GEOLOGIAN TUTKIMUSKESKUS

GEOLOGISKA FORSKNINGSCENTRALEN
GEOLOGICAL SURVEY OF FINLAND

Eastern Finland Office
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ARCHEAN TERRAINS IN EASTERN FINLAND
Deal with: 4514, 4511, 4424, 4423, 4422, 4421, 4414, 4413, 4412, 4411, 4341, 4334, 4333, 4332, 4331, 4324, 4323, 4322, 4321, 4314, 4244, 4243, 4242, 4241, 4234.

The activities of the Archean Terrains in Eastern Finland Project (12201 and 210 5000) in Suomussalmi, Hyrynsalmi, Kuhmo, Nurmes, Rautavaara, Valtimo, Lieksa, Ilomantsi, Kiihtelysvaara, Eno, Kontiolahti, Tohmajärvi and Tuupovaara areas during years 1992 – 2001

GTK

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1. INTRODUCTION

1.1. ARCHEAN BEDROCK GEOLOGY AND MINERAL RESOURCES IN EASTERN FINLAND

The project "Archean terrains in eastern Finland" (GTK Project 12201) was initiated at the Kuopio regional office of the Geological Survey of Finland in early 1992, during a general restructuring of research and operational activities. The project thus represented a new approach to research in the Department of Bedrock and Mineral Resources, with Elias Ekdahl as program manager, seeking to more effectively integrate regional bedrock investigations and mineral exploration assessment.

In geographic terms the project covered a large part of eastern Finland (Figure 1.1) and had as its original objectives:

1. To continue and complete exploration-related investigations relating to gold mineralization in the Hattu schist belt, and to undertake similar assessments of the gold potential elsewhere in the Ilomantsi greenstone belt, especially between Kovero and Kiihtelysvaara, as well as further north, in the Kuhmo and Suomussalmi greenstone belts.
2. To undertake systematic bedrock mapping within the GTK 100 000 mapping program, including completion and revision of the Lentiira (4414 + 4432), Nurmes (4321) and Naarva (4333) mapsheets, and to provide a general regional overview of the evolution of the Archean bedrock of eastern Finland.

From 1994, the project goals were expanded to include potential for nickel mineralization associated with komatiitic volcanism, particularly in the Suomussalmi and Kuhmo greenstone belts.

Research in the early stages of the project was undertaken by Erkki Luukkonen (EJL, geologist), who was Project Leader from 1993 - 1998, Timo Heino (TOH, geologist 1993 - 1996), Markku Tenhola (MKT, geologist), Aimo Hartikainen (AAH, geologist), Markku Kilpelä (MAK, geologist, 1992 - 1995), Jouni Lerssi (geophysicist, 1992 - 1993), Antti Mäkelä (ASM, research assistant) and Martti Saastamoinen (MIS, research assistant). Between 1994 and 1998 additional contributions were made by geophysicists Jarkko Jokinen (JJ, 1993 - 1994) and Matti Niskanen (MJN, 1994-), and geologists Markku Kilpelä (MK) and Kimmo Pietikäinen (KJP, 1996 - 1998). Tapio Hakoaho joined the project in 1998, when Kimmo Pietikäinen also took on the role of Project Leader. GTK technical and support staff, including Tarmo Kemppainen (TK), Matti Haverinen, Ossi Heikkinen (OH), Pertti Huusko (PH), Seppo Karjalainen (SMK), Eino Leinonen, Pertti Moilanen, Hannu Repo, Urho Tolonen and Kauko Väänänen, were actively involved throughout the project in POKA drilling, till sampling, and in boulder-train and reconnaissance field investigations. Additional mapping was undertaken by undergraduate students employed on a contract basis during field seasons, namely Jukka Jokela (KJJ, 1992), Tua Welin (TCW, 1983 - 1991), Jussi Kinnunen (JPK, 1995 - 1997), Jyrki Liimatainen (JTL, 1999), Tero Niiranen (TTN, 1997 - 1998), Hannu Ojanen (1995), Iikka Ylander (IJY, 1994) and Jani Rautio (JJR, 1999).

Project planning made extensive use of previously available geological data from the Archean of eastern Finland and contiguous parts of Russian Karelia. This included a synthesis of Archean structural evolution based on regional mapping in the Kuhmo and Suomussalmi regions (Luukkonen 1992), as well as a review of GTK research and exploration for gold mineralization in the Hattu schist belt, published as Geological Survey of Finland Special Paper 17 (Nurmi and Sorjonen-Ward, 1993). Practical experience and results obtained during the latter investigations provided a useful background for designing project strategies in the Kuhmo and Suomussalmi greenstone belts.

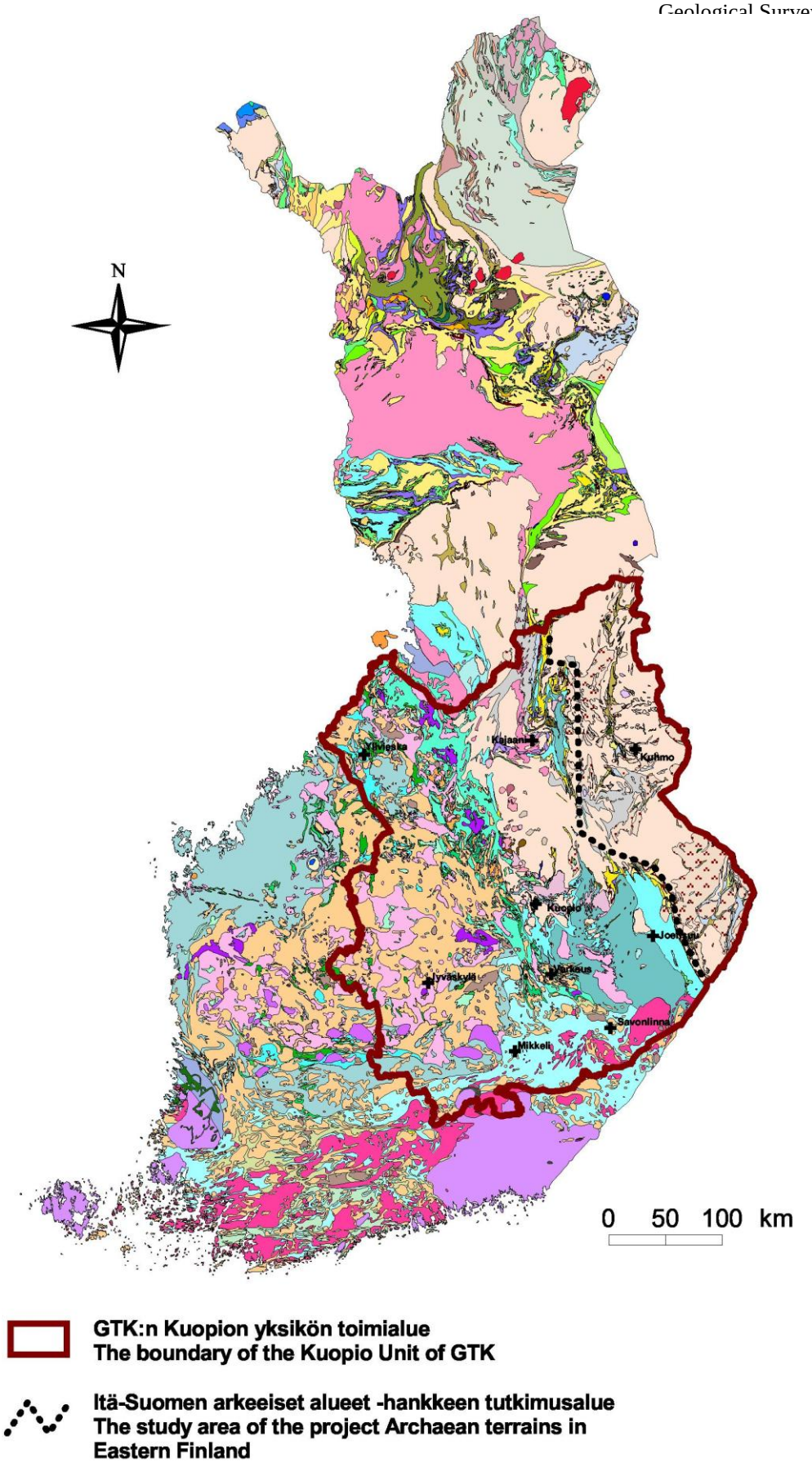


Fig. 1.1. Boundaries of the Kuopio Unit of GTK and location of the area studied in the GTK project “Archaean Terrains in Eastern Finland”.

In contrast, there was comparatively little understanding of controls on nickel mineralization associated with ultramafic volcanism. Therefore, collaboration was sought with research programs at the University of Turku in Finland and the Division of Exploration and Mining at CSIRO (Commonwealth Scientific and Industrial Research Orgainization), in Perth, Western Australia. Staff from GTK also participated in exchange visits to key terrains, to become more familiar with volcanic facies architecture and processes and controls on the distribution of nickel mineralization.

Specific tasks assigned to the project "Archean terrains in eastern Finland" (GTK Project 12201) were as follows:

1. Completion of assessment of gold mineralization in the Hattu schist belt segment of the Ilomantsi greenstone belt.
2. Delineation of terrain potentially prospective for gold in other greenstone belts in eastern Finland.
3. Assessment of potential for nickel mineralization associated with komatiitic volcanism in the Archean greenstone belts of eastern Finland.
4. Complete and where necessary, revise regional mapping within the Lentiira (4414 + 4432), Nurmes (4321) and Naarva (4333) 100 000 mapsheet areas.
5. Reconnaissance and detailed bedrock mapping in the Kuhmo and Suomussalmi greenstone belts, to facilitate understanding of the occurrence and distribution of mineralization.
6. Local to targeted prospect-scale till geochemical sampling to support mineral exploration in the Ilomantsi, Kiihtelysvaara, Kuhmo and Suomussalmi greenstone belts.
7. Regional to local scale exploration geophysics in the Ilomantsi, Kuhmo and Suomussalmi greenstone belts.
8. Exploration-oriented research and publication of results.
9. Reporting of results according to GTK and ministerial requirements and guidelines.

Exploration-oriented research was undertaken from regional to local scale, using the following approach:

1. Selection of areas considered prospective for Ni and Au mineralization
2. Identification of potentially favourable rock units (komatiitic Ni deposits)
3. Identification of potentially favourable structural architecture and alteration (structurally controlled orogenic Au deposits)
4. Assessments based on previous investigations undertaken by GTK (and its predecessors), the universities of Oulu and Turku, and exploration by Outokumpu Mining (and its predecessor, Outokumpu Oy Malminetsintä).
5. Direct targeting of nickel and gold mineralization

Exploration strategies and methods:

1. Selection of areas considered prospective for Ni and Au mineralization and target delineation
   a) integrated interpretations based on
   - regional to prospect scale bedrock mapping
   - low-altitude airborne geophysical data
   - regional to prospect scale till geochemical data
   - lithogeochemical analysis
   - glacial boulder tracing
   - POKA and deeper diamond drilling of bedrock

2. Identification of potentially favourable rock units (komatiitic Ni deposits)

a) Recognition of potentially suitable komatiitic units
b) Delineation of appropriate volcanic facies and reconstruction of environment of eruption and/or emplacement
c) Determination of structures and textures within komatiites
   - identification and interpretation of primary features
   - reconstruction of primary facies relationships after assessing effects of structural disruption
d) Assessment of Ni-prospectivity using lithogeochemical data
e) Application of geophysical techniques to reveal paleochannel signatures
f) Tracing of mineralized glacial erratics
g) Detailed outcrop mapping at prospect scale
h) POKA and deep diamond drilling

3. Identification of potentially favourable structural architecture and alteration (structurally controlled orogenic Au deposits)
   a) Recognition of potentially favourable structural trends based on bedrock mapping, interpretation of airborne and ground-based geophysical data
   b) Assessment of prospective structures based on detailed till geochemical surveys
   c) Delineation of prospective zones with alteration features characteristic of hydrothermal gold mineralization
   d) Tracing of anomalous glacial erratics
   e) Selective POKA and deep diamond drilling

4. Utilization of previously available information
   a) Bedrock geological data obtained from Outokumpu Mining
   b) Reports produced (in Finnish) by various research programs undertaken by the Geology Department of the University of Oulu, in particular the Kuhmo, Archean Terrains, and North Karelia mineral resource assessment projects ("Kuhmon malmiprojekti", "Arkeeisten alueiden projekti" and "Pohjois-Karjalan malmiprojekti" respectively)
   c) Unpublished undergraduate (pro gradu) and doctoral theses, company reports, publications resulting from university-based research projects, and reports and maps produced during previous GTK investigations

Collaboration within GTK:

- Processing and interpretation of low-altitude airborne geophysical data
- Application and development of further specialized geophysical techniques
- Reconnaissance metamorphic studies
- Isotopic age determinations
- Mineralogical studies(sulfides and metamorphic silicate mineral assemblages)
- Studies of surficial and glacial sediments in relation to mineral exploration

Collaboration with other organizations:

- Deep seismic (refraction) surveys conducted by the Department of Geophysics of Oulu University
- Paleovolcanology of komatiitic magmatism and controls on nickel mineralization, with the University of Turku and CSIRO Division of Exploration and Mining
- Scientific exchanges with researchers from various institutes in Russia

1.2. PREVIOUS INVESTIGATIONS

The Archean bedrock of eastern Finland (Figure 1.2) had been mapped at reconnaissance (1: 400 000) scale by the Geological Survey of Finland (Geologian Tutkimuskeskus, known formerly as Geologinen Komissio and Geologinen tutkimuslaitos) during the early part of last century (Frosterus & Wilkman 1920b, 1921, 1924a, b; Matisto 1954, 1958). More detailed mapping was undertaken later within the 1: 100 000 scale bedrock mapping program, including the mapsheets Ilomantsi (Lavikainen 1973), Eno (Laiti 1983; Kesola 1998), Tohmajärvi (Nykänen 1967, 1968), Kiihtelysvaara (Nykänen 1971a, b), Oskajärvi (Lavikainen 1975, 1986), Kuhmo (Hyppönen 1973, 1976, 1978, 1983; Luukkonen 1993, 2001), Hyrynsalmi (Luukkonen 1986) ja Suomussalmi (Luukkonen 1987, 1988). Further detailed mapping of greenstone belts in particular, was undertaken through various research programs at the University of Oulu, funded by the former Ministry of Trade and Industry (MTI), including the Kuhmo Mineral Resource Exploration Project (Kuhmon Malmiprojekti), the Archean Terrains Project (Arkeeisten alueiden projekti) and the Karelian Mineral Resource Exploration Project (Pohjois-Karjalan malmiprojekti), summarized by Piirainen (1985). The Kuhmo Komatiite Project undertaken by the University of Turku was also in part funded by the Outokumpu Foundation. Mapping and resource estimation for Archean iron formations in eastern Finland was also carried out within the project supported by Rautaruukki Oy (Niiniskorpi 1975).

