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ON THE ORIGIN OF ULTRABASIC ROCKS AND DEFECTIVE STRUCTURAL FORMULAE OF A FEW CHROMITES ASSOCIATED WITH THE SAID ROCKS, FOUND IN THE VICINITY OF COMMON BOUNDARIES OF SHIMANE, TOTTORI, OKAYAMA AND HIROSHIMA PREFECTURES

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Outline of Geology

Ultrabasic body was intruded into Palaeozioc sediment at the time of preorogenic cycle in about the end of Jurassic period. In the Cretaceous period quartz-porphyry and granite were intruded into ultrabasic rock, and Tertiary layers were sedimented. Gabbro is intruded into ultrabasic rock in dyke structure, but a part of it is a xenolith of dyke type. (Geological map will be given in a separate paper.)

Granite and Related Rocks

The descriptions of granite and related rocks in Tari district, Tottri prefecture have been shown in the paper (1957-1960).

Biotite granite develops to southeastward of serpentinite mass of Takase mine of Okayama prefecture. The granite exposed at Mimuro, is megascopically a fine or medium granular rock with quartz, feldspar, biotite and/or hornblende. In thin section, the minerals found in the specimen (Fig. 1) are quartz, orthoclase ($\gamma=1.527$), plagioclase (albite twinning), biotite

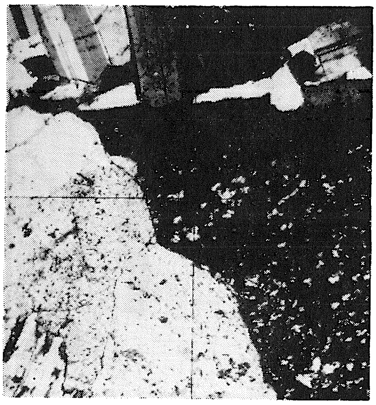

Fig. 1 Photomicrograph of biotite granite (T-40). Crossed nicols, × 45
Mimuro, Shingo-chō, Atetsu-gun, Okayama pref.

($\beta = \gamma = 1.646$) and/or hornblende, magnetite, apatite, and minor amounts of augite, zircon. The orthoclase is partly altered to sericite, and the biotite and/or hornblende is usually altered to chlorite with separation of magnetite along cleavage surfaces.

The chemical composition of the specimen is as shown in Table 1.

The alkali contents of the specimen are higher than granite (Anal. Kitahara, 1957, p. 46) on the Tari environs. The contents of total iron, magnesia, and lime of the former are lower than one of the latter.

Quartz porphyry is exposed mainly to eastward of the serpentinite mass. The quartz porphyry at Nagahisa is megascopically grayish white liparitic appearance with quartz phenocryst. Under the microscope, the minerals found in the specimen are composed of phenocryst of rounded or corroded quartz and partly sericificated orthoclase ($\gamma = 1.541$), and groundmass of quartz, somewhat sericificated orthoclase and albite.

The chmical analysis of the sample is as shown in Table 1.

It has been said that the quartz porphyry was generated at earlier stage than the granite intrusion. Granite porphyry and quartz porphyry were intruded into the ultrabasic rock. The relations between the porphyrys and the serpentinite are observed at the chromite deposits of the mine.

Table 1.

	Wt.%		Atom. Ratios when O=160		
Sample No.	T-40	T-46		T-40	T-46
SiO_2	73.05	74.42	Si	63.6	62.8
TiO_2	0.13	0.14	Ti	0.1	0.1
Al_2O_3	14.30	16.04	Al	14.6	15.9
Fe_2O_3	0.55	0.46	Fe^3	0.3	0.3
FeO	1.65	0.27	Fe^2	1.2	0.2
MnO	0.03	0.00	Mn	0.02	0
MgO	0.54	0.45	Mg	0.7	0.6
CaO	1.97	0.12	Ca	1.8	0.1
Na_2O	3.25	2.62	Na	5.5	4.3
K_2O	3.86	3.79	K	4.3	4.1
P_2O_5	0.19	0.03	P	0.1	0.02
H_2O+	0.54	1.69	H+	3.1	9.5
H_2O-	0.12	0.18			
	100.18	100.21			

T-40 : Biotite granite, Mimuro, Shingo-chō, Atetu-gun, Okayama pref.

T-46 : Quatrz porphyry, Nagahisa, Shingo-cho, Atetsu-gun, Okayama pref.

