EXPERIMENTAL STUDY ON A PYROXENE-SPINEL SYMPLECTITE AT HIGH PRESSURES AND TEMPERATURES

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Introduction

Many authors have carried out the experimental studies on the subsolidus relations of the system $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$ and of the multi systems conceivably representing the upper mantle compositions, in order to elucidate the phase equilibria of the upper mantle. Above all, many discussions have been focused on the stability relations between spinel and garnet peridotites.

In several cases, however, the garnets in garnet peridotites are considered to break down to the symplectite composed of pyroxenes and spinel. For example, KUNO (1967) and KUNO and AOKI (1969) discussed the origin of the peridotite nodules assuming such a kind of symplectites as the break-down product of garnet.

IGI (1953) and BAMBA (1953) have reported symplectite of similar type in their pioneer works on the Horoman layered peridotite intrusion situated in the Hidaka metamorphic terrain in Hokkaido, North Japan.

One of the writers (KOMATSU) has suggested in his re-investigation on the intrusion, three possibilities on the formation of symplectite as follows (KOMATSU, in preparation):

- 1) Break-down of garnet,
- 2) Reaction between plagioclase and orthopyroxene,
- 3) Reaction between orthopyroxene and interstitial liquid.

As shown by previous investigation (KUSHIRO and YODER, 1964, 1966; KUSHIRO *et al.*, 1967; GREEN and RINGWOOD, 1967b; MACGREGOR, 1965, 1970), the univariant curve representing the reactions; $\text{pyroxenes} + \text{spinel} = \text{garnet} + \text{pyroxenes} + (\text{olivine})$ depends on the bulk chemistry of the reaction system.

The writers determined the univariant curve mentioned above to see the chemical dependencies

of the reactions using the symplectites of the Horoman intrusion in order to apply the results to the considerations of the origin of the Horoman intrusion.

The results of the present experiment may suggest that the garnet peridotite of limited chemical compositions can be stable at a physical condition of the lower crust.

Geological outline of the Horoman peridotite intrusion

The Horoman peridotite intrusion lies at the southwestern end of the Hidaka metamorphic belt which is consisted of schistose hornfels and migmatites. The gabbros and granites of late Mesozoic age are associated with them.

The intrusion is layered peridotite complex of about 2,700 m thick and is developed elliptically about 10 km from south to north and 7 km from east to west. This peridotite intrusion is composed of dunite, lherzolite, plagioclase-lherzolite with minor pyroxenite and gabbro.

The petrographic investigation on the intrusion was reported by IGI (1953) and BAMBA (1953) for the first time. The conspicuous layered structure of the mass and the presence of pyroxenes-spinel symplectite were noticed by them.

Recently, petrochemical re-investigation of the intrusion were carried out by several authors (ONUKI, 1965; KOMATSU and NOCHI, 1966; NAGASAKI, 1966; TEMPAKU, 1967).

One of the writers (KOMATSU, in preparation) divided the complex into two layered series of peridotites, such as the lower and the upper layered series.

The layered series of the Horoman complex ranges symmetrically from dunite, through lherzolite to plagioclase-lherzolite in the lower layer from bottom to upward, and vice versa in the upper layer. The pyroxenite and gabbro are intercalated as thin bands or lenses in above mentioned layers.

The purple-brownish spinel-rich "clot" in which pyroxenes-spinel symplectites are enclosed are

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present in lherzolite, whereas the plagioclase-pyroxenes-spinel symplectites are restricted to plagioclase-lherzolite. The symplectitic intergrowths of pyroxenes and spinel are also noticed at the margin of irregular shaped orthopyroxene in the "clot" (See plate).

Many investigators have interpreted this layered structure to be formed due to crystal accumulation during the fractionation of a primary magma.

Komatsu (in preparation) has concluded also from the volumetric estimations of the layering units and from the petrography that the layered intrusion is brought about by the fractionation of a picrite basaltic magma.

Experimental procedures

Apparatus and pressure-temperature calibrations

The experiments at pressures higher than 20 kb were carried out using split-sphere type high pressure apparatus similar to that described by Ito *et al.* (1968) and KAWAI *et al.* (1969). The piston cylinder type apparatus was employed for the experiments at pressures lower than 20 kb.

The pressure calibration of the split-sphere type apparatus were performed by some fixed points of phase transition of metals, such as Bi_I-Bi_{II} (25.5 kb), Ti_{II}-Ti_{III} (36.7 kb), and Bi_{III}-Bi_{IV} (78 kb) at room temperatures.

