GEOLOGIAN TUTKIMUSKESKUS – GEOLOGISKA FORSKNINGSCENTRALEN
GEOLOGICAL SURVEY OF FINLAND

Opas – Guide 16

Excursion guide, excursion C 3
Metallogeny and ore deposits in South Finland

Geological Survey of Finland
Espoo 1986

GEOLOGIAN TUTKIMUSKESKUS - GEOLOGISKA FORSKNINGSCENTRALEN
GEOLOGICAL SURVEY OF FINLAND
Opas - Guide 16

17e NORDISKA VINTERMÖTET
Helsinki 1986

Excursion Guide, Excursion C 3

METALLOGENY AND ORE DEPOSITS OF SOUTH FINLAND

Edited by Gabor Gaál

GEOLOGICAL SURVEY OF FINLAND
Helsinki 1986

CONTENTS

17e NORDISKA VINTERMÖTET
Excursion 3 C, Metallogeny and Ore Deposits of South Finland,
May 16.-20.5.1986

General outline of the excursion and daily routes

Excursion leader: Gabor Gaál
Geological Survey of Finland

The daily routes and the location of the excursion and overnight stops are illustrated on the geological map of Finland in Fig. 1.

OUTLINE OF THE PROGRAM

May 16, Friday: The Vammala nickel-copper mine and tin mineralization in the rapakivi granite of Eurajoki.

7.30 -	Departure by bus in front of the Main Post Office, Helsinki
7.30 - 9.30	Helsinki - Vammala
9.30 - 10.15	Review of the geology of the Vammala mine and the geology of the Pori - Kylmäkoski nickel belt (J. Aarnisalo and K. Vormisto) - *coffee* -
10.15 - 11.30	Stop 1-1: Underground visit in the Vammala mine (K. Vormisto)
11.30 - 12.30	- *lunch* -
12.30 - 13.00	Stop 1-2: Kovero-oja, schollenmigmatite (J. Aarnisalo)
13.00 - 13.30	Stop 1-3: Stormi, Rahkila, migmatites (J. Aarnisalo)
13.30 - 14.00	Stop 1-4: Haavisto, contact of peridotite with migmatite (J. Aarnisalo)
14.00 - 15.30	Stormi - Lapijoki, - *coffee* -

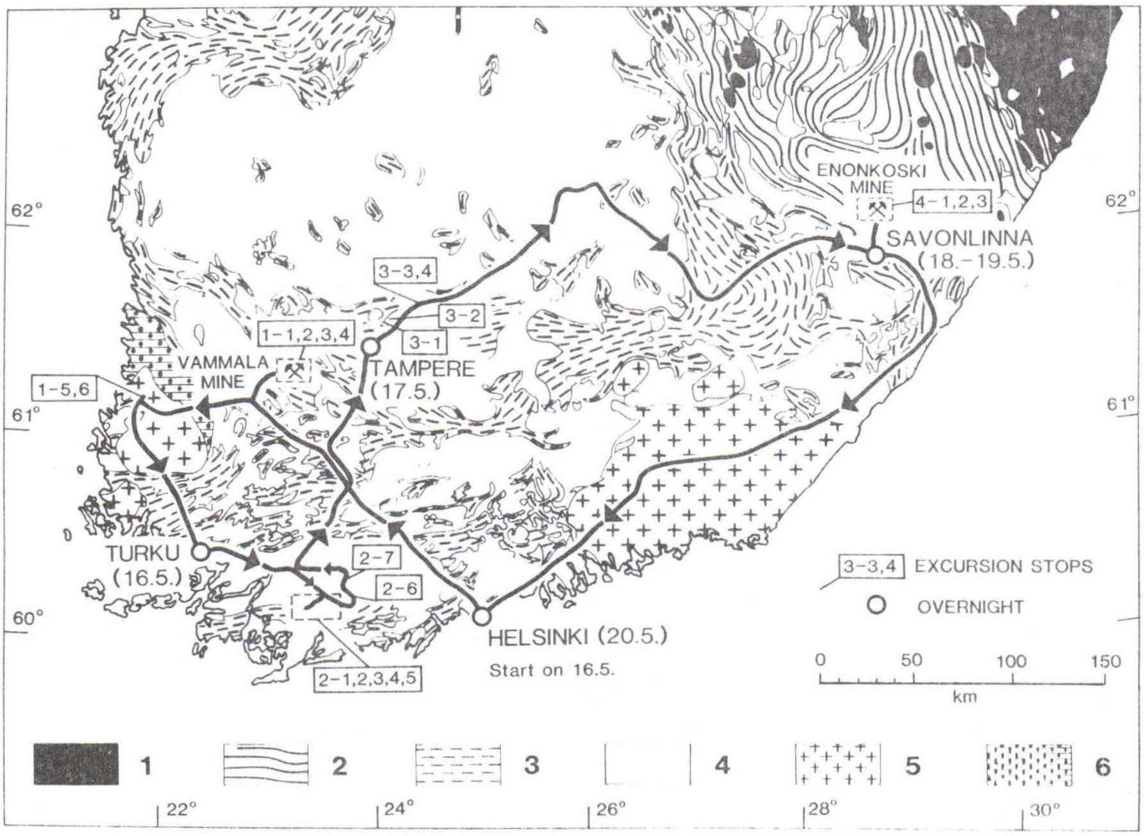


Fig. 1. The daily routes of Excursion C 3 on the geological map of Finland (Simonen 1971, Geol. Rundschau 60). Explanation: 1. Archaean rocks (> 2.5 Ga), 2. Karelian schists, 3. Svecofennian schists, 4. Granitoids (1.9 - 1.8 Ga), 5. Rapakivi intrusions, 6. Jotnian sediments.

15.30 - 17.30	Stop 1-5: Koivuniemi, greisen in topaz-bearing granite (I. Haapala)
	Stop 1-6: Koivuniemi, cassiterite-bearing greisen (I. Haapala)
17.30 - 18.45	Lapijoki - Rauma - Turku
19.30 -	- *Dinner at Cumulus Hotel* -
Overnight	Cumulus Hotel, Turku Eerikinkatu 28, 20100 Turku (Tel: 921-514 111)

May 17, Saturday: Sulphide ore deposits in the Orijärvi - Aijala field and the geology of Orijärvi and West Uusimaa.

8.00 - 9.00	Turku - Orijärvi
9.00 - 10.00	Review of the geology of the Orijärvi region (V.-P. Isomäki and L. Westra) - *coffee* -
10.00 - 10.45	Stop 2-1: Hyypiämäki, agglomerate and pillow lava (V.-P. Isomäki)
10.45 - 11.30	Stop 2-2: Kavasto, metagraywacke (L. Westra)
11.30 - 12.30	Stop 2-3: Metsämonttu, exhausted Zn-Pb mine and environment (V.-P. Isomäki)
12.30 - 13.00	Stop 2-4: Aijala, folded sulphide-bearing metatuffite (V.-P. Isomäki)
13.00 - 14.00	- *lunch* -
14.00 - 14.45	Stop 2-5: Vetio, road cutting, cordierite, andalusite and F_1/F_2 folding in metagraywacke (L. Westra)
14.45 - 15.30	Stop 2-6: Kolmijärvi, F_2+F_3 interference patterns in mica schist (L. Westra)
15.30 - 16.30	Stop 2-7: Nuppulankulma, mylonitized and folded marble (L. Westra)
16.30 - 17.00	- *coffee* - *in Suomusjärvi*
17.00 - 18.00	Suomusjärvi - Tampere
19.30 -	*Dinner at Cumulus Hotel*
Overnight	Cumulus Hotel, Tampere Koskikatu 5, 33100 Tampere (Tel: 931-35 500)

May 18, Sunday: Tungsten mineralization at Kangasala and the Orivesi area.

8.00 - 12.00	Stop 3-1: Kangasala W-mineralization (B. Lindmark)

	Stop 3-2: Road cutting on Highway no. 9, boundary Orivesi/Kangasala, graywacke with interbeds of quartzite conglomerate (I. Laitakari)
	Stop 3-3: Oritupa, Orivesi, glass in narrow apophyses of diabase dikes (I. Laitakari)
	Stop 3-4: Oritupa, Orivesi, subvolcanic breccia (I. Laitakari)
12.00 - 13.00	- *lunch* -
13.00 - 15.30	Jämsä - Mikkeli
15.30 - 16.00	- *coffee* -
16.00 - 18.00	Mikkeli - Savonlinna
19.30 -	*Dinner at Casino Hotel*
Overnight	Casino Hotel, Savonlinna Kasinonsaari, 57130 Savonlinna (Tel: 957-22864)

May 19, Monday: The Enonkoski nickel -copper mine and environments.

8.00 - 8.30	Savonlinna - Enonkoski
8.30 - 9.30	Review of the geology of the Enonkoski nickel-copper mine - *coffee* -
9.30 - 10.30	Stop 4-1: The Laukunkangas exposure, mineralized norite and gabbro (L. Grundström)
10.30 - 11.30	Stop 4-2: Underground visit in the mine (L. Grundström)
11.30 - 12.30	- *lunch* -
12.30 - 13.30	Stop 4-3: Juvola, schollenmigmatites (L. Grundström)
13.30 - 17.00	Geology of the Savonlinna area (G. Gaâl)
19.00 -	*Dinner at Casino Hotel*
Overnight	Casino Hotel, Savonlinna

May 20, Tuesday: Return to Helsinki

8.00 - 9.30	Savonlinna - Punkaharju Geological stops on the roadside (G. Gaál)
9.30 - 10.00	Punkaharju - Parikkala
10.00 - 10.30	- *coffee* -
10.30 - 12.00	Parikkala - Lappeenranta
12.00 - 13.00	*lunch in Lappeenranta* -
13.00 - 16.00	Lappeenranta - Helsinki
18.00 -	*Dinner at Merihotelli Cumulus*
Overnight	Merihotelli Cumulus Hakaniemenranta 4, 00530 Helsinki (Tel: 90-711 455)

GEOLOGY AND ORE DEPOSITS OF SOUTHWESTERN FINLAND

Heikki Papunen
University of Turku, Department of Geology

Introduction

The bedrock of southwestern Finland is composed of Svecofennian supracrustal units and plutonic rocks of mainly felsic composition (Fig. 1) The belt of supracrustals, trending almost east-west from the Åland archipelago through Kemiö island, Orijärvi, Lohja and Hyvinkää and terminating at the Vyborg rapakivi massif in the east is frequently mentioned in the literature as the Orijärvi leptite belt. A schist belt, similar in composition to the Orijärvi belt but separated from it by an intrusion of late-orogenic microcline granite, trends along the southern coastal area from Hanko through Helsinki to the Pellinki archipelago. The late--orogenic granite, often called the Perniö granite, borders the Orijärvi leptite belt in the north and separates the Orijärvi supracrustals from the mainly metavolcanic belt of Hyvinkää, Somero, Jokioinen and Forssa, which forms an arch around the granitoid area of Riihimäki.

History of mining and exploration

The first iron mine in Finland was opened at Ojamo in the parish of Lohja in 1540. Based on this mine, iron foundries were established at Mustio, Antskog and Pinjainen, but it was not long before the ore deposit of Ojamo turned out to be too small to meet the needs of all the new foundries. Some new discoveries were soon made, but of them only Malmberg in the parish of Kisko was to produce a significant amount of ore. The period of the "Great Hate" in the history of Finland (1713-1721) brought ore prospecting and exploitation to an almost total standstill in the first half of the 18th century; activities were revived with the discovery of the small deposit of Sillböle in Helsinki in 1744. Several new deposits were discovered in the area around Helsinki, but they were all of low grade, and at the time of the outbreak of the War of Finland in 1808 not one of the Finnish iron mines was in operation. All the Finnish iron foundries imported the ore from central Sweden, especially from the deposit of Utö in the Baltic archipelago.

The separtion of Finland from Sweden in 1809 suspended the import of iron ore, and as a result ore prospecting was intensified in the southwestern part of the country. Some of the deposits discovered were in production for a short time, but compared with the iron ores of central Sweden, the deposits of southwestern Finland were generally small and of low grade, and contained sulphides and other elements that impeded the production of iron. Dozens of old pits in the area of Orijärvi, however, bear witness to the effectiveness of iron ore exploration in the 19th century. The most productive mines were Malmberg and Vihiniemi in Kisko parish.

The copper deposit of Orijärvi was discovered in 1757 and was in production almost continuously until the 1860's, and again for a short period in the early 20th century; the last productive period was from 1932 to 1954. At the beginning of this century a small silver mine, Aurums Aijala, was also in production. The period of vigorous exploration by Suomen Malmi Oy from 1945 to 1952 unearthed the copper deposit of Aijala and the Zn-Pb-Cu deposit of Metsämonttu. Aijala was in production from 1949 to 1958 and Metsämonttu from 1952 to 1958 and again from 1964 to 1974. In the 1970's the area was the target of intensive sulphide ore exploration by Outokumpu Oy and several ore occurrences were discovered and drilled; exploitation was not economically feasible, however.

Previous descriptions of the area

In the early decades of the 20th century the Orijärvi deposit was owned by "The Finnish-American Mining Company" which, with capital collected from American and Finnish shareholders, tried to modernize and open the Orijärvi mine. The eminent Finnish prospector and geologist Otto Trüsted was asked to evaluate the ore reserves and on the basis of previous magnetic surveys, diamond drilling and his own observations he wrote the first geological description of the deposit (Trüstedt 1909). This paper was used by the company as an advertisement in marketing its new shares. In 1914, Eskola published his dissertation on the geology of the Orijärvi area (Eskola 1914). Based on his meticulous field work, he formulated his ideas on metamorphic facies (Eskola 1915). Eskola (1914) attributed the sulphide deposits and associated cordierite-anthophyllite and other Mg--rich rocks of the Orijärvi area to magnesia metasomatism caused by intrusion of the Orijärvi granitoid. Exploration by Suomen Malmi Oy in the 1940's and 1950's resulted in new concepts of magnesia metasomatism (Tuominen and Mikkola 1950), the origin of the ultrabasic rocks (Mikkola 1955) and of the structure of the whole area (Tuominen 1957). In his paper Tuominen (1957) points out the significance of fault tectonics.

The iron ores of southwestern Finland have been studied by von Knorring (1955). The results of geochemical exploration in the 1970's have been reported by Wennervirta and Papunen (1974), and the origin of the Orijärvi, Aijala and Metsämonttu ores has been reinterpreted by Latvalahti (1979). The metamorphism and structural geology of the supracrustal belt of southwestern Finland has recently been re-examined by the geologists of the Free University, Amsterdam (see Schreurs 1984, 1985; Schreurs and Westra 1985). Details of the economic and bedrock geology have been the subject of numerous unpublished master's theses in the University of Turku.

Geological setting

Stratigraphically, the supracrustal rocks have been divided into Lower, Middle and Upper Svecofennian Groups (Simonen 1980; Latvalahti 1979). The Lower Svecofennian Group consists mainly of felsic metavolcanics that are either pyroclastics or less foliated quartz-feldspar porphyries. Locally preserved layering indicates that there are also sedimentary interbeds between the volcanoclastic rocks. The occurrence of aluminous silicates, andalusite, sillimanite and abundant biotite also indicates the existence of weathering material in the original sequence. The metavolcanics are rhyolite or dacite in chemical composition. In the upper part of the Lower Svecofennian Group intercalations of calc-silicate rocks (skarn), marbles and cherty quartzites represent the original limestone, chert and iron formation horizons. Sill- or dyke-like amphibolites represent the original feeder dykes of the overlying mafic volcanics. The abundant beds of chemical sediments and conglomerates in the upper part of the Group are attributed to a quiet period of volcanism.

The Middle Svecofennian Group consists mainly of intermediate and mafic metavolcanics and minor metasediments. The abundance of pyroclastic rocks, tuffs and agglomerates, interbeds of calc-silicate rocks and banded iron-formations (Algoma type) as well as the local pillow lavas of mafic metavolcanics indicate deposition in varying terrestrial-shallow marine environments.

The Upper Svecofennian Group consists primarily of sedimentary material mixed with minor volcanogenic units. The rocks are tuffites, metagreywackes and mica schists. The occasional bed of conglomerate is also encountered among the turbiditic metagreywackes. The Upper Svecofennian Group represents a waning stage of volcanism and deposition of weathering sediments in a deep basin. The whole Svecofennian succession indicates a transgressive sequence.

"The Orijärvi Batholith" is an intrusive complex varying in composition from tonalite to hornblendite with the felsic phase prevailing. Close to the Orijärvi mine, the tonalite intrusion contains a porphyritic marginal variety with phenocrysts of quartz and microcline in a fine-grained groundmass. The mafic varieties (gabbros and hornblendites) are to be found in the central part of the complex. Locally the mafic rocks form minor layered complexes, like that on the western shore of the lake Iso-Kiskojärvi, where a small titaniferous iron ore is associated with the leyered complex. Mäkelä (1983) is of the opinion that the felsic metavolcanics deposited on the roof of the Orijärvi batholith, but that shortly after volcanism the batholith was mobilized and rose as a dome in the centre of the supracrustal belt.

The microcline granite, known as the Perniö granite, borders the supracrustal belt in the south and north. This granite is very inhomogeneous, having pegmatitic varieties, but is generally only weakly foliated like the other late-orogenic granitoids typical of southwestern Finland. It frequently forms migmatites with the supracrustal rocks.

Deformation and metamorphism

Three phases of folding have been distinguished (Latvalahti 1979; Mäkelä 1983; Schreurs and Westra 1985); the first (F_1) was isoclinal and produced prominent foliation in supracrustal and infracrustal (the Orijärvi batholith) rocks with subhorizontal fold axes. The rocks were intruded subsequently by microcline granitoids (the Perniö granite). The second phase (F_2) resulted in isoclinal folds with NE-SW trending axial planes and subvertical fold axes. The third fold generation (F_3) is characterized by large open folds with N-S trending axial planes (Schreurs and Westra 1985). Numerous postmetamorphic fault planes are encountered in the Aijala-Orijärvi area the most prominent being the Jyly fault zone east of Orijärvi and the Kirkkojärvi-Kiskonjoki fault zone. Numerous minor faults have been identified in the mines of the area.

The rocks of the Aijala-Orijärvi area were metamorphosed into low-pressure amphibolite facies, but farther to the northeast there is an extensive area, called The West Uusimaa Complex (WUC) by Parras (1958), of granulite facies metamorphism. The hypersthene-In isograd that defines the boundary of the granulite complex is c. 10 km NE of Orijärvi. The isograd crosscuts the major tectonic structures of F_1 and F_2 folding and is probably affected by F_3 folding (Schreurs and Westra 1985).

The amphibolite facies metamorphism of the Orijärvi area is associated with the peak of F_2 folding (Latvalahti 1979). The granulite facies metamorphism predates the third fold generation (F_3) and is probably contemporaneous with the later phase of F_2 folding. According to the study of cordierite channel fluids and fluid inclusions by Schreurs (1984) the fluids of the granulite complex are predominantly CO_2 rich whereas H_2O-rich fluids predominate in the amphibolite facies domain, suggesting high-grade rocks with high CO_2 activity. Schreurs (1985) considers the granulite complex to be the result of a low-pressure thermal dome event.

Geochemistry of the volcanics

The bimodal felsic-mafic volcanics of the Orijärvi area represent a typical calc-alkaline trend of differentiation. The sodium and potassium contents of the felsic metavolcanics are not very high, as they are in the "leptites" of central Sweden. The amount of sodium commonly exceeds that of potassium although the tenor of Na_2O never exceeds 5 per cent. The potassic felsic metavolcanics typical of the Bergslagen province in Sweden have not been detected in the Orijärvi area.

Ore deposits

Copper-zinc-lead deposits

The sulphide Cu-Zn-Pb occurrences and deposits are related to the hydrothermally altered felsic metavolcanics. Some minor chalcopyrite impregnations also exist in amphibolites, which are primarily mafic sills (Liipola, Kisko).

Of the sulphide deposits, Orijärvi was mined for zinc and copper, Aijala for copper and Metsämonttu for zinc, lead, copper and silver. The ore bodies were small and their metal contents varied substantially. The sulphides occurred as disseminated or breccia ores and less commonly as minor massive veins. On a large scale, all the deposits are strata-bound; in detail, however, they show crosscutting and breccia structures in relation to the wall rocks. The ore deposits consist of several separate ore bodies, small in size, and narrow and elongated in shape. The shape of the Aijala, Metsämonttu and Orijärvi ore bodies have been affected by folding and the F_2 is parallel to the major axes of the ore bodies. In Aijala and Metsämonttu, the axis is subvertical but at Orijärvi it is less steep, being 45^{o} to 50^{o} northeast.

The Orijärvi deposit is located in a zone of andalusite-bearing felsic cordierite-sericite schists and cordierite anthophyllite rocks. Stratigraphically, it is the lower part of the Lower Svecofennian Group, not far from the contact of the Orijärvi batholith.