Suomen Malmi Oy carried out extensive exploration activity throughout the Kuhmo greenstone belt, as a result of which the Arola nickel occurrence was found, in 1962. Outokumpu Oy Malminetsintä (later known as Outokumpu Mining) also undertook exploration at various stages from the 1950's through to the 1980's within the Kuhmo, Ilomantsi, Kiihtelysvaara, Tipasjärvi, Kuhmo and Suomussalmi greenstone belts. This led to the discovery of molybdenum mineralization at Aittojärvi, north of Suomussalmi, and the Hietaharju and Peura-aho nickel prospects, also in the northern part of the Suomussalmi greenstone belt, as well as various zinc occurrences in the Kiihtelysvaara area, and the Rämepuro gold deposit in the Ilomantsi greenstone belt.

During the 1960's, Kajaani Oy Malminetsintä identified a number of Ag-Zn-Pb occurrences within the Suomussalmi greenstone belt and the Riihilampi nickel occurrence, in terrain to the east of the Kuhmo greenstone belt, and also undertook more detailed evaluation of the Taivaljärvi Ag-Zn-Pb deposit in the Tipasjärvi greenstone belt, which had been found initially during the research program undertaken by the University of Oulu.

Prior to commencement of the current project, GTK had already carried out extensive pre-competitive resource assessments, particularly with respect to gold, in the Ilomantsi, Kiihtelysvaara and Kuhmo greenstone belts, and for nickel in the Tainiovaara area near Lieksa. This earlier phase of GTK research activity resulted in the discovery and preliminary resource delineation of gold mineralization at Kuittila, Kivisuo, Korvilansuo, Muurinsuo, Pampalo and Valkeasuo, in the Hattu schist belt of the Ilomantsi greenstone belt, and at Palovaara in the Kuhmo greenstone belt.

During the initial stages of the project, priority was given to completion of other concurrent research programs in the Archean of eastern Finland, in particular to 100 000 scale bedrock mapping in the Lentiira(4414+4432) and Nurmes (4321) mapsheet areas and to gold investigations throughout the Hattu schist belt in the Ilomantsi region and at Palovaara in the

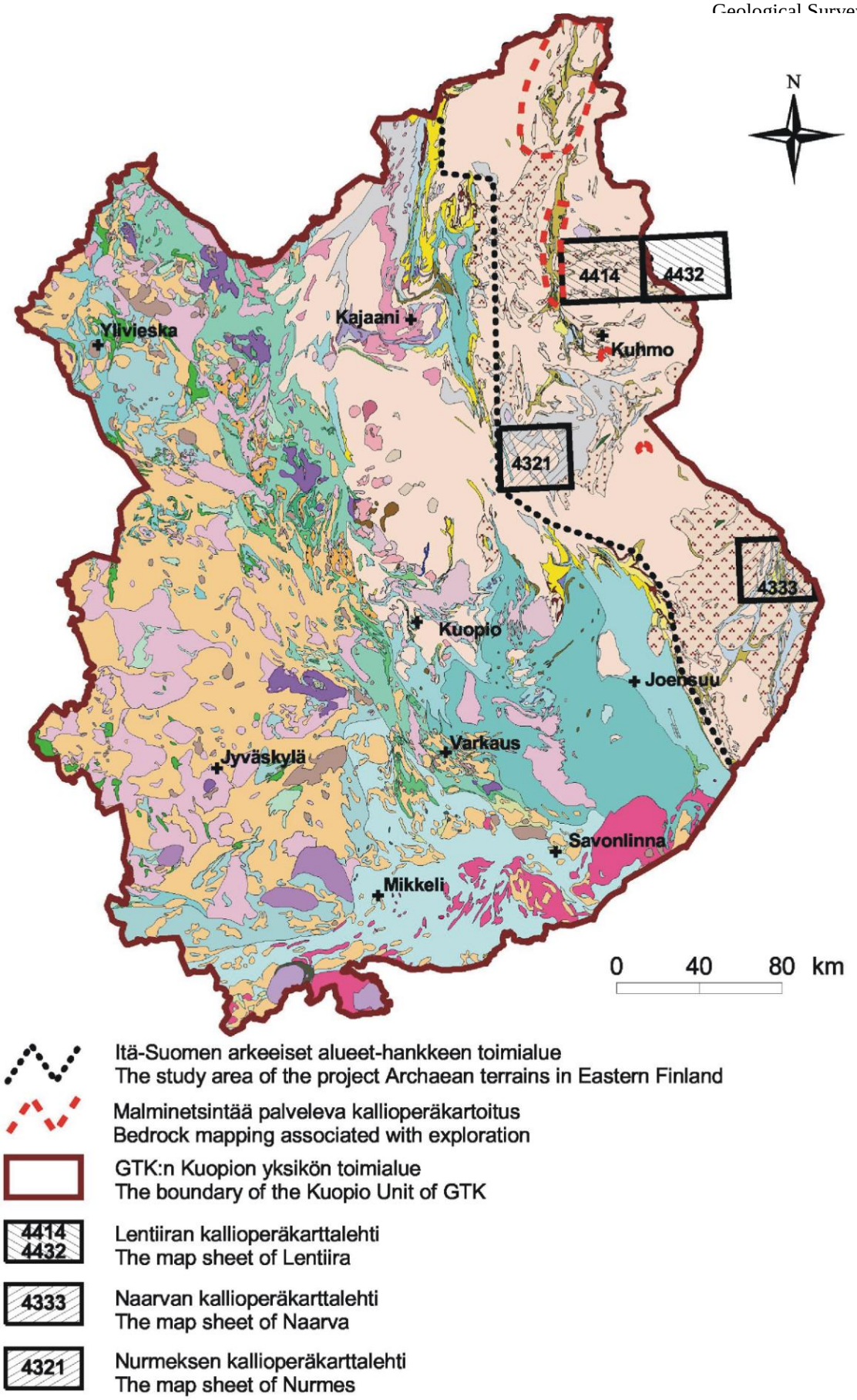


Fig. 1.2. Location of the area studied in the GTK project Archean Terrains in Eastern Finland, also showing areas covered by detailed mapping; bedrock geology after Korsman et al. (1997).

Kuhmo greenstone belt. Experience gained through research in the Hattu schist belt was further applied to gold exploration in the Kuhmo and Suomussalmi greenstone belts, at first in the central part of the Kuhmo belt, between Koskenmäki and Moisiovaara, and within the Tormua segment of the Suomussalmi belt. Interest in the potential of these areas initially arose as a result of anomalous gold values in mineralized boulders submitted to GTK by amateur prospectors. However, effective follow-up investigations required systematic till geochemical surveys and more detailed bedrock mapping, which was subsequently extended to cover large parts of the Kuhmo and Suomussalmi greenstone belts. This in turn required reallocation of resources from the 100 000 scale regional mapping program (Figure 1.2), resulting in postponement of final preparation of the Lentiira and Nurmes mapsheets.

Gold exploration in the Tormua belt led to the identification of the Saarilampi, Housuvaara (= Moukkori), Mullikko and Pahkalampi prospects, each of which was assessed and described in reports submitted in due course to the then Ministry of Trade and Industry for subsequent public tendering. As a result these occurrences were transferred to Endomines Oy in 1998. Subsequent gold investigations were focussed on the western part of the Suomussalmi greenstone belt and the Kuhmo greenstone belt, leading to the discovery of the mineralization at Paskolampi, Seipelä, Pahkosuo, Luoma, Syrjälä ja Kuikka. The latter prospect, which seemed the most promising, was awarded by the Ministray of Trade and Industry, after an international tendering process, to Outokumpu Mining Oy in 2001.

A number of other occurrences, all relatively small, were also discovered and documented throughout the Kuhmo greenstone belt, including Tammasuo, Palovaara, Timola, Aittojärvi, Jousijärvi, Mujesuo, Kangasjärvi, Louhiniemi, Lokkiluoto (initially assessed by Kajaani Oy) and Sepponen; the last of these occurrences is distinctive in being located some distance to the southeast of Kuhmo, outside the greenstone belt proper.

Systematic exploration for nickel sulfide mineralization associated with komatiitic volcanics in the Kuhmo and Suomussalmi greenstone belts began during 1993, based on exploration and research concepts developed by the CSIRO Division of Exploration and Mining in Western Australia. The first indications of this type of mineralization were soon found in the Suomussalmi greenstone belt and at Moisiovaara in the Kuhmo greenstone belt (Sika-aho prospect). Samples submitted to GTK from the Lieksa and Nurmes region led to follow-up investigations due to their resemblance to nickel mineralization at Tainiovaara; it was later established however, that the samples were in fact derived from crushed aggregate sourced from Tainiovaara itself.

Exploration for nickel during the period 1993-1996 was focused mainly on the Moisiovaara segment of the Kuhmo greenstone belt, in an attempt to better understand the context of the Sika-aho occurrence, as well as the mineralization potential of komatiitic olivine (± pyroxene) cumulates in the Suomussalmi greenstone belt. Field work at Sika-aho was completed during 1996 and a report was filed with the Ministry of Trade and Industry in 1997. However, due to the resource being rather small and of relatively low grade, there were no formal expressions of interest shown after the initial tendering process. Simultaneously, investigations were made into the Vaara-Kauniinlampi komatiite-hosted mineralization and Huutoniemi komatiitic cumulates in the Suomussalmi greenstone belt, as well as the Härkövaara komatiitic unit, located outside the main greenstone belt. Of these occurrences, the Vaara-Kauniinlampi mineralization appeared to have the greatest potential; field work and drilling continued until 1999, after which results were documented and a report submitted to the Ministry of Trade and Industry in early 2000. Outokumpu Mining Oy made a successful bid in response to the tendering process in the same year.

Research progress was affected from time to time by a shortage of resources, particularly when some staff were transferred to other duties. This meant that there was much less opportunity for undertaking detailed research into the character and origin of mineral occurrences, emphasis being on more practical aspects of mineral exploration and reporting. However, through interaction and collaboration with various other organizations, useful research results were obtained in the following areas:

- preliminary characterization of metamorphic history of the Kuhmo greenstone belt (Matti Pajunen, GTK)
- improved isotopic dating of critical rock units (Hannu Huhma, Irmeli Mänttäri and Matti Vaasjoki, GTK Isotope Laboratory)
- deep crustal architecture deduced from seismic refraction data, as described below in Section 2.6.6 (Jukka Yliniemi, Department of Geophysics, University of Oulu)
- fluid inclusion studies of mineral parageneses at a number of gold occurrences (see Section 2.6.5), in an attempt to constrain fluid compositions, sources and conditions during mineralization, (Matti Poutiainen, Department of Geology, University of Helsinki)
- mapping and characterization of eruptive and intrusive facies associations in greenstone belts, through collaboration with the University of Turku and the CSIRO Division of Exploration and Mining; this led to significant insights into the overall volcanic architecture and evolution and lithostratigraphical correlation within and between greenstone belts.

Throughout the duration of the project, there was close cooperation with organizations working in adjoining parts of the Fennoscandian Shield in Russia, in particular the Karelian Geological Institute of the Russian Academy of Sciences in Petrozavodsk, the Precambrian Institute of Geochronology at VSEGEI in Petersburg, and the exploration organizations State Company Minerals, also based in Saint Petersburg and Karelian Expedition, based in Petrozavodsk. Additional exchange of information and reciprocal visits took place between GTK staff and geologists working in Archean terrains in other countries, including Australia, Canada, Greenland and South Africa.

Because of the generally poor exposure of bedrock in the greenstone belts of eastern Finland, drilling was essential in better defining rock units and in routine assessment of mineral potential. Reduced demand for drilling and analysis in northern Finland during the course of the project resulted in additional resources and capacity being made available, which greatly enhanced the results of the project.

