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NOTES ON PETROCHEMISTRY OF ULTRAMAFIC
INTRUSIVES —SPECIALLY, ALUMINIUM DISTRI-
BUTION IN CO-EXISTING PYROXENES—

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Abstract: Some petrochemical features of ultramafic rocks are firstly discussed by taking account of mantle norms and M values. The existence of iron-rich ultramafic intrusives, e.g., the Union Bay complex, is pointed out and world-wide occurrences of these complexes are suggested. Commonly the rocks constituting ultramafic intrusives contain less aluminium than mantle peridotite, as represented by peridotite inclusions in basaltic rocks, and have a considerable wide range in their M values, whereas peridotite inclusions show relatively uniform M values. Secondly, the distribution relation of aluminium with four-fold co-ordination and silicon between co-existing clinopyroxenes and orthopyroxenes is discussed. Although tschermakitic molecule may be more soluble in clinopyroxenes than in orthopyroxenes at a given pressure, Al^{IV} contents in orthopyroxenes are greater than those in clinopyroxenes from ordinary ultramafic intrusives. The reverse relation is observed in pyroxenes from peridotite inclusions and the Lizard primary peridotites which were formed at higher pressure. This is interpreted on the basis of physico-chemical considerations.

INTRODUCTION

It is clear that chemistry of the rocks and their rock forming minerals from ultramafic intrusives and peridotite inclusions in basaltic rocks plays an important role in the interpretation of ultramafic petrology, even though the structural or tectonic environment of ultramafic intrusives is an interesting subject. Among several constituent minerals in ultramafic rocks, importance must be also attached to the chemical nature of pyroxenes, because they are very sensitive to changes in physico-chemical conditions.

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In the present paper, the authors offer some petrochemical considerations on ultramafic rocks and their pyroxenes based on earlier contributions and the results of the present studies.

CHEMISTRY OF ROCKS

"Alpine-type peridotite" seems to differ markedly from the ultramafic parts of basaltic layered complexes in the chemical compositions. Hess (1938) noted that the Mg/Fe ratio of "Alpine-type peridotite" is over 7.5 and even in pyroxenite this ratio is above 6.0. This criterion has been applied to many ultramafic intrusives. But, for example, dunites and peridotites from the Union Bay (Ruckmick and Noble, 1959) show considerable lower Mg/Fe ratios. The accumulation of knowledge on ultramafic complexes suggests the

Table 1. Mantle norms*

	1 HM-5	2 HM-11	3 HM-12	4 UD-1	5 UD-2	6 UP-1	7 MP	8 LP
NaCrSi ₂ O ₆	0.15	0.51	0.59	—	0.55	—	0.79	0.55
NaFe ⁺³ Si ₂ O ₆	—	0.35	0.53	0.18	1.73	0.69	0.42	—
CaTiAl ₂ O ₆	0.08	0.08	0.08	—	—	—	0.28	0.40
CaCrAlSiO ₆	0.24	—	—	—	2.28**	—	—	0.32
CaFe ⁺³ AlSiO ₆	0.26***	2.26	3.15	1.46**	0.82	5.03	1.94	—
CaAl ₂ SiO ₆	0.17**	2.02	1.31	—	—	—	3.27	6.51
MgAl ₂ SiO ₆	—	—	—	1.74	—	—	—	0.60
CaFe ⁺³ ₂ SiO ₆	—	—	—	—	—	3.64	—	—
MgFe ⁺³ ₂ SiO ₆	1.40	—	—	—	2.27	—	—	—
CaSiO ₃	—	1.11	0.48	—	—	3.40	0.91	—
MgSiO ₃	0.03	8.63	14.91	—	—	12.39	17.02	22.05
FeSiO ₃	—	0.75	1.35	—	—	1.49	1.67	2.60
Mg ₂ SiO ₄	91.67	77.56	71.14	86.83	78.08	65.45	67.08	59.91
Fe ₂ SiO ₄	6.00	6.73	6.44	9.79	14.28	7.90	6.62	7.06
M****	92.4	90.8	89.9	89.3	80.9	83.0	90.0	89.4

* Molecular per cent

** MgFe⁺³AlSiO₆

*** include MgFe⁺³AlSiO₆ **** M=(Mg+Ni) × 100/(Mg+Ni+Fe⁺²+Fe⁺³+Mn)

1: Dunite from the Horoman intrusion (Onuki, 1965b).