The volume change of KBr and NH₄F at 3.6 kb, 10.8 kb and 18 kb were adopted as fixed point for piston cylinder type apparatus.

The temperature was calibrated using Pt/Pt 13% Rh thermocouple which had been inserted into graphite capsule with no correction for pressure effects on e.m.f.. The run were quenched by switching off the powers to the furnace.

Experimental method

The starting materials which were finely ground using agate mortar was located in the graphite capsule which is set in the pressure medium made of fired pyrophyllite.

The runs were carried out at pressures from 7.5 kb and up to 40 kb and temperatures between 850°C and 1400°C.

The run times vary from 3 to 7 hours, at temperatures lower than 1000°C, and vary from 0.5 to 2 hours at higher temperatures than 1000°C.

All runs have been examined optically and by X-ray powder diffraction. In some cases, microprobe analyses have been applied.

Starting material

The starting material studied are the mixtures

Fig. 1. Complicated feature of symplectite and matrix (Reproduced from composition image of EMX).

A : Symplectite, B : Matrix, Opx; orthopyroxene, Cpx; clinopyroxene, Sp; spinel.

Table 1. Chemical composition of minerals in symplectite.

	1	2	3
SiO ₂	55.2	51.3	—
Al ₂ O ₃	3.4	5.3	59.7
Cr ₂ O ₃	0.7	1.2	9.4
ΣFeO	6.2	2.5	9.9
MgO	33.5	17.2	20.7
CaO	0.7	21.4	—
Na ₂ O	—	0.9	—
Total	99.7	99.8	99.7

Si 1.910}	2.000	Si 1.864}	2.000	Al 1.802}	1.993
Al 0.090}		Al 0.136}		Cr 0.191}	
Al 0.047}		Al 0.091}		Fe ²⁺ +0.212}	1.010
Cr 0.021}		Cr 0.035}		Mg 0.798}	
Fe ²⁺ +0.178}	2.011	Fe ²⁺ +0.073}	2.037	MgAl ₂ O ₄ :	79.4
Mg 1.738}		Mg 0.937}		FeAl ₂ O ₄ :	10.3
Ca 0.027}		Ca 0.833}		FeCr ₂ O ₄ :	10.0
		Na 0.833}			

Ca 1.4	Ca 45.1
Mg 89.4	Mg 50.7
Fe 9.2	Fe 4.2 (Anal. M. Komatsu)

1. Enstatite in symplectite
2. Chromian diopside in symplectite
3. Spinel in symplectite

Table 2. Tentative chemical composition of starting material.

SiO ₂	37.97	SiO ₂	40.1
Al ₂ O ₃	20.72	Al ₂ O ₃	12.8
Cr ₂ O ₃	3.42	MgO	41.8 (mol %)
FeO	6.59	CaO	5.3
MgO	26.48		
CaO	4.64		
Na ₂ O	0.18		
Total	100.0		100.0

Tentatively calculated on the ratios; 50% Opx, 20% Cpx and 30% Sp.

of orthopyroxene-clinopyroxene-spinel symplectite and the fine-grained matrix of the same mineral assemblages which were handpicked from the lherzolite. These mixtures are composed approximately of five parts of aluminous orthopyroxene, two parts of clinopyroxene and three parts of spinel.

The textural features of symplectite and matrix reproduced by means of composition image of microprobe analyser are shown in Fig. 1a, b.

The chemical compositions of the minerals are given in Table 1. The chemical composition of orthopyroxene shows low CaO, and comparatively high Al_2O_3 . The clinopyroxene bears comparatively high Cr_2O_3 , Al_2O_3 and Na_2O . The atomic proportions of these two pyroxenes are represented as $\text{Mg}_{89.4}\text{Fe}_{9.2}\text{Ca}_{1.4}$ and $\text{Mg}_{50.7}\text{Fe}_{4.2}\text{Ca}_{45.1}$ respectively. The spinel comprises 79.7% spinel (*sensu stricto*), 10.3% hercynite and 10% chromite.

The tentative chemical composition of the starting material calculated on the mineral ratios is given in Table 2. This chemical composition of the starting material is similar to the pyrope-rich garnet of the garnet peridotite in kimberlite (O'HARA and MERCY 1963), but is slightly poor in SiO_2 and rich in MgO , compared with the latter.