(Analyst: J. Kitahara)

Descriptions of Ultrabasic and Gabbroic Rocks

Ultrabasic and gabbroic rocks in the Tari district have been studied by the author, and the results were reported in Science Report of Shimane University and in Jounal of the Japanese Association of Mineralogists, Petrologists and Economic Gelogists. In the present paper, the writer describes briefly on the ultrabasic and gabbroic rocks in Takase mine environs. The elliptical, 2 km. long ultrabasic body is located along a northeast trending. The mass is mainly composed of an altered enstatite bearing dunite with accessory amounts of chromite. The amount of enstatite generally varies from zero to about 60 percent in the body, very rarely small irregular pods and dykelike masses contain up to 100 percent enstatite. Saxonite forms 1/3 to 2/3 of the mass, and enstatite rich peridotite is less abundant. Diopsidite composed almost wholly of diopside with dispersed chromite grains is rarely found in the chromite deposits. Near the chromite bodies the saxonite is converted to serpentinite. Further away, residual olivine and pyroxene are found. Although FeO generally dominates over Fe_2O_3, the proportion of one to the other varies considerably, undoubtedly reflecting the character of the serpentinization. The transition from olivine, first to antigorite along subrectangular cracks, and entirely to serpentinite with mesh structure is well shown in a number of sections. There is little doubt that this mesh structure is good evidence of the identify of the original mineral. Chromite is ubiquitous. Mostly it occurs as grains disseminated throughout all rock types. The ultrabasic rock shows little or no contact metamorphic effect on the wall rocks. The lack of chilled margins in either gabbroic and ultrabasic rocks at their mutual contacts results in the formation of dunite, pyroxenite and gabbro which have been intruded without a great break in time.

a) *Ultrabasic Rocks*

Sampling was neither systematic enough nor complete enough to justify a statistically valid estimate of the composition of the entire mass.

Sample No. T-4 *Enstatite Olivine bearing Talc rock*

It seems that the rock was metamorphosed or altered by intrusion of chromite body. Megascopically, it is blue black in color and shows serpentinite like appearance. In thin section (Fig. 2), olivine is partly altered to serpentine along cleavage planes. Enstatite ($\gamma = 1.668$) is partly altered to serpentine, sometimes completely altered to talc. Talc is fibrous, 0.7 mm. in size, and $\gamma = 1.584$. It was generated by hydrothermal metamorphism or alteration of olivine and enstatite. Talc/ol/en = 5/4/1. Magnetic mineral and chromite are rarely found in the

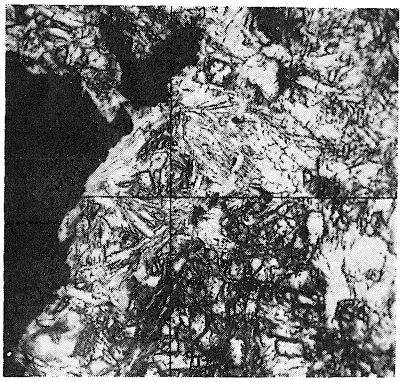

Fig. 2. Photomicrograph of enstatite olivine bearing talc rock (T-4).
Open nicol, × 45
New 2nd level of Takase mine, Okayama pref.

Fig. 3. Photomicrograph of serpentinized saxonite (T-5).
Open nicol, × 45
New 2nd level of Takase mine, Okayama pref.

specimen. The chemical composition of the specimen is as shown in Table 2.

Bowen and Tuttle (1940) and Bennington (1950) have shown that talc is stable at higher temperatures and pressures than serpentine. The conversion of serpentine to talc by the addition of silica and removal of magnesia may be illustrated by the following equation (Turner 1948).

$$\underset{\text{serpentine}}{(OH)_4Mg_3Si_2O_5} + SiO_2 \longrightarrow \underset{\text{talc}}{(OH)_2Mg_3Si_4O_{10}} + \underbrace{MgO + H_2O}_{\text{(removed in solution)}}$$

Sample No. T-5 *Serpentinized Saxonite*

It occurs near chromite body. Megascopically, the sample alters to a reddish tint. Under the microscope (Fig. 3), olivine is almost alter to serpentine ($\beta = 1.569\pm$) with rare olivine relics, and sometimes altered to yellowish chlorite. Enstatite is found in common or less common amounts. Chromite is observed as one which included in enstatite and/or stringers. The chemical composition of the sample is as shown in Table 2. The specimen is comparatively rich in ferric oxide content.

Table 2.

	Wt.%				Atom. Ratios when O = 160				
Sample No.	T-4	T-5	T-6	T-17		T-4	T-5	T-6	T-17
SiO_2	44.28	38.52	38.75	42.05	Si	39.5	33.1	33.8	41.5
TiO_2	0.09	0.04	0.04	1.82	Ti	0.05	0.03	0.05	1.4
Al_2O_3	1.92	0.78	0.97	5.28	Al	2.0	0.8	0.1	6.2
Cr_2O_3	0.24	0.19	0.98	0.05	Cr	0.2	0.1	0.6	0.04
Fe_2O_3	5.91	6.04	5.12	4.55	Fe^3	4.0	3.9	3.4	3.4
FeO	1.05	0.73	2.37	3.26	Fe^2	0.8	0.5	1.7	2.7
MnO	0.05	0.15	0.15	0.07	Mn	0.04	0.1	0.01	0.06
MgO	34.98	39.20	39.95	17.19	Mg	46.9	50.6	52.3	25.4
CaO	0.48	0.30	0.03	22.22	Ca	0.5	0.3	0.05	23.4
Na_2O	0.05	0.07	0.06	0.57	Na	0.09	0.07	0.1	1.1
K_2O	0.02	0.03	0.03	0.11	K	0.02	0.03	0.03	0.1
P_2O_5	0.04	0.02	0.02	0.04	P	0.03	0.01	0.01	0.04
H_2O+	7.81	12.19	10.48	2.34	H+	46.5	69.9	60.9	15.4
H_2O-	3.02	1.82	0.88	0.71	Fe/Mg	0.10	0.09	0.10	0.24
	99.94	100.08	99.83	100.26					