2: Peridotite from the Horoman intrusion (Onuki, 1965b).

3: Plagioclase bearing peridotite from the Horoman intrusion (Onuki, 1965b).

4: Dunite from the Union Bay complex (Ruckmick and Noble, 1959).

5: Dunite from the Union Bay complex (Ruckmick and Noble, 1959).

6: Peridotite from the Union Bay complex (Ruckmick and Noble, 1959).

7: Mantle peridotite (Kushiro and Kuno, 1963).

8: Average composition of the Lizard peridotites (Green, 1964).

possibility that some iron-rich complexes would be found in the world. Probably there is some diversity in chemical composition

among ultramafic intrusives.

On the other hand, some chemical differences have been noted between rock-forming minerals from ultramafic intrusives and peridotite inclusions (Onuki, 1963). The chemical nature of constituent minerals naturally reflects the chemistry of the host rocks. Consequently some differences can be recognized between ultramafic intrusives and peridotite inclusions.

Mantle norms (Kushiro and Kuno, 1963) and M values of the rocks from the Horoman intrusion (Onuki, 1965b), the Union Bay complex (Ruckmick and Noble, 1959), the Lizard intrusion (Green, 1964) and a representative composition of the mantle peridotite (Kushiro and Kuno, 1963) are shown in Table 1 for comparison.

M values defined as

$$M = \frac{(Mg + Ni) \times 100}{Mg + Ni + Fe^{+2} + Fe^{+3} + Mn}$$

are lower in the Union Bay rocks than those of the rocks from other intrusives, clearly showing the iron-rich nature of the former. A peridotite has also a higher M value than a dunite in the Union Bay complex. If they were derived from a common magma, this fact could be interpreted only by unusual concentration of iron ore in the dunite. The present authors emphasized that this iron-rich nature and the characteristic zoning of the Union Bay complex are very significant for ultramafic petrology. Chemical data of rock-forming minerals in the Union Bay complex are unfortunately not available, but an iron-rich nature may certainly be expected also in the mineral chemistry.

Peridotite of the upper mantle may be variable in modal mineral composition, because peridotite inclusions in basaltic rocks show various mineral assemblages. Judging from the chemical composition of olivine and other constituent minerals in many peridotite inclusions, M values of mantle peridotites may not be so variable. Heterogeneity of the upper mantle is possible, but we have insufficient evidences concerning the cause of the considerable diversity in the iron content.

Mantle peridotites, *i.e.*, peridotite inclusions and St. Paul's rocks (Tilley, 1947), show relatively uniform M values according to available data, whereas intrusive peridotites or dunites have a considerably wide range in their M values even in the same body as shown in Table 1. This fact is easily elucidated by the hypothesis that ultramafic intrusives passed at least once through a magmatic stage as a result of complete melting of mantle peridotite.

Mantle peridotite contains more Al_2O_3 than intrusive peridotites as reflected in such mineral chemistry as the more aluminous nature of both orthopyroxene and clinopyroxene from peridotite inclusions. This feature is clearly shown in the amounts of Al-carrying pyroxene molecules of the calculated mantle norms (Table 1). The plagioclase bearing peridotite from Horoman does not contain as much alumina as the mantle peridotite.

Green (1964) divided the Lizard complex into a primary and a secondary assemblage and he thought that the former assemblage was formed in the same environment as peridotite inclusions in basaltic rocks and the latter was produced by recrystallization of the former at a much shallower level. Plagioclase is contained in the latter, but it is not observed in the former. In the case of Lizard the decreasing solubility of Al_2O_3 in pyroxenes plays an important part in the formation of plagioclase. Green has shown a reaction equation indicating that the aluminous pyroxenes recrystallized to normal pyroxenes and plagioclase at lower pressure.

