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The Metallogeny of the Japanese Islands.

By

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With 1 Map.

1. Magmatic Emanations and their Petrification.

Since SVANTE ARRHENIUS[1] made public the results of his studies on the chemical properties of water in high temperatures, the world's geologists have been more or less influenced by him, their views on metallogeny changing gradually from the hydrothermal to the magmatic theory. Heavy metals were formerly supposed to have been brought up by hot springs in the form of mineral solution. But at present ore-deposits are believed to have been deposited by gas, or by a mixture of gas and liquid, or by liquid only, emitted from magma while cooling. This is asserted by J. H. L. VOGT,[2] who calls this "eruptive after-action." This view naturally leads us to believe that where ore-deposits exist, there must be found igneous rocks, near or distant, from which the materials of the ore-deposits were emitted. Prof. KOTÔ,[3] in his recent paper entitled "*Geology and Ore-deposits of the Holgol Mine*," 1910, calls these rocks "ore-bringers."

It had already been recognized by MATTEUCCI, LACROIX,[4] GAUTIER,[5] and others that a great many elements always exist in emanations. When the latter cool, these elements form different kinds of minerals. It is in this way that petrification of emanations takes place.

1) Svante Arrhenius: "Zur Physik des Vulkanisms," Stockholm, 1900.
2) The Genesis of Ore Deposits," p. 642.
3) B. Kotô: *Jour. Coll. Sci. Imp. Univ. Tokyo*, Vol. XXVII., Art. 12, 1910.
4) Matteucci and Lacroix: The Digest in *Economic Geology*, Vol. II., No. 3, p. 258, 1907.
5) Gautier: *Economic Geology*, Vol. I., p. 690, 1906.

The petrification may often be seen distinctly in recent lavas. As an example, let me explain here the occurrence of tridymite in Ishigami-yama, a hillock in the environs of the city of Kumamoto. This hill is a part of a lava flow extruded from Kibô-san, a now extinct volcano, and is composed of amphibole-pyroxene andesite. The rock is fresh in composition, whitish in color, with conspicuous phenocrysts of amphibole converted into the pseudomorphs of magnetite and augite grains by the resorption of the original crystals. In the miarolitic fissures and cavities formed during the consolidation of the lava, several minerals are found, such as tridymite, phlogopite, breislakite,[1] specular iron, and *calcite*, all forming very fine crystals. The tridymite is in hexagonal plates, sometimes attaining 5 mm. in diameter. The mineral, when picked out of the rock cavities, is transparent, but very soon becomes whitish and translucent on exposure to the air. The change of color may be clearly explained by microscopic study. The tridymite occurs in the form of a pile of thin laminæ, and has, when it is picked out of the rock cavities, a light-brownish liquid in the interspaces between the plates. When exposed to the air, the liquid immediately evaporates and the tridymite becomes whitish by total reflection of light. The liquid contained in the tridymite is supposed to be what is left of juvenile water extruded from the cooling lava.

The presence of calcite as an emanation-product in recent lava is, so far as known, extremely rare. The other minerals in the miarolitic cavities are also supposed to be all of juvenile origin, and not of the vadose formation; in other words, all belong to the so-called fossil emanations of Lincoln.[2] To prove it, I shall give here the following three data: (1) the side-wall of the miarolitic cavities and fissures presents the slaggy aspect usually seen on the surface of lava, (2) the cavities and fissures are perfectly closed as if to prevent the infiltration of vadose water, (3) the andesite in which the cavities and fissures are found is quite fresh, showing that the minerals in question are not decomposition-products.

1) It was so determined by B. Kotô.

2) Lincoln.: "Economic Geology," Vol II., No. 3, p. 258,1907.

2. Classification of Ore-deposits.

von Waldenstein[1] and von Cotta[2] were the first geologists to try (in 1824 and in 1859) to classify ore-deposits. Since then, many methods of classification have been proposed from time to time. Groddeck's system,[3] which takes as the basis of classification the origin of the deposits, is perhaps the best of all. He divided ore-deposits into two groups, *viz.*, original and fragmentary deposits.

Van Hise[4] a little later classified them into three groups, namely, those of igneous origin, those which are the direct result of sedimentation, and those which have been deposited by underground water. A classification based on the magmatic theory is perhaps the best for us, when looked at from the standpoint of the theory. The greater part of the ore-deposits in the case of the heavy metals is of igneous origin, and also since there are, in my opinion, hardly any other deposits of heavy metals found in Japan. Accordingly I shall here classify them into five categories, based on the magmatic theory:

a) Magmatic segregations.
b) Contact deposits.
c) Mineral veins.
d) Replacement deposits.
e) Impregnation deposits.

This classification has been made quite independently by me for the special treatment of Japanese ore-deposits. I am, however, very glad to notice its close resemblance to that of Richard Beck, made public in the third edition of his "Lehre von den Erzlagerstaetten," 1909.

Magmatic segregations are heavy metals accumulated in a magmatic body. Contact deposits are the so-called fossil ema-

1) von Waldenstein: "Die besonderen Lagerstätten der nützbaren Mineralien," 1824.
2) von Cotta: "Lehre von den Erzlagerstätten," 1859.
3) von Groddeck: "Die Lehre von den Lagerstätten der Erze" 1869.
4) Van Hise: "The Genesis of Ore Deposits," pp. 282–432.
5) Lincoln: *Loc. cit.*

nations of LINCOLN,[1] deposited between the ore-bringers and the preëxisting rocks, the latter of which obstructed the passage of the emanations from the former. When the emanations force themselves into the fissures of the rocks and deposit heavy metals there, we have mineral veins. When the magmatic emanations, by their strong rush and chemical action, dissolve part of rocks, make cavities of various forms, and deposit heavy metals therein, then we have replacement deposits. Impregnations are the ore-bodies disseminated in the rock-masses.

3. The Order of Petrification of Emanations.

LINCOLN[2] has classified emanations into four groups, i. e., actual, fossil, repressed, and potential emanations. "Actual emanations may be observed as gases and vapours from lava streams expelled from volcanic vents." "Fossil emanations are the more or less well-preserved remains and traces of actual emanations. The complete preservation of past emanations is often seen as inclusions in minerals, while partial preservation is common in druses and in lithophyses, at contacts and in veins." "It is well to remember in this connection that the mineral veins and contacts frequently appear to be in whole or in part of magmatic origin."