T-4 : En. ol. talc rock, New 2nd level of Takase mine.

T-5 : Serpentinized saxonite, New 2nd level of Takase mine.

T-6: Serpentinized saxonite,——————————

T-17 : Pyroxenite, New 3rd level of Takase mine.

(Analyst: J. Kitahara)

Sample No. 6 *Serpentinized Saxonite*

It occurs at a distance from a chromite body. Megascopically, it is a black rock. In thin section, olivine ($\gamma = 1.790$, somewhat altered one) is partly altered to serpentine along cleavage planes, and sometimes almost altered to serpentine ($\beta = 1.568-$) with separation of dusty magnetite. Enstatite alters to chlorite. Serpentine altered from olivine/chlorite altered from enstatite $= 3/1 - 5/3$. Chromite is yellowish brown with black part, and spottily dispersed and chromian magnetite is present in linear form. The chemical composition of the specimen is as shown in Table 2.

Sample No. T-17 *Pyroxenite*

The rock was intruded between an ultrabasic rock and a chromite body. Megascopically, it is gray black in color and comparatively hard. Under the microscope, diopside is abundant, 0.1—1.5 m.m. in size, $c \wedge Z = 38.7^\circ$, $\gamma = 1.714$, $(+)\ 2V = 59^\circ$. The mineral is partly altered to epidote like mineral. Enstatite is commonly present, 0.1—0.3 m.m. in size, and $\gamma = 1.669$. It is crystallized before than diopside. Chromian magnetite and apatite are scarecely found in the specimen. The chemical composition of the sample is as shown in Table 2. From the table, it is realized that the specimen is comparatively rich in alumina, iron oxide, and lime contents.

The differentiated order of ultrabasic rocks from peridotite magma is generally as shown in the following description. Dunite→ Enst. Dunite→ saxonite→enstatitite→marchite→diopsidite.

b) *Gabbroic Rocks*

Sample No. T-21 *Gabbro*

It occurs as dyke form which intruded in serpentinite. Megascopically, the sample is hard and seen as dioritic rock. Under the microscope, plagioclase is common, $n_2 = 1.571$ on (001), and corresponding content is An_{68}. It is partly kaolinized and sometimes completely calcitized. Hornblende is abundant, X=pale green, Z=green, $\gamma = 1.696$, $c \wedge Z = 18.5^\circ$, and $(-)2V = 43^\circ$. It is sometimes included in plagioclase. Magnetite or ilmenite is less common. The chemical composition of the specimen is as shown in Table 3.

Table 3.

	Wt.%						Atom. Ratios when O = 160				
Sample No.	T-21	T-23	T-24	T-28	T-35		T-21	T-23	T-24	T-28	T-35
SiO_2	46.82	38.98	48.16	43.54	32.60	Si	45.5	36.6	47.0	41.5	28.9
TiO_2	1.83	2.36	1.84	1.98	1.94	Ti	1.3	1.7	1.4	1.4	1.3
Al_2O_3	15.81	10.51	13.78	17.21	18.15	Al	18.1	11.6	15.8	19.3	18.9
Cr_2O_3	—	—	—	—	—	Cr	—	—	—	—	—
Fe_2O_3	3.40	2.62	3.77	3.42	1.90	Fe^3	2.5	1.8	2.8	2.4	1.3
FeO	11.35	3.27	10.94	5.39	3.34	Fe^2	9.2	2.5	8.8	4.3	2.5
MnO	0.19	0.08	0.20	0.07	0.00	Mn	0.2	0.06	0.2	0.06	0
MgO	5.14	19.43	6.51	7.78	28.18	Mg	7.5	27.4	9.6	11.1	37.5
CaO	10.56	16.13	12.55	14.91	2.78	Ca	11.0	16.2	13.1	15.2	2.7
Na_2O	2.94	0.38	1.51	2.26	0.63	Na	5.5	0.7	2.8	4.1	1.1
K_2O	0.19	0.00	0.16	0.22	0.15	K	0.2	0	0.2	0.2	0.2
P_2O_5	0.08	0.04	0.22	0.05	0.03	P	0.1	0.03	0.2	0.05	0.02
$H_2O+(CO_2)$	1.43	5.32	0.51	2.80	8.85	H+	9.2	33.4	3.2	17.8	52.3
H_2O-	0.23	0.50	0.04	0.35	0.94						
	99.97	99.62	100.19	99.98	99.49						

T-21 : Gabbro, New 3rd level of Takase mine.
T-23 : Meta-gabbro, New level of Takase mine.
T-24 : Gabbro, New 3rd level of Takase mine.
T-28 : Gabbro, New 2nd level of Takase mine.
T-35 : Chlorite rock, New 2nd level of Takase mine.