If recrystallization can occur in peridotite with aluminous pyroxenes formed at higher pressure, as in the case of the primary assemblage in the Lizard complex and peridotite inclusions, plagioclase must be always present in the recrystallized assemblages. Consequently, the possibility of recrystallization cannot be disregarded in a feldspathic peridotite, although plagioclase could also have formed by direct crystallization from liquid. In other words, plagioclase-free peridotites have probably not been formed by recrystallization. But it is a very difficult problem, though important, to determine whether ultramafic intrusives have undergone recrystallization or not.

NEW ANALYSES OF PYROXENES

Two pairs of orthopyroxene and clinopyroxene were carefully separated from the highly serpentized rocks belonging to the so-called Mineoka ultramafic belt in Boso and Miura Peninsulas. These pyroxenes were chemically analysed. The analytical results and their atomic ratios on the basis of $\text{O}=6$ are given in Tables 2 and 3.

Some detailed consideration on the chemical nature of pyroxenes including other analyses from the Mineoka ultramafic belt will be mentioned in another paper.

Table 2. Chemical compositions of clinopyroxenes

	Wt. %		Atomic ratio (O=6)				
	1 KM-20	2 KN- 1		1 KM-20	2 KN-1		
SiO ₃	53.18	53.44	Si	1.936	1.937		
Al ₂ O ₃	2.78	2.99	Al	0.119	0.127		
TiO ₂	0.32	0.28	Ti	0.009	0.008		
Cr ₂ O ₃	1.09	0.84	Cr	0.031	0.024		
Fe ₂ O ₃	0.49	0.45	Fe ⁺ ³	0.014	0.012		
FeO	2.42	2.19	Fe ⁺ ²	0.073	0.066		
MnO	0.10	0.09	Mn	0.003	0.003		
MgO	16.92	17.28	Mg	0.924	0.940		
CaO	21.63	21.75	Ca	0.843	0.845		
Na ₂ O	0.57	0.41	Na	0.040	0.029		
K ₂ O	0.02	0.01	K	0.001	0.000		
H ₂ O+	0.05	n. d.	Total	3.993	3.991		
H ₂ O-	0.10	n. d.					
Total	99.67	99.73					
M*	91.1	92.1					
Ca	45.4	45.3					
Mg	49.7	50.4					
Fe	4.9	4.3					

* $M = \text{Mg} \times 100 / \text{Mg} + \text{Fe}^{+2} + \text{Fe}^{+3} + \text{Mn}$

1: Chromian diopside, Kamogawa.

2: Chromian diopside, Kinugasa.

Analyst: H. Onuki.

MOLECULAR COMPONENTS OF PYROXENES

Chemistry of both the clinopyroxenes and the orthopyroxenes in ultramafic rocks is highly variable depending on the physico-chemical environment where they formed. Calculations of both types of pyroxenes to molecular components can elucidate complicated chemical variations. For the clinopyroxenes, Kushiro (1962), and Yoder and Tilley (1962) have already suggested procedures for the calculation of molecular components from the chemical analyses. Onuki (1965a) has shown a somewhat modified method of the calculation, which is not changed essentially from Kushiro's method.

For orthopyroxenes, a convenient calculation is constructed by the authors. Calculation method suggested by the authors for both kinds of pyroxene are as follows:

Clinopyroxene

1. $\text{NaCrSi}_2\text{O}_6$

2. $\text{NaFe}^{+3}\text{Si}_2\text{O}_6$

Orthopyroxene

$\text{NaCrSi}_2\text{O}_6$

$\text{NaFe}^{+3}\text{Si}_2\text{O}_6$

Table 3. Chemical compositions of orthopyroxenes

	Wt. %		Atomic ratio (O=6)		
	1 KM-20	2 KN-1		1 KM-20	2 KN-1
SiO ₂	55.75	55.73	Si	1.930	1.918
Al ₂ O ₃	2.35	2.49	Al	0.096	0.101
TiO ₂	0.31	0.28	Ti	0.008	0.007
Cr ₂ O ₃	0.70	0.83	Cr	0.019	0.022
Fe ₂ O ₃	0.61	0.62	Fe ⁺³	0.016	0.016
FeO	5.22	4.77	Fe ⁺²	0.151	0.134
MnO	0.11	0.10	Mn	0.003	0.003
MgO	33.14	34.30	Mg	1.721	1.770
CaO	1.36	0.76	Ca	0.050	0.028
Na ₂ O	0.08	0.08	Na	0.005	0.005
K ₂ O	0.01	0.01	K	0.000	0.000
H ₂ O+	0.05	n. d.	Total	3.999	4.004
H ₂ O-	0.01	n. d.			
Total	99.70	99.97			
M*	91.0	91.9			
Ca	2.6	1.4			
Mg	88.7	90.6			
Fe	8.7	8.0			

