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The Mustavaara vanadium-bearing magnetite gabbro should be classified as "in magmas by late separation-late solidification (with or without fluid injection) immiscible melts, metal-oxygen rich, metal-phosphorus rich or, in the usual shorthand, Magmatic-3b.

ORIJÄRVI-AIJALA-METSÄMONTTU

Middle Precambrian	Zinc, Copper, Lead, Gold, Lead	Hypothermal-2 and -1

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Notes

The deposits of Orijärvi, Aijala, and Metsämonttu all lie in the Orijärvi leptite zone made famous by the classic studies of Pentti Eskola (1914, 1915) on the classification of mineral facies and on iron-magnesium-silicate metasomatism. The Orijärvi deposit is about 30 kilometers north of the town of Tammisaari (60°30'N, 23°50'E) on the southern coast of southwestern Finland and the Aijala (east) and the Metsämonttu (west) mines are located about 10 kilometers west-southwest of the Orijärvi mine. The first copper discovery on the Orijärvi property was made in 1757. Systematic regional prospecting, however, was not begun in this (Kaski) area until after the end of World War II (late 1945). The first economic ore was not found at Aijala until 1947, when the East (Itämalmi) and West (Länsimalmi) bodies were located. The Aijala and Metsämonttu ore bodies are about 1.5 kilometers apart, with the original estimates showing one million tons of ore at Aijala and 0.6 million at Metsämonttu. These tonnages probably were considerably increased because, in the early 1950s, 100,000 tons annually were being mined at Aijala and 70,000 from Metsämonttu. The literature on the mine geology was scarce until the recent publication of Latvalahti (1979); that on the rocks of the area is extensive. The several types of iron ore in the area are not considered here.

From 1932 to 1942, about 30,000 tons of ore was mined annually from the Orijärvi mine; in that period the grade was 1.4 per cent lead, 1.0 per cent copper, 4.5 per cent zinc, 0.4 grams gold, and 10 grams silver per ton; after 1942, the grade gradually went down. In 1948, mining of old dumps (accumulated when only copper ore was mined) was begun, and total production was increased to 40,000 tons per year; this ore averaged 0.7 per cent copper, 0.8 per cent lead, and 2.5 per cent zinc but no amounts for gold or silver are mentioned. In 1954, the mine was reported to have passed its prime, and, in 1963, when I visited the area, all mining had ceased. At Aijala, the ore was said (Varma, 1954) to have the following mineral content: chalcopyrite 5.2 per cent, sphalerite 0.9 per cent, pyrite 16 to 18 per cent, pyrrhotite 2 to 3 per cent, galena 0.01 per cent; at Metsämonttu, these mineral percentages were, in the same order, 0.25 per cent, 6.9 per cent, 9 to 10 per cent, 18-20 per cent, 0.12 per cent. Silicates and carbonates amount to 75 per cent of the Aijala ore, higher than the 65 per cent at Metsämonttu. The grade of the two ore bodies was, at Aijala, 1.8 per cent copper, 0.6 per cent zinc, 21.6 per cent iron, 17.4 per cent sulfur, and only arsenic (0.16%) of all other metallic ore elements was over 0.1 per cent; at Metsämonttu, only 0.1 per cent copper, 4.6 per cent zinc, 18.6 per cent iron, 16.1 per cent sulfur, and 0.1. per cent lead. Aijala ceased production in 1958 and Metsämonttu in 1974.

Eskola (1963) states that the leptite zone of southwest Finland, in which the ores are contained, is a belt of supracrustal rocks of middle Precambrian (Svecofennian) age. According to Latvalahti (1979), the volcanic activity that produced the leptites occurred about 1900 million years ago with the orogeny that later affected them being no younger than 1800 million years ago. The leptite zone is some 110 kilometers long and extends from the southwest coast to the Lohja district to the northeast. Although most of the leptites in the area of the mines are of volcanic origin, some sedimentary leptites are present. These rocks are made up mostly of quartz and feldspar, and range in grain size from fine (hälleflinta) to medium (leptite), to coarse (leptitic gneiss). Some mafic or intermediate volcanics are included in the leptite sequence. The leptites comprise the lower Svecofennian group in which the original materials were lavas, pyroclastites, and epiclastites. Some limestone and iron-formation lenses are interlayered with the dominant leptites as are some arenites. The thickness of the group is less than 3000 meters. Above the lower Svecofennian group is the middle group, mainly mafic to intermediate rocks that originally were lavas, pyroclastics, and epiclastics and also include random limestone layers; the group has a thickness of between 500 and 1000 meters. The upper group is composed of arenaceous and argillaceous rocks - phyllites, mica schists, graywackes, graywacke schists, mica gneisses, and arkosites; the thickness ranges widely but is less than 3000 meters. The volcanic rocks are sodium-rich, the sedimentary leptites potassium-rich.