(Analyst: J. Kitahara)

Sample No. T-23 *Meta-gabbro*

It occurs at footwall of a chromite body, but would have been intruded between a chromite body and a serpentinite. Megascopically, it is a white rock in color. Under the microscope, it is almost kaolinized. Kaolinization of plagioclase is due to hot solution in association with gabbro intrusion. Hornblende is partly altered to epidote. Index γ of more or less altered hornblende is 1.643—1.669. Titanite is almost altered to leucoxene.

As the sample have a xenolith of pyroxenite containing abundant enstatite and olivine of less common, it seems that the rock was intruded later than pyroxenite. The chemical composition of the specimen is as shown in Table 3. The composition shows that SiO_2 and alkali contents of the sample are poorer than those contents of normal gabbro, and the contents of MgO and H_2O of the former are richer than those of the latter.

Sample No. T-24 *Gabbro*

It occurs as a intruded dyke into a serpentinite. Megascopically, it is a hard rock with dark black color. Under the microscope (Fig. 4), plagioclase is common, $n_2=1.564$ on (001), and corresponding content is An_{54}. Albitized one is sometimes observed. Hornblende is abundant. Index $\gamma=1.677$, $c\wedge Z=18.1°$, $(-)2V=77°\pm$. It is generally X=faint brown, Z=brown, and partly altered to epidote. Apatite is less common, and included in plagioclase and hornblende. Magnetite or ilmenite is less common. The chemical composition of the sample is as shown in Table 3.

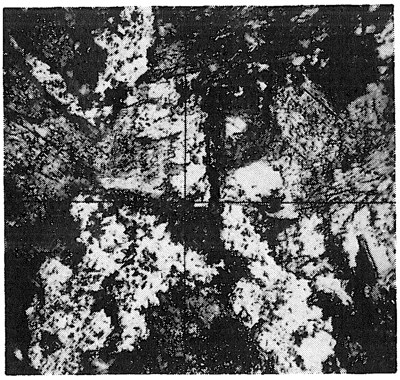

Fig. 4. Photomicrograph of hornblende gabbro (T-24).
Open nicol, × 45
New 3rd level of Takase mine, Okayama pref.

Sample No. T-28 *Gabbro*

It occurs as dyke form xenolith with 5 m. width in a chromite body. Microscopically, plagioclase is abundant and partly altered to calcite. Index γ of turbid plagioclase is 1.557 on (001). Pargasite is common, colorless, $\gamma=1.6525$, $(+)2V=61°$. It is partly altered to epidote or zoisite. Magnetite or ilmenite is rare. Hematite is scarce. It is yellowish red, and included in plagiocalse. The chemical composition of the sample is as shown in Table 3. From the table, it is realized that the hydrothermal alteration of the specimen is comparatively low grade.

Sample No. T-35 *Chlorite rock*

The rock was intruded into a chromte body of a middle part of a chromite deposit. Megascopically, the sample is white in color. In thin section, faint green chlorite mineral is abundant. Index γ of the chlorite is $1.579\pm$. The chlorite is produced by the hydrothermal alteration or metasomatism of hornblende. Epidote like mineral is less common. Ilmenite alters to leucoxene.

Apatite is scarce. The chemical composition of the sample is as shown in Table 3. As the specimen is poor in CaO and iron oxide contents, and rich in MgO content, so it is a rather chlorite rock than meta-gabbro.

It is considered that meta-gabbro is caused by hydrothermal metasomatism of normal gabbro. The metasomatism is characterized by increase of MgO and H_2O in gabbro, and decrease of SiO_2 and alkali in it. The original rock of chlorite rock is regarded to be hornblende rich gabbro or hornblendite.

Origin of Ultrabasic Rock and Gabbro

The relation between ultrabasic rock and gabbro can be observed in the underground of chromite deposits as well as in the field. According to present theory, gabbro has been considered to be a segregation dyke of ultrabasic rock. The writer came to consider that these two rocks were formed from separate magma each other, therefore the author gives the reason in the following.

