ON THE NICKEL-BEARING PYRRHOTITE AND GRAPHITE DEPOSIT AT OSHIRABETSU, TOKACHI PROVINCE

(Geological and petrological studies on the basic plutonic rocks in the Hidaka mountains, Hokkaido. 1-st. Report)

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I. Introduction

Oshirabetsu, Tokachi province, situates at the eastern coast of the Erimo Penninsula about 40 km. NE from its point. It occupies the south-eastern ends of the Hidaka mountains, which geologically extend from the coast of the Okhotsk Sea NE to the Erimo Penninsula into the Pacific Ocean. Being covered by the newer volcanics at the center of our island, Hidaka zone is composed chiefly of folded sedimentaries of the unknown age. In the southern half *viz.* Hidaka Mts. sens strico, there is a narrow but continuous zone of the migmatite along the core of the mountains. On the both sides of the migmatite, the slate and the sandstone are transformed into the hornfels and biotite schist etc. Plutonic intrusion of ultrabasic to acidic rocks occurs in the zone of, or junction of, the migmatite and the thermal metamorphic rocks. They are peridotite, olivine gabbro, gabbro, norite, hornblende gabbro and their derivatives.

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The ore deposits under consideration develop in some places in the massive gabbro and norite groups. And their mode of occurence and mineral paragenesis are shown to have much in common with each other. These are met with the deposits of Horoman, Hidaka prov., Okushibetsu, Teshio prov., and Oshirabetsu, Tokachi prov. Especially the ore deposit in the latter shows the most typically developed type among them.

The notable feature of the deposits is an association of the pyrrhotite and the graphite. There may be difference in the scale of the deposits but there is almost complete agreement in this paragenesis. And neither accidental xenolith of the carbonaceous slate nor carbonate rock has been found in each of the igneous bodies. Considering these modes of occurence and the results of observation of the deposits in detail, the writer has come to assumption that the pyrrhotite and the graphite are not deposited under the accidental conditions but are carried out under some common conditions of the magmatic evolution in this zone.

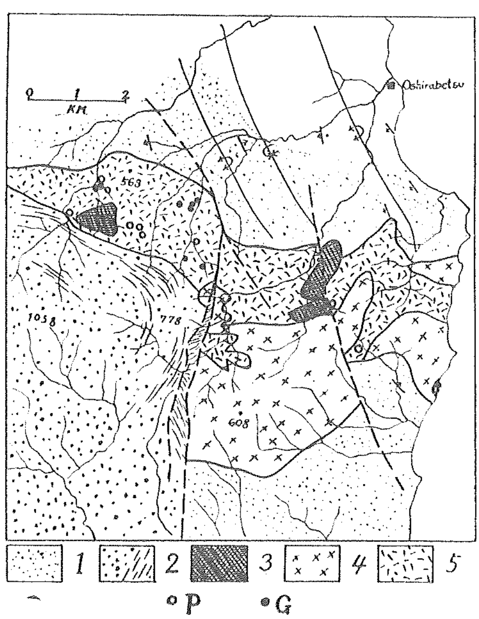

Fig. 1. The geological sketch map of Oshirabetsu region, Tokachi Province in Hokkaido

1) Thermally metamorphosed Hidaka sedimentaries
2) Biotite gneiss and migmatite
3) Olivine gabbro
4) Granite
5) Main intrusives of gabbro groups

Outcrops mainly of
P : Pyrrhotite, G : Graphite

II. Outlines of general geology

The results of making a survey of the Oshirabetsu district are shown on the simplified map. (Fig. 1) The area includes a sill of the main intrusives of gabbro, norite, hornblende gabbro, a stock of granite and olivine gabbro, which are surrounded by slate and sandstone of the Hidaka complex at the north-east, and are bounded by biotite schist and migmatite derived from the Hidaka group at the south-west.

The greater parts of the sedimentary complex of the

Hidaka group in this district consist of sandstone and shale, interbedded with the bed of calcareous nodules. The whole is folded into a series of isoclinal folding which dips steeply towards the south-west. Sub-parallel with the trends of the plutonic body, they are affected by thermal metamorphism and extend a wide belt of hornfelses, yet the true crystalline hornfelses are not detected except at the very junction with the plutonics. Throughout the entire zone the metamorphism keeps its grade so low that the original clastic structures of the sediments are conserved, or in other words, the contact effect is not induced directly by the plutonic intrusion but it may have been brought about by the ascending of the thermal gradient as resulted by the formation of migmatite in the center of the folded mountains.