2. SUMMARY OVERVIEW OF INVESTIGATIONS CARRIED OUT DURING THE PROJECT

2.1 BEDROCK GEOLOGICAL MAPPING

During the project, systematic bedrock mapping was undertaken on the Lentiira (4414 + 4432), Nurmes (4321) and Naarva (4333) mapsheets, as part of the ongoing 1:100 000 scale mapping program (Figure 1.2). The Lentiira mapsheet was published in 1993, and accompanying explanatory notes in 2001. Field work for the Naarva mapsheet was completed in 1998 and for Nurmes in 2001, with the 1: 100 000 map being published in 2003 and explanatory notes in 2005.

Detailed bedrock geological mapping was also undertaken at 1: 10 000 and 1:20 000 scale to support exploration research activity in selected areas throughout the Suomussalmi, Kuhmo and Ilomantsi greenstone belts. Other areas specifically mapped in detail included Sepponen (4324 08) and Pesovaara (4341 01). Several detailed profiles across key sections of the greenstone belts in the Kiihtelysvaara area were also made, in order to better characterize lithological variations and stratigraphic relationships.

Regional coverage of the Suomussalmi greenstone belt is now complete at 1: 200 000 scale and for much of the greenstone belt, 1: 20 000 scale maps are available. Similarly,1: 200 000 scale compilations have been prepared for the areas around Moisiovaara, Arola, Vuosanka and Ensilä in the Kuhmo greenstone belt, with additional detailed 1: 20 000 coverage available for selected key areas. All outcrop observation data from the Suomussalmi and Kuhmo greenstone belts have been recorded in the GTK bedrock databases (KALPEA, and its successor, KAPALO).

2.2 GEOPHYSICAL INVESTIGATIONS

Geophysical investigations were carried out at three different levels, namely airborne surveys, ground-based profiling and petrophysical measurements, either in the laboratory or in the field. Airborne survey data, (particularly when acquired from flights with terrain clearance of 30-40 m) is of greatest value in district to target-scale interpretation, enabling the delineation of strongly magnetized or conductive rock units and structures. Where necessary, higher resolution ground-based surveys were conducted over prospective target areas. Petrophysical measurements were made in the laboratory or using down-hole geophysics for ascertaining rock properties (density, susceptibility, remanence, and resistivity) in specific mineral occurrences.

In this section, we also describe the processing and interpretation of the geophysical data. Results from earlier investigations are also reviewed, particularly with respect to surveys in the Ilomantsi greenstone belt. Processed geophysical data can be obtained from the Geological Survey of Finland, with low-altitude airborne survey data available as contour plots and line profiles printed at 1: 20 000 scale. Numeric data are also released in ASCII format as Geosoft xyz files; ground survey data are also available in Geosoft xyz format.

2.2.1 Airborne geophysics

2.2.1.1. Higher-altitude airborne geophysical surveys

The first airborne geophysical survey covering the entire country was undertaken between 1951 – 1972, at a flight elevation of 150 m and with a line spacing of 400 m. A feature of this programs was simultaneous systematic measurement of total magnetic field intensity (TMI), electromagnetic (AEM) in-phase and quadrature components and radiometric gamma-ray counts.

The magnetic data have been interpolated onto a 1km x 1km grid, known as FINMAG 2.0 (Korhonen, 1993). Digitized gridded data have been leveled to the 1 965.0 datum and the lithospheric anomaly field has been obtained by subtracting the DGRF-65 field (Definite International Geomagnetic Reference Field 1965) from the absolute measured field.

2.2.1.2. Low-altitude airborne geophysical surveys

GTK has also flown airborne geophysical surveys with a terrain clearance of 30-40 m and a standard line spacing of 200 m. Systematic surveys commenced in 1972 and by 2008, on completion of the program, coverage was available for the entire country, with some areas having been reflown at progressively higher resolution (Figure 2.2.1.2a). For the present project, the Kellojärvi area within the Kuhmo greenstone belt (1:20 000 scale mapsheets KKJ 4411 12 and KKJ 4412 10) was flown at a line spacing of 100 m and a measurement interval of between 10-50 m, depending on measurement technique and survey year. As with the earlier higher altitude program, these surveys provide simultaneous data acquisition for total magnetic field intensity (or magnetic flux density), electromagnetic field response and natural background gamma radiation intensity.

Total magnetic field intensity is measured from fixed wing aircraft equipped with a transverse horizontal gradiometer system fitted to the wingtips. This system has the advantage of facilitating interpolation of the magnetic field gradient between flight lines. Prior to 1992 proton magnetometers (with a sensitivity of 0.5 nT) were in use but these have since been replaced by cesium magnetometers, which are considerably more sensitive, with an accuracy of as low as 0.0001 nT; most airborne surveys in the project area were flown before 1992 and hence data was acquired using the older proton magnetometer system.

Frequency domain airborne EM Slingram in-phase and quadrature measurements are currently recorded at two frequencies (3125 and 14 368 Hz, vertical coplanar coil), compared to the single frequency of earlier surveys (at 3 220 Hz with a vertical coaxial coil), resulting in a substantial improvement in determining apparent resistivity. Natural gamma radiation spectra for calculation of total radiation (1.2–3.1 MeV), K, Th and U (1.65–1.87 MeV) abundances are also collected during airborne surveys using a 256-channel spectrometer. Flight line navigation and positioning is nowadays based on DGPS (Differential Global Position System) but prior to 1993 the Doppler navigation system was in use.

Low-altitude airborne surveys over the project area have been critical in delineating targets for detailed investigation. In particular, the magnetic survey data have been very important in exploration for komatiite-hosted nickel mineralization, since the abundance of magnetite in ultramafic rocks correlates with an intense positive magnetic response. Precise delineation of the distribution of ultramafic rocks on the basis of airborne magnetics therefore assists in delineating key areas for bedrock investigation.

The locations of the Suomussalmi, Kuhmo and Ilomantsi greenstone belts are shown on the low-altitude total magnetic intensity images, where they are readily apparent as anomaly maxima (Figures 2.2.1.2b and 2.2.1.2c). Swarms of Proterozoic mafic dykes, with orientation maxima with NW-SE, WNW-ESE and E-W trends, are also readily discernible as linear positive anomalies, transecting granitoids and gneisses adjacent to the greenstone belts; within the greenstone belts themselves, contrasts in magnetic response are relatively less and they are consequently more difficult to distinguish from greenstone belt lithologies. This feature is evident from inspection of the airborne magnetic images for both the Suomussalmi and Kuhmo greenstone belts (for example Figures 3.1.1a and 3.2.1a) and in the Hattu schist belt within the Ilomantsi greenstone belt (Figure 3.3.1.4.4).

Many features of structural origin, for example ductile shear zones and fault and fracture networks, are discernible in airborne survey data as linear magnetic minima, where fluid-rock interaction during deformation and metamorphism has destroyed or recrystallized magnetic minerals. Conversely, precipitation of pyrrhotite in some shear zones may in some cases generate linear positive anomalies. Such structures, for example those transecting the Kuhmo greenstone belt, are of considerable exploration interest due to their potential association with hydrothermal gold mineralization. However, further assessment of prospectivity requires more detailed investigation, for which till geochemical sampling is especially effective.

Prior to the dissolution of the Soviet Union, it was not possible, for various political and security reasons, to negotiate permission for airborne surveys in close proximity to the Finnish-Soviet border. This lack of airborne coverage was partly compensated for by extensive ground geophysical measurements; within the present project area for example, the Tormua belt, which represents the northeastern branch of the Suomussalmi greenstone belt, was surveyed in great detail. Nowadays it is possible to design and conduct airborne surveys to the national border, although this change in policy occurred too late to be of benefit to the present project.

2.2.2 Ground-based geophysical surveys

During the current project, detailed ground geophysical surveys were carried out over a combined area of more than 300 km^2 at various locations within the Suomussalmi, Kuhmo and Ilomantsi greenstone belts. Additional detailed profiles and measurements were undertaken in key areas, as well as some *in situ* down-hole measurements. Petrophysical properties were also measured on samples in the laboratory, with results being used in modeling geophysical responses in the field.

2.2.2.1 Geophysical survey methods and procedures

Surveys can be divided into two types, those that related to comprehensive terrain coverage and those that were focused on specific mineralization targets. The most widely used method for systematic surveys was Slingram-magnetic profiling(line spacing/point separation = 2 - 5), while induced polarization technique (IP) was particularly useful in delineating gold-prospective areas characterized by fine sulfide disseminations. Detailed magnetometry measurements were carried out at some gold prospects although this method was of greatest value when investigating nickel potential. To ascertain the geophysical signatures of mineralized intersections in drill core, charged potential measurements were made. Most ground geophysical surveys were undertaken by GTK personnel using GTK equipment, although some specialized measurements were contracted out to industry, notably Suomen Malmi Oy and Astrock Oy.

Slingram measurements were made using a horizontal loop system (HLEM) with a base frequency of 14 kHz, which is an ideal compromise for detecting relatively weakly conductive features (for example shear zones and fracture zones), as well as more prominent conductors. The abundance throughout the project area of planar, steeply dipping rock units and contacts, such as graphitic phyllites and schists, and tectonic contacts between units containing graphite and sulfide minerals, is also highly suited to Slingram surveys. An additional aim was to identify conductive horizons within ultramafic units, as an aid in exploration for massive nickel sulfide mineralization. With a 60 m loop configuration, depth of penetration was relatively shallow, so that it was generally assumed that features of interest extended to the ground surface. In some

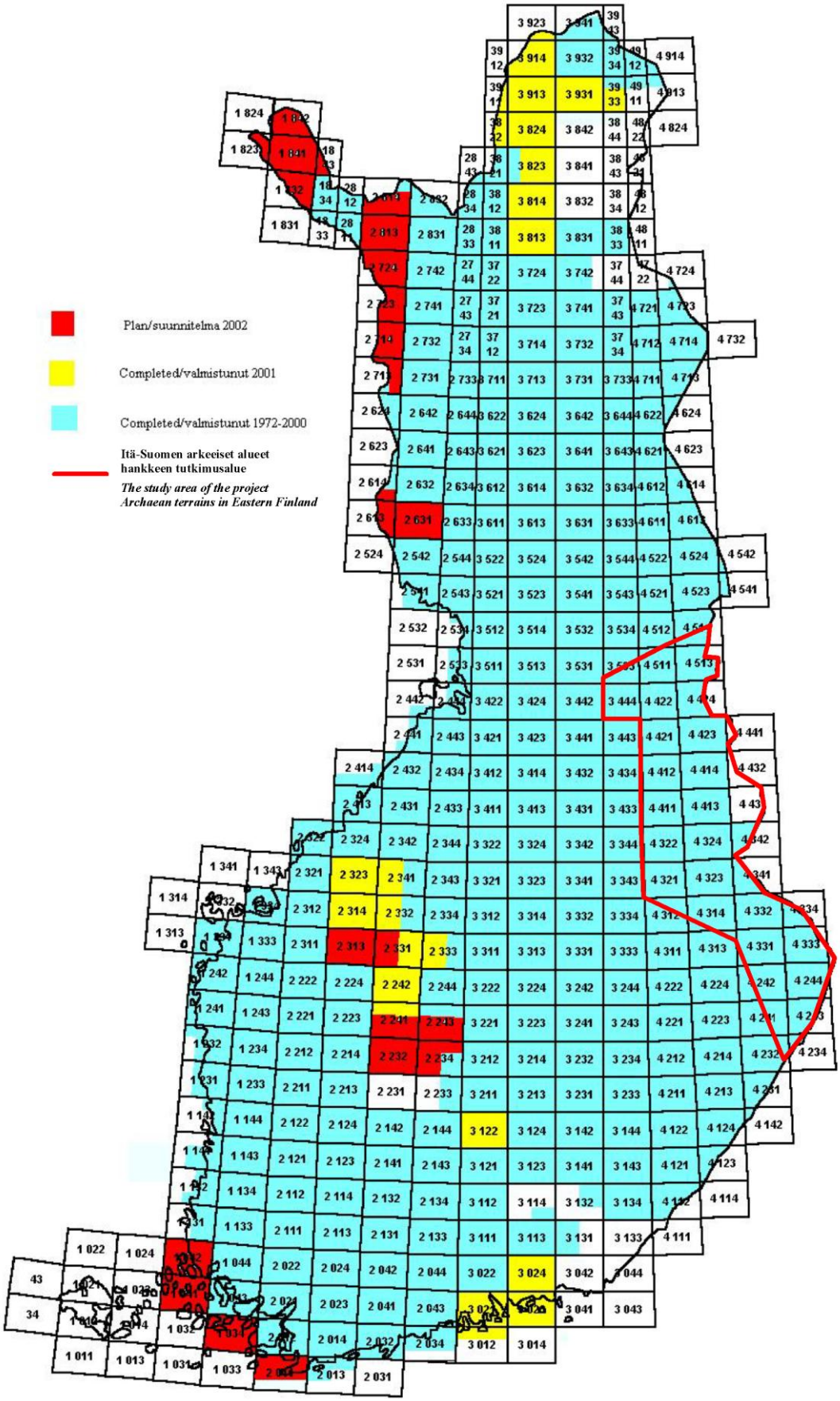


Fig. 2.2.1.2a. GTK low-altitude airborne geophysical survey coverage, showing FIN_KKJ 1: 100 000 scale mapsheet grid and location of the area studied in GTK project "Archaean Terrains in Eastern Finland".