The Orijärvi deposit had two ore types: Cu-Zn ore in cordierite-anthophyllite-quartz rock (hard ore) and Zn-Pb-Cu ore in tremolite skarn (soft ore). Both ore types contains weakly to heavily disseminated sulphides with local massive patches. Laterally, the ore horizon, characterized by calc-silicate rocks and quartz rocks, also contains a massive pyrite ore, mined in the "Nygruva" pit west of the Orijärvi pits. The footwall of the ore is non-foliated, coarse-grained cordierite-anthophyllite rock; farther south the fine-grained contact variety of Orijärvi tonalite borders cordierite-anthophyllite rock. The hanging wall of the ore is a felsic cordierite-mica gneiss, but a massive amphibolite, originally a thick mafic sill, intersects the ore horizon and forms the hanging wall of the main sulphide occurrence. The calc-silicate rock (tremolite skarn) does not crop out. To the north of the Orijärvi mine, the rocks are andalusite and cordierite-bearing felsic mica gneisses with intercalations of magnetite-bearing skarn horizons. The primary structures and textures are very seldom preserved.

The Iilampi Zn-Pb-Ag-Au occurrence is in the felsic schist 1.7 km NW and stratigraphically above the Orijärvi deposit. The sulphides occur as Ag and Au-bearing sphalerite-galena impregnation. The wall rocks are silicified and contain a stockwork of biotite-rich veins.

The Aijala and Metsämonttu deposits lie 1.5 km apart in a stratigraphic horizon characterized by cherts, marbles and sulphide-facies iron-formations in the contact between felsic metavolcanics and intermediate to mafic pyroclastic rocks. There are several sulphide occurrences in the mineralized horizon, which extends for about 3 km; a small Ag-bearing occurrence, Aurums Aijala, is located between Aijala and Metsämonttu.

The Aijala deposit contained several separate ore bodies conformable with the axial plane of F_2; their axis is parallel to the subvertical fold axis plunging 80-85^{o} southwest. The main constituent of the ore bodies is either chalcopyrite or pyrite; the exploitable copper ores also comprised minor galena, sphalerite, arsenopyrite and iron sulphides. The copper ore bodies extended from the surface to a depth of 220 m, where a fault dipping steeply northwards abruptly cuts the ore. The deeper parts are pyritic ore bodies; no exploitable copper ore has been discovered.

Three ore types occurs in the Metsämonttu deposit: Zn-Pb ores with sphalerite, galena, pyrrhotite and pyrite as main minerals; Zn-Fe sulphides with pyrite, pyrrhotite and sphalerite, and the copper ore bodies with chalcopyrite, pyrrhotite and pyrite. The Zn-Pb ores occur mainly in chlorite-bearing diopside skarns and dolomites; the Zn-Fe ore bodies are in muscovite-cordierite gneisses and the copper ore bodies in cordierite gneisses. The Cu/(Zn+Pb) ratio tends to be higher in the ores of the cordierite-bearing host rocks than in the ores of the skarn host rock.

The Metsämonttu ore zone is subvertical but divided by a fault dipping 25^0 south and cutting the ore body at a depth of 140 m. Although the block below the fault was moved 280 m southwards, the continuation of the ore zone was discovered after intense underground exploration. Below 550 m the ore zone is cut by another fault with the same trend but with a displacement of only 60 m. The ore between the faults amounted to 1 mill. tonnes. The deeper parts below the 550 m fault zone were not exploited because of the very weak rocks in the shear zone and the low grade of the deep ore bodies.

The occurrence of hydrothermally altered rock types associated with the ores is characteristic of the sulphide mineralization in the Aijala-Orijärvi area. The altered rocks include dolomitic limestones and chlorite-bearing tremolite skarns that developed from limestones by hydrothermal alteration and metamorphism, and quartz rocks, sericite-quartz schists, cordierite-biotite rocks and cordierite anthophyllite rocks that originated from felsic and mafic volcanics. In the Metsämonttu deposit a funnel-shaped, well-defined stock of cordierite-anthophyllite rocks widens from surface downwards and lies parallel to the mineralized zone. The whole mineralized contact between felsic metavolcanics and intermediate pyroclastics from Metsämontu to Aijala is characterized by Mg-rich skarn rocks and sericite and quartz-rich rocks. This zone of altered rocks resembles the blanket-type of alteration noted in many massive sulhpide deposits. Stratigraphically below the Orijärvi deposit there is an extensive mass of cordierite-anthophyllite rocks.

It is interesting to note that the supracrustal rocks are also altered outside the actual mineralized zones and especially at the gradual contacts of the felsic intrusive rocks. Large masses of altered rocks, especially cordierite-anthophyllite rocks, exist at Björknäs, about

1.5 km S of Aijala and at Venetkorpi, 2.5 km SW of Aijala (Mäkelä 1983). "Quartz eyes" indicate silification of the intrusive rocks.

The change in chemical composition is hard to decipher because one can only very seldom identify the primary rock type. The general trends are: increase in MgO and in some cases also in FeO^*; significant increase in the K_2O/Na_2O ratio because of the increase in potassium and decrease in sodium; decrease in CaO and local increase in SiO_2. The primary mineral assemblages of hydrothermally altered rocks altered during regional metamorphism, hence the mafic rocks that were originally montmorillonite or chlorite-altered, for instance are now cordierite-antophyllite rocks when in the amphibolite facies, and cordierite-hypersthene rocks when in the granulite facies.

Nickel-copper deposits

The Ni-Cu ore province of southwestern Finland, the Pori-Kylmäkoski nickel belt, was located in the exploration programme of Outokumpu Oy in the 1960's. Sulphide-bearing Svecokarelian ultramafic rocks exist in a linear belt trending from Pori to Kylmäkoski. The area is characterized by migmatized Svecokarelian mica gneisses with intercalations of graphitic schists and calc-silicate rocks. Some of the ultramafic host rocks of the Ni-Cu sulphides display features; agglomerate structures and surficial alteration, that indicate extrusion of ultramafic magma near to or even on the sea floor. The nickel ore province of southwestern Finland is a part of major Svecokarelian nickel province that surrounds the central Finland granitoid area.

Copper-tungsten mineralization associated with granodioritic intrusion

The exhausted Ylöjärvi Cu-W mine is located about 15 km northwest of Tampere. The deposit was discovered in 1937 and the mine produced from 1942 to 1966 about 4 Mt ore containing 0.68 % Cu and 0.04 % WO_3. The wall rocks of the mineralized tourmaline breccia pipe are pyroclastic metavolcanics and the breccia pipe is associated with the Hämeenkyrö granodiorite intrusion (Himmi et al. 1979). According to Gaál et al. (1981) the granodiorite intrusion contains anomalously high tenors of copper close to its eastern contact zone and the tourmaline breccia pipe. According to Himmi et al. (1979) the tourmaline breccia was formed at the periphery of the granodiorite massif in folded metavolcanics that had already attained their current mineral composition through regional metamorphism. The ore type of Ylöjärvi is unique in Fennoscandia and it has certain similarities with the Tertiary tourmaline breccia pipes from the Central Andes. The age of the tourmaline breccia of Ylöjärvi is about 1850 Ma. The main ore minerals were chalcopyrite and arsenopyrite and scheelite was the carrier of tungsten. The ore minerals occurred together with tourmaline in the matrix of the breccia.

Tin mineralizations associated with rapakivi granites

Numerous tin mineralizations are known in southern Finland. They are confined to a belt extending from the archipelago of Åland (Ahvenanmaa) in the west to lake Ladoga (USSR) in the east and are all associated with massif of rapakivi granites. In the Finnish mineralizations tin is usually found in greisen and quartz veins as well as in pegmatites. In the Pitkäranta area, north of lake Ladoga, USSR, tin mineralization occurs in skarn zones at the southwestern margin of a rapakivi granite massif (Haapala 1977).

References

Eskola, P., 1914. On the petrology of the Orijärvi region in southwestern Finland. Bull. Comm. géol. Finlande 40. 279 p.

Eskola, P., 1915. On the relation between the chemical and mineralogical composition in the metamorphic rocks of the Orijärvi region. Bull. Comm. géol. Finlande 44, 145 p.

Gaál, G., Front, K. and Aro, K., 1981. Geochemical exploration of a Precambrian batholith, source of a Cu-W mineralization of the tourmaline breccia type in southern Finland. Jour. Geochem. Exploration 15, 683-698.

Haapala, I., 1977. Petrography and geochemistry of Eurajoki stock a rapakivi-granite complex with greisen-type mineralization in southwestern Finland. Geol. Surv. Finland, Bull. 286. 128 p.

Himmi, R., Huhma, M. and Häkli, T.A., 1979. Mineralogy and metal distribution in the copper-tungsten deposit of Ylöjärvi, Southwest Finland. Econ. Geol. 74, 1183-1197.

Knorring, O. von, 1955. A mineralogical and geochemical study of metamorphic iron ores of SW Finland. Ph.D. Thesis, University of Leeds. 169 p.

Mäkelä, U., 1983. On the geology of the Aijala-Orijärvi area, Southwest Finland. In Laajoki, K. and Paakkola, J. (eds.) Exogenic processes and related metallogeny in the Svecokarelian geosynclinal complex. Geol. Surv. Finland, Guide 11, 140-159.

Mikkola, T., 1955. Origin of ultrabasics in the Orijärvi region. Bull. Comm. géol. Finlande 168, 39-51.

Parras, K., 1958. On the charnockites in the light of a highly metamorphic rock complex in southwestern Finland. Bull. Comm. géol. Finlande 181. 137 p.

Schreurs, J., 1984. The amphibolite to granulite-facies transition in West Uusimaa, SW Finland - A fluid inclusion study. Journ. Metam. Geol. 2, 327-341.

Schreurs, J., 1985. The West Uusimaa low pressure thermal dome, SW Finland. Ph.D. Thesis, Free University, Amsterdam. 179 p.

Schreurs, J. and Westra, L., 1985. Cordierite-orthopyroxene rocks: the granulite facies equivalents of the Orijärvi cordierite-anthophyllite rocks in West Uusimaa, Southwest Finland. Lithos 18, 215-228.

Simonen, A., 1980. The Precambrian in Finland. Geol. Surv. Finland, Bull. 304. 58 p.

Tuominen, H., 1957. The structure of an Archean area: Orijärvi, Finland. Bull. Comm. géol. Finlande 177. 32 p.

Tuominen, H. and Mikkola, T., 1950. Metamorphic Mg-Fe enrichment in the Orijärvi region as related to folding. C.R. Soc. Geol. Finlande 23, 67-92.

Trüstedt, O., 1909. Orijärvi malmfält. Geoteknillisiä tiedonantoja. Geol. Surv. Finland, Bull. 5. 26 p.

Wennervirta, H. and Papunen, H., 1974. Heavy metals as lithogeochemical indicators for ore deposits in the Iilinjärvi and Aijala fields, SW Finland. Geol. Surv. Finland, Bull. 269. 22 p.

THE VAMMALA NICKEL-COPPER MINE

Kauno Vormisto
Outokumpu Oy

Introduction

The first indications of potential nickel ores at Vammala emerged in 1960. Studies undertaken on the ground until 1973 were supplemented with underground investigations that lasted until early 1978.

Currently c. 350,000 tonnes of ore are mined annually. By the end of 1983 a total of c. 2.18 million tonnes of ore had been mined. At the end of 1983 the in situ ore reserves of the mine were about 4 million tonnes at 0.7-0.8% Ni and 0.45% Cu. The Vammala mine employs c. 110 people.

Geology

General set up

The bedrock in the Vammala area represents a deeply eroded section of the Svecofennian mountain range. It is composed predominantly of pelitic, intensely metamorphosed mica gneisses altered into veined gneisses, which in places contain portions of volcanic amphibolites and black schist intercalations. Concretions indicating elevated calcium values are fairly abundant. The lithology suggests that sedimentation took place under conditions of the miogeosynclinal stage.

Most of the plutonic rocks in the area are synorogenic plutonites, quartz dioritic and granodioritic in composition. Granites are very rare. Mafic and ultramafic intrusives occur either as minor differentiates in association with the intermediate massifs or as small individual intrusions (Fig. 2). The plutonic rocks crosscut the gneisses.

Schollenmigmatites are common and indicate zones of complex tectonics.

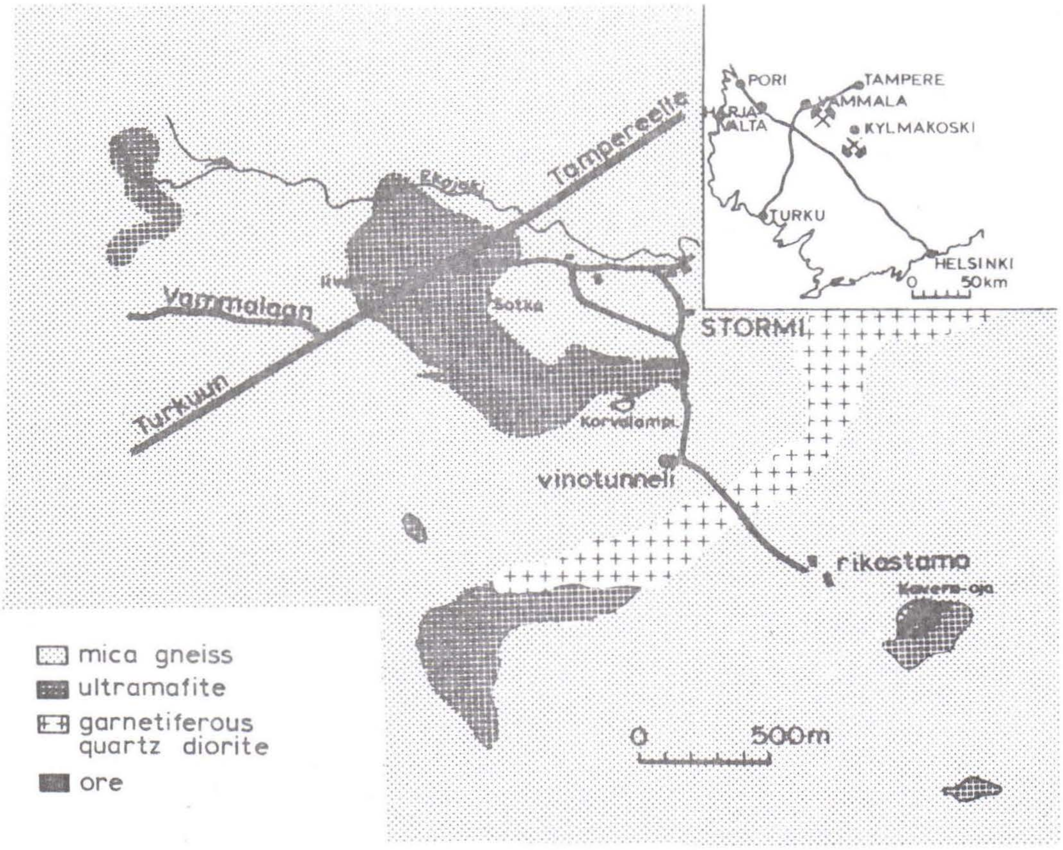


Fig. 2. A simplified geological map of the Vammala mine area.

Stormi ultramafic intrusion

The Stormi intrusion is a body about 1.5 km long. It has a surface area of about 50 ha on the ground. Its eastern end, a spout or tongue in appearance, extends to a depth of 150-200 m and the potlike western end to a depth of 250-350 m.

Adjacent to the intrusion there are banded and striped mica gneisses and veined gneisses in which small garnet porphyroblasts and oval concretions are fairly common. Cordierite or sillimanite-bearing interlayers, or both, occur in gneisses with gradual contacts. There are also graphite--bearing layers. The contact with ultramafite often exhibits a narrow amphibole-bearing variant of a contact gneiss.

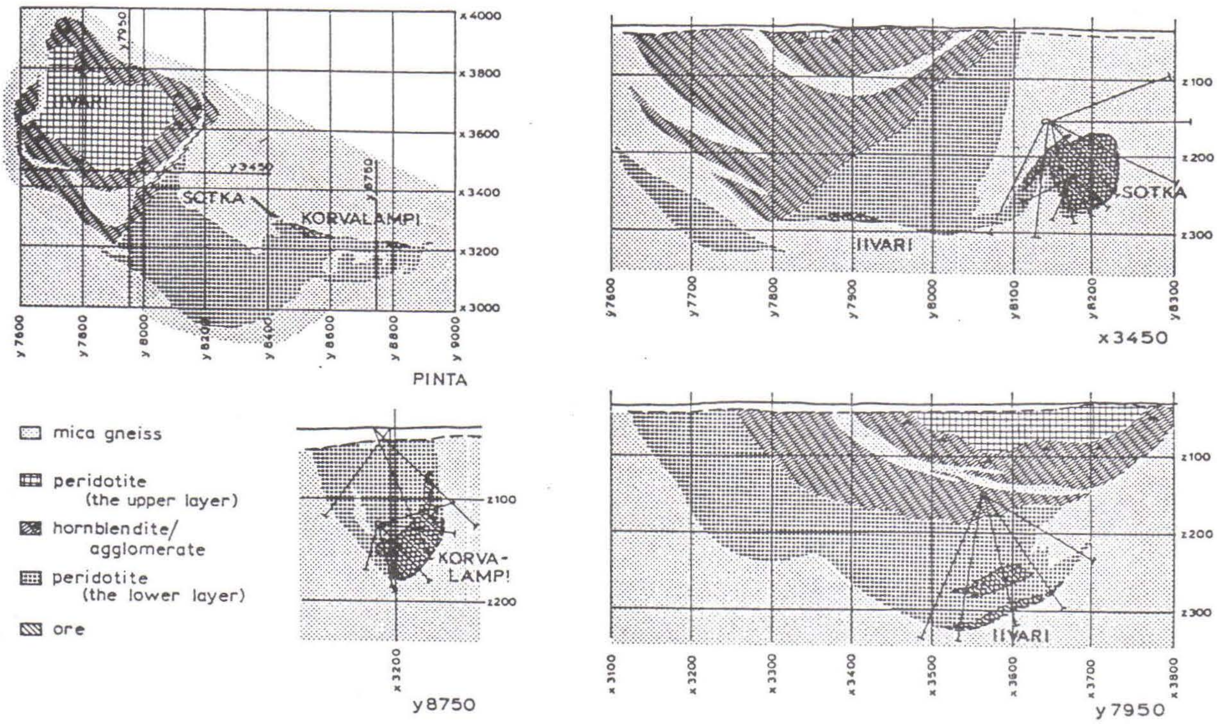


Fig. 3. A geological surface plan and some vertical cross-section.

The Stormi intrusion exhibits subconformable contacts with the gneisses. It is composed of at least three comagmatic macrolayers, which intruded in the still unconsolidated sediments one on top of the other. The layered structure is best developed in the western portions of the intrusion, where the fingering of the tongues of the intrusion with gneiss is most clearly visible (Fig. 3).

The uppermost ultramafic layer is locally intensely serpentinized peridotite, which has often undergone cataclasis. The primary sulphides have turned almost completely into oxides.

The uppermost layer is underlain by a hornblendite layer up to 150-200 m thick. The main rock type is a fine-grained granoblastic amphibole rock. In places the rock is olivine(serpentine-)bearing cortlandite. Agglomeratic layers have been encountered in the upper portion of the layer. Sulphides occur in it only as microscopic dissemination.

The lowermost ultramafic layer is composed of peridotite. Portions that can be recognized as dunites in primary composition occur in the base. The original cumulate structure is also often visible. In the contact of the layer with mica gneiss there is a zone, up to a few metres thick, that in places contains perknitic portions. The grade of serpentinization increases clearly from the contact towards the inner portions of the layer.

The lowermost layer is richest in sulphides, and as a matter of fact all the sulphide accumulations classified as economic ores are associated with this layer or with its tongues.

Orebodies

Economically the most important sulphide accumulations in the Stormi intrusion are the orebodies of Korvalampi, Sotka and Iivari.

The borders of the orebodies, which are defined by concentration, depend on the cut-off grade applied (Fig. 2).

The Korvalampi orebody is an elongated, steeply dipping plate, 5-40 m thick, that follows the northern contact of the eastern part of the intrusion. It crops out in places and its lower edge extends to a depth of 120-170 m.

The Sotka orebody is a direct continuation to NW of the Korvalampi orebody (Fig. 4). It is located in a tongue that forks out from the main intrusion. At the SE end it is similar to the Korvalampi orebody in dimension and grade, but it swells to a thickness of 60-70 m at the NW end, where the highest grade in the mine is encountered.

The Iivari orebody is located at the western end of the intrusion at a depth of 250-300 m and is composed of several gently dipping sulphide accumulations with ill-defined boundaries.

