The Natsume Nickel Deposits, with special Reference to the Microscopic Investigations of the Ores.

By

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I. History, situation and topography.

The Natsume§ nickel deposits were originally worked for copper ores, and afterwards for nickel on a small scale. It had long been abandoned before the Fujita mining company began to prospect the deposits in 1915. Bnt the work was again given up the next year.

The late Prof. Wataru Watanabe[1], Prof. Takeshi Hirabayashi[2] and

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§) 夏梅鑛床.
1) Unpublished.
2) Takeshi Hirabayashi, "On the nickel and cobalt ore deposits," (in Japanese) Nippon Kogyo Kaishi, No. 296, pp. 1051-1055, 1909.

Mr. Keijirō Nishio[3] studied the deposits. As their studies were undertaken when the mine was not worked, they could only study the deposits by the rocks and ores standing outside of the adits. The author, however, who was the manager of the last working, was able to study the deposits *in situ*, and the results of his investigation are presented in this paper.

Natsume is a village standing in Kuchi-ōya-Mura, Yabu-gun, Hyōgo-Ken.† The village is situated about ten miles west of Yabu-station^ on the "San-in" railway line× and about seven miles south of the Akenobe mine.*

A small river called "Ōya-gawa"‡ runs from south-west to north-east, crossing the village Natsume. The river takes in the water of the Akenobe river° on the bank of which the celebrated Akenobe tin mine stands. The valleys of the Ōya-gawa and the Akenobe-gawa are rich in metallic deposits.

The nickel deposits of Natsume lie on the steep-sloped hill-side of the north bank of the Ōya-gawa, at an elevation of 200 metres above the sea-level. The ore minerals here present are niccolite, chalcopyrite, arsenopyrite, pyrrhotite, magnetite, zincblende, pyrite and galena. The most abundant and widespread are magnetite and pyrrhotite, next to them chalcopyrite, arsenopyrite and niccolite, and the rare galena, zincblende and pyrite. The chemical analysis shows the presence of manganese, but it is invisible. Chromite and cobalt ore are absent, and quartz, calcite and serpentine are also found associated with the ores.

II. Geology.

The Geology hereabouts is considerably complicated (Pl. I). The rocks developed here are diorite, serpentine, liparite, Paleozoic group, Mesozoic group, older Tertiary system and Alluvium. Of these rocks, diorite,

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3) Unpublished.
†) 兵庫縣養父郡口大屋村.
^) 養父驛.
×) 山陰線.
*) 明延鑛山.
‡) 大屋川.
°) 明延川.

serpentine and the Mesozoic members have intimate relations with the ore deposits.

The north region of the Ōya-gawa consists of serpentine intruded by liparite, and also Mesozoic and Tertiary rocks; the west of the Akenobe-gawa diorite, serpentine, Mesozoic and Tertiary rocks; and the east of the same river or the south of the Ōya-gawa, liparite and Mesozoic group. The diorite passes into the serpentine without any clear boundary between them.

In the immediate neighbourhood of the ore deposits (Pl. II), serpentinized diorite and serpentine cover the wide area, and the Mesozoic group is developed along the northern bank of the Ōya-gawa, the contact line running parallel to the river (Pl. II). The Mesozoic group here consists of clay-slate, and sandstone. The former has reddish brown colour and well-developed cleavages, and the latter is a finely granular kind.

The serpentine has usually dark greenish colour, but greenish-yellow, translucent when pure, while in Naka-mura,* a little west of Natsume, it has black colour and white patterns of some mineral. This rock has clearly altered from diorite which is occasionally found on the surface as well as in the adits. This passes into a greenish gray fine-grained rock (diorite-porphyrite) as it proceeds toward the contact-line; and near the contact, penetrating into the cleavages of the Mesozoic slate, a rock consisting of alternating bands of green and red has been produced. The slate and sandstone have silicified and mineralized with ore-minerals by the intrusion of the diorite. These two related rocks (diorite and serpentine) cover a large area running north-westward from the Prov. of Bizen† to the Prov. of Wakasa‡ presenting metallic and non-metallic ore deposits here and there. In the village of Oitomi, Tamba§ province, a garnierite deposit is observed in serpentinized diorite, the mineralized zone having a thickness of 50 feet and can be traced to a distance of 3 miles.

Natsume nickel deposits exist in the serpentinized diorite near the contact-line to which the mineralized zone runs parallel. Two faults have

*) 中村. †) 備前. ‡) 若狹. §) 丹波老富.

occurred parallel to the contact-line after the deposits had been originated and they cut the deposits longitudinally from East to West. They are observed in the Adit No. 2 (Pl. III, Fig. 2). Crushing, sliding and brecciation have occurred against the rocks and the deposits.

Under the microscope, diorite is a holocrystalline granular, sometimes showing the ophitic structure. It is composed of oligoclase, andesine, magnetite, apatite and quartz. Orthoclase is absent. Oligoclase is light brownish gray; polysynthetic twinning marked; and always remains fresh. This mineral is enclosed by hornblende crystals, or is occasionally corroded by andesine (PL. IV, Fig. 1). Hornblende is pan- or hypidiomorphic; colour, yellow-green; and shows a reticulate appearance, alteration beginning from the cracks (PL. VI, Fig. 4).

Diorite-porphyrite is a marginal phase of the diorite; shows the ophitic structure; and is composed of the phenocrysts of the lath-shaped plagioclase and the ground mass of chlorite together with the partly altered hornblende (PL. VI, Fig. 3). Secondary calcite is also present. This rock often shows the micro-spheroidal structure consisting of the kernel of the same rock and the shell of quartz (PL. VII, Fig. 2).

Serpentine in thin section, is colourless or light green, a transparent fibrous variety. Occasionally pyrrhotite and arsenopyrite present along the cleavage planes of hornblende (now altered), and magnetite inclosed in the same crystal (PL. VI, Fig. 4). This rock has clearly altered from diorite. PL. VI, Fig. 2 shows the hornblende changing into serpentine, and PL. VI, Fig. 4 the three individual crystals of hornblende which have now changed to serpentine. Black minerals in Fig. 4, same plate, are pyrrhotite of the second generation replacing the hornblende along the cleavage planes and at the margins.

III. Ore deposits.

1. In general.

The serpentine has been mineralized along the contact-line. Crossing this mineralized zone five adit-levels have been driven for the purpose of prospecting the deposits by the Fujita mining company (PL. III, Fig. 1–5).

Of these adits, No. 2 is the most developed one by which 120 feet of serpentine and 60 feet of the Mesozoic rocks were cut. At points 70 feet and 90 feet from the entrance, two E-W parallel faults are observed. These faults are also seen in the other adits, except in No. 5.

The two offsets running eastward in the Adit No. 2 (PL. III, Fig. 2) have been driven along these fault-lines which are filled with white clay together with fault-pebbles. Affected the faulting, rocks of both sides were crushed, but no remarkable change has been made among the sedimentary rocks. In the crushed zone, 70 feet in width, the rocks altered into green clay while the ores and other resistant minerals have remained as pebbles. Northward from a point about 130 feet from the entrance, serpentine stands without change.

Magnetite, pyrrhotite, arsenopyrite, and chalcopyrite are the most abundant and widespread, and found in every part of the adits. Niccolite associated with arsenopyrite is present only in the crushed zone, especially in that between the two faults. There remains now an open stope in place of the bonanza. The faults, however, have no relation to the origin of the deposits at all, the former being younger.

The most important part of the deposits has been broken by the fault movements and changed into clays and pebbles as stated before. Clays are derived chiefly from feldspars, serpentine and other ferro-magnesian minerals; have white colour along the fault-lines; and green in the distant part. Pebbles were produced by the brecciation chiefly of the metallic minerals, quartz and other undecomposed parts of the rocks. In the pebbles rich in niccolite, the nickel content is 30–40 per cent; in those of barren serpentine it is very poor, below 0.1 per cent. The author studied the characters of the ores by means of the pebbles and boulders collected from various parts of the mineralized zone. The pebbles and boulders have varying sizes, ranging from ½ inch to 20 feet in diameter, and consist of ores and serpentine. Niccolite occurs associated with arsenopyrite in spheroidal form with concentric shells.

The diameters of the spheroids vary from a fraction of an inch to one foot. The thickness of the shells also varies from a microscopic width to several inches. The centres of the spheroids usually do not coincide with those of the pebbles (PL. IV and V). Two or more spheroids are often present in one pebble (PL. V, Fig. 1). Each shell is composed of niccolite, arsenopyrite, serpentine and magnetite, and differs in colour, composition and structure from the others.

Besides, niccolite also occurs in granular form associated with arsenopyrite, pyrrhotite, chalcopyrite, magnetite and calcite. Pyrrhotite is usually found in the outside of the spheroids, but rarely making a kernel of the latter. Pyrrhotite and chalcopyrite are intergrown with arsenopyrite in the outer shells of the spheroids. Pyrite and galena occur in the quartz stringers. Zincblende has no definite home but usually occurs in magnetite mass cutting it by vein form.

2. Mineralography.

Niccolite.

Niccolite occurs in spheroidal form with arsenopyrite or in granular form with chalcopyrite, arsenopyrite, pyrite and others.

a) Spheroidal niccolite:

The chief minerals forming the spheroids are niccolite and arsenopyrite; and the subordinate serpentine and magnetite. A typical spheroidal ore, observed in the section cut by the plane passing the centre of the spheroid, is composed of concentric alternating layers or shells of gray and pink (PL. IV, Fig. 1 and 2). The gray shell is a layer of the solid arsenopyrite with or without the inclusion of minute grains of niccolite and serpentine (PL. VIII, Fig. 1). The pink one (or sometimes grayish pink) is a layer consisting of the radiated prismoids of niccolite, the interstices of which are filled with and replaced by arsenopyrite (PL. VIII, Fig. 3 and 4). When the replacement of niccolite by arsenopyrite advances, a beautiful network is produced (PL. VII,

Fig. 4), and still more advances, the "micrographic structure" (PL. VIII, Fig. 4). In the section cut tangentially to a spheroid, a niccolite prismoid shows the polygonal section, and arsenopyrite has been deposited and replaces niccolite at the margin, thus showing also the network (PL. XIV, Fig. 4). This network apparently cannot be distinguished from that in the section cut by the plane passing the centre of the spheroid, but in the former case, the meshes show a nearly regular polygonal form, while in the latter, they are elongated parallel to the radii of the spheroid (PL. VII, Fig. 4). We are now going to explain the characters of the most typical spheroids in detail.

Specimen No. 1, (PL. IV, Fig. 1) a fault pebble, natural shape; the cut and polished surface is shown.

1, kernel, colour pink. Under the microscope, arsenopyrite presents itself in fine grains embedded in niccolite, the two minerals showing the "micrographic structure" (PL. XI, Fig. 3).

2, colour steel gray, and macroscopically radiated structure. Under high magnification, granular aggregation of arsenopyrite and serpentine, the latter inclosing the magnetite grains. Arsenopyrite replaces the two (PL. VII, Fig. 3).

3, steel gray, compact aggregate of arsenopyrite. Niccolite grains are also seen replaced by the former (PL. VIII, Fig. 1).

4, same as 2.

5, Pink, compact structure. Under the microscope, a network of arsenopyrite in niccolite, the latter replacing the former (PL. VII, Fig. 4).

6, same as 4.

7, same as 5.

8, same as 2.

9, Pink, compact structure. Under the microscope, rounded grains of arsenopyrite are present in niccolite. Microscopic subspheroidal structure is seen (PL. VIII, Fig. 2).

Specimen No. 2, (PL. IV, Fig. 2) a fault pebble, natural form, cut and polished surface is shown.

1, pink, granular structure. Under the microscope, arsenopyrite grains are visible embedded in serpentine.

2, gray, radiated structure. Under the microscope, niccolite and arsenopyrite occur in " micrographic intergrowth." The arsenopyrite replaces niccolite and chalcopyrite simultaneously (PL. IX, Fig. 2).

3, pinkish gray, radiated structure. Under the microscope, " graphic structure " of niccolite and arsenopyrite is shown.

4, same as 3.

5, same as 3.

6, same as 4.

7, same as 3.

8, Outside of the spheroid. Arsenopyrite, chalcopyrite and serpentine are present here.

Specimen No. 3, (PL. V, Fig. 3) fault pebble, natural form, cut and polished surface is shown.

1, Outside of the spheroid. Under the microscope, chalcopyrite and pyrrhotite grains embedded in serpentine are seen, the last corroding the former two (PL. X, Fig. 1).

2, Under the microscope, the radiated arsenopyrite replaces chalcopyrite (PL. IX, Fig. 2).

8, Pink colour, Under the microscope, a typical radiated structure of niccolite and arsenopyrite is developed, the latter mineral replacing the former (PL. VIII, Fig. 3 and 4),

Specimen No. 4, (PL. IV, Fig. 3) a fault pebble, natural form, broken surface is shown. This specimen is of seemingly granular structure.

1, serpentine, barren. The outside of the spheroid.

2, Gray, compact structure. Under the microscope, indistinct radiated structure of niccolite and arsenopyrite is seen. The two minerals intergrow micrographically. (PL. IX, Fig. 1).

3, Gray, macro-granular and "micrographic" structure by niccolite and arsenopyrite is observed, the latter replacing the former (PL. XI, Fig. 3).

4, kernel. Intergrowth of chalcopyrite, arsenopyrite, niccolite and serpentine. Under the microscope, serpentine replaces chalcopyrite, and arsenopyrite replaces niccolite and serpentine simultaneously (PL. XII, Fig. 5).

Specimen No. 5, (PL. V, Fig. 2) fault pebble, cut and polished surface is shown.

1, Kernel, Steel gray, compact structure. Under the microscope, "graphic intergrowth" of niccolite and arsenopyrite is seen (PL. IX, Fig. 1).

2, The second shell. Pink, macro- and "micrographical," radiated intergrowth of niccolite and arsenopyrite, the latter replacing the former (PL. VIII, Fig. 4).

3, The third shell, Same as 1.

