

Studies on the Chromites and their Occurrences  
in the Tari District, Tottori Prefecture,  
Japan (II)

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北原順一：鳥取県多里地方のクロムテツ鉱  
並に産状に関する研究

Introduction

In a previous paper (Kitahara, 1957), the writer described the outlines of his studies on the chromites and their country rocks in the Tari district, Tottori Prefecture.

In another previous paper (Kitahara, 1958), the writer dealt principally with the results of his studies on the chromites, including the description of leucocratic differential rocks in the region.

In the present paper the writer wishes mainly to describe his studies on the differential dykes generated from peridotitic magma containing chromic oxide, and a few minerals formed by metamorphic or metasomatic replacement in the country rocks of the chromite deposits in the said region.

The origin of chromite deposits in the same region is also mentioned briefly in this paper.

Differential Dyke Rocks

Dykes of dioritic, leucocratic and bastitic rocks, and veins of diopside cut across ultra-basic rocks in the region. It is regarded to the writer that these dykes and veins represent a part of liquid magma after the greater part of magma had crystallized as the ultra-basic rocks.

Diorite Dykes

The writer described briefly the outlines of his studies on the diorites in the previous paper (1957).

Most diorites show in dyke form, but a dyke form inclusion of diorite is observed. It is believed that these diorites was formed later than chromite deposits judging from

relations between diorites and chromite deposits. These diorites consist mainly of plagioclase and hornblende with variable ratios between plagioclase and hornblende. The leucocratic rocks composed predominantly of quartz and plagioclase as described in the previous paper (1958) are regarded as one extreme case.

The occurrences and optical properties of the several samples of these diorites are given as follows.

#### Diorite No. 1

Locality: At about 100 m. north western valley side of the Wakamatsu mine.

Occurrence: This is exposed in dyke form in dark serpentinite.

Megascopically, it is a blue rock.

Under the microscope, this is holocrystalline. The essential minerals are as follows.

Plagioclase: subhedral. 0.2-0.3 mm. in size.  $n_1=1.550$  on (001) and (010),  $n_2=1.556$  on (001), and corresponding content is  $An_{44}$  (Mol%). Chloritized and calcitized.

Hornblende: 0.5 mm. in size. Pleochroic with  $X$ =pale yellow,  $Y$ =pale green,  $Z$ =pale brown.  $(-)\ 2V=69^\circ$ .  $N_g=1.669$ ,  $N_m=1.653$ ,  $N_p=1.650$ .  $c\wedge Z=17^\circ 20'$ . Ratio of hornblende to plagioclase is 3/2. Somewhat chloritized.

Diopside: Less common. 0.1 mm. in size. Colorless.  $c\wedge Z=32^\circ$ .

The chemical composition of the specimen is shown in Table 1, No. 1.

#### Diorite No. 2.

Locality: At the South 5th level of Wakamatsu mine.

Occurrence: It is intruded into the fissure of chromite body.

Megascopically, it is a hard rock and dark grey in colour.

Under the microscope, the essential minerals are plagioclase and hornblende.

Plagioclase: Subhedral. 0.1-0.7 mm. in size. Twinning. Slightly turbid.  $n_1=1.545$  on (001) or (010), and corresponding content is  $An_{34}$  (Mol).

Hornblende: Subhedral. Strongly pleochroic with  $X'$ =yellowish green,  $Z'$ =bluish green.  $(-)\ 2V=66.8^\circ$ .  $N_g=1.675$ .  $c\wedge Z=17.5^\circ-21.3^\circ$ . Ratio of hornblende to plagioclase is 1/1.

Magnetite or ilmenite: Common or less common. Included in hornblende.

Apatite: Less common or rarely found. Included in plagioclase and hornblende.

Leucoxene: Opaque whitish aggregate. Alteration product from ilmenite.

The chemical composition of the sample is given in Table 1, No. 2

#### Diorite No. 3

Locality: At the Hirose level of Hirose mine.

Occurrence: This is intruded into serpentinite as a dyke.