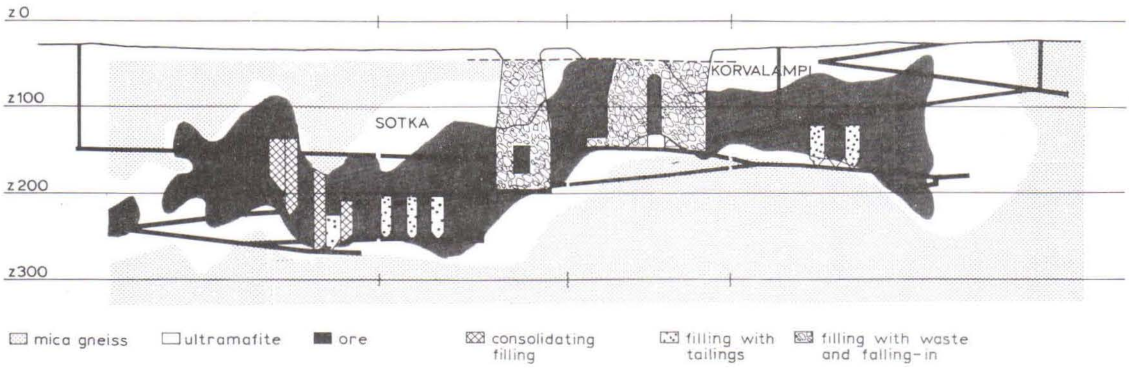


Fig. 4. The vertical longitudinal projection of Sotka-Korvalampi.

Sulphide textures and assemblages

A netlike intergranular texture predominates among the sulphides in the ores. Coarse sulphide segregations, nests and stringers are encountered close to the contacts and even in the gneiss. In general, the grain size of the sulphides diminishes towards the internal parts of the intrusion.

The predominant sulphide assemblage in the ore is pyrhotite + pentlandite + chalcopyrite + cubanite + mackinawite. Mackinawite usually occurs as fine-grained inclusions in pentlandite and is clearly more common than cubanite.

Secondary pyrite is a common constituent among the sulphides. Valleriite occurs casually as fine-grained dust between the silicates. Apart from the intergrowths between pentlandite and mackinawite, other intimate relationships worth mentioning between sulphides are the pentlandite exsolution bodies in chalcopyrite, the cubanite lamellae in chalcopyrite and the vrey complex intergrowths of pentlandite-mackinawite-pyrrhotite-chalcopyrite-magnetite.

The secondary magnetite produced by serpentinization and the oxidation of pyrrhotite has crystallized in the cleavages in pentlandite and chalcopyrite as a network and in silicates as dustlike clouds.

References

Häkli, T.A., Vormisto, K., and Hänninen, E., 1979. Vammala, a nickel deposit in layered ultramafite, Southwest Finland. Economic Geology 74, 1166-1182.

Matisto, A., 1971. Kallioperäkartan selitys, 2121 Vammala. English summary: Explanation to the Map of Rocks. Suomen geologinen kartta 1 : 100 000.

A BRIEF INTRODUCTION TO THE GEOLOGY OF THE VAMMALA AREA

Jussi Aarnisalo
Outokumpu Oy

General geology

The Vammala area (Figs. 5 and 6) is part of the well-known Pori-Kylmäkoski Ni-Cu-belt (Häkli et al. 1979; Papunen 1980; Häkli and Vormisto 1985). The rocks in the region are Svecofennian supracrustal rocks intensely folded and metamorphosed into migmatitic mica gneisses and kinzigites, with associated and conformably foliated granodiorites and quartz diorites, mafic to ultramafic bodies, and crosscutting dykes (Matisto 1971; Häkli et al. 1979; Papunen 1980). Abundant, intensely folded graphite gneisses occur as interlayers within the migmatitic mica gneisses and kinzigites.

The predominant migmatite types in the area are veined gneisses, schlieren and schollen or agmatitic migmatites. The schollen migmatites in particular, but also the veined gneisses and schlieren migmatites, frequently contain fragments that are psammitic, skarniferous, amphibolitic, diopside gneissic, gabbroic or hornblenditic in composition. These fragments are remnants of more competent interlayers, dykes or sills that have resisted the intensive, high amphibolite to granulite facies metamorphism common in the area. The predominant, strongly migmatized and recrystallized parts of the paleosome evidently range from pelitic to rather psammitic in composition, with occasional calcareous portions. Intermediate and acid tuffaceous material also seems to occur as interlayers. The tuffaceous amphibolite and hornblende gneiss fragments, the interlayers and the more extensive skarn amphibolite layers indicate mafic to intermediate volcanic activity during sedimentation. The types and diversity of the sedimentary material, and the marked layering of the sediments, which vary greatly in thickness, suggest that the sedimentation took place in a marine shallow water-deep water transitional zone.

Migmatization has occurred in several phases, causing the apparent

Fig. 5. General geological map of the Vammala area, compiled from geological maps of Finland and mapping by Outokumpu Oy Exploration. Explanation: 1. Generally migmatic mica gneiss and kinzigite, 2. Graphite gneiss and black schist, 3. Amphibolite, uralite porphyrite and basic volcanics, 4. Acid and intermediate volcanics, 5. Granite, 6. Pegmatite granite, 7. Porphyritic granite, 8. Granodiorite and quartzdiorite, 9. Porphyritic granodiorite, 10. Diorite, gabbro and peridotite. After Aarnisalo et al. 1982.

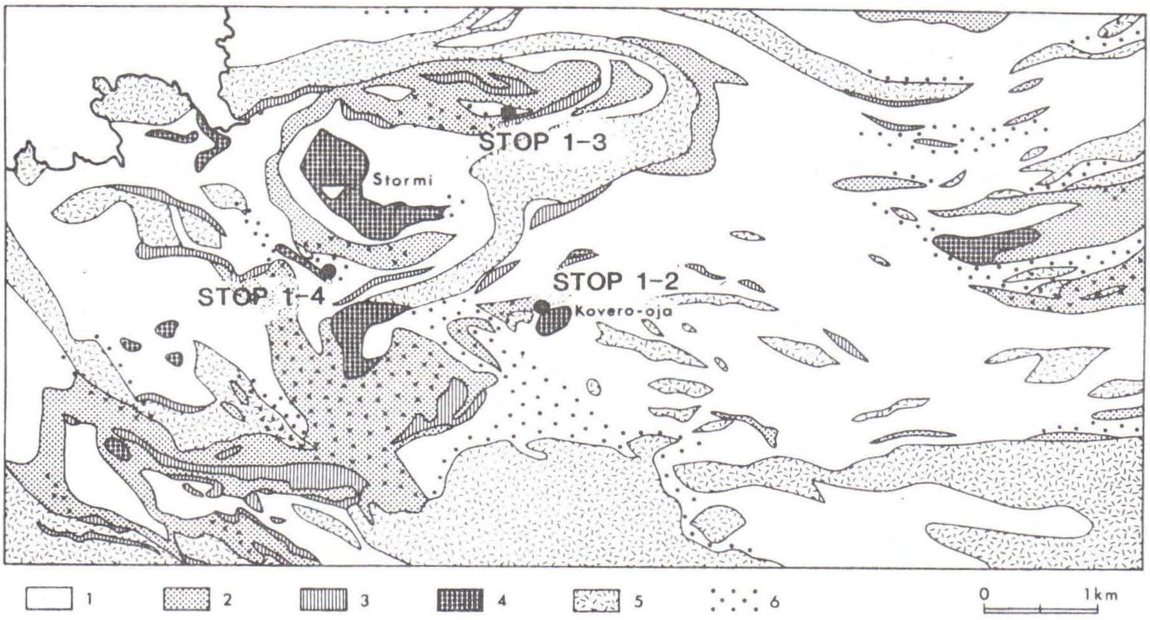


Fig. 6. Geology of the surroundings of Stormi Ni-Cu-mine in the Vammala area. Explanation: 1. Mica gneiss, 2. Kinzigite, 3. Graphite gneiss, 4. Ultramafite, 5. Diorite, 6. Schollen migmatite. After Häkli et al. 1979. Excursion stops in the vicinity of the mine are marked on the map.

complexity of the migmatites. The oldest phases exhibit trondhjemitic neosomes, but the neosomes of the later major migmatization phases are granodioritic or granitic in composition. In some places, migmatization has advanced to the nebulitic stage, with trondhjemite gneiss or granodiorite gneiss as matrix. These rocks are, therefore, often difficult to distinguish from plutonic rocks. The oldest felsic plutonic rocks in the area appear to be garnetiferous quartz diorites with cataclastic schistosity. They form subconcordant sheets which were folded together with the supracrustal country rocks during the major deformation phases. The quartz diorites and granodiorites occur as larger massifs, too. Some of these massifs are porphyritic with large microcline idioblasts. Granites occur rarely, and then mostly as pegmatitic or aplitic veins and dykes.

Peridotites predominate among the mafic plutonic rocks, but hornblendites, perknites and cortlandites are also encountered, as are noritic gabbros. Most of the mafic plutonic rocks occur as isolated and rather small bodies, often next to, or surrounded by, graphite gneisses.

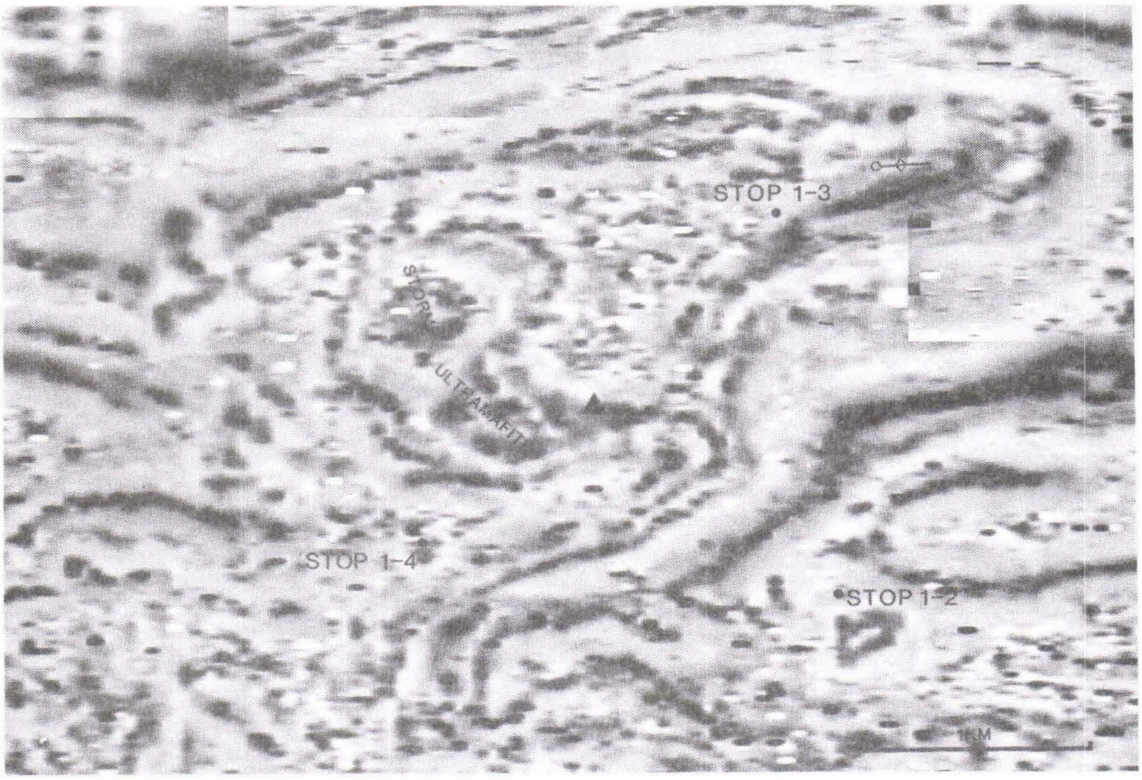


Fig. 7. High pass-filtered image ofthe ground survey magnetic data of the surroundings of Stormi Ni-Cu-mine (▲). The graphite gneiss horizons together with the associated amphibolite layers are shown as distinct, continuous belts. These "marker horizons" reveal the polyphase folding of the bedrock. The excursion stops are marked on the image.

They intruded into or on top of the marine sediments in several pulses, sometimes imparting a layered structure to the bodies. Even during the early deformation and migmatization phases mafic dykes and possibly also small bodies intruded the supracrustals, as can be seen elsewhere in the Pori-Kylmäkoski Ni-Cu belt. The youngest diabase dykes crosscut the major fold structures and felsic massifes, indicating relatively long mafic magmatic activity in the region.

The graphite gneiss horizons usually also contain some pyrhotite and pyrite, and can thus be mapped with magnetic and EM surveys. Occasionally the graphite gneisses are associated with magnetic amphibolite layers, which together form clear magnetic anomaly belts that can be used as "marker horizons" for the structural analysis of the area (Fig. 7) (Aarnisalo et al. 1982; Aarnisalo 1984). The serpentinized ultramafic rocks also produce magnetic anomalies, as do some other mafic rocks. In

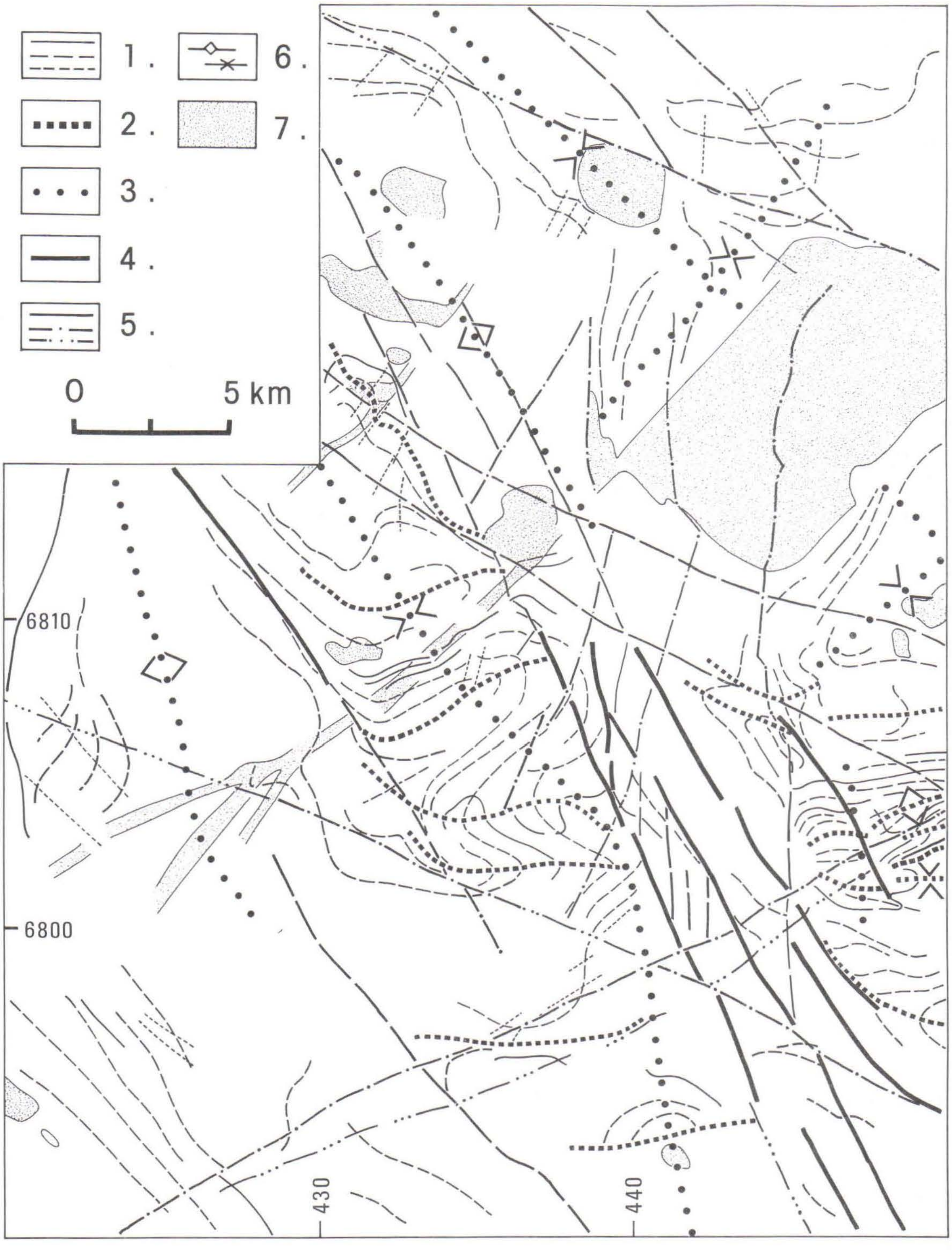


Fig. 8. A tentative interpretation sketch of major structural features deduced from integrated airborne geophysical, Landsat and topographic data. Explanation: 1. Fold axial traces from relatively older to younger, 2. Axial traces of major younger folds, 3. Axial traces of regional antiformal and synformal structures, 4. Major shear zones with apparant horizontal separation, 5. Younger regional faults and fractures, 6. Antiformal and synformal attitude of folding, 7. Gamma-ray spectrometric anomalies indicating potassium-rich granitoids and a structural lineament. After Aarnisalo 1984.

the Vammala area, the anomaly belts reveal the polyphase folding which can be used along with field observations to unravel the structural evolution of the area. For instance, the Stormi ultramafic body seems to be lying in the core of major older synformal structure that was deformed during later regional episode into folds trending roughly E-W. Further, a younger regional fold pattern oriented N-S can be detected in the refolding system of the regional E-W folds. The structural evolution of the area also involved later transcurrent and vertical movements along major shear and fault zones, dividing the bedrock into blocks that, at present, are at different erosional levels. Younger fracturing and minor faulting can be perceived from Landsat imagery, topographic images and low-altitude airborne geophysical EM out-of-phase images (Fig. 8) (cf. Aarnisalo 1984).

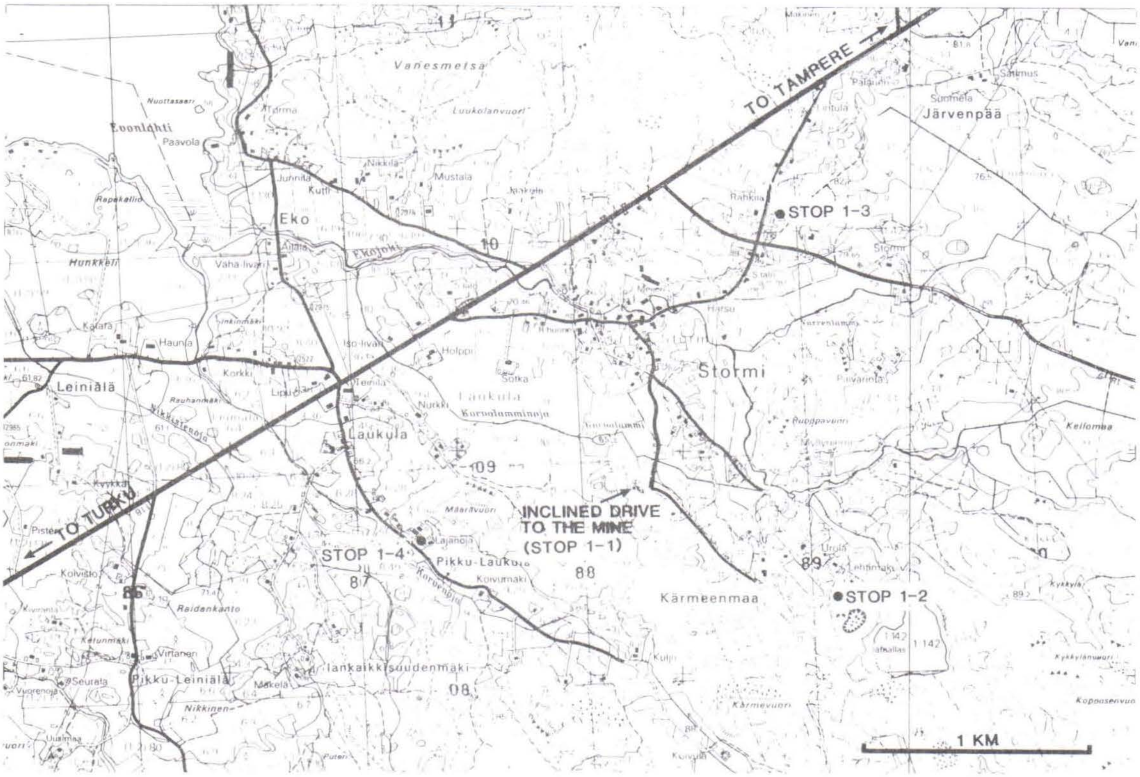


Fig. 9. Map of the surroundings of Stormi Ni-Cu-mine. The locations of the excursion stops are marked on the map.

Excursion stops

The location of the outcrops to be visited are shown in Figs. 6, 7 and 9.

