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The metallogeny of Finland

by Aimo Mikkola

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The metallogenic epochs and types of mineral deposits in Finland are discussed. The Archean iron and nickel-copper mineralizations are associated with greenstone belts. The Proterozoic ores include chromite and iron-vanadium-titanium deposits in layered mafic intrusions, stratabound copper and polymetallic deposits, nickel-copper deposits connected with ultramafic intrusions, and hydrothermal sulphide deposits. The only deposit of Paleozoic age is an apatite bearing carbonatite intrusion.

Key words: economic geology, mineral deposits, metallogeny, Precambrian, Finland.

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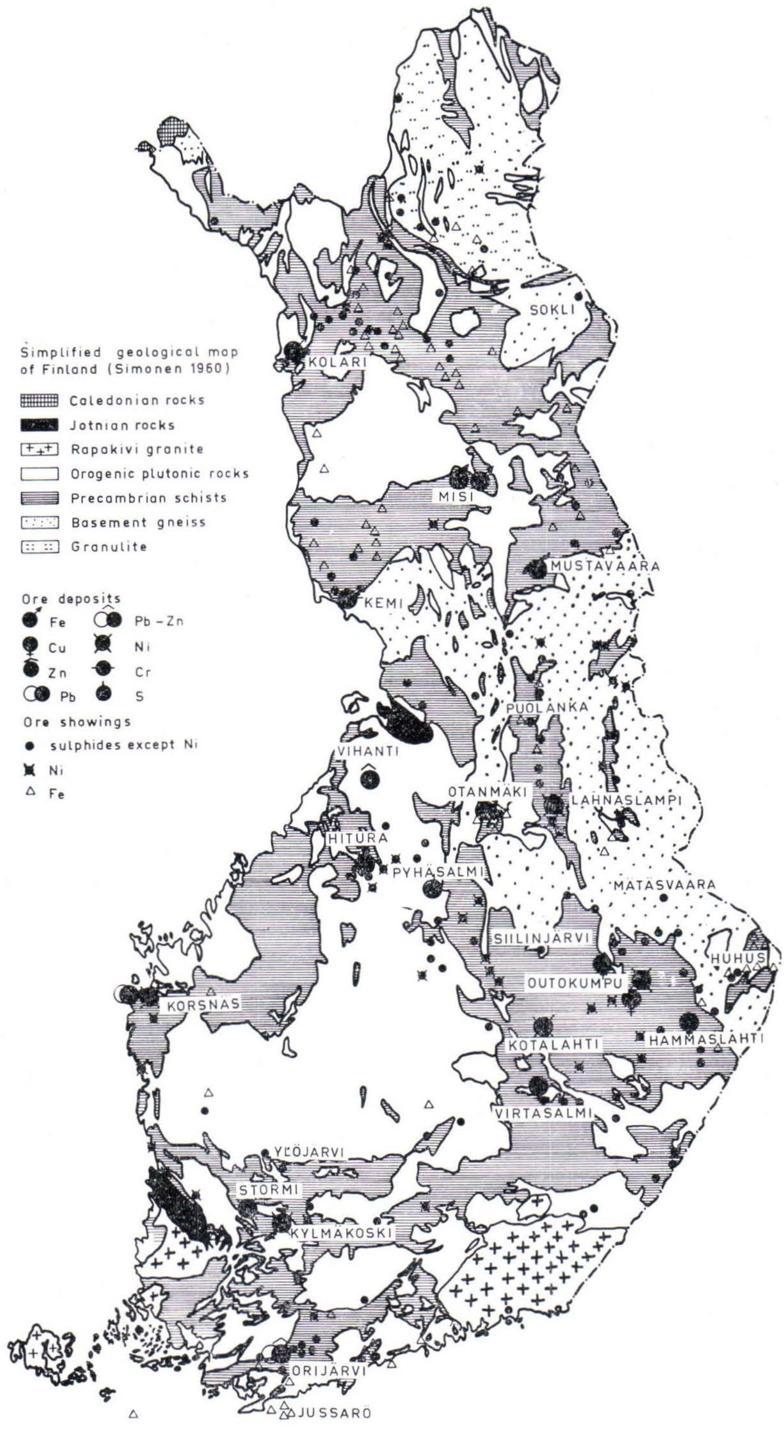

Fig. 1. A geological map showing ore deposits and showings in Finland.

INTRODUCTION

The study of metallogeny includes the genesis of ore deposits, the type and composition of a mineralization, the time of emplacement and the structural features controlling the ore deposition. Hence the metallogeny of a certain area can be studied in a variety of ways, depending on where the emphasis is needed. The Baltic Shield is a rather small and well defined area. Its geological events and lithology have been satisfactorily established and are generally accepted. In any discussion on metallogeny it is reasonable to work within the same broad limits as in the general geology (Simonen 1979).

For the sake of the reader this article has been divided into sections on the basis of geological eras, namely Archean (Presvecokarelidic), Early Proterozoic and Middle Proterozoic (Svecokarelian, Rapakivi and Jotnian). Some repetition is inevitable in the discussion on the genetics of ore deposits, but because the main mineralization epochs in Finland occurred during Early and Middle Proterozoic, it should not bother the reader too often.

Ore deposits in Finland represent wholly different classes genetically. Magmatic ore formation is represented by deposits connected with igneous and volcanic activity. Most ore deposits are metamorphosed; the origin of some is readily discernable, that of most can only be inferred. Thus ore deposits in Finland are classified as metamorphic. Unmetamorphosed sedimentary deposits are insignificant (Quaternary bog and lake iron ores). The location of known ore deposits and showings is shown in Fig. 1. A detailed reference list has been omitted from the following discussion. The author refers to Professor Kahma's paper (1973) »The main metallogenic features of Finland», which contains complete references concerning individual deposits up to 1973. References since that date are given in the list.

ARCHEAN ORE DEPOSITS

An Archean age in the range 2 500—3 000 Ma (cf. the Presvecokarelidic basement of Simonen) has been determined for Finnish rocks northeast and north of the NW-striking shear belt, Lake Ladoga—Gulf of Bothnia (Raahe), (Fig. 2). The area may be divided into two main units: the granitoid association and the greenstone belt association. Both contain a small number of ore deposits and ore showings; unfortunately, however, none of the known deposits is currently of economic importance.

The greenstone belt unit consists of several isolated patches in eastern and northern Finland; from south to north they are Ilomantsi, Kuhmo—Suomussalmi, Salla, Jauratsi and Kittilä (Fig. 3). The Kittilä belt has been interpreted to belong