4, The outside of the spheroid. Intergrowth of chalcopyrite and arsenopyrite, the latter replacing the former.

Specimen No. 6, (PL. V, Fig. 1), a fault pebble, broken surface is shown. This specimen consists of three spheroids, the upper, lower and lower right.

1, Pinkish gray, macro- and microscopically radiated structure of arsenopyrite and niccolite. The niccolite, at first, replaced by calcite, then calcite replaced by arsenopyrite (PL. XIII, Fig. 2).

2, Bronze yellow, macro-compact granular pyrrhotite of the second generation, replacing the older minerals.

3, Grayish black, but turns steel gray by polishing. Macroscopically compact granular structure, and microscopically fine-granular arsenopyrite replacing calcite (PL. XIII, Fig. 3). When it tarnishes it is often mistaken for chromite viewed with the naked eye.

4, Calcite replacing pyrrhotite of the second generation and replaced by arsenopyrite. In the latter case, arsenopyrite shows the crystal structure of the calcite, (PL. XIII, Fig. 3).

b) Granular niccolite:

Niccolite rarely occurs in massive form, mixing with chalcopyrite, pyrrhotite, arsenopyrite and serpentine. In this case, niccolite can not be found with the naked eye. Under the microscope, niccolite is intimately associated with arsenopyrite, inclosed by the latter. In PL. XIV, Fig. 2, irregularly formed niccolite grains are incosed in arsenopyrite replaced by the latter. In PL. XIII, Fig. 4, niccolites with arsenopyrite shells are imbedded in chalcopyrite, and in PL. XIV, Fig. 2, in pyrrhotite. In the above mentioned cases, two stages of replacement are assumed, that is, niccolite by arsenopyrite and arsenopyrite by chalcopyrite or pyrrhotite.

The aggregate of niccolite and arsenopyrite has macroscopically a different colour depending upon the amount of each component. Thus when niccolite predominates over arsenopyrite, the colour tends towards pink, while when arsenopyrite is more in amount, the colour tends towards gray. Notwithstanding that the proper colour of arsenopyrite is tin-white, it appears blue§ by illusion under the microscope when it is intimately intergrown with niccolite.

Though niccolite always associates with arsenopyrite, the generations and origins of the two minerals are different. Niccolite has no inclusion of serpentine, while arsenopyrite not only usually has it, but replaces it (PL. VII, Fig. 3; PL. IX. Fig. 4; PL. X, Fig. 4; PL. XI, Fig. 3 and PL. XII, Fig. 4).

When niccolite, arsenopyrite and serpentine occur together, the serpentine is always inclosed and replaced by arsenopyrite, while niccolite not only is free from serpentine (PL. VIII, Fig. 3 and 4; PL. IX, Fig.

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§) The eye-nerve being paralyzed by the bright pink colour of niccolite, the complementary colour (blue) appears on the white arsenopyrite. This defect can be taken off by etching with concentrated nitric acid. On etching, niccolite easily turns dark brown while arsenopyrite remains bright.

1; PL. XI, Fig. 3 and PL. XII, Fig. 4), but often is corroded by serpentine (PL. XI, Fig. 3), From the evidence above mentioned, it is assumed that the niccolite may be older than serpentine and is of magmatic orign, and the arsenopyrite younger than the same rock and of hydrothermal origin. The discussions that the arsenopyrite is a hydrothermal mineral are described in the later article.

As niccolite occurs only in spheroids associated with calcite, serpentine and arsenopyrite or enclosed by the latter in mixed ore, and as it has not been discovered in any other place, its relations to other minerals than these cannot be clearly affirmed.

Arsenopyrite.

Arsenopyrite also occurs in massive form free from niccolite or in mixture with chalcopyrite, pyrrhotite, serpentine, calcite and magnetite. Where this mineral presents itself free from other minerals, it has an idiomorphic form and occasionally develops the zonal structure by etching with nitric acid (PL. X, Fig. 4). This mineral replaces serpentine, chalcopyrite, pyrrhotite, magnetite, calcite and niccolite, and is replaced by chalcopyrite and pyrrhotite of the second generation. PL. VII, Fig. 3 shows the replacement of serpentine and magnetite by arsenopyrite; PL. IX, Fig. 2 arsenopyrite cutting niccolite and chalcopyrite simultaneously in fine veins. In PL. IX, Fig. 3 arsenopyrite runs along the boundaries of niccolite and chalcopyrite, replacing the two. Fig. 4 in the same plate arsenopyrite replaces chalcopyrite and serpentine. A part of a thin (about 1 c.m.) calcite vein carrying arsenopyrite is enlarged in PL. XI, Fig. 1 in which long slender pyrrhotite crystals are replaced by calcite. In PL. XI, Fig. 2 in which a part of PL. XI, Fig. 1 has been highly magnified, arsenopyrite replaces pyrrhotite and calcite, the action beginning from the boundaries of the two minerals. In PL. XIII, Fig. 2 arsenopyrite replaces calcite which replaces niccolite in turn. Where the replacement of calcite by arsenopyrite has gone freely, the latter often keeps the structure of the replaced crystal. PL. XIII, Fig. 3 shows that the cleavages of calcite remain in arsenopyrite crystals.

Magnetite.

Magnetite is the most widespread and the oldest mineral, and occurs throughout the ore deposits. It is occasionally corroded by serpentine (PL. VII, Fig. 1 and 3; PL. X, Fig. 3). In PL. VII, Fig. 1 magnetite shows its crystal form somewhat rounded at the margin by the corrosion of serpentine. This suggests that magnetite is older than serpentine.

Pyrrhotite and chalcopyrite are present in two generations. The crystallization of the minerals of the first generation occurred before the consolidation of the rock silicates, and those which belong to the second generation after the consolidation of the silicates. Pyrrhotite is always older than chalcopyrite in either generation.

Pyrrhotite of the first generation.

This is clearly of magmatic origin and corroded or replaced by the minerals of later birth. PL. X, Fig. 1 shows serpentine corroding pyrrhotite and chalcopyrite§ showing an appearance resembling that of quartz porphyry, and PL. X, Fig. 3, PL. XII, Fig. 3 and PL. XIV, Fig. 1 show serpentine corroding pyrrhotite. PL. XIII, Fig. 3 shows calcite replacing pyrrhotite. PL. XI, Fig. 2 shows pyrrhotite replaced by arsenopyrite at first and then by calcite.

Pyrrhotite of the second generation.

This is hydrothermal in origin and replaces the older minerals. PL. VI, Fig. 4 shows the pyrrhotite of the second generation replacing hornblende in diorite, the action beginning along the cleavage planes. This mineral often occurs in minute flakes in the small fissures of serpentine. In this case, it has a pinkish bronze colour and is often mistaken for niccolite.

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§) "Pyrrhotite" and "chalcopyrite" in this article mean those of the first generation.

Chalcopyrite of the first generation.

This occurs with pyrrhotite* and is magmatic in origin. PL. IX, Fig. 2 and 3 show the chalcopyrite replaced by niccolite and cut by the fine veins of arsenopyrite, and Fig. 4 chalcopyrite corroded by serpentine and replaced by arsenopyrite. PL. X, Fig. 1 shows chalcopyrite corroded and cut by serpentine.

Chalcopyrite of the second generation.

This is hydrothermal in origin. PL. X, Fig. 2 shows chalcopyrite† replacing pyrrhotite and serpentine, and PL. XII, Fig. 1 chalcopyrite replaced by calcite. PL. XIII, Fig. 4 shows chalcopyrite replacing arsenopyrite.

The minerals explained below are considered to have originated from hydrothermal solutions.

Calcite.

This is very rare. It replaces pyrrhotite (PL. V, Fig. 1 and PL. XIII, Fig. 3) arsenopyrite (PL. XI, Fig. 2) niccolite (PL. XIII, Fig. 2) and is replaced by arsenopyrite (PL. XIII, Fig. 3).

Zincblende.

This mineral has black colour, and may often be taken for chromite. It is very rare and makes fine veins in serpentine and magnetite masses. It is replaced by galena (PL. XII, Fig. 2).

Quartz.

Very rare. It plays no important rôle in the ore deposits. It occurs as stringers and is rarely cut by pyrite stringers (PL. XIV, Fig. 3) or replaces chalcopyrite (PL. XII, Fig. 1).

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*) "Chalcopyrite" and "pyrrhotite" in this article mean those of the first generation.
†) "Chalcopyrite" in this article means that of the second generation.

Galena.

Very rare. It presents itself in minute specks associated with zinc blende and replaces the former (PL. XII, Fig. 2).

Pyrite.

Very rare. It occurs associated with quartz. It shows a crystal form and rarely cuts quartz in minute veins (PL. XII, Fig. 3).

3. Origins of the ores and their associated minerals.

Of the minerals mentioned in the previous articles, magnetite, pyrrhotite and chalcopyrite of the first generation, niccolite as well as the rock silicates are considered to have been crystallized from molten magma, and the others originated from hydrothermal solutions. As for the origins of the rocks silicates we need not here touch on them.

The evidence that suggests the origins of arsenopyrite, zincblende quartz galena, pyrite and calcite are as follows:

1. Quartz is undoubtedly hydrothermal in origin, because it is entirely absent in serpentine and diorite as their primary constituent mineral, but is present in fine veins cutting serpentine diorite and the metamorphic slate.
2. Calcite and galena are well-known hydrothermal minerals, and need no farther explanation.
3. As zincblende occurs in fine veins cutting serpentine, perhaps it is also of hydrothermal origin.
4. As arsenopyrite and pyrite replace calcite and quartz respectively, these two are also hydrothermal ores.
5. Pyrrhotite and chalcopyrite of the second generation which replace arsenopyrite must also be of the same origin.

The following evidence suggests the origins of magnetite, niccolite, pyrrhotite and chalcopyrite of the first generation:

1. As magnetite, niccolite, and pyrrhotite and chalcopyrite of the first generation crystallized earlier than the rock silicates and

were corroded by the latter, these are undoubtedly of magmatic origin.

2. Serpentine has never been inclosed in the above mentioned minerals.
3. As these minerals do not associate with quartz and calcite, they have no intimate relations with hydrothermal action.
4. These minerals have never been found in either the sedimentary or the metamorphic rocks, while the hydrothermal minerals zincblende, arsenopyrite, quartz, galena, pyrite and calcite are found in the same rocks.

4. Sequence of the minerals.

The observed microscopical relations could all be satisfied if the minerals had been deposited in the order given below:

Magmatic	Magnetite.	oldest
	Pyrrhotite of the first generation.	
	Chalcopyrite of the first generation.	
	Niccolite.	
	Rock silicates.	
Hydrothermal	Calcite.	
	Arsenopyrite.	
	Calcite.	
	Pyrrhotite of the second generation.	
	Chalcopyrite of the second generation.	
	Quartz.	
	Pyrite.	
	....	
	Zincblende (proper situation unknown).	
	Galena (proper situation unknown).	

Calcite continued its crystallization until arsenopyrite had crystallized. Of the hydrothermal minerals, the stuations of zincblende and galena are unknown because their relations to other minerals could not be positively ascertained.

5. Micrographic intergrowth of niccolite and arsenopyrite.

That niccolite and arsenopyrite show together the "micrographic intergrowth" in the spheroids has been explained before.

Two kinds of graphic intergrowth are known among us. One of the kinds is the primary intergrowth which clearly indicates the simultaneous crystallization of the two minerals involved and may be interpreted as a eutectic mixture. The other is the secondary or graphic intergrowth due to replacement. This is produced by the replacement of one mineral by another.

The first kind is found in very many abyssal and hypabyssal igneous rocks, and occationally in sulphide aggregations. Laney[4], Gilbert and Pogue[5], Graton and Murdoch[6], Ray[7] describe their investigations of the ores of this intergrowth.

The second kind is very often found in the secondary enriched copper minerals. Rogers[8], Segall[9], and Whitehead[10] give good examples of this type.

The "graphic intergrowth" of niccolite and arsenopyrite in the spheroidal ores of the Natsume mine clearly belongs to the second kind. The structure is invisible with the unaided eye. Under the microscope, the "graphic intergrowth" highly resembling that in rocks is easily observed. (PL. VIII, Fig. 4; PL. IX, Fig. 1 and PL. XI, Fig. 3). Thus one may believe the simultaneous crystallization of the two minerals. Not only, however, have they been determined to be of different ages by mineralographic examinations, but under high magnifications, undoubted metasomatic relation appears. The following descriptions suggest the character of the intergrowth:

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4) Laney, F. B., Proc. of U. S. Nat. Museum, Vol. 40, p. 520, Economic Geol., Vol. 6, p. 397.
5) Gilbert, C. C., and Pogue, G. E., Proc. of U. S. Nat. Museum, Vol. 45, pp. 609–625.
6) Graton, L. C., and Murdoch, J., Trans. Am. Inst. Min. Eng., Vol. 45, p. 768.
7) Ray, J. C., Economic Geol., Vol. 9, No. 5, p. 479.
8) Rogers, A. F., Mining and Scientific Press, Oct. 31, 1914, p. 686.
9) Segall, J., Economic Geol., Vol. 10, No. 5, p. 649.
10) Whitehead, W. L., Economic Geol., Vol. 11, No. 1, pp. 6–10.

1. Arsenopyrite and niccolite are variable in amount in different parts of the same specimen.
2. Arsenopyrite sometimes makes a network in niccolite. PL. VII, Fig. 4 and PL. VIII, Fig. 1 show the network of arsenopyrite, the net being delivered from the solid arsenopyrite layer.
3. Graphic arsenopyrite often has inclusions of niccolite grains. PL. VIII, Fig. 3 shows a part of a shell in a spheroid in which niccolite grains are inclosed.
4. In the spheroidal ores, niccolite always intergrows with arsenopyrite, while the latter occasionally occurs free from the former. This shows the excess of arsenopyrite. That the arsenopyrite crystallized later than niccolite has already been proved. These facts do not agree with the eutectic law that the excess component in a eutectic mixture crystallizes first.
5. Arsenopyrite in the graphic aggregate shows irregular embayments and occasionally connected with fine veins crossing the niccolite. This suggests the replacement of niccolite by arsenopyrite. PL. XIII, Fig. 1 and PL. XI, Fig. 4 show every appearance of replacement.
6. Where calcite is abundant in the spheroidal shell, two stages of replacement are certain. PL. XIII, Fig. 2 shows calcite replacing niccolite at first, and then replaced by arsenopyrite.

