SVERIGES GEOLOGISKA UNDERSÖKNING

SER. Ca AVHANDLINGAR OCH UPPSATSER I A4 NR 63

G. GAÁL (Ed.)

PROTEROZOIC MINERAL DEPOSITS IN CENTRAL FINLAND

7th IAGOD SYMPOSIUM
AND NORDKALOTT PROJECT MEETING

EXCURSION GUIDE NO 5

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With contributions by T. Alapieti, M. Ekberg, G. Gaál, L. Grundström, J. Kujanpää, J. Lahtinen, J. Parkkinen, V-J. Penttilä and V. Perttunen

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AUTHORS

G. Gaál
Geological Survey of Finland
SF-02150 Espoo 15
Finland

T. Alapieti
Department of Geology
University of Oulu
Linnanmaa
SF-90570 Oulu
Finland

M. Ekberg
Outokumpu Oy
Pyhäsalmi Mine
SF-86900 Pyhäkumpu
Finland

L. Grundström
Outokumpu Oy
Enonkoski Mine
SF-58160 Karvila
Finland

J. Kujanpää
Outokumpu Oy
Kemi Mine
PL 8
SF-94101 Kemi
Finland

J. Lahtinen
Lapin Malmi Oy
Kairatie 56
SF-96100 Rovaniemi
Finland

J. Parkkinen
Outokumpu Oy
SF-83500 Outokumpu
Finland

V-J. Penttilä
Outokumpu Oy
Pyhäsalmi Mine
SF-86900 Pyhäkumpu
Finland

V. Perttunen
Geological Survey of Finland
PO Box 77
SF-96101 Rovaniemi 10
Finland

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Falu copper mine has been continuously mined for more than 900 years. Copper plate engraving from 1687 in Dahlberg's *Svecia Antiqua et Hodierna*.

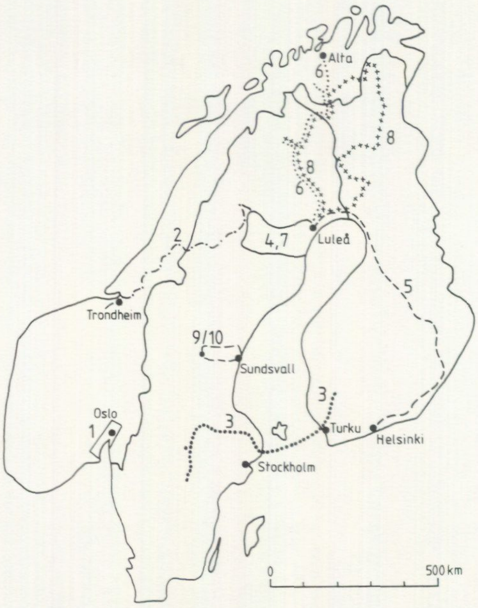
FOREWORD

Mining has ancient traditions in Scandinavia and Finland. In Bergslagen, Sweden, numerous mines produced Cu, Fe and Ag already during the medieval period. Some of them, e.g. Falun and Dannemora, are still active and are thus among the oldest operating mines in the world. Minerals like scheelite, gahnite and långbanite were first recognized in this region and the word skarn (originally having a pejorative connotation in Swedish meaning crap and whore) was used as a name for a certain mineral association for the first time by the old miners in Bergslagen. The most famous mining districts in Norway are Kongsberg, where silver was produced 1623–1957, and Røros, where copper was mined from 1644 until recently. The first mine in Finland was the Ojamo iron ore deposit, which was opened in 1540.

In addition to these ancient workings, ore bodies in several new mining districts have been exploited during the last century. Some of the most important of these occur in northern Sweden such as the Kiruna iron ores, the sulphide ores in the Skellefte district, the Laisvall Pb-mine and the Aitik Cu-Au mine. The sulphide ores in the Outokumpu district and in the Vihanti-Pyhäsalmi area are the most well-known Finnish deposits discovered during this century. In Norway, numerous deposits of pyrite and base metals were discovered round the turn of the century in the Sulitjelma and Grong districts and have been of major importance for the Norwegian mining industry. The discovery of extensive Mo-mineralization in the Oslo area, Norway and Pt-mineralization in the Kemi area, Finland have not led to any significant mining but have revealed new aspects of the metallogeny in the Nordic countries.

As a result of this long tradition in mining, the question of how ores are formed has been debated longer than any other geological problem in Scandinavia and Finland. It is therefore of special interest for the Nordic countries that the International Association on the Genesis of Ore Deposits (IAGOD) this year will arrange its 7th symposium in Scandinavia. The symposium, which is held in Luleå, Sweden, is arranged by the Geological Surveys of Sweden, Finland and Norway and the Luleå University of Technology. As an important part of the symposium programme, nine pre- and post-symposium excursions covering most of the important mining districts in Norway, Sweden and Finland are arranged (see overleaf). For these excursions, guide books have been written and are now available amongst the publications of the Geological Survey of Sweden (SGU Ca 59–67). The Swedish part of excursion no 6 was prepared in 1980 and was published by the Geological Survey of Finland. To all who have been involved in planning and organizing the excursions as well as writing the guide books I would like to express my sincere thanks.

Krister Sundblad, Geological Survey of Sweden
coordinator of the IAGOD-excursions 1986



1. Metallogeny associated with the Oslo Paleorift
Guide book: SGU Ca 59.
Excursion leader: S. Olerud.
Topic: Porphyry molybdenum mineralizations (Nordli, Hurdal and Bordvika, Drammen). Native silver-bearing veins at Kongsberg. Mineralizations associated with the Drammen granite; contact metasomatic Zn-Pb deposits (Konnerudkollen), intramagmatic Mo deposits.

2. Stratabound sulphide mineralizations in the central Scandinavian Caledonides
Guide book: SGU Ca 60.
Excursion leaders: M.B. Stephens and A. Reinsbakken.
Topic: Early Palaeozoic, massive Cu-Zn sulphide mineralizations in both volcanic (Gjersvik, Joma, Løkken and Stekenjokk) and sedimentary (Ankarvattnet) environments. The Laisvall sandstone-hosted, disseminated Pb-Zn deposit.

3. Mineral deposits of southwestern Finland and the Bergslagen province, Sweden
Guide book: SGU Ca 61.
Excursion leaders: H. Papunen and I. Lundström.
Topic: Proterozoic Zn-Cu-Pb deposits in volcanosedimentary environments including the mined-out Orijärvi and Aijala deposits in Finland, and the Garpenberg and Åmmeberg deposits in Sweden; the iron ore deposit of Dannemora in Sweden. Deposits associated with intrusive rocks include the Vammala Ni-Cu mine in Finland and the Wigström W deposit in Sweden.

4. Massive sulphide deposits in the Skellefte district
Guide book: SGU Ca 62.
Excursion leader: D. Rickard.
Topic: Proterozoic Cu-Zn-(Pb-As-Au) mineralizations in volcanosedimentary environments, including the Boliden, Långsele, Näsliden and Kristineberg deposits.

5. Proterozoic mineral deposits in central Finland
Guide book: SGU Ca 63.
Excursion leader: G. Gaál.
Topic: Early Proterozoic mineralizations including the Kemi Cr mine, PGE mineralization in the Penikat layered intrusion, Pyhäsalmi Cu-Zn deposit, Outukumpu Cu-Co-Zn mine and the Enonkoski Ni-Cu deposit.

6. Precambrian mineral deposits in northernmost Scandinavia
Guide books: SGU Ca 64 (Norwegian part)
Geol. Surv. Finland (1980), Guide 078 A+C, part 1 (Swedish part)
Excursion leaders: J.S. Sandstad and H. Lindroos.
Topic: Precambrian copper and iron ore deposits including visits to two of the largest mines in northern Europe: Kiirunavaara underground mine (Fe) and Aitik open pit operation (Cu, Au). In addition, the Raipas, Repparfjord, Bidjovagge and Viscaria Cu deposits and Au prospects in the Gällivare area will be shown.

7. Proterozoic mineralizations associated with granitoids
Guide book: SGU Ca 65.
Excursion leader: B. Öhlander.
Topic: Mineralizations associated with Proterozoic granitoid intrusions including the Pleutajokk, Rävaberget and Björklund U deposits, the Allebouda and Kåtaberget Mo deposits, the Storuman W mineralization and Tallberget Cu-Mo deposit.

8. Archaean and Proterozoic geology in northern Finland, Norway and Sweden
Guide book: SGU Ca 66
Excursion leaders: T. Sjöstrand, M. Often and V. Perttunen.
Topic: Archaean and Proterozoic geological environments in the ore-bearing Nordkalott area, including greenstone belts and granulites.

9/10. Enåsen Au deposit and Alnö alkaline complex
Guide book: SGU Ca 67.
Excursion leaders: T. Lundqvist, S. Sundberg and P. Kresten.
Topic: Geology at and around the Proterozoic Enåsen Au deposit and the Alnö alkaline complex.

IAGOD-excursions 1986

PROTEROZOIC MINERAL DEPOSITS IN CENTRAL FINLAND

CONTENTS

BASE METAL, CHROMITE AND PGE DEPOSITS OF CENTRAL FINLAND: METALLOGENY OF AN EARLY PROTEROZOIC CONTINENTAL MARGIN

G. Gaál

EARLY PROTEROZOIC METALLOGENY RELATED TO MAJOR TECTONIC FEATURES OF THE BALTIC SHIELD

The Baltic Shield exhibits geochronological zonation with younging ages from NE to SW. Conclusive evidence has been given for an age of 3.1 Ga with a possible additional 0.4 Ga crustal residence time for the oldest rocks in the NE part of the shield, while the youngest Precambrian granites in the southwestern part have been dated at 0.9 Ga, followed by Palaeozoic reworking of the western margin during the Caledonian orogeny (0.6–0.4 Ga). The Precambrian crustal evolution took place in six successive orogenies, the Saamian (≥3.0 Ga), Lopian (2.9–2.6 Ga), Svecofennian (2.0–1.75 Ga), Gothian (1.75–1.55 Ga), Hallandian (1.5–1.4 Ga) and Sveconorwegian orogenies (1.25–0.9 Ga), forming the three principal domains of the Baltic Shield: the Archaean Domain in the northeast, the Svecokarelian Domain in the centre and the Southwest Scandinavian Domain in the west and southwest (Gorbatschev and Gaál 1986). The major crustal forming event of the Baltic Shield is represented by the Svecofennian orogeny with accreted Early Proterozoic crust as a result of Andean type plate tectonic processes (Hietanen 1975).

The economically most important metallogenic provinces were generated in Early Proterozoic times either during the cratonic Karelian stage after consolidation of the Archaean

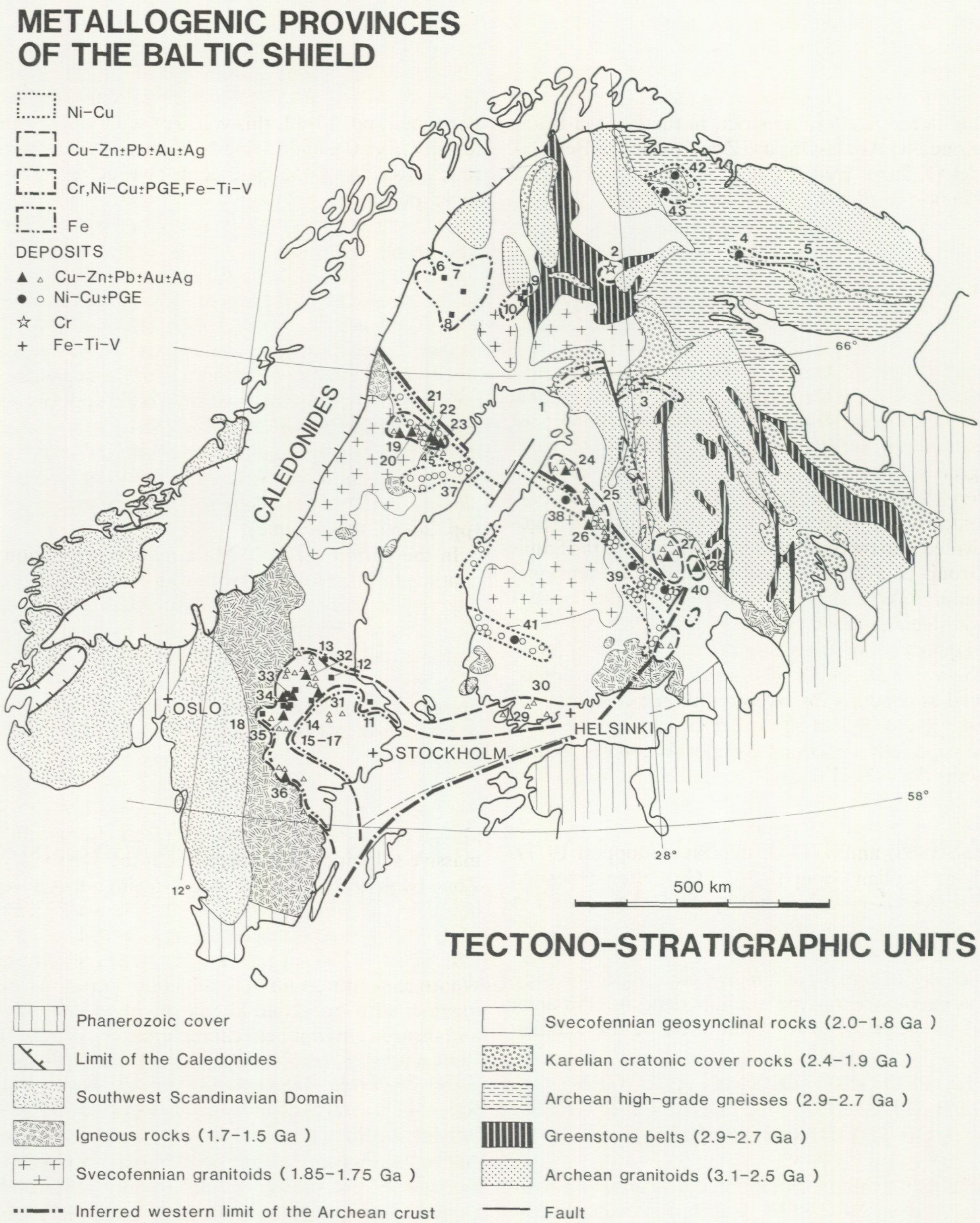


Fig. 1. Early Proterozoic metallogenic provinces and major tectonic subdivisions of the Baltic Shield. Explanations: *Cr deposits:* 1. Kemi, 2. Koitelainen; *Fe-V-Ti deposits:* 3. Mustavaara; *Ni-Cu deposits* in layered igneous complexes: 4. Monchegorsk, 5. Imandra-Varzuga; *Fe-deposits:* 6. Kiruna, 7. Svappavaara, 8. Malmberget, 9. Hannukainen, 10. Rautuvaara, 11. Dannemora, 12. Vingesbacke, 13. Vintjärn, 14. Norberg, 15. Grängesberg, 16. Blötberget, 17. Håksberg, 18. Persberg-Nordmark; *Zn–Cu±Pb±Ag±Au deposits:* 19. Kristineberg, 20. Näsliden, 21. Udden, 22. Renström, 23. Långdal, 24. Vihanti, 25. Pyhäsalmi, 26. Kangasjärvi, 27. Outokumpu, 28. Hammaslahti, 29. Aijala, 30. Orijärvi, 31. Garpenberg, 32. Falun, 33. Gränsgruvan, 34. Saxberget, 35. Kaveltorp-Ljusnarsberg, 36. Åmmeberg; *Ni-Cu deposits:* 37. Lappvattnet, 38. Hitura, 39. Kotalahti, 40. Enonkoski, 41. Vammala, 42. Pechenga, 43. Allarechka.

crust or during the ensuing Svecofennian orogeny (Fig. 1). The first group of economic deposits (Cr, PGE, Ni-Cu, V-Ti-Fe) is associated with 2.4 Ga old mafic layered plutonic complexes in the Archaean craton in the Kemi-Koillismaa belt, in the Koitelainen, Monchegorsk and Fedorova-Pana fells, while the second group (Cu-Zn, Ni-Cu, Cu-Mo) is associated with subduction-related magmatism in the period 1.97–1.8 Ga in the Skellefte District, in the Ladoga-Bothnian Bay Zone, the Aijala-Orijärvi Zone and in the Bergslagen District (Kahma 1978; Frietsch *et al.* 1979; Mikkola 1980; Gorbunov *et al.* 1985; Papunen and Vorma 1985).

KARELIAN PROVINCE – METALLOGENY OF THE CRATONIC STAGE

The Archaean crust of the eastern part of the Baltic Shield consolidated 2.5 Ga ago. Its western segment adjoining the Svecokarelian Domain has been named the Karelian Province or Karelian Craton. Consisting of granitoids (3.1–2.5 Ga) and greenstone belts (2.9–2.7 Ga) it has an Early Proterozoic terrestrial volcano-sedimentary cover (2.5–2.1 Ga). The cratonic cover, collectively called the Karelian sequence, is divided into two groups. The deposition of the Sumi-Sariola Group (2.5–2.3 Ga) was controlled by tensional faults trending NW and ENE, creating a moderate relief covered by tholeiitic volcanic rocks, talus breccias, conglomerates and quartzites with occasional carbonate rocks at the top (Gorbunov *et al.* 1985). The tensional faults trending ENE served as conduits for layered plutonic complexes of the northern Baltic Shield about 2.4 Ga ago. These complexes are especially important for metallogenesis as they host chromite deposits (Kujanpää, pp. 15–19, this volume), PGE mineralizations (Lahtinen and Alapieti, pp. 13–14, this volume), Ni-Cu deposits (Papunen and Vorma 1985; Gorbunov *et al.* 1985) and V-Ti-Fe deposits (Juopperi 1977). The overlying Jatulian Group (2.3–2.1 Ga), often deposited on a thin regolith layer, consists chiefly of conglomerates and quartzites with tholeiitic volcanic intercalations and with carbonates and graphite-bearing schists at the top. Sporadic mineralizations of minor economic importance are met with as unconformity-type uranium deposits (Piirainen 1968) and palaeoplacer gold at the base of the Jatulian group.