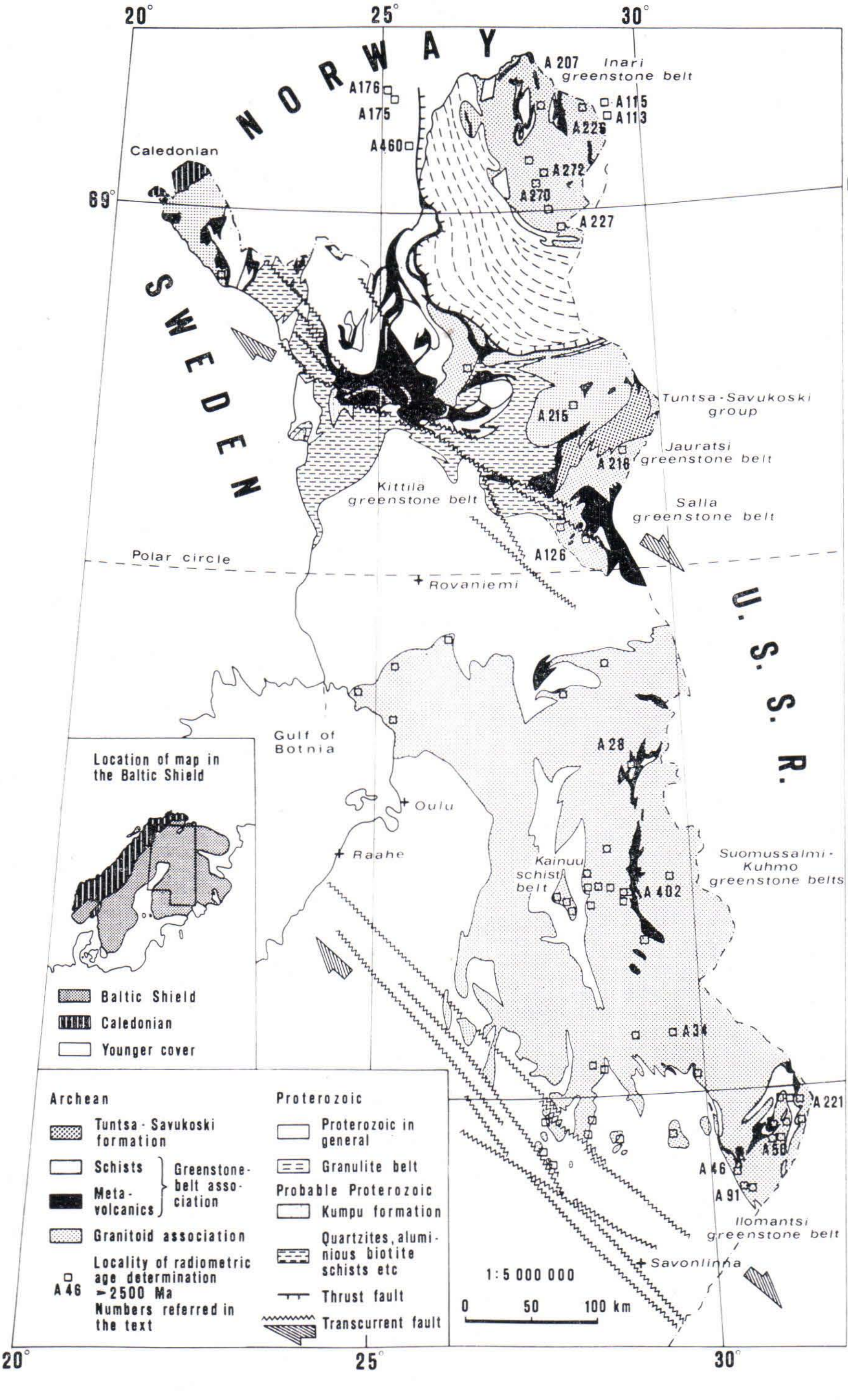

Fig. 2. Archean rocks in Finland (after Gaál *et al.* 1978a).

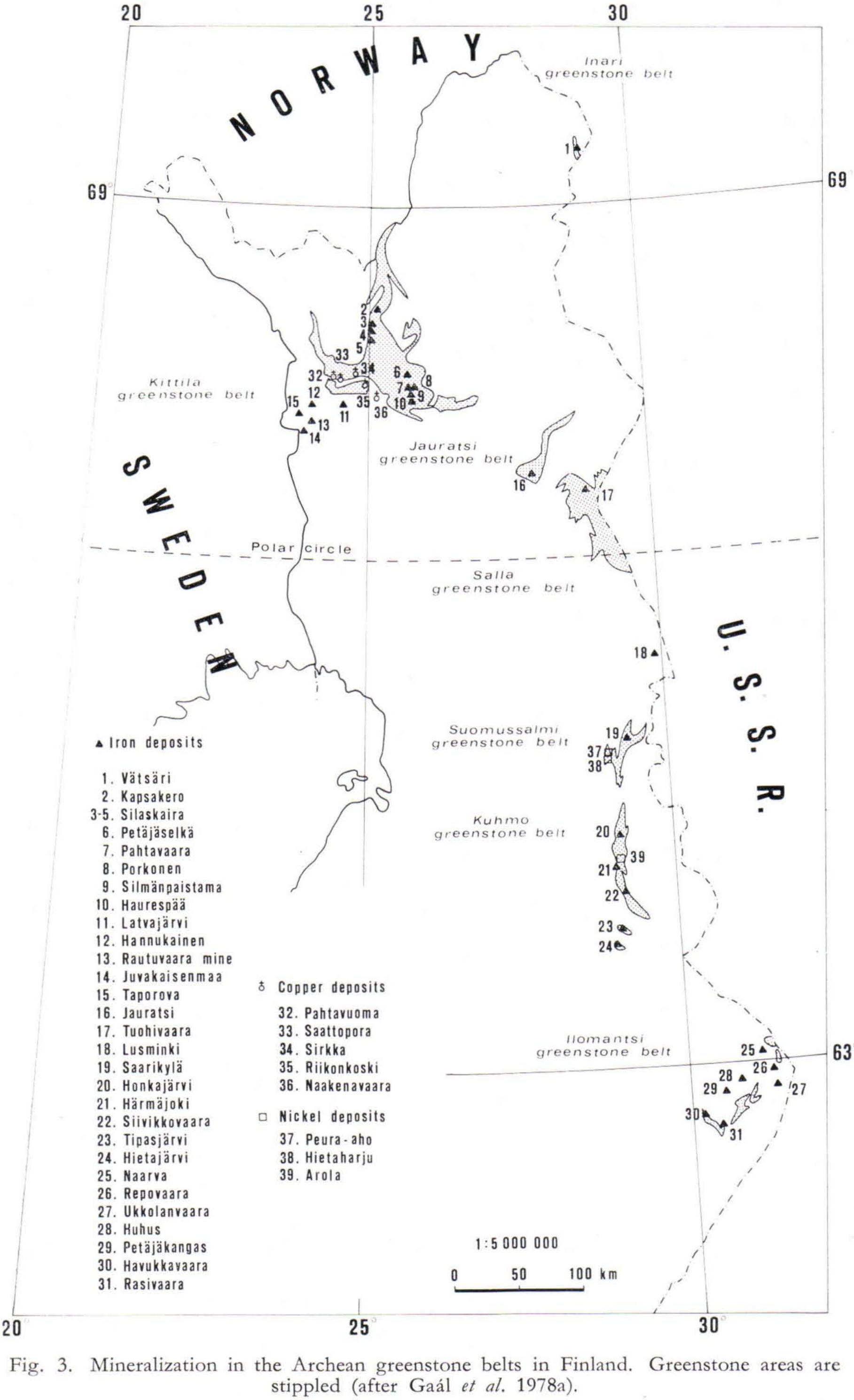

Fig. 3. Mineralization in the Archean greenstone belts in Finland. Greenstone areas are stippled (after Gaál *et al.* 1978a).

to the Svecokarelidic group (Simonen 1979), but there is evidence for including it in the Archean greenstone belt unit (Gaál *et al.* 1978a).

Iron mineralization

The greenstone belts contain ore mineralizations of two different types: banded iron formation in metasediments and metavolcanics (Lehto and Niiniskorpi 1977), and base metal sulphide mineralization associated with serpentinites, and basic and intermediary volcanics. The banded iron formations are common in all belts, but with the present economic situation they are not worth exploiting. The Huhus deposit is the best known in the Ilomantsi belt. It consists of intercalated quartz-magnetite-amphibole bands in quartz-feldspar schists, which are believed to be of volcanic origin. The iron formation may be tens to hundreds of metres thick, but the quartz-magnetite bands are only a few metres. An individual deposit may be a few hundred metres long. The iron content in thinly banded grunerite-magnetite rock is about 30—35 % Fe (mostly in silicates); the other type, quartz-magnetite-hornblende ore contains about 30 % Fe (mostly in magnetite). The P_2O_5 content is 0.1—0.2 % and manganese is usually less than 0.1 % MnO.

