

1. OLIVINES FROM LHERZOLITE INCLUSIONS OF ITINOME-GATA, JAPAN

KEN-ICHIRO AOKI* and IKUKO SHIBA*

Abstract

Olivines, which constitute from 55 to 85 per cent of lherzolite inclusions, occur as coarse xenomorphic-granular form, intergranular polygonal form among the former crystals, or as small euhedral grains in an aggregate comprised of plagioclase, olivine, and spinel transformed from garnet through pyroxene-spinel symplectite.

Thirty five olivines were analyzed by conventional and atomic absorption methods for major and minor elements. The range in composition is from Fo_{91.7} to Fo_{84.0}; the most frequent interval is from Fo_{91.7} to Fo_{88.0}.

Comparing the frequency distribution for olivine compositions from lherzolite inclusions in alkali basalts with that of garnet lherzolite inclusions in kimberlites, both have the same patterns of histogram, but the former has lower Fo content (about Fo₉₀ and Fo₉₂ in averages respectively). Accordingly, the source region of garnet lherzolites has a slightly higher MgO content than that of lherzolites just below the M-discontinuity.

Both Ni and Co contents in olivines decrease abruptly with a decrease in magnesian content as is pointed out by many investigators. But the Ni/Co ratio preserves a rather constant value having no relation to the increase or decrease of forsterite content.

Introduction

Forsteritic olivine is the most important constituent mineral and occupies more than 55 to 67 per cent by volume of the upper mantle (HARRIS *et al.*, 1967; RINGWOOD, 1969; CARTER, 1970). Therefore, detailed geochemical studies of olivines from lherzolite inclusions in alkali basaltic rocks, which may be fragments of upper mantle materials, is thought to be well worthwhile. Since the first systematic mineralogy and chemistry of lherzolite inclusions were reported by Ross *et al.* (1954), these inclusions throughout the world have been studied by many petrologists and geochemists. However, an understanding of the chemical features of olivines are rather neglected, because of their simple composition lying on the Mg-rich side of the Mg₂SiO₄—

Fe₂SiO₄ solid solution.

The present study deals with the chemistry of some major and minor elements in olivines from the lherzolite inclusions of Itinome-gata. It has already been shown that a fairly large variety of the rock types of ultramafic and mafic inclusions of Itinome-gata are represented elsewhere (HAYASHI, 1954; KUNO, 1967; AOKI and KAMEYAMA, 1970; KUNO and AOKI, 1970; AOKI, 1971; AOKI and SHIBA, 1971, 1973, in press).

Petrographic Description

Lherzolite inclusions, up to 30 cm in diameter and rounded in form, are rare constituents of alkali basalt air-fall lapilli and accidental tuff breccia that mainly consists of Tertiary volcanics and sedimentary rocks and Cretaceous granitic rocks which were ejected from the Itinome-gata crater in Holocene time. The mode of occurrence and

* Institute of Mineralogy, Petrology and Economic Geology, Tohoku University, Sendai, Japan

petrology of the lherzolite inclusions have already been described by KUNO (1967), KUNO and AOKI (1970), and AOKI and SHIBA (1973), so that only a brief summary of olivines in lherzolite inclusions need be given here.

The lherzolites can be subdivided into two groups on the basis of the presence or absence of primary garnet: 1) garnet lherzolites and 2) spinel lherzolites. Many spinel lherzolites have an indistinct foliation owing to selective enrichment of orthopyroxenes and chromian spinels. Rarely fine strings of plagioclase are observed. No foliation has been recognized in garnet lherzolites. Therefore, it is not so difficult to draw a line between spinel lherzolites and garnet lherzolites in hand specimen. YOSHINO (1971) and SHIBA (1973) found preferred crystal lattice orientation of olivines both types of lherzolites. This shows that olivines in spinel lherzolites are more developed than those of garnet lherzolites. These features would be formed by recrystallization as a result of pressure release during upward transport under dry conditions from the original site to shallower levels.

Olivine constitutes from 55 to 85 per cent and averages 70 per cent in lherzolite inclusions. It occurs in the following three ways in the host rocks: a) coarse xenomorphic-granular form, mostly less than 5 mm in size, b) intergranular polygonal form among the former grains, up to 1 mm in size, and c) euhedral grains in aggregates comprised of plagioclase, olivine, and pale green spinel transformed from garnet through pyroxene-spinel symplectite. The last type is limited only to garnet lherzolites. Simple wide-spaced translation lamellae subparallel to [100] and undulating extinction, which are not as well-developed as in olivines of lherzolite inclusions of other localities, are sometimes observed in coarse-grained olivines.