THE SVECOFENNIAN OROGENY – METALLOGENY OF AN EARLY PROTEROZOIC CONTINENTAL MARGIN

The Archaean craton in the proximity of the Svecofennian complex was intruded 2.2–2.0 Ga ago by NW-trending dolerite dykes. This event marked rifting and successive disintegration of the Archaean crust, leading to the development of a passive continental margin 2.1–2.0 Ga ago (Gaál 1986). The palaeoenvironment of the continental margin is characterized by shelf-deposited carbonate rocks (e.g. the Rantamaa Formation, Perttunen, pp. 10–12, this volume) and upper to middle fan turbidites (e.g. Martimo Formation, Perttunen, pp. 10–12, this volume) separated by an unconformity from the underlying Jatulian or Archaean basement rocks. Rifting of the basement gave access to ascending tholeiitic magma, as testified by tholeiitic volcanic intercalations in the turbidites that are also the source of the copper mineralization of the Hammaslahti deposit (Ward 1986).

In the period 2.0–1.9 Ga the passive continental margin was converted into an active continental margin (Fig. 2a). It has been speculated that rifting continued along the continental margin and that the oceanic crust was exposed in a marginal basin owing to generation of the depositional environment of Outokumpu-type Cu-Co-Zn deposits as a result of back-arc spreading (Park *et al.* 1984). Subsequent recumbent folding, polyphase deformation and metamorphism render the genesis of the Keretti and Vuonos deposits perplexing; some of the problems are outlined by Parkkinen (pp. 26–30, this volume).

In the period 1880±20 Ma a massive formation of new continental crust followed within an island-arc environment, implying one or several W-dipping subduction zones (Fig. 2b). The overwhelming majority of the volcanic and plutonic rocks of this environment yields ages of 1880±20 Ma, except for a few tonalitic gneisses close to the exposed margin of the Archaean basement that are slightly in excess of 1900 Ma (Gaál 1986). There is a marked accumulation of deposits of various types near the Archaean-Proterozoic boundary. The deposits form the NW–SE trending zone named the Ladoga-Bothnian Bay Zone (Mikkola 1980) also known as the Main Sulphide Ore Belt (Kahma 1973). The massive sulphide Cu-Zn deposits of the Vihanti-Pyhäsalmi Zone (Kahma 1973) are associated with bimodal volcanism in a typical island-arc environment, as shown by the example of the Pyhäsalmi mine (Ekberg and Penttilä, pp. 20–25, this volume). The Ni-Cu deposits of the zone are associated with synorogenic differentiated tholeiitic intrusions occurring together with trondhjemite magma in an intensely faulted and sheared environment characterized by dextral transcurrent faults in medium- to high-grade metamorphosed metapelites right at the junction with the exposed Archaean basement rocks (Gaál 1985). A typical example of the latter deposit type is presented at the Enonkoski Ni-Cu mine (Grundström, pp. 31–35, this volume). The third deposit type occurring in this same environment comprises porphyry Cu-Mo deposits hosted by various granitoid rocks coeval with the surrounding calc-alkaline volcanics (Nurmi *et al.* 1984).

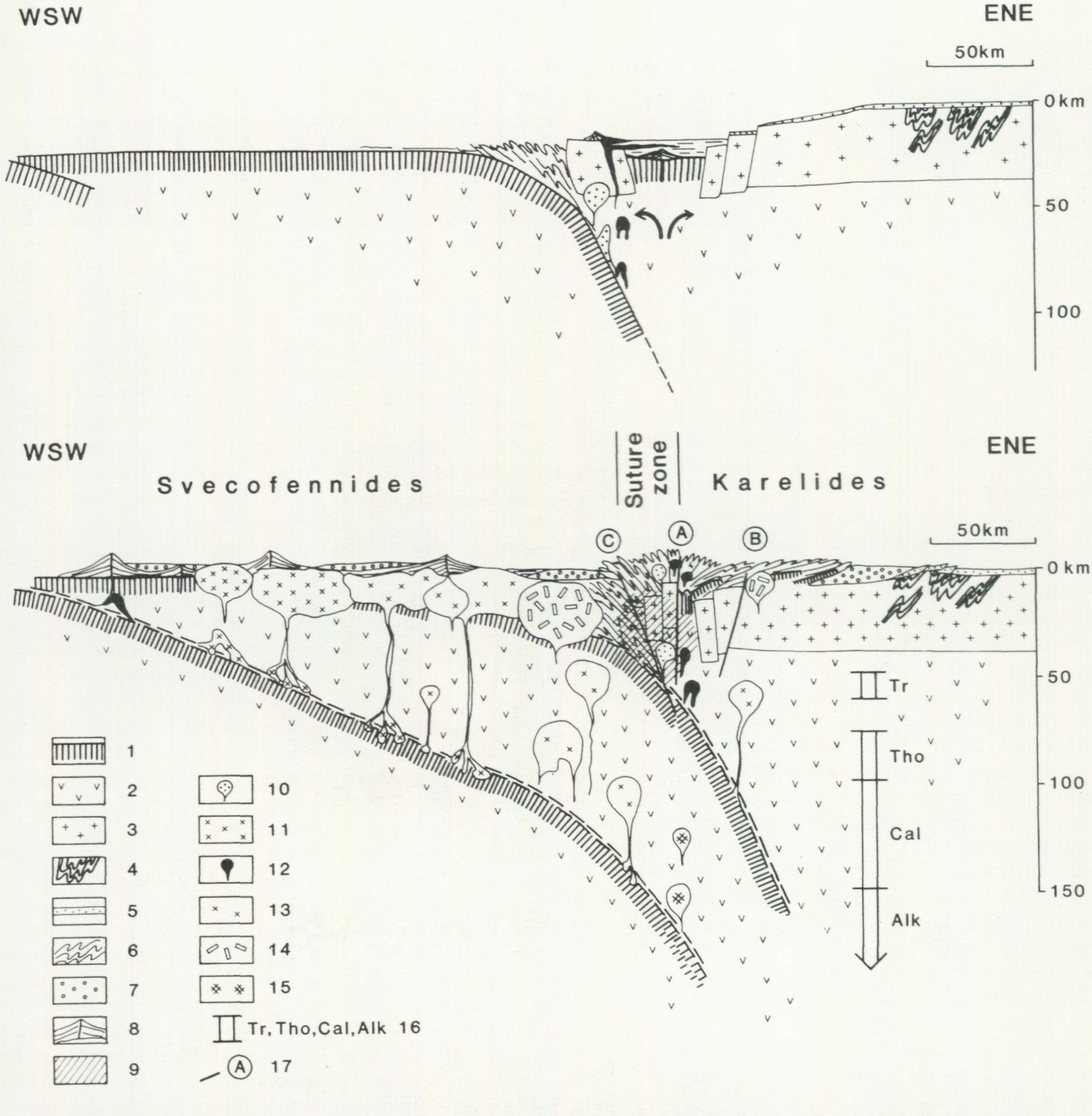


Fig. 2. Plate tectonic model for the Svecofennian orogeny of the Baltic Shield c. 1920 Ma ago (above) and c. 1880 Ma ago (below), approximately to scale (Gaál 1986). Explanations: 1. Oceanic crust; 2. Upper mantle; 3. Archaean granitoids; 4. Archaean greenstone belts; 5. Early Proterozoic platform cover; 6. Eugeosynclinal sediments; 7. Younger proximal turbidites; 8. Volcanic rocks; 9. High-grade metamorphism; 10. Trondhjemite-tonalite magma; 11. Tholeiite magma; 12. Ni-bearing gabbro-peridotite; 13. Calc-alkaline magma; 14. Porphyritic granite-granodiorite; 15. Alkaline magma; 16. Generation depth of trondhjemite-tonalite (Tr), tholeiitic (Tho), calc-alkaline (Cal) and alkaline (Alk) magma; 17. Faults: A. Haukivesi fault; B. Suvasvesi fault; C. Pihlajavesi/Kolkonjärvi fault.

EXCURSION PROGRAMME

The excursion route is depicted in Fig. 3. The programme comprises ore deposits and their geological setting including the Kemi Cr mine, PGE mineralization in the Penikat layered intrusion, the Pyhäsalmi Cu-Zn deposit, Outokumpu Cu-Co-Zn mine and the Enonkoski Ni-Cu deposit.

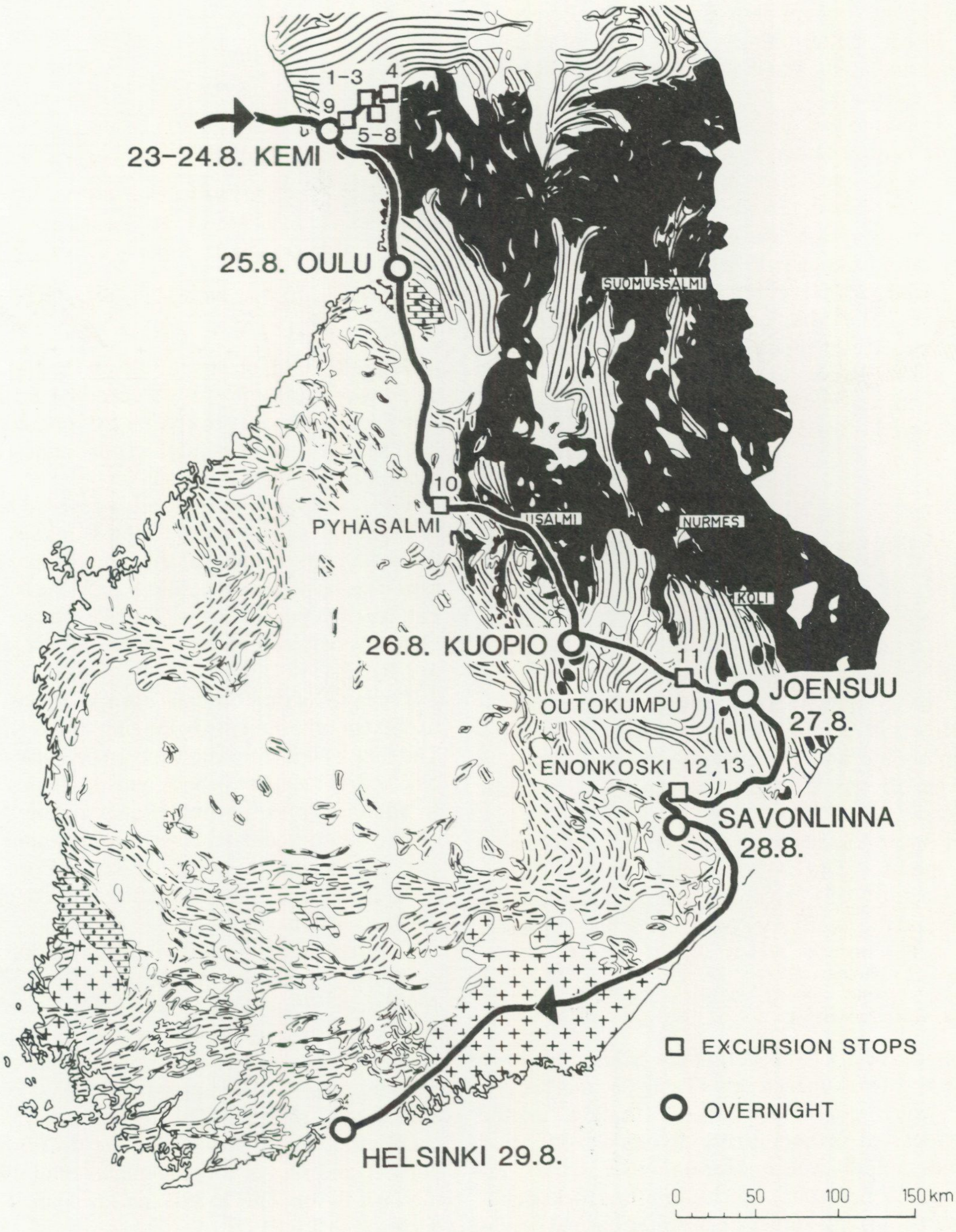


Fig. 3. The route of Excursion no. 5 on the geological map of Finland (Simonen 1971).

DAY 1. THE PRECAMBRIAN GEOLOGY OF THE PERÄPOHJA SCHIST BELT

V. Perttunen

The Early Proterozoic Peräpohja Schist Belt is situated in northwestern Finland to the north of the Gulf of Bothnia. In the southeast it is separated by an unconformity from the Pudasjärvi Granite Gneiss Complex, and in the north and west it is bounded by younger plutonic rocks. The Peräpohja Schist Belt consists of alternating sedimentary and volcanic formations and mafic sills, but it also includes a few felsic to mafic plutonic intrusions.

The only economic ore deposit discovered so far is the Kemi chromite deposit mined by Outokumpu Oy and situated in a layered ultramafic–mafic intrusion. Small Cu-Au occurrences have been detected in mafic dykes. One of them, the Kivimaa deposit, was mined by Outokumpu Oy (Rouhunkoski and Isokangas 1974). Many of the dolomite and quartzite deposits are economic and are being exploited by Lohja Oy (quartzite) and Partek Oy (quartzite and dolomite). During this excursion interest will focus on the main stratigraphic units. Economic geology will be included in the visit into the Kemi chromite mine and the PGE mineralizations in the layered intrusions (Fig. 4).

LITHOSTRATIGRAPHIC UNITS

Basement

The basement of the sedimentary-volcanic Peräpohja Schist Belt consists mainly of felsic rocks, trondhjemitic, granodioritic or granitic in composition. The texture is mostly gneissose but homogeneous variants are also widespread. Amphibolite and mica gneiss are rare except as xenoliths. The zircons of the felsic gneisses give late Archaean ages.

A chain of layered intrusions occurs between the schists and the felsic gneisses. The U-Pb zircon age of the intrusions is 2440 Ma (Alapieti 1982). An unconformity exists between the intrusions and the overlying Peräpohja Schist sequence.

The Peräpohja Schist Belt

The supracrustal rocks of the Peräpohja Schist Belt have been divided into two supergroups (Table 1): the Karelia Supergroup, which consists mainly of shallow marine sedimentary rocks of orthoquartzite-dolomite association alternating with tholeiitic volcanic formations, and the overlying Svecofennia Supergroup, which comprises rocks deposited by turbidity currents under deep-water basinal conditions.

TABLE 1. Lithostratigraphy of the Peräpohja area.

SUPERGROUP	GROUP	FORMATION
SVECOFENNIA	KALEVA	Martimo Phyllite Formation
KARELIA	UPPER JATULI	Rantamaa Dolomite Formation
		Tikanmaa Volcanic Formation
		Kvartsimaa Quartzite Formation
	MIDDLE JATULI	Jouttiaapa Volcanic Formation
		Kivalo Quartzite Formation
	LOWER JATULI	Runkaus Volcanic Formation
		Sompujärvi Formation
PUDASJÄRVI GRANITE GNEISS COMPLEX		

A thin regolith occurs locally on the Basement Complex. The lowermost unit of the Peräpohja Schist sequence is a thin conglomerate overlain by quartzite and impure siltstone. The thickness of this sedimentary Sompujärvi Formation is less than 100 m.

The Sompujärvi Formation is covered by 40 to 100 m of subaerial lavas belonging to the Runkaus Formation. The flows are massive with chlorite and epidote amygdales at the top. The lavas are tholeiitic basalts with a rather uniform pattern of major elements. There is a large variation in trace elements between the lava flows. All the lavas are enriched in LREE.

The lavas of the Runkaus Formation pass sharply into 100 to 1500 m of sediments belonging to the Kivalo Formation. The bulk of this formation consists of pink and grey to white quartz arenites. Cross-beds and ripple marks are common. In addition to well-rounded quartz grains, the quartz arenites contain minor feldspar in quartz and rarely dolomite cement. The upper part of the Kivalo Formation consists of pink quartz arenites alternating with thick, recrystallized dolomite layers.

The deposition of the Kivalo Formation was interrupted by eruptions of subaerial lavas of the 400 to 700 m thick Jouttiaapa Formation. Occasional interflow sediments, mainly quartzite and siltstone, occur as layers up to 5 m thick. The tops of the lava flows commonly exhibit amygdaloidal texture. The amygdales consist of calcite, quartz, epidote and chlorite. The zeolite minerals, analcime and laumontite, occur in some of the drill hole samples. The number and size of the amygdales diminish downwards in the lava flows. The Jouttiaapa lavas are K-poor tholeiites depleted in LREE.