As the emanations begin to get cool, the minerals begin to be formed, and petrification occurs. From frequent observations, I have come to the conclusion that the order of petrification of emanations is similar to that of the formation of rock-forming minerals in magma; for in both cases, the falling of temperature is the chief agent in forming minerals from liquids or gases at high temperature. The following list shows the order of petrification of emanations observed in Japanese ore-deposits:—1. magnetite, 2. chromite, 3. hematite, 4. garnet, 5. augite and hornblende, 6. scheelite, 7. pyrite, 8. cobaltite, 9. chalcopyrite, 10. barite, 11. argentite, 12. gold, 13. quartz, 14. tetrahedrite and enargite, 15. calcite. The minerals at the head of the series are those

1) Lincoln: *Economic Geology*, Vol. II., No. 3, p. 258, 1907.
2) *Loc. cit.*

formed at high temperature, and, as we go downwards, the temperature of their formation is lower. Minerals having a high position in the petrification order are spoken of as "of the higher order of petrification." Not only does the order indicate the order of the formation of the minerals, but also their position in certain deposits. The higher the order of petrification, the lower is the position of the minerals in the ore-deposits, for it is natural that the temperature of emanations in rock fissures should become higher the lower we go. The reason of the constant association of quartz with gold, and the transition of quartzose gold ores into sulphides in the bottom of mineral veins may be readily understood in the order of petrification of emanations above cited. LINDGREN[1] enumerated persistent minerals according to their positions, ranging from the contact metamorphic or igneous condition to the surface of the earth, as shown in the following list, *viz*:—pyrite, chalcopyrite, bornite, arsenopyrite, galena, zincblende, molybdenite, gold, quartz, calcite, etc. The reader will easily recognize the essential coincidence between my petrification order and the above list.

In magmatic segregations found in Japan, only the first two minerals in my petrification order occur, of which chromite in serpentine is the only one workable. Contacts constitute the best reservoirs for all the magmatic emanations, and therefore various minerals are found there. Of these minerals, magnetite, chalcopyrite, cobaltite, and sometimes gold are being worked. In mineral veins which are located far from the source of the ore-bringer, the temperature must be lower than in magmatic segregations and contacts, and initial products such as magnetite and chromite can not journey through so long a passage. Accordingly there occur only pyrite and such minerals as are of a lower order than it, of which the copper and gold ores are chiefly being worked. Ores occurring as impregnations and replacements do not present many points of difference from those in veins, but are very complex in their composition; for all elements of the emanations are shut up in them as in the case of contacts. This is especially true of replacements, such as those in the Kosaka Mine.

1) Lindgren: *Economic Geology*, Vol. II., p. 122, 1907.

4. Metallogenetic Provinces.

In Japan, there are several kinds of ore-bringers, such as granite, diorite-porphyrite, liparite, and andesite; serpentine is also supposed sometimes to have a genetic relation to ore-deposits. All these rocks occupy their own areas, which we call here metallogenetic provinces, after A. M. FINLAYSON,[1] who made similar divisions of the British Isles. Granite is very extensively exposed in Japan, but it is not always associated with ore-deposits. As an ore-bringer it is most frequent in Korea, and also in many places in northern Kyûshû as well as in western Honshû (the Main Island). Quartz-porphyry associated with ore-deposits in central Japan is also asserted to be the marginal facies of this particular province including Korea and other regions. These localities therefore may be called the *Korean Province.*

Diorite is not scanty in Japan, and a noteworthy fact is that diorite-porphyrite is rather better suited to be an ore-bringer than diorite proper. The ore-deposits formed by emanations from diorite-porphyrite are chiefly found in the Paleozoic formation in the outer zone of North Japan, with their center in the *Kitakami* Mountain-land, which, possessing most numerous deposits of this sort, may give the name to this *Province.* Liparite lava is not very often met with in this country, but the rock doing the function of an ore-bringer is found more frequently in the form of dykes or necks, nearly always in the inner zones of North and South Japan, which are put together under the name of the *Kosaka Province,* the Kosaka Mine being its exponent. Besides liparite, propylite is sometimes found doing the work of an ore-bringer in this province. Andesite is the volcanic rock of widest occurrence in Japan, but it is not always associated with ore-deposits. The rock which serves as an ore-bringer is rather the older rock of this kind, recent andesite lava being always barren of the useful heavy metals. The greater part of the andesite that acts as an ore-bringer is supposed to have erupted in the later period of the Tertiary and the earlier portion of the Diluvial, and intrudes Tertiary sediments, forming dykes, necks, or denuded volcanoes.

1) Finlayson: *Quart. Jour. Geol. Soc. London*, p. 281, 1910.

The andesite of this kind is chiefly found in the inner zone of the Ryûkyû (Loo-choo) arc, where gold mines are very hopeful, especially in Satsuma, and to this metallogenetic province the name *Satsuma* is given. The Sado island, famous on account of the rich Sado gold mine, is also supposed to belong to this province, judging from the properties of the ores from the mine.

Pyrite beds in Japan have for a long time been supposed to be of aqueous origin, but at present they are treated as bedded veins. Their ore-bringer is not yet definitely known, but the author believes that it may be serpentine or a like rock, just as VOGT[1] explains the origin of the pyrite deposits of Norway as related to gabbro. Such beds occur in the outer zones of South Japan and the Ryû-Kyû arc. The largest of the kind is in the Besshi mine, for which reason the author calls these regions the *Besshi Province.*

5. The Korean Province.

The mineral resources of the Korean Province are gold and copper, sometimes with cobalt, zinc, lead, arsenic, and tungsten. The origin of the deposits in the Korean Province is most clearly explained in "The Geology and Ore-deposits of the Holgol Mine," an instructive paper by Prof. KOTÔ.[2] The Holgol mine is situated in the northeastern portion of Hoan-haidô in Korea. The geology of Holgol and its neighborhood is composed of highly metamorphosed argillite, calcareo-siliceous slate, limestone, porphyritic granite, and basalt. Prof. KOTÔ describes these rocks in a most elaborate manner ; and, from various facts obtained by this study, he comes to "the conclusion that the gold is juvenile, and must have come from deep in the interior as an exudation from the eutectic mixture of the granitic magma."