1-2. Kovero-oja

Schollen migmatite with mica gneissic, garnet rich mica gneissic and skarniferous fragments in a schlieren mica gneiss matrix that occasionally contains sillimanite, cordierite and garnet. Part of the matrix may be "hybrid" rock affected by the Kovero-oja peridotite body nearby. Another exposure shows a larger remnant of a more competent, folded, psammitic layer with skarniferous inclusions (a boudinaged layer or concretions ?) and pelitic, highly metamorphosed and deformed beds on either side of it. The psammitic layer indicates roughly the trend of the original layering, which is also revealed by the magnetic anomaly belts nearby (Fig. 7). The outcrop is situated almost at the hinge of a major regional fold trending roughly E-W. The most marked schistosity visible in the bedrock is along the axial plane of this fold, while the original bedding runs around the hinge.

1-3. Stormi, Rahkila

An outcrop of veined gneiss with conspicuous folding. The folds are the parasitic folds of a regional antiform trending roughly E-W, which is seen in Fig. 7. Note that the migmatization processes producing the veined gneisses took place before this regional folding phase. In places, a younger generation of schlieren migmatite has developed along the axial planes of the folds.

1-4. Haavisto

The contact of the small Haavisto peridotite body with schollen-migmatitic mica gneiss. The schollen migmatite is composed of gabbroic, skarniferous, hornblende gneissic and mica gneissic fragments embedded in trondhjemitic veined gneiss or schlieren gneiss matrix. Some pegmatitic or aplitic veins and dykes indicate later, incipient "remigmatization". The trend of the schistosity expressed by the veining turns subparallel to the contact of the peridotite, where the rock is sheared and intruded by a pegmatite dyke some 0.5 m wide. The veined gneiss - schlieren gneiss matrix is also folded in a roughly N-S direction. A fragment reveals that the mica gneiss was already folded before the major migmatization.

References

Aarnisalo, J., Franssila, E., Eeronheimo, J., Lakanen, E., and Pehkonen., 1982. On the integrated use of Landsat, geophysical, and other data in exploration in the Baltic Shield, Finland. Photogr. J. Finland 9 (1), 48-64.

Aarnisalo, J., 1984. Image processing and integration of geophysical, Landsat and other data as a tool for mineral exploration in glaciated Precambrian terrain. Internat. Symp. Rem. Sens. Env., third thematic conference on Remote Sensing for Exploration Geology, 16-19 April 1984, Colorado Springs, Col., Proceedings I, 107-128.

Häkli, T.A., Vormisto, K. and Hänninen, E., 1979. Vammala, a nickel deposit in layered ultramafite, southwest Finland. Econ. Geol. 74 (5), 1166-1182.

Häkli, T.A. and Vormisto, K., 1985. The Vammala nickel deposit. In Papunen, H and Gorbunov, G.I. (Eds.) Nickel-copper deposits of the Baltic Shield and Scandinavian Caledonides. Geol. Surv. Finland, Bull. 333, 273-286.

Matisto, A., 1971. Explanation to the map of rocks, sheet 2121 Vammala. Geol. Surv. Finland. 44 p.

Papunen, H., 1980. The Kylmäkoski nickel-copper deposit in southwestern Finland. Bull. Geol. Soc. Finland 52, 129-145.

THE EURAJOKI RAPAKIVI GRANITE STOCK AND ASSOCIATED GREISEN-TYPE MINERALIZATION

Ilmari Haapala
University of Helsinki, Department of Geology

Anorogenic or postorogenic rapakivi granites are found in several early Proterozoic shield areas around the world. Tens of rapakivi batholiths or stocks are known to occur in a broad belt extending from the Ukrainan Shield through the Baltic Shield, southern Greenland, Labrador and mid-continental U.S. to California. The ages of the rapakivi granites range from 1.76 Ga to 1.40 Ga, and they are typically 100-300 Ma younger than the common orogenic granitoids of the shield areas. The rapakivi granites are often associated with anorthosites and gabbros, in several cases also with diabases. This bimodal charater indicates involvement of both mantle-derived and and crustal materials in the formation of these igneous complexes. The initial $^{87}Sr/^{86}Sr$ values of the granites vary widely, but the gabbros and anorthosites show mantle-type initial ratios (Anderson 1983).

The rapakivi granite batholiths of Finland are multiple intrusions, the early phases being hornblende- and fayalite-bearing orthoclase-andesine granites, the main phases biotite (+ hornblende)-bearing granites and the latest intrusive phases leucocratic microcline-albite granites which often contain topaz as a minor constituent. The main intrusive phases are characterized by the rapakivi texture, whereas the late intrusive phases do not contain mantled K-feldspar ovoids. The rapakivi granites are slightly peraluminous or metaluminous rocks characterized by high F, SiO_2, alkalies, Fe/Mg, Zr, Ga and Rb (Vorma 1976, Haapala 1977a). The granites show many characteristics of the A-type granites (Nurmi and Haapala 1986).

The topaz-bearing late-stage granites contain lithian siderophyllite (protolithionite) as the only dark constituent. Typical accessory minerals include fluorite, monazite, bastnaesite, ilmenite, cassiterite

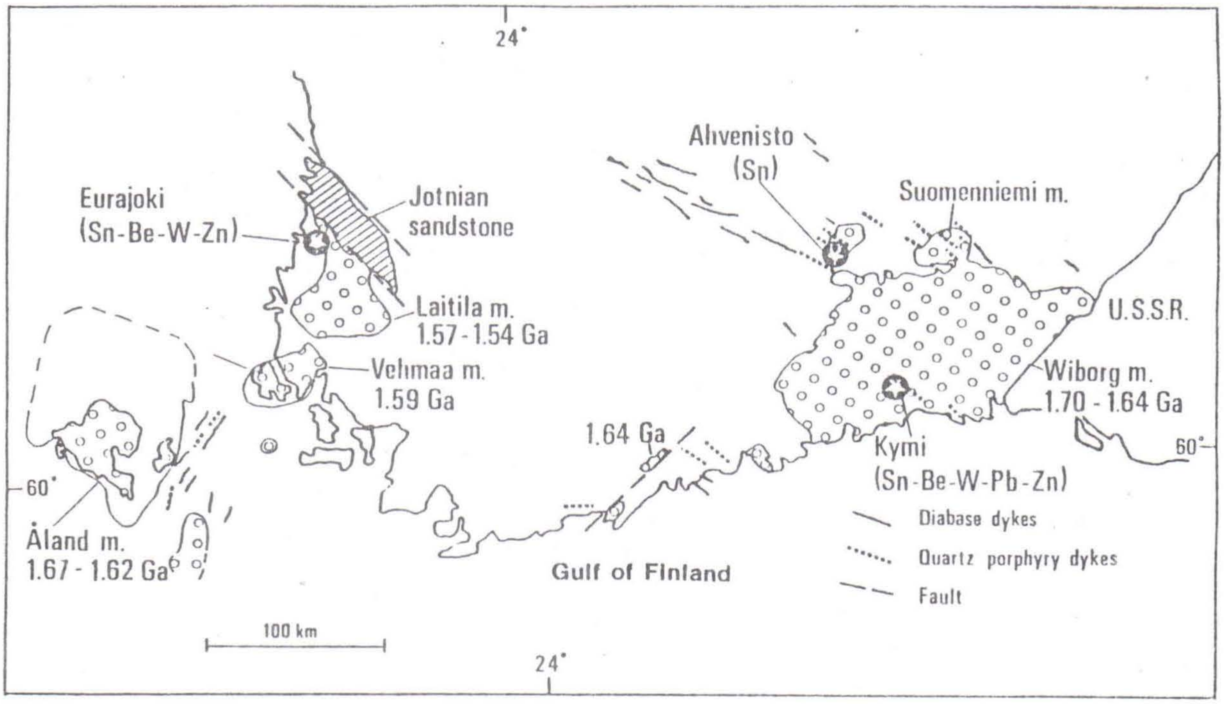


Fig. 10. The rapakivi granite complexes of southern Finland with the intrusion ages (Vaasjoki 1977) and associated mineralization. Marked in the figure are also sets of diabase and quartz porphyry dykes and the sandstone-filled Jotnian graben.

and thorite. These late-stage granites are geochemically anomalous with high F (1-1.5 wt-%), Li, Rb, Ga, Sn and Nb as well as with low Ti, Zr, Br and Ba.

Associated with the topaz-bearing granites are greisen and quartz veins with Sn, Be, W, Zn and Pb mineralization in several areas (Eurajoki, Kymi and Ahvenisto in Fig. 10; Haapala 1977a and b, Nurmi and Haapala 1986). The occurrences found so far have been subeconomic although the tin contents are locally notably high.

The Eurajoki stock is a satellite of the Laitila rapakivi batholith and intrudes Svecofennian gneisses and migmatites. The stock is composed of a 1) hornblende- and fayalite-bearing outer granite (Tarkki granite), 2) biotite-bearing granites and 3) topaz-bearing microcline-albite granites containing lithian siderophyllite (granites 2-3 are called Väkkärä granite). The topaz-bearing granite is geochemically specialized differing clearly from the normal rapakivi granites: high Li, Be, F, Rb,

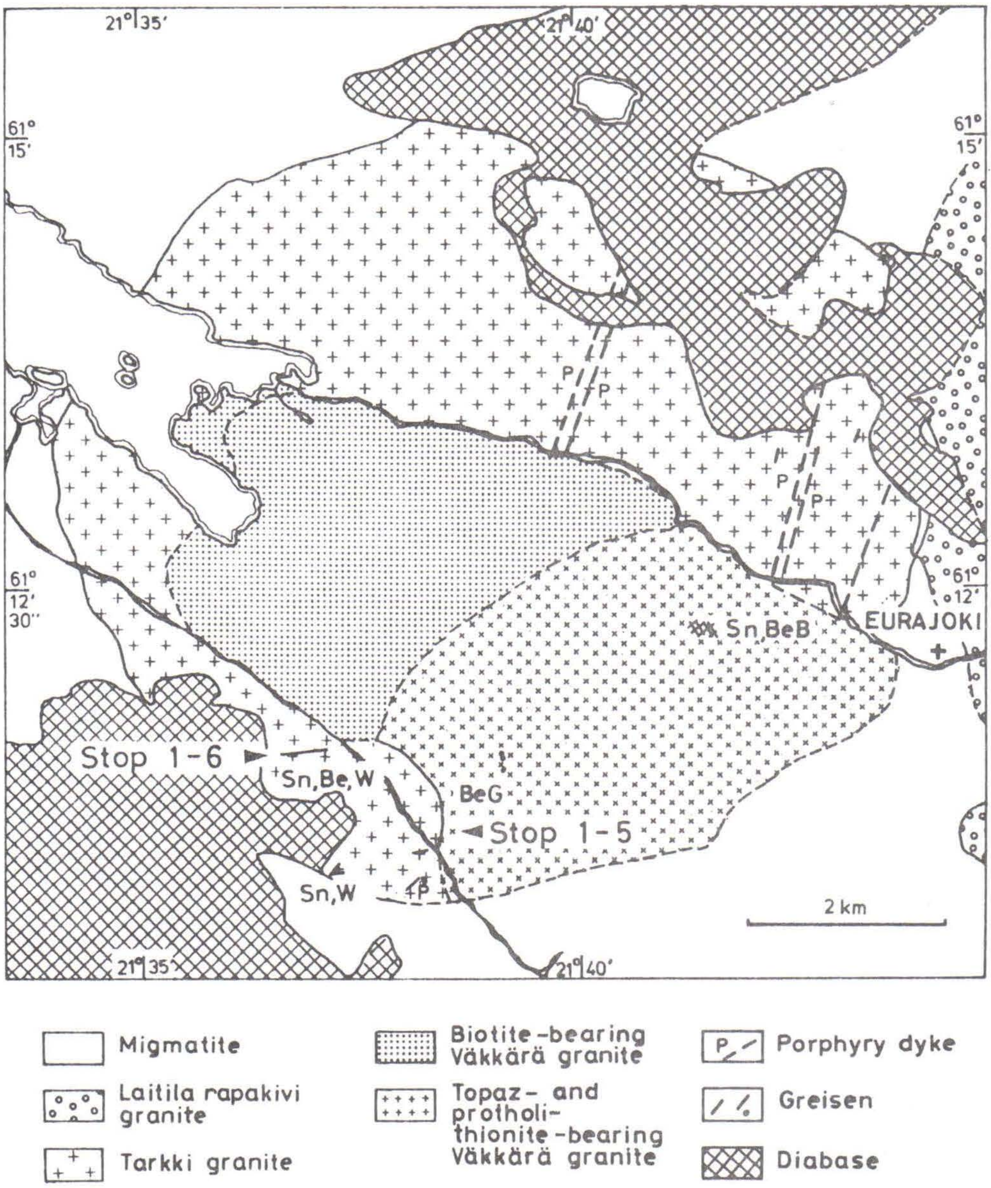


Fig. 11. Geological map of the Eurajoki area, simplified from Haapala (1977a). Sn, cassiterite; W, wolframite; Be, beryl; BeG, genthelvite; BeB, bertrandite.

Ga, Sn and Nb, and low Ti, Sr, Ba and Zr. Nb- and Ta-rich cassiterite, ilmenite, monazite, bastnaesite, columbite and thorite are typical assessory minerals. Subsolidus reactions (exsolution of alkali feldspar, recrystallization, autometasomatic mineral replacements) are typical.

Greisen and quartz veins are found in different parts of the Eurajoki stock; more irregular greisen bodies occur in the topaz-bearing granite (Fig. 11). The amount and association of ore minerals vary widely;

sphalerite, cassiterite and wolframite are often present. As beryllium minerals occur beryl, genthelvite and bertrandite (Haapala and Ojanperä 1972). Two mineralized areas have been studies by deep drilling, but no minable ore bodies have been found.

Excursion stops

1-5. Koivuniemi, Lapijoki (x = 6786.5, y = 534.62).
A greisen lens in the topaz-bearing granite. The greisen body has a zonal structure with quartz-sericite-chlorite-genthelvite greisen at the center (Fig. 12). This greisen body is remarkable as an occurrence of the rare beryllium mineral genthelvite (Zn, Fe, Mn) Be $SiO_{4\ 3}$ S.

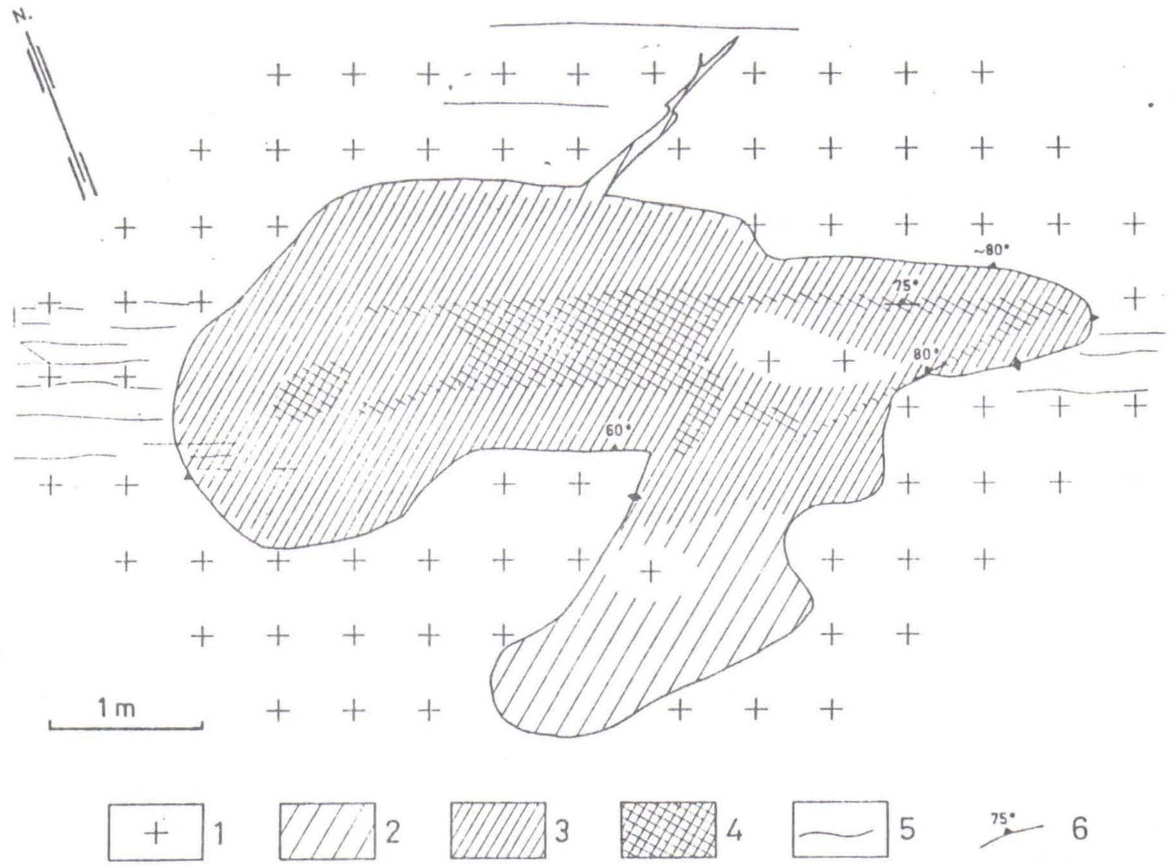


Fig. 12. A genthelvite-bearing greisen body in the topaz-bearing Väkkärä granite (after Haapala and Ojanper. 1972). The greisenization has been controlled by fractures. 1, topaz-bearing Väkkärä granite; 2, quartz--sericite greisen; 3, quartz-sericite-chlorite greisen; 4, quartz--sericite-chlorite-genthelvite greisen.

1-6. Koivuniemi, Lapijoki (x = 6787.22, y = 533.0).
A swarm of greisen veins in the hornblende- and fayalite-bearing granite (Tarkki granite). The veins contain cassiterite, wolframite, molybdenite, sphalerite, chalcopyrite and galena as ore minerals; beryl is common in the central quartz veinlets. The distribution of tin is irregular, locally the tin content of the greisen is about 20 wt-% Sn. Fluid inclusion studies show that cassiterite crystallized from fluids having a minimum temperature of 260^{0}-390^{0} C and a gross salinity equivalent to 3-17 wt-% NaCl, and beryl crystallized from fluids having a minimum temperature of 360^{0}-410^{0} C and a salinity equivalent to 11-17 wt-% NaCl (Haapala and Kinnunen 1979).

References

Anderson, J.L., 1983. Proterozoic anorogenic granite plutonism of North America. Geol. Soc. Am., Mem. 161, 133-154.

Haapala, I., 1977a. Petrography and geochemistry of the Eurajoki stock; a rapakivi-granite complex with greisen-type mineralization in southwestern Finland. Geol. Surv. Finland, Bull. 286. 128 p.

Haapala, I., 1977b. The controls of tin and related mineralizations in the rapakivi areas in southeastern Fennoscandia. Geol. Fören. Stockholm, Förh. 99, 130-142.

Haapala, I. and Kinnunen, K., 1979. Fluid inclusions in cassiterite and beryl in greisen veins in the Eurajoki stock, southwestern Finland. Econ. Geol. 74, 1231-1238.

Haapala, I. and Ojanperä, P., 1972. Genthelvite-bearing greisen in southern Finland. Geol. Surv. Finland, Bull. 259. 22 p.

Nurmi, P.A. and Haapala, I., 1986. The Proterozoic granitoids of Finland: Granite types, metallogeny and relation to crustal evolution. Bull. Geol. Soc. Finland 58 (1), 203-233.

Vaasjoki, M., 1977. Rapakivi granites and other postorogenic rocks in Finland: their age and lead isotope composition of certain associated galena mineralizations. Geol. Surv. Finland, Bull. 294. 64 p.

Vorma, A., 1976. On the petrochemistry of rapakivi granites with special refererence to the Laitila massif, southwestern Finland. Geol. Surv. Finland, Bull. 285. 98 p.

THE GEOLOGY OF ORIJÄRVI AND WEST UUSIMAA

L. Westra
Free University Amsterdam
The Netherlands

The excursion shows a part of the E-W trending Kemiö-Orijärvi-Järvenpää belt of supracrustal rocks of the early Proterozoic Svecokarelides in southern Finland (Fig. 13). This belt has three major components:

(1) Layered volcano-sedimentary rocks.
(2) Prekinematic, commonly almost massive, intrusive rocks (gabbro -tonalite suite).
(3) Synkinematic coarse-grained and massive microcline granites.