The leptite zone in the Orijärvi-Aijala area is bordered by granodiorite; with this rock are associated quartz diorite, diorites, gabbros, and hornblendites. Latvalahti (1979) says that the contacts of plutonic rocks with leptites usually are conformable. In addition to these synkinematic rocks, the north and south borders of the leptite zone later were intruded by post-kinematic microcline granites.

The synkinematic intrusives southeast of the Aijala mine divide the generally westerly trending leptite zone into two parts. The southern part of the zone extends roughly eastward and contains no known ore; it is not mentioned further here. The northern part of the zone trends northeast and includes both the Aijala and Metsämonttu ore deposits; about six kilometers to the east of Aijala, the leptite schist zone separates into two parts, forming a synclinal structure that widens to the northeast. The southern limb of this structure contains no ore. The Orijärvi sulfide ore body lies near the base of the northeastern limb.

The synkinematic intrusive that divides the leptite schist belt forms a diapirically uplifted anticlinal batholith and ranges in composition from granite to granodiorite with some hornblendite sections. Locally, the granite has bent outward the schists that surround it. Partly assimilated fragments occur in the more mafic parts of the intrusive. The postorogenic microcline granite does not outcrop in the vicinity of the various ore deposits.

In the areas of the ore bodies, leptite rocks are higher in proportion than in other parts of the leptite belt.

The leptite rocks of the ore-bearing area have been affected by two phases of folding. In the Aijala-Orijärvi area, the older folding is isoclinal; the fold axes plunge gently to the east. The younger phase also produced isoclinal folds in which the subvertical axes plunge to the southwest at high angles. In both phases, the axial-plane schistosity is subvertical.

Lenses of skarn, limestone, and iron formation interlayered with the leptite show small-scale folding in many places. On the contrary, the acid volcanics only rarely show folds or other structures tectonically caused. The lineation of the second-stage folding is essentially always to be seen, but that of the first seldom is visible. Aijala is a far higher-strain region than Orijärvi; this is indicated by the more intensely deformed ejecta in the former area than in the latter. Further, the axial plane foliation is much more strongly developed at Aijala than at Orijärvi.

Post-metamorphic fault zones occur in the Aijala-Orijärvi area with the most prominent being the Jyly fault zone east of Orijärvi and the Kirkkojärvi fault zone that runs east-northeast about 500 meters north-northwest of the contact between the silicic leptites (southeast) and the intermediate leptites (northwest). The Metsämonttu ore body is cut by a fault at the 135 level that dips gently south; the fault displaces the upper part of the ore body about 270 meters north. A similar fault cuts the ore body on the 540 level and displaces it 80 meters north. The Aijala ore is cut off sharply at the 200 level by a fault and shear zone that dips steeply north. The general area of the Orijärvi ore is cut by several faults and shear zones; north-trending faults east and west of the ore body are the most prominent of these.

Latvalahti (1979) reports that regional metamorphism took place before the intrusion of the microcline granite. In the folding process, the first phase in part came before and in part after the regional metamorphism. The first folding stage had reached its peak before the second phase began. The rocks of the Aijala-Orijärvi area were metamorphosed to the low-pressure amphibolite facies; farther east metamorphism reached the granulite facies.