Ores of the Korean Province occur in veins, or in contacts. The gold ores in mineral veins are always quartzose. The quartz is hard and translucent, generally being very poor in gold content, except when sulphide minerals such as pyrite, galena, or zinc-

1) Vogt: The Digest in " The Genesis of Ore Deposits," p. 652.
2) Kotô: *Loc. cit.*, p. 2.

blende are present. It is a question whether the gold was deposited with sulphide minerals as a primary product, or has been accumulated around the sulphides by secondary enrichment in process of time.

Copper ores in this province are often found in contacts, as at Kapsan in Korea, and Naganobori and other places in Japan proper, where gold veins of the Korean type are very scanty. The author studied contacts in the Naganobori Copper Mine in the prefecture of Yamaguchi. This mine is thirteen miles distant from the Ogôri railway station, near the western extremities of Honshû. There is an extensive '*karst*', called Akiyoshi-dai. Through the limestone a small granite boss 3,000 feet long and 1,700 feet wide, is exposed forming a hillock named Hanano-yama. All around the boss, contacts are found, Naganobori being one of them.

The deposits of the Naganobori Mine are 30 feet thick, the hanging-wall being limestone and the foot-wall granite. The greater part of the ores consist of radially aggregated augite, which is either mixed with garnet crystals, or planted upon garnet nodules. The ground-mass of the ore is a mixture of quartz and calcite, in which cobaltite crystals and chalcopyrite masses are imbedded. The chalcopyrite is always amorphous, but the cobaltite crystallizes in pentagonal dodecahedrons, showing cubical cleavage. Throughout the ore body, mineral veins with symmetrical structure are frequently met with. These consist of quartz in the salband, calcite in the middle, and tetrahedrite on both sides. Branching out from the main body of the contact deposit, veinlets of chalcopyrite traverse the limestone. In my opinion, the ore of the deposit was petrified from the emanations emitted from the granite magma. First, ferromagnesian silicates have crystallized out as garnet and augite, then cobaltite, chalcopyrite, quartz, tetrahedrite and calcite were formed one after the other.

6. The Kitakami Province.

This province gets its name from the fact that the metal mines in it are most flourishing in the Kitakami Mountain-land, situated between the Kitakami Valley and the Pacific Ocean. The mines are nearly always in the Paleozoic formation and are associated with such ore-bringers as diorite, diorite-porphyrite, and sometimes granite. The diorite-porphyrite, green and compact, with phenocrysts not very distinct to the naked eye, is the most favorable rock for ore-deposits. Under the microscope, the felspar is seen to be kaolinized or to form epidote in combination with the decomposition-products of hornblende turned into chloritic matter. Magnetite is always present, being particularly abundant toward the margin of the eruptive masses. I observed a very interesting phenomenon between the diorite-porphyrite and the limestone in the Kamaishi Iron Mine. This mine is the most hopeful one in

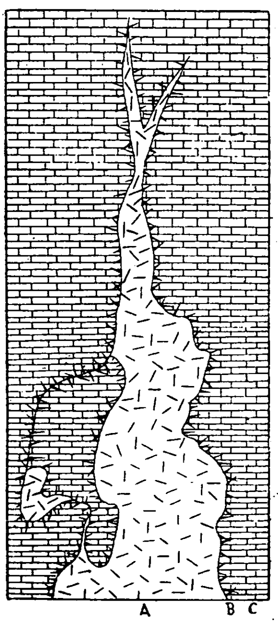


Fig. 1.—Intrusion of diorite-porphyrite into limestone, in Kamaishi Mine. A, Diorite-porphyrite. B, Magnetite crystals. C, Limestone.

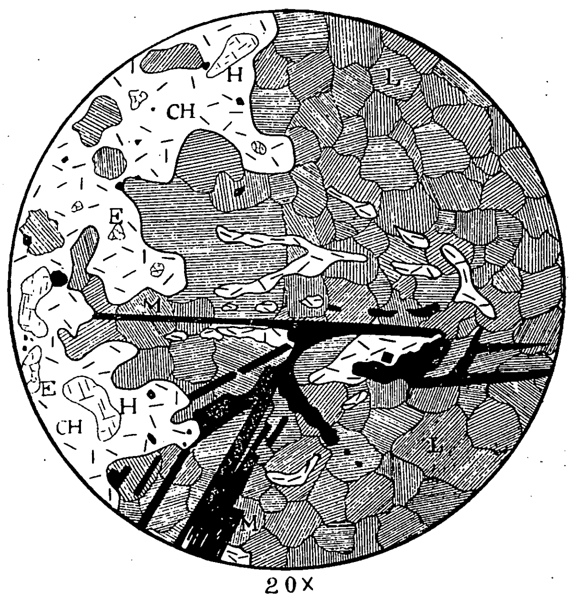


Fig. 2.—Contact of diorite-porphyrite with limestone in the Kamaishi Mine. H, Hornblende. E, Epidote. CH, Chlorite. L, Limestone. M, Magnetite.

this province, and is well known as the only private iron-smelting work in Japan. The deposits belong either to the contact of the diorite-porphyrite with paleozoic limestone, or to that of the diorite-porphyrite with granite, or else the magnetite is wholly enclosed in granite masses. Where the diorite-porphyrite is in contact with limestone, magnetite lamellæ, perhaps flattened rhombic dodecahedrons, are seen projecting from the porphyrite into the limestone (Fig. 1 and Fig. 2). While the porphyrite was in the deep as fused magma at high temperature, it was a eutectic compound with the iron content uniformly diffused throughout. But when the magma was erupted and came into contact with the limestone, its temperature fell and its chemical properties became entirely different from those it had in the deep. Magmatic differentiation took place at the margin of the magma. Magnetite was driven out of it to form the thick deposit between it and the limestone, which finally attained a thickness of 30 feet.

