ULTRA-BASIC ROCKS AND ASSOCIATED ORE DEPOSITS OF HOKKAIDO, JAPAN

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(With 9 Tables and 1 Text-figure)

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I. GEOLOGICAL CONSIDERATION

Geologically speaking the central zone of Hokkaido is very complex forming a special geotectonical unit in Japan, and it offers many fundamental problems which are well worth study from various standpoints. The writer, while engaged in the study of various metamorphic rocks and adjacent ultra-basic rocks of this central zone in the past years, became also deeply interested in ore deposits contained in the ultra-basic rocks. The subject matter of this paper is an outline of the results of field and laboratory investigations with special reference to the ultra-basic rocks and associated ore deposits in Hokkaido. Before proceeding to the consideration of these subjects, it is necessary to give some account of the fundamental geology of the central zone of Hokkaido where the ultra-basic rocks are predominantly developed.

In central Hokkaido, two special complexes, called respectively the Hidaka(1) complex and the Kamuikotan(2) complex, are extensively distributed in belts, running roughly parallel to each other in a longitudinal direction. In varieties and natures of the rocks the Hidaka complex and the Kamuikotan complex are quite different and as a narrow belt of the Cretaceous system is usually developed between them, direct relation of these complexes has not yet been ascertained in the field. Along the eastern side of the Hidaka complex, an unknown Mesozoic formation is widely distributed, on the other hand, the members of Cretaceous and Tertiary systems are developed on the west of the Kamuikotan complex, in consecutive order from the east, running in a sub-parallel direction with close relation to the axial range of the Kamuikota ncomplex (JIMBO, 1892; SUZUKI, 1944), (Fig. 1).

Topographically, the Hidaka and Kamuikotan complexes with their associated intrusive masses generally form the mountaineous regions, while younger strata constitute comparatively low-lands, as these latter rocks resist more feebly the agents of denudation.

The Hidaka complex is composed of the normal Hidaka group and thick schalstein formation. The prominent members of the group, are black slate and fine sandstone interbedded with thin layers of limestone, schalstein and reddish quartzite. In the central zone of the normal Hidaka group, especially along the back-bone ridge of the Hidaka mountain range, there develops a thick formation of hornfels, biotite gneiss, spotted gneiss, amphibolite, phyllite, etc., accompanying with granitic, gabbroic and peridotitic intrusives (SUZUKI, 1934a; 1934d). The most of the gneissose rocks in the group were formerly considered by many observers to be intrusive and injection gneiss which had been rendered crystalline by the lit-par-lit injection due to granitic intrusion, but are regarded by present-day geologists as mostly, if not wholly, migmatite which has originated as a result of granitization (SUZUKI and NEMOTO, 1935; HASHIMOTO, 1948a, 1949; HUNAHASI, 1949; SAWA, 1950; HUNAHASI and HASHIMOTO, 1951).

The thick schalstein formation, which develops along the western margin of the normal Hidaka group, consists chiefly of diabasic tuff, agglomerate, lava, sheet and dike. Doleritic rocks with spilitic nature which bear albite and aegirine-augite as accessory constituents are partly

(1) 日高, (2) 神居古潭.

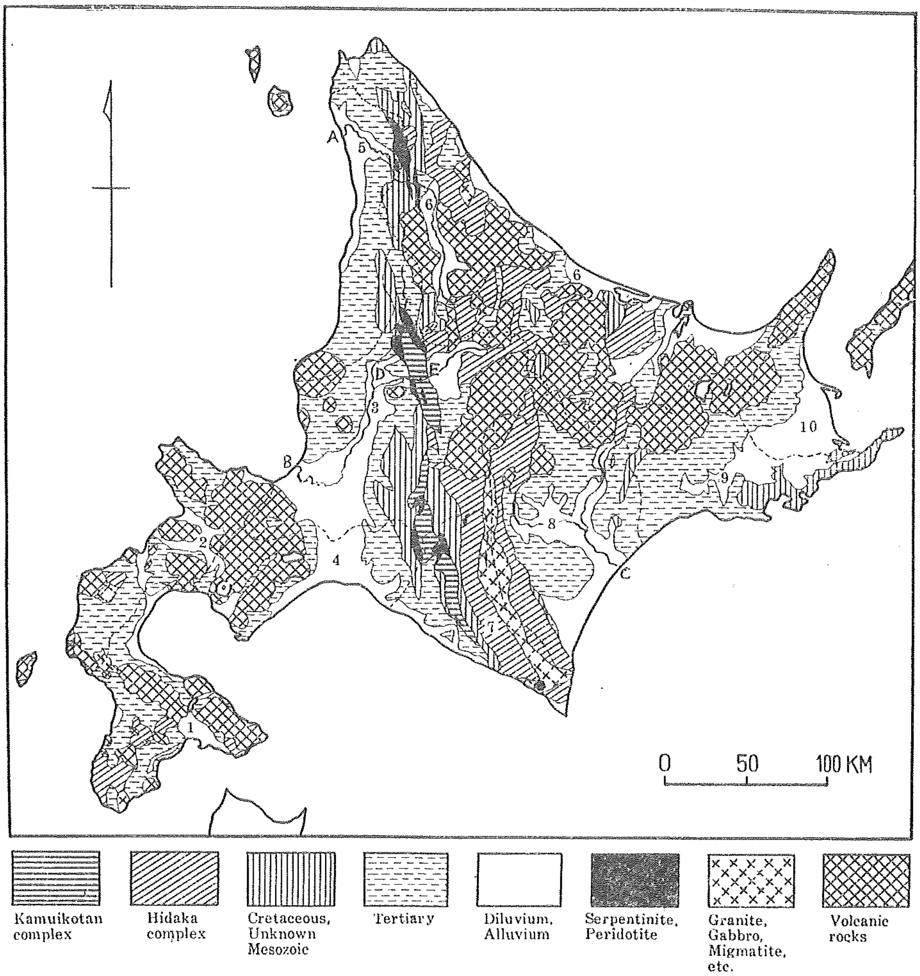

Fig. 1. Geological sketch map of Hokkaido

Provinces: (1) Oshima, (2) Shiribeshi, (3) Ishikari, (4) Iburi, (5) Teshio, (6) Kitami, (7) Hidaka, (8) Tokachi, (9) Kushiro, (10) Nemuro.
Rivers: (A) The Teshio R., (B) The Ishikari R., (C) The Tokachi R., (D) The Uryu R., (E) The Kamuikotan Valley.

exposed, and several instaces of pillow structure have developed in them (SUZUKI, 1951). The schalstein formation is locally grouped together with the thin layers of radiolarian chert and fossiliferous limestone of the Onizashi[1] series for which an early Jurassic age is most probable (OTATSUME, 1940; YABE and SUGIYAMA, 1941; HUKADA, 1949).

Although the rocks obtained from the Hidaka complex show dis-

(1) 鬼刺,

tinctive petrographic features common with those from the so-called Chichibu[(2)] system (Permian-Carboniferous) in Japan proper and other parts, no organic remains except the presence of radiolarian casts in some cherty rocks and crinoid stems in some limestones, have been found in them, while the stratigraphical position and age of the complex are not yet clearly defined.

The zone of the Kamuikotan complex has been traced for more than 200 km. from Teshio[(3)] Province to Hidaka Province though some parts are covered by young Tertiary and volcanic rocks. The most excellent outcrops of the complex occur along the Kamuikotan Valley of Ishikari[(4)] Province, from where the name of the complex was originated. It is probable that the crystalline schists in the Suzuya mountainland in South Saghalin represent, tectonically and petrographically a part of the northern extension of the large zone of the Kamuikotan complex in Hokkaido (SUZUKI, 1934b).

The chief petrological member of the complex is black siliceous schist and next comes an abundance of greenschist. Small amounts of reddish quartzite, phyllite, mylonite, schalstein and crystalline limestone are intercalated in the complex which is usually accompanied by ultra-basic rocks on a large scale. Of these crystalline schists, the siliceous type is assumed to be derived from some siliceous or argillosiliceous sedimentaries and the presence of residual grains of pyroxene or unaltered blocks of diabasic rock in a member of the greenschist would appear to indicate that such rocks originated in most case from schalstein and diabasic rock. The original rocks have now been converted into various greenschists such as diabase schist, chlorite schist, albite epidote chlorite schist, hornblende schist, etc. (SUZUKI, 1932a; 1934b; 1939c; HUNAHASI, 1951b).

The fundamental type rock of the Kamuikotan complex are somewhat crystalline and schistose in structure. The strike of their schistosity is usually parallel to the north-south trend of the complex, but in certain localities, it is nearly at a right angle to that trend indicating that the rock layers show locally a double plunging anticline or more complex structure. For instance, in the Kamuikotan Valley, the Ishikari River appears to flow approximately along the schistosity of the rock crossing the general trend of the complex. In general the zone of the Kamuikotan complex is bounded on both sides by unconformities and young faults which bring the Cretaceous or Tertiary

(2) 秩父, (3) 天鹽, (4) 石狩.

sedimentaries against the deformed crystalline schists, though the nature of the boundary along certain parts is obscure.

The Kamuikotan complex is, like the Hidaka complex, provisionally grouped together with some layers which are considered to be Jurassic, but as to the geological age of the whole Kamuikotan complex, nothing certain can be said. From the geological and petrographical points of view, it may reasonably be assumed that the Kamuikotan complex, so far as the writer is aware, can be readily correlated with the Franciscan formation in California.