Jauratsi is the best known of the iron deposits in the greenstone belts of eastern Lapland. The iron formation is located in a quartzite-black schist sequence. The deposit contains either quartz-magnetite or quartz-hematite-goethite banded ore in a metavolcanic—metasedimentary series. The iron content of the former is about 45 % Fe, but its sulphur content is high (3.3 %); the latter is leaner, and shows low Mn and P contents.

The Kittilä greenstone belt in western Lapland contains several iron deposits of the banded type (Lehto and Niiniskorpi 1977). The deposits represent different facies of a chemically precipitated formation and include oxide, oxide-carbonate and carbonate-sulphide precipitates. The iron minerals in the oxide facies are magnetite, hematite and goethite banded with jasper quartz. The oxide facies is surrounded by basic lavas and tuffagenous schists. The carbonate facies, which consists of mangano-siderite banded with chert and graphite-bearing chlorite-goethite rock, occurs in the tuffagenous schists. The sulphide-bearing iron formation consists of black schists disseminated or brecciated by pyrrhotite and pyrite. The iron content in the oxide facies varies from 25 % to 35 % Fe. In the carbonate facies the Mn content may reach 10 %, the Fe content being 25 %. Phosphorus is usually less than 0.5 % P_2O_5. — The iron formation is not coherent; it is folded, faulted and brecciated and forms a number of small discrete bodies. Although the total tonnage may be great, there are no mineable units.

Nickel and copper mineralization

Nickel-copper sulphide mineralizations have been met with in the Kuhmo—Suomussalmi greenstone belts (Fig. 3). Mafic-ultramafic volcanics of komatiitic composition are associated with large serpentinite bodies, probably intrusive in origin. Three known Ni-Cu deposits occur in the serpentinites interfolded with quartz-plagioclase schists. The largest of these is the Arola deposit with 0.5 % Ni as incoherent bodies; no mineable ore has been found so far.

If it is accepted that the Kittilä greenstone belt is Archean in age, then some space should be devoted to the sulphide deposits found there (Gaál *et al.* 1978a). The Pahtavuoma and Saattopora deposits are located in metavolcanics that contain metasedimentary beds as intercalates (Mäkelä and Tammenmaa 1978). The ore bodies occur in the contact of these rock types and have as host either mica schist or some other derivative of metasediments. Phyllite is characteristically the host rock in the Riikonkoski deposit. The ore mineralization consists of chalcopyrite and pyrrhotite, which occur as very fine-grained dissemination or as fracture filling in the brecciated host rock. According to Mäkelä and Tammenmaa (1978), the ore deposits are of the stratabound type. The sulphur is partly of volcanic origin and partly derived from sulphate minerals in the original sediments.

Molybdenum mineralization

In North Karelia at Mätäsvaara a molybdenum deposit occurs in the gneiss-granite unit of the Archean basement. A total of c. 1.1 million t of ore assaying 0.151 % MoS_2 had been extracted before the deposit was mined out in 1947. The deposit consists of sulphide mineralization in association with quartz-albite veinlets. Some pyrite and chalcopyrite are allied with the molybdenite. Mätäsvaara is the only mine that has produced molybdenite in Finland.

Carbonatite mineralization

The Siilinjärvi deposit (Fig. 1) represents a carbonatite mineralization of late Archean time. It is located in an ultramafic-alkaline intrusion situated at the intersection of the northern margin of the Lake Ladoga—Gulf of Bothnia zone and north-south aligned fractures. The deposit is about 16 km long and up to 1.5 km wide. Glimmerite and carbonatite, the primary derivatives, were followed by syenite that intruded in the marginal zone and in the surrounding bedrock. The main constituents of the glimmerite are phlogopite, alkali amphibole and apatite. Carbonatite (sövite) and glimmerite form a series of mixed rocks. The Siilinjärvi carbonatite deposit belongs to the late Archean metallogenic epoch, about 2 600 Ma ago (Kouvo, personal communication.

EARLY PROTEROZOIC ORE DEPOSITS

It has been stated in many contexts that the majority of known Finnish ore deposits are located in a rather restricted zone extending in a NW direction from Lake Ladoga (Mikkola and Niini 1968, Mikkola and Vuorela 1974; Kahma 1978, Vuorimiesyhdistys 1978). This zone (the Lake Ladoga—Gulf of Bothnia zone, Fig. 4) contains ore deposits of different types and metallogenic epochs.

Strata-bound copper mineralization

Economically the most important ore deposits are those of the massive stratabound sulphide type. These include the unique Outokumpu type, representing the oldest mineralization epoch during Proterozoic time. The Outokumpu type of mineralization is associated with the volcanism, that manifests itself as basic lavas and diabase dykes (Simonen 1979) penetrating the Jatulian sediments. The age of these diabase dykes varies form 2 250 to 2 150 Ma. The lead age of the Outokumpu ore is 2 100 Ma. The ore deposits of the Outokumpu type are located in the »Outokumpu formation» (Fig. 5), which consists of black schists, skarn and quartz rock together with serpentinites. The principal ore minerals are chalcopyrite, pyrite, pyrrhotite, and sphalerite with minor cobaltian pentlandite and cubanite. The chromium content is a peculiar feature of the skarn rock between dolomite and quartz rock.

A submarine exhalative-sedimentary origin has lately been postulated for the Outokumpu ore type (Mäkelä 1974, Peltola 1978). The ore deposits are in marked stratigraphic association with the enclosing metasedimentary and metavolcanic rocks. — Altogether seven Outokumpu-type copper deposits are known within an area of about 60 by 100 km in the Outokumpu zone. Three of them, Outokumpu, Vuonos and Luikonlahti, are being exploited.

The Hammaslahti copper deposit (Fig. 1) which lies in a north-south shear zone at the