The most distinguished feature of the main intrusives is that the igneous body shows heterogeneous mineral comopositions and textures. With reference to its mineral composition alone, it may be said that the main intrusives are classified into some igneous rock facies as following.

1) Diabasic olivine gabbro facies
2) Pyroxene gabbro and norite or hyperite facies
3) Syeno-noritic gabbro facies
4) Dioritic gabbro facies

The diabasic olivine gabbro facies which is surrounded by relatively coarser pyroxene gabbro and others, shows that it occupies the earliest phase of the formation of the body as it is permeated by gabbro and hyperite groups. The pyroxene gabbro and hyperite facies develop so intimately related that it is hardly discriminated each other with naked eyes. In these facies it is very often found that the coarser pegmatitic facies of the same mineral constituent intrudes irregularily into the host with vaguely contact. And further the place of these later facies may be represented by hornblende gabbro or dioritic gabbro with the same manner as noted above.

The texture of almost all of them is entirely massive but in a few points earlier facies is observed to possess the foliation that is caused by the arrangement of plagioclase and pyroxene. This foliated fabric can be traced to some extence until the later massive facies wipes out the groundcoat after the manner of permeation.

Except olivine gabbro, the white orbs are locally scattered in the pegmatitic parts of the other rocks. The orbs are usually constituted by the single crystal of quartz or aggregates of large crystals of quartz rimmed with radially posted pyroxenes or hornblendes.

These orbs are thought not to be xenolith. Genetically the formation of the orb may be related with the mechanism of the graphite precipitation. Virtually the quartz orbs are very often found near the deposition of the graphite and a reverse the case. The origine of these heterogeneity is now beyond our question. But so for as the writer's reserch is concerned, these phenomena seem to be chiefly caused by the metasomatic circumstances followed soon after the formation of the earlier igneous facies.

III. The pyrrhotite deposit

As briefly stated above, the pyrrhotite deposits that are distributed in the gabbro, norite or hornblende gabbro facies are seen in more or less parallel to the elongation direction of the sill. Although several outcrops offered a promising prospect during the war, they had little economical importance. With regard to the wall rocks and mode of mineralisation, the pyrrhotite deposits are assorted to 4 distinct facies.

1) Pyrrhotite associated with gabbro-norite facies.

Wall rock shows, under the microscope, either ophitic or hypautomorphic granular texture. Plagioclase of composition An_{50} to An_{55} have rather insistently made their own crystalization. The zonalities are not remarkable. The augite builds xenomorphic crystals, but in some cases the ophitic texture appears. The automorphism of the orthopyroxene sits between plagioclase and augite.

But in the norite, the hypersthene is mostly rounded idiomorphic. The brown amphibole and cummingtonite often surrounds the pyroxene in its center. The sulphide occurs in the mesostasis of the silicates, forming the disseminated ore or so-called "*Goma kô*". Especially in the olivine bearing type, it is enclosed in the brown hornblende.

The form of the sulphide depends on the form of the intersitual spaces of the earlier silicates, and usually the contact of the sulphides against rock minerals is smooth. The great portion of the sulphides consists of the pyrrhotite, and brings very small irregular granules of the pentlandite which show themselves in flame-like form or as granule at the periphery of the pyrrhotite or at the points contact with the chalcopyrite.

The chalcopyrite, which arranges itself in some directions with small lenticular form, is also enclosed in the pyrrhotite. The succession of the sulphide is the pyrrhotite, chalcopyrite and pentlandite. The graphite is scattered throughout the ore, replacing the former sulphide.

The pyrrhotite associated with hornblende gabbro facies.

As to the mafic minerals, the pyroxene is not stable in this facies, and has been converted into the amphibole. Therefore, predominant are the pale greenish brown hornblende and the ragged crystals of the cummingtonite. The plagioclase is a composition An_{55}, not so fresh as that of earlier facies. It sometimes is irregularly replaced by the quartz. The pyrrhotite deposit is chiefly accompanied with this facies and represents two distinct types.

2) The type of the mottled ore, so-called "*Hanmuku kô*".
3) The type of the massive ore, so-called "*Muku kô*".