The diagnostic metamorphic-mineral assemblage in the ore area is muscovite-quartz-plagioclase (An_{20}) with the reaction locally producing sillimanite and andalusite. At Orijärvi, the mica gneiss actually is a cordierite-sericite mica gneiss, and it contains andalusite and sillimanite. Latvalahti calculates that the confining pressure was about three kb and the temperature 650° ± 30°C. Eskola (1915) maintained that the Orijärvi granodiorite mass caused contact metamorphism, the PT conditions of which were about the same as, or slightly lower than, those of the regional metamorphism which he contends followed the intrusion. This contact metamorphic aureole (?) surrounds the western two-thirds of the synkinematic silicic intrusive; this aureole is not duplicated, except to a minor extent, around the major mass of the granodiorite farther south from the Orijärvi area. Eskola considered that, northeast of the granodiorite mass is a belt, some 200 meters wide, of cordierite-anthophyllite rock. On its northeast, this rock is bordered by amphibolite. In turn the amphibolite is succeeded by leptite.

In vertical section, at right angles to the ore contact, the major ore lens follows the cordierite-anthophyllite amphibolite contact; further, the smaller ore lenses, as much as 50 meters from this contact, have the same attitude as this latter feature. In the two rock types just discussed, limestone and skarn lenses are intercalated. The skarns are composed mainly of tremolite and actinolite, and, in parts of some ore volumes, these two minerals are the matrix of the ore.

Into the country rocks of the Orijärvi area was intruded what Eskola called oligoclase granite in 1914 but considered to be granodiorite in 1963. Surrounding the western two-thirds of this granodiorite is a contact-metamorphic aureole, not duplicated, except to a minor extent, in the major mass of granodiorite to the south of the Orijärvi body. North(east) of the mass of granodiorite is a belt, some 200 meters wide, of cordierite-anthophyllite rock that, to its north(east), is bordered by a band, some 100 meters wide, of amphibolite, still farther north, the amphibolite is bordered by leptite. The ore and small associated bodies of skarn are located between the amphibolite (northeast) and cordierite-anthophyllite rock with one or two smaller ore lenses being entirely within the latter rock type. The major ore lenses are located at a southward bulge in the amphibolite contact.

The granodiorite, to which Eskola considers the ores (see below) to be genetically related, almost certainly was introduced into the area at the end of the middle Precambrian and during or after the metamorphism of the host rocks of the ore. The host rocks, whether denoted as Svecofennian or

Karelian, are definitely middle Precambrian, and various age dates on the igneous material appear to confirm this. The ore deposits of the Orijärvi area, therefore, are classified as middle Precambrian in age.

Eskola's original concept was that the ore fluids were the same that contact-metamorphosed the leptites and limestones and came from the granodiorite (oligoclase granite). This idea was critized orally by Brögger on the grounds that a granite was not a good source of magnesium; this criticism is less valid now that the granite has been agreed to be a granodiorite. It remains true, however, that a magnesium-rich ore fluid might have been more likely to have come from a magma more mafic than one of granodioritic composition. Geiger (1917) suggested that the ores at Falun (where host rocks, altered wall rocks, and ore are similar to those at Orijärvi) were formed in much the same way as those at Orijärvi. This argues against the concept that the amphibolites were the result of regional metamorphism (at least in the ore area) because the amphibolitized mafic dikes at Falun contain cummingtonite in the ore field but lack it outside of that area. This mineral relationship also occurs at Orijärvi where cummingtonite is a principal constituent of the amphibolite in its border facies.

In 1950, Tuominen and Mikkola reexamined the magnesium-rich rocks in the Orijärvi area and suggested that the cordierite and anthophyllite accumulated in the fold hinges in small anticlines and synclines in the altered layered leptites. They considered that such positional relationships meant that, during folding, silicates of magnesium, iron, and aluminum crystallized at low temperatures, in the presence of considerable water (fluid?) as micas, chlorite, and talc and moved plastically to the fold crests and troughs. The introduction of magnesium and iron forced the transfer of calcium, potassium, sodium, and silicon to the competent leptite layers where they are supposed to have produced feldspars as well as andalusite and sillimanite. These authors also thought that the ore-mineral constituents were introduced in the same manner as the iron and magnesium.

Eskola (1950) thought this concept, to some extent, improved on the hypothesis of a magmatic origin for the ore fluids, but he pointed out that the anthophyllite-cordierite rock and the Orijärvi ore bodies do not occur in a fold crest. Eskola, for this and other reasons such as the lack of correlation between Tuominen's geomagnetic map and the plastic folding shown in the exposures in the mine area, believes that Tuominen's interpretation is greatly exaggerated.