According to Whithead[11], the difference between the secondary graphic structure by chalcocite and bornite and that of a true metallic eutectic is that the veinlets in places seem to be more lenticular in the sulphide mixture and are more acutely ended; the contacts between the bornite and the intergrowth are also not smooth as between the silver and the eutectic, but veinlets of chalcocite penetrate the solid bornite and give a serrate contact. The relations resembling those between the chalcocite and the bornite are also observed in the "graphic intergrowth" in the Natsume ores (PL. XIII, Fig. 2; PL. VII, Fig. 4 and PL. VIII, Fig. 1). When

11) Whitehead, W. L., Loc. cit. pp. 6–7.

the amounts of the two minerals (niccolite and arsenopyrite) are equal, the intergrowth very much resembles the structure of the true eutectic (PL. VIII, Fig. 3 and 4; PL. IX, Fig. 1 and PL. XI, Fig. 3). When one component mineral become predominant, the intergrowth loses much of its resemblance to the eutectic structure (PL. VII, Fig. 4; PL. VIII, Fig. 1 and PL. XII, Fig. 4).

6. Origin of the spheroidal ores.

In a spheroid, niccolite is assumed to have been crystallized from magma and arsenopyrite has entered it by replacing the former. Replacement is interpreted to have occurred taking the parallel concentric fractures in the niccolite-spheroids as the accesses of the penetrating solution. Thus, in the accesses themselves where the replacement was strongest and the filling of the fractures had also occurred, solid arsenopyrite shells have been produced. On the contrary, in the zones between the fractures, as the replacement was weak the replacing solution having been derived from the solid arsenopyrite zones, and here filling has not occurred, the replacement has taken place only along the interstices of the prismoids. The structure produced in such a way must be what are shown in PL. VIII, Fig. 1, 3 and 4. When the replacement is a little more advanced, the network has been produced by the branching of the arsenopyrite, and still more advanced "graphic structure," niccolite prismoids having been cut off into irregular pieces. How the original spheroids of niccolite were built, and how the concentric fractures were made, explanations are offered in the next article.

7. Genesis of the ore deposits.

Probably at the end of the Mesozoic era, diorite intruded into the sedimentaries of the Mesozoic members. The sedimentaries, chiefly slate, was baked and silicified. At the contact, a banded rock was produced by penetration of the magma into the cleavages of the slate, and the diorite itself differentiated into diorite-porphyrite with micro-spheroidal fabric.

The diorite magma segregated the metallic minerals at the cooling part near the contact-line (PL. II).

Thus the mineralizing zone was produced at the present position. By contact action of diorite against the slate, zincblende, galena, pyrite, chalcopyrite and pyrrhotite of the second generation, quartz and calcite were produced from the hydrothermal solutions, and at the same time, diorite magma and diorite-porphyrite were serpentinized. On cooling of the diorite magma, the mineral first crystallized is magnetite. This mineral has microscopically a crystal form and was uniformly scattered in the magma (PL. VII, Fig. 1 and PL. X, Fig. 3). Thus, this mineral is found even in the minute specks of serpentine inclosed in the ore (PL. VII, Fig. 3). Crystallized next was pyrrhotite of the first generation. It corrodes magnetite and is corroded by the later minerals, especially by serpentine (PL. X, Fig. 1; PL. XII, Fig. 3 and PL. XIV, Fig. 1). Then chalcopyrite of the first generation crystallized corroding the pyrrhotite and corroded by serpentine and others (PL. X, Fig. 1 and PL. XII, Fig. 4).

Next to the crystallization of the chalcopyrite, niccolite was segregated in nodular form showing the spherulitic structure consisting of radiated prismoids of the same mineral. The prismoid has a polygonal section (PL. XIV, Fig. 4). Niccolite is also impregnated into the ores outside of the spheroids. The spherulitic structure is said to be produced by the rapid cooling of a rock magma.[12] Owing to the rapidity of cooling, concentric fractures occurred in the nodular niccolite. These fractures gave place for the penetration of arsenopyrite solution. The niccolite spherulite, being a rapid growth, caught the still fluid diorite magma within the spaces occupied by the prismoids. Iddings gives good examples of such a fabric[13]. Thus, minute specks of serpentine are always fouud in the interstices of the prismoids and never in the prismoids themselves (PL. VIII, Fig. 4 and PL. XI, Fig. 3).

After the niccolite had crystallized, on the one hand, the residual

12) Iddings, J. P., Igneous rocks, Vol. I, p. 228, 1909.
13) Loc. cit. p. 229.

magma possessing a composition corresponding to diorite, cooled and consoliated, corroding and cementing the interstices of the older ore minerals. On the other hand, the diorite penetrating into the cleavages of the slate, the metamorphic slate with green and brown bands were produced. Then, as the after action of the diorite intrusion, the hydrothermal change occurred in the intruded rocks and in diorite itself. At the contact with the Mesozoic sedimentaries, the diorite was differentiated into diorite-porphyrite showing a marked micro-spheroidal fabric. This fabric as well as the spheroidal form of the niccolite show that there was tendency towards production of the spheroidal structure in the silicate- and metallic-magmas which were differentiated from the diorite-magma.

Calcite is the first mineral formed by the hydrothermal action, but the formation continued after arsenopyrite had crystallized. Thus, it replaces and is replaced by arsenopyrite (PL. XI, Fig. 2; PL. XIII, Fig. 2 and 3).

The second mineral from the hydrothermal solution was arsenopyrite. This mineral has clearly been produced after the rock silicates because it replaces serpentine (PL. VII, Fig. 3). This mineral also replaces niccolite taking the concentric fractures in the spherulitic niccolite as its accesses of replacement. The filling of the fractures and the replacement of both sides of them also occurred simultaneously. At the fractures themselves, solid arsenopyrite layers were produced (PL. VIII, Fig. 1); and on both sides of the fractures, the beautiful radial structure of niccolite and arsenopyrite, the solution penetrating among the radiated prismoids of niccolite (PL. VII, Fig. 4 and PL. VIII, Fig. 1, 3 and 4). The specks of serpentine previously presented in the spaces between the niccolite prismoids were also replaced. Thus, the beautiful spheroidal ore with the alternating shells of the solid arsenopyrite and the radiated niccolite-and-arsenopyrite (PL. IV, and PL. V). PL. VIII, Fig. 1; PL. X, Fig. 4; PL. XIII, Fig. 1 and 2 and PL. XIV, Fig. 4 show every appearance of replacement. As has already been mentioned, when the replacement is somewhat advanced, the network of arsenopyrite is produced (PL. VII, Fig. 4); and when still more advanced, the prismoids of niccolite were cut in pieces and the "micrographic structure" is formed (PL. VIII, Fig. 4, PL. IX, Fig. 1 and PL. XI, Fig. 3). On the outside of the spheroids, arsenopyrite replaces niccolite, calcite, serpentine, and chalcopyrite and pyrrhotite of the first generation, or sometimes it formed an aggregate free from other minerals (PL. XIV, Fig. 1, 2, 3 and 4; PL. XI, Fig. 1 and 2; PL. XIII, Fig. 1, 2, 3 and 4; and PL. XIV, Fig. 2).

Then pyrrhotite of the second generation was made. This replaces hornblende, arsenopyrite and serpentine (PL. VI, Fig. 4; and PL. XIV, Fig. 2).

Next to the foregoing mineral, chalcopyrite of the second generation became consolidated. This replaces pyrrhotite of the second generation and arsenopyrite (PL. X, Fig. 2 and PL. XIII, Fig. 4).

After the crystallization of chalcopyrite, quartz was deposited in fine veins cutting diorite, serpentine, the sedimentary rocks and the metamorphic slate as well as ores, but was very small in amount.

Then pyrite crystallized in very small amount. It occasionally cuts the quartz in fine veinlets (PL. XIV, Fig. 3).

Galena, and zincblende are also hydrothermal minerals, but very rare. Galena replacing zincblende has been observed in the specimen (PL. XII, Fig. 2). But their ages cannot be positively ascertained, this being the only specimen found in the mine.

After the minerals had been made over, the strong faults transversely cut the mineralizing zone. Crushing and brecciation occurred against the deposits and the country rocks. Soft part of the deposits and rocks have been changed to clayey matter, and the hard and undecomposed parts remain as pebbles in the former. In the niccolite spheroids occasionally brecciated structure appears, the small pebbles of niccolite being cemented by pulverized niccolite and arsenopyrite (PL. V, Fig. 4). This suggests that the faults have clearly occurred after ore-formation.

After the ores had been formed, the surface water has been oxidising the outcrops and has changed the primary niccolite into annabergite in the gossans.

IV. Prof. Hirabayashi's opinions[14] on the genesis of the Natsume nickel deposits and the author's arguments against them.

Prof. Hirabayashi observed here the following minerals:

pyrrhotite	(much),	zincblende	(very little),
chalcopyrite	(fair amount),	arsenopyrite	(very little),
chromite	(fair amount),	galena	(rare),
niccolite	(little),	quartz	(little).
gersdorfite	(little),		

He states that niccolite usually occurs inclosed in pyrrhotite or associated with chromite, while gersdorfite independently forms nodules. These two minerals are clearly secondary in origin and sometimes present covering other minerals. The pink niccolite often occurs in thin films intercalated in the parallel fissures in serpentine contacting the clay veins.

On the genesis of the deposits, he thinks that at first the minerals mentioned above were concentrated in massive form in serpentine, nickel probably contained in the pyrrhotite. Afterward, nickel ores were dissolved, and on reduction of the solution, they deposited covering the pyrrhotite and chromite. The faults then crushed the deposits and they turned the ores into the nodular form. About the ages of the faults he does not give a clear explanation.

The author has not discovered chromite and gersdorfite either under the microscope or by chemical analysis. In the niccolite-arsenopyrite shells of the spheroidal ores, the component minerals cannot be detected with the naked eye and consequently when niccolite and arsenopyrite associate in favourable ratio, the niccolite may be taken for gersdorfite containing some iron.[15] The author who carefully examined many specimens of

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14) Loc. cit. p. 1053.

15) According to Dana (System of Mineralogy, 6th. edition, 1914, p. 90) gersdorfite is essentially a sulph-arsenide of nickel, $NiAsS$ or $NiS_2 . NiAs_2$. Iron replaces the nickel, often to a considerable amount.

pyrrhotite could not find a nickel mineral in them. No evidence suggesting tne secondary deposition of the nickel ore, except annabergite, has been found. Prof. Hirabayashi mentions the presence of the sliced niccolite in the fissures of serpentine, but it has been determined to be pyrrhotite of the second generation.

V. Summary and conclusions.

The Natsume nickel mine is the sole one producing the primary ore in Japan. The neighbourhood of the deposits is composed of serpentine, serpentinized diorite and Mesozoic slate and sandstone. By the contact action of the diorite the Mesozoic strata have been baked and silicified, and banded metamorphic slate has been produced near the contact. The diorite changed into diorite-porphyrite with the micro-spheroidal structure near the contact as a marginal facies. Magnetite, pyrrhotite and chalcopyrite of the first generation, niccolite as well as the rock silicates have been segregated from the diorite magma; and calcite, arsenopyrite, pyrrhotite and chalcopyrite of the second generation, quartz, pyrite, zincblende and galena have been produced by the hydrothermal action of the same magma. Serpentinization of both the diorite and diorite-porphyrite probably was derived from the same action. Cobalt and chromite are here absent. The deposits occur along the margin of the serpentine, partly of the serpentinized diorite and diorite-porphyrite.

Two faults transversely cut the deposits, and by these the ores and gangs have been changed into pebbles and clays.

Nickel weighs 40 per cent in the most concentrated ores and 0.1 to 0.01 per cent in gangs.

Niccolite at first was produced in a radiated spheroidal form. Afterward, replaced by arsenopyrite solution penetrating through the concentric fractures due to the rapid cooling, a beautiful, concentrically banded structure was produced in the spheroids. In the concentric fractures themselves where replacement and filling occurred together, the solid arsenopyrite shells formed; and on both sides of the fractures where the solution had penetrated into the interstices of the niccolite prismoids, the beautiful shells of the radiated structure. In these shells, the two minerals often show either the "graphic structure" or the network depending upon the degree of replacement. As niccolite crystallized earlier than the rock silicates and was corroded by them, it is undoubtedly of magmatic origin, and as arsenopyrite replaces calcite and quartz which are considersd to be hydrothermal minerals, it must also be hydrothermal in origin. That the niccolite is magmatic in origin and the arsenopyrite hydrothermal, is most important for classifying the Natsume nickel deposits.

Niccolite, it is known, has been formed by magmatic segregation and hydrothermal action.

The well-known example of magmatic niccolite associated with chromite is that at Malaga in Spain[16], in connection with the nickel-pyrrhotite deposits. Here the reddish niccolite has been found in serpentine and peridotite. The types of ore may be differentiated: 1, consists of a fine-grained mixture of chromite and niccolite, small grains of the former being embedded in the latter; 2, is distinguished by the amount of augite and niccolite present; and 3, by the presence of plagioclase and pyroxene in addition to the two. According to Gilman[17], there is no doubt about the magmatic segregation of both the chromite and niccolite.

Niccolite formed by hydrothermal action is found in small amount in the "Lead-silver-zinc lode" at Temiskaming[18], Canada and at Schneeberg[19]; and in the "Cupriferous siderite lodes" in the Kitzbühel district in the Tyrol[20]. At Schladming in Styria[21], fahlbands occur in schists. They are traversed by vertical quartz lodes. In the neighbourhood of and within the fahlbands, nickel ores are found in the form of nodules and nests, consisting in greater part of niccolite and niccolite-arsenopyrite. He considers these occurrences are undoubtedly hydrothermal in origin. In Worthington offset, Sadbury, niccolite is present in small amount. Accord-

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16 and 17) Gilman, F., "Notes on the Ore deposits of Malaga Serpentines," Trans. Inst. Mining and Metal., pp. 159–165. 1896.