Twenty-one representative lherzolite in-

clusions from Itinome-gata have been analyzed (KUNO and AOKI, 1970; AOKI and SHIBA, 1973). The spinel lherzolites have a wide range of composition. Based on the MgO content they can be divided into three groups; high (47–49%), moderate (41–39%), and low (33%). The first is characterized by low CaO and Al_2O_3 contents, and negligible amounts of modal clinopyroxene. Therefore, on petrographic basis it should be called harzburgite, but as a matter of convenience this group is classified in the lherzolite series. The last has a very high CaO content and a higher modal clinopyroxene than orthopyroxene. The moderate MgO content group exceeds 90 per cent by volume of spinel lherzolites. The low group is extremely rare. Garnet lherzolites fall within the chemical variation of the moderate and low MgO content groups, but almost all of them have moderate MgO contents.

Analytical Procedure

Lherzolites were first crushed (–8 to 24 mesh) for selection of olivines by hand-picking. Then, olivines were crushed to pass through a 150-mesh sieve and separated very carefully by a Franz isodynamic separator. Purity of the analyzed sample is estimated to be better than 99.5 per cent. Of the 34 separated olivines 11 were analyzed by conventional wet methods for SiO_2 , TiO_2 , Al_2O_3 , FeO, MnO, and MgO. The other 23 olivines were analyzed by atomic absorption spectroscopy for Al_2O_3 , FeO, MnO, and MgO. In the latter case, FeO and MgO were determined by comparison with the olivines analyzed by wet methods. All of minor and trace elements such as Ca, Ni, Co, Cu, and Zn were also determined by atomic absorption spectroscopy.

Sample treatment of atomic absorption spectroscopy is as follows. Accurately weigh 300 mg of sample into a 100-ml Teflon

beaker. Moisten with water and add 10 ml HF and 5 ml HNO₃. Cover and heat on a hot plate to decompose. Rinse off and remove cover, then evaporate to dryness on the hot plate. Add 5 ml HNO₃, rinse down the walls of the beaker with a little water and again evaporate to dryness. Add 20 ml HCl (1:4), cover and warm to dissolve salts completely. Transfer to a 100-ml volumetric flask, and 10 ml of the 15,000 ppm Sr solution and 5 ml of the 10,000 ppm Cs together,

then dilute to volume with water. For the determination of MgO and FeO, the sample solution is diluted to 1500 and 30 times, respectively. All final solutions contain 1500 ppm Sr and 1000 ppm Cs. All elements were analyzed by a Perkin-Elmer atomic absorption spectrometer model 303. A mixture of acetylene and nitrous oxide is used as fuel for Al₂O₃ determination. Acetylene-air and three slot burner head are used for the other element determinations.

Table 1. Chemical analyses of olivines in spinel lherzolites

	1	2	3	4	5	6	7
SiO ₂	40.55	40.75	40.54	40.44	40.41	40.41	39.62
TiO ₂	tr	0.01	tr	tr	tr	tr	0.01
Al ₂ O ₃	tr	0.02	0.03	tr	tr	0.14	0.14
Cr ₂ O ₃	0.017						
Fe ₂ O ₃	0.19						
FeO	8.40	8.94	10.25	10.89	11.32	11.28	13.29
MnO	0.11	0.12	0.16	0.17	0.16	0.16	0.22
MgO	50.67	49.25	48.18	47.82	47.34	47.25	45.81
NiO		0.42	0.44	0.37	0.28	0.38	0.36
CaO	tr	0.12	0.07	0.15	0.03	0.08	0.05
Na ₂ O	none						
K ₂ O	none						
H ₂ O	0.61						
Total	100.547	99.63	99.67	99.84	99.54	99.70	99.50
Co ppm		305	288	283		250	259
Zn ppm		55	59	72		69	59
Si	0.990	1.000	1.001	1.000	1.003	1.001	0.994
Al		0.001	0.001			0.004	0.004
Fe ⁺³	0.004						
Fe ⁺²	0.171	0.183	0.212	0.225	0.235	0.234	0.279
Mn	0.002	0.003	0.003	0.004	0.003	0.004	0.005
Mg	1.842	1.801	1.772	1.761	1.751	1.744	1.713
Ni		0.008	0.009	0.007	0.004	0.008	0.007
Ca		0.003	0.002	0.004	0.001	0.002	0.001
XYZ	3.009	2.999	3.000	3.001	2.997	2.996	3.003
Fo mol %*	91.2	90.7	89.2	88.5	88.1	88.0	85.8

* $100 \text{ Mg}_2\text{SiO}_4 + \text{Ni}_2\text{SiO}_4 / \text{Mg}_2\text{SiO}_4 + \text{Ni}_2\text{SiO}_4 + \text{Fe}_2\text{SiO}_4 + \text{Mn}_2\text{SiO}_4$

1. HK63111602a 2. HK50061803b 3. 6982408 4. HK64081205a 5. HK64081206d
6. HK64081205b 7. 6982314

No. 1; analyst, H. HARAMURA (KUNO and AOKI, 1970).

Nos. 2-7; analyst, K. AOKI and I. SHIBA.