Volcanism was followed immediately by a platform stage,

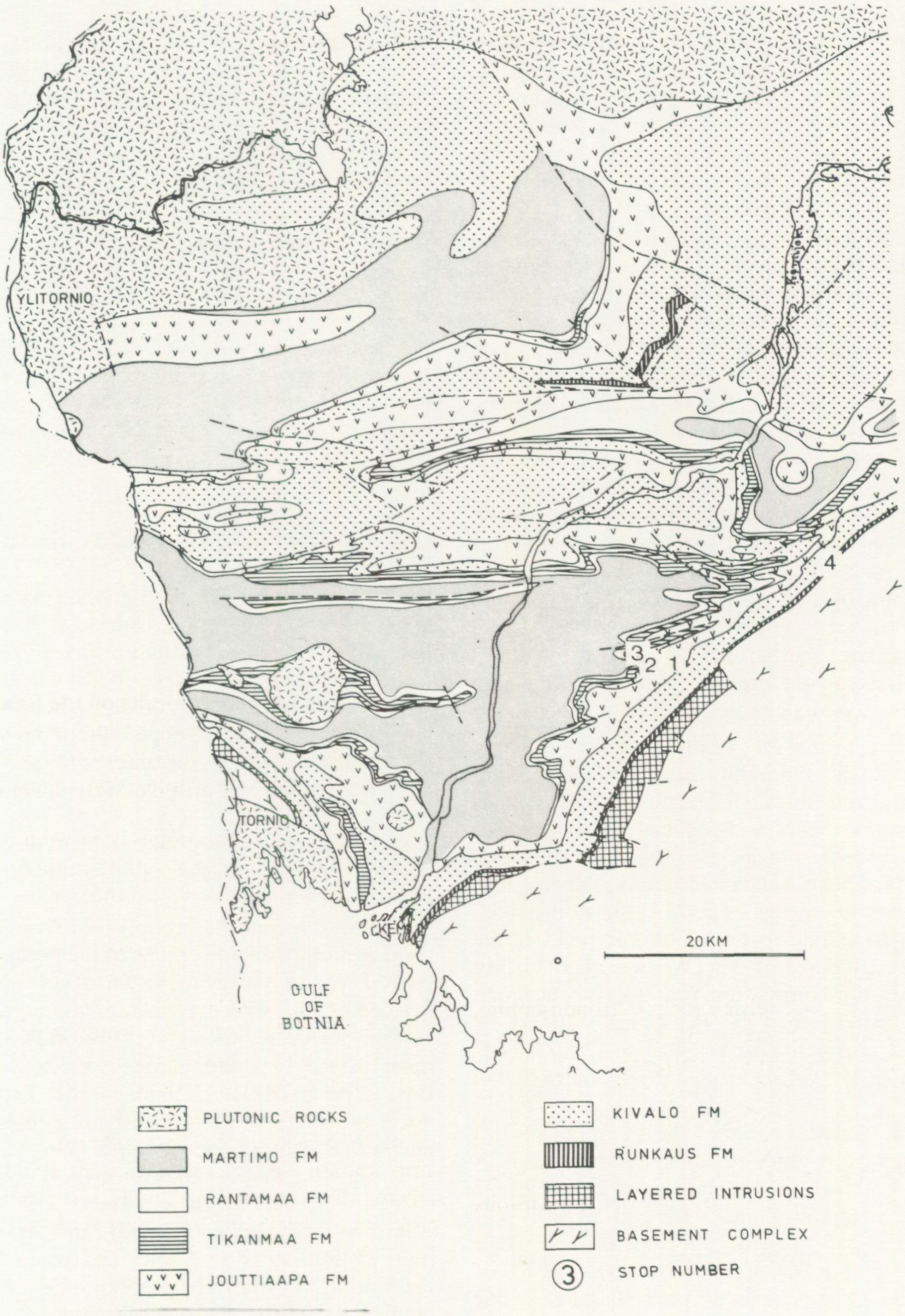


Fig. 4. Geological map of the Peräpohja Schist Belt with excursion stops.

indicating that the regional tectonic pattern changed slightly during the volcanic event. The overlying Kvartsimaa Formation consists mainly of very mature pink or white quartz arenites. The accessory minerals include well-rounded zircon and tourmaline grains. Dolomite-bearing quartzite and dolomite occur as rare interbeds 0.5 to 10 m thick. The pure quartzite is massive and glassy. Impure quartzite exhibits distinct cross-bedding, ripple marks, mudcracks and dolomite stromatolite structures.

The Kvartsimaa Formation is overlain by the 100 to 300 m thick Tikanmaa Formation, which consists of green to green-grey mafic tuffitic layers mostly 0.1 to 20 cm thick. Graded bedding is typical. Chemically the tuffitic layers are tholeiitic basalts. As a result of weathered material mixed with the tuff layers the range of chemical composition is greater than in the other two volcanic formations.

The episode of mafic volcanism was followed by sedimentation of the 100 to 300 m thick Rantamaa Formation. The main rock type is light yellow to grey stratified dolomite. Quartz arenite and dolomite-bearing quartzite layers with thicknesses up to 10 m are common in the dolomite, and stromatolite structures are frequent. Quartz-rich sediments exhibit cross-bedding and ripple marks.

The rocks of the Rantamaa Formation indicate that the slow transgression that began after the Jouttiaapa Formation was active during the deposition of the Rantamaa Formation. After the subsidence of the shallow shelf, deep-water conditions were established and the sediments of the Svecofennian Supergroup were deposited. The Martimo Formation is a more than 2000 m thick sequence of argillaceous strata, recording sedimentation under deep basinal conditions. Since the basal black shale directly overlies the dolomites at the top of the Rantamaa Formation, it is concluded that these conditions were established rapidly.

MAGMATISM AND METAMORPHISM

Mafic sills with thicknesses up to 200 m are common in the quartzites of the Kivalo Formation; some of the sills are distinctly differentiated. Near the base there is an ultramafic cumulus rock. The primary cumulus mineral is olivine, whereas the intercumulus minerals include clinopyroxene, brown amphibole and mica. Higher up clinopyroxene appears as a cumulus mineral with olivine. The bulk of the sill consists of cumulus plagioclase, clinopyroxene and magnetite. Quartz appears as an intercumulus mineral. Zircon dating has assigned an age of c. 2200 Ma to the sills.

The largely intermediate to felsic plutonic rocks of the Haparanda Suite, dated at 1880 Ma (Welin *et al.* 1970), cut the rocks of the Martimo Formation, representing the upper age limit of the evolution of the Peräpohja supracrustal sequence. Later, the microcline granites of Central Lapland, dated at about 1800 Ma, intruded the northern part of the schist belt.

Most of the supracrustal rocks of the Peräpohja Schist Belt have undergone low-grade regional metamorphism. A typical stable mineral pair in the carbonate rocks is dolomite and quartz; in the metapelites, muscovite and chlorite occur with quartz and feldspars. The metamorphic grade is higher in the west and north, in the vicinity of the plutonic rocks. Biotite and cordierite appear as porphyroblasts in pelitic rocks, and impure carbonate rocks contain tremolite and even diopside.

STOP DESCRIPTIONS

Stop 1. – Mihkailinmaa, Tervola, 50 km northeast of Kemi. Tholeiitic mafic volcanics.

Lava flows exhibit fine-grained, amygdaloidal flow tops. The amygdales consist of calcite, epidote, quartz and chlorite. Analcime and laumontite amygdales have been detected in some samples drilled from that area. The flows are mainly medium to coarse in grain size. The main minerals include amphibole, albite, epidote, chlorite and quartz. Preliminary Sm-Nd datings give 2100 Ma ages for the lavas of the Jouttiaapa Formation; zircon has not been obtained in sufficient quantity for dating.

Stop 2. – Tikanmaa quarry, Keminmaa, 55 km northeast of Kemi. Quartz arenite.

Very pure quartz arenite, typical of the Kvartsimaa Formation. Detrital heavy minerals include well-rounded zircon and tourmaline. Primary sedimentary structures are only locally preserved. Distinct ripple marks and rare cross-bedding can be seen. The deposit is being exploited by Lohja Oy.

Stop 3. – Jouttiaapa, Tervola, 55 km northeast of Kemi. Mafic tuffite.

Small outcrops of very fine-grained mafic tuffite. Bedding is distinct on the weathered surfaces. The thickness of the beds is 0.5 to 20 cm, locally up to 5 m. Graded bedding is common except in the thicker beds. Chemically the tuffites are tholeiitic basalts. Thin dolomite-bearing layers are common in the tuffites of the upper part of the Tikanmaa Formation. Magnetite porphyroblasts are frequent, hence this formation gives distinct positive aeromagnetic anomalies.

Stop 4. – Runkausvaara, Simo, 60 km NE of Kemi. Granite, conglomerate, mafic volcanics, ultramafic cumulate of a diabase sill.

This stop includes a group of outcrops which provide a good section of the lower part of the Peräpohja Schist sequence. The Late Archaean Basement consists of pink, coarse-grained granite with greenish, medium-grained inclusions. A thin paleoregolith layer exists on the granite, passing upwards into a conglomerate with well-rounded granite clasts. The matrix is rich in magnetite. The thin conglomerate is followed by a laminated unit consisting of quartzite and silt. This sedimentary unit is 40 m thick.

The lavas of the Runkaus Formation, which number from two to five, overlie the sediments with a sharp contact. Interflow sediments are insignificant. Amygdales are common at the top of the flows and consist of chlorite and epidote. The massive part of the flows consists of amphibole, albite, chlorite and epidote.

In one outcrop, the lower contact of a two hundred metres thick differentiated diabase sill can be seen. The primary mineral assemblage consisting of olivine, clinopyroxene, brown amphibole and phlogopitic mica was altered into talc, serpentine and amphibole. The U-Pb age of zircon from the plagioclase-clinopyroxene-magnetite cumulate of this sill is 2200 Ma.

DAY 2. PGE MINERALIZATIONS OF THE EARLY PROTEROZOIC PENIKAT LAYERED INTRUSION, FINNISH LAPLAND

J. Lahtinen and T. Alapieti

PGE exploration at the Penikat Layered Intrusion was initiated by Outokumpu Oy in 1981, and since 1982 has been continued by Lapin Malmi, a prospecting organization established in Finnish Lapland as a joint venture between Outokumpu Oy and Rautaruukki Oy. The University of Oulu has cooperated with Lapin Malmi in the study of stratigraphy, petrology and ore mineralizations of the Penikat Intrusion. Since 1986 Outokumpu Oy has been responsible for the PGE exploration. During this time three important PGE mineralizations (SJ, AP, PV) has been found in the intrusion, and their extensions are known for almost the entire length of the intrusion.

GEOLOGICAL SETTING

The Penikat Intrusion is part of an extensive NE-trending layered intrusion belt with an age of about 2440 Ma and is located along the Archaean/Proterozoic boundary. The Penikat Intrusion is about 23 km long and 1.5–3.5 km wide. It is divided by faulting into five west-dipping blocks, which represent different levels of erosion (Fig. 5). The intrusion can be divided into three principal geological units: the Marginal Series, the Layered Series and the Granophyre. The latter unit is not dealt with in the present context.

The Marginal Series against the Archaean basement complex begins with a thin, fine-grained chilled margin. It is followed by a more coarse-grained, noncumulate-textured and slightly contaminated gabbroic rock, and bronzite cumulates.

The Layered Series consists of alternating sequences of ultramafic, gabbroic and anorthositic rocks, reflecting in broad outline the general fractional crystallization order of basic magma. It is therefore divided into five (I-V) megacyclic units (MCU) from bottom to top. It is typical of the Layered Series of the Penikat Intrusion that several, often very thin, layers are highly persistent throughout the intrusion.

DESCRIPTION OF MEGACYCLIC UNITS I-V

In this description, the following abbreviations of cumulates will be used: bC=bronzite cumulate, pC=plagioclase cumulate, aC=augite cumulate and oC=olivine cumulate.

The lowermost megacyclic unit (MCU I) begins with a

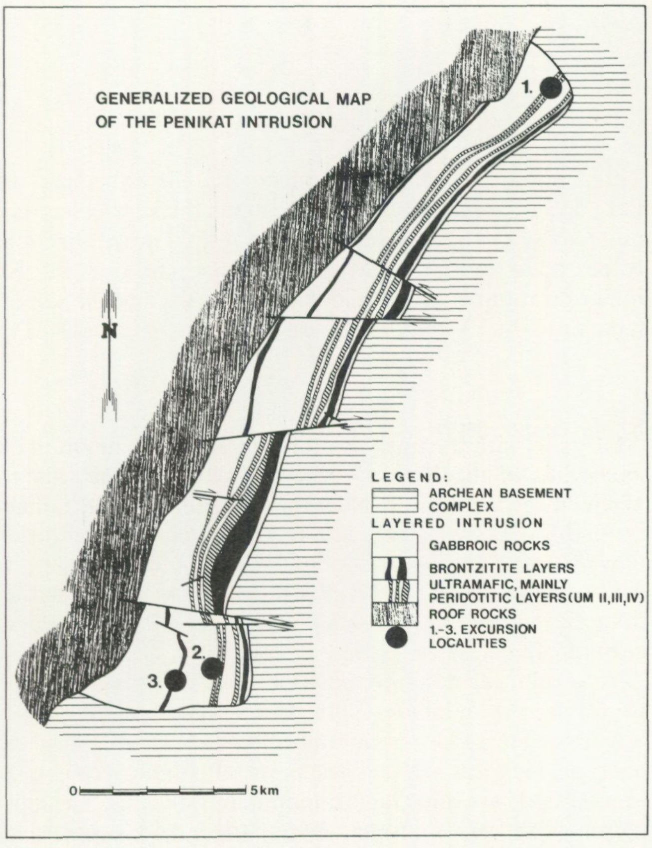


Fig. 5. Generalized geological map of the Penikat intrusion.

bronzitite (bC) layer with interlayers of chromite-bearing cumulates or even chromitites. Bronzitite is followed by gabbroic rocks (plagioclase-bronzite-augite cumulates).

Megacyclic units II and III resemble each other very closely, both having an ultramafic base and a gabbroic top. The ultramafic part begins with a thin bronzitite (b±oC) layer, which is followed by a peridotite (oC) layer and a bronzitite (bC) layer. Chromite disseminations and occasionally chromitites are typical interlayers in the ultramafic rocks of the MCU II and III. The mafic upper parts of MCU II and III are composed mainly of gabbronorites (pbaC).

MCU IV is the thickest megacyclic unit in the Layered Series. Unlike MCU II and III, it is characterized by a thin ultramafic layer at the base and thick layers of mafic and leucocratic rocks. The ultramafic base begins with a thin bronzitite followed by a peridotite (oC) layer, which in turn is followed by gabbroic and anorthositic rocks. A typical feature of the lower part of the unit is the rather strong rhythmic layering just above the ultramafic base.

The uppermost megacyclic unit (MCU V) is the only one that does not contain any olivine-bearing cumulates. It begins with a rather thin bronzitite (bC) layer, followed by a thick gabbronorite (pbC-pbaC) layer and a gabbro (paC) layer.

PGE MINERALIZATIONS

Three important PGE mineralizations are known in the Penikat Intrusion. All of them are in the thickest megacyclic unit (MCU IV). The lowermost one, the SJ mineralization, is located at the base of MCU IV; the second one, the AP mineralization, is in the middle of the unit; and the uppermost one, the PV mineralization, is at the top of MCU IV.

SJ MINERALIZATION

The SJ mineralization is located at the ultramafic base of MCU IV. A typical site is the lowermost (c. 0.5–1 m thick) bronzitite (b±oC) layer. However, the SJ mineralization may also occur in the peridotite (oC) layer above, or in the gabbronorite (pbaC) of MCU III, just below the bronzitite. Sometimes bronzitite contains considerable amounts of chromite.

As a rule, the SJ mineralization is a PGE mineralization totally free of sulphides, although sulphide-bearing types also exist. The grade of mineralization varies widely, and the average thickness is about one metre. Platinum-group minerals (PGM) are tiny grains interstitial to silicates. The most common species are sperrylite ($PtAs_2$) and isomertieite ($Pd_{11}Sb_2As_2$). The Pd to Pt ratio is fairly constant, being about 1.5–2.

AP MINERALIZATION

The AP mineralization is located in the middle of MCU IV, about 200–400 m above the base of the unit. The layer controlling the existence of the mineralization is a mottled anorthosite (pC) underlain by a rather thick homogeneous gabbronorite (pabC) layer and overlain by a gabbronorite (pbC), which in turn is overlain by another gabbronorite (pbaC).

The PGE mineralization is mainly associated with the gabbronorite (pabC) immediately below the mottled anorthosite and with the mottled anorthosite itself. The gabbronorite layer above the mottled anorthosite may also be mineralized.

The AP mineralization represents a disseminated sulphide deposit type, with chalcopyrite, pyrrhotite and pentlandite, and sometimes also pyrite as the main sulphides. The platinum-group minerals, with the vysotskite-braggite series, (Pd, Pt, Ni)S and sperrylite, $PtAs_2$, are associated with the sulphides as tiny inclusions or scattered grains at the edges of the sulphides. The thickness of the mineralization varies widely, the average being about 0.35 m. The Pd to Pt ratio is constantly about 3.5.

PV MINERALIZATION

The uppermost PGE mineralization of the Penikat Intrusion, PV, is located near the top of MCU IV and is normally associated with the uppermost layer of MCU IV, which is an anorthositic or gabbroic plagioclase cumulate (pC). Plagioclase cumulate is overlain by the bronzitite layer of MCU V.

PV also represents an intercumulus–associated disseminated sulphide mineralization with chalcopyrite, pyrrhotite and pentlandite as the main sulphides. The principal PGM, the majority of which are associated with sulphides, are sperrylite, $PtAs_2$; braggite, (Pt, Pd, Ni)S and cooperite, PtS.

The mineralization varies in thickness, but the average is about 1 m. The PV mineralization is the only platinum-dominant PGE mineralization in the Penikat Intrusion, the Pt to Pd ratio being 1.2–2.0.