Megascopically, it is a hard rock with fine grained felspar and coloured mineral.

Under the microscope, it is hollocrystalline. The essential minerals are as follows.

Plagioclase: Subhedral. Albite law twin. 0.2-0.8 mm. in size. Colourless and slightly kaolinized. The index is  $n_1=1.548$  on (001) and (010), and corresponding content is  $An_{40}$  (Mol).

Biotite: Anhedral or subhedral. Pleochroism is strong with  $X'$ =pale yellow,  $Z'$ =brown. Seen as margin of hornblende.

Hornblende: Anhedral or subhedral. 0.05-0.90 mm. in size. Weak pleochroic with  $X'$ =light green,  $Z'$ =pale yellow green.  $(-)\ 2V=67.4^\circ$ .  $N_g=1.673$ .  $c \wedge Z=16.2^\circ$ . Ratio of hornblende to plagioclase is 1/1 or 3/2. Perfect prismatic cleavage angle is  $124^\circ$ .

Accessory minerals: Apatite, magnetite or ilmenite.

Leucoxene: Greyish white. Alteration product from ilmenite.

The chemical composition of the sample is indicated in Table 1, No. 3

Diorite No. 4

Locality: At the Inazumi deposit of Hinokami mine.

Occurrence: This is intruded between serpentinite and chromite body.



Fig. 1 Photomicrograph of diorite (No. 4).  
Inazumi deposit of Hirose mine. Open nicol  
 $\times 54$

This is megascopically dark grey in colour with felspar and coloured mineral. The powder of the specimen is greyish blue.

Under the microscope (Fig. 1), the essential minerals are as follows.

Plagioclase: Subhedral. 0.3-1.0mm. in size. Pericline twin. Slightly calcitized. The indices are  $n_1=1.550$  on (001) and (010);  $n_2=1.557$  on (001), and corresponding content is  $An_{44}$  (Mol). Decomposed plagioclase:  $n_2=1.542$ .

Hornblende: Anhedral or subhedral. Pleochroic with  $X'$ =pale yellow,  $Y$ =yellowish green,  $Z$ =green.  $(-)$

$2V=69.70^\circ$ .  $N_g=1.689$ ,  $N_m=1.688$ ,  $N_p=1.686$ .  $c \wedge Z=18^\circ$ . Partly chloritized. Ratio of hornblende to plagioclase is 1/1.

Accessory minerals: Apatite, spinel and magnetite or ilmenite.

The chemical composition of the sample is as shown in Table 1, No. 4.

Diorite No. 5

Locality: At the Hinokami deposit of Hinokami mine.

Occurrence: It occurs in dyke form inclusion in serpentinite.

This is megascopically greyish blue in colour and somewhat different from such diorites as mentioned above.

Under the microscope, the essential minerals are as follows.

Plagioclase: 0.2-0.5 mm. in size. Pericline twin. Angle between (001) cleavage and twinning lamellae is  $-8.2^\circ$ .  $n_1=1.562$  on (001) or (010),  $n_2=1.566$  on (010),  $n_3=1.568$  on (001), and corresponding content is  $An_{64}$  (Mol).

Pargasite: Colourless. 0.5 mm. in size.  $N_g=1.643$ ,  $N_m=1.627$ ,  $N_p=1.623$ ,  $N_g-N_p=0.020$ .  $c\wedge Z=18^\circ-20^\circ$ .  $(+ )2V=65^\circ\pm 1^\circ$ . Slightly chloritized. Ratio of pargasite to plagioclase is 3/2.

Magnetite: Fine patch.

The chemical composition of the sample is as given in Table 1. No. 5.

Table 1.