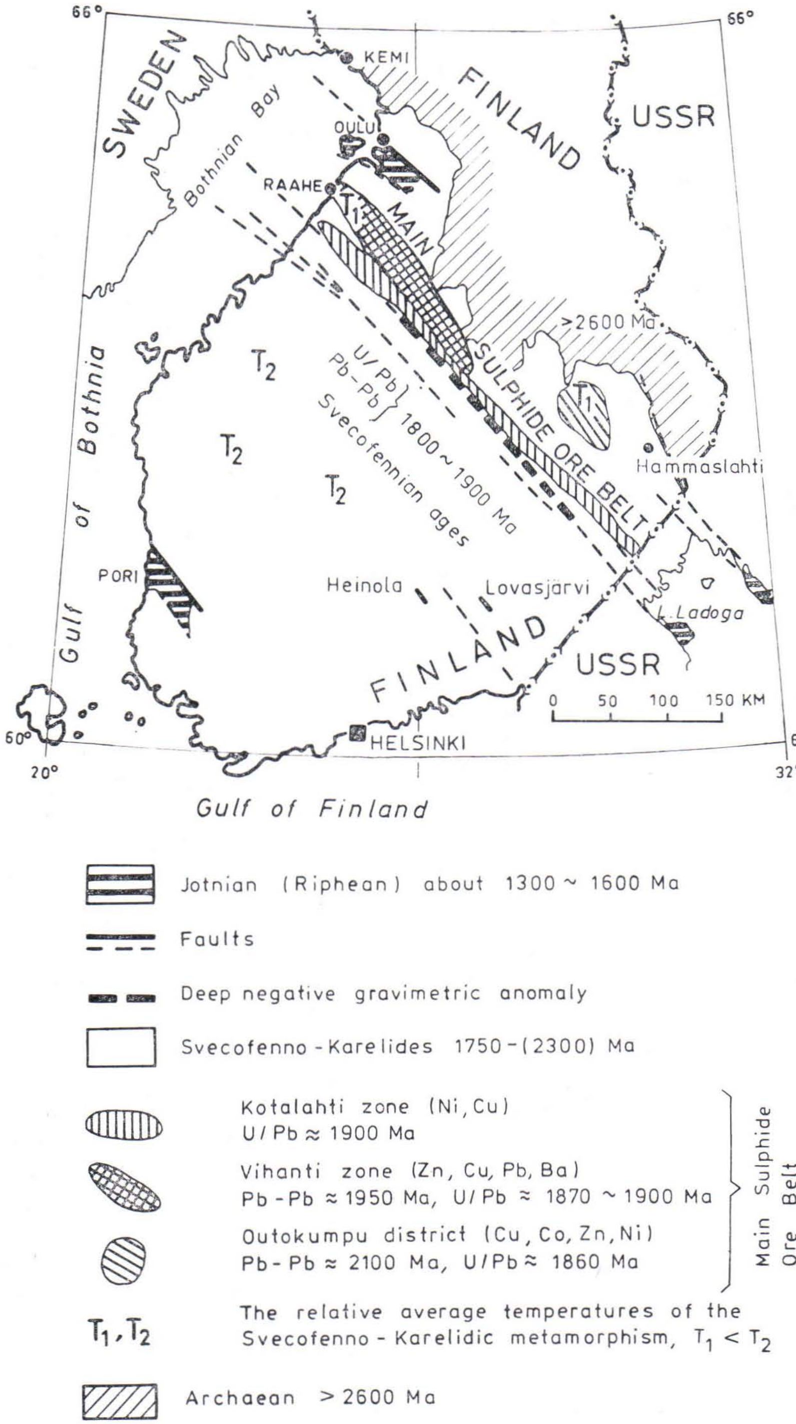

Fig. 4. The Lake Ladoga—Gulf of Bothnia zone (after Kahma 1978).

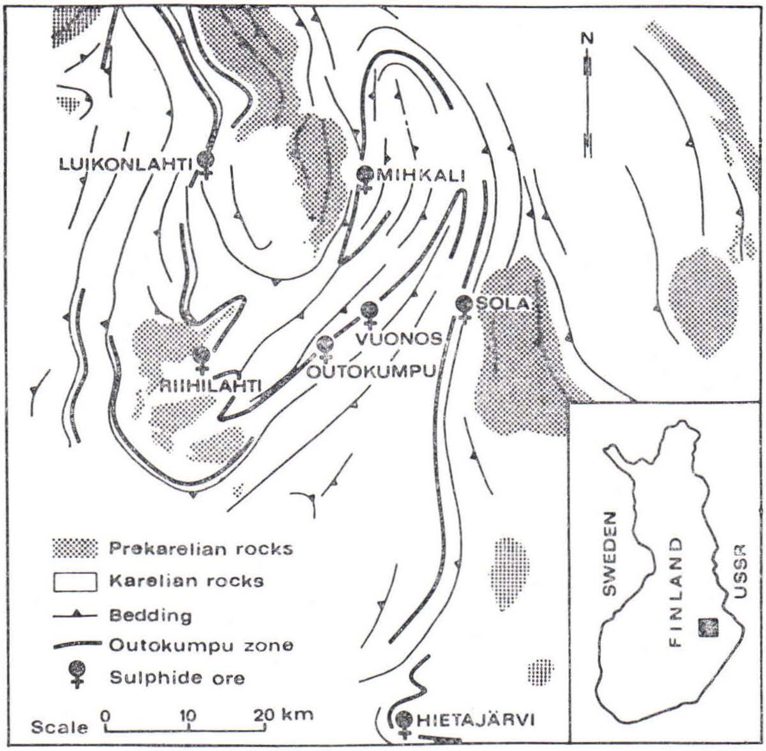

Fig. 5. Location of the Outokumpu district showing the Outokumpu zone (after Huhma and Huhma 1970).

southeastern end of the Lake Ladoga—Gulf of Bothnia zone, is a special type of stratabound mineralization. The main host rock of the ore is an impure quartzite. The ore material, chalcopyrite, pyrrhotite, small quantitities of sphalerite, and other sulphides, occurs as dissemination or breccia filling in the host. Hyvärinen and his coworkers (1977) consider that the ore derives from Jatulian sediments but that it was remobilized and redeposited during the first phase of Proterozoic deformation. In contrast to the Outokumpu-type ore, the Hammaslahti ore is almost free from cobalt and nickel.

Chromium and iron-titanium mineralization

Oxide ore mineralizations connected with basic intrusions have lately attracted the attention of mining geologists in Finland. This is largely because different ore types connected with basic intrusions are being currently mined.

A series of mafic intrusions occurs in northern Finland in the border zone between Archean basement and the Svecokarelian schist formation (Fig. 6). From west to east the intrusions are Kemi, Penikat, Suhanko, Syöte, Porttivaara and Näränkävaara (Piirainen *et al.* 1974). Two of these intrusions contain mineable oxide ores (chromite in the Kemi intrusion and vanadium-bearing magnetite-ilmenite ore in the Porttivaara intrusion). In several places there are marked sulphide mineralizations containing pyrrhotite, pentlandite and chalcopyrite, although not in mineable quantities. These intrusions are 2 440 Ma old (Kouvo, personal communication). Thus their emplacement predates Svecokarelian sedimentation.

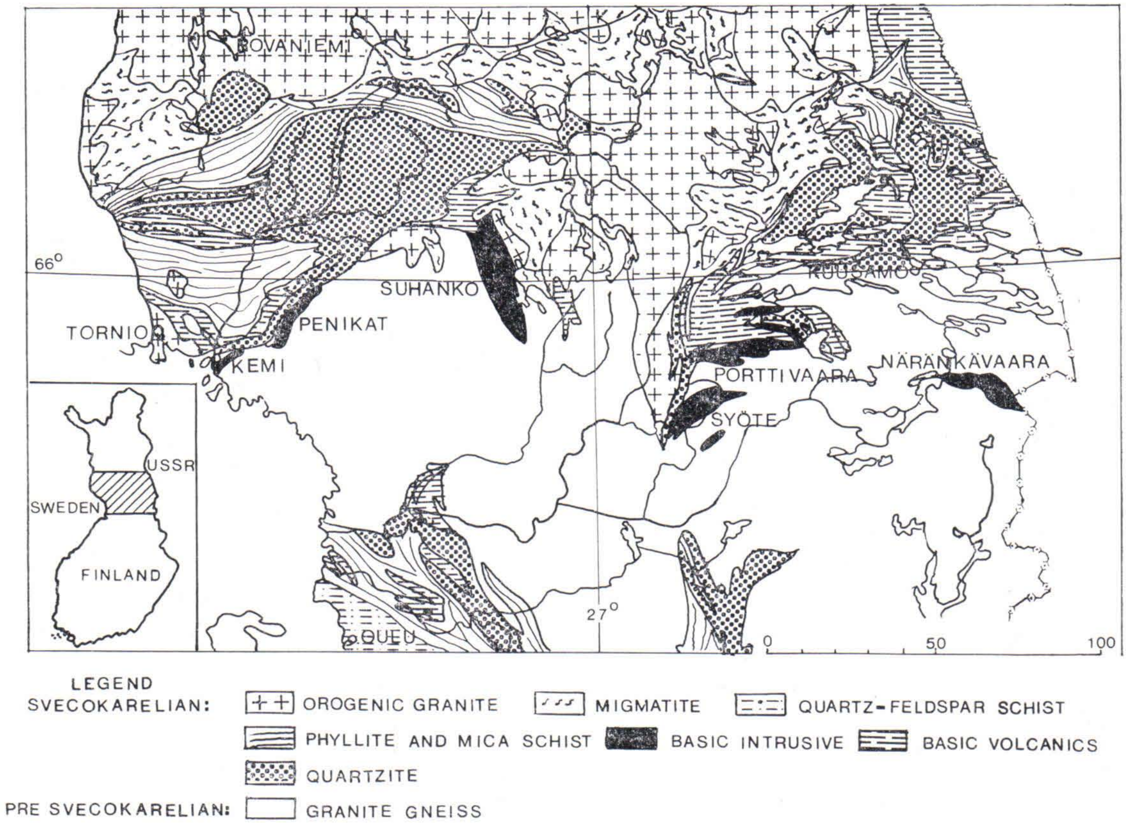

Fig. 6. Basic intrusions along the margin of the Archean basement (Piirainen *et al.* 1974).