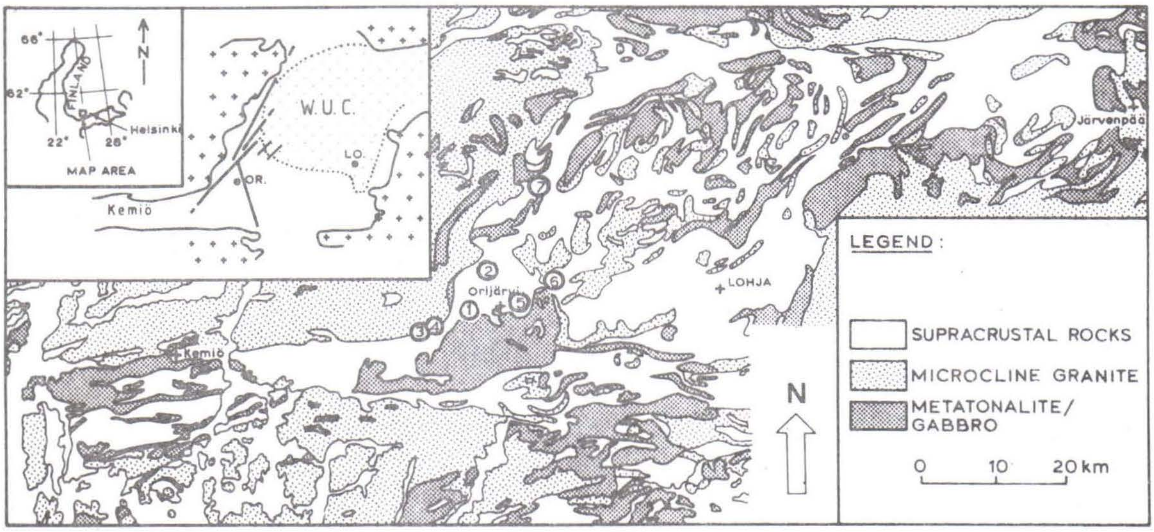


Fig. 13. The Kemiö-Orijärvi-Järvenpää belt, mainly after Härme (1960). The inset shows the main shear zones; stippled area: the West Uusimaa Granulite Complex (WUC).

In Orijärvi and West Uusimaa the volcano-sedimentary pile is dominated by felsic and mafic tuffs, volcanic breccias, with intercalations of pillow basalts, marbles and some greywackes. A smaller proportion of the volcano-sedimentary rocks comprise pelites and garnet-cordierite-biotite gneisses (kinzigites on the geological maps of the GSF). The stratigraphic succession and thickness of the various rock series are unknown, but is it suggested here that the pelites originally overlay the main volcanic pile. This interpretation is consistent with Simonen's general stratigraphy of the Svecofennian in Finland (Simonen 1980, cf. Latvalahti 1979). A thin but almost continuous belt of pillowed basalts with intercalations of ultramafic lavas has been mapped between the pelitic series and the main volcanic series (Wever 1985).

The gabbro-tonalite suite and the volcanites shows striking geochemical similarities and are considered to be syngenetic. The whole igneous suite is similar to rock associations of recent Circum Pacific Island Arcs (Colley and Westra, in press; Hietanen 1975; Latvalahti 1979). The chemistry of the associated ultramafic lavas is between that of komatiites and picrites but closer to picrites and hence, they are classified as picritic basalts (Schreurs et al., in press). The following is Latvalahti's (1979) description of the sulphide ores of the Orijärvi district:

"The Cu-Zn deposit of Aijala and the Zn-Pb deposit of Metsämonttu are both sulfide disseminations or breccias in the upper part of the acid volcanite group in a pyroclastic unit with quartz and plagioclase phenocrysts. The Orijärvi Zn-Cu ore deposit consists of sulfide disseminations, breccias and veins of massive sulfides in a zone of cordierite-sericite and cordierite-anthophyllite rocks. Even though the proportion of massive sulfides is low, the Aijala Cu-Zn, Metsämonttu Zn-Pb, and Orijärvi Zn-Cu ores may be allied with massive Precambrian volcanic-exhalative sulfide ores as their proximal type."

The cordierite-anthophyllite and associated rocks of Orijärvi have been studied in detail by Schippers (1981). He successfully applied the sea-floor alteration model to the origin of these rocks. Chemically identical rocks, but with hypersthene in place of anthophyllite, have been found from the high-grade rocks of the West Uusimaa Granulite Complex near Lohja (Schreurs and Westra 1985).

Thermotectonic evolution

The tectonic evolution of the Kemiö-Orijärvi-Järvenpää belt (Schreurs and Westra, in press) is characterized by three successive fold generations (Fig. 14). The first one (D_1) is responsible for the dominating foliation (S_1) and locally shows isoclinal intrafolial folds. D_1 is tentatively related to thrusting and imbrication tectonics at plate collision contacts. The main deformation (D_2) is probably related to a N-S compressional regime, which first created upright folds trending E-W. Further crustal shortening tightened these F_2 folds in the western part of the belt (Kemiö), whereas shear zones and megaboundins or tectonic lenses of competent rock bodies developed in the eastern part (NE of Orijärvi-Lohja). The tectonics of this phase is probably controlled by differential movement between large-scale migmatite/K-granitoid masses. D_3 is characterized by strongly disharmonic open folds (F_3) with steep B_3 axes and axial planes trending between NW and NE. F_3 folds are preferentially developed in pinch areas of megaboundins in the eastern part of the belt. D_3 is of minor importance and could possibly represent an elastic reaction to the relaxation of one major N-S, D_1/D_2 compressional regime of the main stage of crustal shortening.

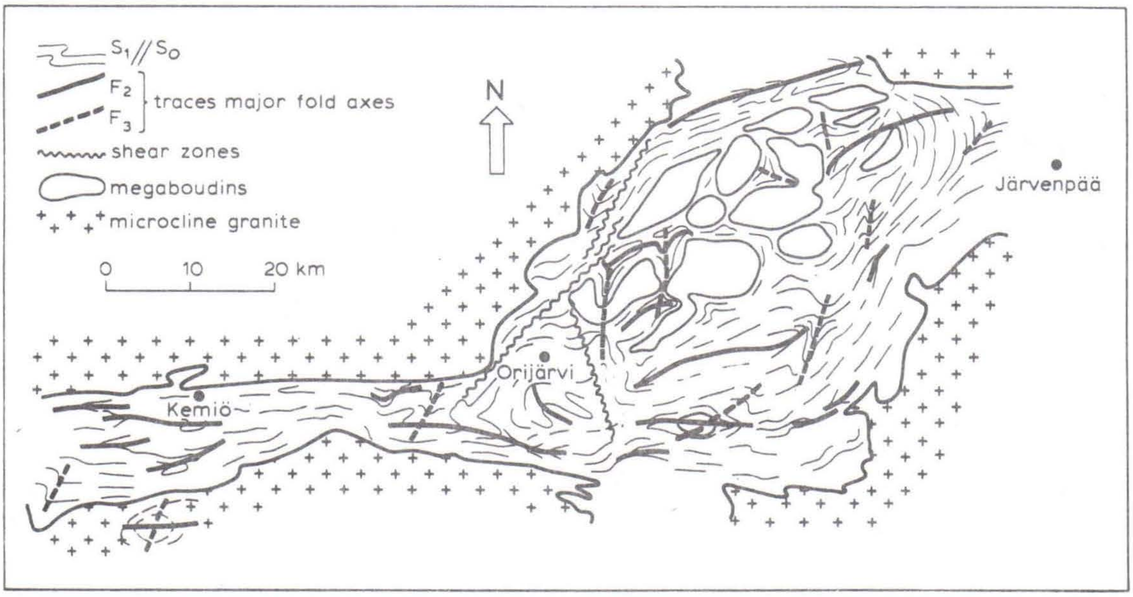


Fig. 14. Structural sketch map of the Kemiö-Orijärvi-Järvenpää belt.

Metamorphism has taken place mainly under amphibolite facies conditions, although in the eastern part of the belt the metamorphic temperatures increased to granulite facies during F_2 folding (Parras 1958). The granulites of this West Uusimaa Complex have been interpreted (Westra and Schreurs 1985) as a low-pressure thermal dome, principally because of the isobaric temperature increase from 550^{o}-$650^{o}C$ to 700^{o}-$825^{o}C$ at very low pressures of around 4 Kb in a narrow transition zone only 2-3 km wide. This thermal dome could be attributed to mafic intrusions at depth.

The Orijärvi Triangle

The Orijärvi Triangle is one of the few early Proterozoic, deep crustal fragments that show well preserved primary features. Moreover, Orijärvi is a key area for our understanding of the tectonics of the belt because it is apparently a low strain area, affected by D_1 only.

The area is shaped like a triangle with shear zones as the standing sides (Tuominen 1957) and the huge Orijärvi granodiorite as the base. It consists of a series of acid to basic tuffs and agglomerates with intercalations of greywackes (stop 2, 5 and 6), mafic dikes, pillow basalts, marbles, and, close to the top of the Orijärvi granodiorite, several alteration pipes and cells of cordierite-anthophyllite rocks. S_0 is well developed in all exposures within the triangle. The only deformation is an open-style folding with axial plane cleavage/schistosity (S_1). S_1 bends sigmoidally, with sinistral symmetry, into the shear zones bordering the triangle (Fig. 15). It is suggested that the stress in the N-S compressional regime during D_2 was taken up by the shear zones (Ploegsma and Westra, in prep.).

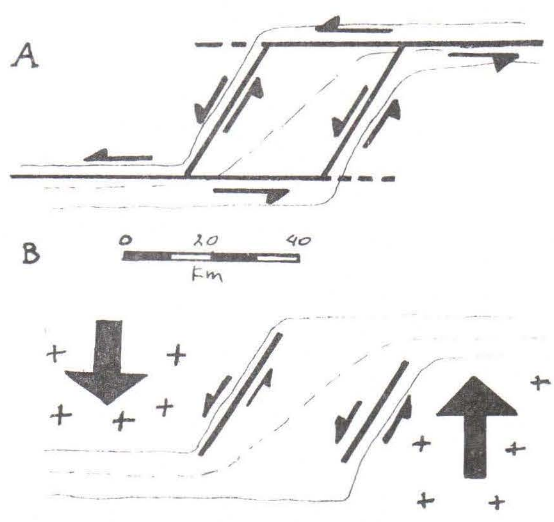


Fig. 15. Two models to explain the typical diamond shape in part of the Svecofennian in southern Finland. A. A hypothetical sinistral wrench fault system, with second order faults. B. Faults developed by differential movement of granitoid masses in a N-S compressional regime.

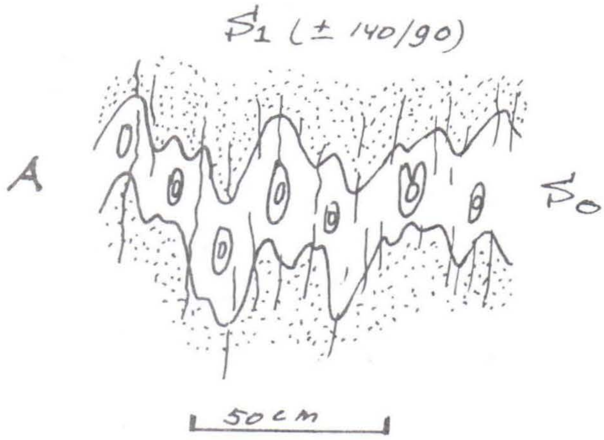


Fig. 16. Excursion stop 2-2: Kavasto. A. F_1-folded sedimentary layering with calcareous nodules flattened parallel S_1 axial plane. B. Rotation of quartz-filled tension gashes by simple sinistral shear. The plane of shear is parallel to the close-by Kisko Shear Zone.

Excursion stops

2-2. Kavasto quarry (x= 472.73, y = 685.09).
Exposure in metagreywackes, within the Orijärvi Triangle, only a few hundreds of metres east of the Kisko Shear Zone (Fig. 16).

Well-preserved sedimentary layering with calcareous nodules, probably sedimentary concretions.

The deformation is characteristic of the whole Orijärvi Triangle and shows only one folding phase (F_1): open folds with widely spaced axial plane cleavage and flattened nodules.

Typical of the exposure are quartz-filled veinlets and tension gashes. Two main systems have developed, one of them parallel to the shear zone (NE). En echelon tension gashes rotated by simple sinistral shear can also be observed.

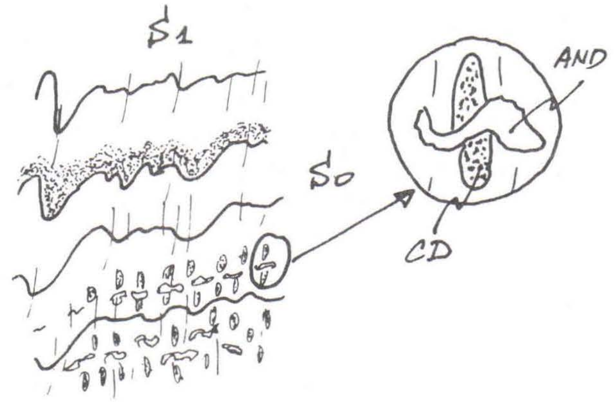


Fig. 17. Excursion stop 2-5: Vetio. F_1-folded sedimentary layering and andalusite crystals. Cordierite porphyroblasts in S_1.

Andalusite porphyroblasts were formed synkinematically to postkinematically with respect to the folding. The calcareous nodules show a zonal mineral composition with, locally, grossular in the core. Epidote usually predominates in the central parts, hornblende in the middle and biotite in the outerparts of the nodules.

2-5. Vetio, road cutting (x = 475.04, y = 681.30).
Exposure in metagreywackes, similar to those of stop 2. Well-preserved sedimentary layering with graded bedding and pseudonodules (Fig. 17).

Open F_1 folds with axial plane cleavage and microfaults. The exposure is particularly interesting for the presence of an arrested pelitic reaction: andalusite + biotite + quartz = cordierite + K-feldspar.

Andalusite is present as elongated white crystals, microfolded by F_1. Cordierite forms dark lenses with the long axes parallel to S_1. Microscopically, the andalusite appears to be annealed in subdomains after the deformation. Sillimanite is also present, partly in contact with andalusite, partly enclosed in cordierite. These assemblages narrow down the conditions of metamorphism during D_1 (+ 550°-600°C and 2.5-3 Kb at $P_{H2O} = 0.4\ P_{tot}$.).

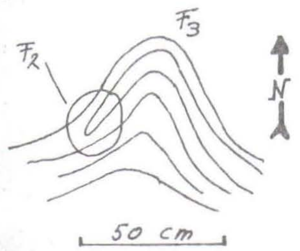


Fig. 18. Excursion stop 2-6: Kolmjärvi. F_2 + F_3 fold interference pattern.

2-6. Kolmijärvi (x = 682.65, y = 481.20).
Probably the same horizon of metagreywackes as the rocks at stop 5, even though the locality is well outside the Orijärvi Triangle. Sedimentary layering is completely absent, having been transposed and overprinted by a schistosity and differentiated layering that is, most likely, the same as the cleavage within the Triangle. The new foliation here has therefore been coded S_1.

Typical of this exposure and the surrounding area is the folding of S_1, which shows F_2 + F_3 interference patterns (Fig. 18). F_2 is isoclinal with axial plane traces striking E-W and F_3 has axial planes with a northerly strike.

2-7. Nuppulankulma (x = 694.26, y = 479.21)
This exposure is located in the middle of the northern extension of the Kisko Shear Zone. The rocks are strongly mylonitic marbles and tuffaceous biotite gneisses that were affected by at least two successive generations of isoclinal folding. One of the folded marble layers shows a well-developed sheath fold. This exposure has not yet been studied in detail, but there is evidence that the folding originated within the shear zone, and is probably related to the D_2 deformation phase.

In this area the Kisko Shear Zone acts as the western boundary of the West Uusimaa Granulite Complex.

(The tectonics and petrology of the Kisko Shear Zone are the subject of the doctoral dissertation by M. Ploegsma, Free University Amsterdam.)

References

Colley, H. and Westra, L., 1986. Igneous activity and mineralization in the Svecofennides of South Finland. Geol. Soc. London. Spec. Publ., in press.

Härme, M., 1960. The geological map of Finland, Turku, Sheet B1. Published by the Geological Survey of Finland.

Hietanen, A., 1975. Generation of potassium-poor magmas in the Northern Sierra Nevada and the Svecofennian in Finland. J. Research U.S. Geol. Survey 3, 631-645.

Latvalahti, U., 1979. Cu-Zn-Pb ore s in the Aijala-Orijärvi area, southwest Finland. Econ. Geol., 74 (5), 1035-1059.

Parras, K., 1958. On the charnockites in the light of a highly metamorphic rock complex in SW Finland. Bull. Comm. géol. Finlande 181. 137 p.

Ploegsma, M. and Westra, L., in preparation. The Orijärvi Triangle: a low strain area in the deep Proterozoic crust of SW Finland. To be presented to Geologie & Mijnbouw.

Schippers, M., 1983. The cordierite-anthophyllite rocks of Orijärvi, Finland. Int. Report, Free University, Amsterdam. 43 p.

Schreurs, J. and Westra, L., 1985. Cordierite-orthopyroxene rocks; the granulite facies equivalents of the Orijärvi cordierite-anthophyllite rocks in West Uusimaa, SW Finland. Lithos 18, 215-228.

Schreurs, J. and Westra, L., 1986. The thermotectonic evolution of a Proterozoic, low pressure, granulite dome, West Uusimaa, SW Finland. Contrib. Mineral. Petrol. (in press).

Schreurs, J., Van Kooperen, P. and Westra, L., 1986. Ultramafic rocks of early Proterozoic age in West Uusimaa, SW Finland. N. Jb. Mineral. (in press).

Simonen, A., 1980. The Precambrian in Finland. Geol. Surv. Finland, Bull. 304. 58 p.

Tuominen, H.V., 1957. The structure of an Archaean area: Orijärvi, Finland. Bull. Comm. geol. Finland 177, 1-32.

Westra, L. and Schreurs, J., 1985. The West Uusimaa Complex, Finland: an early Proterozoic low pressure thermal dome. In Tobi, A.C. and Touret, J.L.R. (Eds.) The deep Proterozoic crust in the North Atlantic Provinces. NATO ASI Series C, 158, 369-382. Reidel.

Wever, H.E., 1985. On the occurrence of pillow structures and scapolite-bearing carbonate lenses in banded clinopyroxene-amphibolites of the West Uusimaa Granulite Region, SW Finland. Int. Report, Free University, Amsterdam. 35 p.

THE SULPHIDE ORE DEPOSITS IN THE ORIJÄRVI-AIJALA FIELD

Olli-Pekka Isomäki
Outokumpu Oy

Introduction

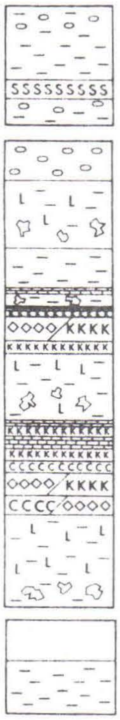
The Orijärvi-Aijala field in southwestern Finland (Fig. 13) is part of a formation of infracrustal and supracrustal rocks transecting southern Finland from east to west. It is part of the Svecokarelian belt and is c. 1,900 Ma in age (Simonen 1980). In this part, the belt is a leptite zone characterized by fine-grained felsic metavolcanics and quartz-feldspar metasediments. The zone is comparable to the leptite zone in Central Sweden (Eskola 1963; Gavelin et al. 1976; Latvalahti, 1979; Lundqvist 1979). The geology of the Orijärvi region was first made known by Eskola (1914, 1915) in his studies on petrology and in his concepts of metamorphic petrology. Later Tuominen and Mikkola (1950) and Tuominen (1951, 1957) wrote about the origin of the cordierite-anthophyllite rocks and the tectonics of the area. More recently, Latvalahti (1979; Mäkelä 1983) has described the volcanogenic ore deposits with alteration zones in the Aijala-Orijärvi field. Schreurs (1985) and Westra and Schreurs (1985) have studied metamorphic features from Orijärvi to the eastern Lohja area, from the amphibolite facies to the granulite facies, respectively. Ulla Mäkelä (1983; Latvalahti 1979) has compared the stratigraphy (Fig. 19) with that of the leptite zone in Central Sweden, where ore deposits of the same type occur at Bergslagen.

Economic geology

Three larger sulphide deposits have been mined in the Orijärvi field, the Orijärvi Cu-Zn-Pb mine (1760-1954), the Aijala Cu-Zn-S mine (1949-1958) and the Metsämonttu Zn-Pb-Ag mine (1952-1974). All the deposits have been mined out, and the mines are now closed. In addition, some smaller deposits, e.g. Nyckeln (Zn) and Iilijärvi (Zn, Cu, Au), have operated for short periods. The largest known, but not yet mined, deposit is Attu (Zn, Pb, Ag) at the western end of the Finnish leptite zone.

STRATIGRAPHY OF THE LEPTITE BELT.

