305	72	<i>an + sp + gl</i>



Text-fig. 4 Liquidus phase relations on the 0.2 wt% MgCr_2O_4 plane of the Di-An-Fo- MgCr_2O_4 system. Heavy lines are boundary curve and light lines isotherm.



Text-fig. 5 Liquidus phase relations on the 0.5 wt% MgCr_2O_4 plane of the Di-An-Fo- MgCr_2O_4 system. Heavy lines are boundary curve and light lines isotherm.

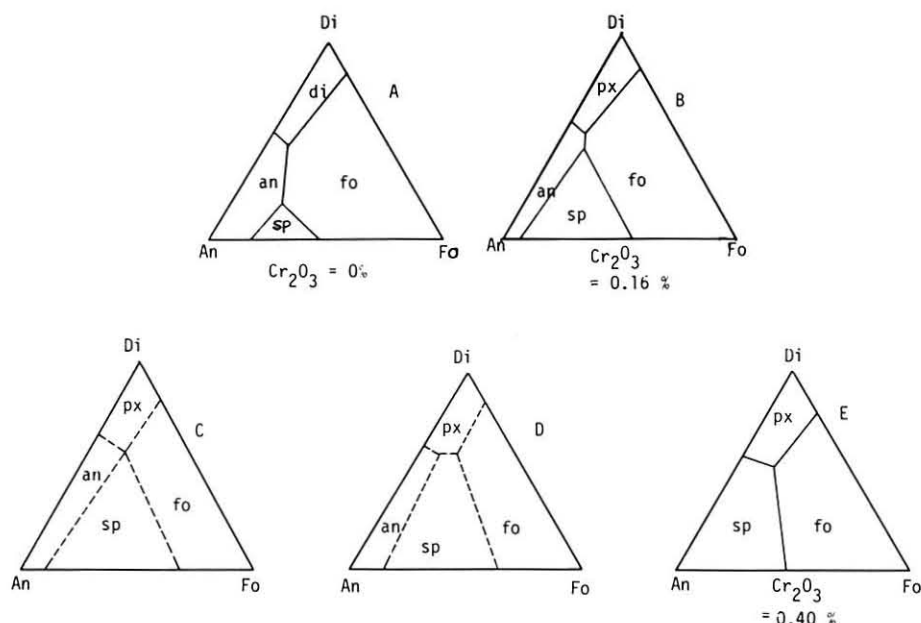
spinel + forsterite + liquid passes through this point. Clinopyroxene and spinel are in reaction relation along this curve, therefore the spinel present at liquidus disappears and clinopyroxene appears at subliquidus temperatures.

Table 5 Runs on the 0.5 wt% MgCr₂O₄ plane of the system diopside-anorthite-forsterite-MgCr₂O₄

Composition (wt%)			Temp. (°C)	Time (h)	Phases Present
CaMgSi ₂ O ₆	CaAl ₂ Si ₂ O ₈	Mg ₂ SiO ₄			
89.5	0	10.0	1390	18	<i>gl</i>
			1385	20	<i>cpx + gl</i>
84.5	0	15.0	1425	18	<i>gl</i>
			1420	5	<i>fo + gl</i>
79.5	0	20.0	1350	48	<i>cpx + fo + gl</i>
			1460	20	<i>gl</i>
79.5	10.0	10.0	1455	20	<i>fo + gl</i>
			1340	20	<i>gl</i>
69.5	15.0	15.0	1335	45	<i>cpx + gl</i>
			1355	45	<i>gl</i>
64.5	25.0	10.0	1350	24	<i>fo + gl</i>
			1340	24	<i>fo + gl</i>
59.5	20.0	20.0	1330	24	<i>cpx + fo + gl</i>
			1330	22	<i>gl</i>
59.5	25.0	15.0	1325	18	<i>fo + cpx + gl</i>
			1420	20	<i>gl</i>
59.5	30.0	10.0	1415	20	<i>fo + gl</i>
			1360	18	<i>gl</i>
49.5	30.0	20.0	1355	18	<i>fo + gl</i>
			1330	24	<i>fo + gl</i>
39.5	30.0	30.0	1310	48	<i>cpx + fo + gl</i>
			1320	18	<i>gl</i>
39.5	40.0	30.0	1315	20	<i>sp + gl</i>
			1300	48	<i>sp + gl</i>
39.5	40.0	30.0	1295	20	<i>cpx + gl</i>
			1405	18	<i>gl</i>
39.5	40.0	30.0	1400	24	<i>sp + fo + gl</i>
			1330	5	<i>sp + fo + gl</i>
39.5	40.0	30.0	1325	24	<i>cpx + fo + gl</i>
			1470	5	<i>gl</i>
39.5	40.0	30.0	1460	20	<i>fo + gl</i>
			1450	18	<i>fo + gl</i>
39.5	40.0	30.0	1430	18	<i>sp + fo + gl</i>
			1470	5	<i>gl</i>
39.5	40.0	30.0	1460	3	<i>sp + gl</i>
			1430	5	<i>fo + sp + gl</i>
39.5	40.0	30.0	1310	24	<i>fo + sp + gl</i>
			1305	24	<i>an + fo + sp + gl</i>