18, 19, 20 and 21) Beyschlag, Vogt and Krusch, "Ore Deposits" Transl. by Truscott, Vol. I, pp. 667, 680, 907 and 948 respectively.

ing to Coleman[22], this is probably deposited by circulating water and accompanied by quartz as a gang mineral. In Inshizwa, niccolite occurs in dolerite dykes cutting the main sheets and occasional arsenides of the same series of metals. According to Goodchild[23], the niccolite appears to have been introduced after the consolidation of the dykes, for it is associated with alteration products of a seemingly secondary character. It may have resulted from arsenical pneumatolysis.

Thus, the nickel deposits of Natsume establishes a new type, which belongs neither to the "Niccolite-chromite type," nor to the "Hydrothermal lode type."

The author is greatly indebted to Prof. Hiki of Kyoto Imperial University for numerous valuable advice; to Mr. R. Kimura of the Geological Survey of Japan for the examinations of the rock slides; to Mr. M. Waki of the Chemical and Geological Laboratory of the Fujita Mining Company for the photomicrographic work and other kind assistance, and lastly Mr. T. Oyama for the drawings of the maps.

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22) Coleman, A. P., "Nickel Industry" p. 46.
23) Goodchild, W. H., Loc. cit. p. 50.

Explanations of the Plates.

PLATES IV.

Fig. 1. Ore spheroid (fault pebble).

Each shell differs in colour depending on the amount of niccolite.

Cut and polished. × 1.5 diam.

1. Pink colour,, radiated aggregate of niccolite and arsenopyrite.

2, 4, 6 and 8. gray colour, granular aggregate of arsenopyrite and serpentine. A small amount of niccolite presents itself also.

3. gray colour, compact aggregate of arsenopyrite.

5 and 7. pink colour, radiated aggregate of arsenopyrite and niccolite.

9. pinkish gray granular arsenopyrite in niccolite.

Fig. 2. Ore spheroid (fault pebble). Cut and polished.

1, 5 and 7. Colour pink, radiated aggregate of niccolite and arsenopyrite.

2, 3, 5 and 6. Colour gray, radiated aggregate of nlccolite and arsenopyrite.

4. Colour gray, granular arsenopyrite in serpentine.

8. arsenopyrite and chalcopyrite grains in serpentine.

× $\frac{2}{3}$ diam.

Fig. 3. Ore spheroid (fault pebble), Cut and polished.

The banded appearance is very indistinct in this specimen.

1. Serpentine.

2, 3 and 4. Granular aggregate of niccolite and arsenopyrite.

5. Chalcopyrite in serpentine.

× $\frac{1}{3}$ diam.

Fig. 4. Fault pebble. This photograph shows the mode of occurrence of ores in serpentine. Cut and polished.

Sp. = serpentine. Ca. = secondary calcite. Sph. = pyrrhotite, arsenopyrite and limonite.

× $\frac{3}{5}$ diam.

PLATE V.

Fig. 1. The ore composed of the three spheroids. Broken surface.

1. Colour pinkish gray, radiated structure of arsenopyrite and niccolite associating with calcite.
2. Bronze yellow colour, granular pyrrhotite of the second generation.
3. Colour grayish black, compact granular structure by arsenopyrite and calcite.
4. Calcite replacing pyrrhotite of the second generation and replaced by arsenopyrite.

Natural size.

Fig. 2. Ore spheroid (fault pebble). Cut and polished. ×2.

1. Kernel, steel gray colour, compact intergrowth of niccolite and arsenopyrite.
2. Colour pink, radiated intergrowth of niccolite and arsenopyrite.
3. The outside of the spheroid. Intergrowth of chalcopyrite and arsenopyrite.

Fig. 3. Ore spheroid (fault pebble). Cut and polished. ×2.

1. Chalcopyrite and pyrrhotite grains in serpentine.
2. Radiated arsenopyrite replacing chalcopyrite.
3. A typical radiated structure by niccolite and arsenopyrite.

The section cut along the A-B, has been magnified in PL. XIV, Fig. 4.

Fig. 4. Brecciated ore produced by faulting action. Cut and polished. Angular ore (niccolite and arsenopyrite) fragments are cemented with finer fragments of ores and serpentine.

1 and 3 = finely ground zone. 2 = coarsely ground zone. ×2.

PLATE VI.

Fig. 1. Diorite.

Ol = oligoclase. An = andesine. H = hornblende.

Parallel Nicols. Magnif. 100 diam.

Fig. 2. Serpentinized diorite.
Sp=serpentine altered from hornblende. H=hornblende.
F=feldspar. Parallel Nicols. Magnif. 82 diam.

Fig. 3. Diorite-porphyrite.
White, lath-shaped=feldspar. Gray, rough=hornblende filling the interstices of the feldspars. Black=ores. Parallel Nicols.
Magnif. 82 diam.

Fig. 4. Serpentine altered from diorite.
The outlines of the three original hornblende crystals are recognized by the different orientations of the sieve structure. Black-pyrrhotite of the second generation.
Parallel Niccols. Magnif. 51 diam.

PLATE VII.

Fig. 1. Magnetite crystal in serpentine.
Black-magnetine. Sp=serpentine.
Parallel Nicols. Magnif. 115 diam.

Fig. 2. Diorite-porphyrite with microscopic spheroids.
The kernel is the same rock outside of the spheroids and the shells quartz.
Crossed Nicols. Magnif. 50 diam.

Fig. 3. Serpentine associated with magnetite grains replaced by arsenopyrite. The shell 2 in PL. I, Fig. 1 has been enlarged.
Mg=magnetite. Sp=serpentine. Ar=arsenopyrite.
Vertical illumination. Magnif. 170 diam.

Fig. 4. Network of arsenopyrite in niccolite. Under the higher magnification, the two minerals intergrow in graphic structure. This figure is the magnified photomicrograph of the shell 1 in PL. IV, Fig. 1.
Vertical illumination. Magnif. 70 diam.
The arrow-head points to the centre of the spheroid.

PLATE VIII.

Fig. 1. The shell 3 of Specimen No. 1 shown in PL. IV, Fig. 1 and

both sides of it have been enlarged. Horizontal broad band in middle is the shell 3 consisting of arsenopyrite. This band has been produced by filling, together with replacement of a concentric fracture. The residual niccolite nuclei are seen remaining as inclusions. Both sides of the arsenopyrite band are the radiated intergrowth of niccolite and arsenopyrite which has been formed by the replacement of niccolite by arsenopyrite, the replacing solution delivered from the middle arsenopyrite zone, formerly a concentric fracture, penetrating into the spaces between the radiated prismoids of niccolite.

Etched with nitric acid.

Gray and white (Ar)=arsenopyrite. Black and dark (Ni)=niccolite.

Vertical illumination. Magnif. 170 diam.

The arrow-head points to the centre of the spheroid.

Fig. 2. The shell 9 in PL. IV, Fig. 1 has been magnified.

The microscopic sub-spheroids are shown.

Black=niccolite. Lighter-arsenopyrite.

Etched with nitric acid. Vertical illumination.

Magnification 70 diam. The arrow-head points to the centre of the spheroids.

Fig. 3. A typical radiated structure of niccolite and arsenopyrite. 3 in PL. V, Fig. 3 has been magnified.

Etched with nitric acid. Black=niccolite. White, and radial=arsenopyrite. Vertical illumination.

Magnif. 70 diam. The arrow-head points to the centre of the speroids.

Fig. 4. Fig. 3 has been highly magnified.

Not etched. "Micrographic intergrowth" of niccolite and arsenopyrite is seen.

Ni=niccolite. Ar=arsenopyrite. Sp=serpentine.

Vertical illumination. Magnif. 150 diam.

The arrow-head points to the centre of the spheroids.

PLATE IX.

Fig. 1. "Micrographic intergrowth" of niccolite and arsenopyrite. 2 in Pl. V, Fig. 2 has been enlarged. Graphic form=niccolite. Ground=arsenopyrite. Vertical illuminatiod. Magnif. 70 diam. The arrow-heah points to the centre of the spheroid.

Fig. 2 and 3.
Arsenopyrite replacing chalcopyrite and niccolite simultaneously.
Ch=chalcopyrite. Ni=niccolite. Ar=arsenopyrite.
Etched with nitric acid.
Vertical illumination. Magnif. 70 diam.

Fig. 4. Arsenopyrite replacing chalcopyrite and serpentine.
Ar=arsenopyrite. Ch=chalcopyrite. Sp=serpentine.
Vertical illumination. Magnif. 70 diam.

PLATE X.

Fig. 1. Chalcopyrite and pyrrhotite corroded by serpentine.
Prh=pyrrhotite. Ch=chalcopyrite. Sp=serpentine.
Vertical illumination. Magnif. 70 diam.

Fig. 2. Pyrrhotite of the second generation replaced by chalcopyrite of the same generation.
Prh=pyrrhotite. Ch=chalcopyrite. Sp=serpentine.
Vertical illumination. Magnif. 70 diam.

Fig. 3. Pyrrhotite and Magnetite in serpentine.
White=pyrrhotite. Black=intergrowth of magnetite and serpentine. Gray=serpentine. This black part observed with transmitted light is shown in PL. VII, Fig. 1.
Vertical illumination. Magnif. 70 diam.

Fig. 4. Zonal structure of arsenopyrite.
Black spots are inclusions of serpentine.
Vertical illumination. Magnif. 70 diam.

PLATE XI.

Fig. 1. Arsenopyrite and pyrrhotite replaced by calcite.

White elongated=arsenopyrite, pyrrhotite or aggregates of the two minerals. Black=calcite.

Vertical illumination. Magnif. 70 diam.

Fig. 2. Same as Fig. 1, but highly magnified.

Pyrrhotite corroded by arsenopyrite, and calcite replaces these two minerals.

Ar=arsenopyrite. Prh=pyrrhotite. Black=calcite.

Vertical illumination. Magnif. 135 diam.

Fig. 3. "Graphic intergrowth" of niccolite and arsenopyrite.

Ni=niccolite. Ar=arsenopyrite. Black=serpentine.

Vertical illumination. Magnif. 70 diam.

Fig. 4. Arsenopyrite replacing niccolite in irregular veinlets.

Black=niccolite. White=arsenopyrite. Etched with nitric acid.

Vertical illumination. Magnif. 70 diam.

PLATE XII.

Fig. 1. Chalcopyrite replaced by quartz.

Ch=chalcopyrite. Dark=quartz.

Vertical illumination. Magnif. 70 diam.

Fig. 2. Galena replaces zincblende, the former penetrating the latter acicularly.

Gl=galena. Black=serpentine. Zn=zinc blende.

Vertical illumination. Magnif. 70 diam.

Fig. 3. Pyrrhotite corroded by serpentine.

Prh=pyrrhotite. Black and gray=serpentine.

Vertical illumination. Magnif. 70 diam.

Fig. 4. Arsenopyrite replacing serpentine and niccolite, and chalcopyrite replaced by serpentine are shown.

Ch=chalcopyrite. Ar=arsenopyrite. Ni=niccolite. Black=serpentine.

Vertical illumination. Magnif. 70 diam.

PLATE XIII.

Fig. 1. Replacement of niccolite by arsenopyrite.

Radially arranged arsenopyrite veins are connected with fine veinlets of the same mineral. The arrow-head points to the centre of the spheroid.

White (Ar) = arsenopyrite. Dark = niccolite.

Etched with nitric acid. Vertical illumination. Magnif. 90 diam.

Fig. 2. Replacement of niccolite by calcite, then calcite replaced by arsenopyrite, the replacement by arsenopyrite biginning from the boundaries of niccolite and calcite.

Ni = niccolite. White = arsenopyrite. Black part in the middle of arsenopyrite veins is calcite.

Etched with nitric acid. Magnif. 90 diam.

The arrow-head points to the centre of the spheroid.

Fig. 3. Calcite replacing pyrrhotite; and arsenopyrite replacing calcite are shown. The cleavages of calcite are observed in the arsenopyrite. Slightly etched with nitric acid to develop the structure.

Ar = arsenopyrite. Ca = calcite. Prh = pyrrhotite.

Vertical illumination. Magnif. 90 diam.

Fig. 4. Granular niccolite ore. Arsenopyrite replaces niccolite, then is replaced by chalcopyrite of the second generation. Thus, the niccolite possessing the arsenopyrite shells has been embedded in chalcopyrite.

Ni = niccolite. Ar = arsenopyrite. Ch = chalcopyrite.

Etched with nitric acid. Vertical illumination. Magnif. 70 diam.

PLATE XIV.

Fig. 1. Pyrrhotite of the first generation corroded by serpentine.

Prh = pyrrhotite. Sp = serpentine.

Vertical illumination. Magnif. 70 diam.