Mineral Chemistry

Chemical analyses of olivines from representative spinel lherzolites and garnet lherzolites are given in Tables 1 and 2 together with their atomic ratios on the basis of O=4. Partial analyses of olivines in lherzolites are

also given in Table 3. In this case, the rocks are selected by random sampling in order to know the exact nature of variation of olivine compositions. The accuracy of analyses of olivines is checked by adding the SiO₂ to balance each oxide, and summing the weight per cents of Mg₂SiO₄, Fe₂SiO₄,

Table 2. Chemical analyses of olivines in garnet lherzolites

	8	9	10	11	12	13	14
SiO ₂	40.66	40.70	40.86	40.70	39.58	40.50	40.30
TiO ₂	0.01	0.01	0.01	0.01	tr	tr	0.15
Al ₂ O ₃	0.21	0.20	0.21	tr	0.11	0.43	0.25
Cr ₂ O ₃							0.03
Fe ₂ O ₃						0.02	0.00
FeO	9.68	9.77	9.34	9.81	14.89	9.21	10.26
MnO	0.13	0.13	0.14	0.13	0.21	0.13	0.09
MgO	48.65	48.77	48.67	48.65	44.57	50.03	48.60
NiO	0.40	0.38	0.39	0.40	0.29		0.41
CaO	0.05	0.07	0.17	0.12	0.05	tr	0.07
Na ₂ O						tr	0.04
K ₂ O						tr	0.03
H ₂ O						0.15	0.33
Total	99.79	100.03	99.79	99.82	99.70	100.79	100.56
Co ppm	302	273	301	300	210		
Zn ppm	52	60	49	45	46		
Ti	0.999	0.998	1.003	1.001	0.998	0.989	0.989
Si							0.003
Al	0.006	0.006	0.006		0.003	0.012	0.009
Cr							0.001
Fe ⁺³						0.000	
Fe ⁺²	0.199	0.200	0.192	0.203	0.314	0.188	0.210
Mn	0.003	0.003	0.003	0.003	0.005	0.003	0.002
Mg	1.781	1.782	1.779	1.782	1.675	1.819	1.777
Ni	0.008	0.008	0.008	0.008	0.004		0.008
Ca	0.001	0.002	0.004	0.003	0.001		0.002
Na							0.002
K							0.001
XYZ	2.997	2.999	2.995	3.000	3.000	3.011	3.004
Fo mol %	89.9	89.8	90.2	89.7	84.0	90.5	89.4

8. 6982312 9. 6982401 10. HK67051201 11. HK64081206c 12. 6982313 13. HK58012403
14. HK36072601c

Nos. 8-12; analyst, K. AOKI and I. SHIBA.

No. 13; analyst, H. HARAMURA (KUNO and AOKI, 1970).

No. 14; analyst, M. D. FOSTER (ROSS et al., 1954).

Table 3. Partial analyses of olivines in spinel lherzolites and garnet lherzolites

Sp. N.	SiO ₂	Al ₂ O ₃	FeO	MnO	MgO	NiO	CaO	Total	Fo mol %	Co ppm	Zn ppm
1 72010802	40.46	0.21	9.90	0.14	48.40	0.40	0.07	99.58	89.6	278	58
2 72010803	40.76	0.19	10.28	0.14	48.65	0.40	0.06	100.48	89.4	275	1483
3 72010804	40.28	0.19	10.20	0.13	48.02	0.40	0.04	99.26	89.3	279	46
4 72010805	40.42	0.13	10.33	0.14	48.13	0.40	0.03	99.58	89.2	285	1396
5 72010806	40.64	0.19	11.14	0.15	47.92	0.37	0.10	100.51	88.4	253	64
6 72010807	40.98	0.09	9.22	0.13	49.49	0.40	0.07	100.38	90.5	282	1695
7 72010808	40.45	0.09	10.30	0.14	48.15	0.39	0.10	99.62	89.2	274	50
8 72010809	41.36	0.09	10.34	0.15	48.39	0.39	0.03	100.75	89.4	281	46
9 72010810	40.53	0.23	9.80	0.14	48.56	0.37	0.07	99.70	89.7	277	1643
10 72010811	40.77	0.09	9.94	0.14	48.77	0.39	0.11	100.21	89.6	290	52
11 72010812	41.03	0.09	9.59	0.14	49.35	0.38	0.07	100.65	90.1	241	49
12 72010813	40.51	0.17	10.25	0.14	48.25	0.39	0.10	99.81	89.3	246	272
13 72010814	40.56	0.20	10.38	0.15	48.28	0.39	0.06	100.02	89.1	250	57
14 72010815	40.58	0.18	10.11	0.14	48.43	0.40	0.09	99.95	89.4	253	247
15 72010816	40.55	0.18	9.90	0.14	48.46	0.39	0.17	99.79	89.6	252	58
16 72010817	40.63	0.14	10.16	0.14	48.44	0.40	0.13	100.04	89.4	252	316
17 72010818	40.75	0.12	10.43	0.15	48.43	0.37	0.17	100.42	89.1	246	62
18 72010819	40.74	0.25	10.19	0.14	48.62	0.38	0.09	100.41	89.4	253	49
19 HK63111602a	40.62	0.39	8.74	0.13	49.16	0.36	0.25	99.65	90.8	250	278
20 HK64081205d	40.99	0.13	8.01	0.11	50.20	0.41	0.05	99.90	91.7	275	44
21 HK64081205c	40.89	0.09	9.08	0.13	49.42	0.39	0.12	100.12	90.6	253	48
22 HK67051202	40.93	0.15	9.73	0.14	49.14	0.39	0.07	100.55	89.9	275	288
23 HK64081206e	40.74	0.20	10.57	0.15	48.38	0.38	0.11	100.53	89.0	264	52