Effect of Chromium on the Liquidus Phase Relations on the Join Diopside-Anorthite-Forsterite

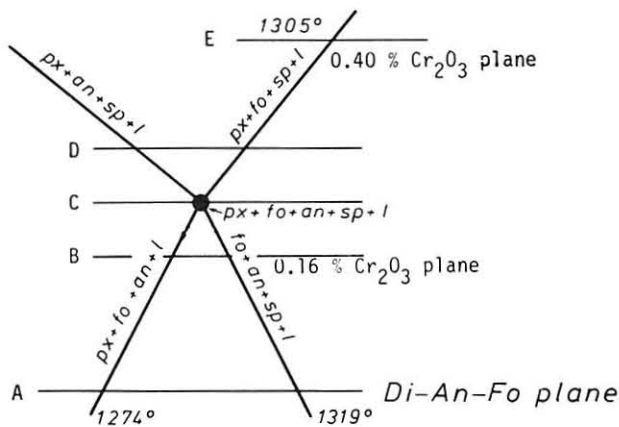
The change of liquidus phase relations on the join diopside-forsterite-anorthite with increasing MgCr₂O₄ content from 0 to 0.5 wt% (0.4 wt% Cr₂O₃) is demonstrated in Text-fig. 6. The join diopside-forsterite-anorthite forms a thermal divide in the quaternary system forsterite-diopside-CaTs-SiO₂ (Presnall et al., 1978). On the 0.5 wt% MgCr₂O₄ plane, however, the point having the "invariant" assemblage clinopyroxene + anorthite +



Text-fig. 6 Change of the liquidus phase relations on the planes at various Cr content of the Di-An-Fo-MgCr₂O₄ system. Cr increases in the order of A, B, C, D, and E. A is quoted from Osborn and Tait (1957). B and E are present work. Di, CaMgSi₂O₆; An, CaAl₂Si₂O₈; Fo, Mg₂SiO₄; px, clinopyroxene; an, anorthite; sp, spinel; fo, forsterite.

forsterite + liquid is not observed and the assemblage clinopyroxene + forsterite + spinel + liquid appears. The latter assemblage does not represent the “invariant” assemblage of ternary system, but “univariant” assemblage of quaternary system, suggesting that the join is no longer thermal divide.

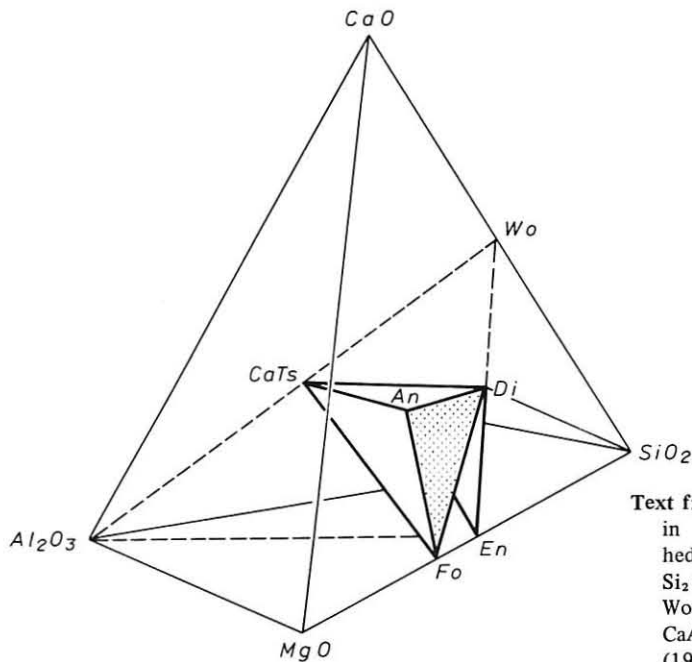
The results obtained in this study show, although the present system belongs to the quinary system CaO-MgO-Al₂O₃-Cr₂O₃-SiO₂, that as Cr₂O₃ content is very low the system can be treated as the quaternary system CaO-MgO-Al₂O₃-SiO₂, and that the spinel field increases and the anorthite field decreases considerably with increasing Cr content. Arculus et al. (1974) demonstrated in the study of the system MgO-iron-oxide-Cr₂O₃-SiO₂ that the pyroxene-silica boundary surface is bulged toward silica compared to the Cr-free system. Whereas in the present system bulging of phase boundary with the addition of Cr is not observed. The phase relation is schematically shown in Text-fig. 7. Judging from this relation, when Cr₂O₃ content is increased, the point showing the liquid coexisting with clinopyroxene, anorthite, spinel and forsterite is expected between 0.16 and 0.40 wt% as demonstrated in Text-fig. 6C, which is an “quaternary invariant point”. Increasing chromium content, the plane cutting two “univariant curves”, clinopyroxene + forsterite + spinel + liquid and clinopyroxene + anorthite + spinel, is expected to be as shown in Text-fig. 6D. This plane is no longer thermal divide, and therefore the Cr content of the plane of Text-fig. 6C, a little higher than 0.16 wt% in Cr₂O₃, is critical for the join diopside-anorthite-forsterite to behave as thermal divide.