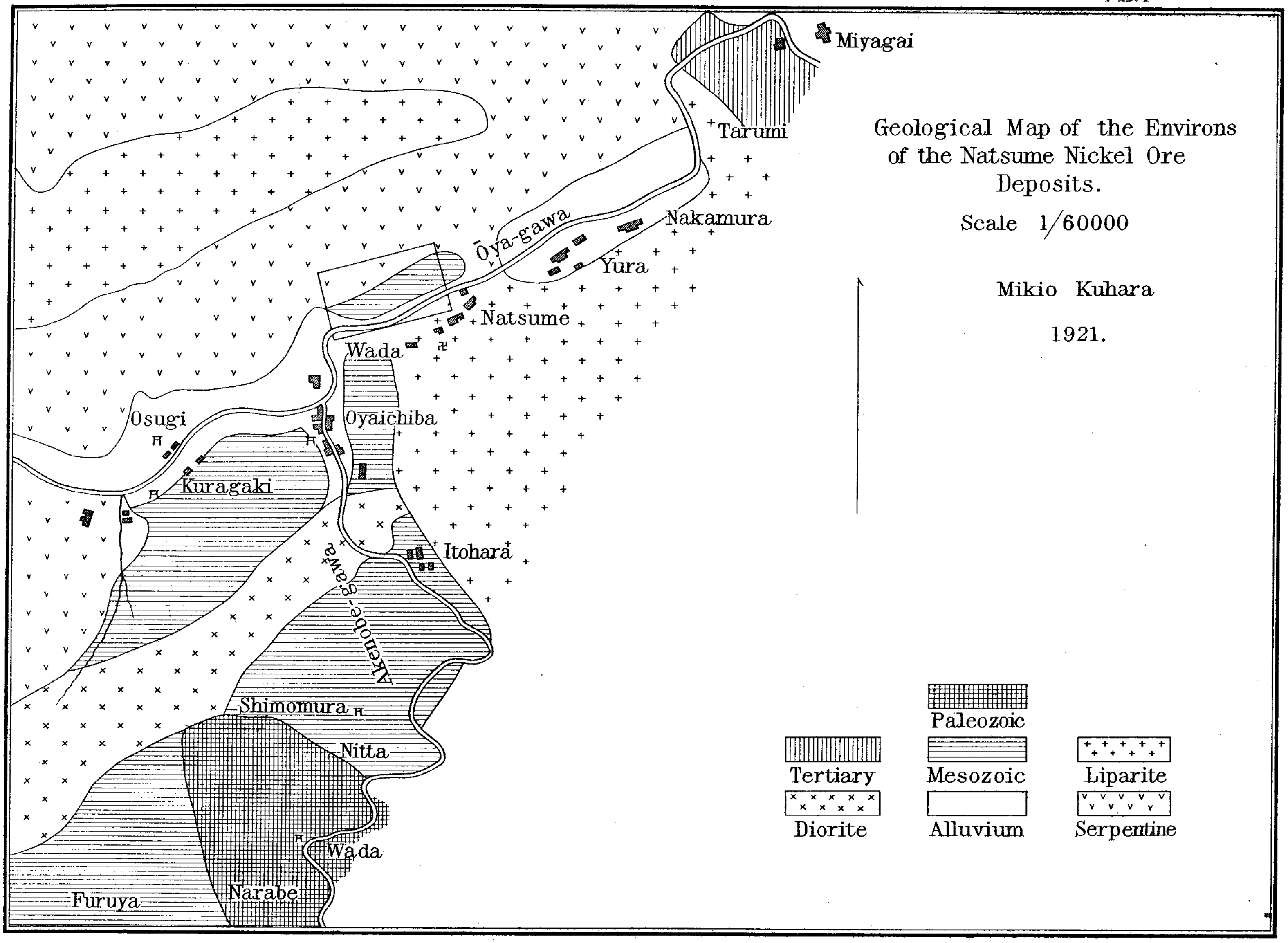
Fig. 2. Arsenopyrite replaces niccolite, then is replaced by pyrrhotite of the second generation. Thus, the arsenopyrites possessing the

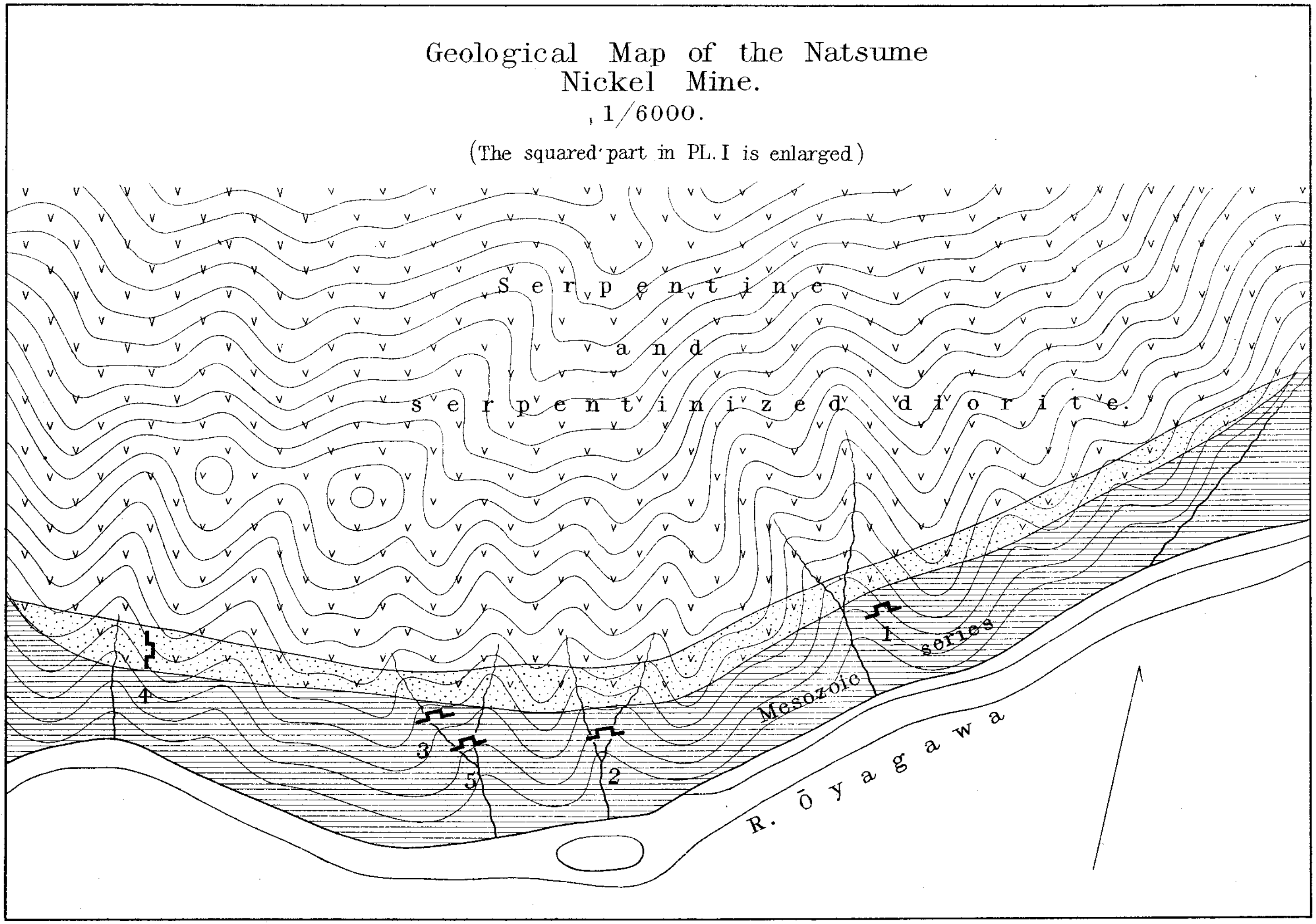
niccolite nuclei have been embedded in pyrrhotite.
Ni = niccolite. Ar = arsenopyrite. Prh = pyrrhotite.
Vertical illumination. Magnif. 70 diam.

Fig. 3. Pyrite replacing quartz in fine veinlets.
Py = pyrite. Q = quartz.
Vertical illumination. Magnif. 70 diam.

Fig. 4. Specimen No. 3 in PL. V, Fig. 3 has been cut along the line A-B, or the cross sections of the radiated niccolite prismoids shown in PL. VIII, Fig. 3 corresponds to this figure. Etched with nitric acid.
Black parts show the sections of the niccolite prismoids, and white the arsenopyrite replacing the margins of the former.
Vertical illumination. Magnif. 70 diam.

PL. I


Geological Map of the Environs of the Natsume Nickel Ore Deposits.
Scale 1/60000
Mikio Kuhara
1921.
Miyagai
Tarumi
Nakamura
Yura
Ōya-gawa
Natsume
Wada
Osugi
Oyaichiba
Kuragaki
Itohara
Akenobe-gawa
Shimomura
Nitta
Wada
Narabe
Furuya
Paleozoic
Tertiary
Mesozoic
Liparite
Diorite
Alluvium
Serpentine

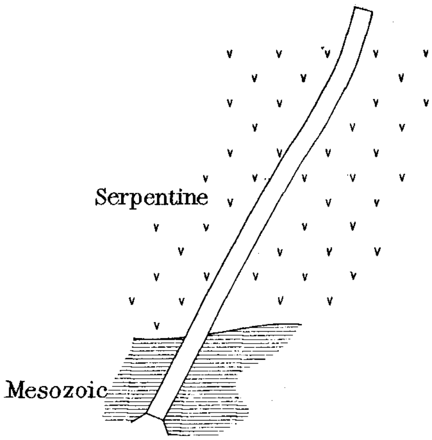


Dotted area------ Mineralized zone.

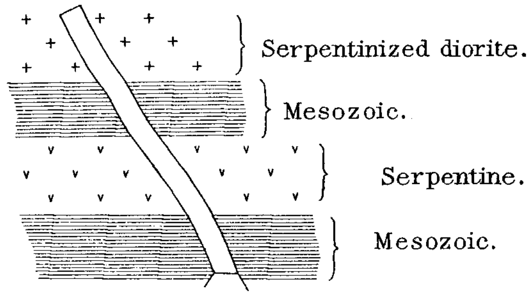
PL. III

Underground Map of the Natsume Nickel Mine.

1/600.



Adit No. 3.
Fig. 3.



Adit No. 1.
Fig. 1.

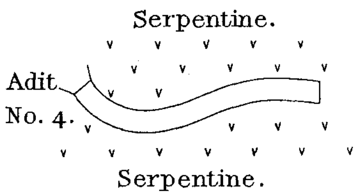
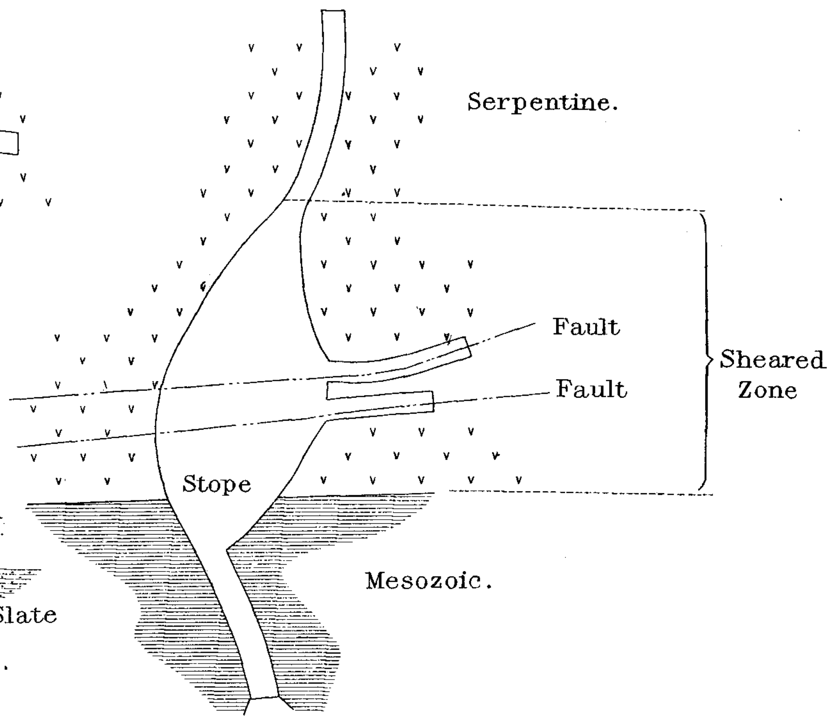
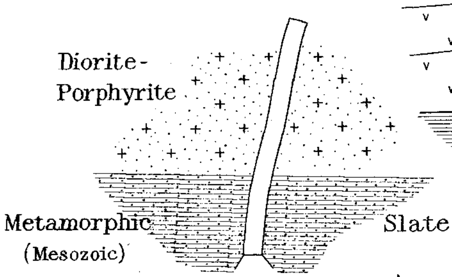


Fig. 4.



Adit No. 2.
Fig. 2.



Adit No. 5.
Fig. 5.

Plate IV.

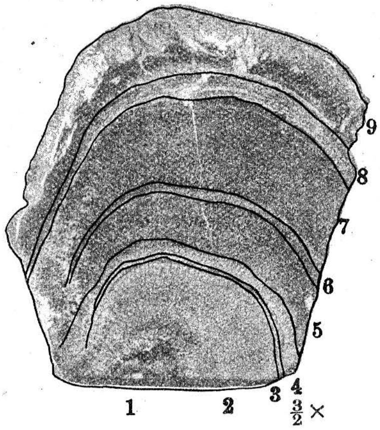


Fig. 1.

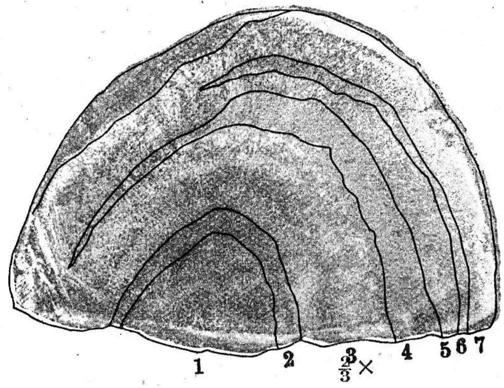
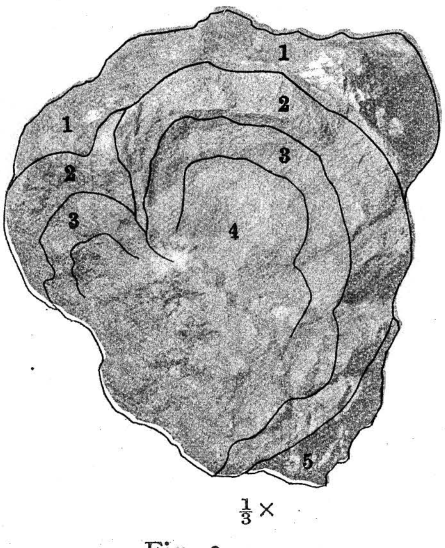


Fig. 2.