Mn₂SiO₄, Ca₂SiO₄, and Ni₂SiO₄. The sums of each analysis deviate from 100 per cent by ± 0.8 per cent. These results seem reasonable for the discussion of olivine chemistry.

As can be seen in the tables, olivines are characterized by the narrow ranges for both major and minor components (except Zn). The complete range in composition is from Fo_{91.7} to Fo_{84.0}. 35 of 37 olivines are concentrated between Fo_{91.7} and Fo_{88.0}; only two are dispersed toward less forsteritic compositions. There is also no chemical difference between olivines from the spinel lherzolite series and the garnet lherzolite series.

In all cases of newly analyzed olivines, Si ions are very close to 1.000 ranging from 0.994 to 1.003. This indicates that the tetrahedral site of olivine is only filled by

Si⁴⁺. This site rejects the substitution of other cations for Si as is commonly observed in other mafic silicates such as pyroxenes, amphiboles or micas.

Negligible amounts of Al ions, up to 0.006, are always present. It is still open to question concerning the presence of Al ions in olivines whether it occurs as impurities in analyzed samples or as a substitution for other major ions in the structure. Although the intensity for Al determination by an atomic absorption spectrometry is very low, and quantitative data for Al in olivines is insufficient, all routine runs except one show an apparent presence of Al₂O₃ less than 0.23 per cent (AOKI and SHIBA, 1971, this paper).

The sum of Fe and Mg shows a narrow range from 1.97 to 1.99, occupying 98.5 to 99.5 per cent of the X position of the minerals.

It follows that Fe and Mg proportions have a reciprocal relation. Mn atoms increase regularly with an increase of Fe. Minor amounts of Ca are always detected. The replacement of Mg by Ca is not significant.

Respective minor and trace amounts of Ni and Co atoms move in harmony with the Mg. Unique concentrations of Zn are observed, varying widely from 50 to 1700 ppm. Based on Zn concentration the olivines can be divided into three groups: low (50 to 70 ppm), medium (250 to 320 ppm), and high (1400 to 1700 ppm). The low concentration group is the most common. There is some regularity among the three groups in that the Zn value of the medium and high concentration groups is increased five times and the square of five as much as that of the low group. The abundance of Zn has no relation to any major or minor elements, and Zn_2SiO_4 olivine does not occur in nature nor has it been synthesized. Accordingly the factors governing the behavior of Zn in olivine structure are unknown. More geochemical studies on olivines are strongly needed for an advanced discussion on the role of the Zn atoms. In all olivines, the line intensity of Cu does not essentially exceed background

intensity for atomic absorption spectrometry. Therefore, Cu contents would be less than 1 ppm.

Discussion

As is discussed elsewhere (KUNO, 1967; KUNO and AOKI, 1970; AOKI and SHIBA, 1973), all the lherzolite inclusions of Itinomegata have been more or less subjected to recrystallization under isochemical conditions during transportation from their original sources to the top of mantle. Their final assemblages are plagioclase lherzolite. The $100 \text{ Mg}/(\text{Mg} + \text{Fe}^{+2} + \text{Fe}^{+3})$ ratios of lherzolite inclusions and their constituent minerals are given in Table 4. The ratios of the lherzolites are very close to those of olivines. Also the distribution coefficient of Mg and Fe among coexisting olivines, orthopyroxenes and clinopyroxenes are essentially identical. Accordingly, some minor components in the olivines as well as those of pyroxenes have moved in or out in accordance with the environment. However, the distribution of Mg and Fe among coexisting major constituents seem to be essentially preserved during long periods of geologic time.