TOP



GRYTHYTTAN	LJUSNARSBERG	ÅMMEBERG	UTÖ	AIJALA-ORIJÄRVI
CGL META-ARGILLITE, GRF-SLATE, SPILITES	MICA SCHIST		PARAGNEISS GRW, SUBGRW DACITIC TUFFITES	TUFFITES ARENITES VOLCANIC CGL GRW, MICA SCHISTS
GRW, CGL	GRW			
				BASIC VOLCANIC ROCKS (PYROCL. + LAVAS)
K-HÄLLEFLINTA, LIMESTONE, Mn-RICH IRON ORE	LEPTITE SCHIST, SPILITES, LEPTITE, Mn-RICH IRON ORE, LIMESTONE	SKARN, LIMESTONE, LEPTITE (EPI-CLASTIC SEDI-MENTS + TUFFS + LAVAS)		
Na-HÄLLEFLINTA, LIMESTONE, Mn-POOR IRON ORE, CHERT	LEPTITE, Mn-POOR IRON ORE, LIMESTONE	LEPTITE (EPICLAS-TIC SEDIMENTS + TUFFS + LAVAS) SKARN CHEMICAL SEDI-MENTS (LIME-STONE, QZT)	HÄLLEFLINTA LEPTITE, LIMESTONE, IRON ORE	CGL, LIMESTONE, IRONFORM., CHERT, ACID VOLCANIC ROCKS (PYROCLASTIC)
		LEPTITE - HÄLLE-FLINT (LAVAS + TUFFS)	GRV, SUBGRW	
SUNDIUS (1923)	MAGNUSSON (1940)	HENRIQUES (1964)	GAVELIN et al. (1976)	MÄKELÄ (1983)

Fig. 19. Stratigraphic sections across the leptite belt in Sweden and in the Orijärvi-Aijala field. Compiled by Ulla Mäkelä (1983).

The Orijärvi mine (Figs. 20 and 21) was one of the oldest in Finland. The deposit was discovered in 1757, and the first claim was made in 1760. About 1.2 million tonnes of ore were hoisted. In the last years (1932-1954) the grade was c. 0.8% Cu, 3.5% Zn, and 1.1% Pb in 0.5 million tonnes of ore (after Turunen, 1957). The best-quality ore was in diopside-tremolite skarn ("blötmalm"), and some was also in sericite schists, quartz rocks and cordierite-anthophyllite rocks ("hårdmalm"). The ore was locally and genetically associated with the hydrothermal alteration zone within the felsic metavolcanic formation (Latvalahti 1979).

The ore deposit of Aijala was discovered by Suomen Malmi Oy (Finnexploration) in 1945 and that of Metsämonttu by the same company in 1946. The main targets of drilling in the area were the electric anomalies in the zone, where two small mines (Silvergruvan and Aurums Aijala), now

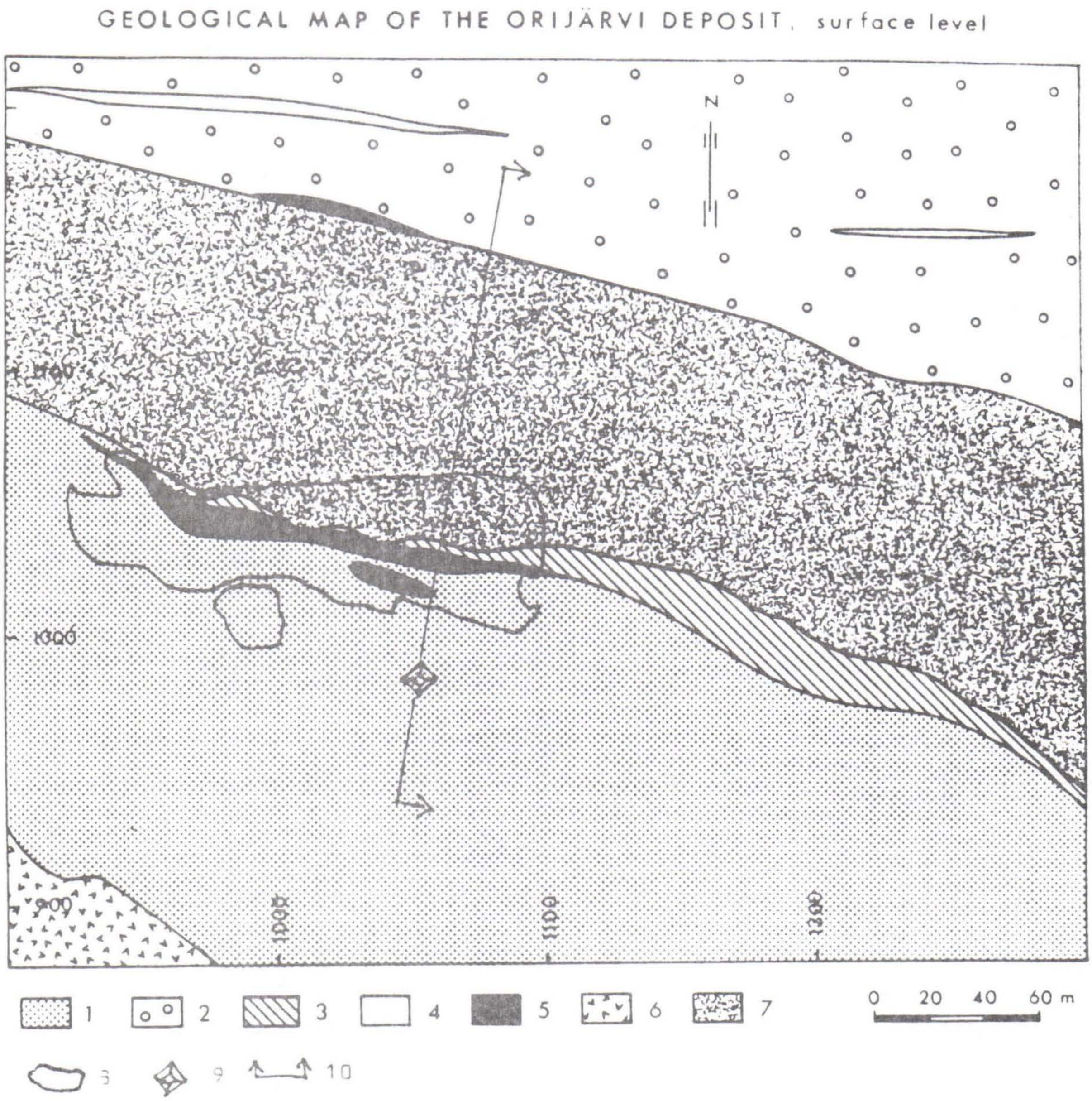


Fig. 20. Surface plan of the Orijärvi ore deposit: 1. cordierite-anthophyllite rock, 2. felsic cordierite bearing sericite gneiss, 3. quartz rock, 4. magnetite bearing skarn, 5. pre, 6. hypabyssal contact variant of granodiorite, 7. mafic subvolcanic dyke, 8. open pit, 9. main shaft, 10. section no. 12. The geology is according to Latvalahti (1979).

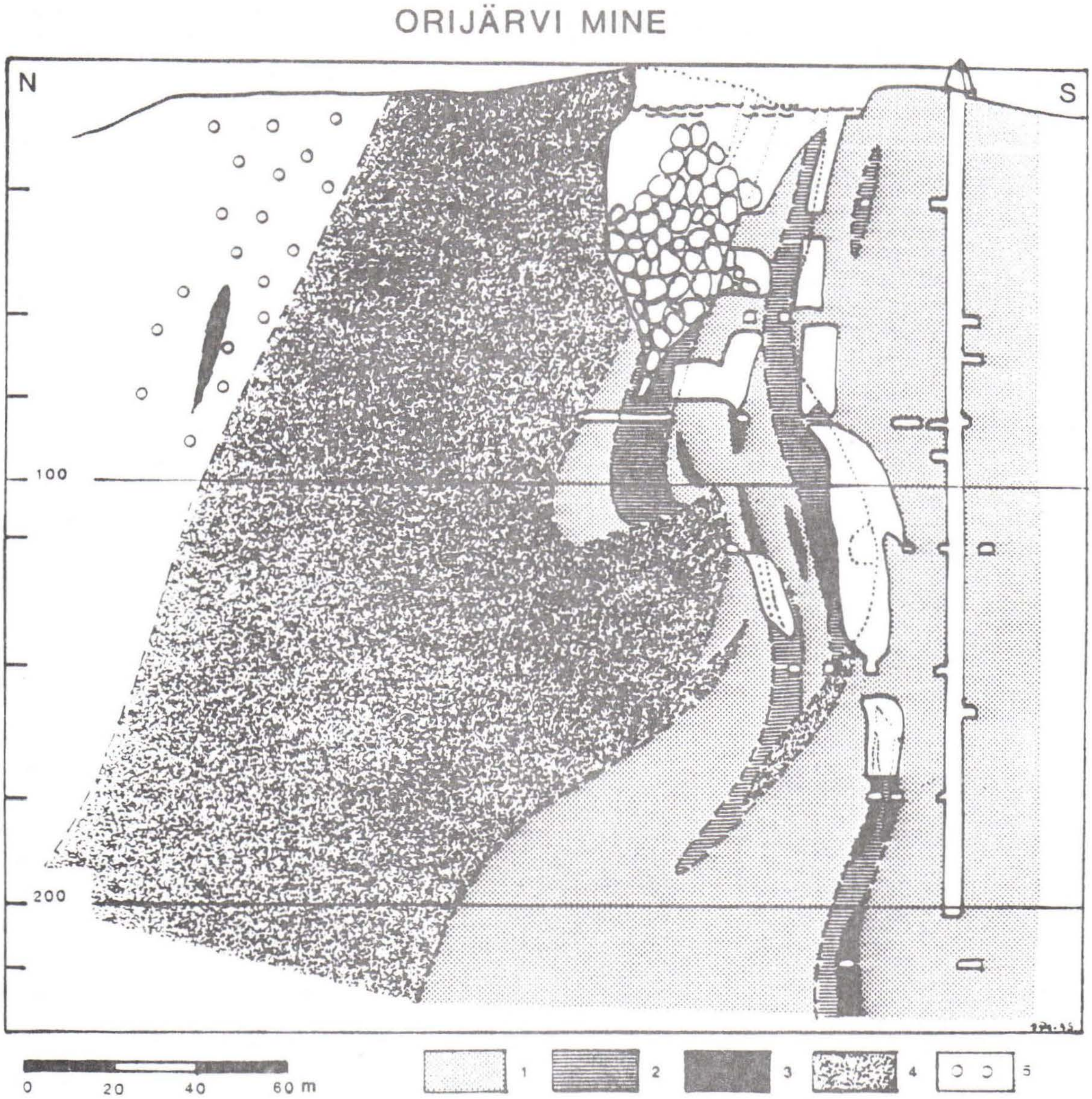


Fig. 21. Section no. 12 across the Orijärvi ore deposit. The site of the section see Fig. 3. The keys: 1. cordierite-anthophyllite rock, 2. skarn, 3. ore, 4. mafic dyke, 5. felsic cordierite-sericite gneiss; open is the open pit with block filling, stopes, drifts and the main shaft.

closed, were located. The total production of the Aijala mine was 0.8 million tonnes of ore grading 1.59% Cu, 0.7% Zn, 14.2% S, 0.7 g/t Au and 14 g/t Ag (Warma 1975). Besides copper and zinc, pyrite concentrate was also produced. Almost 1.5 million tonnes of different ores with an average grade of 3.5% Zn, 0.8% Pb, 13.3% S and 25 g/t Ag (Warma op.cit.) were extracted from the Metsämonttu mine (Fig. 22). These two mines are located in the same mineralized stratigraphic horizon close to the contact between the felsic and more mafic metavolcanites, but in the felsic metavolcanites. Here, too, the highest-grade ores were in skarn and dolomitic limestone.

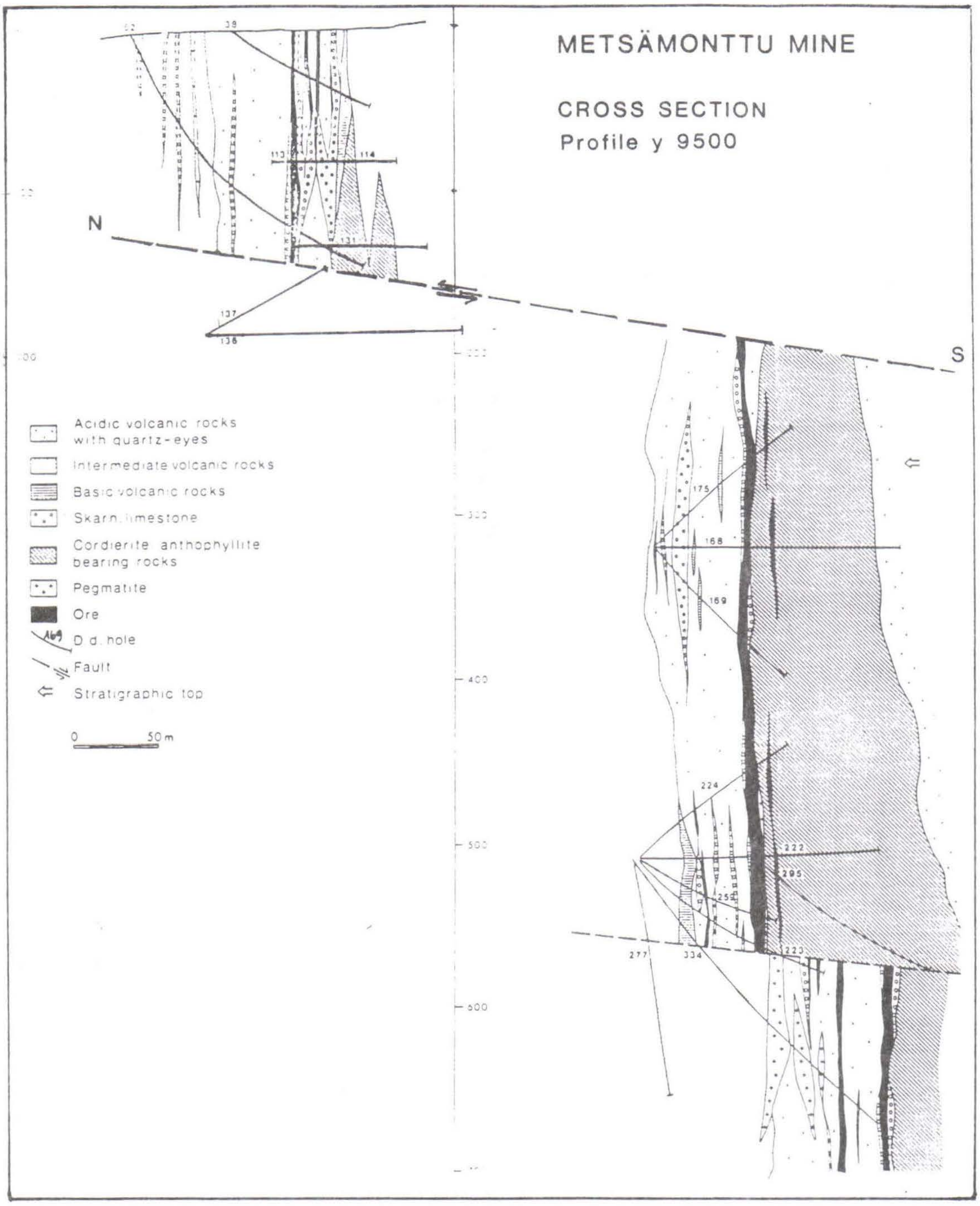


Fig. 22. Section, y = 9500, across the Metsämonttu ore deposit. Modified from Latvalahti (1979).

The finnish leptite zone contains not only sulphide deposits but also iron formations (von Knorring 1955; Sipilä 1981). Some of the magnetite ores (e.g. Malmberg mine) were mined in the last century, but the deposits are all rather small and uneconomical today.

Geology of the ore deposits

The mineralizations occur within felsic pyroclastics and in the limestone layers intercalated with them. The volcanism in the Orijärvi-Aijala field is considered to be related to the Orijärvi felsic batholith, which is composed mainly of quartz and granodioritic rocks. The majority of the leptitic supracrustal rocks are calc-alkalic metavolcanics (Table 1). The intermediate and mafic volcanics tend to be more tholeitic in composition (Table 2). There are the distinct hydrothermal alteration (Table 3) associated with the ore deposits has produced cordierite-anthophyllite rocks in the inner alteration zones and sericite, cordierite and/or andalusite

Table 1. Chemical compositions of felsic metavolcanics (Mäkelä, 1983).

	1	2	3	4	5	6
SiO_2	70.75	73.85	72.35	74.25	76.20	66.35
TiO_2	0.33	0.20	0.25	0.38	0.34	0.39
Al_2O_3	13.50	12.93	13.96	13.00	12.31	13.84
Fe_2O_3	3.18	3.31	3.04	2.57	0.64	5.86
MnO	0.03	0.04	0.03	0.03	0.02	0.09
MgO	0.94	1.61	1.19	1.14	0.14	2.20
CaO	3.57	3.65	2.85	1.95	2.80	2.54
Na_2O	4.72	2.14	3.08	3.35	3.63	4.92
K_2O	1.80	1.11	2.12	1.89	1.03	1.72
Total	98.1	98.84	98.89	98.56	97.11	97.91

1. Even-grained metavolcanite. Aijala (x = 6675.420 y = 463.810).
2. Acidic metavolcanite with phenocrysts. Aijala (x = 6675.496, y = 464.456).
3. Acidic metavolcanite with quartz eyes. Aijala (x = 6675.256, y = 456.568).
4. Acidic metavolcanite with quartz eyes. Aijala (x = 6675.532, y = 463.866).
5. Quartz-eyed fragment in quartz-eyed metavolcanites. Aijala (x = 6675.530, y = 463.808).
6. Hornblende and biotite bearing fragment in quartz-eyed metavolcanite. Aijala (x = 6675.684, y = 465.318).

1-6. Wet chemical analyses (Lukkarinen 1979).

Table 2. Chemical compositions of intermediate-mafic metavolcanics according to Mäkelä (1983).

	1	2	3	4	5	6	7	8	9
SiO_2	60.20	53.70	48.00	50.80	55.50	47.40	45.80	56.50	48.60
TiO_2	0.51	0.59	0.55	0.60	0.68	0.46	0.49	0.37	1.11
Al_2O_3	14.58	15.05	17.76	17.40	15.50	16.30	18.80	14.50	13.70
Fe_2O_3	7.98	9.59	10.54	-	-	-	-	-	-
FeO	-	-	-	10.60	9.20	12.60	12.60	7.55	10.40
MnO	0.13	0.16	0.20	0.19	0.18	0.25	0.19	0.12	0.14
MgO	3.84	5.26	6.51	3.98	2.86	6.10	6.06	2.44	9.15
CaO	7.77	7.69	11.49	10.90	8.69	8.79	8.24	13.60	7.51
Na_2O	1.79	3.37	2.11	3.32	3.41	2.06	1.57	0.25	3.34
K_2O	1.29	1.15	0.21	0.42	0.50	0.10	0.99	0.10	1.06
Total	98.09	98.56	97.37	98.21	96.52	94.06	94.74	95.43	95.01

1. Intermediate metavolcanite. Aijala (x = 6676.392, y = 465.140).
2. Intermediate tuff containing plagioclase and hornblende phenocrysts. Aijala (x = 6675.180, y = 461.420).
3. Basic metavolcanite. Orijärvi (x = 6676.292, y = 465.552).
4. Basic metavolcanite, pillow lava. Orijärvi (x = 6680.35, y = 470.74).
5. Basic metavolcanite, lava. Orijärvi (x = 6680.36, y = 470.75).
6. Basic metavolcanite, tuff. Orijärvi (x = 6681.27, y = 472.93).
7. Basic metavolcanite, cummingtonite bearing tuff. Orijärvi (x = 6681.25, y = 472.93).
8. Epidote skarn fragment in basic metavolcanite (x = 6681.26, y = 472.93).
9. Basic metavolcanite, pillow lava. Toija, appr. 2.5 km NW from Kisko (x = 6684.95, y = 469.02).

1-3. Wet chemical analyses (Lukkarinen 1979).

4-9. XRF analyses, Outokumpu Oy.

schists and gneisses, quartz rocks and skarns in the outer zones (Latvalahti, 1979). The chemistry and ore mineralogy of the different bodies, even in the same deposit, varies, (Fig. 23), copper tending to be richest in quartz-bearing rocks, and zinc and lead in skarns and limestones.

Table 3. Chemical compositions of unaltered and altered rocks (Latvalahti, 1979).