The Kemi intrusion is a lens roughly 10 km long and 2 km wide. The footwall of the intrusion is composed primarily of dunite, peridotite and pyroxenite. At the bottom of this zone there is a banded chromite horizon. The ultrabasic zone is overlain by a horizon of pyroxene and anorthosite gabbros. The bottom contact of the basic intrusion has altered to talc-carbonate rock.

The persistent chromite layer parallel to the footwall contact of the intrusion varies from a few centimetres to several metres in thickness. Altogether it contains six swellings, which incorporate the bulk of the ore reserves. The largest ore body, Elijärvi, is about 700 m long and a maximum of 100 m wide. According to the mineral composition of the host rock, two different ore types are distinguished: a soft ore in tremolite or talc-carbonate rock and a hard ore in serpentinite. Chromite is the only ore mineral. The other oxides include magnetite, ilmenite, hematite and rutile. The ore contains an average of 25—27 % Cr_2O_3; its Cr : Fe is 1.55 (Kahma 1973).

A layered intrusion of the same age (2 440 Ma, Kouvo, personal communication) has been met with at Sodankylä in Central Lapland. Known as the Koitelainen gabbro, it contains a chromite horizon 1.3 m thick which assays an average of 20 % Cr_2O_3.

A magnetite-ilmenite-bearing layered basic intrusion, the »Porttivaara intrusion» (Piirainen *et al.* 1974, Juopperi 1977), is located in northern Finland about 140 km northeast of the town of Oulu (Fig. 6). The layered structure is due to rapid pulsative intrusions, whose crystallization took place as a continuous process involving the entire magma. The sequence of the layering from the bottom upwards is: marginal zone, pyroxene gabbro, anorthosite gabbro, magnetite gabbro, and a second anorthosite gabbro. The magnetite gabbro is of economic value owing to the vanadium incorporated in magnetite. The magnetite itself and ilmenite are not useable, however, because of their intergrowth texture. The ore horizon contains small quantities of chalcopyrite. The average vanadium content of the magnetite concentrate is 0.90 %.

MIDDLE PROTEROZOIC DEPOSITS

During the late Svecokarelian orogeny magmatism produced several important ore deposits of different type. They can be grouped into three epochs: 1 925—2 000 Ma, 1 850—1 880 Ma and the Svecofennian group 1 800—1 850 Ma. Each of these epochs is characterized mainly by a specific type of mineralization.

Strata-bound sulphide mineralization

The northwestern end of the aforementioned Lake Ladoga—Gulf of Bothnia zone is characterized by massive stratabound polymetallic sulphide deposits. The type localities are the Vihanti and Pyhäsalmi deposits, which have been mined since 1954 and 1962, respectively. The lithology of both deposits is characterized by metavolcanics and metasedimentary rocks. In the Vihanti deposit the volcanics are represented by acid tuffs and tuffites with chemically precipitated carbonate rocks in the early stage. Ore deposition is connected with volcanism. The bottom of the sequence is a narrow uraninite-apatite horizon upon which massive iron sulphide bodies have deposited. Next in the sequence come copper and iron, which precipitated with carbonate to form a dissemination. Zinc ores were formed during the final stages of carbonate sedimentation. The volcanic sequence was closed by the eruption of quartz porphyry and acid tuffs. The lower contact of the Vihanti ore sequence is sharp; but upwards, however, the volcanic complex grades through weathered volcanic material into mica-gneiss of real sedimentary origin (Rauhamäki *et al.* 1978).

The main minerals in the zinc orebodies are sphalerite, iron sulphides, chalcopyrite and galena. The metal contents fluctuate from 5 to 14 % Zn, 0.4 to 1.0 % Cu, 0.3 to 0.7 % Pb; gold and silver are present in small amounts. The iron sulphide form separate bodies with pyrite as the predominant mineral. Small amounts of chalcopyrite and sphalerite give a 0.2 % to 0.4 % content of copper and zinc.

Another type deposit of exhalative-sedimentary origin is the Pyhäsalmi pyrite-sphalerite deposit about 100 km southeast of Vihanti (Helovuori 1979). It is located in a metavolcanic—metasedimentary sequence. Unlike Vihanti, it is dominated by volcanic rocks, which are composed of acid and basic derivatives including tuffites, agglomerates and plagioclase porphyries. The metasediments are represented by minor quartzites, dolomites and their derivatives. The orebody is a rather steeply dipping bended lens about 600 m long in a sericitized quartzite (acid metavolcanics). It contains an average of 0.85 % Cu, 2.8 % Zn and 4.9 % BaO. The ore is of a massive pyrite variety, in which sphalerite occurs as narrow stringers conformable with the country rock. Chalcopyrite forms veins and fracture fillings caused by past ore deformation and mineralization. The age of the Pyhäsalmi ore formation is 1 970 Ma.

In addition to these mineable deposits there are several deposits and showings of uneconomic