Table 4. $100 \text{ Mg}/(\text{Mg} + \text{Fe}^{+2} + \text{Fe}^{+3})$ ratios of lherzolites and their constituent minerals

	Spinel lherzolite)						
	1	2	3	4	5	6	7
Whole rock	91.5	90.5	88.8	88.2	87.7	87.3	85.6
Olivine	91.2	90.7	89.2	88.5	88.1	88.0	85.8
Orthopyroxene	91.6	90.3	88.4	89.4	88.2	88.7	85.7
Clinopyroxene	90.7	90.6	89.9	89.0	91.1	89.2	87.2
	Garnet lherzolite						
	8	9	10	11	12	13	14
Whole rock	89.8	89.5	89.5	89.5	83.9		
Olivine	89.9	89.8	90.2	89.7	84.0	90.5	89.4
Orthopyroxene	89.6	89.7	90.0	89.4	86.2	90.5	89.6
Clinopyroxene	90.4	90.2	91.2	90.5	87.1	91.1	89.4

Numbers are the same as those in Tables 1 and 2.

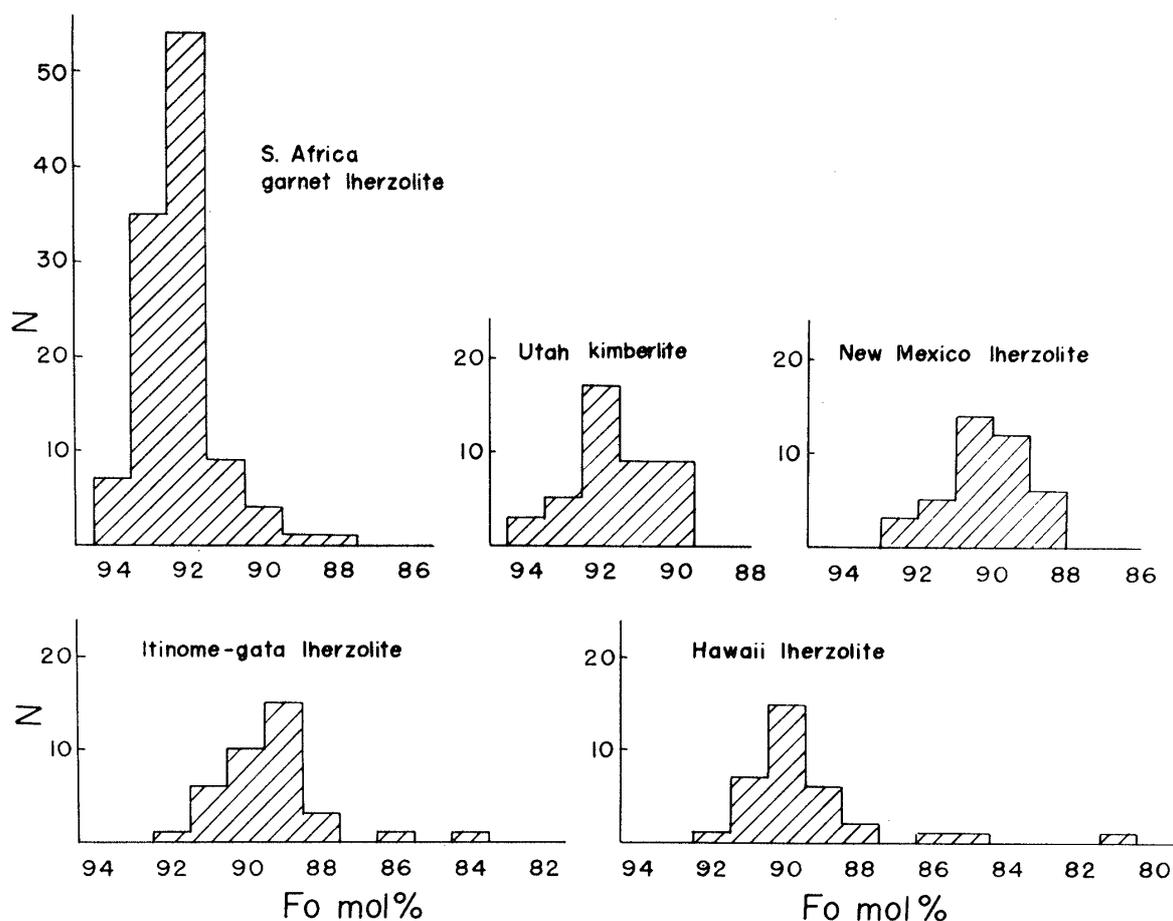


Fig. 1. Frequency distribution of olivine composition of lherzolite inclusion, garnet lherzolite inclusion and kimberlite.