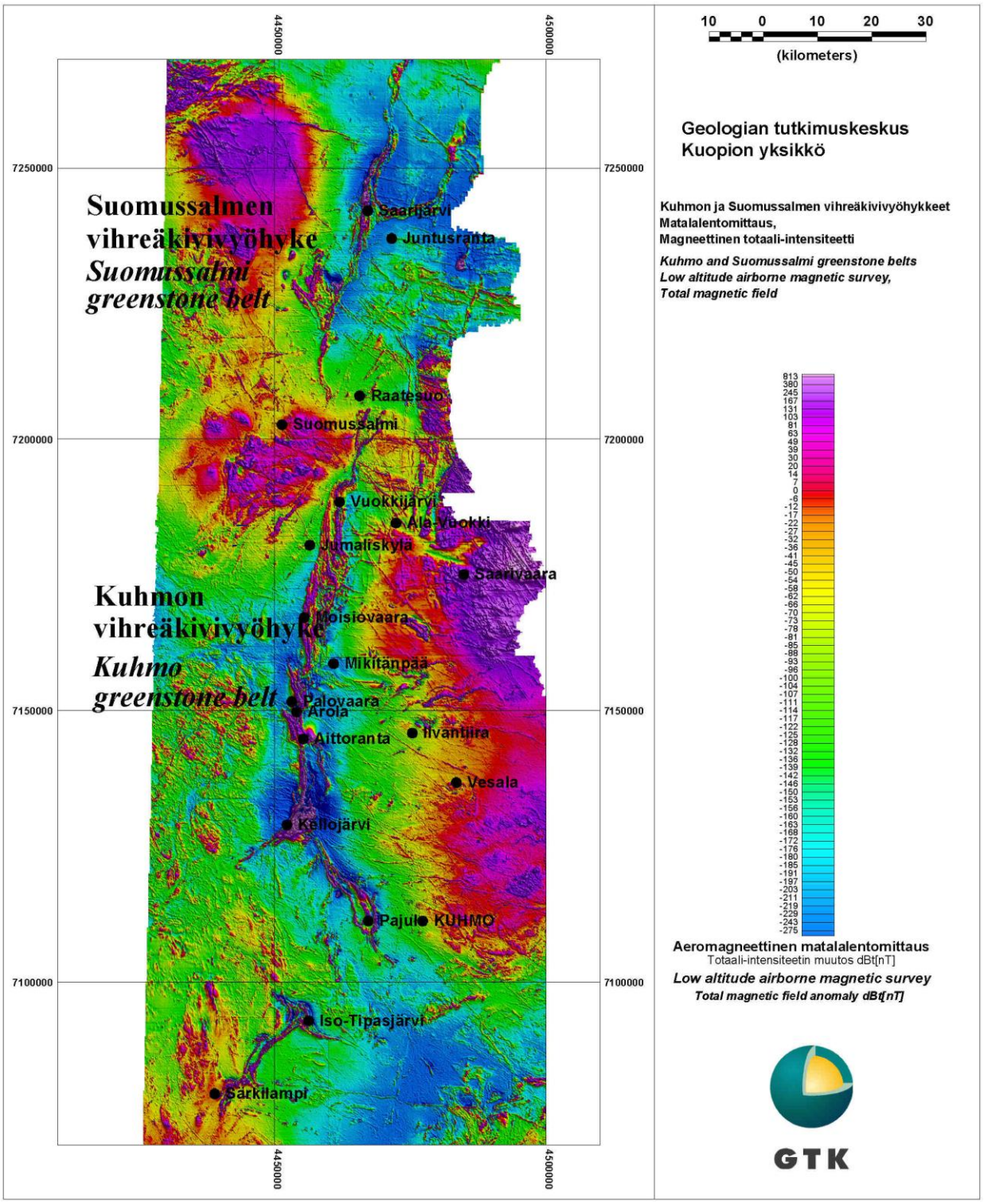


Fig. 2.2.1.2b. Low altitude aeromagnetic map (total magnetic intensity) of the Kuhmo and Suomussalmi Greenstone Belts.

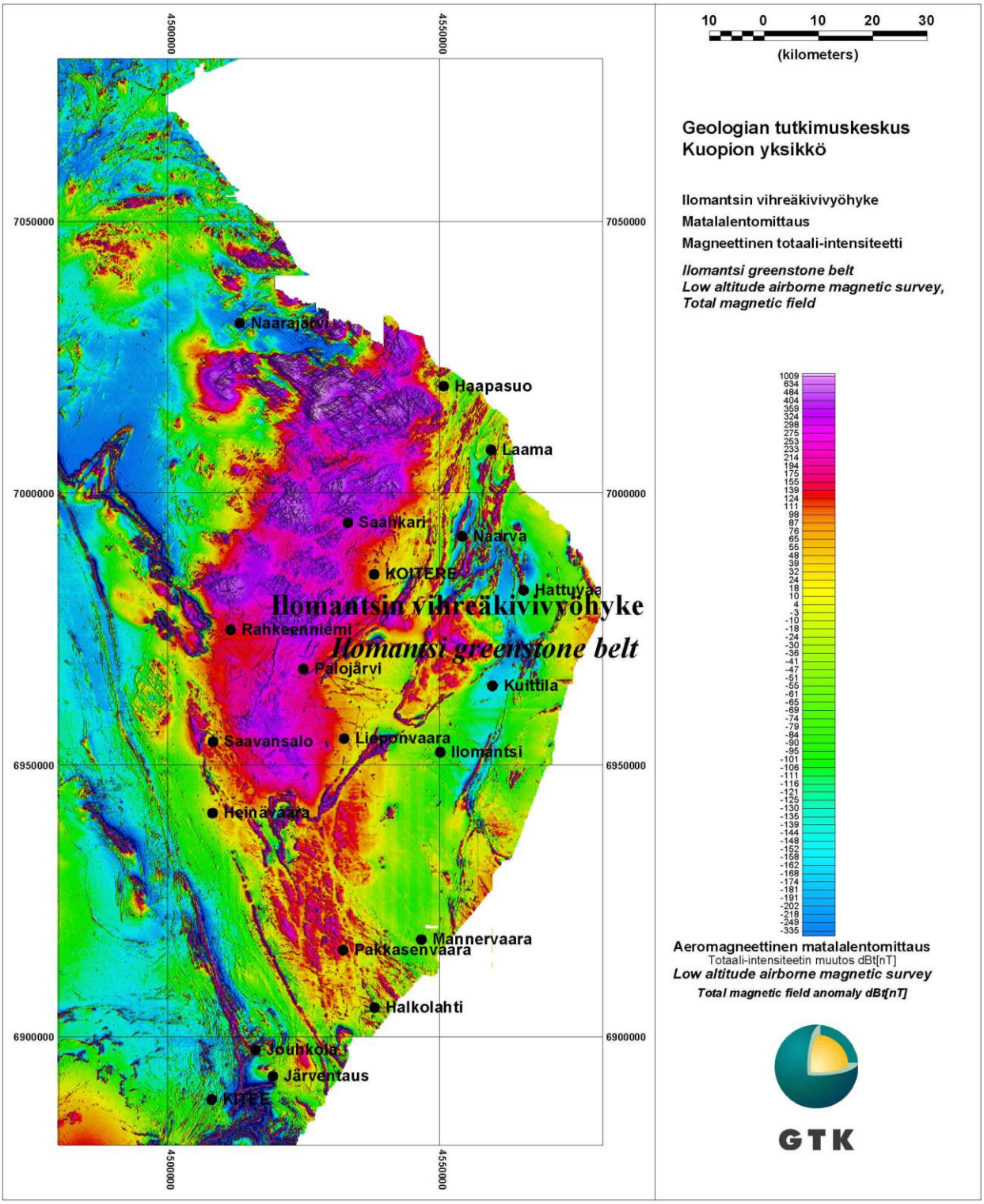


Fig. 2.2.1.2c. Low altitude aeromagnetic map of the Ilomantsi Greenstone Belt.

cases however, it did prove possible to delineate gently dipping subsurface features with Slingram surveys, such as the Hoikkalampi serpentinite in the Suomussalmi greenstone belt (see Section 3.1.1.2.5.1).

Sampo soundings (Gefinex 400 S) and EM-37 surveys were used in the detection of more extensive and deeply sourced conductors. Sampo is a multifrequency electromagnetic method operating within the frequency range 2 - 20 000 Hz. The system records apparent resistivity profiles for different frequencies as a function of depth from a given measuring point and the most common coil separation distance used in these surveys was 400 m (150-750 m). Profiles across komatiitic sequences were often problematic due to their irregular and discontinuous nature and the restricted horizontal extent of rock units compared to the desired survey depth. In general the anomalies generated by SAMPO soundings can be attributed to graphitic or sulfide-bearing conductors in rocks near the margins of komatiitic units. The transient electromagnetic EM-37 technique was applied to a single deep drill hole in the Kellojärvi area, which had been drilled for the purpose of testing a conductive horizon revealed by SAMPO soundings. However, due to technical difficulties encountered during the survey, results are not considered reliable.

Magnetic total field intensity measurements were made using a proton magnetometer, the main purpose being to identify and delineate magnetite-bearing ultramafic rock units. Diurnal and other time-dependent variations in intensity were corrected with reference to a ground station taking measurements at one minute intervals. Earlier magnetic surveys, in the Ilomantsi greenstone belt, also included measurement of the vertical component of the total magnetic field. In general, detailed surveys over mineralized prospects were designed with a line spacing of 10 m and point separation of 5 m. This approach, with a tightly spaced grid was highly suited to discerning internal structures within horizons of interest, particularly where overburden thickness was only a few meters or less.

Induced polarization (IP) surveys based on a dipole-dipole system (n = 3, a = 20 m) were particularly useful in delineating gold mineralization at prospect scale. This is principally because finely disseminated sulfides, which are characteristic of alteration assemblages related to gold, generate strong IP chargeability anomalies. Arsenopyrite is commonly present in mineralized horizons but IP anomalies are usually relatively weak and difficult to discriminate from background noise if no other sulfide phase is present, making it more difficult to trace gold-critical zones dominated by arsenopyrite alone. The thickness and composition of overburden can also have a significant effect on the resistivity distribution obtained from IP profiles. It is also necessary to account for the presence of magnetite when conducting IP surveys over intensely magnetic serpentinites, as magnetite generates an IP chargeability anomaly wherever magnetite abundances are sufficient that bulk susceptibility of the rock exceeds 0.05 SI units (Aravanis, 1995).

Systematic gravity surveys were only undertaken at the Huutoniemi prospect in the Suomussalmi greenstone belt, although gravity profiles were measured across other parts of the belt. Gravity surveys proved useful in discriminating between different rock types but were not effective in directly delineating mineralized zones. This is partly due to the effect of variable overburden thickness, which in itself can generate significant anomalies. Serpentinized ultramafic bodies are generally less dense than surrounding rock units, while associated mafic volcanic lithologies may generate positive anomalies.

The methods employed and areal distribution of ground geophysical surveys and profiles are listed in Tables 2.2.2.1a, 2.2.2.1b and 2.2.2.1c. Systematic surveys are listed in terms of area (km^2) and profiles in terms of line kilometers (lkm). Other profiles and surveys are listed as either line kilometers or points, and drill-core logging is measured in meters (m). The areas covered by

systematic ground geophysical surveys are also shown on the low-altitude airborne magnetic images, for the Suomussalmi and Kuhmo greenstone belts (Figure 2.2.2.1a) and Ilomantsi greenstone belt (Figure 2.2.2.1 b).

2.2.3 Petrophysical measurements

Petrophysical properties of rocks were measured both in the laboratory and *in situ* within drill holes. Samples for laboratory analysis were selected from representative drill core and from hand specimens collected from outcrops and in some cases glacial erratics. Parameters routinely measured in the laboratory were density (kg/m$^{3)}$, susceptibility (SI) and magnetic remanence (mA/m). Vector components of the remanence tensor were also measured from selected oriented samples. Where necessary, electromagnetic responses, including conductivity and chargeability potential were also tested, at frequencies of 0.1, 10 and 500 Hz.

Table 2.2.2.1a.Geophysical ground measurements in the Suomussalmi Greenstone Belt.

	Magnetic + Slingram/MaxMin (HLEM)	**Gravi-metric**	***Induced polarization***	***Mise-à-la-masse (on surface/ in drill hole)***	***Sampo method***	***Petrophysics in lab. (D, K, J)***	***Petrophysics in lab. (App. Res.)***	***Measure-ments in drill hole***	***VLF/ VLF-R***	***Other***
Tormua	31 km^2 573 lkm		12 km^2 183 lkm						27 lkm	
Saarikylä	16 km^2 322 lkm	350 points 7 lkm	11 km^2 220 lkm	0.4 km^2 2556 m	300 points	264	126	6216 m	4 lkm	Spectral IP 558 points
Kiannan-niemi	21 km^2 437 lkm	2.9 km^2 58 lkm	1.7 km^2 35 lkm		117 points	3	3	1134 m		Detailed mag. 0.3 km^2 31 lkm
Härkö-vaara	7 km^2 77 lkm	489 points 10 lkm			80 points 7 lkm					
Total	75 km^2 1409 lkm	2.9 km^2 75 lkm	25 km^2 428 lkm	0.4 km^2 2556 m	497 points	267	129	7350 m	31 lkm	

Table 2.2.2.1b. Geophysical ground measurements in the Kuhmo Greenstone Belt.