Text-fig. 7 Schematic diagram showing the relationship between invariant point and univariant curves, and the planes shown in Text-fig. 6 as A, B, C, D, and E correspond to those in Text-fig. 7. px, clinopyroxene; an, anorthite; sp, spinel; fo, forsterite; l, liquid.

Petrologic Significance

The system CaO-MgO-Al₂O₃-SiO₂ is an important model to elucidate genesis and differentiation of basaltic magma (Schaerer and Yoder, 1970; O'Hara and Bigger, 1969). Presnall et al. (1978, 1979) paid special attention on the sub-system Di-Fo-SiO₂-CaTs and called simplified basalt tetrahedron (Text-fig. 8). The join diopside-anorthite-forsterite is a thermal barrier, dividing the system diopside-anorthite-forsterite into the SiO₂-saturated part and the SiO₂-undersaturated part and Yoder and Tilley (1962) proposed



Text fig. 8 Simplified basalt tetrahedron in the CaO-MgO-Al₂O₃-SiO₂ tetrahedron. Di, CaMgSi₂O₆; An, CaAl₂-Si₂O₈; Fo, Mg₂SiO₄; En, MgSiO₃; Wo, CaSiO₃; Sp, MgAl₂O₄; CaTs, CaAl₂SiO₆. After Presnall et al. (1978)

the expanded basalt tetrahedron, Qz-Ol-Di-Ne, as a fundamental model for basaltic magma, and showed that this tetrahedron is divided into two parts by the join clinopyroxene-plagioclase-olivine at 1 atm; one represents tholeiite and the other alkali basalt. They discussed on this basis that tholeiite can not be derived from alkali basalt magma by fractional crystallization at shallower depth and vice versa. On the other hand, Presnall et al. (1978) made a high pressure experiment on the join diopside-anorthite-forsterite and clarified that this join can not be thermal divide at the pressure higher than 4 kbar, and discussed that tholeiite magma can be derived from alkali olivine basalt magma above the pressure of 4 kbar.

The experimental results in the present study clearly show that, when a small amount of Cr, about 0.2 wt% in Cr_2O_3 , is present, the join diopside-anorthite-forsterite is no longer thermal divide even at 1 atm. This value of Cr_2O_3 content is expected in natural rocks (Cox and Jamieson, 1974; Dietrich, 1981). Therefore, Cr is effective to lower the critical pressure, 4 kbar, shown by Presnall et al. (1978), and it is possible to derive tholeiite magma from alkali basalt magma by fractional crystallization below 4 kbar, even at 1 bar.

The effect of Cr on the system diopside-forsterite-anorthite- SiO_2 is very important in the discussion on partial melting of the mantle. As stated before spinel field expands by the addition of Cr, while anorthite field diminishes, resulting in disappearance of the assemblage clinopyroxene + anorthite + forsterite + liquid. This gives considerable influences on the relationship among the "invariant" points and "univariant" curves; in other words, the chemical composition of liquid generated by partial melting of the mantle would be influenced by Cr content.

Acknowledgements

Profs. K. Yagi and Y. Katsui encouraged me during the study and read the paper in manuscript. Mr. S. Terada and Dr. M. Akasaka helped me in the laboratory. Mrs. S. Yokoyama typed manuscript. I am indebted to all of these persons of Hokkaido University. Part of the cost for the present study was defrayed by the grant for Scientific Research from the Ministry of Education, Science and Culture of Japan.