STOP DESCRIPTIONS

Stop 5. – Kirakkajuppura, 40 km northeast of Kemi. SJ Mineralization.

Rocks of MCU III and the base of MCU IV within a 100 m long outcrop at hill Kirakkajuppura.

Magmatic layering in gabbroic (pbaC), pyroxenetic (bC, b±oC) and peridotitic (oC) rocks and also the PGE mineralization itself, can be seen in the outcrop area. All the cumulates are cut by later pegmatites.

Of special interest is the irregular form and cutting behaviour of the lower contact of MCU IV, which is also the site of PGE mineralization.

Stops 6–8. – Ala-Penikka, 22 km northeast of Kemi. AP Mineralization.

Stop 6. Magmatic layering in the lower part of MCU IV between the SJ and AP mineralizations. Alternating pC, bC and pbaC layers.

Stop 7. AP mineralization, normal thin reef. PGE mineralization within a thin mottled anorthosite (pC) between gabbronorite (pbC) and mineralized gabbronorite (pbaC) layers.

Stop 8. AP mineralization, thick PGE-mineralized zone at structural basin. Same rocks and mineralization as at stop 2, but mottled anorthosite is much thicker.

Stop 9. – Paasivaara, 21 km northeast of Kemi. PV mineralization.

Rocks of the upper part of MCU IV anorthosite (pC)-hosted PGE mineralization and rocks of the lower part of MCU V.

DAY 3. THE KEMI CHROMITE DEPOSIT

J. Kujanpää

The Kemi chromite mine and mill are located 10 km northeast of the town of Kemi, near the northeastern shore of the Gulf of Bothnia at a latitude of about 65°45'N. The Tornio works (ferrochrome plant and stainless steel works) are situated 10 km south of the town of Tornio, 25 km west of the Kemi mine. The Kemi mine and the Tornio works together form the Stainless Steel Division of Outokumpu Oy. The chromite ores are associated with a mafic-ultramafic layered plutonic complex in the contact zone between the Archaean basement consisting of migmatic granites and the Karelian schist of the Peräpohja region. The layered intrusion extends from Kemi northeastwards for about 15 km, with a maximum width of 1 900 m. The chromite deposit was discovered in 1959 by a local prospector, who found the first chromite boulder among the blocks stoped from a shallow water canal cutting the Kemi layered intrusion at what is now the westernmost orebody of the mine. The decision to start beneficiation of the ore was made in 1964, and mining started on an industrial scale in 1968.

GEOLOGY OF THE KEMI AREA

The Kemi-Tornio-Rovaniemi area, or the Peräpohja Schist Belt, is a distinctly defined geological unit of triangular shape (Fig. 4). It is bordered in the north by the Proterozoic Central Lapland granite and in the south by the Archaean Pudasjärvi granite gneiss. The base of the triangle, from Tornio to Ylitornio, is formed by the river Tornionjoki; the apex is the Misi iron ore district, some 150 km northeast of Tornio.

The structure of the Peräpohja Schist Belt is dominated by two east–west trending synclines, the Martimojoki syncline and the Kemijoki syncline, separated by the Korpijärvi anticline (Mikkola 1949). The schist belt is characterized by mafic igneous rocks and low-grade metamorphism.

The stratigraphy of the sedimentary rocks is best established in the southern part of the area, although locally it has also been traced elsewhere. The following description of the rocks is based on geological maps of the Geological Survey of Finland (Perttunen 1971a,b, 1972, 1975). Lowest in the sequence is a basal conglomerate resting on the basement gneiss complex. It has been encountered at Laurila, on the western shore of the river Kemijoki, in a cutting of the Veitsiluoto fresh water canal in the Kemi belt, in the Penikat zone northwest of Ala-Penikka, at Sompujärvi and at Suhanko in the Ranua area. This unit is succeeded by products of the first stage of volcanism, e.g. the agglomerates west of Kemi airport and at Sompujärvi. The volcanites are overlain by the Kivalo quartzite, averaging 2 km in thickness and extending for at least 100 km northeast of Kemi. The Kivalo quartzite is overlain by a 1–5 km thick pile of spilitic greenstones of the second stage of volcanism. The latter are amygdaloidal mafic lavas with local agglomerates and metadiabases. The lavas are covered by orthoquartzite with dolomite intercalations, up to half a kilometre thick, exposed in the Kvartsimaa quarry in Alatornio and in some other places. This quartzite is overlain by the uppermost volcanic unit which is composed of mafic tuffitic schists with graded bedding. The largest dolomite deposits in the area are found above the tuffitic schists. The thickness of the greenschist-dolomite zone is maximum one kilometre. Black schists are encountered in association with greenschists in the central part of the Peräpohja area, particularly in the northwestern corner. The topmost unit consists of phyllites with graded bedding intercalated with the Taivalkoski conglomerate.

Within the contact zone between the Archaean basement complex and the overlying Karelian schists, sixteen mafic-ultramafic plutonic layered intrusions of the same age occur over a distance of 250 km along the line Tornio-Kemi-Ranua-Taivalkoski-Kuusamo (Alapieti 1982). The three westernmost intrusions, the Penikat, Kemi and Tornio layered igneous complexes (Fig. 4), contain chromite mineralizations. At present only the Kemi layered igneous complex is known to host economic concentrations of chromite.

The Penikat layered intrusion, which is a sill-like body dipping 45°–55E° to NW, is over 20 km long and on average 2 km thick. It is cut by numerous transversal faults. In the lower part of the complex, which consists mainly of gabbro, there are rare intercalations of serpentinized layers of peridotite with chromite-rich layers. The thickness of these intercalations is between 10 and 200 metres. Near the bottom of the complex a coherent horizon of pyroxenite is encountered with a continuous, less than 20 m thick, plagioclase-rich chromite layer (Kujanpää 1964).

The Tornio layered igneous complex was discovered in the late 1970s by the Exploration Department of Outokumpu Oy. The Swedish Geological Company started exploration in the early 1980s to investigate the continuation of the complex on the western side of the river Tornionjoki. In the Tornio area the intrusion forms a 6 km long, roughly 400 m thick slab dipping 65°–75° NW (Fig. 4). The lower part of the complex is mainly pyroxenite with thin peridotite layers. Both pyroxenite and peridotite host chromite-rich layers up to 40 cm in thickness. The upper part of the complex consists of gabbro with pyroxenite interlayers (Söderholm and Inkinen 1982).

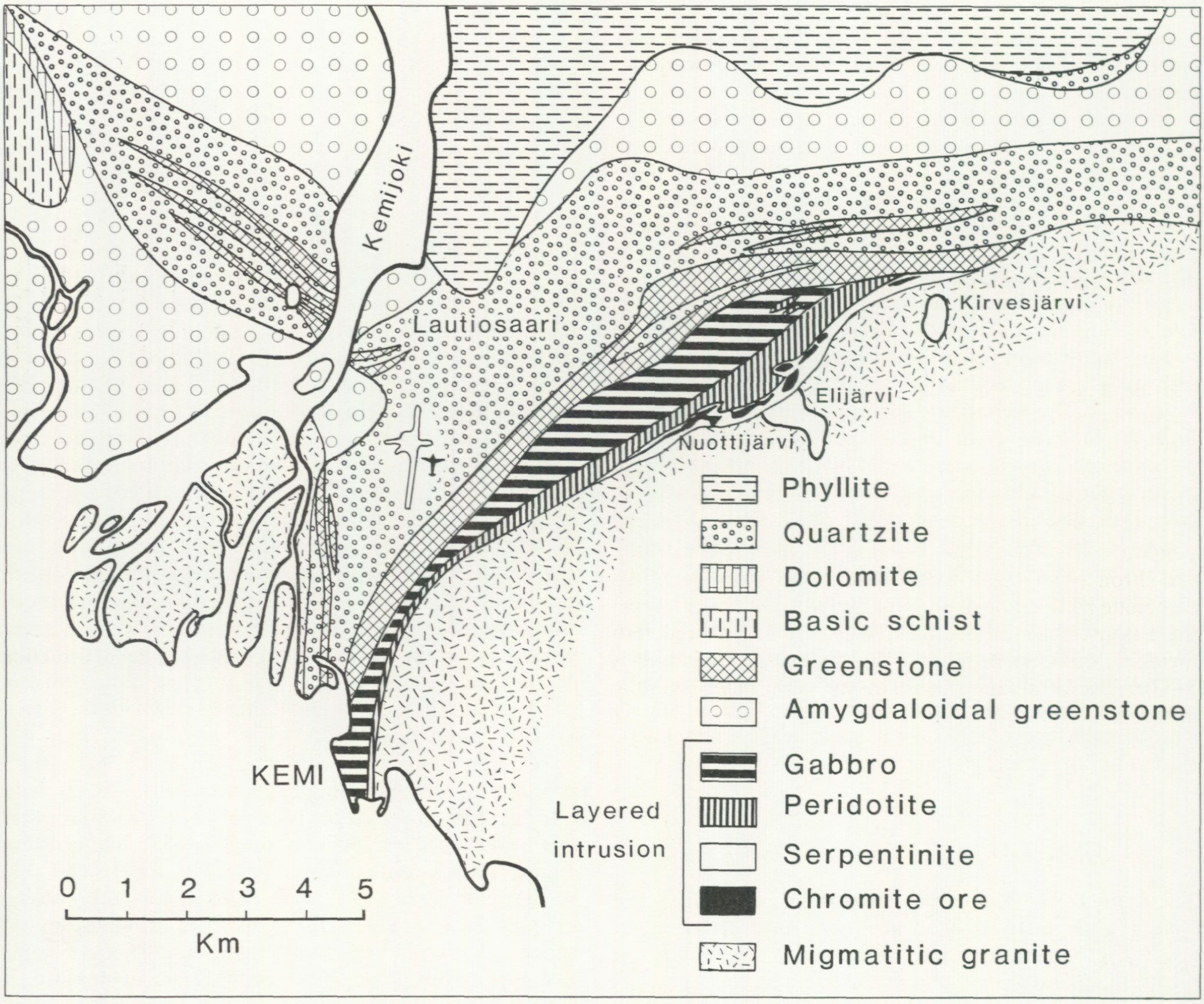


Fig. 6. Geological structure of the Kemi layered intrusion.

The plutonic rocks intersecting the southwestern part of the Peräpohja Schist Belt belong to the Haaparanta Igneous Suite (Härme 1949). Some parts of these plutonic complexes, for example the Nosa granodiorite near the river Kemijoki, might represent a remobilized Archaean basement complex (Söderholm and Inkinen 1982).

Dating by the Geological Survey of Finland has assigned an age of 2700–2800 Ma to the Archaean basement complex. The zircon age of the Kemi and Penikat layered intrusions is 2440 Ma (Alapieti 1982), which is similar to the age given by the whole rock total lead isochron (Manhes *et al.* 1980).

GEOLOGICAL SETTING OF THE KEMI LAYERED IGNEOUS COMPLEX

The Kemi layered igneous complex is a typical example of a stratified, *in-situ* differentiated mafic-ultramafic plutonic intrusion. Starting at the town of Kemi on the shore of the Gulf of Bothnia, the Kemi intrusion extends northeastwards for 15 km, varying in width from 300 to 1900 m. The complex has the shape of a slightly curved plate dipping northwestwards.

The known part of the layered intrusion begins at Kemi, where it is about 500 m wide; south of the airport it narrows down to 250 m and then widens again until at Elijärvi it is as much as 1900 m wide. The formation thins very rapidly from Elijärvi northeastwards and pinches out north of Kirvesjärvi (Fig. 6). The igneous complex is poorly exposed, and has been observed in only a few scattered small outcrops, in a railway cutting at Kemi, in a shallow fresh-water canal west of Nuottijärvi and in a few clusters of outcrops in the Elijärvi-Nuottijärvi area; nowhere are the contacts of the igneous complex exposed. Nevertheless, owing to a fairly dense drilling grid, the southeastern boundary of the zone is well established in the Nuottijärvi-Elijärvi-Kirvesjärvi area (Fig.

6). In 1977 the southeastern contact of the zone was exposed in the course of earth removal from the Viia open pit, and at present it is visible in the footwall of the pit, close to the ramp.

The upper part of the sequence is composed of amphibolitized and saussuritized pyroxene gabbros with anorthosite and pyroxenite interlayers. In the middle of the complex, immediately above the ultramafic lower part, these rocks are unaltered and mainly noritic in composition. The gabbro unit is up to 1 km in thickness. The lower part of the complex is composed entirely of ultramafic rocks, largely of alternating peridotite, pyroxenite and dunite layers, and chromite ore. The coherent chromite-rich horizon occurs about 50 to 200 m from the bottom of the complex. As a result of autometasomatism, peridotites have altered into serpentinites and talc-carbonate rocks around the ore; however, the primary features of peridotite are still well preserved. Magmatic layering is best developed immediately above the coherent chromite horizon in a zone from 20 to 50 m thick. The layering is due to the alternation of narrow peridotite, pyroxenite, serpentinite, talc-carbonate rock and chromite layers. At the base of the sequence the talc-carbonate rock is intensely deformed at the contact against the basement gneiss complex, where it has altered into mylonitic talc-chlorite schist. The thickness of this unit is 5–50 m. The ultramafic unit attains the same thickness as the gabbro unit, i.e. up to 1000 m.

CHROMITE ORES IN THE KEMI LAYERED INTRUSION

The continuous chromite horizon, conformable with the southeastern contact of the complex, varies in thickness between a few centimetres to several metres. However, in the Nuottijärvi-Elijärvi area (Fig. 7), which is the thickest part of the complex, the chromite horizon shows several successive swells for about 6 km. Moreover, the horizon has two forks, one at the eastern shore of lake Nuottijärvi and another at the northeastern end of lake Elijärvi. The swells in the chromite horizon vary between 20 and 90 metres. In 1982 the total reserves were estimated to some 38 million metric tons of ore at a cut-off grade of 20% Cr_2O_3. Five open pits were planned with the aid of a computerized two-dimensional or inventory register, a three-dimensional ore model and an optimization program of the open pit. The deepest level of the optimized open pits is 230 m below the ground surface.

The Elijärvi orebody has been investigated by means of drill sections 25 m apart down to a depth of 300 m; the deepest drill hole intersected the ore at a depth of 450 m. Information on the Viianranta and Viianlahti orebodies has also been obtained from a depth of some 300 m, and the Viianmaa orebody has been intersected by drill holes at a depth of 250 m. Data are not available on other orebodies from below the +200 level. Estimated ore resources outside the planned open pits are about 110 million metric tons; thus, the total chromite ore resources in the Kemi layered intrusion add up to some 150 million metric tons.

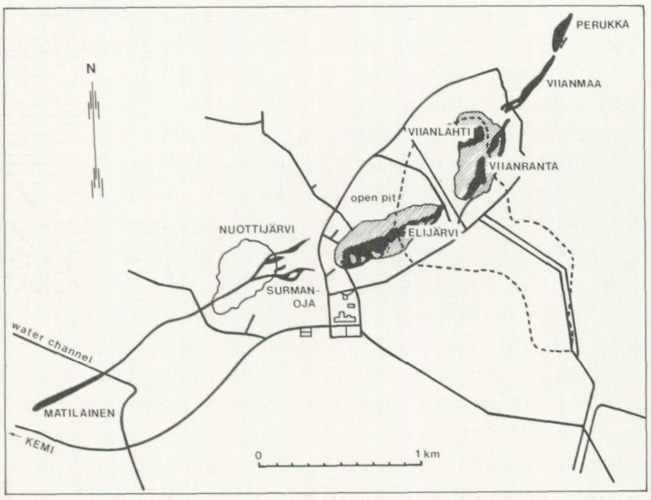


Fig. 7. Chromite ores and the site of the mine in the Kemi zone.

Elijärvi orebody

The Elijärvi orebody is the best-known part of the deposit, with six million metric tons of ore mined between 1966 and 1985. The detailed structure of the orebody is illustrated in Fig. 8, which shows the surface plan and cross-sections

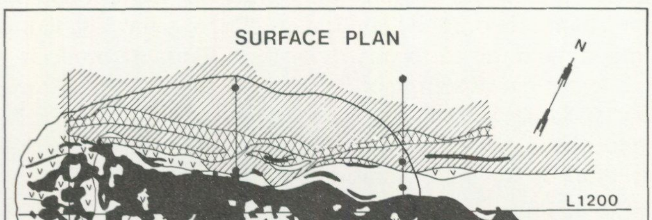


Fig. 8. Surface plan and three sections of the Elijärvi orebody.

across the centre and both ends of the open pit. The layered structure in the hanging-wall country rock and in the upper part of the ore is a typical feature of the Elijärvi orebody. The lower part of the orebody and the whole western end are intensely brecciated, and the ore contains abundant serpentinite and talc-carbonate rock fragments. The footwall of the ore consists of talc-carbonate rocks with small serpentinite portions showing disseminated chromite and chromite nodules and accumulations varying in size and shape. In terms of host rock, the ore can be divided into two main types: soft talc-rich ore and hard serpentine-rich ore. The latter accounts for about 15 % of the total open pit ore reserves. The euhedral chromite grains average 200 microns in size. The gangue minerals include talc, serpentine, magnesite, dolomite and kämmererite. Very fine-grained uvarovite occurs locally in the upper parts of the ore horizon. The accessory oxides are magnetite, ilmenite, haematite and rutile. Sulphides, which occur only as microscopic grains, include pyrite, chalcopyrite and millerite.