Experimental results

The stability of garnet

The results are given in Table 3 and Fig. 2. The main features of the stability of garnet have been summarized as follows:

(1) Without seeding: At 1200°C, the garnet did not appear at pressures, 20 kb, and 25 kb, however, it appeared at 27.5 kb. At 1400°C,

Fig. 2. The experimental results for the composition of the symplectite mixture plotted on P-T diagram.

Table 3. The results of experiments on the composition of the symplectite mixture.

Run No.	Pressure (Kb)	Temperature (°C)	Duration (min.)	Phase Present	Comments
Ho. 12	40	1400	60.	Gar+Opx+Cpx+Residual Sp.	
Ho. 07	33	1200	20.	Gar+Opx+Cpx+Residual Sp.	
Ho. 16	30	1100	30.	Gar+Opx+Cpx+Ol+Res. Sp.	A trace of olivine is present.
Ho. 13	30	1400	30.	Gar+Opx+Ol+Residual Sp.	The Cpx is not recognized.
					A. trace of olivine is present.
Ho. 10	29	1200	30.	Gar+Opx+Cpx+Residual Sp.	
Ho. 14	27.5	1200	30.	Gar+Opx+Cpx+Residual Sp.	
Ho. 15	27.5	1400	30.	Gar+Opx+Cpx+Residual Sp.	
Ho. 09	25	1200	30.	Opx+Cpx+Sp.	The garnet is not recognized.
Ho. 08	20	1200	30.	Opx+Cpx+Sp.	The garnet is not recognized.
Ho. 17*	20	1200	60.	Gar+Opx+Cpx+Ol+Res. Sp.	A trace of olivine is present.
Ho. 18*	20	1300	60.	Gar+Opx+Cpx+Ol+Res. Sp.	A trace of olivine is present.
Ho. 19*	20	1400	60.	Gar+Opx+Ol+Residual Sp.	Euhedral garnet are abundant.
					The Cpx is not recognized.
Ho. 21*	30	1300	30.	Gar+Opx+Ol+Residual Sp.	Euhedral garnet are abundant.
					A trace of residual spinel is survived.
Ho. 26*	17.5	1325	60.	Opx+Cpx+Sp.	The garnet is broken down. A trace of Cpx is present.
Ho. 39*	15	1300	120.	Opx+Sp.	The garnet is broken down.
Ho. 27*	15	1200	180.	Gar+Opx+Sp.	The seeded garnet is survived.
Ho. 38*	13.5	1000	180.	Gar+Opx+Sp.	The Cpx is not recognizable.
Ho. 36*	11	1030	180.	Opx+Sp.	The garnet is broken down.
Ho. 32*	11	1130	180.	Opx+Sp.	The garnet is broken down.
Ho. 37*	9	960	240.	Opx+Sp.	The garnet is broken down.
Ho. 40*	7.5	850	420.	Gar+Opx+Sp.	The seeded garnet is survived and increases.

Symbols: * Seeded with 20% of garnet-bearing sample. Opx, orthopyroxene; Gar, garnet; Cpx, clinopyroxene; Sp, spinel; Ol, olivine.

Table 4 a. Chemical compositions of the synthesized garnet (30kb, 1300°C).

	1	2	3	4
SiO ₂	42.24	39.9	42.3	42.4
Al ₂ O ₃	22.62	22.2	21.3	21.5
Cr ₂ O ₃	3.23	4.5	4.3	3.9
FeO	3.78	5.0	4.4	4.5
MnO	0.16	—	—	—
MgO	25.01	23.2	25.8	25.3
CaO	4.28	4.0	2.9	3.7
Si	2.905	2.850	2.927	2.928
Al	0.095	0.150	0.073	0.072
Al	1.739	1.722	1.665	1.678
Cr	0.171	0.257	0.233	0.216
Fe ³⁺	0.101	0.060	0.116	0.116
Fe ²⁺	0.115	0.240	0.137	0.145
Mn	0.009	—	—	—
Mg	2.584	2.468	2.661	2.601
Ca	0.315	0.305	0.216	0.274

Table 4 b. Molecular proportions of the synthesized garnet.