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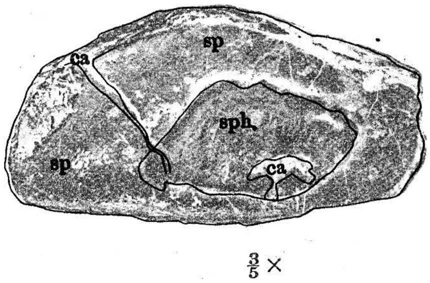

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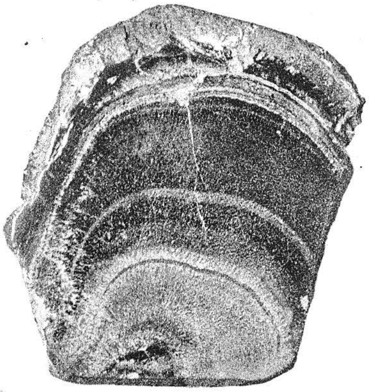

$\frac{3}{2}\times$

Fig. 1.

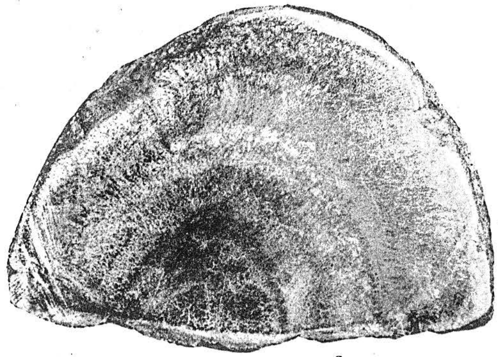

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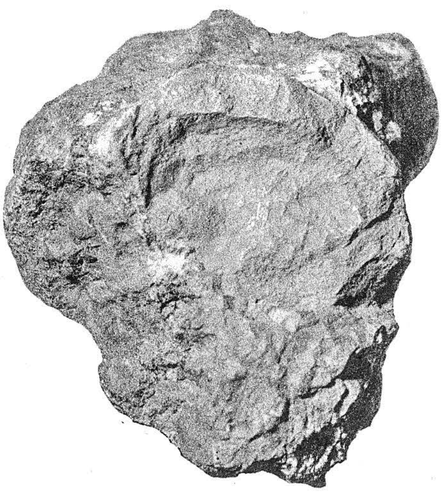
Fig. 2.



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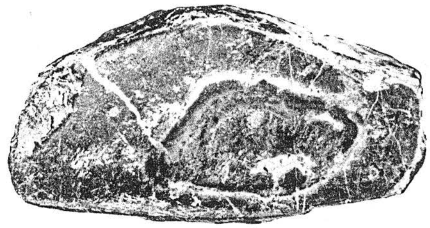


$\frac{3}{5}\times$

Fig. 4.

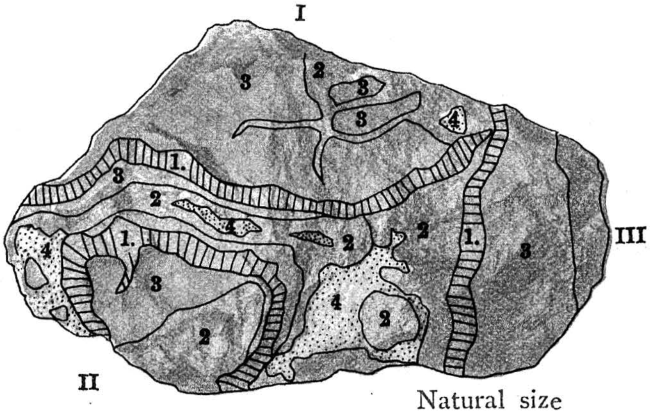
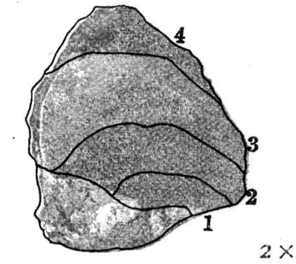


Fig. 1.



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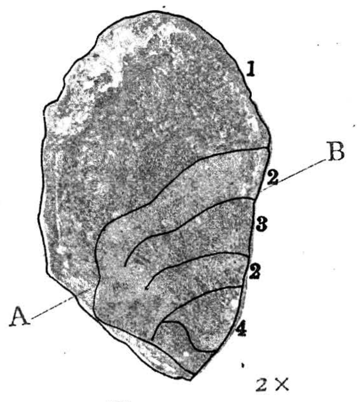

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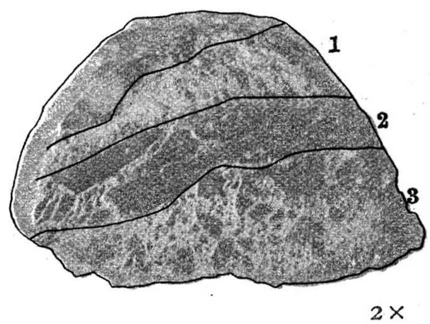
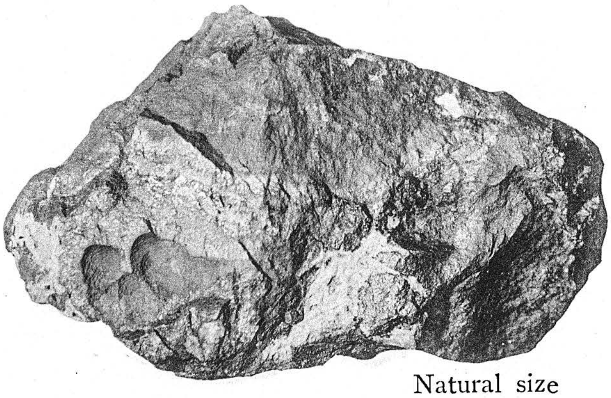


Fig. 4.

Plate V.

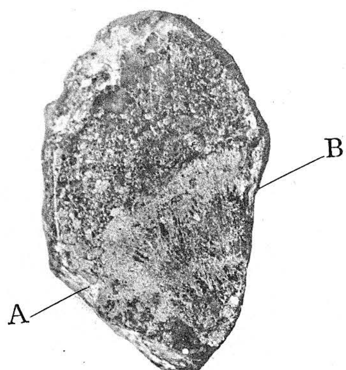


Natural size

Fig. 1.

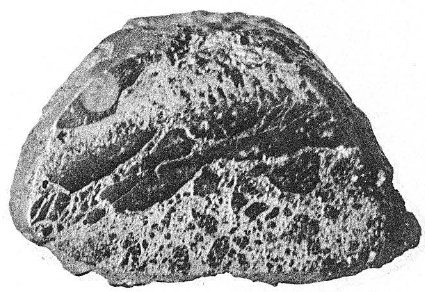
2 ×

Fig. 2.



2 ×

Fig. 3.



2 ×

Fig. 4.

Plate VI

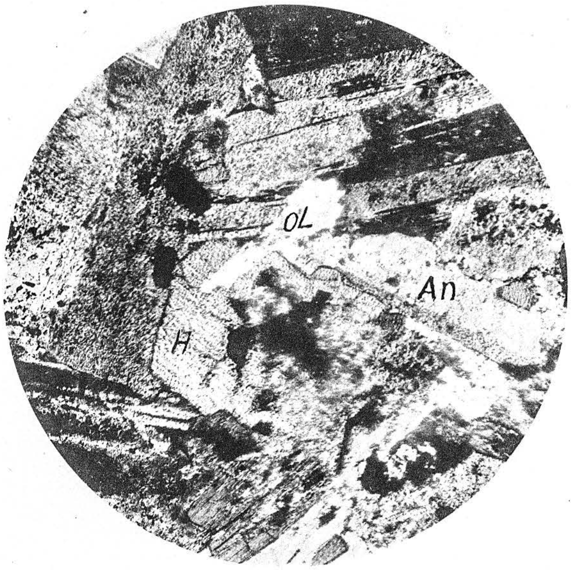


Fig. 1.

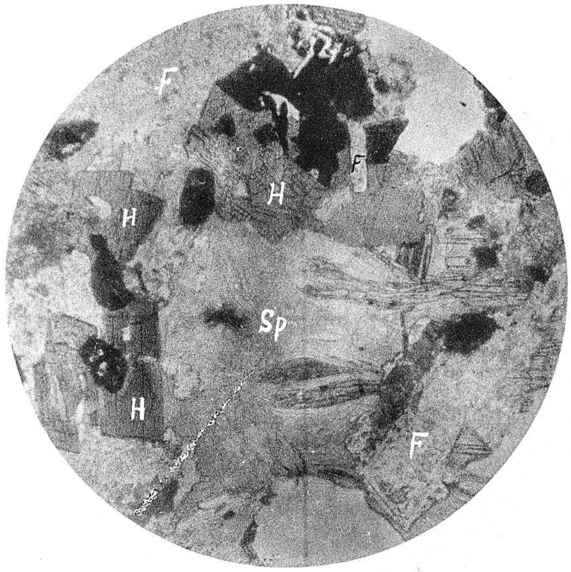


Fig. 2.

Fig. 3.

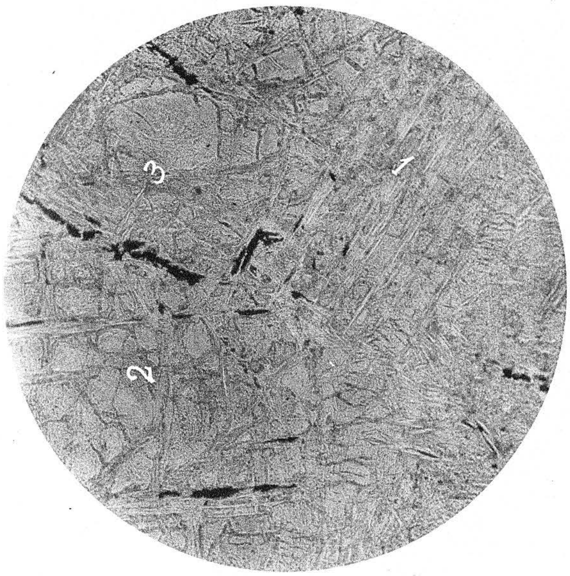


Fig. 4.

Plate VII.

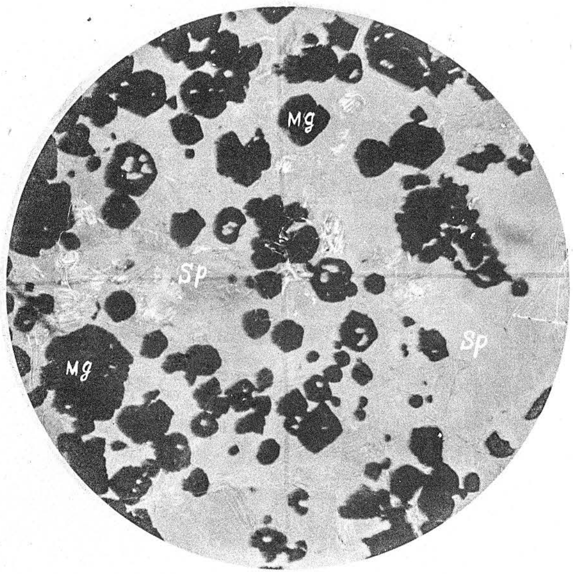
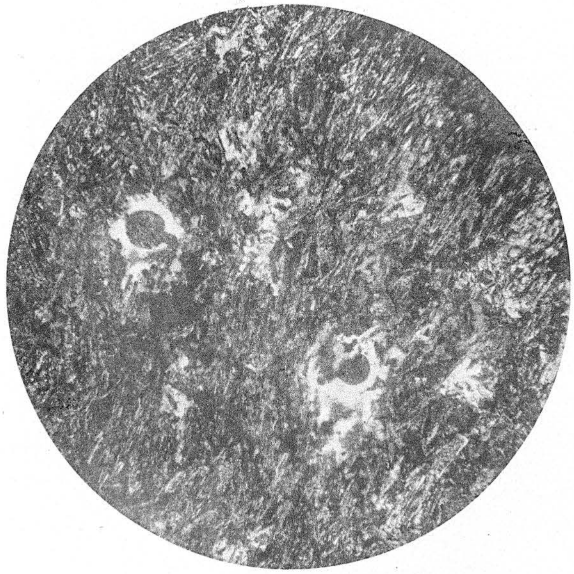


Fig. 1.



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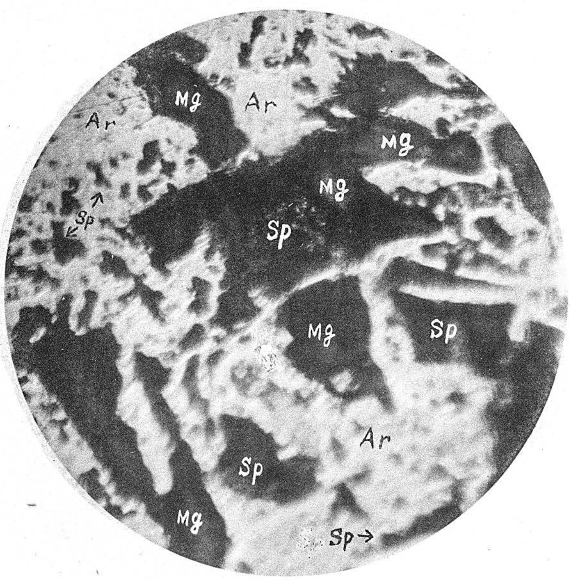

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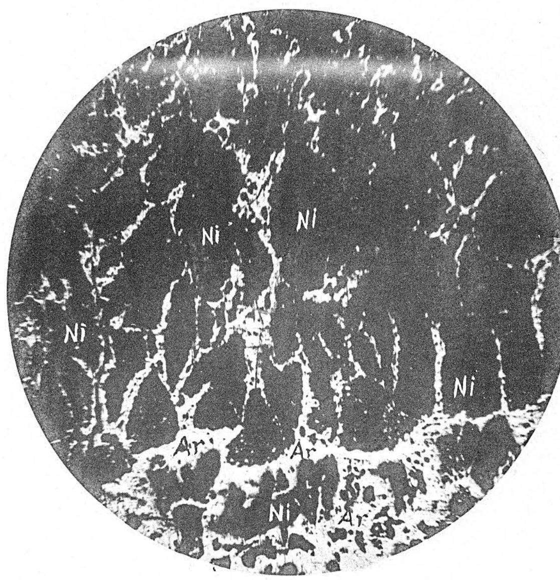


Fig. 4.