$M^* = \text{Mg} \times 100 / \text{Mg} + \text{Fe}^{+2} + \text{Fe}^{+3} + \text{Mn}$

1: Enstatite, Kamogawa.

2: Enstatite, Kinugasa.

Analysts: 1, T, Tiba; 2, H. Onuki.

Table 4. Calculation of the orthopyroxene KM-20

Atomic ratio	NaCrSi ₂ O ₆	CaTi Al ₂ O ₆	MgCr AlSiO ₆	MgFe ⁺³ AlSiO ₆	MgAl ₂ SiO ₆	CaSi O ₃	Mg SiO ₃	FeSi O ₃	rema ins
Z { Si 1930	{ 10 —	—	14	16	25	42	1666	154	3
Y { Al 96		16	14	16	25	—	—	—	—
{ Ti 8	—	8	—	—	25	—	—	—	—
{ Cr 19	5	—	14	—	—	—	—	—	—
{ Fe ⁺³ 16	—	—	—	16	—	—	—	—	—
X { Fe ⁺² 154	—	—	—	—	—	—	—	154	—
{ Mg 1721	—	—	14	16	25	—	1666	—	—
W { Ca 50	—	8	—	—	—	42	—	—	—
{ Na 5	5	—	—	—	—	—	—	—	—
Molecular proportion	0.5	0.8	1.4	1.6	2.5	2.1	83.3	7.7	99.9

3. $\text{NaAlSi}_2\text{O}_6$	$\text{CaTiAl}_2\text{O}_6$
4. $\text{CaTiAl}_2\text{O}_6$	$\text{MgTiAl}_2\text{O}_6$
5. CaCrAlSiO_6	MgCrAlSiO_6
6. $\text{CaFe}^{+3}\text{AlSiO}_6$	$\text{MgFe}^{+3}\text{AlSiO}_6$
7. $\text{CaAl}_2\text{SiO}_6$	$\text{MgAl}_2\text{SiO}_6$
8. $\text{CaCr}_2\text{SiO}_6$	$\text{MgCr}_2\text{SiO}_6$
9. $\text{CaFe}^{+3}_2\text{SiO}_6$	$\text{MgFe}^{+3}_2\text{SiO}_6$
10. CaSiO_3	CaSiO_3
11. MgSiO_3	MgSiO_3
12. FeSiO_3	FeSiO_3

Table 5. Molecular proportions of analysed clinopyroxenes

	1 KM-20	2 KN-1
$\text{NaCrSi}_2\text{O}_6$	3.1	2.4
$\text{NaFe}^{+3}\text{Si}_2\text{O}_6$	1.0	0.5
$\text{CaTiAl}_2\text{O}_6$	0.9	0.8
$\text{CaFe}^{+3}\text{AlSiO}_6$	0.4	0.7
$\text{CaAl}_2\text{SiO}_6$	4.9	5.3
CaSiO_3	39.3	39.4
MgSiO_3	46.6	47.5
FeSiO_3	3.8	3.4

Table 6. Molecular proportions of analysed orthopyroxenes

	1 KM-20	2 KN-1
$\text{NaCrSi}_2\text{O}_6$	0.5	0.5
$\text{CaTiAl}_2\text{O}_6$	0.8	0.7
MgCrAlSiO_6	1.4	1.7
$\text{MgFe}^{+3}\text{AlSiO}_6$	1.6	1.6
$\text{MgAl}_2\text{SiO}_6$	2.5	2.7
CaSiO_3	2.1	1.0
MgSiO_3	83.3	85.0
FeSiO_3	7.8	6.8

In both methods, K is added to Na, and Mn and Ni are added to Fe^{+2} and Mg, respectively.