Fig. 1 compares the frequency distribution for olivine compositions in lherzolite inclusions of Itinome-gata based on chemical analyses with those of olivines in garnet lherzolite inclusions in kimberlites, South Africa (MATHIAS *et al.*, 1970), kimberlite from Utah (McGETCHIN and SILVER, 1970), lherzolite inclusions in alkali basalts from New Mexico (CARTER, 1970), and from Hawaii (WHITE, 1966; KUNO, 1969). The olivines in lherzolites of Itinome-gata have compositions very similar to those of New Mexico and Hawaii. There are conspicuous differences between the olivines in lherzolite inclusions of alkali basalts and those of kimberlites. Although the distribution patterns are the same, the former have a lower Fo molecule (about 2 per cent). Recently a great number of

garnet lherzolite and spinel lherzolite inclusions throughout the world have been analyzed, and their systematic chemical variations have been explained as due to different degrees of partial fusions of the undepleted mantle materials. The garnet lherzolite inclusions in kimberlites have slightly higher MgO/total FeO as compared with lherzolite inclusions in alkali basalts. These facts suggest that both bulk rock and olivine compositions indicate that the source region of garnet lherzolites have slightly higher MgO contents than that of lherzolites just below the M-discontinuity.

The contents of Al and Ca in clinopyroxenes and orthopyroxenes seem to be related to physico-chemical conditions of their crystallization or recrystallization, and systematic

studies have been carried out by many investigators. On the other hand, the study of Al and Ca in olivines are neglected because of their minor amounts and the difficulty of their highly accurate determination.

It would be expected that Al and Ca contents in olivines also reflect their formation under pressure and temperature conditions. Indeed, forsterite and fayalite form a solid solution containing small amounts of the components CaMgSiO_4 and CaFeSiO_4 , respectively (KUSHIRO, 1969;

BOWEN *et al.*, 1933; YANG, 1973). Olivines from Itinome-gata contain up to 0.25% of Al_2O_3 and 0.17% of CaO, corresponding to 0.4% of $\text{Ca}(\text{Mg,Fe})\text{SiO}_4$ molecule in forsterite-fayalite solid solution.

Ni is one of the most important minor elements in Mg-rich olivines, and its content shows regular but abrupt decrease with increasing Fe^{+2} . Numerous interpretation have been proposed for the substitutions among these elements. Co, which has similar ionic radius to Mg, is also thought to have

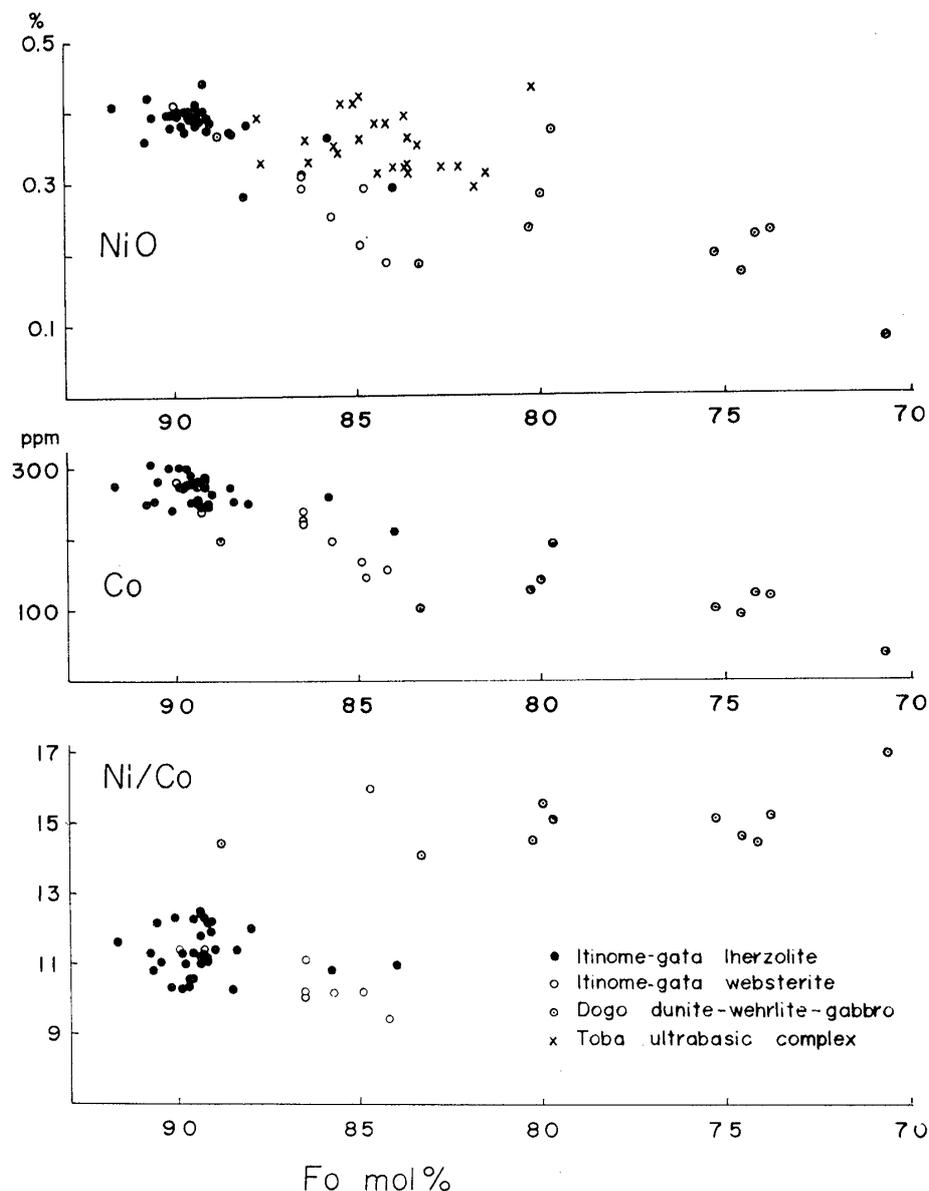


Fig. 2. NiO and Co contents and Ni/Co ratio of olivine.