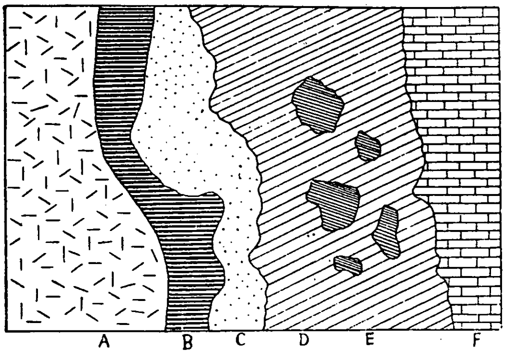


Fig. 3—Arrangement of minerals in the contact deposit of the Kamaishi Mine. A, Diorite-porpyrite. B, Magnetite. C, Garnet. D, Quartz. E, Calcite with gold. F, Limestone.

The arrangement of minerals in this contact deposit is highly instructive as to the order of the petrification of emanations (Fig. 3). Magnetite is found on the side of the diorite-porphyrite, garnet constituting the central zone comes next, and quartz on the side of the limestone. In the quartz, calcite masses are scattered about, and in them the gold is remarkably rich. The gold grains are usually microscopic, being sometimes as large as 1 cm. in length, and 0.2 cm. in diameter. They are of two kinds. One is like granulated zinc in form, and is supposed to have been solidified from the fused drops of gold in the liquid emanations exuded from the diorite magma. The colour of the gold is very fine being almost like that of pure gold. The other kind of gold is always in long prismatic crystals, acutely pointed at both ends. These are perhaps rhombic dodecahedrons, elongated on an axis. They are paler in colour, are found in the cleavage of calcite, and are supposed to be of secondary origin in contrast with the former, which are of primary origin.

Arguing from the arrangement of the minerals in the ore-deposit, I have come to the conclusion that the order of the petrification of emanations in the Kamaishi Mine must have been as follows: magnetite, garnet, quartz, gold, and calcite.

As a typical example of the mineral veins in the Kitakami Province, I shall here choose the Shikaori Mine, not very far from the Kamaishi Mine. The deposits of this mine are bedded veins running S. 5° W. along the stratification of the Paleozoic formation. As in the case of the Korean Province, the ores are composed of the hard translucent quartz of a whitish colour, which is characteristic of the so-called old vein of Prof. Vogt. The gold content in the ore is very variable. As a whole the ore is not very rich, but big nuggets have sometimes been found in the veins. A nugget called "monster"[1] consists of thick plates of gold in the cracks of the quartz ore. The fineness of the gold is estimated at 882.844 and the nuggets 910 grammes in weight. From the specific gravities of the quartz, the gold, and the nugget, I have estimated its value at 950 yen. This is one of the largest nuggets ever got from mineral veins in Japan, and is considered to be one of the best specimens of the kind in the world. Gold veins containing coarse grains of gold disposed in an irregular manner are also often found in this province, and constitute the source of gold placers.

7. The Besshi Province.

This metallogenetic province comprises the entire outer zones of South Japan and the Ryûkyû Arc, and the southern part of the outer zone of North Japan. In this province, the pyrite beds are most important—stibnite and gold veins as well as manganese beds being of rather subordinate value. The Besshi Copper Mine contains the best of the pyrite beds in this province, and for this reason it is called the Besshi Province in this paper.

The pyrite beds are chiefly found in the so-called crystalline

1) The description of "Monster" is given in detail in my work "Gold," p. 284, Tôkyô, 1910. (*Japanese*)

schists, the Sambagawan Series of Prof. KOTÔ.[1] They are also sometimes met with in the Paleozoic formation. As mother rocks, basic rocks such as chlorite schist[2] and graphite schist are the most favorable; serpentine is often found near the beds. Pyrite beds occur in the crystalline schists in nearly concordant stratified form, cutting them crosswise in a few instances. The pyrite beds consist of an intimate admixture of pyrite and chalcopyrite. They are so compact that these two minerals can only be distinguished from each other under the microscope after polishing, or in a few cases by the naked eye. According to SAKAWA,[3] the pyrite in the ore is usually in rounded grains, but sometimes it is crystallized, when it attains 0.7 cm. in diameter. The interspaces between the pyrite grains are filled with massive chalcopyrite, which often enters even into the cracks of the former.

Pyrite beds sometimes form lenticular bodies or rounded nodules. When they are found in the decidedly younger formation, i. e., the Paleozoic, they are usually roundish. The structure of the pyrite beds in the so-called crystalline schists is often very complex. In the central portion, there are very rich copper ores containing rock fragments, the outline of which is either rounded or indented. On one or both sides of the rich zone of the pyrite beds, there are found highly contorted ores, with regularly stratified schists on their outer sides. These contorted ores constitute the "shear zone" of Sakawa.

From the facts above stated, and after very careful examination of a great many pyrite beds in Japan, he comes to the conclusion that they are bedded veins of epigenetic origin. In my opinion, however, the original form of the pyrite beds must have been that of replacements brought up in different successive periods. After their deposition, a strong mountain-making force flattened them

1) Kotô "On the so-called Crystalline Schists of Chichibu." *Jour. Sci. Coll. Imp. Univ.* Tokyo, Vol. II.

2) It is said that greater part of the so-called chlorite schist near the pyrite beds is amphibole-schist.

3) Sakawa: "Report on Cupriferous Pyrite Beds." *Bull. Imp. Geol. Surv. Japan*, Vol, XXII., No. 1. (Japanese).

into the form of beds, at the same time causing regional metamorphism of the country rocks. After such a geological change, a fissure was formed along the middle line of the bed, and the side-rock masses slipped down, producing the shear zone on the exterior part of the bed. Finally, a secondary enrichment took place around the faulted rocks, filling up the interspaces of the fissure. Thus the rock fragments in the beds are rounded or indented on their exterior by the dissolving action of the vadose water. This explanation will, I think, solve the varied structures of the pyrite beds in a very natural way. S. Ishikawa,[1] a Mining Inspector, enumerates 59 copper mines of this species in Japan, namely, 27 in crystalline schists, and 32 in the Paleozoic formation.