Applying these calculation methods, excess or deficiency of cations does not exceed 0.05 on the basis of 0=6 in ordinary cases. It is presumed that the purification of pyroxenes for analysis was extremely unsatisfactory when the value is more than 0.1.

For example, calculation of molecular components for the

orthopyroxene (KM-20) is shown in Table 4. And also, the calculated molecular proportions of pyroxenes from the Mineoka ultramafic belt are shown in Tables 5 and 6.

ALUMINIUM-SILICON DISTRIBUTION IN CO-EXISTING PYROXENES

Al atoms in the pyroxene structure occur in either Y or Z position. Green (1964) discussed aluminium-silicon distribution in co-existing clinopyroxene and orthopyroxene by a distribution co-efficient K_{Al} defined as follows:

$$K_{Al} = \frac{(Al^{IV} / Si)_{cpx}}{(Al^{IV} / Si)_{opx}}$$

He also stated that two pyroxene pairs from "intrusive" peridotites (Dawros and Webster-Addie) have higher Al_2O_3 in orthopyroxenes than in clinopyroxenes and have distribution co-efficient of less than 1.0, whereas many pyroxene pairs from peridotite inclusions in basaltic rocks and the Lizard peridotite body have distribution ratios more than 1.0.

The present authors have examined the distribution relation of aluminium with four-fold co-ordination and silicon between the co-existing lime-poor and lime-rich pyroxenes making by use of Al^{IV} determined by the previously described method of calculation of molecular components.

K_{Al} values of many pyroxene pairs from ultramafic intrusives and peridotite inclusions in basaltic rocks are shown in Table 7. All pyroxene pairs from ultramafic intrusives except the Lizard peridotite intrusion have K_{Al} values less than 1.0. This suggests that Al^{IV} in orthopyroxenes are always higher than those in the co-existing clinopyroxenes in the case of ultramafic intrusives.

On the other hand, pyroxene pairs from the primary assemblage in the Lizard peridotites have K_{Al} of 1.06 and 1.18, showing that Al^{IV} in orthopyroxenes are lower than those in the co-existing clinopyroxenes. Green (1964) considered that the primary assemblage in the Lizard peridotites has crystallized in an environment similar to that of peridotite inclusions in basalts. Pyroxene pairs from many peridotite inclusions (Ross *et al.*, 1954; Hamad, 1963) show the same relation with one exception (R-9).

The difference of K_{Al} between ultramafic intrusives and peridotite inclusions and the exceptional primary peridotites might be attributed to the pressure difference at the time of the crystallization.

Table 7. Al-Si distribution of co-existing pyroxenes

No.	Orthopyroxene			Clinopyroxene			K _{Al} *	Reference
	M**	Al ₂ O ₃ Wt. %	Al ^{IV} /SiWt. %	Al ₂ O ₃ /SiWt. %	Al ^{IV} /Si			
Low pressure type	HM-2	91.7	2.53	0.0369	2.54	0.0346	0.94	Onuki, 1965b
	HM-11	91.1	3.27	0.0484	3.59	0.0485	1.00	"
	HM-8	90.7	3.49	0.0512	3.58	0.0470	0.92	"
	HM-10	90.3	3.52	0.0534	4.00	0.0524	0.98	"
	HM-12	90.0	3.54	0.0543	4.04	0.0526	0.97	"
	D- 1	86.4	2.69	0.0446	2.05	0.0340	0.76	Rothstein, 1958
	KM-20	91.1	2.35	0.0368	2.78	0.0364	0.99	In this paper
	KN- 1	92.1	2.49	0.0386	2.99	0.0387	1.00	"
	R-1	89.2	3.91	0.0453	5.14	0.0640	1.64	Ross <i>et al.</i> , 1954
	R-2	89.2	4.10	0.0502	5.97	0.0596	1.19	"
High pressure type	R-3	89.8	4.80	0.0574	6.58	0.0787	1.37	"
	R-4	90.2	5.32	0.0630	6.46	0.0655	1.04	"
	R-7	89.4	3.50	0.0453	4.69	0.0575	1.27	"
	R-8	91.2	2.97	0.0400	4.08	0.0231	0.58	"
	HA-1	89.4	3.24	0.0360	4.92	0.0540	1.50	Hamad, 1963
	L-1	89.5	6.59	0.0835	7.09	0.0884	1.06	Green, 1964
	L-2	89.5	6.30	0.0814	6.80	0.0961	1.18	"