Viianranta and Viianlahti orebodies

Mining started in the Viia open pit (including the Viianranta and Viianlahti orebodies) in early 1977 (Fig. 7). Over four million metric tons of ore have been extracted from this pit in seven years. Fig. 9 shows the surface plan of the Viia orebodies and two sections, one across the western end of the Viianranta orebody and the other across the Viianlahti orebody and the eastern parts of the Viianranta orebody.

The geological setting of the Viia ore bodies differs from that at Elijärvi in that hanging-wall peridotites have been altered into talc-carbonate rocks and the typical layered structure is lacking or almost completely obliterated. Serpentinite portions are very rare in both the hanging wall and

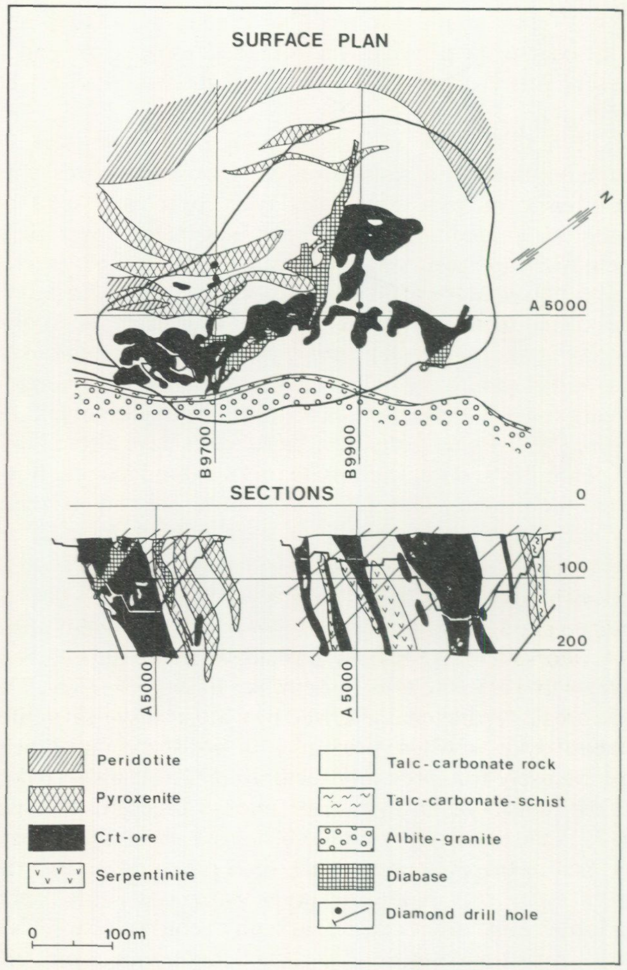


Fig. 9. Surface plan and two sections of the Viianranta and Viianlahti orebodies.

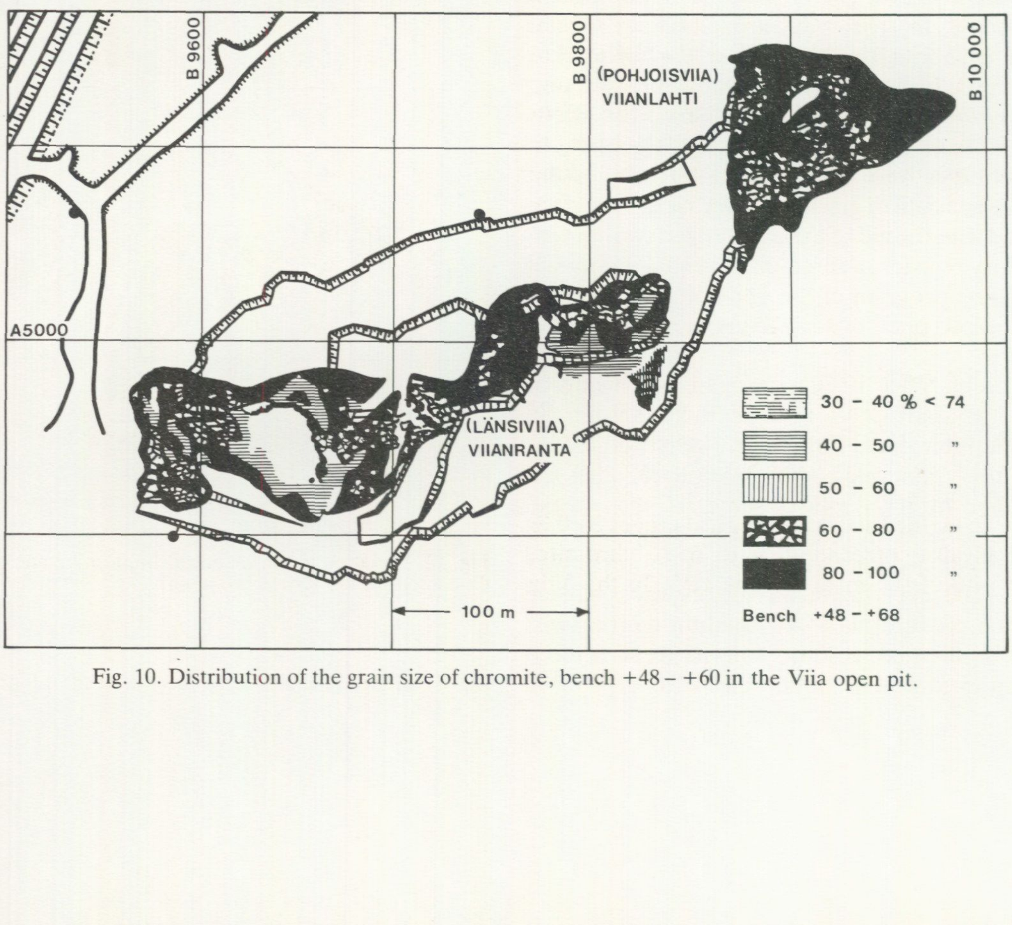


Fig. 10. Distribution of the grain size of chromite, bench +48 – +60 in the Viia open pit.

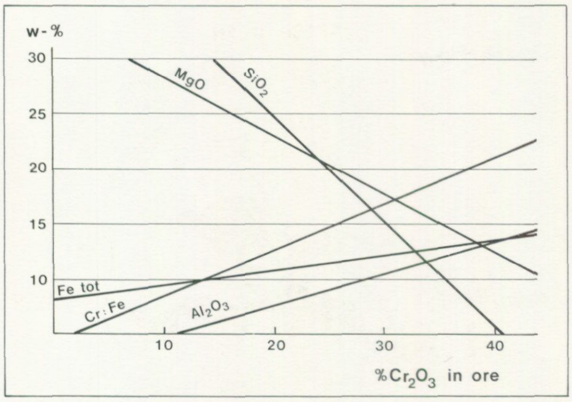


Fig. 11. Variation in the chemical composition of the orebodies in the Kemi layered intrusion.

the footwall, and the ore does not contain the hard, serpentine-rich type. Talc and dolomite are practically the sole gangue minerals in the ore. The Viianranta orebody is broken into several fragments and shows a breccia structure similar to that in the lower part of the Elijärvi orebody. The Viia area is further characterized by wide, transversal albite-diabase dykes in whose proximity the ore and country rocks are intensely fractured and tectonized. The diabase dykes follow long fault lines, causing intense brecciation, especially in the eastern parts of the Viia orebodies. Cataclasis is marked in the chromite in the Viia orebodies; hence, the average grain size is much smaller than in the Elijärvi ore, and some parts of the ore are difficult to concentrate. This is particularly the case for the Viianlahti orebody and the eastern fragments of the Viianranta ore, whereas the western part of the Viianranta orebody has large areas with unbroken chromite. In order to optimize production, it is essential to know the distribution of the grain size of chromite. The grain size is, therefore, determined regularly in connection with sampling conducted by percussion drilling. Fig. 10 illustrates the distribution of the average grain size of chromite through one bench in the Viia open pit; mapping of this type has been used successfully in the planning of the mining sequence.

Composition of the chromite ores

The variation in the main components as a function of the Cr_2O_3-content in the Kemi chromite ores is illustrated in Fig. 11. The variation from one orebody to another can be seen from the figures in Table 2, which shows the main Cr_2O_3-content and the average value of the Cr/Fe ratio *in situ* in various orebodies.

The ore mined from the Elijärvi open pit averages 26.0 % Cr_2O_3, mineralogically corresponding to 65 % chromite. The average density of the mined ore is 3.45. In the Viia open pit the average Cr_2O_3-content is about one percentage point higher than in the Elijärvi open pit.

TABLE 2. Average composition of the Kemi chromite ores.

Orebody	Cr_2O_3	Cr/Fe
Matilainen	26.8	1.43
Nuotijärvi	29.5	1.53
Surmaoja	28.9	1.52
Elijärvi	26.5	1.51
Viianranta	27.4	1.56
Viianlahti	28.5	1.65
Viianmaa	28.9	1.60
Perukka	30.6	1.71

The chromites of the Kemi layered intrusion are iron-rich aluminian chromites, and can be termed alumoberezowskites (Vaasjoki and Heikkinen 1961). The Cr-content in the majority of the chromites is in the range of 32–36 %, the mean value being 34 % Cr. The chromites that contain less than 32 % Cr, are mostly zoned grains with iron-rich rims around cores of normal chromite. Fig. 12 shows the variation in the composition of the Kemi chromites. Trace element assays in the chromites give 0.15–0.35 % Ti, 0.15–0.20 % Mn and less than 0.1 % V.

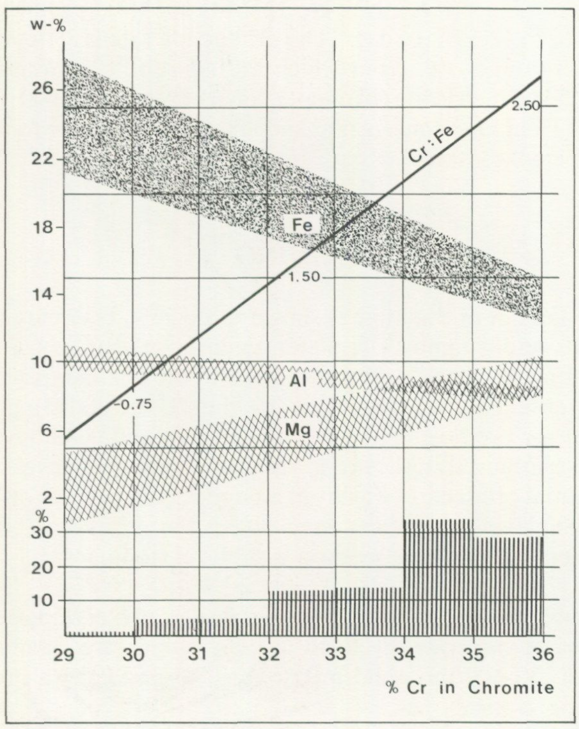


Fig. 12. Variation in the chemical composition and distribution of the Cr-content in the Kemi chromites.

DAY 4. THE PYHÄSALMI Cu-Zn-PYRITE DEPOSIT

M. Ekberg and V.-J. Penttilä

The Pyhäsalmi deposit is situated in the province of Oulu, central Finland. The ore deposit was discovered in August 1958 when a local farmer was digging a well in his yard. The well ended in massive pyrite ore, and Outokumpu Oy immediately implemented geological mapping and geophysical survey in the area using magnetic, electromagnetic and gravimetric methods. The first holes were drilled in October of the same year. By the summer of 1959 the inventory drilling was concluded and work started on sinking a shaft in late July. The development work for open-pit mining got under way at the same time, and production started in March 1962. All mining was shifted underground in 1976.

The ore is estimated to contain 0.85 % Cu, 2.85 % Zn, 37 % S, 4.9 % BaO, 0.06 % Pb, 0.4 ppm Au and 14 ppm Ag. The present ore reserves are 12.2 Mt and total production has been 18.5 Mt to date. The production rate is 850 000 t/y underground ore, from which the concentrator produces 20–25 000 metric tons of copper concentrate, 30–40 000 metric tons of zinc concentrate and 400–500 000 metric tons of pyrite concentrate.

MINING

The lay-out of the mine is shown in Fig. 13. There are two shafts and a ramp. The 500 m deep main shaft is for ore hoisting and personnel transport, and the auxiliary shaft is for ventilation and waste-rock hoisting. There is also a blind shaft for ore hoisting between the +730 and +400 levels. The crushing stations are at the +400 and +660 levels.

Initial production was from an open pit to a depth of 125 m. Sublevel caving was used above the +250 level. The present main mining method is sublevel stoping with backfill.

Sublevel stopes are worked transversally or longitudinally, at intervals of 30–40 m. The stopes are relatively small, 30–100 thousand metric tons, to prevent wall rock caving in the stopes.

There is a strong horizontal stress field, with the greatest compression perpendicular to the strike. The ore is hard and strong but it is enveloped by weak, hydrothermally altered country rocks.

GEOLOGICAL SETTING

The Pyhäsalmi ore deposit is located in the Ruotanen Schist Belt, in the northern part of the 350 km long Svecofennian Schist Belt. The Ruotanen Schist Belt trends almost N–S and dips vertically or subvertically eastwards. The belt, which is 2–3 km thick and 30 km long is bordered in the east by a gneissose granodioritic intrusion and in the west by a porphyritic granite. The Pyhäsalmi ore deposit is located roughly in the middle of the schist belt associated with metavolcanic rocks. The metavolcanics are bimodal; intermediate volcanics are very rare. The southern part of the Ruotanen belt is composed mainly of mafic volcanics. Northwards the felsic metavolcanics gradually become predominant over the mafic metavolcanics.

The mafic metavolcanics with primary structures are considered tuffs, lavas, pyroclastic breccias or agglomerates in origin, whereas the felsic metavolcanics are considered tuffs or dykes. These felsic metavolcanics are also encountered as fragments in pyroclastic breccias. In some places, the felsic metavolcanics also contain intercalations of mafic metavolcanics.

The contact between unaltered volcanics and hydrothermally altered sericite quartzites and cordierite-bearing rocks is fairly sharp. The ore is enveloped by altered rocks (Figs. 14 and 15) which at the surface are about 100 m thick in the west and 300 m thick in the east. At the +660 m level, however, the altered rocks are only 10 m thick. The sericite quartzites are foliated and contain pyrite, and occassionally also chalcopyrite and sphalerite as dissemination or stringer mineralizations. The sericite quartzites are alteration products of the felsic volcanics and locally contain pinitized cordierite porphyroblasts.

Cordierite-bearing gneisses, which are common to the east of the ore, grade here and there into cordierite-anthophyllite rocks and mica rocks. The cordierite-bearing rocks are alteration products of the mafic volcanics. A talc-chlorite (anthophyllite-cordierite) rock zone of 3–15 m thickness exists in the western part of the ore, being partly inside the ore or very near the footwall contact. The zone is 100–200 m long and 200–300 m high. This talc-bearing rock often assays 3–10 % zinc. The chemical compositions of some rock types of the Pyhäsalmi area are presented in Table 3.

ORE TYPES AND STRUCTURES

The orebody is 650 m long and has a thickness of 80 m at the center. It is known to continue in the south to a depth of 750 m, where the thickness is 5–15 m only. The orebody is roughly conform with the enveloping schists. The shape of the orebody is complex as a result of polyphase deformation, and it resembels an open "S" which thins out at both ends.

The ore is of a massive type, but disseminated and stringer ores also exist in the sericite schists around the massive body. The contacts of the massive ore are sharp and often conform. Here and there remobilized sulphide veins cut the country rocks. In some places the pyrite content gradually increases in the sericite quartzites towards the ore but even then the contact is sharp.