From late Mesozoic time central Hokkaido has been periodically subjected to earth-movements producing pressure from the east with accompanying igneous activities. The effects are noticeable along the mountain range where the imbrication of strata, great terrestrial displacement and deformation of rocks may be recognized. As a result, it is difficult to estimate the thickness of each of the rock zones of the Hidaka and Kamuikotan complexes on account of the overturning and repetition of their formation. The clearest examples of the orogenic movement are to be found not only in the tracts of the central zones but in the Palaeogene Ishikari coal field along the western margin of the central Hokkaido zone. Recumbent folds and overthrusts are often seen there (NAGAWO, etc., 1933; NAGAWO, 1934). The great orogenic movements in central Hokkaido accompanied and followed by metamorphism, igneous activity and migmatisation, have been fully discussed by M. HUNAHASI and S. HASHIMOTO (1951) from the tectonic points of view and the whole activity is lumped together as the "Hidaka orogeny" by them.

The ultra-basic rocks which will be chiefly considered in the present paper, have only a limited development, being restricted mainly to the tectonic lines in or along the metamorphic zones of the Kamuikotan and Hidaka complexes, though the volume of the rocks in the latter is exceedingly small and their petrological nature is usually different compared with that of the former. Large ultra-basic masses in the Kamuikotan complex run approximately south-north in special sections between the Teshio-Kitami[1] boundaries at the north to Hidaka Province at the south. The outcrops of these ultra-basic rocks in the Kamuikotan zone are bounded by contorted crystalline schist of the Kamuikotan complex or by sedimentaries of Cretaceous and Tertiary age though locally faults can be recognized along the boundaries between the

(1) 天鹽-北見.

ultra-basic rocks and the others.

Some ultra-basic masses gave rise to contact metamorphic effects with the rocks of the Kamuikotan complex and adjacent Cretaceous formation; on the other hand ultra-basic rocks are enclosed as pebbles in the Neogene and Palaeogene Tertiary conglomerate beds, the former of which lie directly on the ultra-basic masses. From these facts it may probably be safely assumed that the most of the intrusion of the large ultra-basic masses in the central Hokkaido zone belongs to an early Tertiary orogenic period (MURATA, 1936; HARADA, 1939; SUZUKI, 1943b).

An outline of the ore deposits closely related with the ultra-basic rocks in the central zone of Hokkaido will be presented later in this paper.

II. ULTRA-BASIC ROCKS AND ASSOCIATED DIKE ROCKS

As previously noted, the ultra-basic rocks in Hokkaido usually occur in or along the areas of the Kamuikotan complex in the form of comparatively large lenses or belts extending from the north to the south in linear direction along tectonic lines, but as small fragments, ultra-basic rocks also occur in the metamorphic zone of the Hidaka complex (SUZUKI, 1939c; HUNAHASI, 1951a; HUNAHASI and HASHIMOTO, 1951). One of their distinctive features is that the greater portion of the ultra-basic rocks in relation to the Kamuikotan complex is now represented by serpentinite, but the ultra-basic rock of the Hidaka complex is comparatively fresh and still shows peridotitic nature. Large serpentinite bodies in the Kamuikotan complex zone occur in three separate localities, viz., the Teshio-Kitami[(1)] mountain range, Uryu[(2)] mountain-land and Yubari-Yufutsu-Saru[(3)] district, in order from the north to the south. The most northerly outcrop is a roughly belt-formed mass, covering an area of approximately 45 km. length by 7 km. maximum width, and striking about north and south. The outcrop of the Uryu mountain-land, which occurs some 40 km. to the south of the above, shows an irregular form, approximately 43 km. in length and 10 km. in width at the most southerly part, rising with steep sides to a height of 700 m. or more, above the surrounding young sedimentaries. Finally, some 90 km. farther south, three large bodies of serpentinite occur in the Yubari-Yufutsu-Saru district. They form irregular-shaped masses, covering respectively

(1) 天鹽-北見, (2) 雨龍, (3) 夕張-勇拂-沙流.

areas of approximately 25×4, 18×4 and 15×6 km. (NEMOTO, etc. 1937).

In addition to these main localities, numerous small outcrops of serpentinite occur as lens or mass in the Kamuikotan zone, showing their long axes roughly parallel to the regional strike of the county, as is the case in the large masses. The total area where serpentinite is exposed in the Kamuikotan complex far exceeds in size any other area where such phenomena are observed in Japan.

In general the areas of ultra-basic, especially of serpentinite, are covered by thick soil or fanglomeratic materials; excellent outcrops of the rock are usually rarely observable except at river cliffs, open-cuts of asbestos mine and adits in chromite deposits.

It is noticeable that the serpentinites contain numerous residual remains of unaltered constituents such as olivines, pyroxenes and spinel group minerals, indicating that the original intrusives were peridotitic rock. Fresh peridotite and the original forms which have now been converted into serpentinite, can be classified into several types from the standpoint of predominant constituentes and their proportions: dunite, saxonite, harzburgite, wehrlite, amphibole peridotite, picrite, plagioclase-bearing dunite, etc.

From the petrological natures, these ultra-basic rocks can be divided into two main classes, the one is composed chiefly of black crystals of serpentinized olivine and bastitised rhombic pyroxene of light greenish colour; the other is represented by dunite though it often shows close association with augite dunite, plagioclase dunite, or gabbroic rock. Sharply banded arrangement of these rock facies is often seen in a peridotite mass. M. HUNAHASI (1950) gives the name "Sasame* type" to the former and "Hidaka type" to the latter. The Hidaka type rock is widely distributed not only in the Hidaka complex but also in the Kamuikotan complex; the Sasame type rock is, however, rather small in volume in both complexes, compared with the former.

Field observations suggest that serpentinisation of the most of the original peridotites probably resulted from auto-metasomatism during the consolidation of the magma as well as from ascending hydrothermal solution which must also have emanated from differentiated dike rocks which were numerously intruded in the ultra-basic masses themselves.

In general large serpentinite body is massive and compact though with many irregular cracks and fissures; often it contains numerous relict minerals, showing mesh structure. But a small lens or narrow

* "Sasame" means dwarf bamboo(sasa)-pattern.

belt of serpentinite has frequently a rude or fine foliation which usually coincides with that of the contiguous schist. Relict mineral is scant or almost absent in it. The fissures of massive serpentinites are often filled up by the veinlets of magnesite, aragonite, clayey material, aqua-creptite, zeolite, or pectolite (HARADA 1934). The presence of schistose serpentinite would be dependent upon the operation of shearing stress which may occur without obvious chemical reconstitution or may result merely in the formation of antigorite. Excellent examples of schistose serpentinite with a slight linear arrangement of antigoritic flakes, are known at the Kamuiyama(1) district, the south of the Kamuikotan of Valley. Some special serpentinites which contain considerable amounts talc, phlogopite or actinolite are locally seen in the Kamuikotan complex zone. They were produced by hydrothermal metasomatism and dynamic action on normal serpentinite.

Fresh peridotitic rocks are mainly known in the metamorphic zone in the Hidaka complex. Most of them occur as a small mass or sill, but a peridotite mass which intruded in the amphibolite area of the Horoman(2) district in Hidaka Province, is comparatively large, 10 km. in maximum diameter. In this body, three petrographical facies can be recognized, viz., dunite, pyroxene dunite and olivine gabbro. Through the whole rock body, the chief components show a regular arrangement, layer by layer, which is considered probably to have originated in consequence of flowage in the magma (HUNAHASI, 1948; 1950; HUNAHASI and HASHIMOTO, 1951; IGI and BANBA, 1950).

Though the volume is usually small, fresh peridotitic rocks often occur in the serpentinite masses belonging to the Kamuikotan complex, in the form of an irregular body or rounded mass. An example of pyroxene dunite mass at Iwanai-dake(3) (960 m) on the east side of the Saru River(4) in Hidaka Province is 2 km. in maximum diameter; its marginal facies show gradual transition to serpentinite. The rock is characterised by its content of a large amount of disseminated chromite-spinel grains in some parts. Another example is numerous rounded blocks of pyroxene dunite, 0.1–1.0 m. in diameter, in the serpentinite mass of the Yamabe(5) district of Ishikari Province. These blocks usually have sharp boundary with the surrounding serpentinite.

Looking out over the ultra-basic rocks in Hokkaido, no useful ore minerals have been found in fresh peridotite in the Hidaka complex in spite of the fact that several ore deposits are closely associated with

(1) 神居山, (2) 幌満, (3) 岩内岳, (4) 沙流川, (5) 山部.

in the serpentinite in the Kamuikotan complex.

To summarise what has been described above, the ultra-basic rocks of Hokkaido can roughly be classified by their petrographical nature into five main types, though they are some close interrelations with each other: (1) massive serpentinite showing mesh structure, with or without relict minerals, (2) schistose serpentinite, (3) talcose serpentinite, (4) actinolite-fels, (5) peridotite, enclosing dunite, pyroxene dunite and chromite-rich dunite, etc.