	Magnetic + slingram/ MaxMin (HLEM)	***Gravi-metric***	***Induced polarization***	***Mise-à-la-masse (on surface/ in drill hole)***	***Sampo method***	***Petrophysics in lab. (D, K, J)***	***Petrophysics in lab. (App. Res.)***	***Measure-ments in drill hole***	***Other***
Moisio-vaara	17 km^2 345 lkm	206 points 2 lkm	2.1 km^2 99 lkm	0.3 km^2 2104 m	132 points	118	51	3336 m	Detailed mag. 0.03 km^2 *Spectral IP* 322 points
Arola-Vuosanka	24.1 km^2 493 lkm		5.2 km^2 104 lkm		82 points	8	8		
Kellojärvi + Sepponen	2.4 km^2 48 lkm		0.5 km^2 10 lkm					EM37 1 drill hole	
Total	43.5 km^2 886 lkm	206 points 2 lkm	7.8 km^2 213 lkm	0.3 km^2 2104 m	214 points	126	59	3336 m	

Table 2.2.2.1c. Geophysical ground measurements in the Ilomantsi Greenstone Belt.

	Magnetic (total intensity / vertical component)	**Slingram**	***Induced polarization***	***Mise-à-la-masse (on surface)***	**VLF-R**
Ilomantsi (digitized areas)	100 km^2 1500 lkm	68 km^2 1050 lkm	66 km^2 900 lkm	0.06 km^2	3 lkm

Down-hole *in situ* measurements were made for Wenner conductivity and susceptibility, with a point separation of 5cm. Natural gamma radiation (total counts) were also measured from several drill holes, although additional useful information could have been more obtained by measuring radiation spectra.

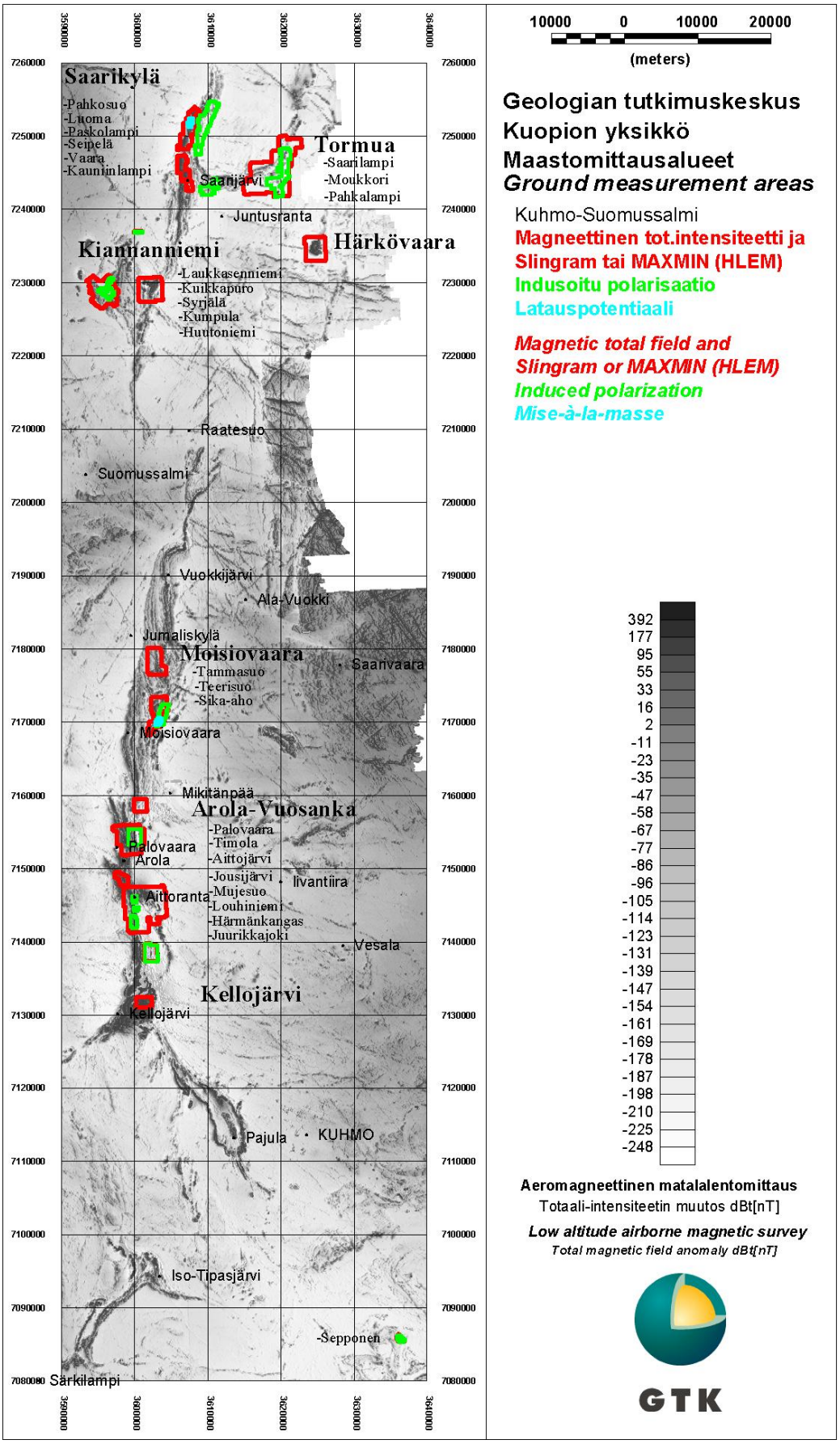


Fig. 2.2.2.1a. Index map of ground geophysical measurement surveys in the Kuhmo and the Suomussalmi Greenstone Belts, showing areas covered by different methods.

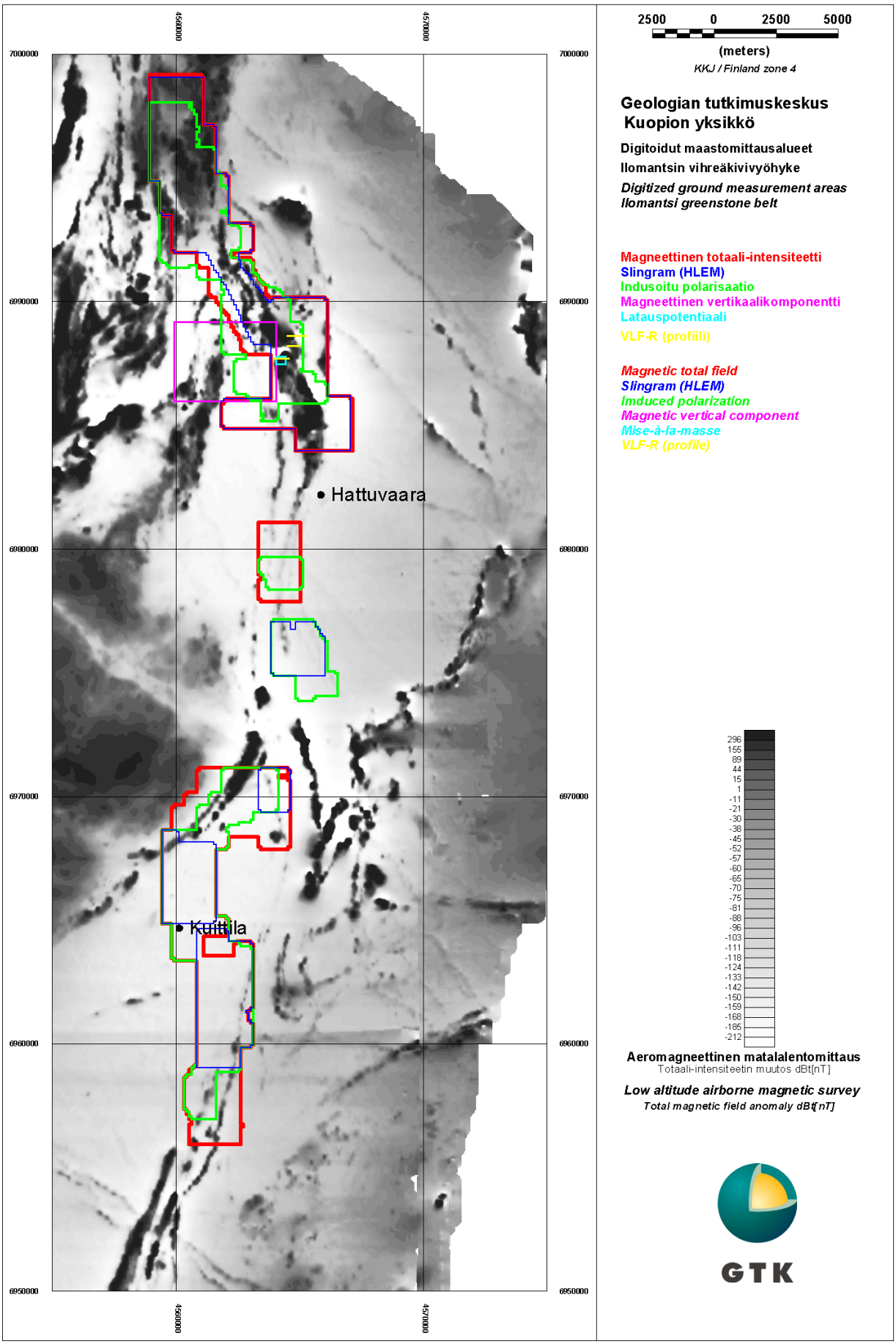


Fig. 2.2.2.1b. Index map of ground geophysical measurement surveys in the Ilomantsi Greenstone Belt, showing areas covered by different methods.

2.2.4 Processing and interpretation of geophysical data

Geophysical data processing and visualization and map production was done at first with Geosoft™- and later with OASIS Montaj™ –software. Colour scales were generally used on map outputs for visualization and interpretation, while profiles were used for evaluating the location, orientation and extent of sources for the more important anomalies, in order to improve selection of targets for drilling.

Processing also including output of various derivative maps for accentuating particular wavelengths or enhancing gradients, to highlight known or inferred anomalies associated with mineralization. The use of AGC signal enhancement (Automatic Gain Correction) allowed relatively weak anomalies to be displayed effectively on the same maps; AGC images have been particularly useful for investigating the internal structure of serpentinite bodies.

Composite colour images were used to reveal specific combinations of parameters that might be relevant to mineralization, for example, a rock unit or shear zone that is both magnetically strong and a good conductor. The colour composite maps are produced by assigning different color schemes to various datasets, for example magnetic and Slingram in-phase and quadrature, in order to accentuate the desired parameter and range of values.

Results of SAMPO soundings were typically displayed by plotting apparent resistivity as a function of depth, which is most appropriate for modeling and visualization of horizontal features, but less suitable for representing the location or depth of steeper structures. Therefore, interpretation of position and orientation of steeper conductors was attempted by deploying in-line measurement of ellipticity and tilt angle. When a vertical conductor is situated between the transmitter and receiver, at a distance from the transmitter approximately equivalent to 1/8 of the coil separation, an ellipticity maximum and a minimum angle of inclination are obtained. The bimodal anomaly resulting from the coil separation and the ellipticity, together with the frequency corresponding to the maximum response, then allow the relevant parameters, typically conductivity, to be classified.

Modeling of potential field data (both magnetic and gravimetric) was at first performed with Magix software, which was later superseded by the Encom Model Vision software package.

2.2.5 Influence of susceptibility on interpretation of Slingram measurements

Rocks with inherently high magnetic susceptibility tend to generate a positive real electromagnetic anomaly during Slingram surveys. Figure 2.2.5 illustrates such a real anomaly from a HLEM Slingram survey, due to a resistive, magnetic rock unit. A coil separation of 60 m and an overburden depth of 4 m were used in calculations, resulting in a real anomaly of about +9 % for a relatively resistive (K = 0.2 SI) serpentinite body. The weak real anomaly generated by the tabular conductor within the serpentinite body may be overlooked, since it is not readily discernible as a negatively conducting horizon. Measuring the imaginary quadrature component in Slingram surveys did however enable the recognition and delineation of weakly conductive domains within serpentinite bodies. Signal enhancement was also effective in delineating real component anomalies within serpentinites, as this diminishes the magnitude of change in intensity of the EM response attributable to magnetic susceptibility. Relatively weak bedrock conductors can be detected, and discriminated from shear or fracture zones and conductive overburden by a combination of filtering of the imaginary component and signal enhancement of the real component. On the other hand, an extensive subhorizontal conductive layer, at a

relatively greater depth, will also generate a positive Slingram real anomaly (see Section 3.1.1.2.5.1).