Chemical Compositions of Diorites						Atom. Ratios when O=160					
No.	1	2	3	4	5	No.	1	2	3	4	5
SiO <sub>2</sub>	56.02	54.25	54.95	57.18	54.70	Si	51.3	51.1	51.2	52.6	49.8
TiO <sub>2</sub>	0.57	0.72	1.09	1.03	0.31	Ti	0.4	0.5	0.8	0.7	0.2
Al <sub>2</sub> O <sub>3</sub>	16.59	14.98	14.38	16.76	16.42	Al	17.9	16.6	15.8	18.2	17.6
Fe <sub>2</sub> O <sub>3</sub>	0.48	4.61	2.63	0.14	0.78	Fe <sup>3</sup>	0.2	3.3	1.8	0.1	0.5
FeO	6.24	7.44	7.91	8.12	3.37	Fe <sup>2</sup>	4.8	5.8	6.1	6.2	2.6
MnO	0.20	0.23	0.23	0.18	0.07	Mn	0.2	0.2	0.2	0.2	0.1
MgO	5.35	5.71	7.02	3.97	9.10	Mg	7.4	8.1	9.8	5.5	12.5
CaO	8.01	7.42	7.56	7.03	8.61	Ca	7.9	7.5	7.5	7.0	8.4
Na <sub>2</sub> O	3.30	3.47	2.76	3.36	3.12	Na	5.8	6.3	5.0	6.0	5.4
K <sub>2</sub> O	0.99	0.78	0.42	0.61	1.06	K	1.2	0.9	0.4	0.7	1.2
P <sub>2</sub> O <sub>5</sub>	n.d	0.09	0.12	n.d	n.d	P	—	0.1	0.1	—	—
H <sub>2</sub> O <sup>+</sup>	1.80	0.50	0.67	1.25	1.90	H <sup>+</sup>	11.0	3.2	4.1	7.6	11.9
H <sub>2</sub> O <sup>-</sup>	0.36	0.19	0.29	0.43	0.47						
Total	99.91	100.39	100.03	100.05	99.91						

No. 1: 100m NW valley side of Wakamatsu mine.

No. 2: South 5th level of Wakamatsu mine.

No. 3: Hirose level of Hirose mine.

No. 4: Inazumi deposit of Hinokami mine.

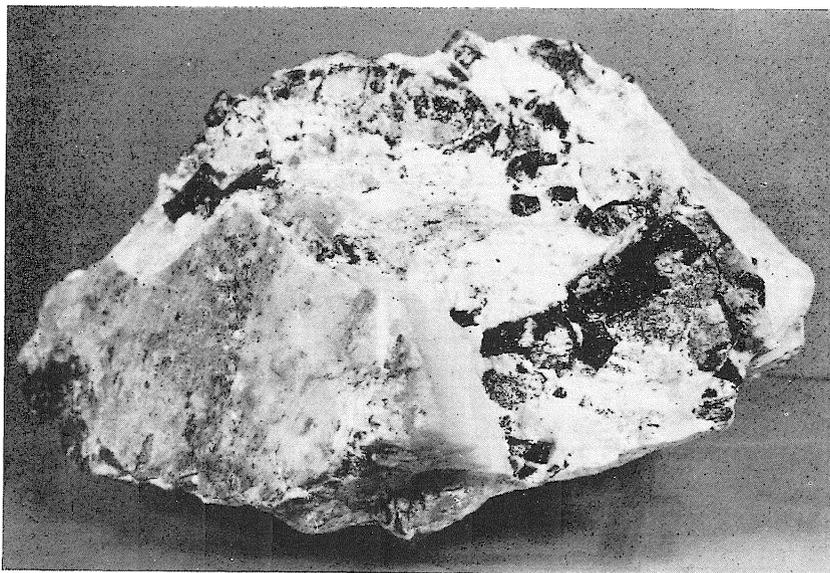
No. 5: Hinokami deposit of Hinokami mine.

From the Table I showing the chemical compositions of diorites, the oxide contents in the rocks may be described as follows.

Since the diorite (No. 5) has pargasite as mineral constituent and each of the other diorites (Nos. 1, 2, 3, and 4) contains common hornblende, it is understood that the former is lower in iron oxide ( $\text{FeO} + \text{Fe}_2\text{O}_3$ ) content than the latter four samples and the former is higher in magnesia ( $\text{MgO}$ ) content than the latter ones. The alumina ( $\text{Al}_2\text{O}_3$ ) content in these diorites is generally abundant next to silica ( $\text{SiO}_2$ ) content in the rocks. The content of silica in the diorites almost corresponds to the average value calculated from the chemical compositions of diorites shown by Daly. The content of lime ( $\text{CaO}$ ) in the former is rather higher than those in the latter.