On the basis of the work he did in the Orijärvi area, Eskola put forward his concept of metamorphic facies. It was not until 1939, that Eskola put his ideas on this subject in his final form. At that time, he added three facies to the five he had defined in 1920 to give a total of eight. These eight facies are: (1) sanidinite, critical minerals are sanidine and pigeonite that occur as xenoliths in volcanic rocks, indicating pyrometasomatic conditions (in Lindgren's sense of the term); (2) hornfels (now called pyroxene hornfels) critical assemblages are diopside-hypersthene and orthoclase-andalusite that occur in the inner zones of contact aureoles (typically seen in the Oslo area); (3) amphibolite facies in which hornblende and plagioclase are critical, and this assemblage, occurring at Orijärvi, suggests higher pressures there than in the Oslo pyroxene-hornfels facies, but its development in the outer zones of contact aureoles indicates lower temperatures (Eskola considered water essential to the formation of this facies); (4) greenschist, critical minerals are muscovite-chlorite-quartz and albite-epidote-quartz and the facies is a product of regional metamorphism in the upper levels of the crust [pressure and temperature lower than those facies (1) through (3) above]; (5) eclogite, where the association of omphacite with pyrope-almandine and rutile are critical - the high density of this assemblage indicates formation by extreme metamorphism at great depths and high temperature; (6) granulite, critical minerals are quartz-orthoclase-plagioclase-almandine-hypersthene, while hornblende, micas, wollastonite, and grossularite are absent - probably these assemblages are due to regional metamorphism at high temperatures and pressures in a dry environment (indicated by lack of hydrous minerals), (7) epidote amphibolite (now called albite-epidote amphibolite), critical minerals are quartz-albite-epidote-hornblende, and these formed under conditions intermediate between the greenschist and amphibolite facies; (8) glaucophane schist, critical minerals are glaucophane, crossite, lawsonite, and pumpellyite; although Eskola related this facies to eclogite, other authors consider it related to the greenschist and albite-epidote-amphibolite facies.

Eskola (1939) among others, recognized that disequilibrium assemblages of minerals occur, particularly among low-grade, regional metamorphic facies, in which mixtures of minerals assemblages are developed that belong to more than one facies, the relationships in time being indicated by textural criteria such as pseudomorphs of one mineral after another, cross-cutting veinlets, and partially destroyed relics of probably earlier minerals. Because reaction rates are speeded up by increasing temperature, partial replacement of a higher-grade assemblage by a lower one is more likely than the opposite result. Such higher to lower transitions require increased hydration of the rock involved.

A more detailed discussion of the various metamorphically induced mineral assemblages can be found in Fyfe, Turner, and Verhoogen - Metamorphic Reactions and Metamorphic Facies: Geol. Soc. Amer. Mem. 73, 1958. In this discussion, p. 199-239, the authors break down the various temperature-pressure assemblages into those produced in pelitic, calcareous, mafic, and magnesian, and, in places, quartzo-feldspathic rocks. Pelitic rocks are considered by these authors to be the derivatives of aluminous sediments; quartzo-feldspathic to be those of sandstones and of silicic igneous rocks; calcareous those of limestones, dolomites, and marls; mafic as those of mafic and semimafic igneous rocks, tuffs, and some tuffaceous sediments; and magnesian as those of ultramafic igneous rocks and of highly magnesian sediments. If quartz is present in the metamorphic assemblage, the facies is characterized as silica-rich, if it is absent, as silica-deficient. It seems apparent that each of the five rock types given above, if metamorphosed under the same conditions, will produce sufficiently different mineral assemblages that the parent rock can be recognized and, at the same time, can be assigned to the same metamorphic grade.

Certain divisions of these assemblages into subfacies also were made by the authors at that time, but since then they have been decided that subfacies confuse the issue more than they clarify it. Metamorphic rocks, therefore, that contain the minerals of two adjacent assemblages are designated as transition facies, e.g., greenschist-amphibolite transition facies.

From the point of view of the economic geologist, it is unfortunate that the interest in the concept of metamorphic facies developed from Eskola's work in the district has overshadowed the geologic study of the ore deposits of the area. Although an important part of Eskola's work was based on what was then visible in the open-pit of the Orijärvi mine as it was then; the ore that was in that pit is now completely mined out with more geologic attention having been paid to metamorphism than to ore formation.