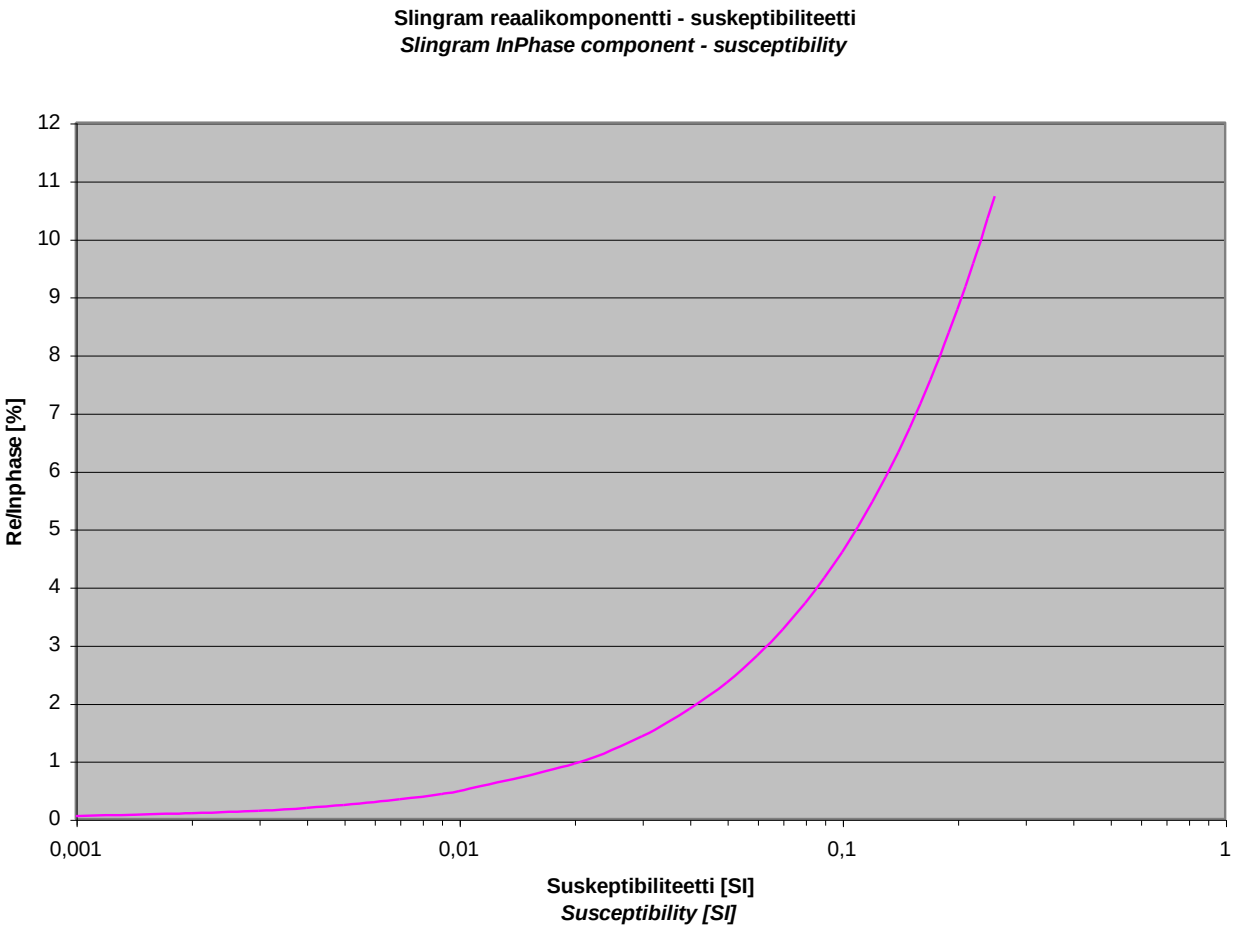


Fig. 2.2.5. Effect of susceptibility on Slingram (HLEM) real (in-phase) component anomalies. Coil separation is 60 meters and overburden thickness is 4 meters.

2.3. GEOCHEMICAL EXPLORATION IN SURFICIAL SEDIMENTS

2.3.1 General background to till geochemistry

Surficial deposits in the project area are dominated by glacial till and to a lesser extent by glaciofluvial sediments deposited during ice sheet retreat. Pre-glacial regolith in the form of deeply weathered bedrock is only rarely encountered, whereas post-glacial soil differentiation, particularly the formation of podsols with a leached A horizon, is widespread. Geochemical analysis of deeper levels of till, particular the fine fraction, and near the bedrcok interface has been a widely used exploration technique in the Archean of eastern Finland, and has been particularly effective in delineation of gold targets (cf. Hartikainen and Nurmi, 1993). This is principally because of the predominance of till units which are of moderate thickness (less than 10 meters) and stratigraphically rather simple and uniform; glaciofluvial deposits can be considerably more complex and diverse in terms of composition and provenance, but have a relatively limited distribution in the present study area. Thus the vast majority of analyzed samples represent till. When combined with data from chip samples taken from the immediately

underlying weathered or fresh bedrock, a coherent dataset is obtained for defining anomalies that can evaluated in more detailed follow-up investigations. Intensive sampling and analysis at the target delineation stage of exploration was generally most effective.

Nevertheless, there are many issues to be dealt with in sampling, analysis and interpretation, including choice of optimal sample spacing and the most appropriate number of samples representative of a given area or stratigaphic horizon, ideal depth of sampling, proportion of reworked weathered material in samples, transport distance of till material and overall stratigraphic position. In areas of exceptionally thick overburden, samples from the upper part of the sequence are less likely to be derived from or representative of the immediately underlying bedrock. As shown in Figure 2.3.1, till thickness throughout the project area varies considerably. Hence, because it is rarely possible to define the precise stratigraphic position of a sample, it has been customary to sample from as deep as possible, preferably from immediately above the bedrock interface, in which case chips of weathered or fresh bedrock may also be recovered. Even though weathered bedrock typically contains higher concentrations of many trace elements compared to those in till, it is nevertheless very difficult to allow for this in a systematic and quantitative manner.

One of the principal advantages of systematic till geochemical sampling is the large number of data, which enhances the probability of identifying a fan-shaped dispersal pattern derived from a mineralized zone or point source. This is particularly important in the case of gold, where highly anomalous values maybe a result of the so-called ”nugget effect”, where a single detrital grain causes signficant skewness within a dataset, but is not necesarily an indicator of proximity to source (Harris, 1981; Nichol et al., 1992). For this reason, in addition to collecting a large population of samples, it is necessary to ensure that individual samples are sufficiently large. Geochemical exploration was performed mainly in two scales: 1) local scale, 16 samples/km^2 and 2) prospect scale, 100 – 400 samples/km^2 along lines.

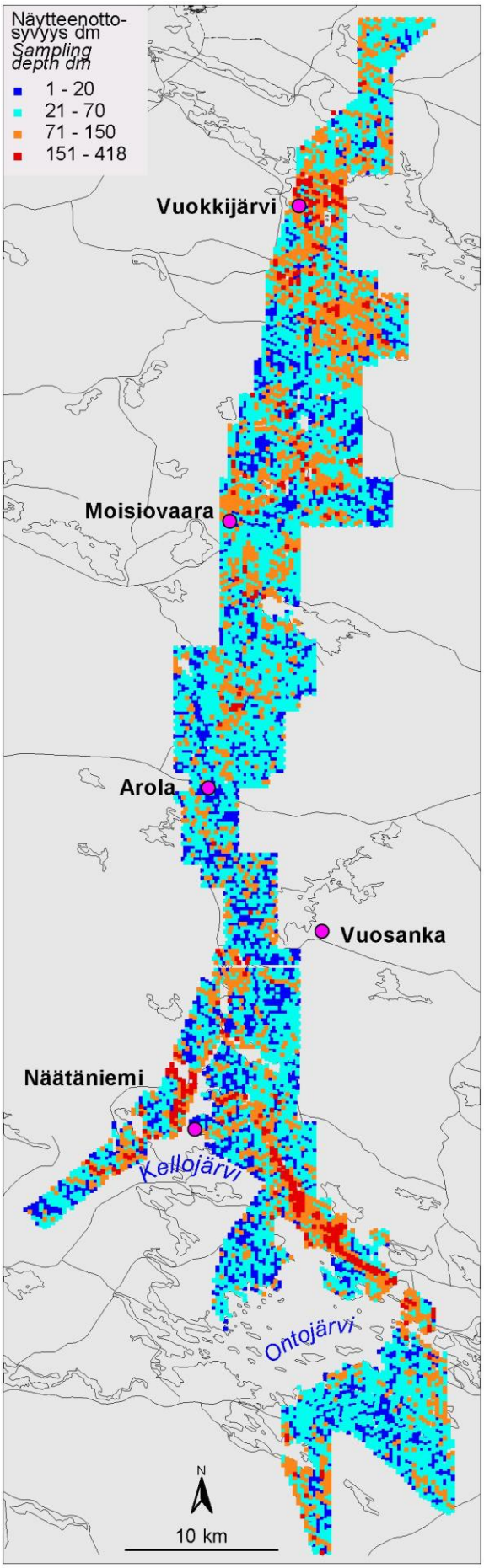
2.3.2 Sampling procedures and preparation

In local scale surveys (16 samples/1 km^2), samples were collected from as deep as practicable in an effort to ensure retrieval of till material from the bottom of till sequence. Weathered bedrock and rock chips were also collected wherever possible. For more detailed surveys at prospect scale (10-20 m sample spacing), all samples were collected as great a depth as possible. Wherever bedrock or regolith were encountered, the overlying till was not sampled. Samples were collected with either a Cobra percussion drill (30 mm diameter) or with the Terri all-terrain vehicle, equipped with a 35 mm drilling rig.

In contrast to sampling preparation techniques used in previous GTK geochemical surveys, all samples were crushed, without sieving, according to prior standard practice in other GTK mineral exploration investigations. Moreover, comparison of analytical results for till material that had firstly been sieved (-0.064 mm size fraction) and samples that were only subjected to crushing showed that this change in procedure was justifiable, resulting in only slight differences in regional anomaly patterns.

All samples of weathered and fresh bedrock chips were retained and kept in storage; from 1992 onwards, till samples were sieved and the fraction > 2mm were also stored.

Sampling and preparation procedures for surveys in the Ilomantsi and Kiihtelysvaara greenstone belt differed somewhat from the above and are described in detail in Sections 3.3.1.4.4 and 3.4.4.



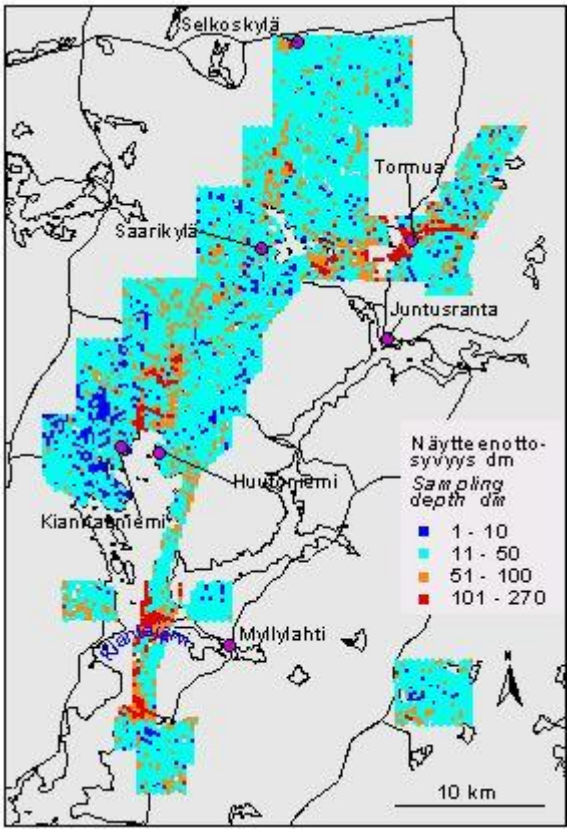


Fig. 2.3.1. Depths of till samples taken at during local scale surveys (16 samples/1 km^2) in the Suomussalmi and Kuhmo greenstone belts.

2.3.3. Analytical methods

Till samples were analyzed using atomic absorption spectrophotometry until 1994, after which Jarrel-Ash Atomcomp-plasma emission spectrometry (ICP-AES) was used. Gold and tellurium were however analyzed separately using a graphite furnace (GFAAS method, Kontas, 1993a,b). Arsenic was analyzed local by GFAAS and ICP-AES in the case of local samples for studies at prospect scale by ICP-AES.

Crushed sample powders were analyzed at the GTK Kuopio laboratories for Co, Cr, Cu, Mn, Ni, Zn, Fe ja Ag (FAAS-method, HCl + HNO_3 -leaching) and for Au using GFAAS; some samples were also analyzed simultaneously for Te and As from the same leachates. Until 1993/1994, Au, Te and As analyses were based on 1g sample separates but later analyses used 5g of material.

Lithogeochemical analyses from outcrops and drill core were at first analyzed using AAS but later data were obtained using ICP-AES. However, Au, Te, Pt and Pd were analyzed using GFAAS, from 5g sample weight; where Au values exceeded 1 ppm, a further analysis was performed weighing a 20g fraction.

Analytical procedures for surveys in the Ilomantsi and Kiihtelysvaara areas differed in some respects, and in many cases a more comprehensive range of elements were analyzed; these are described in detail in Sections 3.3.1.4.4 and 3.4.4.

2.3.4. Till geochemical investigations in the Suomussalmi Greenstone Belt

The Suomussalmi region is characterized by a relatively complex till stratigraphy, with up to four distinct till horizons having been recognized (Saarnisto & Peltoniemi, 1984). The lowermost stratigraphical unit is a compact gray till which was deposited under a northwesterly ice flow regime. This is overlain by a stratified ablation moraine and glaciofluvial sands. The youngest till horizon is more oxidized, greenish brown in color and was deposited with an ice flow direction from the southwest, between 210° - 230°. This latter trend is also evident in glacial striations and the relative abundance of erratic boulders derived from the greenstone belt (Saarnisto & Peltoniemi, 1984). The distribution of some till geochemical anomalies also reflect dispersion of material along a SW-NE (or in some areas nearly W-E) trend, which moreover implies that at least some of the samples represent the uppermost till horizon (Figures 2.3.4a-c).

There have been few studies of glacial transport in the Suomussalmi area, although sporadic clast counts indicate that coarse sand and gravel (>2mm) derived from the greenstone belt are present in till up to 3-4 km from their source areas. The regional distribution of nickel and arsenic till anomalies in particular, and the relatively high gold abundances in till overlying granitoids, further indicate that the fine detrital fraction in till has been transported for a considerable distance (Figures 2.3.4a-c).