Plate VIII

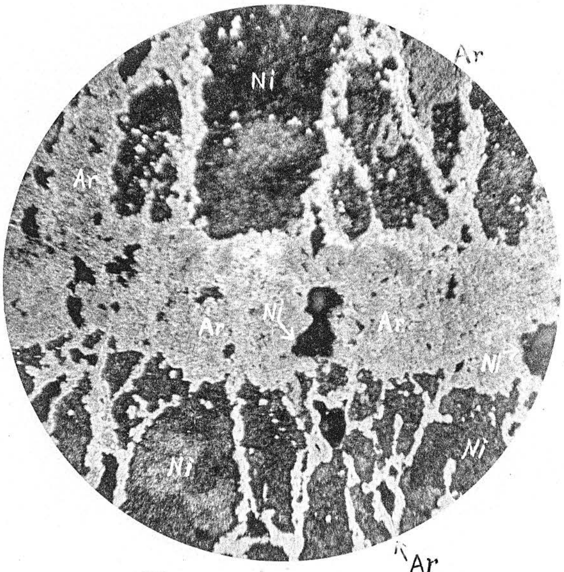


Fig. 1. ↓

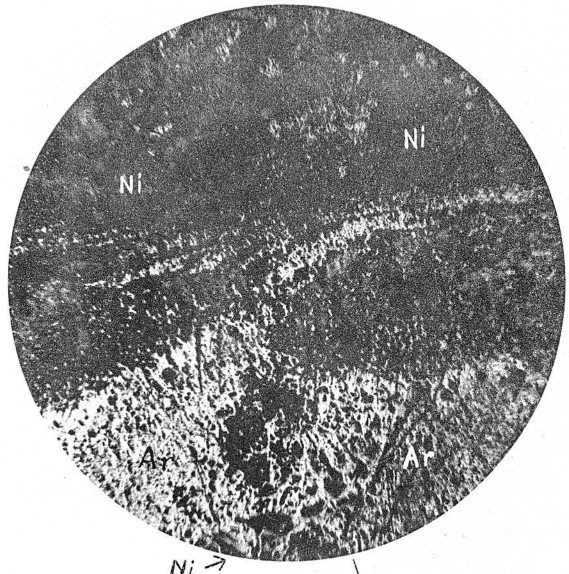


Fig. 2. ↓

Fig. 3. ↓

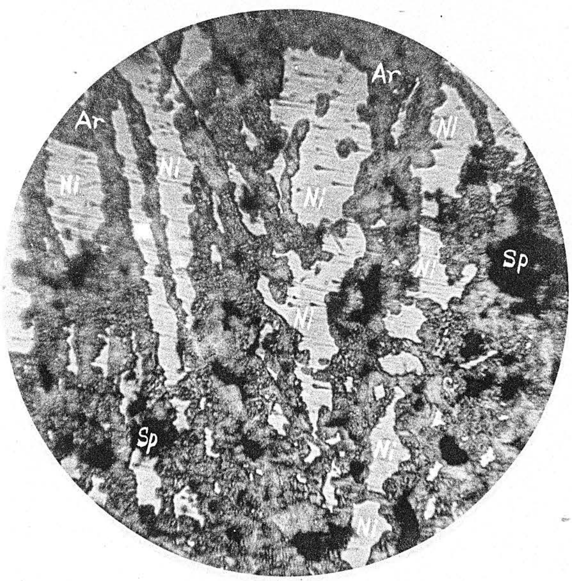


Fig. 4. ↓

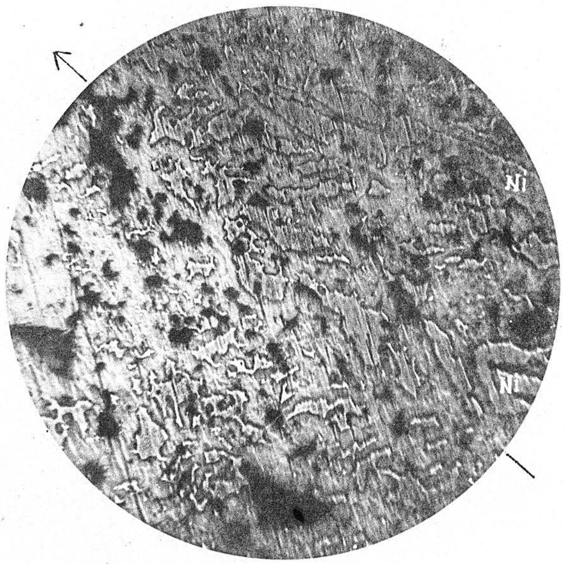
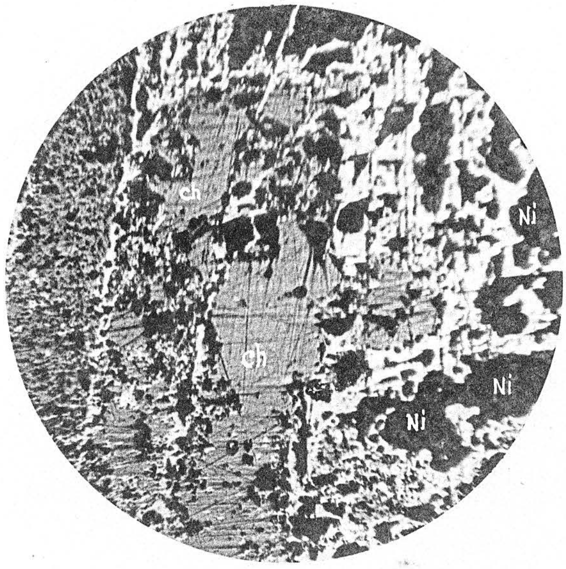


Fig. 1.



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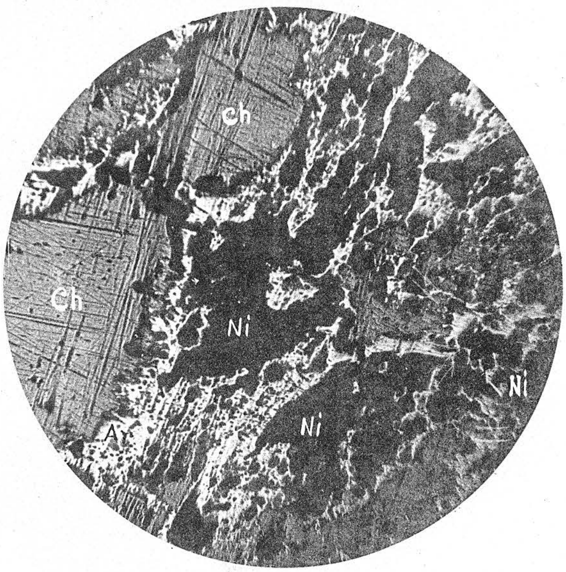

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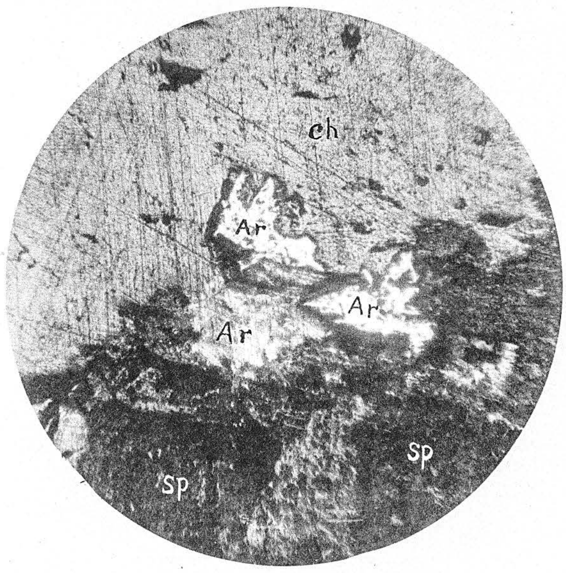


Fig. 4.

Plate X.

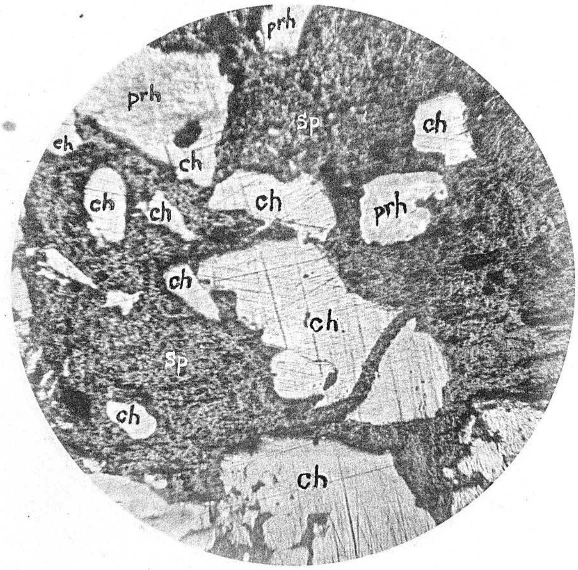


Fig. 1.

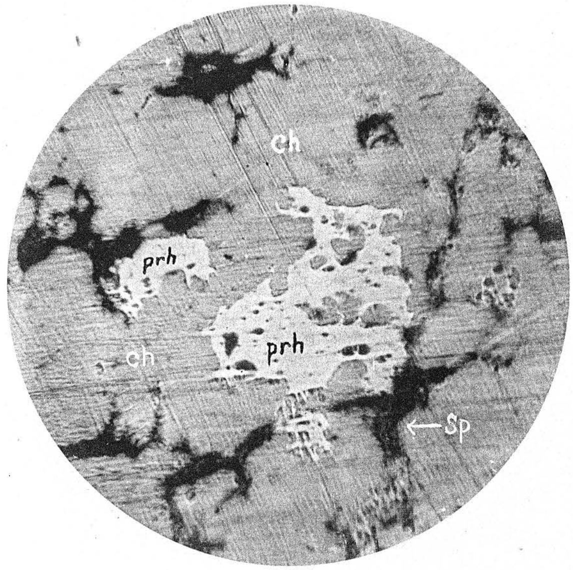


Fig. 2.

prh

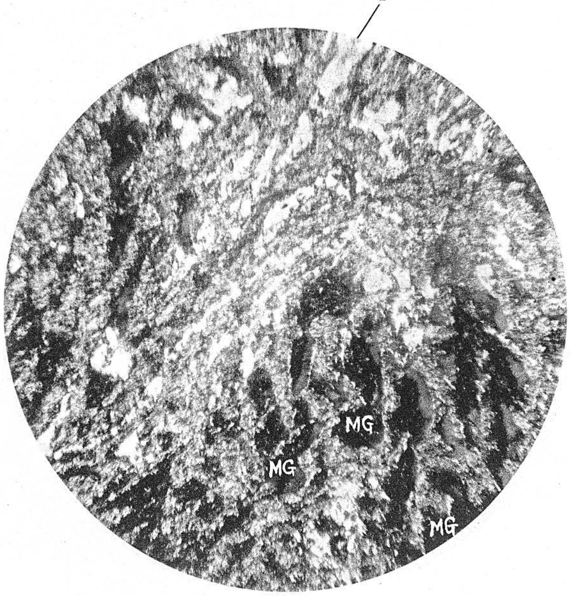


Fig. 3.

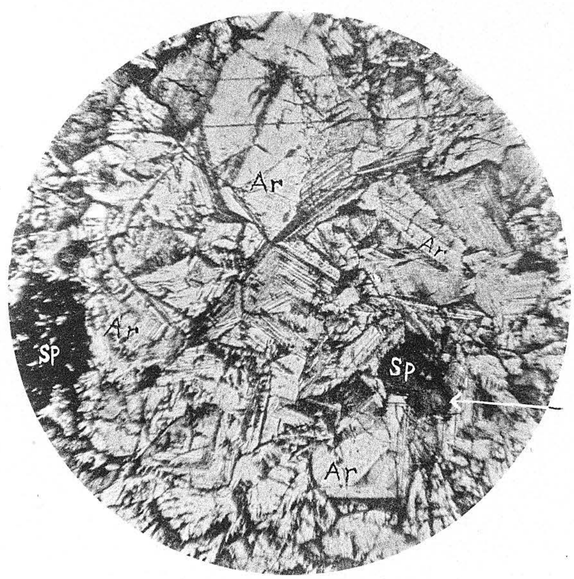


Fig. 4.

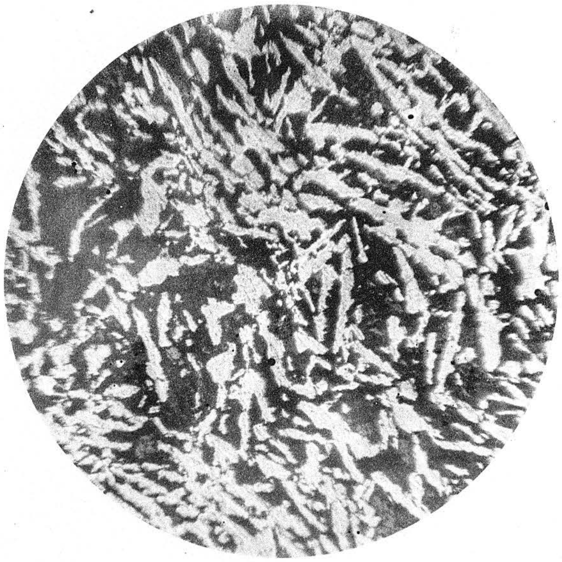
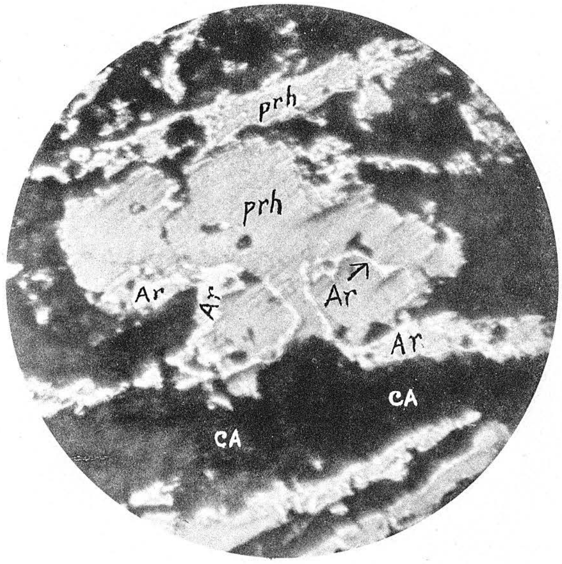


Fig. 1.