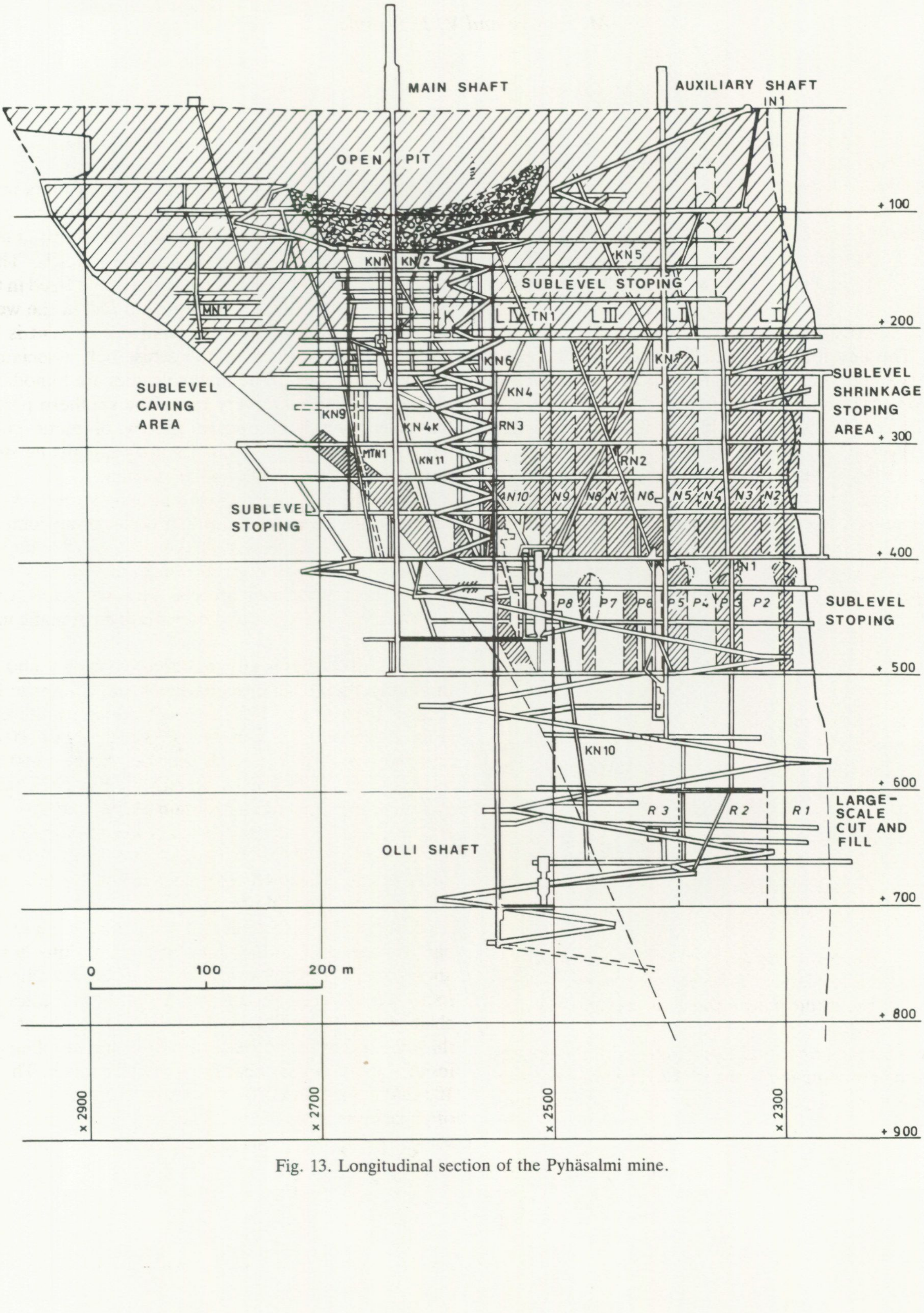


Fig. 13. Longitudinal section of the Pyhäsalmi mine.

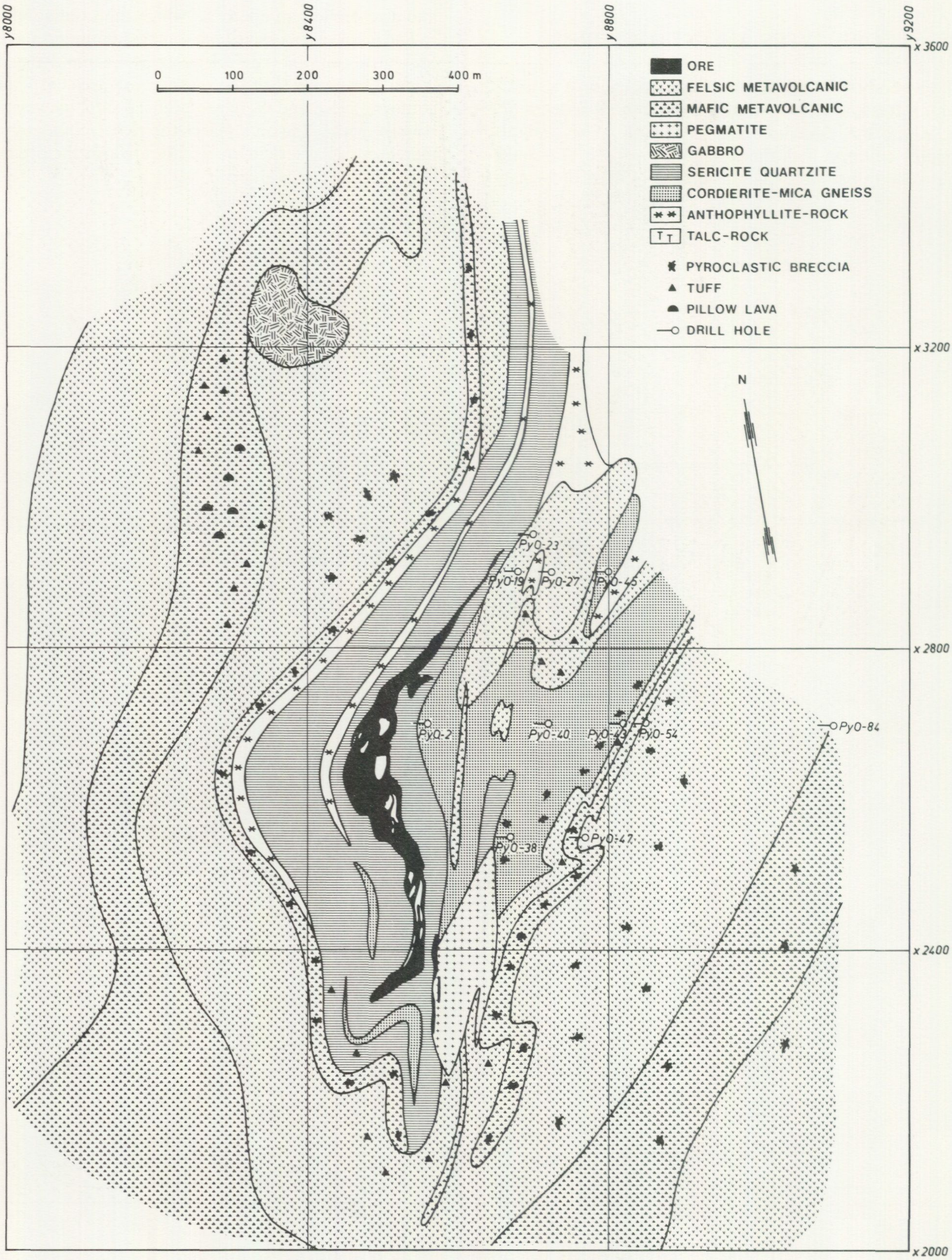


Fig. 14. Surface plan of the Pyhäsalmi ore deposit.

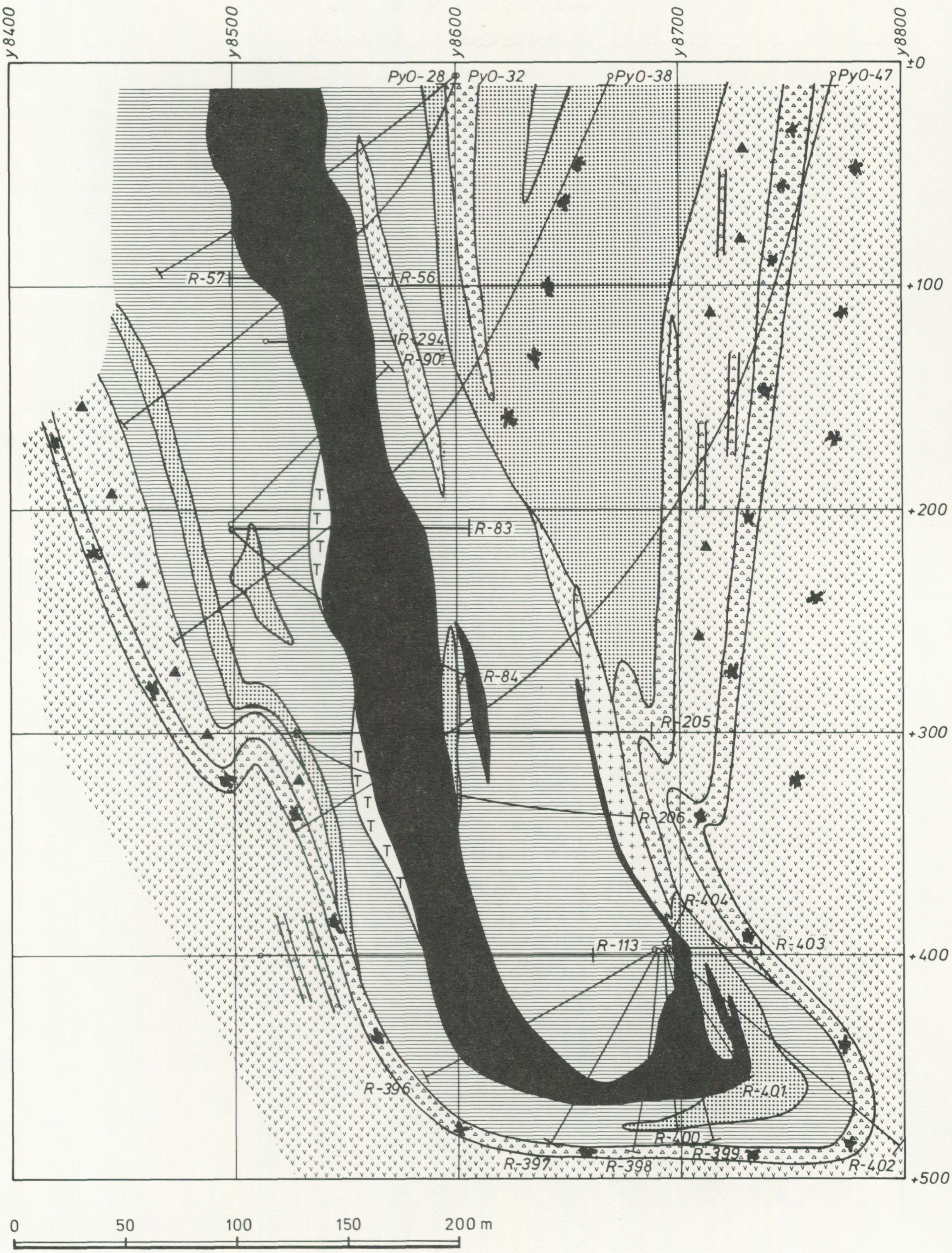


Fig. 15. Vertical cross-section (X = 2550) of the Pyhäsalmi ore deposit. For explanations, see Fig. 14.

TABLE 3. Chemical composition of rocks from Pyhäsalmi mine area.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
SiO_2 (%)	48.9	50.8	47.2	50.8	78.1	71.5	75.3	75.02	72.60	70.53	54.94	49.43	46.51	54.3
TiO_2 (%)	0.48	0.47	0.57	0.48	0.13	0.12	0.09	0.25	0.17	0.18	0.52	0.52	0.53	0.14
Al_2O_3 (%)	14.1	14.8	14.45	14.33	10.1	10.7	11.7	13.22	12.09	14.03	15.15	16.35	16.56	9.44
FeO tot (%)	10.5	9.48	10.72	11.19	2.82	1.79	0.85	2.71	5.76	5.38	8.82	10.46	12.26	2.80
MnO (%)	0.20	0.18	0.23	0.21	0.05	0.03	0.01	0.07	0.01	0.02	0.11	0.34	0.28	0.10
MgO (%)	5.18	4.55	6.50	5.39	0.76	0.57	0.07	0.37	0.57	1.11	5.37	10.45	8.57	25.00
CaO (%)	8.94	6.32	8.89	8.88	2.04	0.68	0.65	0.90	0.18	0.01	0.70	4.75	1.69	0.52
Na_2O (%)	3.95	5.22	2.89	2.79	2.63	5.36	6.03	5.35	0.49	0.32	2.44	1.83	0.45	0.78
K_2O (%)	0.25	0.67	0.73	1.28	1.03	0.72	0.49	1.54	2.64	2.96	1.68	0.94	1.95	0.41
P (%)	0.08	0.12	0.04	0.04	0.00	0.00	0.00	0.02	–	–	0.03	0.03	0.03	0.00
S (%)	0.25	0.24	0.09	–	0.02	0.07	0.05	0.30	5.75	6.07	1.92	0.80	3.38	6.67
Fe (%)	0.92	2.30	1.38	3.07	2.02	1.23	0.64	1.65	–	–	6.07	2.82	8.90	1.59
As (%)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Cu (ppm)	200	107	15	52	15	9	14	27	288	262	134	93	882	301
Zn (ppm)	28	55	37	54	141	90	28	162	1018	152	68	66	579	(9.9%)
Ni (ppm)	13	34	15	18	3	4	5	3	4	4	18	33	45	19
Co (ppm)	14	21	13	26	6	6	8	12	9	18	30	42	46	0
Pb (ppm)	6	22	8	22	18	9	9	34	78	57	20	44	43	512
Ag (ppm)	–	1.6	0.7	–	–	–	–	1	0.3	2.3	1.2	1.5	3.9	6.7
Cd (ppm)	2	2	<1.5	2	2	2	2	<1.5	6	3	3	<1.5	3	–
Sr (ppm)	58	100	207	228	158	108	75	98	49	27	63	104	69	304
Ba (ppm)	437	819	1206	507	528	701	319	659	2961	2463	788	751	1143	(2.87%)
Zr (ppm)	36	36	59	62	135	156	178	163	105	106	76	39	35	280
Cr (ppm)	134	185	200	150	257	261	177	120	200	200	140	140	190	0

1. Basic metalava, railway cutting (1 anal.)
2. Basic metalava, road cutting (1 anal.)
3. Basic metavolcanite, +210 level, 80–100 m west of ore (4 anal.)
4. Basic metavolcanite, drill hole PYO-84, 200 east of ore (7 anal.)
5. Quartz-porphyry, 400 m west of ore (1 anal.)
6. Quartz-porphyry, 200 m west of northern end of ore (1 anal.)
7. Quartz-porphyry, 300 m SE of southern end of ore (1 anal.)
8. Quartz-feldspar-porphyry, drill hole PYO-27, 80 m east of ore (5 anal.)
9. Sericite quartzite, hanging wall, drill hole PYO-40 (10 anal.)
10. Sericite quartzite, foot wall, drill hole PYO-40 (12 anal.)
11. Cordierite gneiss, hanging wall, drill nole PYO-43 (9 anal.)
12. Cordierite-anthophyllite gneiss, hanging wall, drill hole PYO-45 (6 anal.)
13. Cordierite-anthophyllite rock, +210 level. foot wall (4 anal.)
14. Talc-chlorite-rock + ZnS-ore, foot wall +360 level (1 anal.)

The ore contains various country rock fragments, the largest being several thousands of cubic metres in size. Most of the fragments are felsic volcanics, although limestone fragments are also common; fragments of altered rocks are very rarely encountered. Some of the fragments occur randomly in the ore whereas others occur in zones parallel to the longitudinal axis of the ore body; the fragments can sometimes be recognized as boudins.

The chemical composition of the Pyhäsalmi ore varies considerably both horizontally and vertically. The ore is composed mainly of pyrite, with sphalerite and chalcopyrite as minor components. As a rule sphalerite is concentrated in the middle of the ore and chalcopyrite near the contacts. The highest barite contents tend to be in the sphalerite-richest portions.

The Pyhäsalmi ore can be divided into the following types:

1. Coarse massive pyrite ore. This ore type is most common and contains variable amounts of sphalerite and chalcopyrite. In addition, galena, arsenopyrite and magnetite occur as accessory minerals. Barite and calcite are confined to the zinc-rich variants. The ore often exhibits banded structure due ot the sphalerite bands.

2. Porphyroclastic ore with rounded or fractured pyrite phenocrysts in a fine-grained matrix. Phenocrysts are 5–10 mm in diameter. The matrix consists of pyrite, sphalerite and occasional chalcopyrite. The "porphyry" ores were originally massive pyrite ores which obtained their current structure during tectonic movements and deformation after crystallization.

3. Disseminated ore. This ore type occurs near the contacts between the massive ore and the country rock. Pyrite is normally the only sulphide mineral but chalcopyrite and sphalerite occur also sporadically. Some of the disseminated ores show breccia structures, and this ore type may be interpreted as a primary stringer mineralization.

4. Pyrrhotite ore. A selvage of pyrrhotite ore occurs in the southeastern parts of the massive ore, where a pegmatite cuts the ore. Observations indicate that the pyrrhotite is a secondary alteration product of pyrite as a result of the thermal effect on the pegmatite.

5. Ore accumulations at the contact between massive ore and country rock. Accumulations of ore minerals occur at the contacts with country rock fragments. The major ore minerals in this ore type are galena, arsenosulphides, tellurides, molybdenite, as well as silver and gold minerals. These accumulations were produced by remobilization due to tectonic movements after crystallization of the massive ore.

STOP DESCRIPTION

Underground exposures

Stop 11:1. – Unaltered and altered metavolcanics; felsic metavolcanics, sericite quartzites, cordierite-bearing rocks.

Stop 11:2. – Stringer mineralization; pyrite stringer in sericite quartzite.

Surface exposures

Stop 11:3. – Mafic pyroclastic metavolcanics with intensive deformation structures.

Stop 11:4. – Contact between mafic metalava and felsic metatuff.

Stop 11:5. – Mafic and felsic dykes; pyroclastic rocks.

DAY 5. THE OUTOKUMPU (KERETTI) MINE

J. Parkkinen

Since the legendary third drill hole sunk by Dr. Otto Trüstedt in 1910 three massive Cu-Co-Zn sulphide deposits, namely those of Outokumpu (now Keretti), Vuonos and Luikonlahti, and one Ni-Co deposit (Vuonos) have been exploited in the Outokumpu District (Fig. 16). The Keretti Mine, together with several promising prospects, is active at the moment. The Cu-Co-Zn reserves mined to date amount to about 40 million metric tons and the activated reserves still minable to 2 million metric tons.

THE OUTOKUMPU ASSOCIATION

The principal hosts of the ore bodies in the district are quartz and skarn rocks enveloping large serpentinite-dolomite lenses. Known as the Outokumpu Association, the rocks constitute a ribbon-like meandering and intensely folded zone surrounded by Early Proterozoic flysch metasediments: mica schists and gneisses with black schist interlayers that deposited on the Archaean basement (Gaál *et al*. 1975).