	Unaltered rocks		Alteration zones								
			Outer					Inner			
	Tuff with quartz and plagioclase phenocrysts n = 1 d = 2.68	Lime-stone n = 1 d = 2.71	Sericite-cordierite rocks n = 28 d = 2.70		Quartz rock n = 1 d = 2.67	Skarns and skarn-bearing rocks n = 15 d = 3.10		Cordierite mica gneisses n = 13 d = 2.71		Cordierite-anthophyllite rocks n = 11 d = 2.82	
			$\bar{x}_G$	SD		$\bar{x}_G$	SD	$\bar{x}_G$	SD	$\bar{x}_G$	SD
SiO_2	77.59	8.47	71.66	4.40	82.22	37.86	19.97	62.51	4.46	56.19	4.32
TiO_2	0.10	0.02	0.21	0.04	0.10	0.28	0.32	0.41	0.36	0.57	0.14
Al_2O_3	11.75	1.16	13.38	4.35	11.11	14.61	2.60	18.51	3.84	17.86	2.45
FeO^x	1.12	0.72	2.10	1.82	0.41	3.95	3.29	4.61	3.51	10.91	3.19
MnO	0.02	0.13	0.09	0.05	0.01	0.98	0.05	0.15	0.21	0.15	0.09
MgO	0.28	1.65	2.83	1.12	0.28	8.30	4.26	4.97	2.53	9.86	2.39
CaO	1.86	51.47	1.57	1.73	1.17	10.82	6.75	2.02	2.76	1.26	2.04
Na_2O	3.96	0.07	1.31	0.78	2.38	1.09	0.73	0.97	1.03	0.40	0.19
K_2O	1.65	0.32	2.02	1.26	0.59	0.92	0.58	1.76	0.91	1.55	0.69
P_2O_3	0.05	1.78	0.07	0.11	0.03	0.35	1.67	0.14	0.09	0.13	0.03
Total	98.38	65.79	95.24		98.30	79.30		96.05		98.88	

XRF analyses $\bar{x}$ = geometric mean, SD = standard deviation, FeO^x = total iron as FeO, d = density

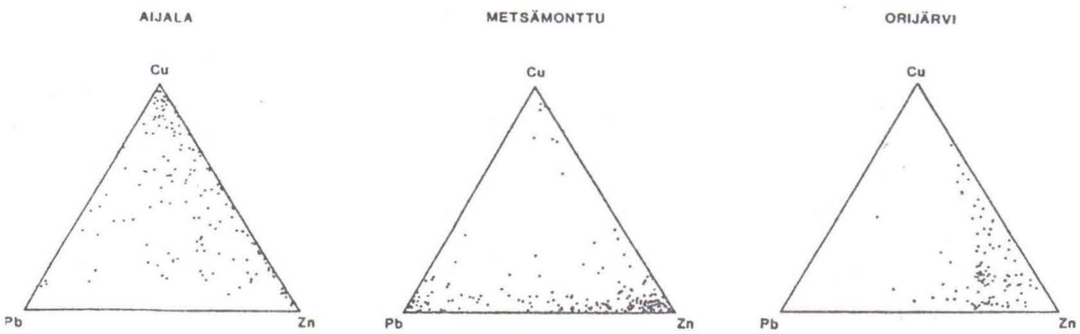


Fig. 23. Compositions of the Aijala, Metsämonttu and Orijärvi ores in Cu-Zn-Pb triangular diagrams. (The data is the same as Latvalahti 1979).

Structurally the ores in all three mines were of brecciated or stringer type although more massive vein ores also occurred. The contacts were usually sharp, and the ores were bound to certain layers. Economically the breccia ores were the most important. Mäkelä considers the ores stratabound and has classified the deposits as Precambrian volcanic-exhalative ores of Kuroko type (Latvalahti 1979; Mäkelä 1983).

Each deposit contained several small orebodies, because the deposits were deformed and remobilized by tectonics. The Orijärvi orebodies are cut by a subvolcanic mafic dyke (amphibolite) (Figs. 20 and 21). In addition, the postmetamorphic faults cut the deposits dramatically (Fig. 22).

Excursion stops in the Orijärvi-Aijala field

2-1. Mafic metavolcanics south of Hyypiänmäki, Kisko (x= 6680.35, y = 470.70). 1 km walk.
The target is a contact between intermediate and mafic metavolcanics, with agglomerate and pillow lava beds in the latter. There are several agglomerate beds with bombs and sharp-edged fragments up to 0.2 x 0.3 m^3 in size. Analyses 4 and 5 in Table 2 are from this site.

2-3. Metavolcanics at Metsämonttu (x = 6675.78, y = 463.80). 1 km walk. See Fig. 22.
Two exhausted mines, Metsämonttu and Aijala, are located in the area. These were operated by Outokumpu Oy in 1949-1974. Total production approached 2.3 million tonnes. The mines are in the same stratigraphic horizon, c. 1.5 km from each other. Metsämonttu was a Zn-Pb-Ag-Cu mine grading 3.5% Zn, 0.8% Pb, 25 ppm Ag and 0.3% Cu. Aijala was a Cu-S mine grading 1.6% Cu and 14.2% S.

Intermediate-mafic metavolcanics crop out in the vicinity of the Metsämonttu mine, displaying skarn-banded tuffite, lapilli tuff and agglomerate intercalations. Pronounced shear schistosity and associated vertical lineation are seen. Felsic pyroclastics with quartz eyes are exhibited. The large mass of cordierite-anthophyllite rocks within Metsämonttu mine is totally "blind" (Fig. 22), the rock type has not been found on the present ground surface.

2-4. Aijala, the sports field near the Aijala mine (x = 6676.06, y = 465.10). The folded micaceous metatuffite is located between the intermediate and the felsic volcanic beds, and above the copper ore bodies.

References

Eskola, P.,1914. On the petrology of the Orijärvi region in southwestern Finland. Bull. Comm. géol. Finlande 40, 279 p.

Eskola, P., 1915. Om sambandet mellan kemisk och mineralogisk sammansättning hos Orijärvitraktens metamorfa bergarter. Bull. Comm. géol. Finlande 44, 145 p. (in Swedish with English summary).

Eskola, P., 1963. The Precambrian of Finlandd. In Rankama, K. (Ed.) The Precambrian 1, 145-264. New York Interscience Publ.

Gavelin, S., Lundström, I. and Norström, S., 1976. Svecofennian stratigraphy on Utö, Stockholm archipelago. Sveriges Geol. Unders., ser c., 719. 44 p.

Knorring, O. von, 1955. A mineralogical and geochemical study of the metamorphic iron-ores of south-western Finland. Ph.D. thesis, University of Leeds. 163 p.

Latvalahti, Ulla, 1979. Cu-Zn-Pb ores in the Aijala-Orijärvi area, southwest Finland. Econ. Geol. 74, 1035-1059.

Lukkarinen, H., 1979. Aijalan ja Metsämontun liuskeista. (On the schists of Aijala and Metsämonttu). Unpubl. master's thesis. University of Turku. 89 p. (in Finnish).

Lundqvist, T., 1979. The Precambrian of Sweden. Sveriges Geol. Unders. Ser. C, 768. 87 p.

Mäkelä, Ulla, 1983. On the geology of the Aijala-Orijärvi area, southwest Finland. In Laajoki, K. and Paakkola, J. (Eds.) Exogenic processes and related metallogeny in the Svecokarelian geosynclinal complex. Guide to field trips for the IGCP projects 91 and 160 in eastern, central and southern Finland, August 17-26, 1983. Geol. Surv. Finland. Guide 11, 140-160.

Tuominen, H.V., 1957. The structure of an Archean are: Orijärvi, Finland. Bull. Comm. géol. Finlande 177. 32 p.

Tuominen H.V. and Mikkola, T., 1950. Metamorphic Mg-Fe enrichment in the Orijärvi region as related to folding. Bull. Comm. géol.Finlande 150, 67-92.

Schreurs, J., 1985. Prograde metamorphism of metapelites, garnet-biotite thermometry and prograde changes of biotite chemistry in high-grade rocks of West Uusimaa, southwest Finland. Lithos 18, 69-80.

Schreurs, J. and Westra, L., 1985. Cordierite-orthopyroxene rocks: the granulite facies equivalents of the Orijärvi cordierite-anthophyllite rocks in West Uusimaa, southwest Finland. Lithos 18, 215-228.

Simonen, A., 1980. The Precambrian in Finland. Geol. Surv. Finland, Bull. 304. 58 p.

Sipilä, P., 1981. Lounais-Suomen rautamalmeista. (On the iron ores in southwest Finland). Unpubl. master's thesis. University of Turku. 106 p. (in Finnish).

Turunen, E., 1957. Orijärven kaivos 1757-1957. Summary: Orijärvi mine in 1757-1957. Vuoriteollisuus-Bergshanteringen 15 (2), 13-24.

Warma, A., 1975. Outokumpu Oy:n Aijalan ja Metsämontun kaivosten vaiheita. Summary: On the Aijala and Metsämonttu mines of Outokumpu Oy. Vuoriteollisuus-Bergshanteringen 33 (2), 94-98.

THE ORIVESI AREA

Ilkka Laitakari
Geological Survey of Finland

The bedrock of the Orivesi area is part of the Svecofennian Tampere schist belt (Seitsaari 1951; Kähkönen and Laitakari 1983) cut by plutonic rocks 1880 Ma in age. The map in Fig. 24 is reproduced from Laitakari (in print). A low altitude aeromagnetic grey-tone map (Fig. 25) is included for correlation.

The southern schist belt consists of mica schists, black schists, greywackes and conglomerates with overlying and interbedded metavolcanic rocks mostly of pyroclastic origin. There are also some acid hypabyssal rocks at the northern border of the belt. Primary structures are well preserved in both metasediments and metavolcanic rocks. The rock types are similar in the northern schist belt but the folding is more complex, and granite veins and dykes are more abundant.

The plutonic rocks vary from gabbro to granite in composition, and there are microcline porphyroblasts in many of the granites and granodiorites. In the northern part of the map sheet area, many of the microcline grains in granites are rounded and have plagioclase mantles as do wiborgite-type rapakivi granites.

The basement of the deposition is not known for sure. Only the age, c. 2400 Ma, of the detrital zircon from the metagreywacke of the Tampere belt indicates the age group of the source area. Many other observations, however, show that the evolution of Svecofennides in general was very rapid and much, maybe most, of the material of Svecofennian sediments derived from the orogenic belt itself.

The folding is isoclinal with a subhorizontal fold axis, and the metamorphism occurred under low-pressure amphibolite facies conditions.

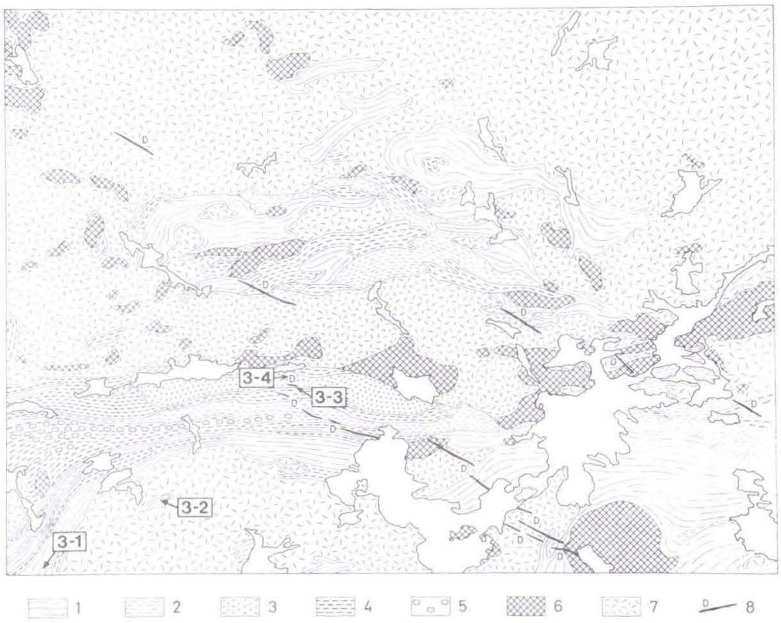


Fig. 24. Main features of the bedrock of map sheet 2142, Orivesi. 1. mica schist and mica gneiss, 2. acid metavolcanic rocks, 3. acid porphyry, 4. basic metavolcanic rock, 5. conglomerate, 6. gabbro and diorite, 7. granitoid, 8. olivine diabase dyke. Scale 1 : 400 000.

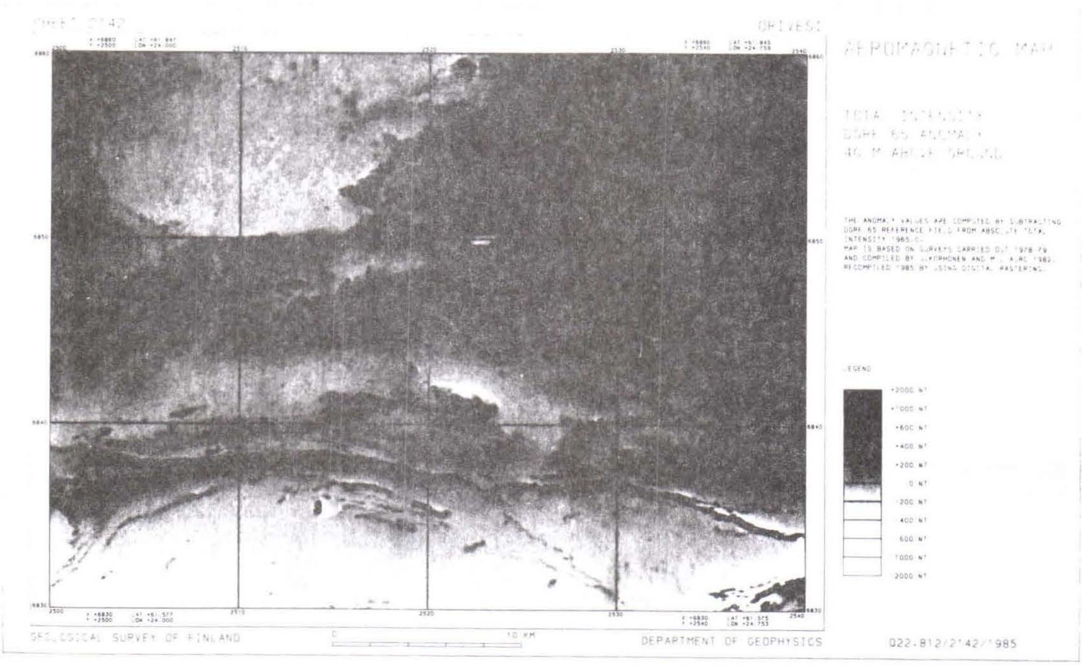


Fig. 25. Aeromagnetic DGRF-65 anomalies of total intensity 40 m above the ground within the map sheet 2142 Orivesi. Scale 1 : 400 000. (Korhonen and Airo 1982).

Two sets of mafic dykes cut all the other rocks types of the area. The majority of the late orogenic porphyrite dykes with uralite and/or plagioclase phenochrysts are less than 2 m wide and trend c. W-E and N-S.

The postmetamorphic olivine diabase dykes belong to the extensive Häme dyke set (Laitakari 1969) some 1650 Ma in age. In the Orivesi area, they are seldom more than 50 m wide and usually trend N 60°W. Most of these dykes have plagioclase phenocrysts and fragments up to 30 cm long. Quartzite xenoliths, which are quite common in the diabases, indicate the presence of quartzite at greater depths, although it is rare at the present erosion level.

Excursion stops

3-2. Road cutting on highway 9, boundary Orivesi/Kangasala. Greywacke with interbeds of quartzite conglomerate (map sheet 2142 01, coordinates x = 6833.92, y = 507.98).

The outcrop is situated in a large inclusion of supracrustal rocks in porphyritic granodiorite. The main rock type of the cutting is meta-greywacke with conglomerate interbeds. The thickness of the strata in the greywacke varies from some millimetres to several metres. In the centre of the outcrop, graded bedding is very clear, the grain size varying from pelitic to coarse psammitic. Many interbeds of conglomerate can be seen in the eastern part of the outcrop. The pebbles, some centimetres in diametre, are well rounded and consist mostly of quartzite. Primary structures have rarely been observed in the quartzite, but the presence of rounded zircon grains suggests sedimentary origin. Some granodiorite is visible at the western end of the cutting.

3-3. Oritupa, Orivesi. Glass in narrow apophyses of diabase dykes (map sheet 2142 05, coordinates x = 6840.10, y = 514.90).

Many dykes of olivine diabase are known not far from the excursion site. The small apophyses seen in the outcrop consist of black, basalt-like rock. The narrow tails, less than 3 cm wide, of some apophyses also contain undevitrified glass (Lindqvist & Laitakari 1980). Precambrian glass is very rare. The presence of glass in the rock shows that the present erosion level is very near that of 1650 Ma ago, since devitrification of glass takes place very rapidly, even at 300°C. Thus the temperature can never have exceeded 300° during the last 1650 Ma.

3-4. Oritupa, Orivesi. Subvolcanic breccia (map sheet 2142 05, coordinates x = 6840.53, y = 514.63).

At the northern border of the Orivesi schist belt there is a zone of acid hypabyssal rock in which many outcrops exhibit fragments of different types of metavolcanic rocks. The excursion outcrop consits of a subvolcanic breccia that displays almost all the metavolcanic rocks types of the Orivesi belt. A mafic porphyrite dyke cuts the subvolcanic breccia.

References

Kähkönen, Y. and Laitakari, I., 1983. Metavolcanics and metasediments of the Proterozoic Tampere schist belt. Geol. Surv. Finland, Guide 11, 110-134.

Korhonen, J. and Airo, M-L., 1982. Aeromagnetic map 1 : 100 000, Map sheet 2142, Orivesi. National open file report of Geological Survey of Finland, report number Q22.812/2142/1982/2.

Laitakari, I., 1969. On the set of olivine diabase dikes in Häme, Finland. Bull. Comm. géol. Finlande 241, 65 p.

Laitakari, I., (in print). Kallioperäkartta, Pre-quaternary rocks, sheet 2142, Orivesi. Geological map of Finland 1 : 100 000.

Lindqvist, K. and Laitakari, I., 1980. Glass and amygdules in Precambrian diabases from southern Finland. Bull. Geol. Soc. Finland 52(2), 221-229.

Seitsaari, J., 1951. The schist belt northeast of Tampere in Finland. Bull. Comm. géol. Finlande 153. 120 p.

TUNGSTEN MINERALIZATION AT KANGASALA

Boris Lindmark
Geological Survey of Finland

The scheelite mineralization at Kangasala is located in the Tampere schist belt, 15 km northeast of the town of Tampere. Scheelite occurs principally in quartz-rich veins that constitute a vein swarm cutting the greywacke mica gneiss at an angle of c. 25^{o}. The vein strike mainly NS and dip 70^{o}W. The host rock strikes 30^{o}, on average, and dips towards 300^{o} at an angle of c. 80^{o}.

As a rule the quartz veins are narrow, the average width being 5 cm. The scheelite occurs heterogeneously along the margins of the veins as coarse-grained crystals. In places it is encountered in the schist, in which case it is usually fine in grain size. The quartz veins contain arsenopyrite, pyrrhotite and some chalcopyrite and sphalerite. Significant values of precious metals have not been recorded. The veins with scheelite occur in an area about 1.5 km long and 100 m or more side. The portion that is of interest is 100 m long and about 15 m wide. On account of the irregular mode of occurrence of the veins, the average grade of the mineralization is low: according to the present study about 0.20% W.

The mineralization, which is within a schist portion located between two granitoidic batholiths (Fig. 26), is probably associated genetically with the emplacement of the granitoids; a detailed study of the genesis is still lacking, however. The bulk of the mineralization is covered by a bog and not exposed.

Excursion stop

3-1. Kangasala. Quartz vein hosted tungsten mineralization in metagreywacke (map sheet 2142 01, x = 6830.30, y = 501.90).