$$*K_{Al} = \frac{(Al^{IV}/Si)Cpx}{(Al^{IV}/Si)Opx} \quad ** M = \frac{Mg \times 100}{Mg + Fe^{+3} + Fe^{+2} + Mn}$$

It appears to the present authors that the Al₂O₃ determination is most erroneous compared with the determination of other components when the indirect method is used for Al₂O₃. Therefore it is expected that K_{Al} values in many pyroxene pairs have some range, though the general tendency might not be different.

It may be concluded that K_{Al} in pyroxene pairs of ultramafic intrusives solidified or recrystallized at lower pressure, probably in the crust, or the upper-most mantle, are approximately 1.0 or commonly slight less, whereas K_{Al} in pyroxene pairs crystallized at higher pressure, probably in the upper-mantle, exceed 1.0.

The present authors made an attempt to explain the difference of K_{Al} in pyroxene pairs between the two types of ultramafic rocks on the basis of physico-chemical considerations. Al atoms with four-fold co-ordination make several molecular components in the two kinds of pyroxene. Therefore the calculation of two types of pyroxene into their molecular components are very useful, for they provide a clear picture of the complicated role of aluminium. For the pyroxene pairs listed in Table 7, the amounts of several molecules containing Al are shown in Table 8. Clinopyroxenes

Table 8. Molecular proportions of several molecules contained Al in pyroxenes

		Cpx				Opx			
		NaAlSi ₂ O ₆	CaTiAl ₂ O ₆	CaFe ⁺² AlSiO ₆	CaAl ₂ SiO ₆	CaTiAl ₂ O ₆	MgCrAlSiO ₆	MgFe ⁺³ AlSiO ₆	MgAl ₂ SiO ₆
Low pressure type	HM-2	—	0.3	1.8	4.1	0.4	1.3	1.8	3.2
	HM-11	—	0.4	1.9	6.2	0.8	1.1	2.4	4.1
	HM-8	—	0.4	1.7	6.3	0.8	1.1	2.5	4.5
	HM-10	—	0.7	1.3	7.2	1.3	1.1	2.6	4.2
	HM-12	—	0.6	1.3	7.3	1.2	1.2	2.4	4.2
	D-1	—	0.7	2.9*	2.2	0.3	0.7	4.8	2.5
	KM-20	—	0.9	0.4	4.9	0.8	1.4	1.6	2.5
	KN-1	—	0.8	0.7	5.3	0.7	0.7	1.6	2.7
High pressure type	R-1	—	1.0	—	10.1	0.2	0.8	—	7.3
	R-2	3.9	0.7	—	9.7	—	2.1	—	7.1
	R-3	3.5	2.1	—	5.0	—	1.5	0.4	9.0
	R-4	3.0	0.8	—	10.3	—	1.8	—	9.6
	R-7	0.4	0.9	—	8.9	0.6	1.1	—	6.1
	R-8	8.9	2.1	—	1.9	0.2	1.9	—	4.2
	H-1	3.3	0.9	—	7.5	—	0.5	3.3	3.0
	L-1	0.5	1.1	—	13.4	0.4	0.6	2.5	11.3
	L-2	—	0.9	3.7	11.5	0.5	1.3	1.9	10.7

* Include CaCrAlSiO₆ 0.1 per cent.

usually carry more tschermakite molecules than co-existing orthopyroxenes from those two types of ultramafic rocks which were crystallized under low and high pressure conditions.