References

- Arculus, R.J., Gillerg, M.E. and Osborn, E.F., 1974. The system $\text{MgO-FeO-Fe}_2\text{O}_3\text{-Cr}_2\text{O}_3\text{-SiO}_2$: Phase relations among olivine, pyroxene, silica and spinel in air at 1 atm. *Carnegie Inst. Wash. Year Book*, 73: 317-322.
- Burns, V.M. and Burns, R.G., 1975. Mineralogy of chromium. *Geochim. Cosmochim. Acta*, 39: 903-910.
- Cox, K.G. and Jamieson, B.G., 1974. The olivine-rich lavas of Nuanetsi: a study of polybaric magmatic evolution. *Jour. Petrol.*, 15: 269-301.
- Dickey, J.S., Jr., Yoder, H.S., Jr. and Schairer, J.F., 1971. Chromium in silicate-oxide system. *Carnegie Inst. Wash. Year Book*, 70: 118-122.
- Dietrich, V.J., Gansser, A., Sommerauer, J. and Cameron, W.E., 1981. Paleogene komatiites from Gorgona Island, East Pacific - a primary magma for ocean floor basalt? *Geochem. Jour.*, 15: 141-161.
- Ikeda, K. and Yagi, K., 1972. Synthesis of kosmochlor and phase equilibria in the join $\text{CaMgSi}_2\text{O}_6$. *Contr. Mineral. Petrol.*, 36: 63-72.
- Ikeda, K. and Yagi, K., 1977. Experimental study on the phase equilibria in the join $\text{CaMgSi}_2\text{O}_6\text{-CaCrCrSiO}_6$ with special reference to the blue diopside. *Contr. Mineral. Petrol.*, 61: 91-106.

- Ikeda, K. and Yagi, K., 1978. Reply to H.D. Schreiber. *Contr. Mineral. Petrol.*, 66: 343-344.
- Irvine, T.N., 1975. Chromium. Its physicochemical behavior and petrologic significance. *Geochim. Cosmochim. Acta*, 39: 779-780.
- Keith, M.L., 1954. Phase equilibria in the system MgO-Cr₂O₃-SiO₂. *Jour. Am. Ceram. Soc.*, 37: 490-496.
- Muan, A., 1975. Phase relations in chromium-oxide containing systems at elevated temperatures. *Geochim. Cosmochim. Acta*, 39: 791-802.
- O'Hara, M.J. and Biggar, G.M., 1969. Diopside + spinel equilibria, anorthite and forsterite reaction relationships in silica-poor liquidus in the system CaO-MgO-Al₂O₃-SiO₂ at atmospheric pressure and their bearing on the genesis of melilitites and nephelinites. *Am. Jour. Sci.*, 267-A: 364-390.
- Onuma, K. and Tohara, T., 1981. Clinopyroxenes and spinels in the system CaMgSi₂O₆-CaAl₂SiO₆-CaCrAlSiO₆: a preliminary report. *Jour. Fac. Hokkaido Univ., Ser. IV*, 19: 495-503.
- Osborn, E.F. and Tait, D.B., 1952. The system diopside-forsterite-anorthite. *Am. Jour. Sci., Bowen Vol.*: 413-433.
- Presnall, D.C., Dixon, J.R., O'Donnell, T.H. and Dixon, S.A., 1979. Generation of mid-ocean ridge tholeiite. *Jour. Petrol.*, 20: 3-35.
- Presnall, D.C., Dixon, S.A., Dixon, J.R., O'Donnell, T.H., Brenner, N.L. and Dycus, D.W., 1978. Liquidus phase relations on the join diopside-forsterite-anorthite from 1 atm to 20 kbar: their bearing on the generation and crystallization of basaltic magma. *Contr. Mineral. Petrol.*, 66: 203-220.
- Schairer, J.F. and Yoder, H.S., Jr., 1970. Critical planes and flow sheet for portion of the system CaO-MgO-Al₂O₃-SiO₂ having petrological applications. *Carnegie Inst. Wash. Year Book*, 68: 202-214.
- Schreiber, H.D. and Haskin, A.L., 1976. Chromium in basalts: experimental determination of redox states and partitioning among synthetic silicate phase. *Proc. Lunar Sci. Conf. 7th*: 1221-1259.
- Schreiber, H.D., 1978. Chromium, blue diopside, and experimental petrology, a discussion. *Contr. Mineral. Petrol.*, 66: 341-342.
- Yoder, H.S., Jr. and Tilley, C.E., 1962. Origin of basaltic magma: an experimental study of natural and synthetic rock systems. *Jour. Petrol.*, 3: 342-532.

(Manuscript received on Oct. 5, 1982)