The ultrabasic rocks are composed of peridotite, saxonite, pyroxenite and others. Composing minerals are mainly olivine, enstatite, diopside and chromite (chromian spinel from the viewpoint of ore classification). These ultrabasic rocks were not formed from gabbro magma, and are considered to be formed by peridotite magma which was produced by concentration of heat or by decrease of pressure of a part of peridotite shell which was forming upper mantle (speed of P-wave 8.2 km./sec.). The ultrabasic rock body was differentiated into dunite →enstatitite→diopsidite, and these transformations were carried out through various intermediate steps as mentioned already. As differentiation from dunite to diopsidite is evolved, the value of Fe/Mg changes from 0.06 to 0.26, however there is a small wave variation between them.

Gabbro is not formed from tholeiite basalt (gabbro) magma which was formed by partial fusion of peridotite of mantle nor is formed as differentiated dyke from peridotite magma as described above. Gabbro is considered to be due to eclogite which is present as irregular lump shape (or pocket) in peridotite shell of mantle, since eclogite is changed into gabbro which has the same chemical composition by decrease of pressure. The gabbro of this district is augite gabbro which does not contain olivine, however in general augite in the rock is altered into amphibole. As described before, since gabbro does not contain olivine, eclogite is saturated with silica having quartz or coesite and is considered to be formed as gabbro magma of tholeiite character through fusion due to pressure decrease. The previously described peridotite magma and gabbro magma due to fusion of coesite (quartz) eclogite can be considered to be formed by intrusion into earth crust almost at the same time through the same tectonic path. The gabbro magma was differentiated into hornblende diorite from gabbroic rock. The close association of the gabbroic and ultrabasic rocks at the district would be most simply explained by the derivation of the both magma types.

The fact that none of the ultrabasic rocks contain any feldspar and the gabbro does not contain olivine and chromite is improbable that the peridotite and gabbro magmas was generated from the same material. The absence of intermediate or gradational rock types between two rock series would fail to explain the intrusive relationships from same magma.

The value of Fe/Mg of total rock of ultrabasic rock series is about the same as Fe/Mg of peridotite shell which formed magma from the beginning. If the value of Fe/Mg in peridotite shell of upper mantle is gradually changed from upper part to lower part, the vertical position of olivine rock magma formed from peridotite shell which was the origin of these rock series may be estimated to certain extent. Judging from peridotite xenolith in basalt, peridotite shell of mantle has been considered to be composed of forsterite $(Mg, Fe)_2SiO_4$, enstatite $(Mg, Fe)SiO_3$, diopside $Ca(Mg, Fe)Si_2O_6$ and chromian spinel $(Mg, Fe)(Al, Cr)_2O_3$. On the other hand, the approximate chemical composition of original eclogite may be generally estimated from the Fe/Mg value of rock of gabbro series. Meta-gabbro which is thought to be effected by metasomatism among gabbro rock is also found. This is produced by metasomatism due to peridotite series rock or by autometamorphism at the time of gabbro intrusion, and outside look is grayish white. Microscopically, alterations of feldspar into clay or chlorite, ilmenite into leucite, and epidote are observed. In chemical composition, decrease of SiO_2 and increase of MgO are marked. This meta-gabbro rock is dyke type, but since a part of dyke in the underground can be only observed, it may be dyke type xenolith. The upper part from Mohorovicic discontinuity or lower part of the earth crust is considered to be gabbro (speed of P-wave 6.5 km./sec.), therefore the meta-gabbro is viewd to be one which the rock of this part was captured in peridotite magma. The other hand, it is seems that the gabbroic rock generated at a level in the mantle under Mohorovicic discontinuity was autometamorphosed as mentioned above.

Fe/Mg of ultrabasic rock body may be different for each place of the world, but sometimes the values may be quite the same. Fe/Mg values of gabbros which intimately associated with peridotite series rocks may be useful for deciding whether magma is formed within the same layer of the mantle. Magma may have intruded into the earth crust not only through one path from the same magma reservoir, but also from several paths. In ultrabasic rock bodies, there should be one which is imbeded in earth crust besides appearing on earth surface.

Peridotite was experimentaly shown to be not fusible under 900°C no matter how much water was added to it. Therefore in order to form water containing peridotite magma, the temperature should be over about 1.000°C. At the temperature of upper mantle of 50 km-150 km from earth surface, formation of water containing peridotite magma is considered to be possible by decrease of pressure (15-50 thousand atmospheric pressure). The ultrabasic rock bodies are metamorphosed to serpentinite partially or totally. However when ultrabasic rock body is formed, it might be changed by itself due to water contained in its body.

Brief Description of Chromite Deposits

The chromite deposits of Hirose and Wakamatsu mines, Tottori prefecture and Takase mine, Okayama prefecture are representative ones in this region, and these mines produce over 90 percent of chromite ore of Japan. These deposits were formed by segregation from ultrabasic magma, and a part of it was formed by intrusion of a segregated part into a mother rock which was in the process of solidification.

The chromite bodies consist of chromite and gangue minerals of olivine, enstatite, diopside, and serpentine or chlorite, and therefore are chromitite. The chromitite is not uniform in texture, the center consists of coarse chromite with few gangue minerals, and margin of the body are formed of fine chromite with abundant gangue minerals.