Certain compositional features, shared by all members of the Outokumpu Association, include low Cu-(8–90 ppm), high Ni-(400–2000 ppm), high Co-(50–150 ppm) and high Cr_2O_3-(1000–5000 ppm) contents. Consequently, chromium-bearing minerals are common, especially in skarn rocks, and pentlandite is a frequent constituent in the sulphide phase of the rocks in the Outokumpu Association.

The serpentinites, with relics of dunites, peridotites and pyroxenites (Haapala 1936), are carbonated and chloritized to variable degrees. They grade into dolomites, particularly at the margins of the lenses. Small occurrences of gabbros and banded amphibolites, possibly pillow lavas, have been encountered in association with the serpentinites (Park & Bowes 1981). Bromine and chlorine are enriched in the serpentinites (Rehtijärvi 1984), and it has been proposed that the serpentinites are of mantle origin and crystallized in an oceanic milieu (Koistinen 1981). Neither internal stratification of the serpentinite lenses nor paths of material transport in these lenses are known.

ORE DEPOSITS

The formation of the Outokumpu ores was contemporaneous with the precipitation of carbon and/or carbonate-bearing chemical sediments, "the Outokumpu quartzites" (Huhma 1976). Age determinations (the U-Pb zircon age of gabbros and the lead age of the ore) indicate that this occurred 1970 to 2100 Ma ago (Koistinen 1981). It seems safe to assume that the quartz-rich cherts formed on the sea floor. This is supported by the presence of chlorine (0–200 ppm) and bromine (0–20 ppm) in the quartz rocks.

Furthermore, the isotopic composition of ore sulphur in the Vuonos deposit indicates that the ore-forming fluids have an exhalative origin (Mäkelä 1974, 1977).

In summary, the ore with its host originated as a result of marine exhalation, and together with the country rocks it underwent metamorphism of the amphibolite facies along with polyphase folding c. 1.85–1.9 Ma ago (Peltola 1978, Koistinen 1981).

UNFOLDING OF THE PRESENT STRUCTURE

Although quartz and skarn rocks as well as massive ore commonly show banded textures and structures, it has been difficult to identify and trace premetamorphic layers in these rocks. However, a local example of probable stratification on a macroscale has been constructed (Figs. 17 and 18). It is possible that the Cu-Co-Zn deposits developed during regional deformation from one wide and thin horizon, which was located in the carbonaceous upper part of a 10 to 30 m thick, possibly discontinuous, chert layer above the carbonate-bearing basal unit (Koistinen 1981). The ore-bearing chert layer deposited on top of a 100–200 m thick ultramafic plate. The primary structures, derived by unfolding of the present ones, highlight some further problems:

(1) The cherty quartz rocks sandwich the ultramafic plate. Is this due to tectonic activity or did the ultramafics intrude the pre-existing chert or gel? Are the cherts a leachate product of the carbonated peridotite?
(2) The lithological boundary between the quartz-rich black schists and the topmost quartz rocks of the Outokumpu Association (which are relatively rich in carbon and sulphur) is obscure. On an outcrop scale there seems to be a gradation from one to the other.

THE Ni OCCURRENCES

The role of the Ni-Co deposits or Ni occurrences is controversial. The deposits, which also are called disseminated ore in stockworks, have been shown to bear several characteristics typical of feeding channels (Treloar *et al*. 1981). These include e.g. the composition (Table 4) and the chemical peculiarities of the host and near-by rocks. These chemical features have been shown to be pre-metamorphic and are now in the form of a cordierite-anthophyllite-chlorite-garnet assemblage, which is not common elsewhere. On the other

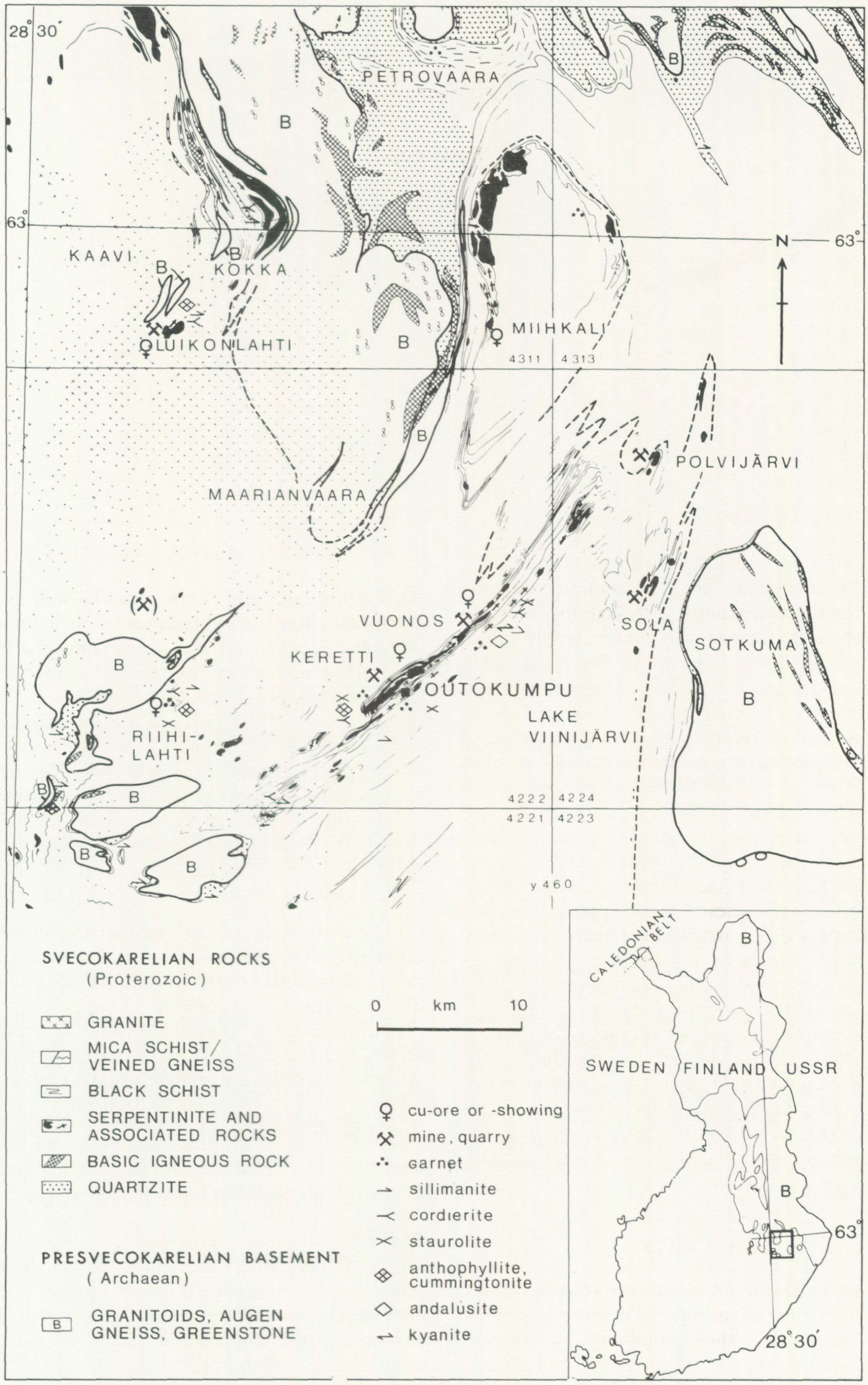


Fig. 16. General geology of the Outokumpu District. After Huhma (1970, 1971) and Koistinen (1981).

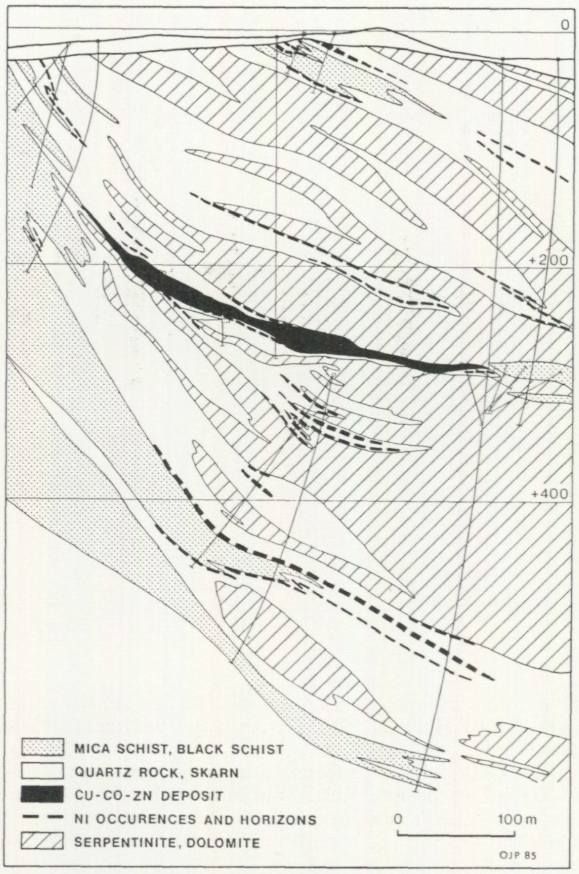


Fig. 17. Geological profile 44 of the Keretti mine, middle of the deposit. On the left, mica and black schists, which form the top of the Outokumpu Association and on the middle right, schists, which form the bottom.

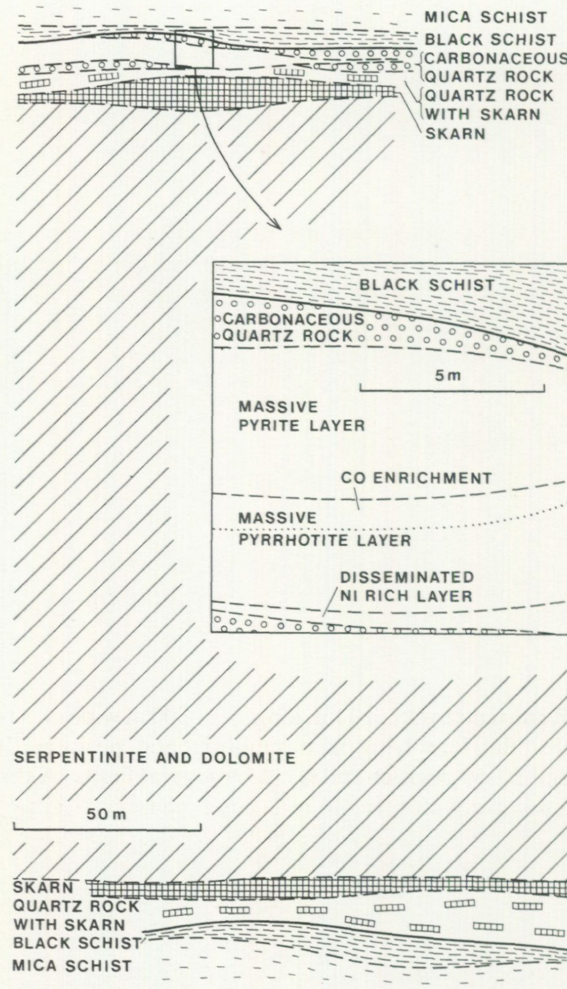


Fig. 18. A tentative diagram; an ore-bearing sequence of the Outokumpu association unfolded. Based on information obtained from the Keretti mine.

hand, the Ni occurrences show a wide regional distribution with and without signs of Cu-Co-Zn ores. At Keretti, the Ni occurrences have been met with at the upper and lower edges of, and in contact with, the Cu-Co-Zn deposit. It has also been found in the same quartz rock horizon hosting the latter, both above and below, as indicated in Fig. 17. In the present context it has, therefore, been located as if it simply was a layer preceding the deposition of the Cu-Co-Zn ores (Fig. 18). The Ni occurrences vary slightly in composition at different localities (Fig. 19).

THE ORDER OF DEPOSITION

The unfolded Keretti ore deposit (Fig. 18) represents a sequence which may give us the key to the order of deposition of various elements. Deposition started with Ni-bearing fluids, poor in iron and sulphur. Next came Cu, Co, Zn and more iron and sulphur-bearing fluids forming the bulk of the body: Cu rich pyrrhotite overlain by pyrite layers. The enrichment of Zn at the hanging wall margin of the upper edge of the deposit can be attributed to mobilization during

TABLE 4. Average composition of the Keretti Cu-Co-Zn and Ni-Co deposits.

%	Cu	Co	Ni	Zn	Fe(S)	S	Ag ppm	Au ppm	SiO2	MgO	CaO
Cu-Co-Zn	3.8	0.24	0.12	1.0	28.0	25.3	9	0.8	38.0	0.4	0.5
Ni-Co	0.35	0.14	0.47	0.1	6.3	3.9		0.15	82	3	2

In addition, the Cu-Co-Zn deposit contains 450 ppm C, 150 ppm Cr_2O_5, 150 ppm V_2O_5, 20 ppm U_3O_8, 50 ppm Pb, 20–150 ppm Sn, 25–50 ppm Se, 6000 ppm Al_2O_3 and 1000 ppm MnO.

deformation of the body. The same may apply to the peculiarities found in the distribution of cobalt. Thus, in the "normal" rocks of the Outokumpu Association, the Ni/Co ratio is high, being c. 10–20 (Fig. 19). In the Ni occurrences or Ni-Co deposits it is c. 3–10, in the vicinity to the Cu-Co-Zn deposit it is 1–3, but in the Cu-Co-Zn deposit it is 1–0.2. This is reflected by the Co-contents of the major Ni-bearing mineral, pentlandite, but also of pyrite (Table 5). Several successive phases of crystallization, coexisting in single pyrite grains, and the amount of cobalt increasing with crystal growth and along with the younging of crystal generations (Hänninen 1981), indicate that cobalt was mobile at a rather late phase or until the peak of metamorphism (Pyrite I to III, Table 5).

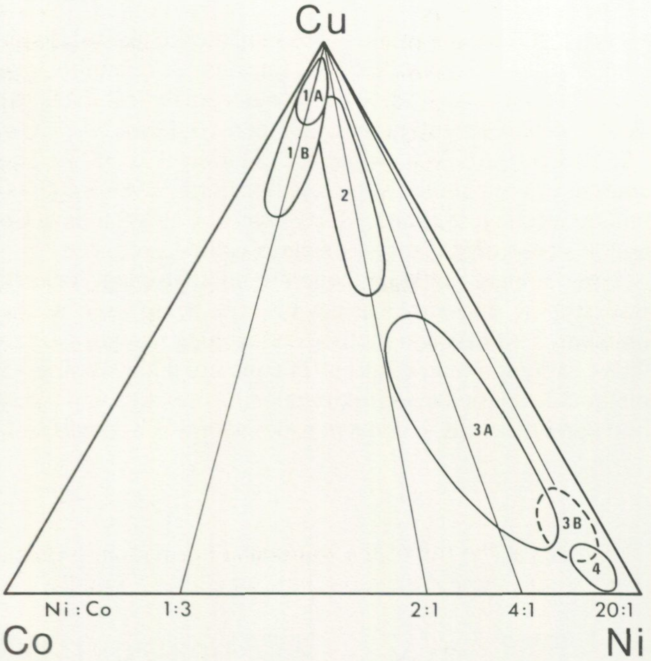


Fig. 19. A tentative Co-Ni-Cu diagram. Based on data by Huhma and Huhma (1970), Huhma (1976), Treloar *et al.* (1981) and Parkkinen and Reino (1985).
1A. Cu-Co-Zn deposits of Keretti and Vuonos, massive ore types.
1B. Cu-Co-Zn deposits of Keretti and Vuonos, disseminated ore types.
2. Low Cu, high Ni margins of the Keretti Cu-Co-Zn deposit.
3A. Typical Ni-Co deposits and Ni occurrences including types close to the contacts with serpentinite.
3B. Ni occurrences in quartz rock and close to the contacts with black schist.
4. Typical non-anomalous rocks of the Outokumpu Association.

EXCURSION PROGRAMME

THE KERETTI MINE

The Keretti deposit is a 4 km long, 100–300 m wide and 1–40 m thick flat lens lying in a subhorizontal position. It is inclined 20–50 degrees and is cut by several faults. A thrust and a reverse fault divide it into three major bodies, two of which crop out. The deposit dips gently to a depth of 300 m and rises back to a depth of 200 m without reaching the surface on this limb (Fig. 20). Most of the ore reserves (originally 28 million metric tons) have been exhausted since mining started in 1913.

The ore occurs in the host rocks as heavy dissemination, banded or nearly massive ore and ore breccia. Two major types, pyritic and pyrrhotitic, predominate, the pyritic ore forming the core, which is enveloped by the pyrrhotitic ore. The pyritic type is absent at the edges and northeastern end of the deposit. There is a marked Co enrichment in both ore types near the lower edge of the deposit and a Zn enrichment next to the hanging wall contact with country rock at the upper edge. In places, a high Ni – low Co zone appears as dissemination in the quartz rock at the margins of the deposit (Fig. 17).

TABLE 5. Compositions of main sulphide minerals, Keretti Cu-Co-Zn ore deposit. Data from Huhma (1967), Mikkola & Väisänen (1972) and Hänninen (1981).