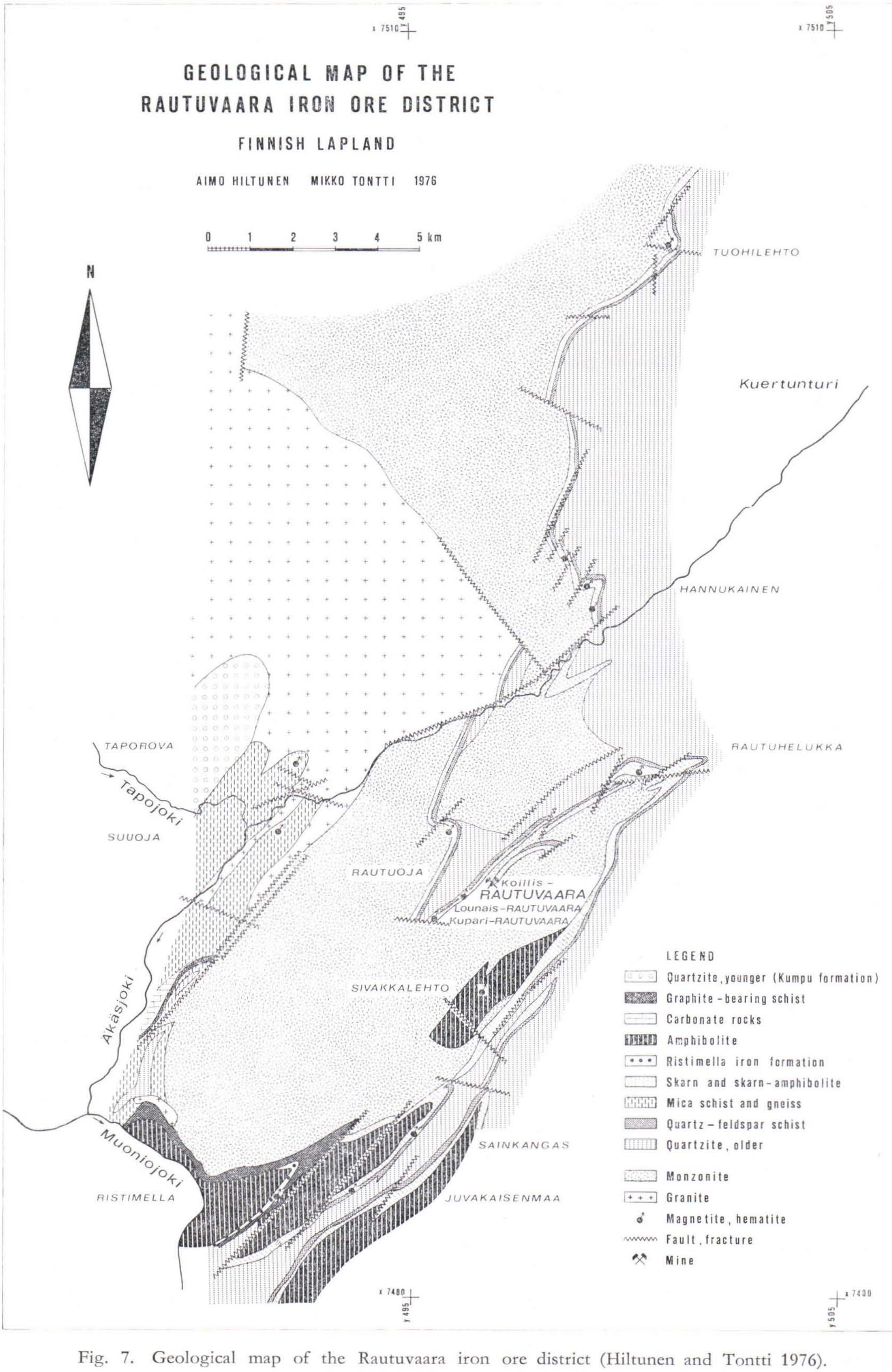

Fig. 7. Geological map of the Rautuvaara iron ore district (Hiltunen and Tontti 1976).

size or grade that belong to the same ore type. Metallogenetically the Vihanti—Pyhäsalmi area corresponds well with those described from other shields. The ore originated from magmatic sources but deposited in either a sedimentary environment (like Vihanti) or partly under hydrothermal conditions (like Pyhäsalmi).

Base metal mineralizations occur also in southwestern Finland, in the Svecofennian schist belt along the coast of the Gulf of Finland, where there are several small polymetallic deposits geologically and genetically comparable with the Vihanti and Pyhäsalmi deposits. The best known are those in the Orijärvi area (Orijärvi, Aijala and Metsämonttu deposits). Orijärvi has been known since 1 757, but Aijala and Metsämonttu were not discovered until after World War II. The deposits, which are small (c. 1—1.5 milj. t) and already mined out, are located in the »Svionian Group» of Svecofennian schists. The main rock types are quartz-feldspar schists (known as leptite), some of which at least are volcanic in origin. Amfibolites represent mafic volcanics. Limestone and dolomite are chemically precipitated sediments intercalated with amfibolites and leptites (Latvalahti 1979).

The immediate host rock of the Aijala and Metsämonttu deposits is a narrow band of leptite adjacent to a volcanogenic amphibolite. The host consists of intercalated narrow bands of quartz-feldspar schist, cordierite gneiss, skarn and amfibolite. The Orijärvi deposit occurs in tremolite skarn and cordierite-antophyllite rocks. The ore deposits are typical polymetallic iron-sulphide deposits. Copper, zinc, lead and some precious metals occur together or in different bodies. About 70 km farther west, another mineralization of the same type, the Attu zinc-lead deposit, occurs in a similar geological environment.

The Svecofennian strata-bound sulphide mineralizations are somewhat younger, 1 800—1 850 Ma, than the deposits at Vihanti and Pyhäsalmi.

Iron mineralization

The Svecofennian leptite formation contains abundant metamorphosed syngenetic iron deposits, especially in Central Sweden. In Finland there are a number of small magnetite deposits along the coast of the Gulf of Finland. Some of them constitute continuous horizons in banded leptites; some may be considered as skarn deposits, their host rock having been altered into reaction skarn by regional metamorphism. The largest and best-known is the submarine magnetite deposit at Jussarö. The ore forms a specific horizon in schists composed of metavolcanics and metasediments. The composition of the ore is typical of banded iron formations. The average content of the ore is 21—27% Fe, 1.7—1.8% Mn, 40—45 % SiO_2, 0.2—0.04 % P and 0.1 % S.

Close to the Swedish border in western Lapland there is another iron ore field, Kolari, which the latest interpretation define as syngenetic stratabound in origin (Hiltunen and Tontti 1976, Mäkelä and Tammenmaa 1978). According to Hiltunen and Tontti, the Rautuvaara iron ore district consists of sedimentary rocks of epicontinental origin, namely quartzites, quartz-feldpar schists, and carbonate and skarn rocks. The latter act as host to the magnetite ore. There is also a weak hematite mineralization in mica schist (Taporova), but it is of a different sedimentary facies. The iron-bearing rocks form a continuous folded horizon; seven deposits have been encountered but the only one exploited to date is that at Rautuvaara (Fig. 7). In the northern branch of the horizon there is another promising deposit, Hannukainen. In the light of their studies on isotopes, Mäkelä and Tammenmaa (1978) have concluded that the ore in the various deposits derives from four strata. The iron content of the Rautuvaara deposit averages 37 % Fe. The ore contains appreciable sulphides, from 2 to 5 %, mainly pyrrhotite. Some of the deposits may have recoverable amounts of copper. In this respect, the Rautuvaara ores differ from those of typical banded iron formations in the

Kittilä greenstone belt (p. 8) and southern Finland (p. 15).

Iron formation similar to that at Kolari has been met with in the Karelian schist belt in Puolanka, eastern Finland (Laajoki and Saikkonen 1977). The iron formation is of a cherty type and occurs in a metasedimentary sequence of rocks of chemical precipitates, namely quartzite, dolomite, iron formation and black schists. The dominant rock in the iron formation proper is an amphibole-rich quartz-magnetite banded rock of mixed oxide-silicate facies. The Puolanka iron formation contains about 20 to 25% Fe, 0.04% Mn, 1.1 % P, 2.0 % S and 40 % SiO_2. No mineable ore has been found so far.

Nickel-copper mineralization in ultramafics and mafics

From the point of view of metallogeny, the most distinctive group is that composed of nickel-copper deposits associated with ultramafic and mafic intrusions. In Finland deposits of this type are concentrated in two zones. The large majority of the known nickel-copper deposits are located on the southwestern margin of the Lake Ladoga—Gulf of Bothnia zone. The nickel belt, which is about 40 to 50 km wide, extends along the whole length of the zone (Fig. 8). The total number of nickel-copper mineralizations known there is 39 (Gaál *et al.* 1978b). Three