On either side of the now-abandoned open pit are both the anthophyllite-cordierite and amphibolite rocks, only the former of which contains any ore. These rocks also contain skarn and limestone intercalations, the skarn having been contact-metamorphically derived from the limestone layers. The skarn is primarily an actinolite-tremolite rock with some of the ore having skarn minerals as matrix materials.

Two types of ore have been recognized. The first is soft ore (blötmalm) that consists of galena, sphalerite, and chalcopyrite, with only accessory amounts of pyrite and pyrrhotite; this ore was developed in the skarn portions of the ore occurrence. The second type, hard ore (hardmalm), is made up of biotite-cordierite-anthophyllite rock and cordierite quartzite; these rocks contain chalcopyrite as equally distributed impregnations or as distinct bands in association with pyrite and pyrrhotite. Sphalerite also is present in this hard ore as patches and small compact masses; galena is present only in minimal amounts. Varma (1954) says that, judging from the appearance of the old open pit, the ore body must have been a connected mass near the surface; this massive body branched downward into projections and lenses. The strike of the ore mass is about east-west, and the dip was about 70°N to a depth of 100 meters. Between 100 meters and 200 meters the dip is southerly at about the same angle; below 200 meters, the dip remains southerly but apparently at a steeper angle than above 200 meters. The ore lens plunges east at from 35° to 50°. Some 100 meters west-northwest of the open pit was a small, isolated lens of ore that consisted principally of sphalerite and pyrite; it extended only about 100 meters below the surface and has been mined out. Further, a weak magnetic anomaly was found along the northern border of the amphibolite north of the open pit; here a narrow zone of sphalerite-galena mineralization was found by diamond drilling; it does not appear to have been worth an attempt to mine it.

The ores at Aijala and Metsämonttu are in the same geological environment as the Orijärvi mine, some 10 kilometers southwest of the latter mine. On the north, the ore zone is bordered by amphibolite and diopside amphibolite; it is intercalated by narrow bands and layers of mica gneisses and mica schists, and some of the mica schist bands may contain arsenopyrite.

On the south, the ore zone is bounded by a quartz porphyry (Varma says blastoporphyritic leptite), then by sericite schist, and, still farther south, by cordierite-mica schists. Pegmatites are present on both sides of the ore zone; they parallel the general strike of the schistosity.

Although both the Aijala and Metsämonttu ore zones trend generally northeast-southwest, the Metsämonttu lenses are definitely northwest of a straight-line continuation of the strike of the Aijala lenses; if, therefore, they are in the same stratigraphic unit, an appreciable fold or fault must lie between the two ore zones. The two ore zones, however, may simply be in the same major rock zone, without being in the same stratigraphic unit. In both zones, the ore occurs mainly, in contradistinction to Orijärvi, as disseminations or breccia cements in limestone or skarn derived from limestone. The dips of the ore bodies, as well as those of the enclosing schists, is quite steep, departing from the vertical by no more that 5° to 10° in either direction. In both areas, the ores are all of lens shape and plunge steeply, but Varma (1954) does not say in what direction, though it more probably is southwest than northeast. The half dozen or so Metsämonttu ore lenses trend generally southwest, but the strike of the most southerly lenses is some 35° more southerly than the major lenses lying northwest of it. The total surface length of the Metsämonttu ore lenses is about 250 meters.

Although the major portion of the Aijala ore is confined to the east (Itämalmi) lens and the west (Länsimalmi) lens, the area of this mine includes about 10 mappable ore lenses on a scale of 1 cm = 100 meters. The total length of the Aijala zone is about 400 meters.