Quite recently very interesting gold deposits have been discovered in *central Kyûshû*, which, upon investigation, seem to be an isolated block from the Besshi Province. The region is hilly with an altitude of about 400 to 2000 ft. above sea level, and is geologically composed of a thick complex of amphibolite and phyllite belonging to the Lower Paleozoic. The amphibolite is a pale green homogeneous rock. The phyllite is a highly contorted lamellar rock, gray to black in colour, showing pearly luster by the presence of the abundant quantity of mica. The latter rock sometimes contains very conspicuous cubic phenocrysts of pyrite, which measure up to 0.5 cm. in diameter, and is usually converted into limonite pseudomorph. Examined under the microscope, the amphibolite consists of elongated green crystals of amphibole and greenish-yellow grains of epidote, cemented by a transparent quartz matrix. Phyllite shows beautiful contortion, microscopically as well as macroscopically, forming alternate layers of quartz, mica and graphite. It is a very noticeable feature that, so much gold exists throughout the rocks for several miles, that sometimes they practically become gold ore themselves. Now, it is a question whether the gold is a primary constituent of rocks, or it had been carried into them at the time of the formation of quartz

1) Ishikawa: "Geology and Ore-deposits of Ôshima." *Jour. Geogr. Soc. Tokyo*, No. 260, 1910 (Japanese).

veins, which traverse the rocks everywhere. The quartz veins sometimes produce very rich gold, but it is most hopeful when the gold forms placers. The placers may be divided into two distinct kinds, original and alluvial. The former is seen on the surface of the mountain region, forming the primary soil. The latter forms the placer beds in the valley. The bedded deposits are found in the form of successive river terraces, the highest and most promising measuring about 200 ft. in height; the next is on a hillside and is about 80 ft. high; while the lowest is only 6 ft. from the valley level and forms part of valley ground. These terraces cover more than several hundred acres, and form horizontal strata of gravels composed of pebbles of amphibolite, phyllite, quartz and andesite cemented by reddish clay, sand of the above stated rocks, and limonite pseudomorph after pyrite. The conglomerate bed contains gold in the high proportion of from 3/1,000,000 to 9/100,000 or 1/100,000 on the average and measures from 6 to 120 ft. in thickness. The gold grains are similar in form to those from old veins, and may be classified into two groups, granular and crystallized. The colour of the granular gold is very fine, being like pure gold, and is much larger in size usually measuring as much as 3 mm. in diameter. Gold nuggets weighing 131 gr. and 67 gr. were once found in the valley. The peculiarity of this granular gold is that it is of a flattened form with cracks in it. The crystallized gold thought to be of a secondary origin is inferior in grade, and usually smaller in size, being not quite 0.5 mm. in diameter. The comparatively large size and flattened form of the granular gold is explained by the fact that the gold was formed in amphibolite or other crystalline schists in old time and subjected to intense mountain-making force during the metamorphosis of these rocks. The ore-bringer of this gold is not yet definitely known; but it is probable that the amphibolite is a rock metamorphosed from the diabase or like rocks which brought up the gold from the interior of the earth, thus doing the work of the ore-bringer itself.

8. The Kosaka Province.

This is the region containing plagioliparite and propylite as ore-bringers, and has Kosaka as its largest and most important mine. The ore-deposits found in this province are chiefly replacements, bearing the so-called "black sulphide ore"; but there are also famous veins of various other kinds. It is a characteristic of this province that abundant sulphide minerals are always present in the ores. The presence of this character may be due to the strong acidity, or high fusing point of the ore-bringer. Even where andesite is the ore-bringer, the emanations emitted from the rocks must have been at a high temperature, and thus andesite itself was changed into propylite. Such a high temperature compels the formation of sulphide minerals, which belong to the higher order of petrification of emanations; in other words, sulphides were formed only in a temperature higher than that in which gold, quartz and calcite (all common minerals in the Satsuma Province) must be formed.

The deposits in the Kosaka Province belong to the younger veins, formed in the later period of the Tertiary or the earlier part of the Diluvium. They are most frequent in the Tertiary sediments or in the ore-bringer itself, forming replacements or veins. The province includes nearly the whole of the inner zone of North Japan, as well as isolated points in the inner zones of South Japan and the Ryûkyû Arc. The deposits in the Kosaka Province may be classified into mineral veins, black sulphide ores, and disseminations.

Mineral Veins:—These veins are of several kinds. They always bear a greater or less quantity of sulphides, but some are composed of auriferous quartz, some of quartzose copper ore, and some rich in lead or zinc. Generally speaking, the deposits in the province are the sulphide-rich, "younger" veins of Vogt.

As a type of the auriferous quartz veins, let me describe the Hasami Gold Mine, for I know it better than any other of these veins. It is situated about five miles to the south of the Arita Station on the Nagasaki line of the Kyûshû Railway. The mine was discovered only fifteen years ago, but at present it is one of the most important and hopeful gold mines in Japan. The deposit is of the true fissure-vein type traversing the Tertiary

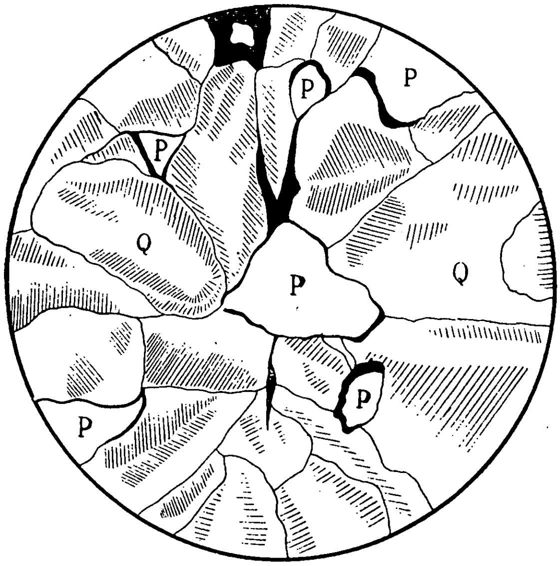


Fig. 4.—Quartzose gold ore of the Hasami Mine. Q, Quartz containing liquid enclosures, in parallel or radial arrangement. P, Pores connected by passages with a lining of siderite.