The excursion target is the exposed area in the east of the mineralization where the quartz veins cut the metagreywacke as described above. The

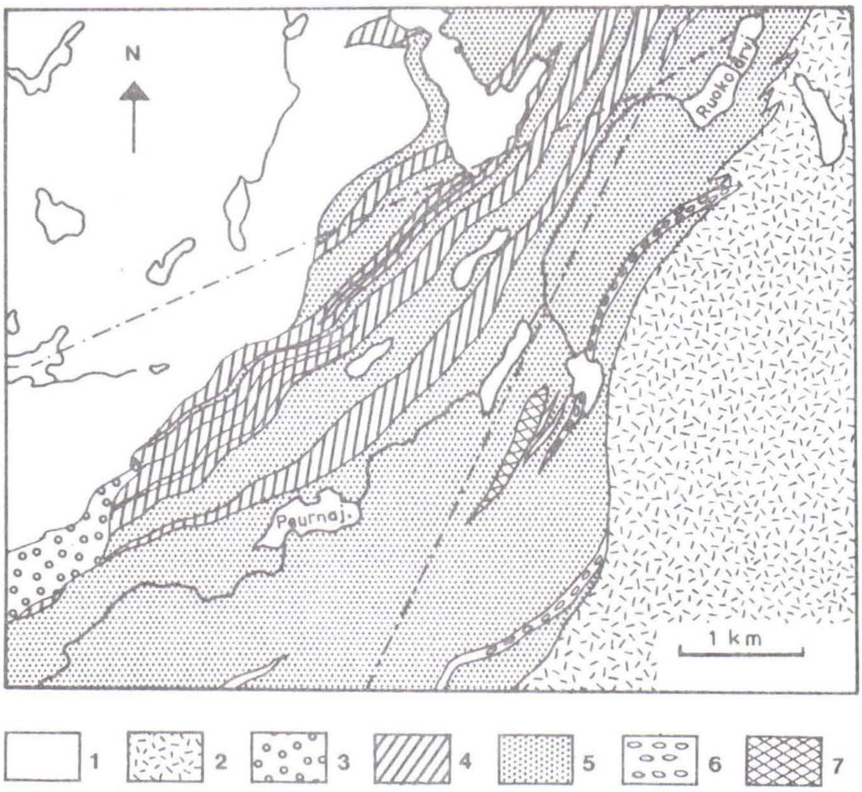


Fig. 26. The tungsten mineralization of Kangasala on the geological map of the schist belt northeast of Tampere (Seitsaari 1951). Explanation: 1. Quartz diorite, 2. Porphyritic granodiorite, 3. Gabbro, 4. Felsic to intermediary volcanic rocks, 5. Mica schist and metagraywacke, 6. Conglomerate, 7. Tungsten mineralization.

veins show some scheelite, tourmaline, arsenopyrite and pyrrhotite. The till at the site is very rich in scheelite.

References

Seitsaari, J., 1951. The schist belt northeast of Tampere in Finland. Bull. Comm. géol. Finlande 153. 120 p.

THE ENONKOSKI NICKEL-COPPER MINE

Leo Grundström
Outokumpu Oy

Geological setting

The Enonkoski Ni-Cu mine at Laukunkangas is located in a Svecokarelian synorogenic plutonic complex in southeastern Finland, about 20 km north of the town of Savonlinna. The ore mineralization was discovered in 1969, but on account of the low grade, it was kept in reserve. The latest phase of investigation, which started in 1979, suggested the existence of an ore deposit in the NE portion of the intrusion (Grundström 1985).

Supracrustal gneisses and various plutonic rocks form the geological setting of the deposit in the Joutsenmäki-Laukunkangas region (Fig. 27). The supracrustal rocks can be subdivided into a volcanogenic section, in which diopside amphibolites predominate, and sedimentogenic schists, composed mainly of metagreywackes and calcareous metasediments. The rocks in the schist area are migmatized to varying degrees. The plutonites occur as major silicic or intermediate intrusions or as minor mafic-ultramafic bodies; the largest is the Joutsenmäki intrusion (Parkkinen 1975). Laukunkangas is one of the minor bodies.

The Laukunkangas intrusion is embedded in a metasedimentary mica gneiss and veined gneiss environment. A narrow but distinct zone of migmatitic veined gneiss occurs between the Varparanta trondhjemite dome and the Laukunkangas intrusion. The gneiss contains calc-silicate gneiss fragments and cummingtonite gneiss, amphibolite and pyroxene quartz diorite close to the conformable contact of the intrusion. The Laukunkangas intrusion does not seem to be associated with any sizeable pluton but occurs as a separate body in an intensely migmatized metasediment suite.

The sulphides have accumulated in the ultramafic rocks at the eastern end of the Laukunkangas intrusion (Figs. 28 and 29). Scattered, lower-grade

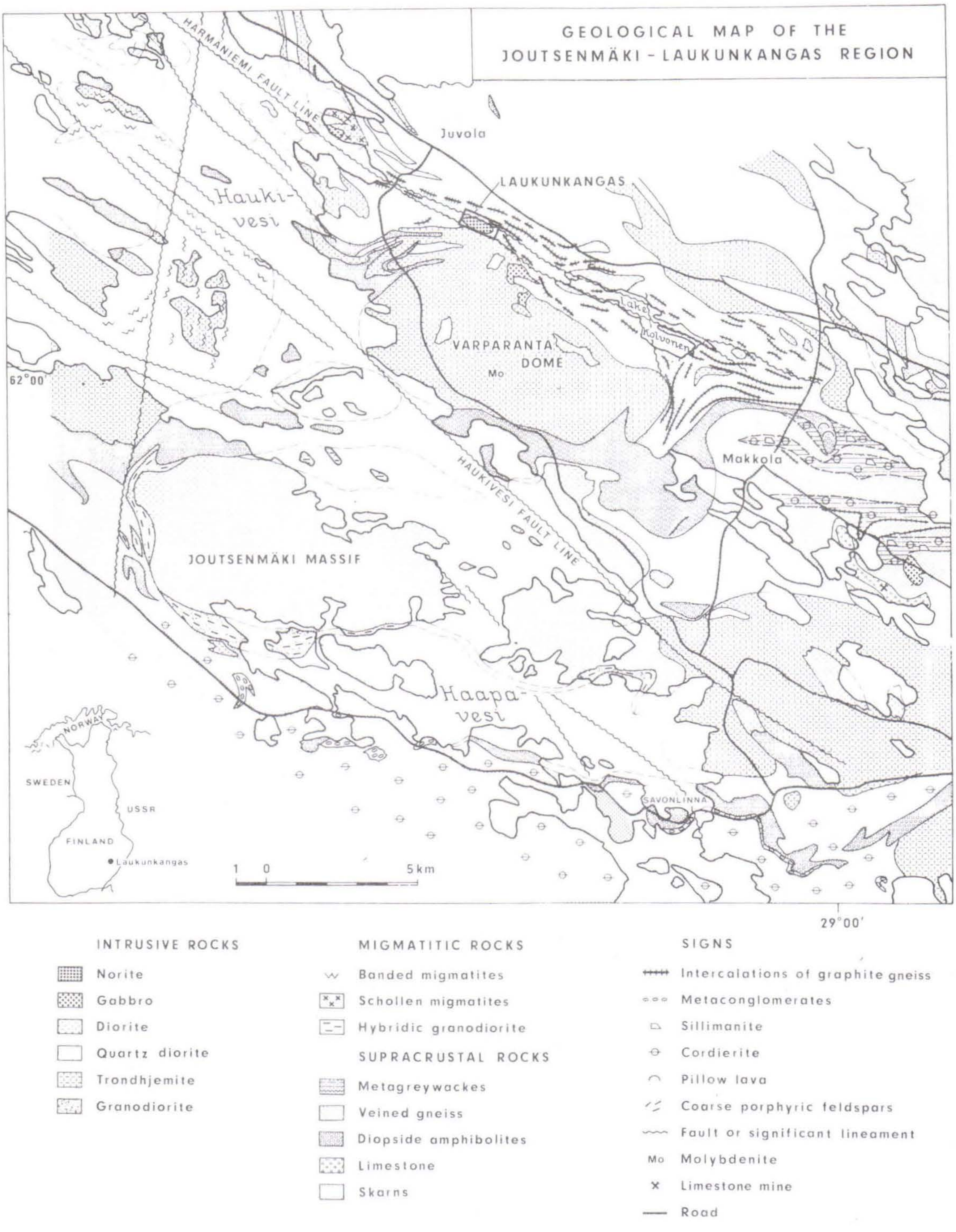


Fig. 27. Simplified geological map of the Joutsenmäki-Laukunkangas region, partly after Gaál and Rauhamäki (1971) from Grundström (1985).

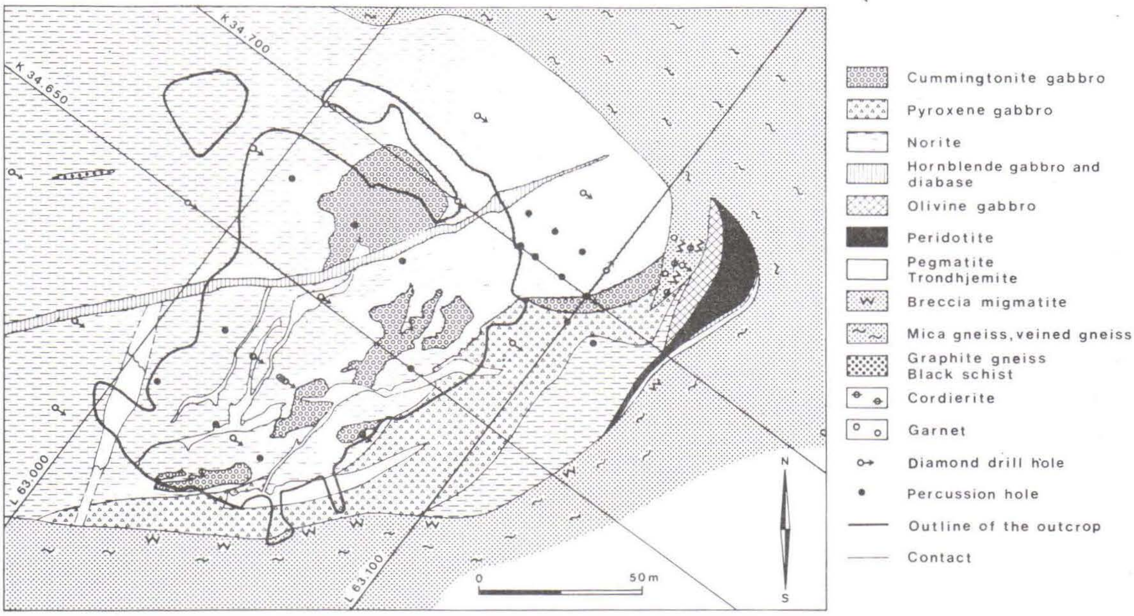


Fig. 28. Geological map of the Laukunkangas gabbro body.

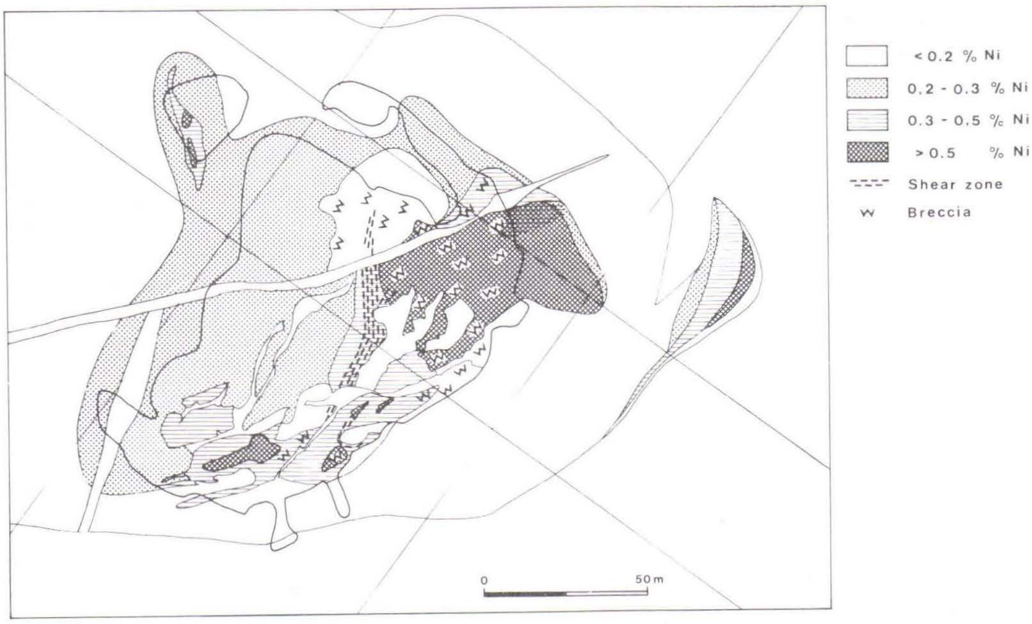


Fig. 29. Nickel contents of the Laukunkangas gabbro body.

occurrences are encountered elsewhere in the intrusion and along its contacts. In the ore reserve assessment, the deposit is subdivided into four independent orebodies:

1. The main orebody consists of the exposed norite portion and the peridotite-predominant high-grade ore northeast and north of it together with the associated massive ores. This orebody extends about 350 m below the surface.

2. The slope orebody is a lower-grade occurrence of sulphides at the northern contact mainly in norite. This potential orebody, which lies between the wall-rock tongue penetrating the intrusion and the wall-rock gneiss proper, is known to extend downwards for 150 m.

3. The deep orebody contains the sulphide occurrences at the southern contact and the scattered, weak lens-shaped dissemination in the middle of the intrusion. They have been traced down to a depth of 800 m.

4. The Leo orebody is located in mica gneiss, trondhjemite and black schist north of the intrusion. This orebody joins the massive ores in the hanging wall of the high-grade ore.

The latest ore reserve estimations, on which the decision to open the mine was based, showed c. 3.8 Mt of ore grading 1.2% Ni. This includes the high-grade main orebody and the Leo orebody above the +250 level. The ore assayed 0.3% Cu, 0.06% Co and 9.2% S. The ore is characterized by the following parameters: Ni/Co = 21.58; Ni/Cu = 3.84; Cu/Co = 5.6.

The deposit

The Laukunkangas intrusion is a pipe-shaped body with an elliptical surface plan. It extends to a depth of at least 800 m; its largest horizontal dimension is about 1 km and its width in the middle of the intrusive is some 300 m. The intrusion consists of a differentiation series of an olivine tholeiitic suite ranging from peridotites to quartz diorites. Emplacement probably took place in two or three stages. The ore mineralization is mainly associated with the peridotites, olivine gabbros and norites.

The zircon age of the sulphide-bearing norite at Laukunkangas, 1880+3 Ma, is typical of Svecokarelian plutonic rocks.

Mining

The main mining method is sublevel stoping. The sublevel interval at the Leo orebody is 15 m but in other parts of the mine it varies from 15 m to 30 m. Cut-and-fill is also used to lesser extent. All drifting and production drilling are done using electro-hydraulic equipment. Some of the stopes are backfilled with waste or cemented rock.

Most of ore is extracted from the sublevel stopes at the +250 m level and is tipped through grizzlies into the ore passes with an electric LHD.

The ore is fed from the ore passes by wagon feeders to the underground jaw crusher (1400 mm x 1100 mm) at the +380 m level. The crushed ore is conveyed to a 1000 cu.m. storage bin next to the shaft, where the ore is automatically hoisted with an 8 t skip to a 2000 cu.m. storage bin.

Excursion stops

4-1. The Laukunkangas exposure.
Overburden has been removed from an area covering about one hectare, and the bedrock has been mapped in detail. The geological map in Fig. 28. shows clearly the members of the differentiation series exposed in the outcrop: norite, cummingtonite gabbro and the pyroxenite gabbro of the marginal zone. Numerous pegmatite and diabase dykes can also be examined and their cutting relations observed. A well-preserved and sharp contact with the country rock gneisses is exposed at the SE margin. The distribution of nickel in the exposure is illustrated in Fig. 29. Intense weathering has attacked the sulphide-rich portions of the exposure during the 15 years that have elapsed since the overburden was removed in 1970.

4-2. Underground visit.
The excursion target is located in an exploration drift at the +175 level (Fig. 30). The contact zone between the high-grade main ore and the host

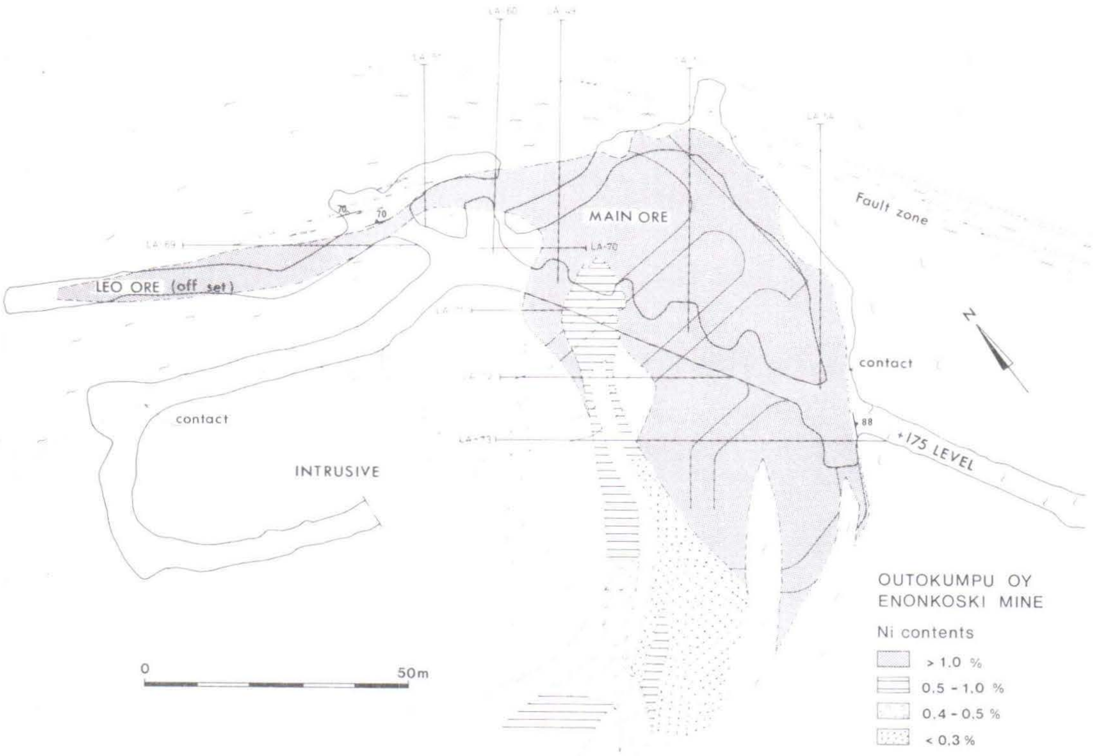


Fig. 30. Horizontal cross-section of the orebodies ofthe Enonkoski mine, +175 level.

rock will be examined. From the contact towards the ore there is first a zone, a few metres wide, in which the ore has invaded the host rock as bands and veins. This is followed by a zone of massive ore with breccia-like fragments. The contact with the disseminated peridotitic ore is clear and sharp. Disseminated ore in norite, one of the main ore types, is also visible. At the northern margin of the complex the Leo orebody of offset type will be examined. This orebody is located in the contact zone and has intruded entirely in a mica gneiss - black schist environment.

4-3. Schollenmigmatites. Juvola, 5 km NW of the Enonkoski mine.
The Juvola area is located some 5 km NW of the Laukunkangas intrusion. Various migmatites with veined gneiss, schlieren and nebulite structures predominate in the area. The plutonic rocks comprise pyroxene-hornblende gabbros, hornblende gabbros and quartz diorites.

The veined gneisses with schollen structures, and the schlieren and nebulite migmatites in the Juvola area are typical of the whole Kotalahti nickel-copper ore zone. They are also encountered in the Pori-Kylmäkoski nickel belt.

The veined gneiss is biotite-plagioclase gneiss with trondhjemite veins. The veins account for about 30-70% of the rock, decreasing eastwards. The schlieren and nebulite migmatites are mica gneisses that have been entirely or almost entirely recrystallized. The former gneissic texture has completely dissappeared and the rock has crystallized into a medium-grained quartz-plagioclase-biotite rock. The sediments varied much in composition, as demonstrated by the abundant fragments of skarn, amphibolite-garnet-mica gneiss, graphite gneiss, etc. Recrystallization took place under the conditions of upper amphibolite facies.

The actual schollen migmatite zones are located where the schlieren or nebulite migmatite grades into veined gneiss. In places the recrystallized neosome contains not only supracrustal fragments but also abundant fragments of mafic and ultramafic plutonic rocks and dykes.

In some places the older migmatite is brecciated by a younger granite, giving rise to schollen structures. The schollen migmatites occur in zones that were more active tectonically and magmatically than the environment. Outside these zones, the formation of the schollen structures was controlled, under the prevailing deformation conditions, by the compositional variation in the metasediment. Some of the layers have been mobilized; some have preserved their former texture and been broken up into pieces in the course of deformation.

The U-Pb age of the neosome in a schlieren structure from the schollen migmatite at Juvola is 2312+15 Ma (Vanhala, 1985) corresponding to the ages of detrital zircons from metagreywackes measured from elsewhere in Finland.

References

Gaál, G. and Rauhamäki, E-, 1971. Petrological and structural analysis of the Haukivesi area between Varkaus and Savonlinna, Finland. Bull. Geol. Soc. Finland 43, 265-337.

Grundström, L., 1985. The Laukunkangas nickel-copper deposit. Geol. Surv., Finland, Bull. 333, 240-256.

Parkkinen, J., 1975. Deformation analyses of a Precambrian mafic intrusive: Haukivesi area, Finland. Geol. Surv. Finland, Bull. 278, 1-61.

Vanhala, H., 1985. Juvolan schollenmigmatiitit. M.Sc. Thesis. University of Helsinki, Department of Geology. 102 p. (in Finnish).

VTT OFFSETPAINO, ESPOO 1986
ISBN 951–690–226–X