Serpentinite is intruded into the Paleozoic formation and invaded in turn by granitic rocks in the region as mentioned before. The writer supposes that the gabbroic dykes were derived from an eclogite in an upper mantle, and the ultrabasic rock masses were originated from an peridotite shell in an upper mantle. The writer has recently clarified that the gabbroic rocks were not dykes which differentiated from an ultrabasic rock.

Segregated chromite forms a portion of an ultrabasic rocks before or after they consolidated as described above. The other hand, the writer supposes that the main chromite bodies were segregated at an early stage in deep horizons, and then a part of the segregated chromite bodies was carried up as solid inclusions during the emplacement of the ultramafic masses.

The FeO in the magma tends to combine with Cr_2O_3, if present, in preference to MgO. This goes on untill the Cr_2O_3 is consumed, then FeO combines with MgO to form silicates, i.e., the presence of Cr_2O_3 deprives the magma of FeO so that the silicates formed after that will be poor in FeO. This was determined by comparing the relative amount of the FeO and MgO in the chromites and associated silicate minerals. The "Mg value" $\left(\frac{\text{MgO molecule}}{\text{Sum of FeO + MgO molecules}}\right)$ of the chromite is lower than that of the silicate.

Crystal Structure of Chromite

Normal chromite may be regarded as having the general formula AB_2O_4, where A is a divalent ion Fe^2, Mg, Mn^2, (Zn) and B a trivalent ion Al, Fe^3, (Mn^3). The A ions are surrounded tetrahedrally by four oxygen ions and the B ions are surrounded octahedrally by six oxygen ions. In some spinels, it is assumed that some of the B ions occupy positions normally taken up by the A ions, and the formula $B(AB)O_4$ may be written.

Chromite from Tari District

The writer has reported the studies on chemical composition and lattice parameter of chromites from the Tari district.

Assuming that the SiO_2 content is all in the form of serpentine or chlorite, this mineral was subtracted from the chromite analysis. The spinel $(MgAl_2O_4)$ magnesiochromite $(MgCr_2O_4)$, ferrochromite $(FeCr_2O_4)$, magnetite $(FeFe_2O_4)$ are chosen as four norm end members of chromite. The lattice parameter is calculated from the molecular proportion of the component end members of a chromite. This requires that the lattice parameter of a chromite is a linear function of the lattice parameters of the pure component end members of the chromite of which the solid solution is considered to be composed.

The calculated lattice parameter of solid solution of chromite =

$$\frac{\Sigma(\text{Lattice parameter of pure end member of chromite}) \times (\text{Molecular proportion in solid solution})}{\Sigma(\text{Molecular proportion of pure end members of chromite})}$$

Most of the differences between calculated and measured lattice parameters of the chromites from the district lie within ±0.01 Å range. The difference between measured and calculated lattice parameters is not markedly outside the ±0.01 Å range, but the fact that in a few specimens, the calculated lattice parameter is higher than the observed may be satisfactory accounted for by recalculation to include some γ-Al_2O_3 and/or γ-Fe_2O_3 (maghemite).

General Formula of Chromite

The ideal formula of a chromite may be written as follows.

$$(Fe^2{}_a,\ Mg^2{}_b,\ Mn^2{}_c)\ (Cr^3{}_l,\ Al^3{}_m,\ Fe^3{}_n)_2O_3,$$

where $a+b+c=l+n+m=1$, and a,b,c and l,m,n are the norm fractions of oxide components of a chromite.

When γ-Al_2O_3 and/or γ-Fe_2O_3 are/is included, the calculation is more complicated. The formula for a solid solution which contains γ-Al_2O_3 and γ-Fe_2O_3 in a chromite may be

$$(Fe^2{}_a,\ Mg^2{}_b,\ Mn^2{}_c,\ Al^3{}_u,\ Fe^3{}_{d-u},\ \square\ {}_{\frac{1}{2}d})\ (Cr^3{}_l,\ Al^3{}_{p+v},\ Fe^3{}_{q+\frac{3}{2}d-v})\ {}_2O_4,$$

where the symbol $\square$ represents a lattice vacancy, and $u=\frac{2}{3}v$, $m+n=p+q+2d$. If x and y are the proportion of Al_2O_3 and Fe_2O_3 calculated as aluminate and ferrite, $1-x$ and $1-y$ are the proportion of Al_2O_3 and Fe_2O_3 calculated as γ-Al_2O_3 and γ-Fe_2O_3 respectively, then $p=mx$, $b=ny$, and $d=\frac{m(1-x)+n(1-y)}{2}$. If γ-Al_2O_3 and/or γ-Fe_2O_3 are/is contained as solid solution in a chromite, the ideal formula mentioned above is unbalanced and then is comprehended that $a+b+c=l+mx+ny$.