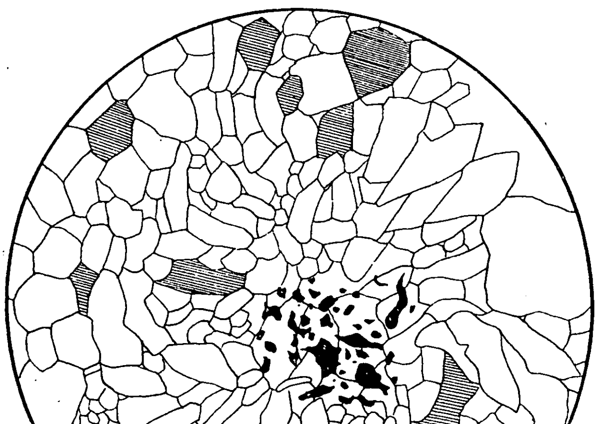


Fig. 5.—Colony of gold in the quartzose gold ore of the Hasami Mine.

sandstone and shale, the former being the more important of the country-rocks. Quartz-trachyte is found in this concession, and is supposed to be the ore-bringer of the gold veins. Several veins are met with running N. 45° W., and dipping 70°–80° SW. They are mostly simple veins, about 5 feet thick, but sometimes assembled together, attaining even 100 feet in thickness. Usually the simple veins are regular in extent, with distinctly banded or brecciated structure. The ores now being worked are stained by limonite, for they belong to the weathered zone. When the working proceeds deeper, much sulphide is expected.

Under the microscope, the quartz in the gold ore shows a granular or hypidiomorphic structure. (Fig.4.) The outline of the quartz is always smooth, in contrast with the indented grains in the old veins. Roundish pores with narrow connecting passages are very noticeable. Both the pores and passages are lined with brown siderite. These phenomena show that, during the formation of the veins, the emanations from the quartz-trachyte (liparite) contained very large quantities of gases which were for the greater part carbonic acid remaining as siderite in some interspaces between quartz grains. This is surely one of the most important properties of the ores.

The gold grains from this mine may be divided into two classes, granular and crystallized. The former is covered with siderite, while the surface of the latter is fresh and brilliant. The gold grains are grouped together in colonies (Fig. 5).

Black sulphide ores: —Ores of this kind are found in the inner zone of North Japan. They were not investigated until late years, and HIRABAYASHI,[1] Geologist to the Mining Bureau, was the first to treat their origin and characteristics in detail. According to him, the black sulphide ore is an intimate admixture of galena, zincblende, and barite. It occurs most frequently in the form of replacements, but, in a few cases, as mineral veins or impregnations. The ore-bringers are quartz-trachyte or andesite, the latter being generally altered into propylite. Hirabayashi gave a single example of *basalt* taking the place of an ore-bringer, but I believe it was only an eruptive succeeding the formation of the deposits, as in the case of the Hol-gol Gold Mine, described by Prof. KOTÔ.[2]

The occurrence of the black sulphide ores furnishes us with materials for making clear the magmatic theory. According to Hirabayashi, there are 43 mines in Japan, in which these ores are worked. They are all in Tertiary beds, and always associated with younger volcanic rocks. In 14 mines, quartz-trachyte is found, in 10 mines andesite or propylite, and in 14 mines both these rocks together. Basalt has been found only in

1) Hirabayashi: "Report on Black Sulphide Ore-deposits," I. and II., Mining Bureau, Tokyo, 1908 and 1910.

2) Loc. cit.

one mine. In the remaining three, their existence was doubtful. When the ore-deposit is in contact with the volcanic rocks, the deposit becomes thinner and thinner as we descend changing at last into a network or dissemination, and passing by imperceptible changes into the volcanic rock itself.

Impregnations:—One of the characteristics of the ore-deposits in the Kosaka Province is the abundance of impregnations. This type of ores is perhaps evidence of the intense pressure and the high temperature of the emanations. The emanations form massive deposits by impregnation in the igneous rocks such as quartz-trachyte or andesite; and sometimes they produce bedded deposits by dissemination in sandstone. When the rocks are traversed by numerous veinlets, the result of emanation is embodied in networks. Sometimes whole masses of igneous rock are changed into metasomatic ores. From these deposits gold is usually worked; copper and iron also are sometimes got from such ores. The vein-stuffs are chiefly quartz and clay; besides, pyrite, hematite, chalcopyrite and barite are found as accessory components. I shall take the Washinosu Gold Mine as an example of impregnation in the Kosaka Province.

The Washinosu Gold Mine[1] is situated in the prefecture of Iwaté in the inner zone of North Japan. The largest part of the deposits in this mine consists of impregnations in quartz-trachyte (plagioliparite) erupted through the Tertiary beds; only a small portion belongs to the Tertiary formation. The hill of quartz-trachyte is about 900 feet above the lowest water level in the concession. Veinlets traversing the eruptive are usually 1 or 2 inches thick, but sometimes they become as much as one foot in thickness, and 300 feet in length. Where the veinlets are very densely crowded, the impregnations are very rich. In the veinlets, quartz and chalcopyrite are most abundant, while barite and micaceous iron exist in small amounts. Gold is rich in the pyritic quartzose ore, but very poor in the chalcopyrite.

There are numerous gold deposits like those of Washinosu in the environs of the mine. They are also developed in the

1) Nishiwada: The Digest of "Report on Gold and Silver Deposits," 1907. (Japanese)

southern extremity of the Satsuma Peninsula in Kyûshû, where there is an extensive lava plain of loose andesite, through which nine independent rocky hills project, rising from 500 to 900 feet above the sea level. They are composed of a hard compact rock of a whitish colour, the petrographical properties of which are not definitely known. One geologist says it is a quartz-trachyte, but others treat it as an andesite silicified. Although all of the rocks are not quartz-trachyte, at least a part of the hills belongs to it; besides, the properties of the ore-deposits are like those of the Washinosu Mine. Nearly all the silicified rock masses of the hills contain a trace of gold. In the Kasuga Gold Mine, which has one of these deposits, the whole rock mass contains 0.0002% gold, but in the clayey veins running through it the gold content is richest going up to 0.02% and even more. In this ore-deposit, I recently discovered barite; which is always present in black sulphide ores, but as yet has not been found in other gold mines in the Satsuma Province.