	1 A	1 B	2 A	2 B	3 A	3 B	4 A	4 B
Fe ₃ ²⁺ Al ₂ Si ₃ O ₁₂	3.8	3.8	7.9	8.0	4.6	4.5	4.8	4.8
Mn ₃ Al ₂ Si ₃ O ₁₂	0.3	0.3	—	—	—	—	—	—
Ca ₃ Fe ₂ ²⁺ Si ₃ O ₁₂	5.0	5.0	3.0	2.9	5.8	5.7	5.7	5.7
Ca ₃ Cr ₂ Si ₃ O ₁₂	—	5.4	—	7.2	—	1.5	—	3.3
Ca ₃ Al ₂ Si ₃ O ₁₂	5.5	—	7.1	—	1.3	—	3.3	—
Mg ₃ Cr ₂ Si ₃ O ₁₂	8.5	3.1	12.6	5.3	11.5	10.1	10.8	7.5
Mg ₃ Al ₂ Si ₃ O ₁₂	76.9	82.4	69.4	76.6	76.8	78.2	75.8	78.7

1 : TK 1, Ave. of 4~5 grains (Anal. JEOL)

2 : KM 1, Ave. of 4~5 grains (Anal. Komatsu)

3 : KM 2, Ave. of 4~5 grains (Anal. Komatsu)

4 : KM 3, Ave. of Ten grains (Anal. Komatsu)

A : All chromium are allotted to the Mg-Cr garnet.

B : The chromium is allotted to Ca-Cr garnet prior to calculate Mg-Cr garnet.

the garnet was present at pressures, 27.5 kb, 30 kb, and 40 kb.

(2) With seeding (The samples including well crystallized garnets obtained at run(1) are added about 20% as seeding material): At 20 kb pressure, the garnet crystallized well from this seeded material, at temperatures, 1200°C, 1300°C and 1400°C. It is suggested that the nucleation boundary reported by BOYD and ENGLAND (1959) in their synthesis of pyrope, exists at 1200°C and pressures between 25—27.5kb.

In the lower pressure region, at 15 kb, 1200°C and 7.5 kb, 850°C, the garnet were not broken down but preserved or slightly increased compared with the seed garnet. The garnet were ascertained to break down at 9 kb, 960°C, 11 kb, 1030 °C and 17.5 kb, 1320°C. When the reaction proceeded, the amount of garnet increased but a trace of spinel was recognizable. This residual spinel is expected to be exhausted in the longer duration than the present experiment.

The univariant curve between the orthopyroxene-clinopyroxene-spinel assemblage and the garnet-pyroxenes assemblage determined experimentally is approximated as

$$T = 44.4P + 534 \quad (T = ^\circ\text{C}, P = \text{kb}).$$

The chemical composition of the garnet

The maximum grain size of the garnet crystallized from the seeded starting material at 30 kb, 1300°C, is about 20μ in diameter. The cell dimension of this synthetic garnet was calculated as 11.48 Å on the (640), (642) and (420) reflections in the X-ray powder diffractions. This value is slightly larger than that of pure pyrope (11.46 Å).

The microprobe analysis exhibited high magnesian and chromian contents of the garnet (Table 4).

The molecular proportion of the garnets are characterized by the existence of knorringite (Mg₃Cr₂Si₃O₁₂) component.

There are two chromian garnet end members such as uvarovite ($\text{Ca}_3\text{Cr}_2\text{Si}_3\text{O}_{12}$) and knorringite. The latter Mg-Cr garnet is major component in the garnet which occur naturally in kimberlite or in diamond crystals as inclusion (NIXON and HORNUNG, 1968; MEYER, 1968; NOVAK, 1970). The knorringite component ranges from 3.1 to 10.1%, when the chromium is allotted to Ca-Cr garnet prior to calculate Mg-Cr component. Alloting all chromium to the Mg-Cr garnet, it ranges from 8.5 to 12.6% and is a major constituent second to pyrope.

Discussion of the results

Crystallization of garnet

The molar ratio of the starting material is calculated as 40.1% SiO_2 , 12.8% Al_2O_3 , 41.8% MgO and 5.3% CaO and is plotted onto the En-Di-Sp surface within the $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$ tetrahedron. This composition approximates to that of garnet in the Fo-En-Di-Gar tetrahedron (Fig. 3).

In the present experiments, olivine is not recognized in the product when the reaction proceeds insufficiently, even though the garnet crystallizes. A trace of olivine is recognized when the reaction proceeds sufficiently.

The present experiments show that the reaction:

takes place at the lower pressure side than the previous results (BOYD and ENGLAND, 1959, 1962;

Fig. 3. A part of $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$ tetrahedron.