The chemical composition of peridotites and serpentinites from Hokkaido will be shown as follows for reference:

TABLE I. Peridotites from Hokkaido

	1	2	3	4	5	6	7	8
SiO_2	39.31	42.16	40.20	40.86	43.28	39.82	42.16	43.12
TiO_2	—	tr	tr	tr	0.03	—	—	—
Al_2O_3	1.27	3.69	1.31	1.89	5.60	2.50	3.58	4.06
Fe_2O_3	4.37	2.72	0.86	2.59	1.72	8.52	9.48	9.35
FeO	7.27	5.13	4.13	5.54	4.77	—	—	—
MnO	n.d.	0.43	0.38	tr	0.46	—	—	—
MgO	38.89	38.69	45.81	45.15	32.80	46.65	40.25	40.01
CaO	6.52	5.38	4.96	2.72	9.56	0.20	0.50	0.96
Na_2O	0.14	0.58	n.d.	—	0.50	—	—	—
K_2O	0.04	0.16	n.d.	—	0.14	—	—	—
H_2O (+)	1.93	0.75	0.44	0.21	0.66	0.62	0.36	—
H_2O (−)				0.34		0.45	1.95	0.96
CO_2	—	—	—	—	—	—	—	0.41
Cr_2O_3	—	—	—	0.17	—	0.78	0.72	0.82
NiO	—	—	—	—	—	0.35	0.38	0.30
Total	99.74	99.69	98.09	99.47	99.57	99.89	99.38	99.99

(1) Dunite. Horoshiri-Dake, Hidaka Prov., (in Hidaka complex) Anal. S. HASHIMOTO, (HUNAHASI and HASHIMOTO, 1950, p. 20).

(2) Pyroxene dunite (A). Apoi-dake, Horoman, Hidaka Prov., (in Hidaka complex) Anal. S. ITO and T. YAMAMOTO, (HUNAHASI and HASHIMOTO, 1951, p. 20).

(3) Pyroxene dunite (B). Apoi-dake, Horoman, Hidaka Prov., Anal. S. ITO and T. YAMAMOTO, (HUNAHASI and HASHIMOTO, 1951, p. 20).

(4) Hornblende pyroxene dunite. Apoi-dake, Horoman, Hidaka Prov., Anal. S. ITO and T. YAMAMOTO.

(5) Peridotite (Gabbroic facies). Apoi-dake, Horoman, Hidaka Prov., (in Hidaka complex) Anal. S. ITO and T. YAMAMOTO (HUNAHASI and HASHIMOTO, 1951, p. 20).

(6) Pyroxene dunite (A). Iwanai-dake, Hidaka Prov., (in Kamuikotan complex) Anal. S.

MORITA, Meiji Min. Co.

(7) Pyroxene-dunite (B), Iwanai-dake, Hidaka Prov., Anal. S. MORITA, Meiji Min. Co.

(8) Pyroxene-dunite (C), Iwanai-dake, Hidaka Prov., Anal, S. MORITA, Meiji Min. Co.

TABLE II. Serpentinites from Hokkaido

	1	2	3	4	5	6
SiO_2	39.39	39.37	39.87	37.29	38.45	53.09
TiO_2	—	—	—	—	—	1.30
Al_2O_3	1.45	0.99	1.00	8.38	3.24	0.89
Fe_2O_3	2.94	5.17	5.24	7.23	3.26	5.42
FeO	5.60	3.77	3.82	2.23	5.16	4.46
MnO	—	—	—	—	—	0.28
MgO	37.84	35.61	36.06	28.20	36.32	20.98
CaO	0.52	0.28	0.28	0.43	0.87	10.49
Na_2O	—	—	—	—	0.25	0.53
K_2O	—	—	—	—	—	0.06
H_2O (+)	—	13.56	13.73	12.37	—	—
H_2O (−)	—	1.19	—	3.32	—	—
Ign. loss	12.79	—	—	—	12.53	3.04
Total	100.53	99.94	100.00	99.45	100.08	100.54

(1) Serpentinite. Kishinosawa, Yamabe district, Ishikari Prov., (in Hikaka complex) Anal. H. KONISHI (SUZUKI, 1941, p. 268).

(2) Serpentinite. Sakaezawa, Yamabe district, Ishikari Prov., (in Hidaka complex) Anal. T. INOUE, Hokkaido Univ.

(3) Serpentinite. country rock of chrysotile vein at the Nozawa mine, Yamabe district, Ishikari Prov., Anal. T. INOUE (SUZUKI, and INOUE, 1948, p. 195).

(4) Serpentinite. Near Kanayama, Sorachi-gun, Ishikari Prov., (in Hidaka complex) Anal. M. SAMBONSUGI, Hokkaido Univ.

(5) Serpentinite. Takadomari, Uryu gun Ishikari Prov., (in Kamuikotan complex) Anal. A. KANNARI (SUZUKI, 1939, p. 30).

(6) Actinolite-fels. Horokanai-pass, Uryu-gun, Ishikari Prov., (in Kamuikotan complex) Anal. A. KANNARI (SUZUKI, 1939, p. 30).

It is worthy to note that the serpentinite masses in the Kamuikotan complex are in places traversed by numerous dike rocks having leucocratic or melanocratic natures which may represent later intrusions. These dikes are compact and hard in usual case, and project into the fields on account of their greater resistance to erosion, compared with the surrounding serpentinite (SUZUKI, 1935a ; 1939c ; 1940).

The representative kinds of the leucocratic rocks are albitite, quartz albitite, hornblende albitite, quartz albitophyre, albite aplite, anorthosite, trondhjemite, pegmatite, micro-diorite, diorite-aplite, gabbro-aplite, etc. Representatives of the melanocratic rocks are hornblendite, titan-augite-fels and diabase. Of these dike rocks, albititic and aplitic types are mostly seen in the masses in Hidaka and Iburi Provinces, while micro-dioritic and trondhjemitic types are mostly seen in the masses of Ishikari Province. In Teshio Province, the leucocratic rocks have rarely been reported, though they may be represented in certain localities by dikes of micro-diorite is traceable for only a short distance.

All these leucocratic and melanocratic rocks show variations in composition and texture ; most of the dike rocks, however, are believed to be genetically related to each other, indicating that they might have been differentiated from the same magma, may be related to the ultra-basic rocks and may belong to a single intrusive series.

The writer has been led by field data to the view that the origin of some leucocrates might be closely related to the genesis of some ore deposits, for instance of chromite, mercury or asbestos. That is to say, these dike rocks, it seems reasonable to consider, may have been precursors in the mineralisation of these kinds of ore, though they are not always so (SUZUKI, 1943a).

In addition to the above-mentioned dike rocks, rodingitic rocks which are chiefly composed of grossuralite and diopside, sometimes assocciated with vesuvianite, are often found as irregularly rounded masses, 0.3–3.0m. in maximum diameter, throughout the whole serpentinite area. From the peculiarities in the composition and occurrence of the rock, question arises whether the mass is a cognate product with serpentinite or it originated accidentally as xenolithic block in serpentinite (SUZUKI, 1940).

As detailed description on these differentiated dike rocks has alreasy been published, some data on their chemical analyses may be of interest as follows:

TABLE III. Differentiated dike rocks associated with serpentinite

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	67.17	57.56	70.24	73.92	60.21	70.45	68.54	53.48	51.11	40.58	38.43	49.12
TiO_2	0.30	0.10	0.07	0.16	0.52	0.10	—	0.05	0.25	tr	tr	1.00
Al_2O_3	18.22	24.96	16.86	16.69	16.70	16.43	17.09	17.83	14.14	15.03	22.06	16.44
Fe_2O_5	0.46	0.24	0.14	0.25	0.28	0.37	2.74	0.15	0.38	3.56	1.70	6.80
FeO	0.65	0.36	0 86	0.50	1.40	0.71	0.45	1.02	8.91	3.90	1.95	6.01
MnO	0.06	—	tr	tr	0.22	0.03	—	0.05	0.28	—	—	0.28
MgO	1.08	0.72	0.73	0.43	5.27	1.53	1.39	3.87	7.78	4.45	2.41	5.75
CaO	0.92	1.82	0.92	0.42	7.23	3.11	2.16	17.72	12.49	26.62	28.56	9.00
Na_2O	9.46	3.61	6.85	7.43	6.75	4.43	2.00	2.12	1.74	1.51	1.35	3.12
K_2O	0.33	0.11	1.94	0.29	0.36	1.07	1.84	0.10	0.24	0.26	0.34	0.47
P_2O_5	—	—	—	—	tr	0.58	—	tr	tr	—	—	tr
H_2O (+)	0.92	9.62	0.86	0.48	1.31	1.54	—	2.69	—	3.56	2.50	—
H_2O (−)	0.31	0.84	9.48	0.20	0.19	—	—	0.48	—	0.50	0.10	—
CO_2	—	0.08	—	—	—	—	—	0.25	—	—	—	—
Ign. loss	—	—	—	—	—	—	3.14	—	2.59	—	—	2.66
Total	99.88	100.02	99.95	99.77	100.45	100.35	99.35	99.81	99.81	99.97	99.40	100.65

(1) Albitite. Shin-nitto Mine, Saru-gun, Hidaka Prov., Anal. S. KOMATSU (SUZUKI, 1940, p. 72).
(2) Albitite (decomposed). Shin-nitto Mine, Saru-gun, Hidaka Prov., Anal. S. KOMATSU (SUZUKI 1940, p. 72),
(3) Quartz albitite. Tanukiiwa, Hatta Mine, Saru-gun, Hidaka Prov., Anal. S. KOMATSU (SUZUKI, 1940, p. 74).
(4) Quartz albitite. Bankei-adit, Nukahira Mine, Saru-gun, Hidaka Prov., Anal. S. KOMATSU (SUZUKI, 1940, p, 74).
(5) Prehnite-bearing hornblende albitite. Tributary of the Ugonai River, Nakagawa-gun, Teshio Prov., Anal. S. KOMATSU (SUZUKI, 1940, p, 79).
(6) Trondhjemite. Horonari Uryu-gun, Ishikari Prov., Anal. T. NEMOTO (SUZUKI, 1935, p. 160).
(7) Trondhjemite. Kishinosawa, Yamabe District, Sorachi-gun, Ishikari Prov., Anal. H. KONISHI, (SUZUKI, 1940, p. 126).
(8) Diorite-aplite. Eastern Hill of Toikanbetsu, Nakagawa-gun, Teshio Prov., Anal. S. KOMATSU (SUZUKI, 1940, p. 271).
(9) Diorite-gabbro-aplite. Takadomari-Penke, Uryu-gun, Ishikari Prov., Anal. A. KANNARI (SUZUKI, 1940, p. 130).
(10) Rodingite (Outer Zone). Kanayama, Sorachi-gun, Ishikari Prov., Anal. M. SAMBONSUGI (SUZUKI, 1940, p. 134).
(11) Rodingite (Inner Part). Kanayama, Sorachi-gun, Ishikari Prov., Anal. M. SAMBONSUGI (SUZUKI, 1940, p. 134).
(12) Diabasic melanocrate. Kamuimura, Kamikawa-gun, Ishikari Prov., Anal, A. KANNARI (SUZUKI, 1939, p. 30).