The mottled ore is not so different as that former facies, except that the pyrrhotite replaces silicates to some degree, forming big granules of segregative habits. It sometimes crosses the ragged crystals of the amphibole, and penetrates into the cleavages of the plagioclase forming the silicified zone of 0.01 mm. width at its contact. The marginal part of the pyrrhotite is replaced by a little amount of the chalcopyrite which projects usually spicular outpart into the silicate. Dusty grains of the chalcopyrite are gathering there. In some instances, the intermittent veinlets of the chlcopyrite penetrate into the pyrrhotite. The pentlandite forms very small irregular grain. It is found between the contact of the chalcopyrite and the pyrrhotite, or it is found at the margin of the pyrrhotite. Having much replaced the silicates with the sulphides, it completely surrounds the remnants of the silicates, and metaphorically speaking, they float in the sulphide. Passing these stages, it is gradually converted into the massive ore.

The massive ore of the pyrrhotite is usually found in association with the former type and often shows the offhoot penetrated into the mottled ore mass. Like the disseminated ore, massive ore forms an irregular body, in the heart of which the silicates are hardly recognizable. On the other hand, at its marginal part there are the silicates of the horblende gabbro to some degree altered. But the alteration is only limited at the contact where the thin film of silicification or the chloritization of the biotite prevails. The manner of the replacement of the sulphide is rather network, and penetrates along the cracks or the joint of the minerals. The amount of the chalcopyrite is as much as in the former type, being sporadically found as irregular veinlets which replace the remnant of chlorite or penetrate into the margin of the pyrrhotite.

4) The pyrrhotite accompanied by gabbro pegmatite.

The gabbro aplitic veins are shown at places in the mother rock and also in the deposit. These veins form commonly segregative schlierens with vague contacts. They are found to be accompanied by the sulphide in the vein. The occurence of the sulphide is not so different as the massive ore, but the difference is that the chalcopyrite forms the intermittent veinlet or irregular grain in the pyrrhotite, or the intergrowth with the prehnite. It is assumed that the stage of this veined ore formation occurs in the later as massive ore etc.

IV. The graphite deposit.

As already stated above, the graphite deposit of this area falls practically on that of the sulphide. But in details, some divergence is found as to the position of each ore. Generally speaking, the sulphide occupies the lower part of the mass, while the graphite posseses the upper part. The mode of occurrence of the graphite shows difference as to the stage of the mineralization. In associated with the disseminated ore of the sulphide, small flakes of the graphite are distributed through the sulphide bearing rock. But the concentration is in so low degree that flakes have only been detected by the examination of the

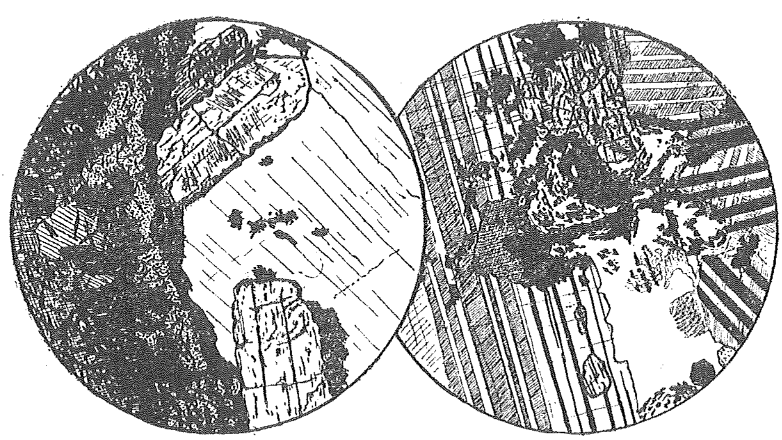

Fig. 2 The graphite accompanied by the pyroxene gabbro × 35
They had mainly replaced the sulphide (left figure in dotted part) or in accord with the replacement by quartz, minute flakes of them had been added in the replaced spaces. (right figure)

polished specimens under the microscope. In places, they have developed as metasomatic veinlet like aggregates which have replaced not only silicates of the wall rock but also sulphide ores. It is commonly found that this type of the deposit is accompanied with the metasomatic or intersitual development of quartz without any noticeable changes to the pyroxene. (Fig. 2)