Experimental results by Boyd and England (1960) have shown that at least 14 wt. per cent and perhaps up to 19 wt. per cent of Al₂O₃ could be dissolved in an enstatite under the pressure of 18.2 kilobars. Al₂O₃ would be held in an enstatite in the form of MgAl₂SiO₆. In Table 9, molecular components of pure enstatite and aluminous enstatites carrying 14 and 19 wt. per cent of Al₂O₃ are shown. Under 18.2 kilobars, an enstatite can contain at most 37.4 molecular per cent of MgAl₂SiO₆.

On the other hand, Clark, Schairer and de Neufville (1963) have shown that CaAl₂SiO₆ forms a complete solid solution with diopside at 20 kilobars in the system diopside-anorthite-silica.

From these experimental data on both orthopyroxene and clinopyroxene, it may be concluded that the clinopyroxene always contains more tschermakite molecules than the co-existing orthopyroxene.

In pyroxene pairs formed at lower pressure, the amount of Al^{IV}

Table 9. Molecular proportions of pure enstatite and aluminous enstatites

	Wt. %			Molecular proportion			
	1	2	3		1	2	3
SiO ₂	60	51.6	48.6	MgSiO ₃	100	72.5	62.6
Al ₂ O ₃	—	14.0	19.0	MgAl ₂ SiO ₆	—	27.5	37.4
MgO	40	34.4	32.4				
Total	100	100.0	100.0	Total	100	100.0	100.0

in orthopyroxenes is nearly equal to that in clinopyroxenes, conversely orthopyroxenes have less molecules with Al^{IV} than co-existing clinopyroxenes in pairs crystallized at higher pressure. A complication arises from the fact that orthopyroxenes contain more of the other molecules with Al^{IV}, besides tschermakite molecule, than do clinopyroxenes in the case of the former. Consequently, in spite of the higher solubility of tschermakite molecule in clinopyroxenes than in orthopyroxenes, K_{Al} values in co-existing pyroxenes formed at lower pressure are not always over 1.0, because Ti, Fe⁺³, Cr and alkali contents have a potential influence on the amounts of Al^{IV} in Z positions of pyroxene structures.

On the other hand, the tschermakite molecule by far surpasses other molecules with Al^{IV} in higher pressure pyroxene pairs. Therefore, such a chemical nature wherein tschermakite molecule is more soluble in a clinopyroxene than in an orthopyroxene directly controls K_{Al} values of pyroxenes formed at higher pressure.

But clinopyroxenes formed at high pressure as in peridotite inclusions in basaltic rocks often contain considerable amounts of jadeite molecule. Although the clinopyroxene is more aluminous than the co-existing orthopyroxene in the case of the exceptional pyroxene pairs (R-8), the K_{Al} value is far less than 1.0. This is understandable by reason of the fact that the clinopyroxene in this pair includes much more jadeite molecule, one of the high pressure components, as compared with other pyroxene pairs from peridotite inclusions. This clinopyroxene with unusual chemical composition, i.e., high content of Na₂O (2.14 wt. per cent), may have been formed under abnormal physico-chemical condition as a constituent mineral of peridotite inclusions, but the authors have come to no definite conclusion.

Probably the solubility of the jadeite molecule in the clinopyroxene is greater than that of the CaAl₂SiO₆ component under

the condition of higher pressure and lower temperature. Consequently, it is possible that the jadeite molecule is not soluble in clinopyroxenes at some P-T condition at which $\text{CaAl}_2\text{SiO}_6$ molecule is soluble. In igneous clinopyroxenes which generally crystallized at higher temperature than the metamorphic ones, the jadeite molecule may be insoluble except at higher pressure condition as in the mantle. But, as regards the definitively quantitative relation between jadeite and tschermakite molecules in clinopyroxenes at higher pressure, the authors have no opinion at present.

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超苦鉄質貫入岩体の岩石化学 —特に共生する輝石間のAlの配分—

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摘 要

超苦鉄質貫入岩体を構成する岩石と玄武岩中の橄欖岩団塊の化学組成をM値($Mg+Ni$) $\times 100/(Mg+Ni+Fe^{+2}+Fe^{+3}+Mn)$ とマントルノルムを用いて比較した。又超苦鉄質岩類中に共存する単斜輝石と斜方輝石における $Al^{IV}-Si$ の配分をしらべ、物理化学的に考察を行った。