### Bastitic Rock

A dyke of bastitic rock cuts across the serpentinite at the 7th level of Wakamatsu mine. The rock includes chromites of irregular form as remnants as shown in Fig. 2.



**Fig. 2** A bastitic rock (white) including remnants of chromite (black).  
7th level of Hirose mine.  $\times 5/8$

Macroscopically, the rock is white with faint greenish tint. The hardness is 2.5–3.0 and the specific gravity is 2.398.

Microscopically, the rock is composed of porphyritic bastite and bastitic matrix. The bastite is an alteration product from enstatite by action of later magmatic water. The average size of the porphyritic one is 0.05–0.30 mm. The bastite is colourless, low refringence and has mean refractive index  $N_m = 1.554 \pm$ . Cleavage (001) may be observed in the mineral. As the mineral is somewhat undulatory, it appears that the rock had been accepted a dynamic metamorphism. A part of bastite is altered to magnesite along

the peripheries and cracks of the mineral. Pale green chlorite and fibrous talc are rarely found. Apatite that is 0.005 mm. in width and 0.05 mm. in length is observed.

The chemical composition of the bastitic rock is as given in Table 2.

Table 2. Chemical Composition of Bastitic Rock

	Wt%	Mols		Atom. Ratios when O=160
SiO <sub>2</sub>	37.59	626	Si	298.7
TiO <sub>2</sub>	0.00	—	Ti	—
Al <sub>2</sub> O <sub>3</sub>	1.00	10	Al	9.5
Fe <sub>2</sub> O <sub>3</sub>	2.74	17	Fe <sup>3</sup>	16.2
Cr <sub>2</sub> O <sub>3</sub>	n.d	—	Cr	—
FeO	0.47	7	Fe <sup>2</sup>	3.3
MnO	0.00	—	Mn	—
NiO	n.d	—	Ni	—
MgO	38.50	963	Mg	459.5
CaO	0.83	15	Ca	7.2
Na <sub>2</sub> O	0.20	3	Na	2.9
K <sub>2</sub> O	0.06	1	K	1.0
P <sub>2</sub> O <sub>5</sub>	0.07	1	P	1.0
(CO <sub>2</sub> )+H <sub>2</sub> O <sub>+</sub>	15.12	840	H <sub>+</sub>	801.7
H <sub>2</sub> O <sub>-</sub>	3.35	186	H <sub>-</sub>	177.5
Total	99.93			

The chemical composition shows that H<sub>2</sub>O<sub>(-110°)</sub> content is comparatively high. As (FeO+Fe<sub>2</sub>O<sub>3</sub>) content is low as shown in Table 2, the white colour of the rock is based upon the content.

### Diopside Veinlet

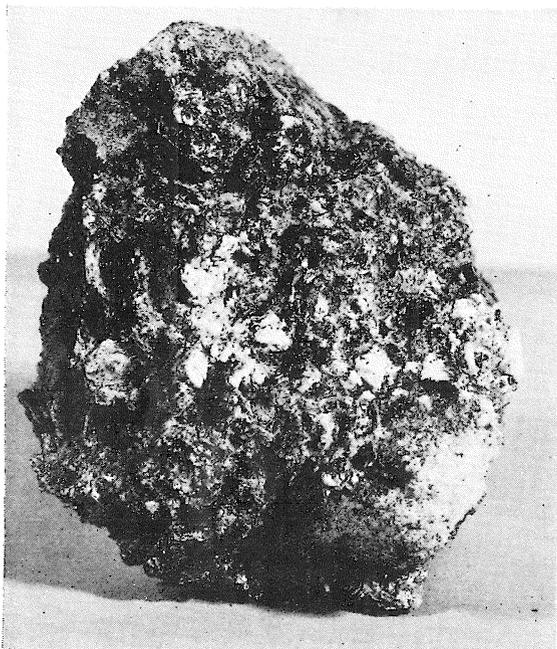
Occurrence: Diopside occurs in veinlet which follow the fissure of partly serpentinized pyroxenite at Inazumi deposit of Hinokami mine. The mineral is crystallized in aggregate of elongated prism up to 7 mm. long on wall.