the same behavior as Ni in olivines. But no available data have yet been reported in spite of the importance of this trace element. NiO and Co contents and Ni/Co ratios are plotted against the Fo mol. per cent, for comparison with those of websterite inclusions of Itinome-gata, inclusions belonging to the dunite-wehrlite-gabbro suite in alkali basalts of Dogo, Oki Islands (AOKI and SHIBA, unpublished) and Toba ultrabasic complex (NAKAMURA, 1971) (Fig. 2).

NiO contents in olivines in lherzolites of Itinome-gata have essentially the same ranges as those of lherzolite inclusions from other localities. They are distributed in the upper part of the field of world-wide ultrabasic rocks from orogenic belts in the NiO-Fo diagram given by NAKAMURA (1971). FORBES and BANNO (1966) pointed out that the Ni-Fe ratios of olivines differ depending on their mode of occurrence. On the other hand NISHIMURA *et al.* (1968) indicate that the NiO content lies on a relatively smooth curve from 0.4 per cent at Fo₉₀ to zero at Fo₇₅ in spite of the difference in their origin. Although lherzolites and websterites of Itinome-gata are considered to have a different origin, the variation of olivines lie on the curve shown by NISHIMURA *et al.* (1968). However, olivines from Dogo, Oki Islands and the Toba complex fall with the range of olivines from the dunite-wehrlite series inclusions from Hawaii (WHITE, 1966) and show a similar trend. But they have a lesser decrease in rate of NiO contents as Fa molecule increases. Accordingly, Forbes and BANNO's conclusion could be reasonable from these results.

As is shown in Fig. 2, Co contents of olivines from Itinome-gata and Dogo, Oki Islands also decrease abruptly with the decrease of forsterite content showing the same tendency as coexisting Ni. The rate of decrease of Co from Itinome-gata is steeper than that of Dogo, Oki Island; that is from about 300

ppm at Fo₉₀ to almost zero at Fo₇₅ and about 200 ppm at Fo₈₉ to nearly zero at Fo₇₀, respectively.

The present investigation clearly demonstrates that the Ni/Co atomic ratio in olivines from Itinome-gata varies from about 9 to 13 with an average of 11, whereas that of Dogo, Oki Islands ranges from 14 to 17 with an average of 15, regardless of the increase or decrease of forsterite content; there is no overlap between them. Such different Ni/Co ratios is attributed to the difference of the source materials in the upper mantle.

Acknowledgements

The authors wish to thank Dr. M. F. SHERIDAN of the Arizona State University for critical reading of the manuscript. A part of the expense of this study was defrayed by a Grant for Scientific Research from the Ministry of Education of Japan.

References

- AOKI, K. (1971), Petrology of mafic inclusions from Itinome-gata, Japan. *Contr. Mineral. and Petrol.*, vol. 30, p. 314-331.
- and KAMEYAMA, E. (1970), Clinopyroxene megacrysts from Itinome-gata volcano, northeastern Japan. *Jour. Japan. Assoc. Min. Pet. Econ. Geol.*, vol. 63, p. 160-165 (in Japanese with English abstract).
- and SHIBA, I. (1971), Ni, Mn and Ca contents of lherzolite olivines of Itinome-gata. *Jour. Japan. Assoc. Min. Pet. Econ. Geol.*, vol. 66, p. 44-48 (in Japanese with English abstract).
- , ——— (1973), Pyroxenes from lherzolite inclusions of Itinome-gata, Japan. *Lithos*, vol. 6, p. 41-51.
- BOWEN, N. L., SCHAIRER, J. F. and POSNJAK, E. (1933), The system CaO-FeO-SiO₂. *Am. Jour. Sci.*, Ser. 5, vol. 26, p. 193-284.
- CARTER, J. L. (1970), Mineralogy and chemistry of the earth's upper mantle based on the partial fusion-partial crystallization model. *Bull. Geol. Soc. Am.*, vol. 81, p. 2021-2034.
- FORBES, R. B. and BANNO, S. (1966), Nickel content of peridotite inclusion and cognate olivine from an alkali-olivine basalt. *Am.*