Lattice Parameter of Chromite

The lattice parameters of spinel, magnesiochromite, ferrochromite, magnetite, γ-Al_2O_3 and γ-Fe_2O_3 are 8.086, 8.305, 8.344, 8.374, 7.88 and 8.315 respectively. The difference between calculated and measured lattice parameters is written by following equation $\frac{0.216X + 0.059Y}{100}$, where X and Y are molecular percents of γ-Al_2O_3 and γ-Fe_2O_3 respectively.

Specific Gravity of Chromite

The specific gravity of spinel, magnesiochromite, ferrochromite, magnetite, γ-Al_2O_3 and γ-Fe_2O_3 are 3.55, 4.43, 5.09, 5.20, 3.66 and 4.88 respectively.

Calculated specific gravity of chromite=

$$\frac{\Sigma(\text{Specific gravity of end member of chromite}) \times (\text{Molecular fraction of end member})}{\Sigma\ (\text{Molecular fractions of end members})}$$

The difference between measured and calculated specific gravities $= \frac{0.11X-0.32Y}{100}$

Chromite from South Level of Wakamatsu Mine

The fact that the calculated lattice parameter of few samples from the district is higher beyond the error than the observed one is satisfactory accounted by the evidence which γ-Al_2O_3 and γ-Fe_2O_3 in the chromite are included as solid solution. There may be small amounts of Al_2O_3 and Fe_2O_3 in some of these samples, undetected by microscopic or X-ray examination.

In the present paper, the author describes on the sample No. 36 from the Chūgiri level of Wakamatsu mine.

The chemical analysis and its molecular fraction of specimen No. 36 (Anal. J.Kitahara, 1961, p. 94 (No. 2010)) is as shown in Table 4.

Table 4.

	Wt.%	Mols
SiO_2	0.82	14
TiO_2	0.23	3
Al_2O_3	23.58	231
Cr_2O_3	41.38	272
Fe_2O_3	8.05	51
FeO	7.88	110
MnO	0.01	0.1
MgO	18.29	457
CaO	0.12	2
H_2O	—	
	100.36	

The serpentine of chlorite impurity associated with the chromite was almost reduced by means of heavy solution separation. The chromite analysis shows impurity of SiO_2, then the serpentine or chlorite impurity was subtracted from the result of the chromite analysis.

The molecular ratios of end members calculated from molecular proportion of the pure chromite analysis rejected serpentine is as follows.

	Mol.%
Spinel ($MgAl_2O_4$)	41.2
Magnesiochromite ($MgCr_2O_4$)	38.8
Ferrochromite ($FeCr_2O_4$)	10.6
Magnetite ($FeFe_2O_4$)	9.4
	100.0

The chromite specimen No.36 has comparatively high content of Fe_2O_3, so that is not considered to be formed under normal magmatic conditions. A calculation of the norm of the chromite indicates that magnetic component is higher than that in the normal chromite. The chromite does not contain exsolved hematite. It seems that the variation in the composition of chromite is due to autometamorphism originated by high temperature water vapour at the later stage of crystallization of the chromite.

The difference between calculated (8.225 Å) and measured (8.207 Å) lattice parameters is 0.018 Å, and that between calculated (4.210) and measured (4.215) specific gravities is 0.005. Therefore those differences are shown by following calculation formulae.

$$\frac{0.206X + 0.059Y}{100} = 0.018$$

$$\frac{0.11X - 0.32Y}{100} = 0.005$$

From the both equations, the values of $X = 3.4$ and $Y = 1.3$ are derived.

As the chromite sample contains 8.4 mol.% of γ-Al_2O_3 and 1.3 mol.% of γ-Fe_2O_3, the molecular percentages of the end members described above are written as following expression.

	Mol.%
Spinel	32.8 (41.2−8.4)
γ-alumina (γ-Al_2O_3)	8.4
Magnesiochromite	38.8
Ferrochromite	10.6
Magnetite	8.1 (9.4−1.3)
Maghemite (γ-Fe_2O_3)	1.3
	100.0

The structural chemical formula of specimen No. 36, therefore, is denoted as follows.
$(\mathrm{Fe}^{2}{}_{0.196}, \mathrm{Mg}^{2}{}_{0.770}, \mathrm{Mn}^{2}{}_{0.0002}, \mathrm{Al}^{3}{}_{0.016}, \mathrm{Fe}^{3}{}_{0.004}, \square_{0.013})\ (\mathrm{Cr}^{3}{}_{0.500}, \mathrm{Al}^{3}{}_{0.388+0.027}, \mathrm{Fe}^{3}{}_{0.030+0.005})_2\mathrm{O}_4$
where $(\text{———————}\ \mathrm{Al}^{3}{}_{0.016}, \mathrm{Fe}^{3}{}_{0.004}, \square_{0.013})\ (\text{———————}\mathrm{Al}^{3}{}_{0.027}, \mathrm{Fe}^{3}{}_{0.005})_2\mathrm{O}_4$ shows the proportion of γ-Al_2O_3 and γ-Fe_2O_3 dissolved as solid solution in the chromite.