9. The Satsuma Province.

The ore-deposits belonging to this province are associated with andesite as their ore-bringer. In contrast to the Kosaka Province, they are characterized by a scantiness of sulphides. The ores are chiefly composed of auriferous quartz and calcite, both belonging to the *lowest*[1] order of petrification and are generally worked for gold. Transition is seen, however, between the Satsuma and the Kosaka Province. For example, in the Sado Gold Mine, which is supposed to belong to the Satsuma Province, quartzose gold ores are associated with some sulphides, and in the Kinkwaseki Gold Mine in Taiwan (Formosa), auriferous enargite masses occur in the form of chimneys, while the Tasei Lode in the Ikuno Mine, which is supposed to belong to the Kosaka Province, is a true quartz vein. Generally speaking, the deposits in the Satsuma Province are true veins, with banded, ring or brecciated ores. The ring ores are most beautifully developed in the

1) Perhaps gold and quartz are of colloidal origin.

Serigano and other gold mines.

First of all, after the formation of fissures, gold, argentite and pyrite were deposited around andesite horses, at the same time that the quartz veins were formed, after that, secondary enrichment took place, and gold together with other minerals was formed upon the andesite nucleus in the inner side of the first ring. Thus double rings were produced there. Together with the above-described processes, silicification also took place in the andesite horses, which were all or nearly all changed into quartz. Although such ring ores are also found in the Kosaka Province, they are most frequent in the Satsuma Province. This is perhaps due to the greater basic property of andesite, compared with quartz-trachyte, shale, and sandstone, which are the most important mother rocks in the Kosaka Province.

The so-called replacement veins of LINDGREN[1] are also often found in the Satsuma Province, and are, as EMMONS[2] stated, distinguished by their unsymmetrical structure, variable size, complex arrangement of minerals, and the preservation in the ore of the microscopical structure of the original rocks. I have studied the replacement veins in the Ôkuchi and Kushigino Gold Mines, in the Satsuma Peninsula, southern Kyûsyû, and therefore will state here the results of my observations.

The andesite, which is the mother rock of the mines, seems to have erupted in the Tertiary or the Diluvial epoch, usually forming low undulating hills due to erosion. The rock is grey and compact, with augite and felspar phenocrysts. The former is conspicuous to the naked eye, but the felspar is not so distinct. Under the microscope, the felspar is seen to be very large, usually twinned in the Carlsbad type, enclosing augite and magnetite. The augite is monoclinic, its pleochroism being very strong. Magnetite is so abundant that the ground-mass often seems black and opaque. Brown coloured glass is abundant in the ground-mass containing microlites of felspar and augite in the fluidal-arrangement. The andesite is the pyroxene-andesite, very com-

1) "The Genesis of Ore Deposits," p. 517.

2) *Loç. cit.*, p. 517.

mon in Japan, but in the Satsuma Province it is frequently rich in the precious metals, notwithstanding the fact that the andesite of other provinces is generally barren of these metals. I made a microscopic study of the ores in the replacement vein in the andesite of the Ôkuchi Gold Mine.

This andesite is generally fresh, but the felspar phenocrysts are decomposed from the central portion into brownish chloritic matter. By the penetration of a mineral solution into the fissures of the rock, felspar is kaolinized, and augite and a part of the felspar are chloritized. The groundmass is at the same time transformed into a mixture of chlorite, kaolin, and quartz. Then silica, separated from the constitution of the rock-forming minerals, is deposited in the rock masses in the shape of veinlets or rounded masses. Magnetite is dissolved, and its iron together with that secreted from the other components is deposited again as pyrite by the chemical action due to the introduction of hydrogen sulphide. The auriferous solution is reduced by the ferrous oxide formed during the decomposition of the felspar and augite, and is deposited in colonies around the chlorite pseudomorph after the augite and felspar, or is imbedded in the kaolin-silica mixture. Thus gold in rich ores exists in colonies, as in the case of the Hasami Gold Mine already referred to. In ores in the replacement veins, gold is never found in the chlorite pseudomorphs or in the quartz veinlets running through the decomposition-products of the mother-rock. It will be seen, therefore, that the introduction of gold began after the chloritization of the rock-forming minerals, and finished before the formation of the veinlets. It is, however, not well established whether the metasomatic change took place at the same time as the formation of the mineral veins, or after the completion of the vein-making and during the period of its secondary enrichment. I am of opinion that the latter is the more probable theory.

10. Summary.

The above statements may be summarized as follows:—

a. During the consolidation of magma, various magmatic emanations are exuded, by the petrification of which ore-deposits are formed.

b. A definite process of deposition of emanations determines the order of petrification, as stated in Section 3, p. 4.

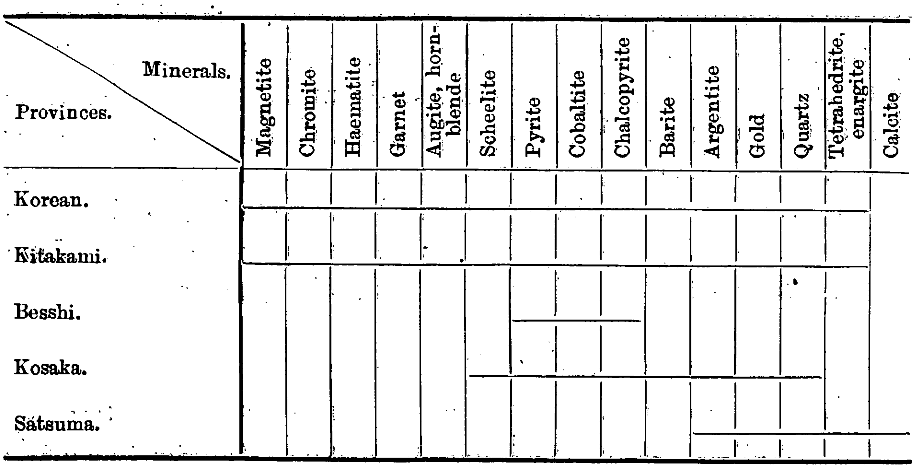
c. The ore-deposits of igneous origin may be classified into five divisions; magmatic segregations, contacts, replacements, mineral veins and impregnations.

d. There are several kinds of igneous rocks called ore-bringers, which produced the ore-deposits by their "eruptive after-action."