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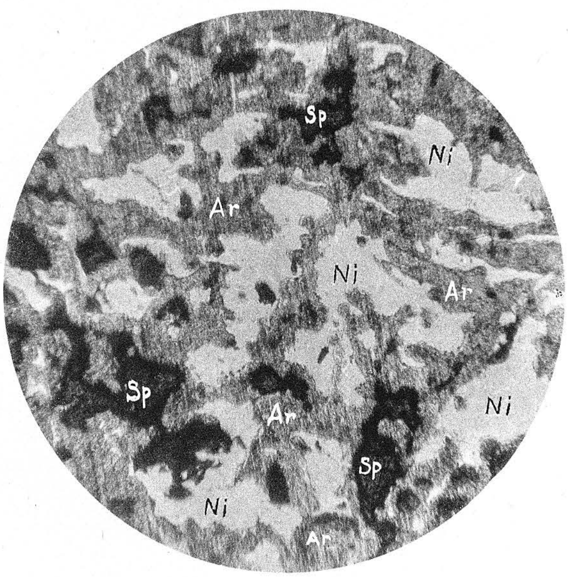

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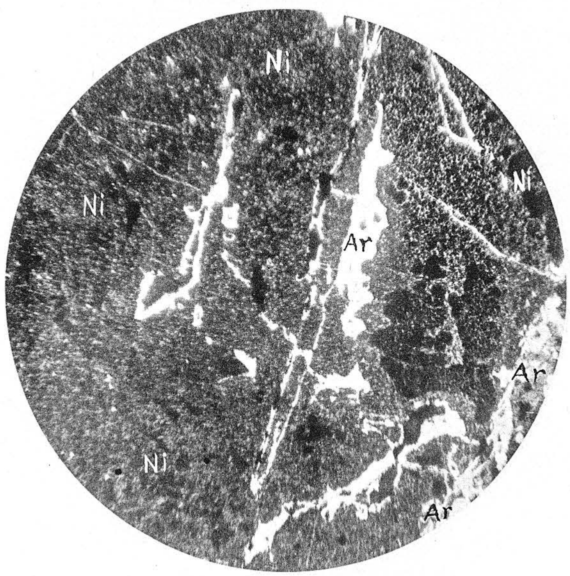


Fig. 4.

Fig. 1.

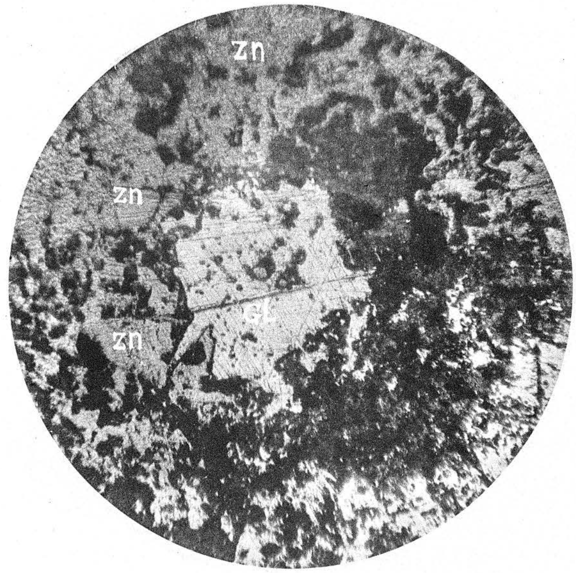


Fig. 2.

Fig. 3.

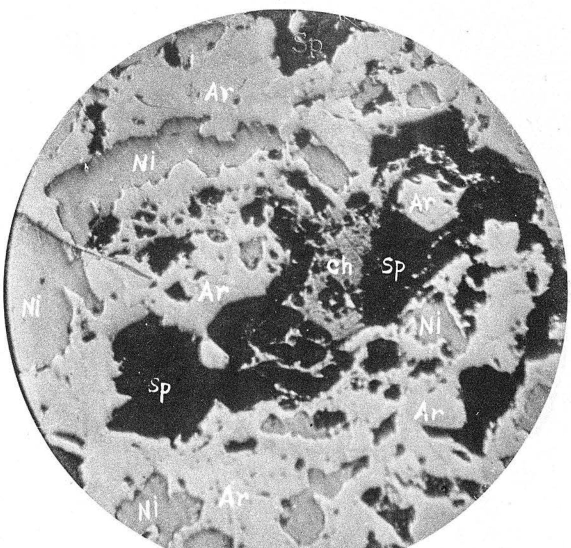


Fig. 4.

Plate XIII.

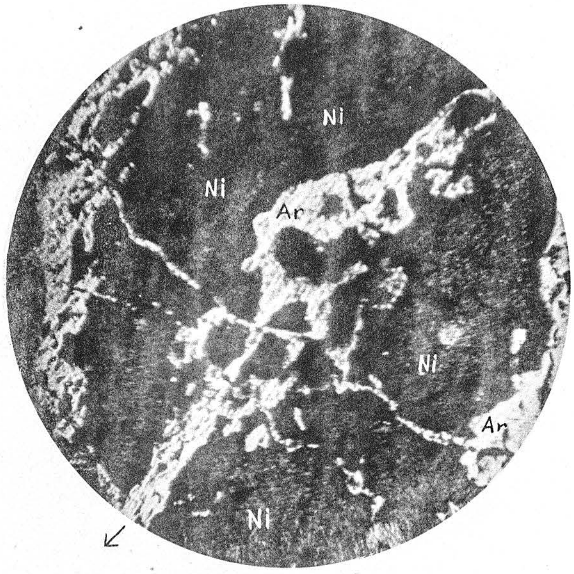
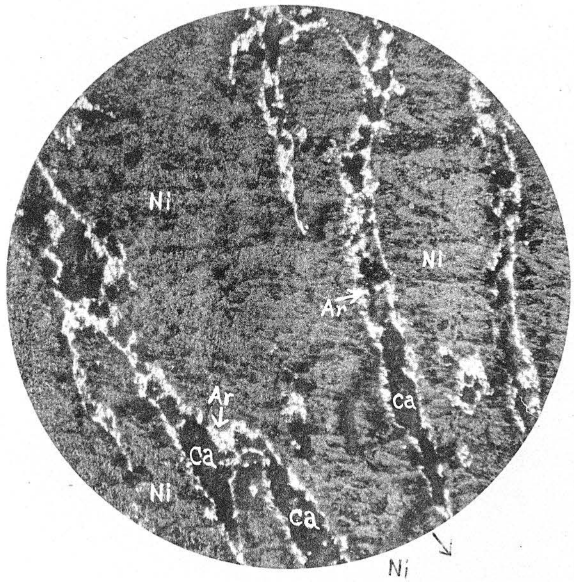


Fig. 1.



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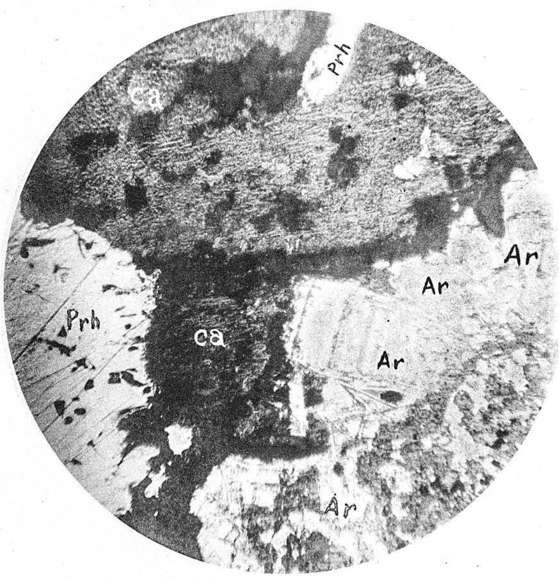

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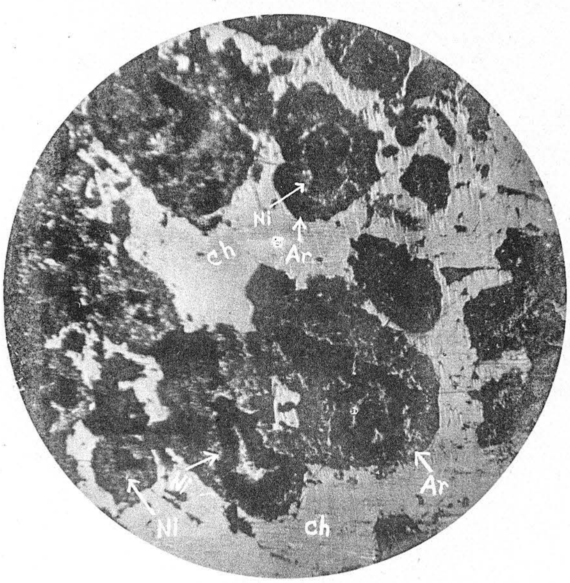

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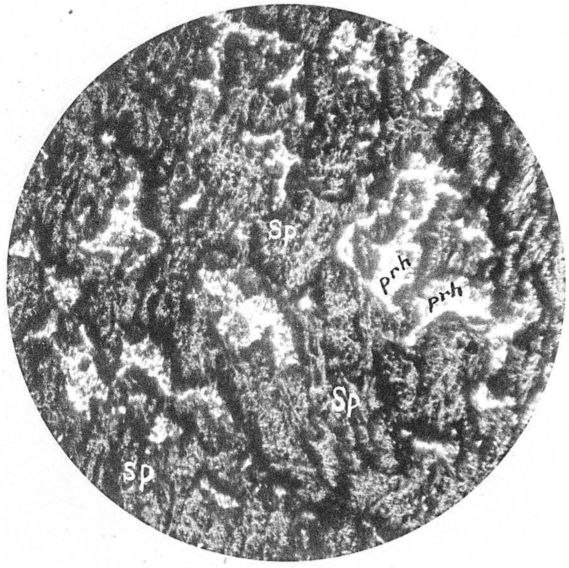
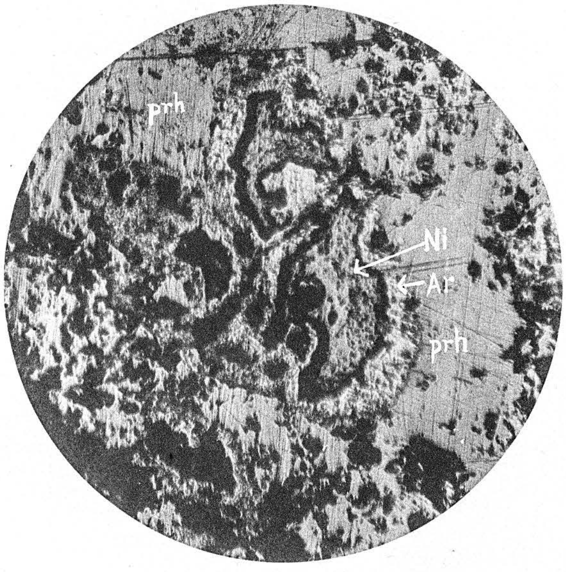


Fig. 1.



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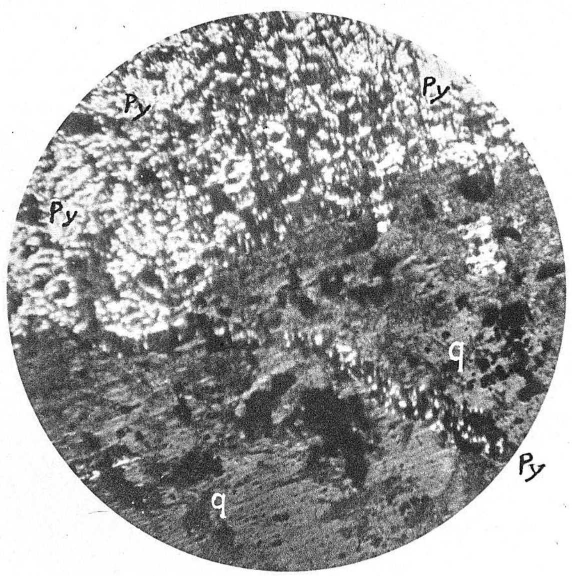

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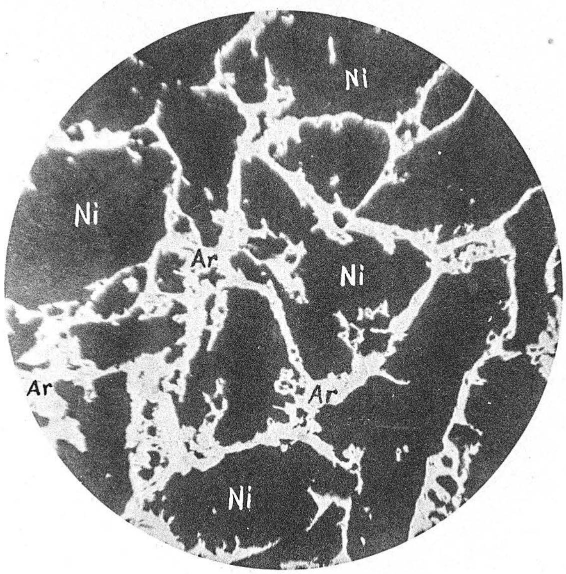

Fig. 4.