III. CONTACT METAMORPHIC ROCKS RELATED TO THE ULTRA-BASIC INTRUSIVES

It is noticeable that various interesting rocks locally develop between the schistose rocks of the Kamuikotan complex and the ultra-basic intrusives, which have attracted special attention because of the presence of some special soda-bearing silicates, such as albite, glaucophane, crossite, riebeckite, crosidolite, aegirine-augite (SUZUKI, 1932b; 1932c; 1934b; 1939a). In addition to these, some special minerals like lawsonite, garnet, piedmontite, sphene, rutile, stilpnomelane, apatite, etc. are also included in similar rocks. These rocks are also characterised by the association of numerous veins or lenticles of each of the following minerals: quartz, albite, epidote, calcite, aragonite, magnesite, chlorite, zeolite, prehnite, pumpellyite, etc. (SUZUKI, 1924; 1931; 1933; 1934c; 1935b; 1938c; 1948a; SUZUKI and YAMAGUCHI, 1933; HARADA, 1940; ISHIBASHI, 1939; YOSHIMURA, 1936).

The combination of the essential constituents in the contact metamorphosed rocks, between normal crystalline schist in the Kamuikotan complex and the ultra-basic intrusives, is very complicated. The rocks may conveniently be subdivided into many classes from the mineral association and micro-structure. Some typical examples of the special contact rocks may be named as follows:

Glaucophane epidote albite chlorite schist
Glaucophane bearing epidote albite hornblende schist
Garnet glaucophane schist
Muscovite garnet glaucophane schist
Zoisite plagioclase glaucophane schist
Calcite bearing garnet glaucophane schist
Diopside bearing glaucophane epidote chlorite schist
Aegirine-augite albite glaucophane schist
Epidote glaucophane quartz schist
Zoisite bearing glaucophane albite quartz schist
Riebeckite albite quartz schist
Aegirine-augite bearing glaucophane albite quartz schist
Garnet albite riebeckite quartz schist
Aegirine-augite and garnet bearing riebeckite albite quartz schist
Lawsonite albite glaucophane schist (veined with pumpellyite)
Piedmontite albite quartz schist

Magnetite bearing garnet quartz fels, etc.

(Among the above-cited rocks, glaucophane will often give place to crossite, and riebeckite to crosidolite).

Excellent localities for these special rocks are known at the Kamuikotan[1] Valley, the Horokanai[2] Pass and Kami-etanbetsu[3] districts of Ishikari Province, Horaisan[4] near the town Mitsuishi[5] in Hidaka Province, and in the Toikanbetsu[5] district of Teshio Province (Suzuki, 1932b; Ishibashi, 1939). The detailed mapping of these localities by many observers has proven that these special rocks have only a limited development in an area along or near a certain serpentinite mass and rarely in a xenolithic block within it, though some geological and lithological differences are found locally.

This fact seem reasonably to indicate that these special rocks are a product brought about by contact metamorphic action due to ultrabasic intrusion and the occurrence of the special minerals in them originated from pyro-metasomatism, primarily owing to the action of some especially soda-rich hydrothermal solution derived from the ultrabasic intrusions. It seems that these rocks have originated in several distinct ways, vez., by uralitisation, sericitisation, albitisation, glaucophanisation, aegirinisation, epidotisation, prehnitisation, serpentinisation etc., which were probably brought about by the metasomatic effect of emanated solution.

Some large masses of amphibolite are known to be inclosed in the serpentinite body at the environs of Horokanai, Ishikari Province. With reference to the chemical side of the problem, the rock is believed to be essentially produced by large scale metasomatism between the ultra-basic rock and later intrusions of gabbroic rock (Hunahasi, 1944).

Various kinds of glaucophane bearing schists somewhat similar to those of the Kamuikotan complex, occur as pebbles in the alluvial deposits along the Obirashibe River and its tributaries which drain the Tertiary area of the Teshio mountain-land. A careful examination of the geology and the river systems, has led the writer to the conclusion that those pebbles could have been washed out from the Neogene Tertiary conglomerate layers in the area (Hachiya, 1902; Suzuki, 1931). This fact indicates that the Neogene layers were deposited after glaucophane bearing rocks had been formed by the intrusion of ultra-basic rocks. Although a detailed description on the contact metamorphosed

(1) 神居古潭, (2) 幌加内, (3) 上江丹別, (4) 蓬萊山, (5) 間寒別.

rocks of the Kamuikotan complex is beyond the scope of this paper, chemical analyses of some crystalline schists and metasomatosed rocks in the complex may be shown, for reference:

TABLE IV. Siliceous schists in the Kamuikotan complex

	1	2	3	4	5	6	7	8
SiO_2	87.96	84.42	90.57	84.40	84.19	76.77	85.80	59.30
TiO_2	0.60	0.30	0.05	0.53	0.20	—	tr	0.25
Al_2O_3	2.43	6.49	3.58	2.80	4.11	0.59	2.73	8.66
Fe_2O_3	0.69	0.82	1.12	1.18	2.77	9.40	1.70	5.21
FeO	1.68	2.44	1.07	1.54	3.59	7.19	2.60	8.05
MnO	—	0.14	0.04	0.42	0.85	—	0.28	0.12
MgO	3.33	1.62	1.25	2.27	1.85	1.50	3.00	9.37
CaO	0.47	0.74	2.53	1.62	0.47	—	1.20	1.24
Na_2O	1.59	0.97	0.19	1.30	1.12	2.78	1.90	6.11
K_2O	—	0.60	0.44	0.82	—	0.08	0.86	0.55
P_2O_5	—	tr	—	0.50	—	0.26	0.31	—
H_2O (+)	1.21	—	0.14	1.50	0.97	1.14	—	1.42
H_2O (−)	—	—	—	0.44	—	—	—	0.32
C_2O	—	—	—	—	—	—	0.10	—
Ign. loss	—	1.84	—	—	—	—	—	—
Total	99.96	100.38	100.98	99.32	100.12	99.71	100.48	100.60

(1) Albite-bearing glaucophane quartz schist. Horokanai-pass, Uryu-gun, Ishikari Prov., Anal. A. KANNARI (SUZUKI, 1934, p. 24).
(2) Glaucophane quartz schist. Horokanai pass, Uryu-gun, Ishikari Prov., Anal. A. KANNARI (SUZUKI, 1934, p. 24).
(3) Glaucophnne quartz schist (Garbenschiefer). Horokanai-pass, Uryu-gun, Ishikari Prov., Anal. T. NAKAYAMA, Hokkaido Univ.
(4) Garnet-bearing albite glaucophane quartz schist. Horokanai-pass, Uryu-gun, Ishikari Prov., Anal A. KANNARI (SUZUKI, 1939a, p. 516).
(5) Riebeckite-bearing albite quartz schist. Kamietanbetsu, Kamikawa-gun, Ishikari Prov., Anal. A. KANNARI (SUZUKI, 1933, p. 618).
(6) Aegirine augite-bearing riebeckite schist. Rail-road cutting near Kamuikotan station ,Ishikari Prov., Anal. A. KANNARI (SUZUKI, 1933 p. 618).
(7) Aegirine-augite-bearing glaucophane quartz schist. Pebble found in Neogene Tertiary conglomerate at the Obirashibe River, Teshio Prov., Anal. A. KANNARI (SUZUKI, 1931, p. 285).
(8) Glaucophane (mineral) from glaucophane quartz schist. Horokanai-pass, Uryu-gun, Ishikari Prov., Anal. T. NEMOTO (SUZUKI, 1939a, p. 517).