The chemical composition of the starting material is plotted onto the En-Di-Sp surface.

Fo; forsterite, En; enstatite, Di; diopside, Pyr; pyrope, Gros; grossular.

GREEN and RINGWOOD, 1967b; MACGREGOR, 1970, O'HARA *et al.*, 1971).

It is well known that the breakdown of the pyrope-rich garnet which contains grossular and almandine components takes place at a lower pressure than that of pure pyrope (BOYD and ENGLAND, 1959).

The univariant curve for the formation of garnet of the composition pyrope₂ grossular₁, using anorthite₁ forsterite₁ composition locates at the lower pressure side than that of present investigation and intersects at temperature about 950°C (KUSHIRO and YODER, 1965) as shown in Fig. 4.

The garnet coexisting with clinopyroxene and orthopyroxene at 18 kb, 1390°C comprises pyrope₈₁ grossular₁₉, taking diopside₁ pyrope₁ composition as starting material (KUSHIRO *et al.*, 1967).

Taking olivine basalt composition as starting material, the garnet coexisting with clinopyroxene at 18 kb, 1330°C is pyrope_{60.5} almandine₂₃ grossular_{16.5} (GREEN and RINGWOOD, 1967a).

In the present experiment, the garnet synthesized at 30 kb, 1300°C shows high pyrope content and is also characterized by the presence of knorringite component. The knorringite-rich garnet have been found in kimberlite or in diamond crystal as inclusion. So the presence of knorringite component suggests the formation of garnet at pressures higher than that of knorringite-free garnet. The uvarovite is stable with CaSiO_3 or Cr_2O_3 at aomospheric pressure, at temperature lower than 1400°C (GELLER and MILLER, 1959).

The X-ray powder diffraction peaks of the garnet formed at the lower pressures and temperatures deflects to the lower 2θ angles. This deflection suggests increase of solid solution of almandine, uvarovite and grossular components at the lower pressures, temperatures.

MACGREGOR (1970) discussed the location of the reaction boundary between spinel and garnet peridotite from his recent experimental results of $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$ system.

In Fig. 4, univariant curves obtained by several authors are shown in which the present result is included. Inspection of Fig. 4 indicates that the location of present curve is similar to that of MACGREGOR's curve (1) with 20.8% Al_2O_3 , 25.3% MgO and $\text{Al}_2\text{O}_3/\text{R}_2\text{O}_3=95.4$. The curve (1) locates about 2.5 kb higher on the isotherm and about 100°C lower on the isobar as compared with the present curve.

The curve (2) is referred to the composition having $\text{Al}_2\text{O}_3/\text{R}_2\text{O}_3=83-78$.

In MACGREGOR's opinion, the higher $\text{Al}_2\text{O}_3/\text{R}_2\text{O}_3$ displaces the univariant reaction boundary

Fig. 4. The univariant curves for the formation of garnet.

Ho; present result. K. Y; 1 : 1 composition of anorthite and forsterite (KUSHIRO and YODER, 1966). Pyr; pyrope (BOYD and ENGLAND, 1960). 1, 2, 3; MACGREGOR (1970)'s composition. S-L; solidus of Salt lake Iherzolite nodule (KUSHIRO *et al.*, 1968).

between the spinel and garnet peridotite to the lower pressure side and the higher $\text{Cr}_2\text{O}_3/\text{R}_2\text{O}_3$ ratio makes the boundary for the higher pressure side, permitting the CaO and total R_2O_3 constant.

It is conceivable why the reaction boundary of the Horoman symplectite mixture locates at the lower pressure side depends chiefly on the solid solution of almandine and uvarovite components in the garnet.

The results obtained here prove that the garnet-bearing ultramafic rocks can be stable at pressures and temperatures of the lower crustal conditions in the limited chemical compositions rich in Al_2O_3 .

The possibility of the garnet peridotite in the Horoman layered ultramafic intrusion

Solidus of peridotitic material is expected to reduce below the ocean geotherm, provided the existence of a slight water at the pressures between 30 kb and 60 kb (KUSHIRO *et al.*, 1968). Thus some basaltic melt could be produced through partial melting of the peridotitic material at the pressures above mentioned under the condition of $P_{\text{H}_2\text{O}} > P$ load.