Surprisingly, the mineral composition of Aijala is quite different from that at Metsämonttu, with chalcopyrite being 20 times more abundant at Aijala than at Metsämonttu and sphalerite 7.5 times as abundant at Metsämonttu as at Aijala. Pyrite is nearly twice as abundant at Aijala than at Metsämonttu, whereas pyrrhotite is seven to nine times as abundant at

Metsämonttu as at Aijala. Galena is low at both mines, but it is 10 times as common at Metsämonttu at at Aijala. Total sulphide content at Metsämonttu averages about 10 per cent greater than at Aijala. This difference in mineral composition is difficult to explain, but perhaps no more so than the difference between the soft and hard ores at Orijärvi where the former ore is higher in the lead and zinc sulfides and the latter in chalcopyrite. At Orijärvi, the sphalerite-rich ore has skarn as its host rock and the chalcopyrite-rich has cordierite-anthophyllite rock as its host. In this instance, the difference may be due to the different reactions occurring between the ore fluid and the two host rocks. If this is so, then perhaps the Metsämonttu ore is largely in limestone and skarn and the Aijala ore principally in mica-cordierite-garnet schist. It is difficult to be certain about the host rocks of the Aijala-Metsämonttu ore lenses because of the small scale of Varma's (1954) cross section for the Aijala ore and his lack of one for the Metsämonttu ore.

Latvalahti (1979) points out that the ores in all three deposits are strata-bound in general, but, in detail they fill fractures and cement breccia masses in the host rocks. The Aijala and Metsämonttu ores are somewhat more definitely strata-bound than those at Orijärvi; the former, she observes, occur at the contacts between silicic volcanics and intermediate-mafic pyroclastic volcanites (at Metsämonttu) or close to them (at Aijala). The Orijärvi deposit, on the contrary, is located (as Eskola says also) in a zone of silicic cordierite-sericite and cordierite-anthophyllite rocks. Latvalahti (1979) indicates that there are two mineralized horizons at Orijärvi that lie in the zone of andalusite-, cordierite-, sericite-, and anthophyllite-bearing rocks. The ore body is in the lower mineralized horizon; the upper zone has only a small Zn-Pb-Au-Ag deposit (Illampi) that apparently is too small and/or low grade to be mined. Cordierite- and anthophyllite lenses occur at several levels in the metamorphosed rocks, although she believes that only some of them are in the mineralized horizons. These metamorphosed rocks range widely in composition and texture. Despite the metamorphism they have undergone, some of these rocks still show relics of primary layering. Latvalahti remarks that a hypabyssal variant of the synorogenic granodiorite, with quartz phenocrysts, is about 200 meters southwest of the Orijärvi deposit. The greatest extent of the ore bodies at all three mines is in dolomitic limestones and skarns. Thus, although the bulk of the ore horizon is composed of siliceous metamorphosed rocks, the ore favors those that still are carbonates or have a carbonate ancestry.

In the three ore deposits, the actual ore bodies consist of several small, narrow, and elongated ore bodies in which the major axis is parallel to the b-lineation of the second phase of folding. The ore bodies are oriented either side by side or en echelon; the orientation depends on the relations of the bodies to the fold structures. At Orijärvi, the axes of the ore bodies dip 45-50° NE; further, at Orijärvi, the deposit is cut by a basaltic subvolcanic dike that greatly complicates the relationships of the ore masses to each other. At Aijala and Metsämonttu, the ore bodies dip more steeply, 80-85° SW. The ore bodies (Latvalahti, 1979) are cut by faults and shear zones that brecciate the ore bodies; dense joint networks, in many places, are filled with zeolite veinlets or chlorite-coated slickensides. The largest fault displacements are at Metsämonttu where unmetamorphosed clay coats the fault surfaces.

The ore bodies of the Aijala area conform to the axial plane of foliation of the second-stage folds. At Metsämonttu, the dolomite skarns and chlorite-bearing tremolite-diopside skarns become less abundant with depth; on the contrary, cordierite-anthophyllite rocks and cordierite-mica gneisses are more common with depth than they were at the surface. By the 510 level, the cordierite-bearing rocks dominate over the skarns. At this level, the grade and size of the ore bodies decrease markedly. The ores at all three deposits are thickest (up to 20 meters) in the skarns, but normally they are less than 10 meters; their strike lengths range from 100 to 150 meters.

The Orijärvi deposit is rather like that at Metsämonttu in wall rocks and wall-rock alteration, distribution of metals, and their modes of occurrence. The Orijärvi ore bodies are located largely in chlorite-bearing tremolite-diopside skarns; quartz- and anthophyllite-bearing rocks are present in the walls of the ore bodies but contain essentially no bodies of economic value. The Orijärvi ores are more broken and smaller than those at Metsämonttu.