e. The Japanese empire is divided from the metallogenetic point of view into five provinces, according to the difference of the ore-bringers. They are as follows:—

Provinces.	*Ore-deposits.*	*Ore-bringers.*
Korean.	Contacts, veins.	Granite.
Kitakami.	Contacts, veins.	Diorite-porphyrite.
Besshi.	Beds.	Serpentine?
Kosaka.	Replacements, veins.	Quartz-trachyte, and propylite.
Satsuma.	Veins, impregnations.	Andesite.

f. The minerals in the ore-deposits in the different provinces are distributed in the order of petrification as in the following table:—



As the reader will see, in the pertrification order all the minerals except calcite are found in the Provinces of Korea and Kitakami. This is because they all belong to the older veins, which means that the formation of the minerals took place in the deep, where the temperature of the emanations was very high, the petrification continuing until the emanations got entirely cool. The pyrite beds in the Besshi Province are supposed to have been emitted from the most basic rocks such as serpentine or gabbro, and therefore only the minerals of the lower position in the petrification order are deposited there. The scantiness of quartz in the pyritic beds is explained by the basic character of the supposed ore-bringers. In the Provinces of Kosaka and Satsuma only the ore-deposits of younger formation are distributed and therefore such minerals as iron oxides or ferromagnesian silicates are never found there. Sulphides are more abundant in the Kosaka Province than in the Satsuma Province, for the fusing point of quartz-trachyte is higher than that of andesite. In the gold veins in the Satsuma Province, sulphides are very scanty, but if we go deep down we shall find much more of the sulphides which are of a higher petrification order than quartz and calcite, the two predominating vein-stuffs of the Satsuma Province.

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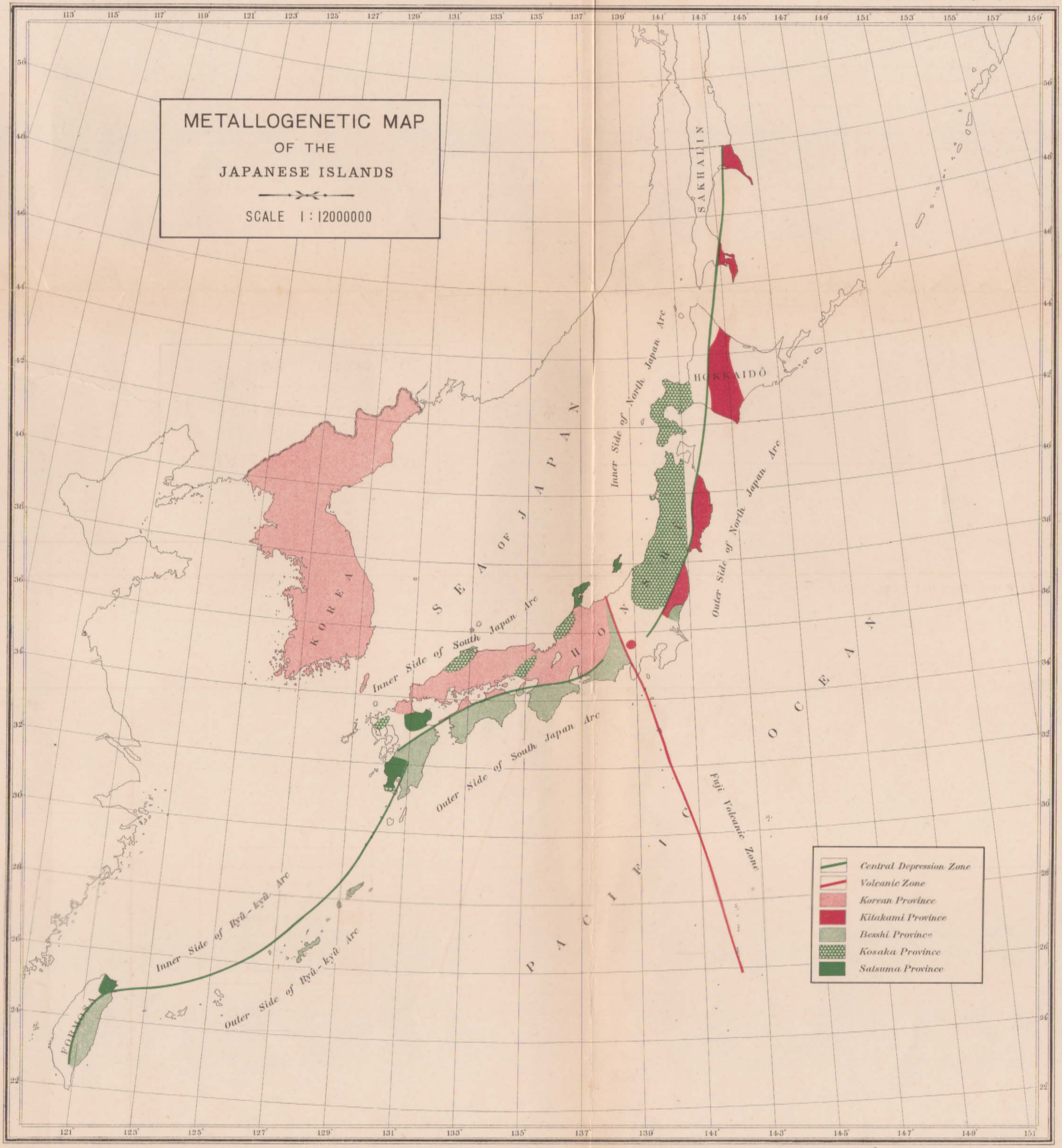
METALLOGENETIC MAP
OF THE
JAPANESE ISLANDS
SCALE 1 : 12000000
Central Depression Zone
Volcanic Zone
Korean Province
Kitakami Province
Besshi Province
Kosaka Province
Satsuma Province
SAKHALIN
HOKKAIDÔ
KOREA
SEA OF JAPAN
HONSHU
PACIFIC OCEAN
FORMOSA
Inner Side of North Japan Arc
Outer Side of North Japan Arc
Inner Side of South Japan Arc
Outer Side of South Japan Arc
Inner Side of Ryû-kyû Arc
Outer Side of Ryû-kyû Arc
Fuji Volcanic Zone