Physical characters: The mineral is black and the streak is yellow. The mineral is prismatic [001] and is composed of (100), (110), (010), (111), and (221) faces.

Optical properties: Plagioclase is rare and 0.1–0.3 mm. in size. Diopside is abundant. The mineral includes enstatite or prehnite. The extinction angle  $c \wedge Z$  is 39°–40°, and optical angle (+)2V is 58.5°. The pleochroism  $X'$  is green and  $Z'$  is colorless. The mineral has the refractive indices of  $\alpha=1.679$ ,  $\beta=1.687$ , and  $\gamma=1.707$ . Some part of the mineral is altered to green, yellow, or brown chlorite. Tremolite is rarely found. The size of the mineral is 0.2–0.5 mm. and the extinction angle  $c \wedge Z'$  is from 6° to 10°. The mineral is radiated or fibrous. Hematite is seldom observed.

A Few Minerals derived by Metamorphism  
or Metasomatism  
Clinochlore

Occurrence: Clinochlore occurs as a secondary mineral in ultra-basic rock, at the Ogiri level of Hirose mine, apparently resulting from metasomatic alteration of aluminous enstatite. The clinochlore sample is shown in Fig. 3.



**Fig. 3** Clinochlore Ogiri level of Hirose mine.  $\times 4/5$

Physical characters: Cleavage of the mineral is (001) perfect and the cleavage flakes are flexible but not elastic. Thin hexagonal tabular crystals are sometimes observed. The mineral shows rather green colour and the streak is faint greenish grey. The hardness is 2.5, and the density, determined by pycnometer, is 2.678.

Optical properties: The mineral is colorless in thin section. The optical plane is parallel to (010). The elasticity axis  $Y$  coincides with  $b$  and the extinction angle  $c \wedge Z$  is  $1.9^\circ$  (optical orientation). The refractive indices determined by immersion liquid have  $\alpha = 1.575$ ,  $\gamma =$

1.581 and the birefringence  $\gamma - \alpha$  is 0.006. The mineral is biaxial and positive. The optical axial angle  $(+)2V$  is  $26.5^\circ$ . It is understood that the mineral belongs to clinochlore judging from the optical properties as mentioned above.

Chemical composition: The chemical composition of the minerals is as shown in Table 3.

The chemical formula calculated from the chemical analysis is  $(\text{Mg}_{4.45}\text{Ca}_{0.06}\text{Fe}^{2+}_{0.06}\text{Fe}^{3+}_{0.16}\text{Cr}_{0.01}\text{Al}_{1.17})_{5.92}(\text{Si}_{2.96}\text{Al}_{1.04})_{4.00}\text{O}_{10.13}(\text{OH})_{7.87}$ , which corresponds almost to the ideal formula of chlorite. It is comprehended that the values of  $\text{H}_2\text{O}$  give an effect to the chemical formula.

The molecular percentages of the end-members are as follows. Antigorite (Ant) is 70.4%, ferroantigorite (FeAnt) is 1.0%, amesite (At) is 28.2% and daphnite (Dn) is 0.4%.