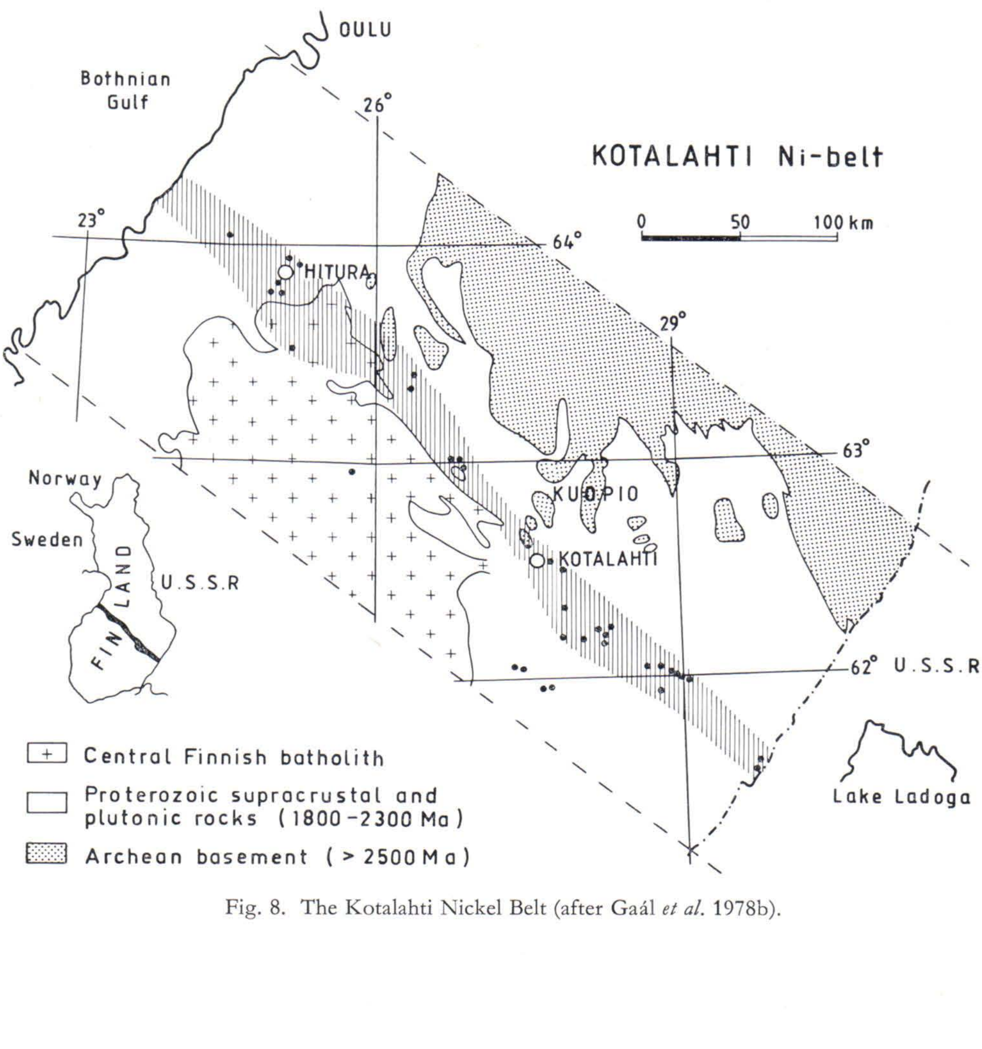

Fig. 8. The Kotalahti Nickel Belt (after Gaál *et al.* 1978b).

of these, Makola, Hitura and Kotalahti, have made mining economically feasible. The mineralizations in the Nickel Belt can be classified into four groups according to the host rock.

1. Ultramafic intrusions with very few or no other differentiates. Serpentinite is the main rock type. In this type (Makola and Hitura) sulphides form very fine-grained disseminations in the serpentinite, but are more coarse grained in the marginal zones of the serpentinite body.
2. Differentiated intrusions mainly with ultramafic rocks but also with gabbros and granodiorites. The Kotalahti deposit is the best-known example in this group. The intrusion consists of peridotite, pyroxenite and perknite. Gabbro, diorite and granodiorite are in a minority. The main ore minerals are pyrrhotite, pentlandite and chalcopyrite with many accessories. They occur as disseminations in ultramafics and gabbro or as breccia-type fracture fillings in these rocks and along the contacts (Papunen 1974). The average nickel content in the sulphide phase is 6.2 %.
3. Differentiated intrusions containing predominantly gabbros but also some peridotites and diorites. This type is reminiscent of layered intrusions and is best represented by the Parikkala intrusion with unexploitable mineralizations.
4. Iron rich hornblendites with little or no nickel mineralization.

Located in migmatic mica gneisses and amphibolites the Kotalahti intrusion proper conforms with the schistosity and trend of the wall-rock. The ore deposit consists of three discrete bodies, the northernmost of which is the biggest. The tectonic position of the intrusion has not been well established. According to Gaál (1972), the location of the Nickel Belt is caused by dextral transcurrent faulting during the second deformation phase of the Svecokarelian orogeny. The age of the nickel intrusions is 1 890 Ma.

Another zone containing ultramafic and mafic intrusions with associated nickel-copper mineralizations (Häkli *et al.* 1979) extends in southwestern Finland southeastwards from the town of Pori on the Gulf of Bothnia (Fig. 9). The length of the zone is about 150 km and the width is 20 to 30 km. The location of the zone is controlled by deep-seated fracturing caused by fault tectonics during Svecokarelian diaphtorism. In this zone there are several small bodies, pipes or plates in shape, and often elongated parallel to the fold axis of the surrounding schists. The predominant rock types in them are peridotites, hornblendites and pyroxenites. The ore mineralization consists of pyrrhotite, pentlandite and chalcopyrite, which occur as disseminations in the host rock or as copper-rich massive veinlets at the bottom or in the contacts of the ultramafic body. Mines have been opened at two of these deposits. The small Kylmäkoski deposit (Isokangas 1978) was mined out in 1974, but the Vammala deposit, which has several ultramafic bodies, may make mining an economic proposition for many years to come.

Iron-titanium mineralization

On the southeastern side of the lake Oulujärvi there are occurrences of basic intrusions with ilmenite-magnetite mineralization. They are known as the Otanmäki ore type. Geologically the Otanmäki deposit is located on the northeastern rim of the Lake Ladoga—Gulf of Bothnia zone (Fig. 4). The deposit consists of innumerable steeply dipping bodies of different size. The host rock of the orebodies is amphibolite that is a derivative of the hornblende gabbro on the southern side. The amfibolite with its closely associated anorthosite and the orebodies form an arch, one arm of which contains several deposits similar to that at Otanmäki; to date only the closest one, Vuorokas, has warranted exploitation. The basic intrusions in the Otanmäki area are interpreted as layered intrusions. Primary banding is still visible in places.

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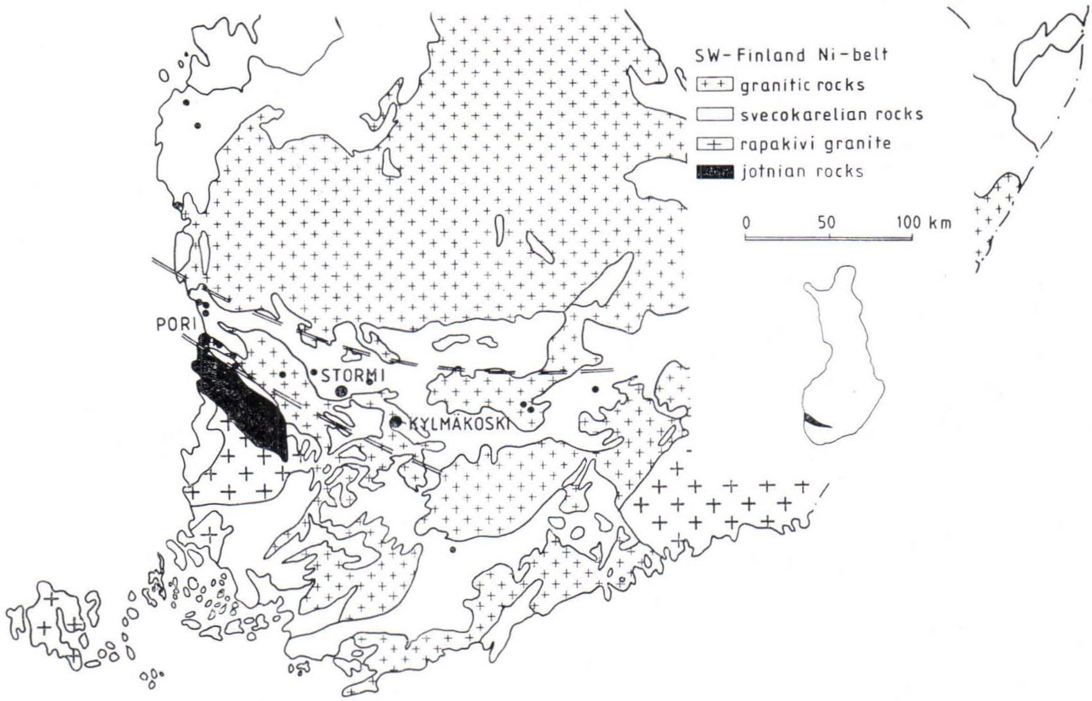

Fig. 9. The Nickel Belt in southwestern Finland.