TABLE V. Greenschists in the Kamuikotan complex

	1	2	3	4	5	6	7	8
SiO_2	42.16	48.56	50.88	48.88	46.72	44.36	54.38	48.79
TiO_2	1.90	2.50	0.75	3.90	4.08	2.42	2.88	0.58
Al_2O_3	13.85	13.90	13.29	13.44	15.20	14.84	8.90	9.25
Fe_2O_3	5.02	9.31	1.67	5.32	4.02	12.01	2.17	7.44
FeO	11.74	6.25	8.60	8.96	5.12	5.45	5.98	6.26
MnO	0.15	0.15	0.28	tr	0.13	0.17	0.17	0.19
MgO	11.03	2.94	8.78	4.21	7.23	5.44	7.25	2.87
CaO	9.47	12.61	8.99	5.80	9.18	8.62	10.36	9.76
Na_2O	2.00	1.24	3.62	3.73	3.62	2.26	4.65	7.34
K_2O	0.14	0.23	0.38	1.71	1.50	0.93	0.67	0.50
P_2O_5	—	0.11	tr	—	0.24	0.24	0.25	0.41
H_2O (+)	—	—	—	3.42	3.12	2.72	1.98	5.72
H_2O (−)	—	—	—	0.36	0.07	0.10	0.74	1.24
Ign. loss	2.61	1.18	3.04	—	—	—	—	—
Total	100.07	99.98	100.28	99.73	100.23	99.56	100.38	100.25

(1) Glaucophane-bearing amphibolite. Horokanai-pass, Uryu-gun, Ishikari Prov., Anal. A. KANNARI (SUZUKI, 1939, p. 27).
(2) Epidote glaucophane schist. Horokanai-pass, Uryu-gun, Ishikari Prov., Anal. A. KANNARI (SUZUKI, 1939, p. 27).
(3) Diabase schist. Near Harushinai, Kamuikotan Valley, Ishikari Prov., Anal. A. KANNARI (SUZUKI, 1939 p. 27).
(4) Epidote glaucophane schist. Kamuikotan Valley, Ishikari Prov., Anal. H. S. Washington (Am. Jour. Sci., 11. 1901, p. 35).
(5) Garnet-bearing aegirine-augite lawsonite glaucophane schist (with pumpellyite). Harushinai, Kamuikotan Valley, Ishikari Prov., Anal. A, KANNARI (SUZUKI 1938, p. 237).
(6) Aegirine-augite albite epidote amphibole schist. Horaisan, near Mitsuishi-town, Hidaka Prov., Anal. M. ISHIBASHI (ISHIBASHI, 1937, p. 448).
(7) Aegirine-augite bearing diabase (A). Hakkin-zawa, Yubari-district, Ishikari Prov., Anal. S. KOMATSU (SUZUKI, 1939, p. 30).
(8) Aegirine-augite bearing diabase (B). Hakkin-zawa, Yubari-district, Ishikari Prov., Anal. S. KOMATSU (SUZUKI, 1939, p. 30).

IV. ORE DEPOSITS ASSOCIATED WITH SERPENTINITE

The ultra-basic rocks in Hokkaido are not only of interest geologically and petrologically, but they are of special importance because of the associated deposits of various kinds of useful minerals, such as chromite, platinum group mineral, chrysotile asbestos, mercury, nickel, copper, etc. (SUZUKI, 1936 ; 1949 ; 1950a).

A. CHROMITE DEPOSITS

The Hidaka-Iburi district in Hokkaido and the district on the Tottori-Okayama-Hiroshima boundaries in south-western Japan undoubtedly have large reserves of massive chromite in Japan, though some remarkable differences between them in respect to the characters of ore deposits appear (SUZUKI and ISHIKAWA, 1939; ISHIKAWA, 1940; BAMBA, 1951). A noticeable fact is that nearly all of the lode chromite deposits are restricted to a small area in both districts, and except for some small deposits, no lode deposits of chromite is known in other places, in spite of the known existence of comparatively large serpentinite masses.

Up to the present, numerous localities of lode chromite have been found in the serpentinite area in Hokkaido. Few of them, however, contain chromite of good quality; and as their output, too, has been extremely small in quantity, the districts which have been under production are but few. Among them are the Hatta,[1] Nitto,[2] Shin-nitto,[3] Hatta-Usappu,[4] Nukahira[5] deposits in Hidaka Province, Yawata,[6] Gampi,[7] Niitaka,[8] Hobetsu[9] deposits in Iburi[10] Province, and only the Shimpo[11] deposite in Ishikari Province* (SUZUKI, 1943b; SUZUKI and SAMBONSUGI, 1939). The largest deposit not only in Hokkaido but in all Japan is the Hatta deposit in Hidaka Province, though it produces a comparatively low grade ore with 41–42 percent Cr_2O_3 and it is now almost completely worked out. It appears that the Hatta ore body was a flat lying pod, and the bottom of it was cut off by a fault.**

In general the massive variety of chromite ore of Hokkaido is compact though is often highly shattered, with black or brownish black in colour; it is composed of an aggregation of crushed chromite fragments with a thin opaque border, the cracks in which are usually filled up with fine grains or flakes of uvarovite, chrom-ochr and kaemmerelite (SUZUKI, 1942a; 1943b, HARADA and ISHIBASHI, 1940, HARADA, 1943). The massive ore in Hokkaido is mostly, if not all, of extremely high grade containing more than fifty percent Cr_2O_3. If this is the case, the pure

* The total production of massive chromite, carrying 40–55 percent Cr_2O_3, in the Hidaka-Iburi district, from 1925 to 1945 was 303,027 metric tons, corresponding to about 45 percent of the national total.

** It is said that the aggregate tonnage of chromite ore in the Hatta mine totaled about 180,000 metric tons from one ore body, during this twenty years; the maximum yearly production of massive ore was 22,372 metric tons in 1939.

(1) 八田, (2) 日東, (3) 新日東, (4) 八田右左府, (5) 糠平, (6) 八幡, (7) 岩美, (8) 新高, (9) 穂別, (10) 膽振, (11) 神邦.

chromite would be very high in Cr_2O_3, inasmuch as considerable quantities of silicates are contained in the ore.

Chemical analyses of chromite and its ore from some places of Hokkaido are shown as follows:

TABLE VI. Chromites and chromite ores from Hokkaido

	1	2	3	4	5	6	7	8
Cr_2O_3	51.21	55.72	57.00	55.61	53.26	59.55	59.12	49.40
FeO	19.38	9.21	19.88	7.56	13.09	13.29	18.25	17.93
Fe_2O_3	2.57	2.14	5.85	—	—	—	—	—
Al_2O_3	15.36	17.63	7.10	35.84	6.53	6.36	8.18	9.07
SiO_2	0.55	0.49	0.64	—	13.13	2.26	—	—
MgO	11.34	15.42	9.49	—	10.53	16.27	7.83	12.32
CaO	—	0.07	0.07	—	4.01	0.10	—	2.00
H_2O	—	—	—	—	0.35	—	—	—
Others	—	—	—	—	—	—	6.60	9.64
Total	100.41	100.68	100.03	99.01	100.90	97.83	99.98	100.36

(1) Chromite (Chrome-picotite). Nishigami Adit, Nukahira Mine, Hidaka Prov., Anal. J. KITAHARA (KITAHARA, 1949, p. 27).
(2) Chromite (Picro-chromite). Kasuga Mine, Iburi Prov., Anal. J. KITAHARA (KITAHARA, 1947, p. 259).
(3) Chromite (Beresofite). No. 6 Adit, Nitto Mine, Hidaka Prov., Anal. J. KITAHARA (KITAHARA, 1947, p. 260).
(4) Chromite ore. No. 12 Adit. Shin-nitto Mine, Hidaka Prov., Anal. Bureau of Mine, Sapporo. (MURATA, 1936, p. 250).
(5) Chromite ore. Zuito Adit, Shin-nitto Mine, Hidaka Prov., Anal. T. NAKAYAMA (SUZUKI, 1943a, p. 59).
(6) Chromite ore. Shinpo mine. Ishikari Prov., Anal. Daido-seiko Co. (SUZUKI, 1943b, p. 52).
(7) Chromite ore, Pankeiyapteushi along the Mukawa River, Iburi Prov., Anal. T. YOSHII. (Ishikawa, 1896, p. 127).
(8) Chromite ore. Pankemoto along the Mukawa River, Iburi Prov., Anal. T. YOSHII (ISHIKAWA 1896, p. 127).

The massive chromite deposits in Hokkaido occur as lens, vein, pot, peascod-mass or flat-lying sheet in form, usually accompanied by deformation and faulting because of thrusting. The outcrops of the ore body are often found at cliffs or in rocky stream bottoms. The boundaries between ore body and country rock where observed in the mine, are usually very sharp, though in some places massive ore grades outward into the normal serpentinite through a more or less thin disseminated chromite ore zone. The wall rock of the massive ore is often veined with aragonite, magnesite, zeolite, picrolite, chrysotile or aquacreptite and is usually characterised by the association of much talcose and clayey materials.

A disseminated chromits ore is often found in certain places but the volume of it is usually small compared with the massive type. The rough disseminated chromite ore in peridotitic rock or hard serpentinite is rather rare in Hokkaido and some samples from Yuwanai-dake[(1)] and the Tomimoto-Shizunai[(2)] mine in Hidaka Province are low grade carrying only 10–20 percent Cr_2O_3. They may be compared with some occurrences in the Tottori district in south western Japan.

At the Zuito[(3)] adit of the Shin-nitto[(4)] mine, and the Nishigami[(5)] adit of the Nukahira[(6)] mine of Hidaka Province, massive chromite ore bodies cut respectively not only the serpentinite but the differentiated dikes of albititic rock in serpentinite and partally enclose small blocks of albitite and serpentinite in the ore bodies themselves. The manner of the occurrences indicates that the origination of massive chromite deposits was later than intrusion of the leucocratic dike rocks (Suzuki, 1943a).

The genesis of chromite deposits has long been discussed by many geologists giving rise to various opinions whether it originated under orthomagmatic or hydrothermal conditions. From the many field data in Hokkaido, the writer inclines to consider that the chromite grains which had formerly accumulated as crystal mush in a lower semi-consolidated magma, were carried upward in solid masses by hot siliceous solution ascending along the weak part in the ultra-basic mass at the hydrothermal stage, and formed various kinds of ore body under variable conditions. It appears that the crystals of chromite were crushed into irregular minute fragments by mutual collision during the ascending process (Suzuki, 1943a).

The writer expresses his sincere thanks to Prof. E. Sampson of the Princeton University, with whom he visited the chromite mines of Hokkaido and who gave valuable suggestions to the writer on the deposits.