The lattice parameters of chromites are controlled by the FeO/MgO ratio, the larger parameters being due to increase in the contents of the $FeO+Fe_2O_3$, especially FeO, and Cr_2O_3 compositions as described in the paper (1961) by the writer. As a part of Fe_2O_3 is contained as γ-Fe_2O_3, the reason which the increase of lattice parameter of chromite mentioned above is not always affected by the Fe_2O_3 content may be resolved.

The calculated lattice parameter is plotted against measured parameter. If there were identical in every way, the points would all lie on the diagonal line. An overall error between the X-ray measurment and calculated lattice parameters might be taken as 0.01 Å.

Source of Defect Chemical Formula

An abnormal chromite bearing lattice vacancy material such as γ-Al_2O_3, γ-Fe_2O_3 occurs in the outer portion of ore body and does not see in the central portion of the body. The chromite in the inner portion of the ore body is presumed to have been formed earlier than that in outer portion. From chemical analyses it is ascertained that the chromite in the inner portion consists chiefly of chromian spinel or picotite while that in the outer portion is composed mostly of the chromian spinel and aluminian chromite which are rich in the magnetite component. When chromite concentrates upon the inner portion and the chromian spinel or picotite which are high at a melting point begins to coagulate in the inner portion, volatile substances from magma such as water vapour become abundant and the water vapour increases. Consequently volatile matter concentrates upon the outer portion and crystallization proceeds from the inner portion to the outer portion. The chromite in the outer portion is rich in a magnetite component by primary autometamorphism at the later stage of crystallization as mentioned in the paper (1962). A chromite in the outer portion was autometamorphosed by the concentration and pressure of water vapour in the melt, resulting in a high Fe_2O_3/FeO ratio, γ-Fe_2O_3 was produced in the course of the autometamorphism and was disolved as solid solution in the chromite. γ-Al_2O_3 was disolved as solid solution in the chromite in the dehyrdation period of later consolidation stage. As in outer portion chromite and silicate minerals are generally poor in Al_2O_3, this outer portion is originally not abundant in Al_2O_3. In the marginal portion silicate minerals are rich in $FeO+Fe_2O_3$, but a part of Al_2O_3 and Fe_2O_3 are considered to have migrated from the silicate groundmass to the chromite when it is consolidating. Defect chemical formula also would be derived by addition of Al_2O_3 and Fe_2O_3 migrated to a chromite from a silicate groundmass.

Conclusions

In the rocks of peridotite series, gabbro and meta-gabbro exist as dykes or as dyke form xenoliths, however ultrabasic and gabbroic rocks are not formed from the same magma as many mining geologists and petrologists have discussed. The ultrabasic and gabbroic rocks are considered to be formed by intrusion of two magmas passing through the same path into the earth crust. Of the above two magmas, peridotite magma is produced by the decrease of pressure of a part of peridotite shell of upper mantle due to partial movement of mantle (such as deep earthquake) or due to activity of earth crust and mantle, and the other gabbro magma (tholeiite character) is produced by pressure decrease of coesite eclogite due to the above mentioned movement which affected coesite eclogite existing as lump (or pocket) condition in peridotite shell.

The most chromites from the region may be expressed by a ideal structural formula $(Fe^{2}_{a}, Mg^{2}_{b}, Mn^{2}_{c}) (Cr^{3}_{l}, Al^{3}_{m}, Fe^{3}_{n})_2O_4$, for the difference between calculated and measured lattice parameters of the chromites lies within$\pm$0.01Å. A few chromite samples are unbalanced and can not denoted by the ideal formula, because the difference between calculated and measured lattice parameters lies beyond an overall error 0.010Å. The unbalanced chromite contained as solid solution γ-Al_2O_3 and γ-Fe_2O_3 is generally described as following structural formula $(Fe^{2}_{a}, Mg^{2}_{b}, Mn^{2}_{c}, Al^{3}_{u}, Fe^{3}_{d-u}, \square_{\frac{1}{2}d}) (Cr^{3}_{l}, Al^{3}_{p+v}, Fe_{q+\frac{3}{2}d-v})_2O_4$, where symbol $\square$ is lattice vacancy, $d=\frac{2}{3}v$, $m+n=p+q+2d$.

The difference between calculated and measured lattice parameters is $\frac{0.206X+0.059Y}{100}$, and the difference between measured and calculated specific gravities is $\frac{0.11X-0.32Y}{100}$, where X and Y are molecular percentages of γ-Al_2O_3 and γ-Fe_2O_3 respectively.

The abnormal chromites occur in the outer portion of chromite deposits, and are produced by primary autometamorphism at later stage of magmatic activity.

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