A total of 17 243 samples were collected from the Suomussalmi greenstone belt, principally representing till and weathered bedrock (Table 2.3.4). In local scale the total proportion of samples derived from weathered and fresh bedrock was 14.2%, whereas in detailed scale investigations, the corresponding proportion was much higher, at 53.4%. Samples were ideally obtained from as deep as was practically possible with percussion drilling equipment, which on average for the Suomussalmi greenstone belt was about 3.5 m. The maximum depth sampled was 27 m and the thickest sequences were found within the esker ridge between Tormua and Saarikylä, and the northern part of the Huutoniemi area and in the western part of the Myllylahti area and also around Vuokkijärvi and in the northern side of lakes Kellojärvi and Ontojärvi (Figure 2.3.1).

Four samples from the local survey yielded Au concentrations in excess of 1000 ppb, the highest being 6 080 ppb. Elevated Au abundances are in general restricted to the northern part of the greenstone belt, along the contact zone between the greenstones and granitoids (Figure 2.3.4a). The relatively high Au concentrations from till samples overlying the granitoids are attributed to material derived from the greenstone belt, which had been transported variable distances (1-2 km) either westwards or towards the northeast. The Seipelä belt, to the southeast of Saarikylä, is also clearly reflected in the distribution of Au in till. The most anomalous sample, with an Au concentration of 6080 ppb, was obtained from the Kiannanniemi area, about a kilometer southeast of the Kuikka gold prospect (see Section 3.1.1.3.2); the Kiannanniemi area as a whole is relatively anomalous with respect to Au.

The distribution of arsenic anomalies closely resemble those for gold, with particularly elevated concentrations in the northern part of the Saarikylä belt and the Seipelä area (Figure 2.3.4a). Elevated arsenic in till over granitoid bedrock is attributed to glacial transport of anomalous detrital material from the greenstone belt. Despite this general coincidence of anomaly patterns, detailed statistical analysis of Au and As concentrations show only a weak correlation, indicating that the most anomalous values of these elements are found in different samples. This contrasts with the strong correlation observed between Au and Te, both in individual samples, and in regional anomaly patterns.

Nickel anomalies in till clearly reflect the distribution of ultramafic rocks in the greenstone belt to the north of Saarikylä (Figure 2.3.4b). Elevated nickel concentrations are also characteristic of the Tormua area. Three samples from the Suomussalmi greenstone belt had nickel abundances in excess of 3000 ppm and were all located within the above-mentioned greenstone belts. The Huutoniemi ultramafic body is however, less evident in the till geochemical data, due to the relatively greater thickness of sedimentary overburden.

Copper and zinc show generally similar anomaly distributions, with the most conspicuous anomalies occurring around Saarikylä itself, and also some distance both to the north and south, as well as at Kiannanniemi (Figure 2.3.4b). Lead is characterized by sporadic high concentrations, as to the north and east of Kiannanniemi, in the area between Saarikylä and Selkoskylä, and at Tormua (Figure 2.3.4b).

Figure 2.3.4c shows the regional scale nickel anomalies in the Saarikylä area in more detail. Elevated nickel concentrations generally coincide closely with the distribution of mafic volcanic rocks, while the ultramafic rock units at Vaara, Rytky, Hoikkalampi and Kauniinvaara also correlate with prominent nickel anomalies. The dispersion of nickel anomalies in till by glacigenic sedimentary processes is particularly evident at Kauniinvaara. Clast counts at these sites shows that komatiitic detritus has been transported for up to four kilometers from the primary bedrock source. The abrupt termination of the nickel anomaly immediately to the east of the komatiites is due to the presence of thick stratified sediments, with the samples in this area consisting of sand.

More detailed prospect-scale surveys were carried out in selected parts of the Suomussalmi greenstone belt to clarify anomalies identified in local scale geochemical sampling. The most important results of these detailed investigations, representing a total of 15 targerts, are presented in tabular form in Appendix 1. Of these, the Isosuo, Iso Housuvaara -Saarilampi, Moukkori, Pahkalampi - Lauttalampi and Lahna-aho targets occur within the Tormua schist belt, whereas the Isopuinen, Teerilampi, Tulilampi, Pahkosuo, Paisesuo - Kiviaho, Paskolampi and Seipelä are located within the Saarikylä greenstone belt; the Syrjälä - Tupakkiloma, Nuottiaho and Kuikka occurrences are at Kiannanniemi. Some of these targets are described in more detail in Section 3.1.1.

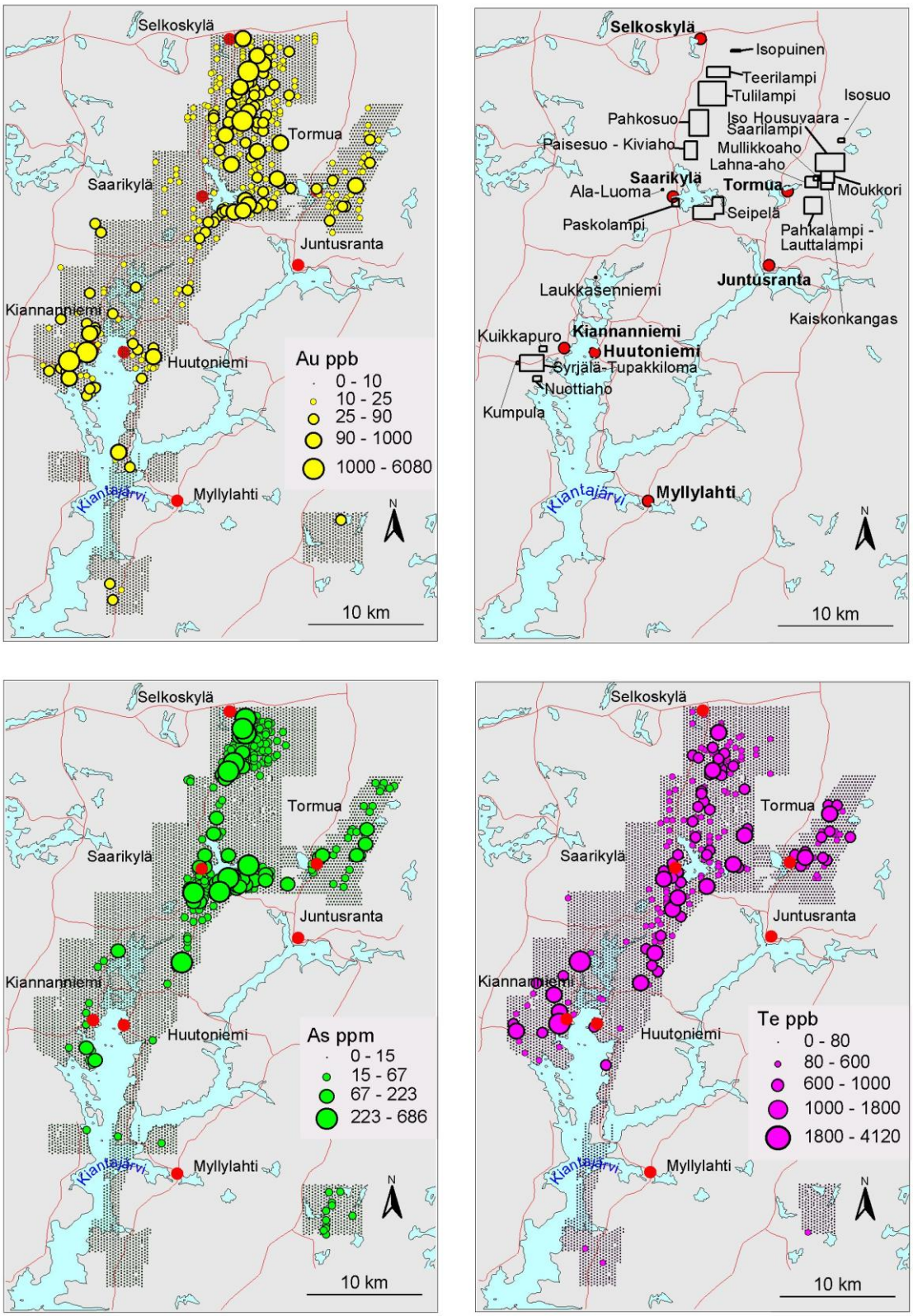


Fig. 2.3.4a. Gold, arsenic and tellurium concentrations in till samples taken during local scale surveys (16 samples/1 km^2); index map of gold exploration targets is also shown for the Suomussalmi greenstone belt.

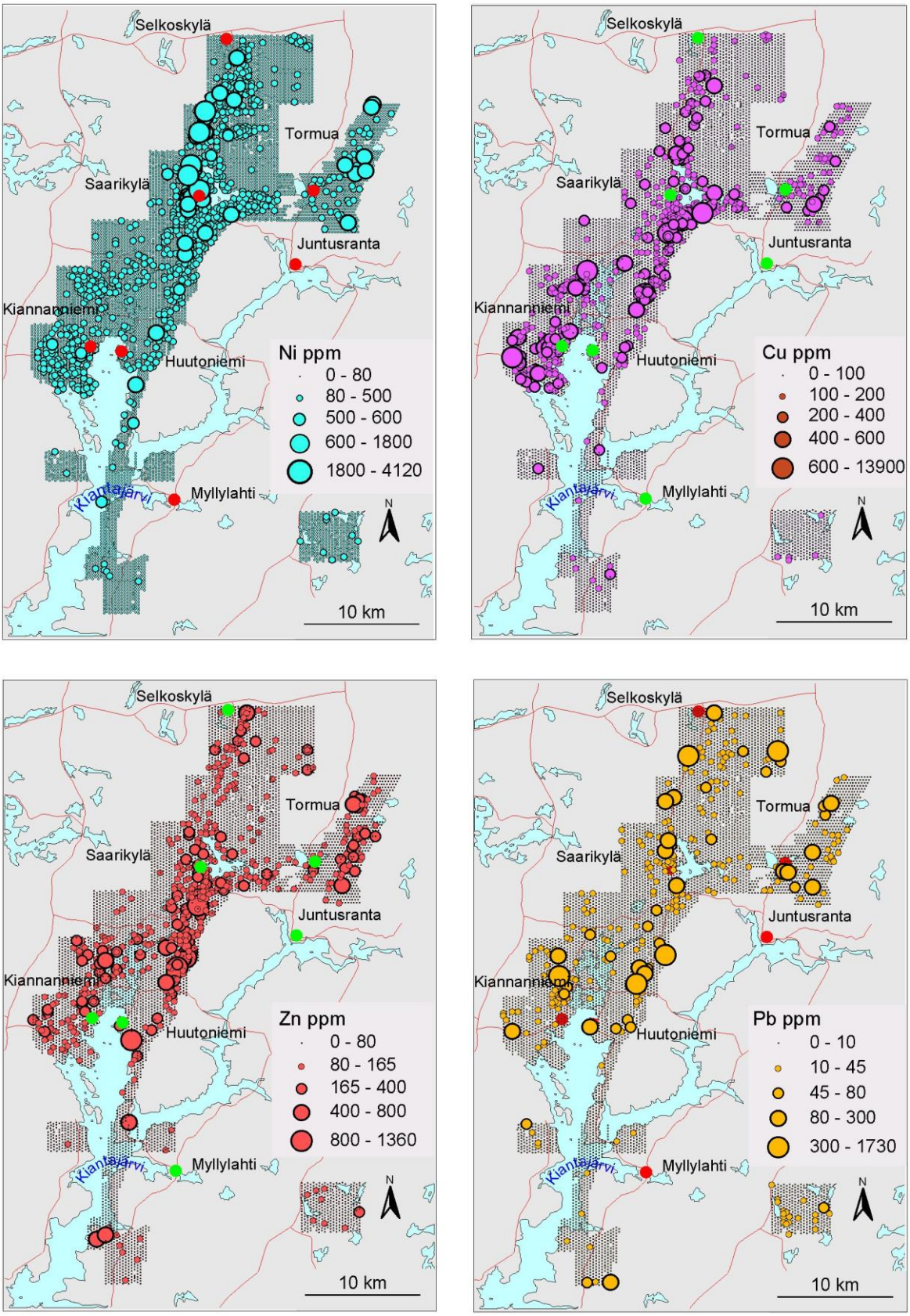


Fig. 2.3.4b**.** Nickel, copper, zinc and lead concentrations in till samples taken during local scale surveys (16 samples/1 km^2), Suomussalmi greenstone belt.