B. PLACER CHROMITE DEPOSITS

Placer chromite deposits are widely found in the areas along streams whose headwaters arise in the serpentinite masses especially of the northern half of central Hokkaido. Such deposits are found in regions

(1) 岩内岳, (2) 富本静内, (3) 瑞東, (4) 新日東, (5) 西神, (6) 糠平.

where no lode deposits are known. Alluvial material, mostly derived from serpentinite, is found both in the present streams and on terraces 2–5 m. above the stream level. The terraces are composed of soil, peat, clay, sandy clay, sand and gravel, though peat and gravel or one of them are absent in certain localities. Bed-rock or hard-pan of the alluvial deposit lies at varying depths 1–3 m. below the surface of the ground. The bed-rock is commonly composed of sedimentaries of Pleistocene or Tertiary age and often serpentinite (SUZUKI, 1942b; 1943b).

Many mining areas have been exploited in Teshio, Kitami and Ishikari Provinces. The areas in the first two provinces, are situated in flat country, into which the waters of the Teshio and Tombetsu Rivers(1) and their tributaries eventually flow, while the areas in Ishikari Province, an along the Uryu River(2) and its tributaries.

In the alluvial deposit, chromite grains commonly accumulate in its lower half the recoverable amount varying from 15–20 kgr. per cubic meter*. Minute amounts of iridosmine and native gold grains, often but not always, occur in the lowest horizon or on the bed rock. They are mined as by-products if they exist in sufficient quantities. Samples of concentrate consist of minute grains of chromite, most of them less than 1 mm. in size, showing plentiful isolated crystals with completely or rounded octahedral form. Usually placer ore show higher grade, Cr_2O_3 45–58 percent, than massive ore, though sometimes it is high in iron-oxide compared with Cr_2O_3, probably owing to the large amount of admixed magnetite impurity.

It is considered that the placer ore has come, not from the detritus of lode deposits, but from the accumulation of the small quantity of accessory chromite which is always present with magnetite as rock-forming minerals in ultra-basic intrusives. Placer chromite is occasionally found in shore beaches of Teshio Province, but it is usually very fine and in low concentration. As an exceptional case, the placer in the Numata(3) district of Ishikari Province is considered to be a re-worked product, which was washed out from surrounding Neogene Tertiary sedimentaries of the district.

* The total production of placer chromite, containing 45–55 percent Cr_2O_3, in Hokkaido from 1925 to 1945 was 26,175 metric tons with maximum annual production of 5,711 metric tons in 1944, corresponding to about a quarter of that of massive chromite in Hokkaido in the same year. The Horokanai-Tsuchiya(4) mine, the largest placer now operated in Japan, has shipped 5,763 metric tons of placer chromite with a maximum 2,100 metric tons in 1943.

(1) 天鹽川及頓別川, (2) 雨龍川, (3) 沼田, (4) 幌加內土谷.

C. PLACER IRIDOSMINE AND NATIVE GOLD DEPOSITS

It is most probable that platinum group metals usually occur in ultra-basic intrusives, but no lode deposit of the metals is known either in Hokkaido or in any part of Japan. As previously stated, such deposits of platinum group metals are always found in extremely minute amount, as a placer iridosmine, in the lowest part or on the bed-rock of placer chromite bearing alluvial deposit which in northern Hokkaido develops surround or near the serpentinite masses. Also the locality of placer iridosmine usually coincides with that of placer chromite, though the recoverable part of the former, is rather restricted in its distribution. As in the case of placer chromite, the mining of placer iridosmine has been mostly carried out in numerous areas along the Teshio, Uryu, and Tombetsu Rivers and their tributaries as well as also on the shore beaches of Teshio Province. The Takadomari(1) district along the Uryu River(2) is the largest producer; the ground is said to yield about 0.3 gr. or less of iridosmine per square meter on the bed rock. Seventy percent of the total production from Hokkaido has been mined from the area along the Uryu River* (SUZUKI, 1950a; WATASE, 1933).

Most of the platinum group metals recovered in the placer deposits in Hokkaido, is in the form of iridosmine crystals which contain iridium and osmium as the essential components (ISHIKAWA, 1895). Real platinum is exceedingly rare in the placer, but some varieties of iridosmine grain from Niseparomappu in the Uryu district and others contain about twenty or more percent of ruthenium and are listed as ruthenosmiridium by S. AOYAMA (1936).

The isolated grain of iridosmine is light gray or whitish gray with metallic luster; it is less than 0.5 mm. in size in irregularly rounded form though often it shows fine crystal form with the face of c (0001), x $(22\bar{4}3)$ and a $(11\bar{2}0)$ (SAKURAI, 1949). According to Y. SHIMADA, a rounded coin-like grain of iridosmine which was found at Takasu of Ishikari Province reaches to 9.4125 gr. and is said to be the largest one ever found in Japan, though it combines a minute amount of native gold grain in itself. It is generally recognizable that the farther the locality is situated from serpentinite body, the finer the grain of iridosmine becomes.

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* From 1925 to 1945, the total production of iridosmine in Hokkaido, was about 164.4 kgr; its production reached a peak of 23,074 gr. in 1944.

(1) 鷹泊, (2) 雨龍川.

The chemical analyses of the platinum group metals found in placer form in Hokkaido are tabulated as follows:

TABLE VII. Platinum group metals from Hokkaido

	1	2	3	4	5	6	7	8	9	10
Ir	54.13	50.98	43.10	49.80	45.49	45.31	39.018	38.23	16.78	—
Os	29.23	33.08	38.48	37.30	33.85	38.01	38.895	37.65	23.64	—
Pt	1.66	tr	tr	1.15	1.34	0.51	—	1.81	49.32	48.90
Pd	1.73	—	—	—	tr	tr	—	0.87	0.38	51.10
Rh	4.44	4.42	5.90	3.92	6.36	1.09	0.988	0.51	6.14	—
Ru	—	11.52	12.52	7.60	12.68	14.70	21.080	21.03	3.74	—
Au	tr	—	—	0.02	—	—	—	—	—	—
Cu	1.29	—	—	0.01	—	—	—	—	—	—
Fe	7.33	—	—	—	—	—	—	—	—	—
Al_2O_3	—	—	—	0.03	—	—	—	—	—	—
Fe_2O_3	—	—	—	0.76	—	—	—	—	—	—
Total	99.81	100.00	100.00	100.59	99.72	99.62	99.981	100.00	100.00	100.00

(1) Iridosmine. Furano-mura, Sorachi-gun, Ishikari Prov., Anal. Bureau of Mine, Japan (MATSUMOTO, 1926, p. 743).
(2) Iridosmine (Fine grain). Takadomari, Uryu district, Ishikari Prov., Anal. Bureau of Mine, Japan (MATSUMOTO, 1926, p. 743).
(3) Iridosmine (Coarse grain). Takadomari, Uryu district, Ishikari Prov., Anal. Bureau of Mine, Japan (MATSUMOTO, 1926, p. 743).
(4) Iridosmine. Kitami Prov., Anal. S. AOYAMA (IWASAKI, 1917, p. 159).
(5) Iridosmine. Takadomari, Uryu district, Ishikari Prov., Anal. Sapporo Branch of the Mint of Japan (Zoheikyoku).
(6) Iridosmine. Toikanbetsu, Horonobe mura, Teshio Prov., Anal. R. TAKAHASHI (TAKAHASHI, 1941, p. 590).
(7) Ruthenosmiridium. Niseparomappu, Uryu district, Ishikari Prov., Anal. S. AOYAMA (AOYAMA, 1936, p. 78).
(8) Ruthenosmiridium. Seiwa, Uryu district, Ishikari Prov., Anal. R. TAKAHASHI (TAKAHASHI, 1941, p. 590).
(9) Platinosmiridium. Takadomari, Uryu district, Ishikari Prov., Anal. Hitachi Min. Co. (WATASE, 1927, p. 10).
(10) Palladiplatinum. Toikanbetsu, Horonobe mura, Teshio Prov., Anal. R. TAKAHASHI (TAKAHASHI, 1941 p. 590).

The placer deposits existing at some places in north-eastern Hokkaido, have derived their iridosmine grains by the reworking of the Neogene Tertiary sediments, especially of conglomerates which are mainly composed of ultra-basic materials. Examples are seen in the area along the Obirashibe River[1] of Teshio Province.

In the placer chromite and iridosmine deposits, some quantities of fine native gold grains usually occur as by-produce of base metal minig operations. Y. SHIMADA's investigation in numerous localities, shows that the ratio of gold grains to iridosmine grains in weight is locally variable, ranging from 5:95 to 90:10. From a detailed examination of the river system, it can only be stated that the placer gold probably came from the serpentinite mass, similarly to the placer iridosmine, but it is impossible at present to conjecture what may be the exact source of that gold.

The writer is particularly indebted to Mr. Y. SHIMADA, the former chief engineer of the Hokkaido Placer Platinum Exploitational Company whose extensive and valuable knowledge of the iridosmine deposits of Hokkaido has been generously shared.

D. CHRYSOTILE ASBESTOS DEPOSITS

In Hokkaido, except for a small amount of inferior amphibole asbestos procuced only in the Shinjo[2] district near the Kamuikotan Valley, comparatively little asbestos worth exploitation has been found. However, since 1937, when chrysotile asbestos, appearing to be the best of the kind produced in Japan, was discovered in the serpentinite area in the Yamabe[3] and Nunobe[4] districts of Ishikari Province, there have been found many kinds of asbestos in other serpentinite areas (SUZUKI, 1941).