Mineral	%Cu	%Co	%Ni	%Zn	%Fe	%S	Remarks
Chalcopyrite	34.6	0.01	0.01		30.4	34.0	
Pentlandite		33.0 1–40	17.0 10–35		14.09 10–35	35.3 33–36	Mean Range
Sphalerite	0.05 –0.1	0.25 0.1–0.5	 –0.1	57.5 53–64	8.5 –10	33.0 32–34	Mean +Mn: Range 0–6%
Pyrite Pyrite I Pyrite II Pyrite III		0.7 –6.0 –0.55 0.38–1.16 0.88–2.21	0.05 –0.2 –0.28 –0.09 –0.03		46.0 40–46	53.0	Mean Range Range Range Range
Pyrrhotite	0.04 –0.06	0.1	0.2 0.1–0.3	0.02 –0.04	60.1 57–61	39.5 39–43	Mean Range

The major minerals in the deposit are pyrrhotite (23.2%), pyrite (21%), chalcopyrite (11%), sphalerite (1.7%), pentlandite (0.5%), quartz (38%), serpentine, dolomite, talc and skarn minerals (2.2%). For more analytical data, see Tables 4–5. Currently, the mill feed contains 2.7% Cu, 0.21% Co, 0.6% Zn, while the dilution is c. 18%. The amount of ore planned to be handled during 1986 is 400 000 million metric tons; hence 10 160 tons of Cu, 589 tons of Co and 885 tons of Zn in concentrates will be produced.

Three mining methods, concrete pillar stoping, inclined wall stoping and sublevel caving, are being used at the moment. The first two methods allow high recovery, up to 98%, with minimum dilution. In concrete pillar stoping – a method developed in Outokumpu – the ore block is divided into parallel rooms, 6 and 8 m wide, with vertical walls and, usually, perpendicular to the strike of the body. In the first phase the six meters wide rooms are stoped and filled with concrete. In the second phase the eight meters wide ore pillars are mined and the stopes are filled with classified tailings, gravel and gangue.

The mine comprises five shafts, a ramp, two main working levels and an underground crushing station. Other shafts serve for ventilation and the Keretti shaft, sunk in 1954, is provided with separate hoists for personnel and ore. The ore is hauled by dumper from the main working levels at depths of +250 and +285 to the jaw crusher at the +320 level. It then drops down into a 6000 tons bin through the crusher. At the +410 level it is fed to the automatic hoisting system and brought up to the concentration plant for crushing, screening, milling and, finally, flotation.

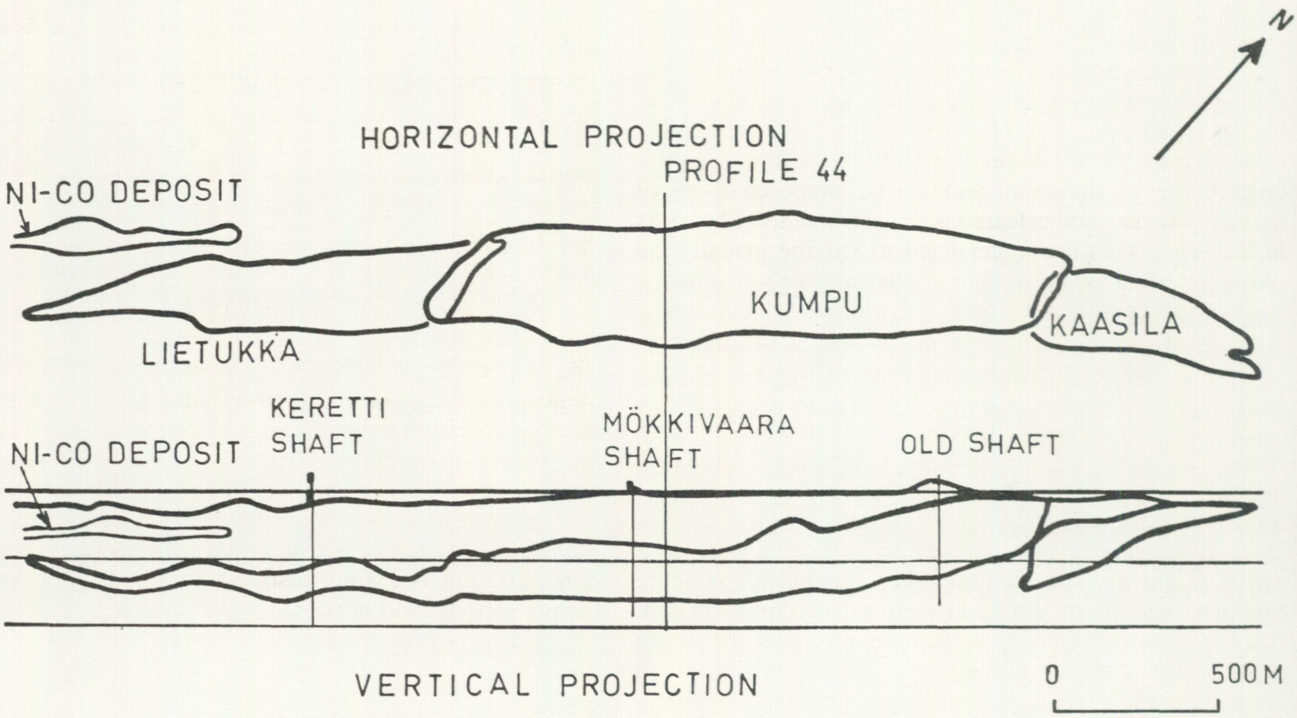


Fig. 20. Horizontal and longitudinal vertical projections of the Keretti ore deposit.

STOP DESCRIPTIONS

Surface

- 11–1 Boulders: various types of ore, skarn rocks, and serpentinite-dolomite.
- 11–2 Specimens, with polished surfaces, made from various ore types; articles made in the workshop of the mine.
- 11–3 Concentration plant.

Level +250

- 11–4 Mica schist and black schist of the country rock.
- 11–5 Banded quartz rock and skarn of the Outokumpu Association.
- 11–6 Talc schist and serpentinite of the Outokumpu Association.
- 11–7 Concrete pillar stopes and support devices of the mine.
- 11–8 Banded pyritic core type and massive pyrrhotitic margin type Cu-Co-Zn ore, and the contact with banded quartz rock.

Level +285

- 11–9 Maintenance hall with vehicles.
- 11–10 Diopside skarn and quartz rock of the Outokumpu Association.
- 11–11 Mica schist and black schist of the country rock.

DAY 6. THE ENONKOSKI NICKEL-COPPER DEPOSIT

L. Grundström

GEOLOGICAL SETTING

The Enonkoski Ni-Cu deposit 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 northeastern portion of the Laukunkangas intrusion (Grundström 1985).

Supracrustal gneisses and various plutonic rocks form the geological setting of the deposit in the Joutsenmäki-Laukunkangas region (Fig. 21). The supracrustal rocks can be subdivided into a volcanogenic section, in which diopside amphibolites predominate, and schists, composed mainly of metagreywackes and calcareous metasediments. The rocks in the schist area are migmatized to varying extent. The plutonites occur as major silicic or intermediate intrusions or as minor mafic-ultramafic bodies; the largest is the Joutsenmäki intrusion (Parkkinen 1975). The Laukunkangas intrusion is one of the minor bodies and has been dated to 1880±3 Ma.

The Laukunkangas intrusion is embedded in a metasedimentary mica gneiss and veined gneiss environment. A narrow but distinct zone of migmatic 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 large pluton but occurs as a separate minor body in an intensely migmatized metasediment suite.

The sulphides have accumulated in the ultramafic rocks at the eastern end of the Laukunkangas intrusion (Figs. 22 and 23). Scattered, lower-grade 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 main orebody.

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 m 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.

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 the ore is extraced 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 m × 1100 mm) at the +380 m level. The crushed ore is conveyed to a 1000 m^3 storage bin next to the shaft, where the ore is automatically hoisted with an 8 t. skip to a 2000 m^3 storage bin.

Fig. 21. Simplified geological map of the Joutsenmäki-Laukunkangas region, partly after Gaál and Rauhamäki (1971) and from Grundström (1985).

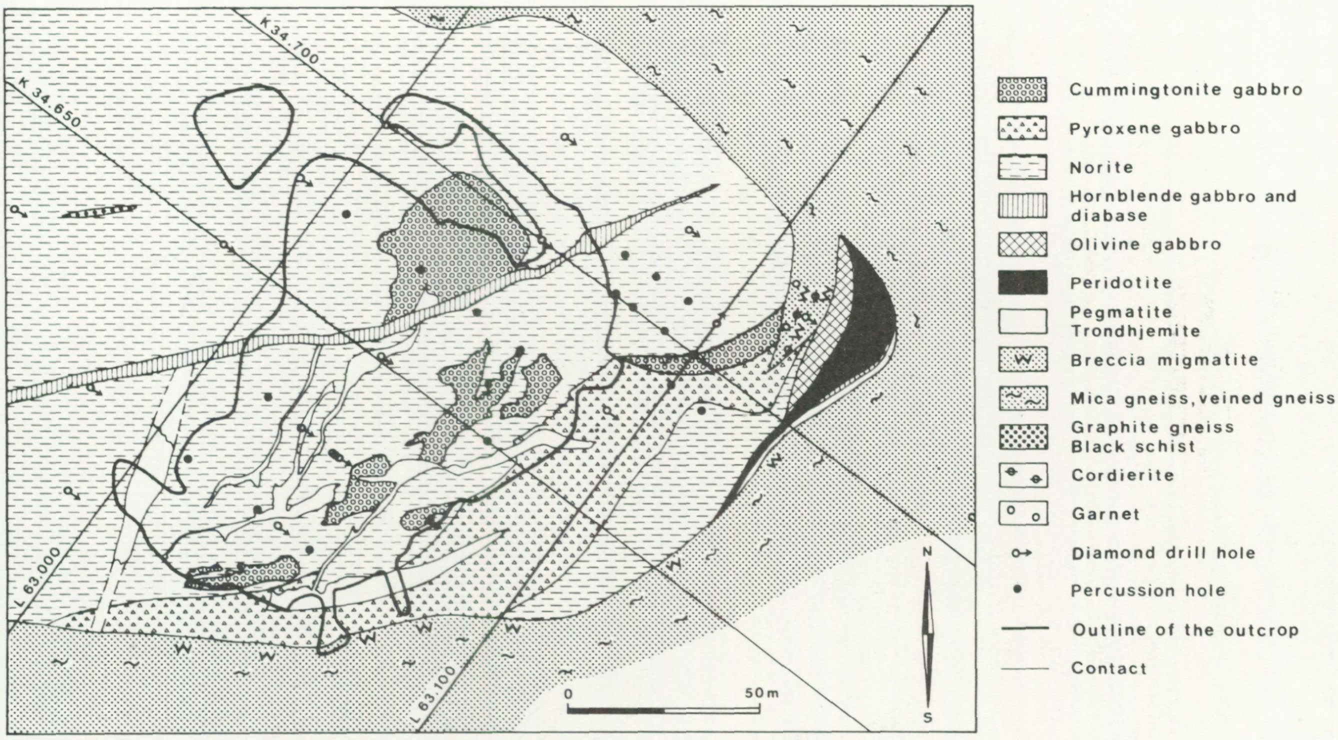


Fig. 22. Geological map of the Laukunkangas gabbro body.

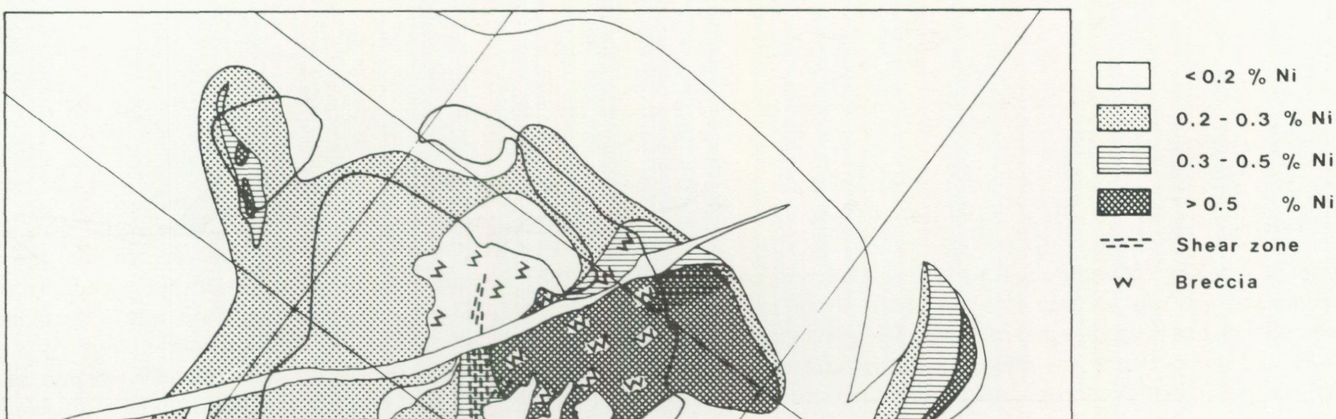


Fig. 23. Nickel contents of the Laukunkangas gabbro body.

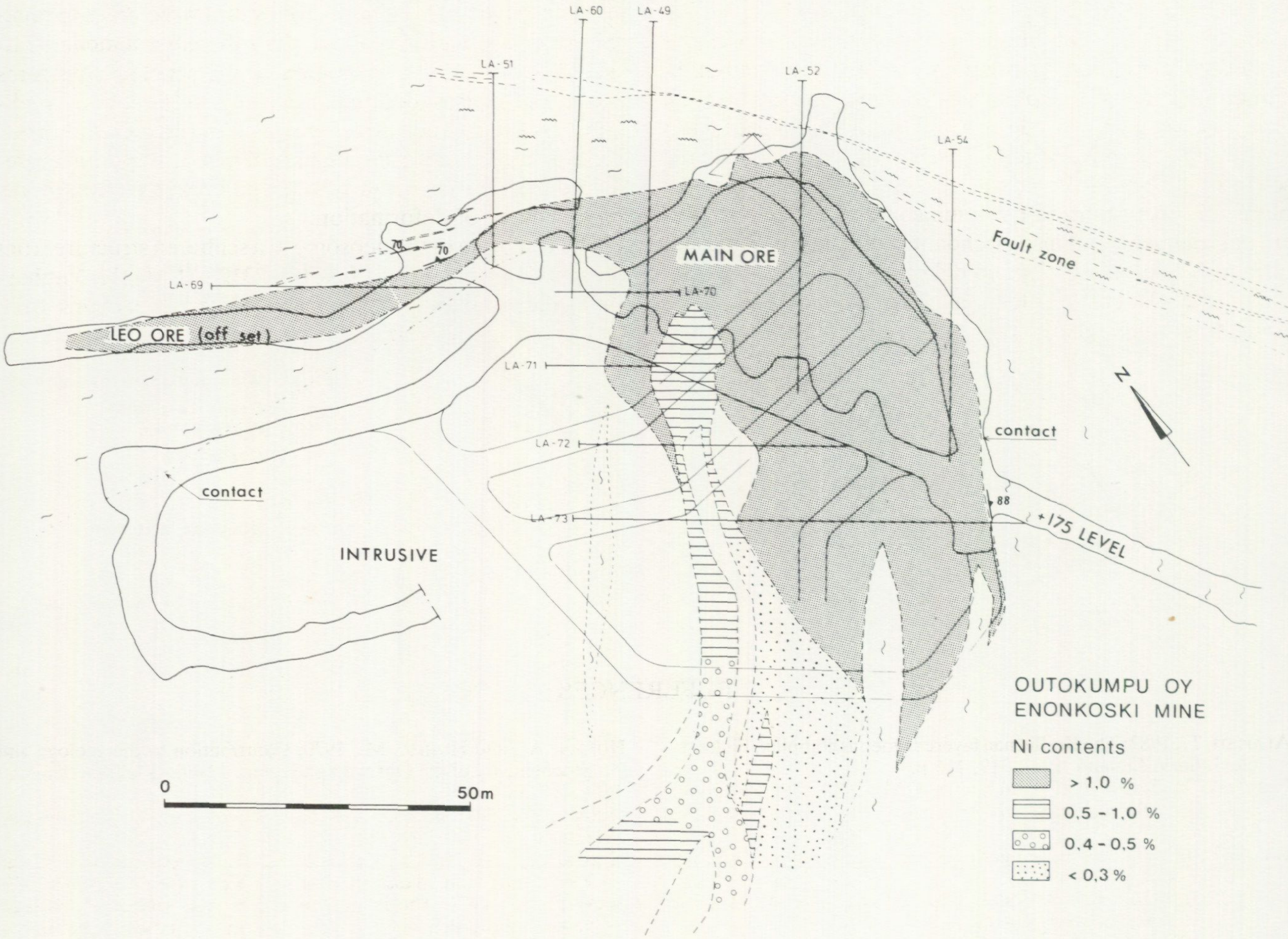


Fig. 24. Horizontal cross-section of the orebodies of the Enonkoski mine, + 175 m level.

STOP DESCRIPTIONS

Stop 13:1. – The Laukunkangas exposure. Overburden has been removed from an area covering about 10 000 m^2, and the bedrock has been mapped in detail. The geological map in Fig. 22 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 southeastern margin. The distribution of nickel in the exposure is illustrated in Fig. 23. 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.

Stop 13:2. – Underground visit. The excursion target is located in an exploration drift at the +175 m level (Fig. 24). The contact zone between the high-grade main ore and the host 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 peridotic 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.

Stop 14. – Juvola, 5 km northeast of the Enonkoski mine. Schollenmigmatites.

The Juvola area is located some 5 km northwest 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 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 show large variations 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 schollenmigmatite 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 tectonically and magmatically active 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 (H. Vanhala 1985) corresponding to the ages of detrital zircons from metagreywackes measured from elsewhere in Finland.

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