Latvalahti (1979) classes the ores at all three deposits as: (1) breccia, (2) massive-vein, and (3) disseminations. Of these, those of type (1) are economically the most important. They clearly cut, brecciate, and replace the wall rock but are generally conformable to the bedding and have sharper contacts with those rocks in structure and metal content. Although the breccia ores normally are skarns and dolomite limestones, minor amounts are in quartz-rich rocks; they include only a few wall-rock fragments of small size. The ores replace amphiboles and pyroxenes along cleavages and brecciate quartz-phlogopite masses. The richest of the ore types in lead and silver are breccia ores in skarn and dolomite limestones; iron sulfides predominate in those in quartz and cordierite rocks, but some chalcopyrite usually is present in these.

The (2) ores form massive sulfide veins with widths from a few centimeters to several meters. Their major minerals are pyrrhotite and pyrite; they have sharp contacts with the wall rocks and locally include wall-rock fragments. Shear zones containing chlorite may be filled with veins of iron sulfides (Latvalahti says they are remobilized sulfides but does not say why) or coarse-grained disseminations of sulfides. Disseminated sulfides also are in places associated with breccia ores in which they replace amphibole and pyroxene. Iron sulfides may be disseminated in various cordierite and mica gneisses.

The chemical composition of the ores ranges widely. The ores at Metsämonttu and Orijärvi are much the same, but the latter ores are less discrete, forming broken, narrow, and discontinuous ore bodies. In both areas, ores in limestones and skarns have a higher (Zn,Pb)/Cu ratio than those in cordierite rocks but at Orijärvi copper is more common in cordierite than it is at Metsämonttu. In this latter deposit, a copper ore body in cordierite gneiss continues in slightly mineralized form to the Aijala deposit. Zinc-lead, zinc-iron, and copper ore bodies are present; zinc-lead ores are located in chlorite-bearing diopside skarns and dolomitic limestones, zinc-iron bodies in mica and cordierite gneisses, and copper ore bodies in cordierite gneiss.

The Aijala ore bodies are principally composed of chalcopyrite (mainly) and pyrite. The deposits down to the 220 level are predominantly chalcopyrite but with some sphalerite, galena, arsenopyrite, and iron sulfides in varied grades. The margins of the Aijala ore bodies are richer in iron than the cores. Most of the copper ore bodies grade into pyrite ores with depth.

The deposits of all three districts have simple mineralogies with pyrrhotite, pyrite, chalcopyrite, sphalerite, and galena as the major minerals; their relative abundances differ from one deposit to the next and from one part of a single deposit to another. Latvalahti says that ore in these various loci both fill open space and replace gangue minerals. She says that fault and shear zones have affected the ore, partly remobilizing and replacing it. She does not give her reasons for this belief, although the concept follows logically from her faith that the ores were originally syngenetic and strata-bound, and the only way they can show replacing and cross-cutting textures is by remobilization and resolution and replacement. Of course, such statements as she makes do not remove the possibility that the replacement and open-space filling resulted from the reactions accomlished by the solutions that also deposited the strata-bound ores. The "original" banded textures (in Latvalahti's opinion) in the ores, therefore, may be the result of replacement rather than of primary deposition. Although certainly the primary ores were somewhat affected by metamorphism attendent on the second phase of folding.

In addition to the minerals already mentioned, the ores also contain cubanite, magnetite, tetrahedrite-tennantite (fahlerz), native silver, and various sulfo-salts, the latter as accessories in association with galena. At Metsämonttu, sphalerite in many places contains exsolution bodies of chalcopyrite and pyrrhotite. Boulangerite is present as inclusions in galena; chalcopyrite contains cubanite lamellae and tetrahedrite inclusions. Orijärvi ore contains, normally, more chalcopyrite than that at Metsämonttu enough to class it as a major mineral. Orijärvi contains more high-temperature minerals (ilmenite, magnetite, gudmundite, molybdenite, and uranitite) than the other two districts.

Below the ore at both Orijärvi and Metsämonttu funnel-shaped alteration pipes of cordierite-anthophyllite rocks are present below and connected with ore above. Further, largely surrounding the ore deposits are alteration envelopes of cordierite-bearing sericite and muscovite schists that, Latvalahti says, are located close to the volcanic discharge channels. Folding, faulting, and "remobilization," Latvalahti believes, have to some extent affected the original locations of ore relative to alteration zones. These relations she cannot imagine as being the result of anything other than remobilization of primary ores and of metamorphism-induced wall-rock alteration.