The most characteristic and widespread type of the graphite deposit is that of pisolitic graphite ore of about 1—3 cm. in diameter. And this type of the ore shall furnish the chief resource of graphite in Hokkaido. The pisolites are distributed in lenticular bodies in gabbro and stand on closely genetic relations with the sulphide ore, but they are commonly associated with the hydrothermal minerals such as prehnite, zoisite, chlorite etc. The pisolitic graphite ore bodies show to have considerable silicified zones on the hanging wall and in a lesser degree the silicification on foot wall. In some parts of the pisolitic ore, where extremly enriched massive graphite lens develop, irregular lenticular quartz lenses lay one over another between the contact of the deposit and the wall rock. In hanging wall the transitional rock of the pisolitic ore and wall rock are found. In these gradually advanced stages of the transition, one can clearly distinguish three distinct stages.

1) First stage.

The wall rock shows that the pyroxene is, as a rule, nomore stable being converted into ragged crystals of the amphibole probably actinolite.

2) Second stage.

The next stage indicates the formation of the porphyloblasts of the quartz and lesser albite, which enclose idiomorphic pyrrhotite at its margin. The core of the porphyloblasts are disseminated with minute flakes of the graphite. As the porphyloblast grows at the expence of the rock minerals, the prehnite, zoisite, epidote and titanite are formed from resorbed minerals. The

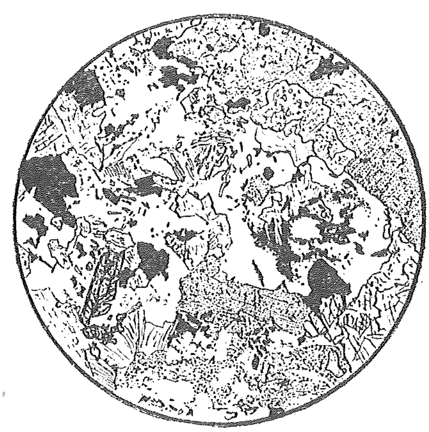

Fig. 3. ×35

The figure shows the early stage of formation of the quartz porphyloblast. Plagioclase and mafics closed by the porphyloblast had become tubid or discomposed and newly appears as prehnite, titanite and chlorite etc.

amount of the porphyloblasts in the rock corresponds 53 to 54 per cent.

3) Third stage.

As the growth of porphyloblast has reached to the orb of 1 to 2 cm. across, their peripheries being replaced by the graphite, it may be said that it has come to the stage of the so-called final coating of the graphite. In some cases, the graphite has almost completely replaced the porphyloblast inwards, forming a characteristic pisolite which occupeis 53 to 56 per cent. Thus in each pisolite, it is very common to find the remnants of the porphyloblast or secondary transformed hydrous silicates. In some cases, it is enclosed by the several small pisolite inside, very big orbs of the graphite have developed among them. Relative proportion of the orbs to matrix represent 63 per cent in this enriched ore.

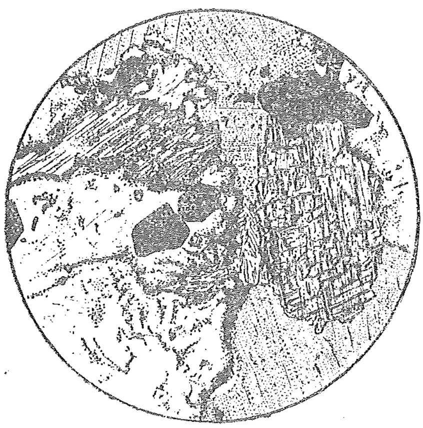

Fig. 4. The porphyloblast grow in more advanced form. × 35

The minute flakes of the graphite appears at the periphey of the pisolitic quartz. Nearly center of the figure, idiomorphic pyrrhotite crystals are noted.

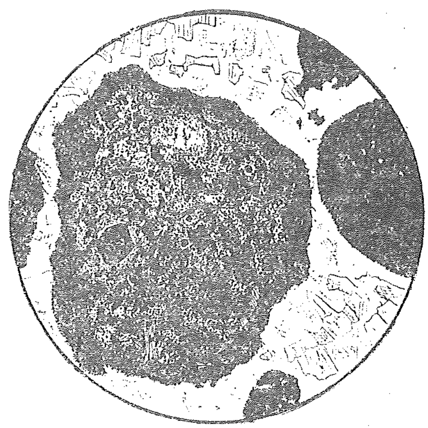

Fig. 5. Pisolitic graphite ore. × 15

Some of the porphyloblasts are almost enitrely replaced by the graphite, the other shows yet remnant of the early constituents considerably. Idiomorphic pyrrhotite are replaced by the graphite aggregates in this stage.