Among the asbestos discovered recently in various localities in Hokkaido there are both chrysotile and amphibole with anthophyllitic, tremolitic or actinolitic nature. The sorts which can be actually used are merely a part of the former; the latter type, though produced in various places, is inferior in quality, small in quantity and not recognized as economically valuable at present. The places known as chrysotile asbestos producing districts in Hokkaido are as follow: the Yamabe,[5] Nunobe[6] and Horokanai[7] districts of Ishikari Province, the Usappu,[8] Shizunai[9] and Mitsuishi[10] districts of Hidaka Province, etc.* Of course,

* Of these districts in Hokkaido, those which are already under production are the Nosawa, Yamabe, and Nunobe mines in the Sorachi district, the Asahi-Usappu[11] mine in the Usappu district, the Urawa[12] mine in the Shizunai district and the Tobetsu[13] mine in the Mitsuishi district. The total production of chrysotile from Hokkaido for 1942-1947 was about 24,500 metric tons with annual production from about 1,500 to 8,200 metric tons. Prior to 1942, Japan imported practically all the chrysotile she needed, but in this year substantial production of chrysotile, except crude class, began in Hokkaido.

(1) 小平蘂川, (2) 新城, (3) 山部, (4) 布部, (5) 山部, (6) 布部, (7) 幌加内, (8) 右左府, (9) 静内, (10) 三石, (11) 朝日右左府, (12) 浦和, (13) 東別.

among these districts, there are places where the production has not yet been undertaken, since only small exposures of chrysotile asbestos are known. The largest producer is the Yamabe district, where the Nozawa,(1) Yamabe and Nunobe mines are situated. At present, probably 95 or more percent of the chrysotile production in Japan is from this area.*

The chrysotile variety of asbestos occurs in each locality as narrow traceable veins which arrange irregularly in usual cases, but often predominantly extending in a certain direction, only in the extremely serpentinized part of the ultra-basic intrusives. Although the chrysotile of the Yamabe district is similar to the best asbestos of Canada and the longest fiber found measures about 3 cm., it is mostly short being of grades lower than 5D on the average. The harder variety from some places in Hidaka Province is considered to contain minute particles of talc filling up the spaces among the fibres.

The chemical compositions of chrysotile veins, and picrolite vein which is intimatly associated with chrysotile veins in every locality in Hokkaido, are as follows:

TABLE VIII. Chrysotile Asbestos from Hokkaido

	1	2	3	4	5
SiO_2	39.00	39.29	40.08	36.94	40.99
Al_2O_3	0.82	1.98	1.58	1.52	1.33
Fe_2O_3	6.07	5.63 (Fe₂O₃ + FeO)	2.29	—	1.49
FeO	3.47		1.87	6.18	2.74
MgO	36.07	38.75	40.65	39.76	39.77
CaO	0.22	1.56	—	0.18	0.18
H_2O (+)	13.07	13.71	13.76	14.72	12.89
H_2O (−)	1.41	—	—	—	0.95
Total	100.13	100.92	100.23	99.30	100.34

(1) Chrysotile asbestos. Sakae-zawa, Yamabe district, Ishikari Prov., Anal. T. INOUE, Hokkaido Univ.

(2) Chrysotile asbestos. Sakae-zawa, Yamabe district, Ishikari Prov., Anal. H. KONISHI (SUZUKI, 1941, p. 268).

(3) Chrysotile asbestos. Sakae-zawa, Yamabe district, Ishikari Prov., Anal. H. KONISHI. (SUZUKI, 1941, p. 268).

* The Nozawa mine in the Yamabe district is the largest one, not only in Hokkaido but in Japan, and its production reached a peak of 5,755 metric tons in 1944.

(1) 野澤.

(4) Chrysotile asbestos. Ogurose-zawa, Nunobe District, Ishikari Prov., Anal. Y. KOMATSUZAKI, Nippon Sekimen Co.
(5) Picrolite. Sakae-zawa, Yamabe District, Ishikari Prov., Anal. T. INOUE, Hokkaido Univ.

Even in a single serpentinite body, the vein of chrysotile does not develop uniformly: but is limited to a particular part, forming rich zone or lens in the body, best suited to open-cut methods of mining. In parts which contain many veins they gradually diminish in proportions, and change into parts which do not contain any vein at all. The rich zones or ore shoots where chrysotile veins develop close together, extend in similar direction and are usually subparallel to the elongated direction of the serpentinite body (SUZUKI, 1946a). It has been pointed out that the occurrence of chrysotile vein may show intimate relation with the joint system which was originated during the consolidation of the ultra-basic rock (SAITO, 1950). To know the direction and dip of the rich zone is important in prospecting as well as in mining ores. For instance, several rich zones have been recognized in the Yamabe district where the largest one is 100 m. wide, 300 m. or more long and attains to the depth of 80 m. or more, dipping 45° eastward.

The condition of the development of asbestos vein in the serpentinite mass is somewhat variable; in the case of working the rich zone chiefly, it is estimated that 2–4 percent, and 6–10 percent in very good condition, of chrysotile fiber can be obtained from the rock. In a new quarry, however it may be only 0.4–0.6 percent for great amounts of waste rock must be removed, judging from the comparison of the rock mined and the amount of chrysotile fiber obtained from the rock.

One thing which has to be noted is that, according to the conditions of production hitherto known in various localities, the part which contain the chrysotile vein, exists in the small scale serpentinite body, or in the margins of some widely distributed rock body. These facts may be applicable to the case of chromite deposits in Hokkaido. Again, in the sertentinite area containing chrysotile veins, there is often noted a tendency of various leucocratic dikes to intrude. From the field evidence, the occurrence of chrysotile vein seems to be genetically connected with the leucocratic dikes intruded into the serpentinite mass, and would represent the latest phase of igneous activity in the area.

The existence of numerous veins of light greenish picrolite is commonly observed in the area where chrysotile veins are well developed. In this case, chrysotile veins scarcely cut one another, the picrolite veins however, intersect not only chrysotile veins but also picrolite veins themselves cross one another. These observations seem to suggest that chrysotile may have crystallized in a instant, prior to the development of picrolite which occurred during a comparatively long time.

Without exception thin black layer, 2 mm. or less wide, exists between chrysotile fiber and rock wall. This layer is chiefly composed of bastite mingled with minute grains of magnetite. Comparing the chemical composition of three materials, viz., chrysotile fiber, black zone and wall rock, in a certain single sample from the Nozawa mine in the Yamabe district, it is conspicuous that the content of iron oxides is quite different in them, notwithstanding the SiO_2 content in each material is nearly constant. The content of $FeO+Fe_2O_3$ in the wall rock is intermediate between those in the chrysotile fiber and black zone, as is shown in the following table (Suzuki and Inoue, 1948).

Table IX. Serpentinite, black zone and chrysotile in a single sample from the Nozawa mine, Yamabe district, Ishikari Province. Analyzed by T. Inoue (Suzuki and Inoue, 1948, p. 195).

	A	B	C	D
SiO_2	39.87	36.73	40.98	39.50
Al_2O_3	1.00	0.98	0.32	0.83
Fe_2O_3	5.24	11.41	1.75	6.15
FeO	3.82	5.86	1.00	3.52
MgO	36.06	32.49	42.43	36.54
CaO	0.28	0.26	0.11	0.22
H_2O	13.73	12.27	13.41	13.24
Total	100.00	100.00	100.00	100.00

Molecular percent

	A	B	C	D
SiO_2	27.36	27.07	27.12	27.35
Al_2O_3	0.40	0.42	0.12	0.34
Fe_2O_3	1.35	3.15	0.43	1.60
FeO	2.19	3.60	0.55	2.03
MgO	37.11	35.42	42.12	37.96
CaO	0.21	0.20	0.08	0.16
H_2O	31.38	30.14	29.58	30.56
Total	100.00	100.00	100.00	100.00

A) Serpentinite. (See p. 120, Table II, No. 3).
B) Black zone.
C) Chrysotile.
D) Chrysotile vein with black zone.

It is probably reasonable to consider that when the chrysotile fiber grew from serpentinite during hydrothermal stage, iron oxides were set free and formed the thin black zone between fiber and wall rock.

E. MERCURY DEPOSITS

As far as is known in Hokkaido, only a few small areas in the ultra-basic rocks have been mined and prospected for mercury deposit of low grade, at the Teshio mine in the Onnenai[1] district of Teshio Province and at Suigin-yama[2] in the Horokanai district of Ishikari Province (Yajima, 1948; 1951; Suzuki, 1950a).

The area of the Teshio mine is in steeply dipping Cretaceous sandstone and shale beds where they were intruded by serpentinite. The ore, consisting mostly of cinnabar and native mercury, occurs along the sedimentaries where they contact with the serpentinite as coating along shear planes and along the fissures in these rocks* (Murata, 1936).

At Suigin-yama, disseminated ore of low grade occurs in the small serpentinite mass in the metamorphics of Kamuikotan complex, but the deposit has not yet been under production though some prospecting has been done with special reference to the placer cinnabar developing around the area (Harada, 1943).

In both areas, where the Teshio and Suigin-yama deposits exist, some differentiated leucocratics occur in association with serpentinite masses and where an immediate contact of dike and mercury deposit has often been found. This fact suggests that these dikes may be specially connected with the occurrence of the deposits.

Besides the examples from the above cited areas, minute grains of cinnabar are often found in the placer chromite and iridosmine deposits in the Uryu district and other localities, but it has not yet been clearly ascertained from where they came.

The largest deposit of mercury in Japan is at the Itomuka[3] mine of Kitami Province in Hokkaido from which has been derived usually eighty percent or more, of the total production in Japan (Yajima, 1951).

* The total production of the minerals from the mine for 1936–1945 amounts to about 100 metric tons.