Meanwhile, at 27 kb, 1460°C, under anhydrous condition, the pyrope-rich garnet composed of pyrope_{68.3}almandine_{17.2} grossular_{14.5} precipitates with or without clinopyroxene as liquidus mineral from olivine basalt (GREEN and RINGWOOD, 1967a).

At 18 kb, about 1300°C, the garnet containing 60% pyrope component crystallizes from the same olivine basalt. This is accordant with the present univariant curve.

Assuming some picrite basaltic melt as the primary magma of the Horoman layered ultramafic intrusion, the pyrope-rich garnet could be crystallized at pressures more than 18 kb at the temperatures not less than 1300°C provided for anhydrous condition.

Thus, as far as the pyroxenes-spinel symplectite is concerned, the prior-existence of pyrope-rich garnet is plausible for the Horoman Iherzolite intrusion.

Based on their high pressure experiments on forsterite-anorthite, KUSHIRO and YODER (1966) suggested also the prior-existence of garnet in the Horoman intrusion.

For the breakdown of the garnet to pyroxenes-spinel symplectite, the following idealized reaction will occur as a result of pressure release:

and/or

Assuming a large volume of residual basaltic liquid, the garnet brought up to its unstable region with host liquid will be dissolved and it can not survive as symplectite. So the crystal accumulation and preceded extreme separation of crystal from the melt at near-liquidus condition are indispensable for the formation of ultramafic rock facies.

The garnet crystallized from the basaltic melt as the liquidus mineral would become unstable through the accumulation process of ultramafic parts.

Conclusion

The univariant curve for the pyroxenes-spinel symplectite composed of the garnet-like composition, to form garnet-pyroxenes assemblage is approximated as $T = 44.4P + 534$ ($T = ^\circ\text{C}$, $P = \text{kb}$), and it situates the lower pressure side than that of pure pyrope or garnet pyrolite.

The present experimental result suggest the possibility for the existence of some garnet peridotite in lower crust.

The prior-existence of garnet in the Horoman Iherzolite intrusion is expected from the present experiment and other previous experiments on the melting and phase transitions for some basaltic and ultramafic materials.

As far as the anhydrous condition is concerned,

the garnet will crystallize at pressure more than 18 kb and temperatures not less than 1300°C from some picrite basaltic magma. This garnet becomes unstable in the course of accumulation of the ultramafic rock facies, and is subsequently replaced by pyroxenes-spinel symplectite.

Above-mentioned process of breakdown of garnet is, however, not conclusive for the formation of pyroxenes-spinel symplectite, since the presence of plagioclase conceivable as liquidus phase in the layered intrusion suggests that the fractionation takes place partly in the magma reservoir within the crust, even though a part of plagioclase would ascribe to the breakdown of pyroxenes-spinel symplectite.

Therefore, it may be also possible that the pyroxenes-spinel symplectite represent the liquid fraction rich in aluminium closed interstitially within the crystal cumulates.

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輝石-スピネル, シンプレクタイトについての高温・高圧下における実験的研究

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(要 旨)

幌満かんらん岩の輝石-スピネル, シンプレクタイトを用いて, 反応

輝石+スピネル $\rightleftharpoons$ ザクロ石+輝石+ (カンラン石) の相境界を検討した。

実験は, 8分割球体型およびピストンシリンダー型の高圧発生装置を用いて, 圧力 40kb, 温度 1400°C 以下の範囲においておこなった。

反応の相境界は, $T=44.2P+534$ ($T=^{\circ}\text{C}$, $P=\text{kb}$) であらわされる。

30kb, 1300°C で生成したザクロ石は, パイロープ組成が 70~80% で, かつ, ノリンジャイト組成が 3~

10%算出されるものである。

実験の結果から, 組成が Al にとむような場合, ザクロ石かんらん岩は, 地殻下部の条件下でも安定に存在し得ることがわかった。

今回の実験結果は, 幌満かんらん岩にザクロ石が存在していた可能性をつよく支持するが, 斜長石かんらん岩相の存在は, 幌満岩体分化過程の一部があきらかに, 地殻内においても, すすんだことをしめすものであろう。

Hidaka.....日高 Horoman幌満

Explanation of plate

The purple-brownish "clot" including symplectites.

Note symplectitic intergrowth grown at the margin of irregular shaped orthopyroxenes.

Lh; lherzolite. Cl; clot. Sy; symplectite. Opx; orthopyroxene.

Sp; chromian spinel. Mx; matrix part.