Table 3. Chemical Composition of Clinochlore

	Wt%	Mols		Atom. Ratios	Ditto when O(OH)=1800
SiO <sub>2</sub>	31.38	523	Si	523	296
TiO <sub>2</sub>	0.00	—	Ti	—	—
Al <sub>2</sub> O <sub>3</sub>	19.85	195	Al	390	221
Cr <sub>2</sub> O <sub>3</sub>	0.18	1	Cr	2	1
Fe <sub>2</sub> O <sub>3</sub>	2.18	14	Fe <sup>3</sup>	28	16
FeO	0.77	11	Fe <sup>2</sup>	11	6
NiO	tr	—	Ni	—	—
MnO	0.00	—	Mn	—	—
MgO	31.52	788	Mg	788	446
CaO	0.59	11	Ca	11	6
Na <sub>2</sub> O	0.03	.3	Na	.6	.3
K <sub>2</sub> O	0.01	.1	K	.2	.1
H <sub>2</sub> O <sub>+</sub>	12.51	695	H <sub>+</sub>	1290	OH 787
H <sub>2</sub> O <sub>-</sub>	0.97	54	O	3181	O 1013
Total	99.99				

Since the recalculated molecular percentages of (3 At+3 Dn), (2 An + FeAnt), (2 FeAnt + 3 Dn), and (2 Ant+3 At) are 3.75 %, 6.25 %, 1.40%, and 98.60% respectively, the mineral may be classified as a clinochlore. The mineral component is projected as a point in Fig. 4 showing chemical and optical classifications of chlorite.

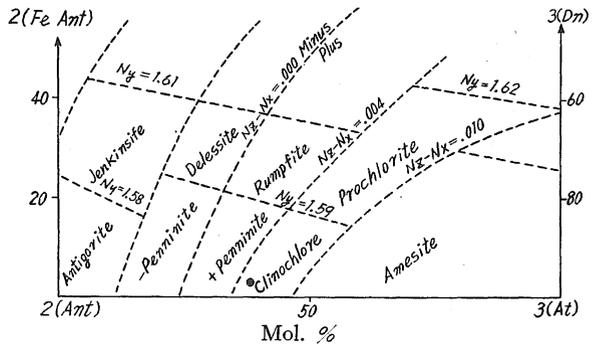


Fig. 4 ●: Clinochlore (the same sample shown in Fig. 3). (Chemical and optical classifications of chlorite).

### Melanite

Occurrence: Melanite occurs in aggregated form in ultrabasic rock and sometimes is scattered in the pyroxenitic rock and chromite at the Ogiri level of Hirose mine.

Habit: Garnet crystal is composed of comparatively large dodecahedral faces {110} and small trapezohedral faces {211}. The largest crystal is 3.5 mm. in size, but the mean size is from 1.0 mm. to 1.5 mm. The interfacial angles of the crystal almost correspond to the theoretical angles of garnet. The large development of {110} of the crystal is caused by a large quantity of Ca<sup>+2</sup> ion with large radius and by comparatively low temperature. The fact that {211} are small, is due to contain small amounts of Mg<sup>+2</sup> and Fe<sup>+2</sup> ions,

Physical properties: The crystal is almost black in colour and vitreous in luster. The hardness is 6 and the density is 3.759. The mineral has resistance to acids.

Optical properties: The garnet is pale yellow and have very high relief. The mineral is from 0.2 mm. to 1.0 mm. in average size. The mineral is isotropic and does not show anomalous birefringence. The refractive index is 1.849.

The chemical composition and the atomic ratios of the garnet are as shown in the following Table 4.

**Table 4.** Chemical Composition and Atomic Ratios of Melanite

	Wt%	Mols		Atom. Ratios	Ditto when O=1200
SiO <sub>2</sub>	35.97	599	Si	599	297
Al <sub>2</sub> O <sub>3</sub>	5.82	57	Al	114	57
Fe <sub>2</sub> O <sub>3</sub>	19.90	124	Fe <sup>3</sup>	248	52
Cr <sub>2</sub> O <sub>3</sub>	3.11	20	Cr	40	123
TiO <sub>2</sub>	0.89	11	Ti	11	20
FeO	1.36	19	Fe <sup>2</sup>	19	5
NiO	0.00	—	Ni	—	9
MnO	0.00	—	Mn	—	—
MgO	0.31	8	Mg	8	—
CaO	32.49	580	Ca	580	4
Alk	n.d	—	Alk	—	288
H <sub>2</sub> O-	0.20	—	O	2430	—
Total	100.05				

As Ti<sup>4</sup> (0.68 Å) cannot easily substitute for Si<sup>4</sup> (0.42 Å), the assumption that a small amount of Al replaces Si to balance the inclusion of Ti<sup>4</sup> in the trivalent group may be explained. The end member molecules calculated from the chemical composition are as follows. Alm 2.99, Py 1.49, Gr 23.88, And 59.70, Ti-And 1.99, Uv 9.95 (Mol%). Since the mineral is chromian grossularite-andradite or andradite supposing from the chemical composition and further more the colour is black as mentioned above, the mineral may be called as a kind of chromian melanite.