V The genesis of the sulphide ores and graphite

From the account of the mineralogical relation, especially as to the type mineral of the wall rock, the formation of the sulphide ores may be described as following.

First phase:

Precipitations under the igneous conditions *viz.* paragenesis of the pyroxene gabbro facies:

That the later stages of the crystallization of the gabbroic magma yield the hornblende and the sulphide in the intersitual sites shows more or less the concentration of the volatiles. But their crystallization, even if the sulphides owe their originatoin to somewhat metasomatic replacement to the rock minerals, has not effected stability of the pyroxene. Similarly the condition of the pyroxene gabbro facies which is described remains unchanged. At this stage comparatively fugitive constituents of the magma have finally given rise to the quartz replacement, accompanying the graphite metasomatism probably by the dissociation of the carbon dioxide vapour concentrated. Succession of the sulphides shows, however some overlapping may be realized, the order of pyrrhotite, chalcopyrite and pentlandite. On account of their occurence the pentlandite represents two distinct stages, the one is somewhat later than chalcopyrite, and the other earlier than that of the graphite.

Second phase:

The second phase shows paragenesis of hornblende gabbro facies which comprises the stage of amphibolitization of the pyroxene and at the same time crystallization of the hornblende directly form volatile concentrated magma. The ore of sulphides are formed rather metasomatically, which replace the more or less earlier formed silicates of the autometamorphic circumstance. The examination of different series of the ore types make out that the sulphide is crystallized first as mesostasis, and leads up to the active replacive behavior against the rock minerals. The succession of the sulphide is perhaps in the same order as described above. An evidence is clearly noticed that interval of the formation of each snlphide is remarkable. Namely, in the stage of the igneous condition, all of the sulphide are aggregated in the same space, while, in a stage illustration the later facies of the magmatic evolution, it is decidedly represented that the veining of the chalcopyrite and pentlandite commonly prevails.

An occurrence of graphite is not current but flacky aggregates cut the silicates and even sulphides.

Third phase:

Next to the ore formation of autometamorphic conditions follows a pegmatitic circumstance which shows the permeation of the aplitic pegmatitic segregative vein or dike. The sulphide that is brought in them, is appearing not so different as that of the massive ore, except its coarse grain size and intimate intergrowth with the prehnite. Succession of the sulphide is pyrrhotite, pentlatdite and chalcopyrite, the last two species being in this phase reversed. The graphite is not considerably detected in these formation.

Fourth phase:

In addition to the phases of igneous to pegmatitic, the fourth phase which comprises seemingly hydrothermal phase is recognized in these rocks. This phase is especially characteristic in the graphite formation. As briefly stated above, graphite has continuously added to the rocks replacing the early formed pyrrhotite and porphyloblasts of quartz and albite. That the sites of replacement are situated at the roof of the sulphide mass is the proof of the concentration of the volatiles which is presented in solution such as water, hydrogen sulphide, carbon dioxide etc. The origin of the graphite is thus concluded to be closely related to the solution that precipitates sulphide. The carbon at a first may be presented in a form of CS_2, keeping equilibrium with the solution, in which sulphide shall be yielded. But fugitive component becomes more and more concentrated in the rest magma, owing to the reaction with water, CS_2 must be converted into carbon dioxide and hydrogen monosulphide. Although vapour pressure of H_2S gradually increases precipitating pyrrhotite at its corresponding composition, it does not lead the reaction to the left side. Thus oncentrated CO_2 will react with H_2 which is a dissociation product of hydrogen sulphide and forms graphite and water.

These reaction will be probably performed in the vapour phase enriched residual magma which permeates near the sulphide mass.

The writer concludes, therefore, that association of the graphite and the sulphide ores of the Hidaka mountains is derived from the same ore solution.

VI. Aknowledgements

I desire, however, here to mention that I owe special and personal thanks to Prof. Dr. Jun Suzuki and that I have reason also gratefully to acknowledge the helpful suggestions and valuable critisism from Prof. Dr. Zyunpéi Harada and my colleague Asist. Prof. Mitsuo Funabashi.