The most important ore minerals are vanadium-bearing magnetite and ilmenite, which contain hematite exsolutions. Also present are pyrite, pyrrhotite and small amounts of other sulphides. The mined ore averages 38—40 % magnetite, 27—31 % ilmenite, and 1 to 2 % pyrite. The magnetite concentrate contains an average of 0.62 % vanadium, which is economically the most important product of the mine. The age of the intrusion is 2 060 Ma in contrast to the Porttivaara deposit (p. 12).

Another type of oxide mineralization within basic intrusions is met with in the Misi area between Rovaniemi and Kemijärvi (Fig. 1). The deposit consists of a magnetite dissemination and breccia-type fracture fillings in altered peridotite. Svecokarelian metasediments and metavolcanics are intruded by rocks of a differentiation series consisting of peridotite altered into serpentinites, gabbros and albitites. Magnetite is believed to have crystallized under hydrothermal conditions. The alteration phenomena could also be post-ore. The ore contains small amount of pyrite, but TiO_2 and P_2O_5 contents are low. There are several small bodies in this area, three of which have warranted mining. The Raajärvi deposit produced a total of 4.4 milj. tons of ore with an average magnetite content of 60 to 70 %.

Sulphide deposits of hydrothermal origin

Southwest of the Lake Ladoga—Gulf of Bothnia zone there are several small sulphide ore deposits that may be classified as hydrothermal mineralizations. The age of the mineralizations is about 1 800 Ma, in other words, they coincide with Svecokarelian plutonism. Some of these deposits belong to the breccia-type mineralization, some are fracture fillings in fault zones. Dissemination proper caused by hydrothermal replacement is only occasionally a dominant feature.

The Ylöjärvi copper-tungsten deposit (Fig. 1) (20 km west of Tampere) is located in metavolcanics of basic and intermediate character. Adjacent to the deposit the predominant rocks are tuffites and agglomerates. The volcanics may have undergone brecciation owing to the intrusion of a granodiorite pluton or gas explosion. The orebody is a pipe about 100 m in diameter on the surface and extending to a depth of 500 m. The matrix of the breccia consists of iron-rich tourmaline, quartz, and apatite with arsenopyrite, chalcopyrite, pyrrhotite, pyrite and scheelite. A total of 4 million tons of ore were mined, averaging 0.76 % Cu and 0.13 % WO_3.

Another sulphide deposit of the same origin as the Ylöjärvi body is the Haveri gold-copper deposit about 15 km northwest of the Ylöjärvi mine. The ore consists of two types of mineralization. The magnetite ore, which occupies one part of the deposit, was mined in the 18th and 19th centuries. The other part consists of a complex sulphide ore containing chalcopyrite, pyrrhotite, pyrite, cobalt minerals, gold, scheelite and several accessories. The sulphides occur in brecciated amfibolite and tuffite beds. Gold seems to follow the cobalt minerals as filling in fractures or the intervening spaces. A total of 1.5 million tons of ore was mined in the forties and fifties averaging 2.8 grams per ton of gold and 0.37 % copper.

The Korsnäs deposit is located on the coast of the Gulf of Bothnia, about 50 km south of the town of Vaasa. It produced about 900 000 tons of ore containing 3.57 % lead and 0.91 % Ln_2O_3. The ore occurs as a fracture filling in a fault trending north-south. The mineable part of the deposit was about 300 m long, 5 to 30 m wide and extended to a depth of 160 m. Besides ore material the fracture fillings contained calcite, feldspar, apatite and skarn minerals.

Ore mineralization in rapakivi

The rapakivi intrusions are products of post-orogenic plutonism that took place about 1 700—1 600 Ma ago. They occur as discrete bodies along the coast of southern Finland and were believed until recently to be wholly devoid of ore mineralizations. Haapala (1977) has now shown that the youngest phase of intrusion contains tin-beryllium mineralization of the greisen type. Cassiterite occurs as a weak dissemination in topaz-bearing granite, and in pegmatite veins and pockets in greisenized parts of granite or in skarn rock. The ore mineralization in the rapakivi is mainly controlled by tectonic zones of weakness. — No mineable deposits have been found so far.

DEVONIAN CARBONATITE MINERALIZATION

The Kola carbonatite-alkaline belt extends into Finnish territory in northern Lapland. In 1967 a carbonatite deposit was found there. The Sokli carbonatite intrusion is a pipelike plug (Vartiainen and Woolley 1976) whose central part, occupying an area of some 20 km^2, consists of sövites and rauhaugites with minor xenoliths and dykes of various kinds. It is surrounded by a broad fenite aureole. The carbonatite intruded in five consecutive stages 392—334 Ma ago. The intrusion of carbonatite started with phoscorites and continued with sövite and metasomatic processes (Mäkelä and Vartiainen 1978). Apatite is the only mineral of economic interest, although uranium and niobium mineralizations occur sporadically. The reserves of the regolithic ore amount to 100 million tons.

CONCLUSION

The emphasis of the foregoing discussion was on mineralization epochs and types of mineralization. In Finland the following mineralization periods can be distinquished. The oldest, which occurred during the Archean era, is associated with greenstone belts. It consists of banded iron formation and nickel-copper ores in connection with ultramafics. The greenstone belt rocks were deposited 2 800—3 000 Ma ago. The Siilinjärvi carbonatite deposit is from the late Archean time.

Early Proterozoic time is marked by the emplacement of layered mafic intrusions allied with chromite and iron-vanadium-titanium ore formation. According to recent determinations, the age of the mineralization is 2 440 Ma. The stratabound copper deposits of the Outokumpu type are somewhat younger. Common lead determinations on Outokumpu galena suggest a model age of 2 250 Ma for the ore deposit, or 2 200 Ma if the new decay constats are used. The Hammaslahti copper deposit is from the same metallogenic epoch.

There were several metallogenic epochs during Middle Proterozoic time. The stratabound volcanogenic deposits in the northwestern part of the Lake Ladoga—Gulf of Bothnia zone (Vihanti and Pyhäsalmi), which represent the oldest epoch around 1 925—2 000 Ma ago, are of the massive polymetallic type. In both the Kotalahti and the Pori belts the nickel-copper mineralization took place 1 850—1 900 Ma ago. The ore formation is connected with ultramafic intrusions. The hydrothermal sulphide deposits (Ylöjärvi, Haveri, Korsnäs) form a coherent age group and are located in Svecofennian terrain aged 1 800—1 850 Ma. They were formed during the Svecofennian stage of Svecokarelian diaphtorism. The latest mineralization phase of Proterozoic time is associated with the intrusion of rapakivi about 1 600—1 700 Ma ago. It consists mainly of a greisen-type ore formation of no economic importance. The carbonatite deposit in Lapland (Sokli) is part of the Kola alkaline province. The age of the mineralization is around 350 Ma.

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