Origin: The formation of melanite is presumably due to a chemical reaction between chromite and adjacent pyroxene or olivine during contact metamorphism of the ultra-basic rock. It is supposed that the reaction between chromite and magnesian mineral took place while a magma containing some calcium was still in part molten state.

#### A Consideration concerning with the Genesis of Chromite Deposits

In the previous papers (1957, 1958), the writer described briefly the occurrences of

chromites in the region.

Scattered or disseminated chromites in certain ultra-basic rock are component of the rock, and then the chromites may be presumed as an accessory mineral in the rock. Since the chromites sometimes enclose serpentinized olivine or enstatite grains and yet the cracks in the chromites are generally filled by the silicate minerals, it is regarded that the chromites crystallized during the period of crystallization of the forsterite or enstatite. It seems to the writer that early formed one such as the disseminated chromite has been subjected the influence of a residual magma along the margins or cracks of the chromite. On the other hand, chromites accumulated or differentiated in parts of rock to form irregular or tabular masses along the contact or in the interior of the rock, and the massive chromites are more or less mixed with the rock. The chromite differentiated from the ultra-basic magma containing chromic oxide is mainly intruded in pre-solidified ultra-basic rocks. Since there is evidence of matamorphism or metasomatic replacement in the country rock, with development of minerals like garnet and chlorite or bleached serpentine as mentioned in the foregoing paragraph, it is cleared that molten chromite has been acted on the country rock. Chromite deposits are not generally seen in fresh normal peridotites and chromite concentration and degree of serpentinization are related each other. Thus chromite may in part be early magmatic, in part late magmatic, but the possibility that chromite is originated by hydrothermal liquid is rejected here as mentioned in the previous papers (1957, 1958). The chromite may be considered as a igneous mineral from the mode of origin of the chromite concentrations, formed during the course of generation of the igneous rocks.

Gabbroic and ultra-basic fractions are separated from a magma, and the gabbroic material is consolidated after the ultra-basic rock containing forsterite and enstatite. The dyke form gabbros in the region are characterized by plagioclase and clinopyroxene or hornblende, and have high lime and alumina content and comparatively low magnesia content. The ultra-basic masses, in the said region, characterized by the primary minerals such as forsterite and enstatite are derived from an environment of high magnesia content and low lime and alumina content. Bowen concluded that ultra-basic rocks intruded in a crystal mush state of olivines instead of a molten state. Since forsterite and enstatite crystallized to form the ultra-basic rocks, in the region, magnesia from the magma is removed, and lime, alumina and silica are enriched relatively. Thus, at a lower temperature, plagioclase and hornblende are crystallized, forming the dyke form gabbroic or dioritic rocks. The mineral components in the ultra-basic mass show no significant change in composition. Chromian magnetites occur as accessory mineral in small amounts throughout the ultra-basic rocks. It appears that,

in the same region, the chemical environment in which small amounts of lime is present with chromic oxide, iron oxide, alumina and magnesia content is most favorable to the concentration of chromite. Chromic oxide does not enter the olivine or enstatite structure in appreciable amounts. As there is a continuous series from  $MgAl_2O_4$  to  $FeAl_2O_4$  and also from  $MgAl_2O_4$  to  $MgCr_2O_4$ , and from that to  $FeCr_2O_4$  it may be expected that any chromic oxide present in magma will easily enter the spinel structure to form chromite. This is due to the similarity in ionic radii of  $Cr^{3+}$  (0.64 Å) and  $Al^{3+}$  (0.57 Å).

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