- Mineral.*, vol. 51, p. 130-140.
- HARRIS, P. G., REAY, A. and WHITE, I. G. (1967), Chemical composition of the upper mantle. *Jour. Geophys. Res.*, vol. 72, p. 6359-6369.
- HAYASHI, H. (1955), Ejecta around Itinome-gata in Oga Peninsula, Akita Prefecture. *Jour. Geol. Soc. Japan*, vol. 61, p. 240-248.
- KUNO, H. (1967), Mafic and ultramafic nodules from Itinome-gata, Japan. *In Ultramafic and related rocks*, ed. by P. J. WYLLIE, p. 337-342, Wiley Press, New York.
- (1969), Mafic and ultramafic nodules in basaltic rocks of Hawaii. *Geol. Soc. Am. Mem.* 115, p. 189-234.
- and AOKI, K. (1970), Chemistry of ultramafic nodules and their bearing on the origin of basaltic magmas. *Phys. Earth Planet. Interiors*, vol. 3, p. 273-301.
- KUSHIRO, I. (1969), The system forsterite-diopside-silica with and without water at high pressures. *Am. Jour. Sci.*, Schairer Vol. 267-A, p. 269-294.
- MATHIAS, M., SIEBERT, J. C. and RICKWOOD, P. C. (1970), Some aspects of the mineralogy, petrology of ultramafic xenoliths in kimberlite. *Contr. Mineral. and Petrol.*, vol. 26, p. 75-123.
- MCGETCHIN, T. R. and SILVER, L. T. (1970), Compositional relations in minerals from kimberlite and related rocks in the Moses Rock dike, San Juan County, Utah. *Am. Mineral.*, vol. 55, p. 1738-1771.
- NAKAMURA, Y. (1971), Petrology of the Toba ultramafic complex, Mie Prefecture, central Japan. *Jour. Fac. Sci., Univ. of Tokyo, Sec. II*, vol. 18, p. 1-51.
- NISHIMURA, M., YAGI, K. and YAMAMOTO, M. (1968), Nickel content of olivines. *Proc. Japan Acad.*, vol. 44, p. 686-691.
- RINGWOOD, A. E. (1969), Phase transformations in the mantle. *Earth Planet. Sci. Letters*, vol. 5, p. 401-412.
- ROSS, C. S., FOSTER, M. D. and MYERS, A. T. (1954), Origin of dunites and of olivine-rich inclusions in basaltic rocks. *Am. Mineral.*, vol. 39, p. 693-737.
- SHIBA, I. (1973), Petrology of ultramafic inclusions of Itinome-gata. *M. Sc. thesis, Tohoku Univ.* (manuscript).
- WHITE, R. W. (1966), Ultramafic inclusions in basaltic rocks from Hawaii. *Contr. Mineral. and Petrol.*, vol. 12, p. 245-314.
- YANG, H. Y. (1973), New data of forsterite and monticellite solid solutions. *Am. Mineral.*, vol. 58, p. 343-345.
- YOSHINO, C. (1971), Petrofabric study of a peridotite nodule from Itinomegata, *Japan. Jour. Sci. Hiroshima Univ.*, Ser. C, vol. 6, p. 275-308.

(Received July 15, 1973)

一の目瀉レルゾライト捕獲岩中のかんらん石

青木 謙一郎・柴 いく子

(要 旨)

レルゾライト捕獲岩の55~85%を構成するかんらん石は3つの産状を示す：a) 粗粒他形結晶, b) 前者の間をうめる多角形の中粒結晶及びc) ざくろ石の分解により生じた輝石・スピネルシンプレクタイトを経て斜長石, かんらん石, スピネルの集合物になったものの中の小型自形結晶。

35個のかんらん石について重量法と原子吸光法により化学分析をおこなった。その組成範囲は $Fe_{0.91.7} \sim Fe_{0.84.0}$; 殆んどものは $Fe_{0.91.7} \sim Fe_{0.88.0}$ である (平均 $Fe_{0.89.5}$)。

アルカリ玄武岩中のレルゾライト捕獲岩, およびキンパーレー岩中のざくろ石レルゾライト捕獲岩中のかんらん石組成の頻度分布を比較した。これらはいずれも同じような形のヒストグラムを示すが, レルゾライト捕獲岩

中のかんらん石はやや Fa に富む (平均 $Fe_{0.90}$ と $Fe_{0.92}$)。従ってキンパーレー岩中のざくろ石レルゾライトの供給された地帯は, アルカリ玄武岩のレルゾライト捕獲岩がもたらされたと考えられる M-不連続面直下よりも Mg に富む物質によって構成されているであろう。

かんらん石中の Ni と Co は Mg の減少と共に急激に減少することは多くの研究者によって指適されている。しかし (Ni/Co は Fe 成分の増減に無関係に一定であり, またその比は地域によって異なるらしい。

地 名	
Dogo	島 後
Oki	隠 岐
Toba	鳥 羽