The Aijala and Metsämonttu ore deposits have a common outer alteration zone that is about three kilometers long. Its maximum width is 100 meters, but it drops down to 0.5 to two meters in the areas between the two deposits. The rocks in the outer margins of this alteration zone have been sericitized, exactly the effect that would be expected from the ore-bearing solutions working their way outward after depositing the ore bodies of the two deposits. Latvalahti considers that the internal heterogeneity of the inner portions of the alteration zones in all three deposits largely is due to the original heterogeneity of the rocks that host the ore, but she also thinks that differences in the altering fluids from one point to another may have been partly responsible for these variations. The alteration of the inner zone is primarily the magnesium alteration that Eskola recognized early in this century. The principal types of rocks in the inner zone are dolomitic limestones and chlorite-bearing tremolite-diopside skarns derived from limestones and cordierite-biotite gneisses and cordierite-anthophyllite rocks produced from silicic tuffs with quartz and plagioclase phenocrysts. Quartz-rich rocks are the result of silicification of silicic rocks.

The quartz-rich rocks and the chlorite-bearing tremolite-diopside skarns occur only in the wall rocks of the ore bodies, whereas, the cordierite-anthophyllite rocks and the cordierite-bearing gneisses make up the alteration pipes below the Orijärvi and Metsämonttu deposits. The former pipe is known to go down 250 meters, without bottom having been found, and the better explored latter pipe reaches at least 600 meters beneath the ore. No alteration pipe is known at Aijala.

In the inner alteration zone, some retrograde metamorphism is shown by sericitization of plagioclase and pinnitization of cordierite.

Eskola still considered, in 1950, that the ores were produced by hypothermal mineralization by ore fluids derived from the synkinematic granodiorite. The same ore fluids, in his opinion, also produced the various types of wall-rock alteration surrounding and intermixed with the ores. On the contrary, Latvalahti (1979) appears convinced the ores were deposited on the sea floor and that the altered pipes were produced by the same solutions during their upward journey. How she explains the envelopes of alteration around the ores is less clear. These alteration zones could not have been formed at the same time as the ores were spewed out on the sea floor, because rocks to be altered in this manner did not exist at that time around the ores. She can explain these envelopes only by reactions generated in the volcanics (largely subsequent to the ores) by the metamorphism attendent on the second stage of folding. To me, even after the lapse of so many years and the present popularity of volcano-genic processes, it seems that Eskola is more nearly correct than Latvalahti.

The contact metamorphism of the host rocks of the ores in the Orijärvi district appears (to me) to have taken place under hypothermal conditions, and, since the ores are found in both calcareous and non-calcareous rocks, the wall-rock alteration alone would be categorized as hypothermal-1 and -2. If, however, it could be shown that the ore sulfides were emplaced under sufficiently lower temperatures than the gangue minerals, the hypothermal category would not be used in the classification scheme employed in these volumes. The presence of cubanite [Fe_2CuS_3] in the Orijärvi ore suggests that the chalcopyrite, with which it is closely associated in time and space, at least formed under hypothermal conditions. The presence of exsolution textures of chalcopyrite and pyrrhotite in sphalerite adds confirmation to the proper place of the Orijärvi area deposits in the modified Lindgren classification being hypothermal. What is known, including the major amounts of pyrrhotite, the small content of galena, and the presence of gudmundite [FeSbS] in the deposit, indicates nothing against the deposit having been formed under hypothermal conditions and probably goes a considerable way to confirm it. The Orijärvi deposits, therefore, are here categorized as Hypothermal-1 and -2. The Aijala and Metsämonttu deposits are similar enough, both in gangue and ore minerals, to those at Orijärvi that these two groups of ore bodies also should be classified as Hypothermal-1 and -2. The minor amounts of sulfosalts associated with galena suggests that some of the ore was formed under mesothermal conditions.

OTANMÄKI

Middle Precambrian	Iron as Magnetite Titanium as Ilmenite Vanadium in Magnetite	Magmatic-3b Metamorphic-C

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