(1) 恩根内, (2) 水銀山, (3) イトムカ.

However as that deposit is genetically connected with the young Tertiary volcanic rocks and not with the ultra-basic rock, a discussion is not pertinent in this paper.

F. NICKEL DEPOSITS

Several small nickel deposits have been known in Hokkaido. They can be divided into two types from the standpoint of their genesis. The Kamikawa(1) deposit near the Kamuikotan Valley in Ishikari Province and the Shoei(2) deposit near Nakatombutsu(3) in Kitami Province, are directly related to serpentinites themselves in the Kamuikotan complex (Ishikawa, 1944a; 1944b; Kinoshita, 1943). The other deposits in the Horoman(4) district of Hidaka Province, in the Oshirabetsu(5) district of Tokachi(6) Province and in the Okushibetsu(7) district of Teshio Province, are due to the veinlets or fine grains of pentlandite or polydymite in the disseminated ore or veins of pyrrhotite in the gabbroic masses intruded in the Hidaka complex (Akaoka, 1941; Kobayashi, 1941; Kato and Kobayashi, 1944; Hashimoto, 1948b; 1951).

At the Kamikawa and Shoei mines, the ores were residual earthy clayey matter derived from decomposition of the underlying serpentinite mass, containing 0.3–0.8 percent nickel and 20–35 percent iron. The residual clay averages nearly several meters in thickness though it varies depending on the topography. Serpentinite blocks of various sizes are commonly found in the lower part of the residual clay.

At the Kamikawa mine, the underlying serpentinite is partly penetrated by numerous veinlets of calcite and quartz, in which a small amount of garnierite and millerite is found especially in the lower part of the residual clay resting on the veined serpentinite, indicating that the deposits were enriched by hydrothermal solution*.

The occurrence of a fine vein of millerite is known in a small isolated serpentinite mass near Shikanai(8) in Hidaka Province but it is very small in quantity and has no economic value.

G. COPPER DEPOSITS

Small and low-grade deposits of cupriferous sulphide are often found in the serpentinized ultra-basic masses themselves in Hokkaido, but no

* From 1941 to 1945, the clay of the Kamikawa mine was mined by open-cut and the total production of crude ore with an average grade 0.6 percent of nickel was about 4,000 metric tons.

(1) 上川, (2) 昭榮, (3) 中頓別, (4) 幌満, (5) 音調津, (6) 十勝, (7) 奥士別, (8) 鹿内.

large workable deposit has been known. The deposits at the Chiroro[1] and Niseu[2] districts in Hidaka Province, for example hold only a scientific interest, occurring as narrow vein or small mass which consists of chalcopyrite, chalcocite or bornite as an essential component (SUZUKI, 1950a).

It is also noteworthy that in the superficial residual clay or soil resting directly on the serpentinite masses in the Shizunai[3] and Usappu[4] districts, there are locally present ore blocks and masses of native copper of irregular shape and size, generally 3–10 cm. in maximum diameter, many of which are slightly accompanied with cuprite, malachite or azurite. They are mostly very pure and of high copper content, but usually exist in small quantity. From the geological and mineralogical viewpoint, it may reasonably be assumed that they originated secondarily from a cupriferous sulphide vein in the neighbouring serpentinite mass, but it is not clear how this was effected, because no close relation between the native copper block and its probable source has been found in any field.

In the outer zone of south-western Japan, there are numerous cupriferous pyrite deposits, so-called Besshi[5] type deposits, which intercalate in the Sambagawa[6] and Mikabu[7] crystalline schists in bedded form and are considered to be metasomatic replacement products by ascending mineralizing solution from ultra-basic intrusions connected with the great crustal movement. But no identical ore deposit has been known in Hokkaido (KATO, 1925a; 1925b; SUZUKI and ISHIKAWA, 1943).

In the zone of the Hidaka complex of central Hokkaido, some small pyrrhotite deposits are known to occur mostly in the metamorphic rock areas. Some cupriferous pyrite deposits represented by the large deposit of the Shimokawa[8] mine in Teshio Province, are known to occur in the slate areas. These sulphide deposits are of quite different nature in comparison with the Besshi type deposit. They are considered genetically to be connected with the diabasic and gabbroic rock intruded in the Hidaka complex and not with the ultra-basic rock in it.

H. TALC AND OTHER DEPOSITS

Besides the various ore deposits above described, there can be cited here other mineral deposits such as, talc, manganiferous iron, magnetite, magnesite, cobalt, corundum, etc., which may possibly occur

(1) 千呂露, (2) 仁世宇, (3) 静内, (4) 右左府, (5) 別子, (6) 三波川, (7) 御荷鉾, (8) 下川.

as useful natural resources in ultra-basic rock. Notwithstanding the wide distrubution of ultra-basic rocks in Hokkaido, most of the above cited materials have not been known in this island and prospect for future important discoveries of them appear to be poor.

With respect to talc, for instance, though talcose serpentinite is known to be plentiful in Hokkaido, it is commonly inferior and useful talc has not yet been found in it. In the small serpentinite mass at Kamietanbetsu[1] in Ishikari Province, a small manganiferous iron deposit with 5-10 percent Mn and 20-30 percent Fe has been prospected but the form and volume of it are not yet ascertained at present. Fresh dunite itself is often used as a refractory material. For this prupose, the peridotites from Yuwanai-dake[2] and Horoman[3] in Hidaka Province were prospected and examined but is said to be not suitable at present to use on account of the large content of pyroxenes in them.

V. SUMMARY

(1) This paper has undertaken to describe in outline the ultra-basic rocks, and associated dike rocks, adjacent contact metamorphosed rocks, as well as various ore deposits closely related with the serpentinite of Hokkaido. Some short account of the fundamental geology of the central zone of Hokkaido where the ultra-basic rocks are predominantly distributed, has also been included. The ultra-basic rocks which have only a limited development, being restricted mainly to the tectonic lines in or along the metamorphic zone of the Kamuikotan and Hidaka complexes, in the form of lenses, belts or masses arranging from the north to the south in linear direction.

(2) The stratigraphical position and the age of the Kamuikotan and Hidaka complexes are not yet clearly ascertained, though from the geological and petrographical points of view, the former complex may be readily correlated with the Franciscan formation in California, and a part of the latter complex may contain distinctive features in common with the so-called Chichibu system in Japan proper and other parts, though these complexes are locally grouped together with the Jurassic sediments.

(3) From late Mesozoic time central Hokkaido has been periodically subjected to orogenic movements producing pressure from the east. Igneous activities accompanied those movements. Many geological facts

(1) 上江丹別, (2) 岩内岳, (3) 幌満.

may reasonably be deduced, for example that most of the intrusion of the large ultra-basic masses in central Hokkaido belong to an early Tertiary orogenic period.

(4) One of the distinctive features is that the ultra-basic rocks related to the Kamuikotan complex are extremely large in size and are now usually represented by serpentinite, those of the Hidaka complex, however, are generally small and comparatively fresh, still showing peridotitic nature. The total area where serpentinite is exposed in the Kamuikotan complex far exceeds any other area where such phenomena are observed in Japan.

(5) The ultra-basic rocks in central Hokkaido can be roughly classified into two main petrographic types ; peridotitic and serpentinitic rocks. Each of them can be respectively subdivided from the standpoint of constituents and structures : peridotitic rocks comprise dunite, saxonite, harzburgite, wehrlite, amphibole peridotite, picrite, plagioclase bearing dunite etc ; serpentinitic rocks include massive serpentinite, schistose serpentinite, talcose serpentinite and actinolite-fels, etc.

(6) The serpentinite masses in the Kamuikotan complex are occasionally traversed by numerous dike rocks of leucocratic and melanocratic nature which may have been differentiated from the same magma related to the ultra-basic intrusives. The representative kinds of those dike rocks are albitite, quartz albitite, quartz albitophyre, albite aplite, anorthosite, trondhjemite, pegmatite, micro-diorite, diorite-aplite, gabbro-aplite, hornblendite, titanaugite-fels, diabase, etc. Some leucocrates may in origin have relation to the genesis of some kinds of ore deposits for instance of chromite, mercury and asbestos. Rounded masses of rodingitic rocks are often found in the serpentinite bodies.

(7) Various interesting contact rocks locally develop between the normal crystalline schists of the Kamuikotan complex and the ultra-basic intrusives. They are characterized by the presence of some of the special silicates such as albite, glaucophane, crossite, riebeckite, crosidolite, aegirine-augite, lawsonite, garnet, piedmontite, stilpnomelane, pumpellyite, rutile, apatite, etc. Most of these special minerals are considered to be a pyro-metasomatic product caused by the action of especially soda-rich hydrothermal solution derived from the ultra-basic intrusion. The contact rocks may be divided into many classes from the mineral association, chemical composition and micro-structure.

(8) The ultra-basic rocks, especially serpentinites in Hokkaido are of special importance because of their associated ore deposits of various

kinds of useful minerals such as chromite, iridosmine, chrysotile asbestos, mercury, nickel, copper, etc., though some of them are not recognized as economically at present. Most of these deposits occur in the ultra-basic bodies themselves; in vein or massive form, they originated under orthomagmatic or hydrothermal condition, but some of them, for instance iridosmine, gold and a part of the chromite, are concentrated as placer deposits in the alluvial plain around the serpentinite masses.

Short descriptions outlining the general properties, the modes of occurrence and the genesis of each deposit were respectively presented in this paper.

(9) Most of the known analyses of the ultra-basic rocks, associated rocks and ores of Hokkaido were cited, but the details on each rock and ore were not touched upon here, as some of them have already been described and it is intended to present the others on some future occasions.

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