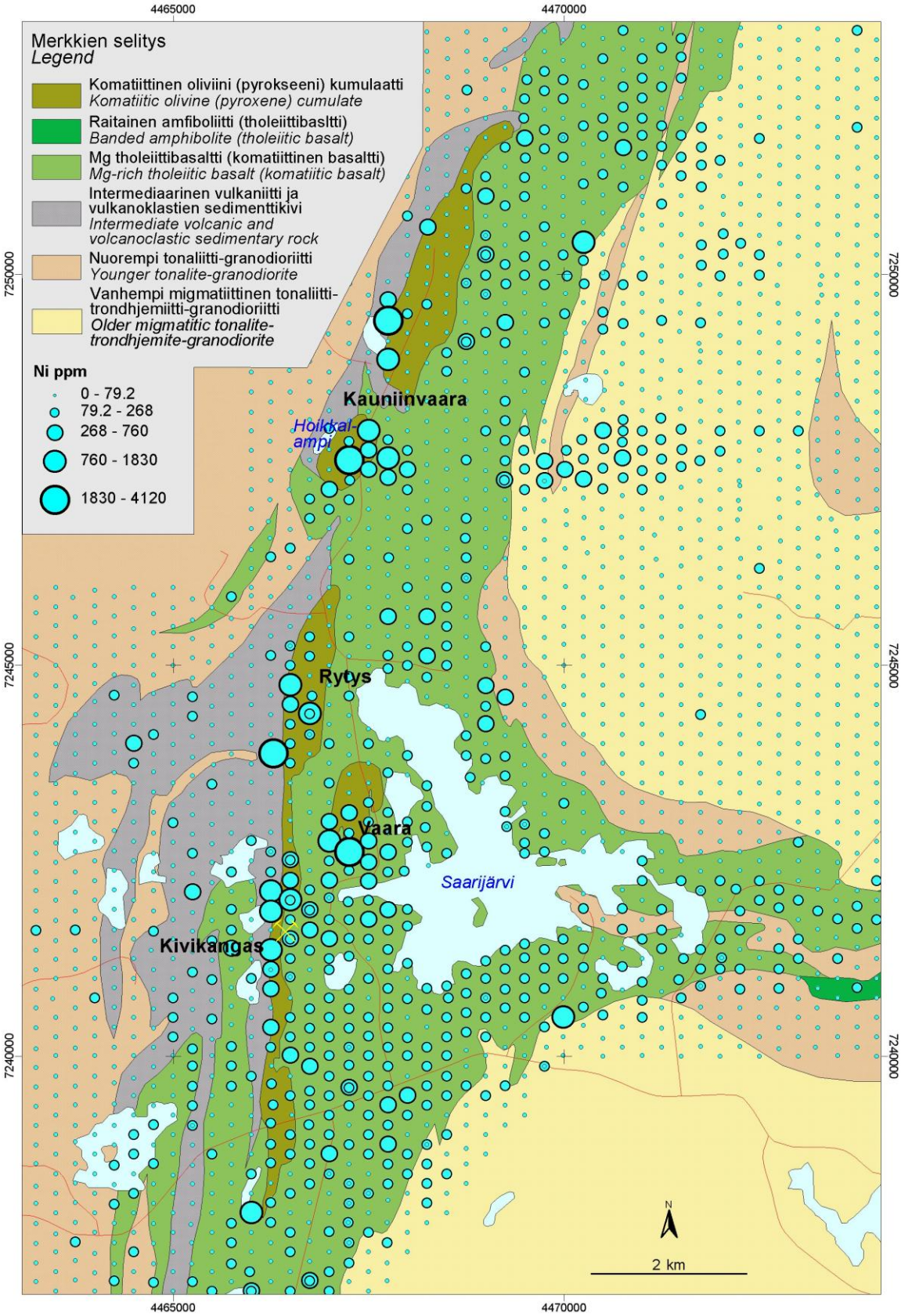


Fig. 2.3.4c. Nickel concentrations in till samples taken during local scale surveys (16 samples/1 km^2) in the Saarikylä area, Suomussalmi greenstone belt. The location of the Kivikangas soap stone quarry is also indicated.

Table 2.3.4. Number of samples taken at different sampling stages in the Suomussalmi Greenstone Belt.

Sampling stage	Till	Till/weathered bedrock	Weathered bedrock	Bedrock	Sand	Gravel	Silt	Total
Local	6610	171	1018	64	23	4	8	7898
Detailed	3484	716	5125	14	6			9345
Total	10094	887	6143	78	29	4	8	17243

2.3.5. Till geochemical investigations in the Kuhmo Greenstone Belt

Three separate till horizons have been recognized in the Kellojärvi area, to the northwest of Kuhmo township. The uppermost unit comprises an ablation moraine, while the lower two units both formed as basal till deposits, with ice flow vectors between northwest and west (270° - 310°). Metal abundances are on average 2.5 times greater in the lower basal till than in the overlying unit (Saarnisto et al., 1980). As in the Suomussalmi area, it was not possible to identify the most suitable sampling level during drilling, so samples were retrieved from as great a depth as practicable.

There have been several investigations into transport of glacial material in the Kuhmo greenstone belt. According to Saarnisto et al. (1980), the proportion of clasts derived from the greenstone belt is highest immediately adjacent to the eastern contact, and decreases by half over a distance of 500 m. Good correlation exists between chemical abundances of different till fractions and the proportion of greenstone belt material, with the highest anomalies being found in proximity to the greenstone-granitoid contact. The highest nickel concentrations were recorded from till almost directly overlying serpentinites, indicating a transport distance of some 50-200 m. However, it is evident that some of the finer material has been transported over much greater distances, for nickel values that are anomalous with respect to regional baseline levels are commonly present some tens of kilometers from the greenstone belt (Saarnisto & Taipale 1984).

A total of 17 936 samples were obtained from the Kuhmo greenstone belt, of which 12101 represent local scale surveys and 5 835 represent detailed target sampling. The frequency of samples of a given type of material is summarized in Table 2.3.5; the proportion of fresh and weathered bedrock samples was 14.9 % in the local scale surveys, compared to 48.8 % in the target scale investigations. These results are very similar to those obtained for comparable materials in the Suomussalmi greenstone belt.

Table 2.3.5. Number of samples taken at different sampling stages in the Kuhmo Greenstone Belt.

Sampling stage	Till	Till/weathered bedrock	Weathered bedrock	Bedrock	Sand	Clay	Silt	Boulder	Total
Local	10072	141	1732	74	62	3	17		12101
Detailed	2594	370	2817	28	22		3	1	5835
Total	12666	511	4549	102	84	3	20	1	17936

Overburden is exceptionally thick over extensive areas to the north and south of Vuokkijärvi, to the north of Moisiovaara and within the esker complexes to the northeast of Ontojärvi.

Elevated arsenic abundances define a narrow anastomosing anomaly which can be traced along almost the entire length of the eastern margin of the Kuhmo greenstone belt (Figure 2.3.5a). The

anomalies are particularly sharply defined in areas both to the south and north of Moisiovaara. The apparent break in the anomaly in the area to the west of Vuosanka is however due to the lack of arsenic analyses in this area during the local scale survey; results of detailed target-scale sampling and bedrock drilling nevertheless reveal that arsenic is present in anomalous concentrations, for example at Iso Aittojärvi, Pieni Aittojärvi and Jousijärvi (Tenhola and Niskanen, 2001). To the south of Ontojärvi, arsenic anomalies are more widely distributed; this suggests that there may be contributions from several distinct sources but so far there have been no attempts to establish their origin or significance.

The arsenic anomalies (Figure 2.3.5a) lie within a northerly trending high-strain zone which is well exposed in exploration trenches on the eastern shore of the lake Iso Aittojärvi. Here the deformation zone is up to some hundred meters wide and is characterized by mylonitic fabric and extensive veining, brecciation and replacement by quartz and tourmaline. Arsenopyrite is also abundant (Tenhola and Niskanen, 2001). According to Luukkonen (1988b), the deformation zone formed in response to west-vergent overthrusting during the late Archean D3 and D4 phases, which were the most prominent folding and faulting events recorded in the Kuhmo greenstone belt.

Elevated gold abundances are also found within the same deformation zone, though the anomalous zones are not so continuous or sharply defined as those for arsenic (Figure 2.3.5a). The most coherent gold anomalies occur between Moisiovaara and Vuokkijärvi, but anomalous zones can also be traced through Vuosanka to Moisiovaara, and in the western part of Ontojärvi. Therefore, gold exploration was almost exclusively focused on this deformation zone and its immediate surroundings. Targets selected for follow-up investigations are shown in Figure 2.3.5a. The Lokkiluoto prospect, at Ontojärvi, which was investigated earlier by GTK (Heino and Kilpelä, 1985) also lies within this As-Au anomalous zo

The highest gold value reported from till was 45 800 ppb, for a sample from the northern shores of the lake Ontojärvi. A further ten samples were taken from the area immediately surrounding this anomalous sample, but none contained significant gold concentrations. This may be due to some uncertainty over the precise location and nature of the sampling site (being located within an area along the lakeshore that was previously submerged but is now exposed). The sample is nevertheless potentially significant, for it lies within the prominent anomaly trend that extends southwards from Vuokkijärvi (Figure 2.3.5a). Additional detailed sampling within this anomalous zone is clearly justified, although the thick glaciofluvial sand deposits make sampling and interpretation rather difficult. Other anomalous areas that warrant further investigation include the eastern shores of Ontojärvi and the area to the south of Ontojärvi, where an isolated Au value of 9420 ppb was recorded from till.

The somewhat discontinuous and irregular gold anomaly patterns, at least when compared to those of arsenic, are primarily attributed to the so-called “nugget effect”, due to the erratic presence, both in bedrock and till, of isolated, relatively large gold grains. This effect, and the resultant irregular pattern of gold distribution, could have been ameliorated somewhat by consistently taking and analyzing larger samples, although this would in turn have had some impact on sampling efficiency.

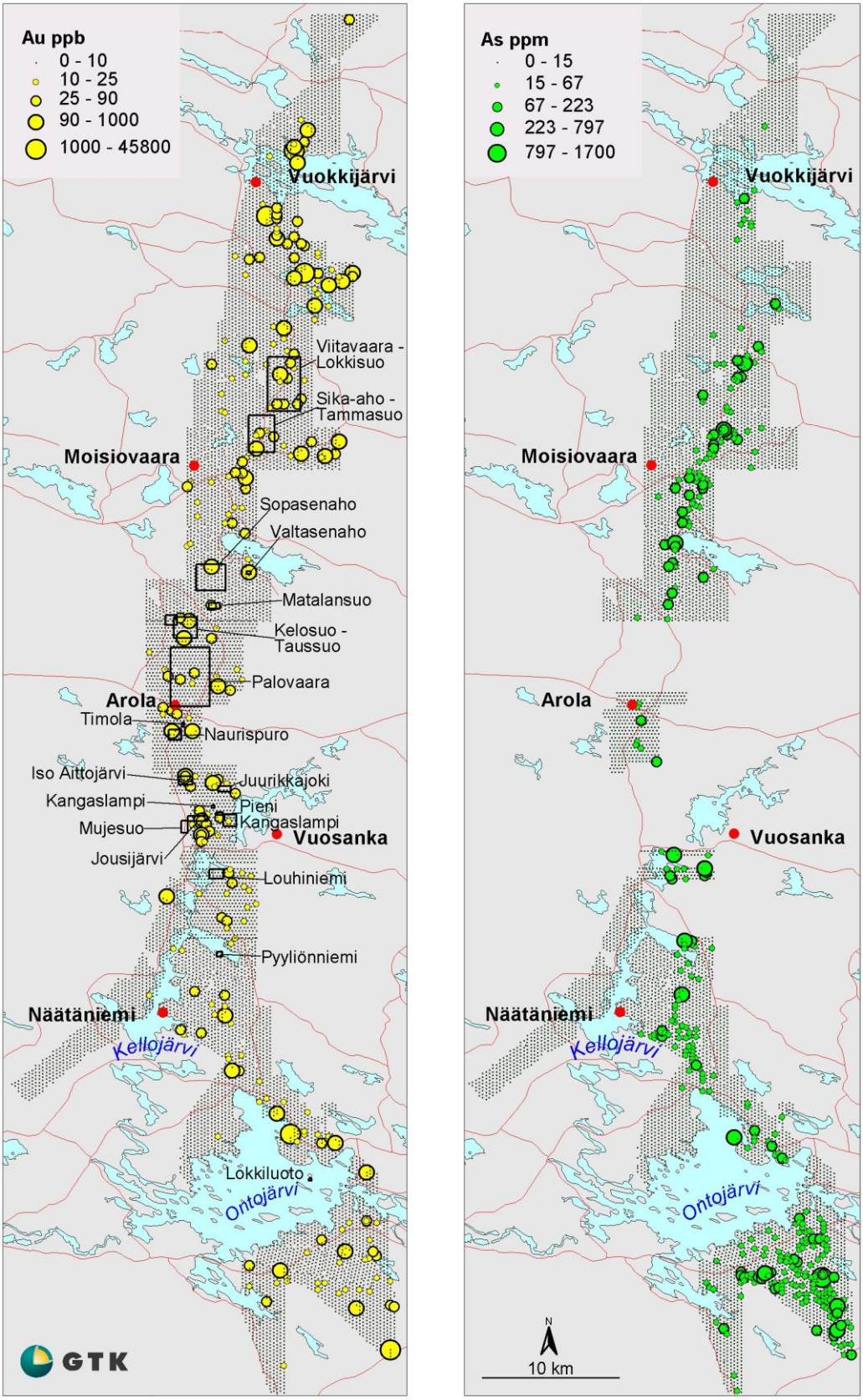


Fig. 2.3.5a. Gold and arsenic concentrations in till samples taken during local scale surveys (16 samples/1 km^2) in the Kuhmo greenstone belt; targets selected for more detailed sampling are also indicated.

Elevated nickel abundances (Figure 2.3.5b) are confined to the Näätäniemi area west of Kuhmo township, as well as the area immediately to the north of Näätäniemi, and to the Palovaara area, north of Arola. The eastern margin and northern extremity of the arcuate Vuosanga belt (Juurikkajoki target, see Appendix 2), the area to the north of Vuokkijärvi, and the Moisiovaara area are also anomalous with respect to nickel. The bedrock mineralization at Arola is not however, apparent in the till geochemical data. Overall, nickel abundances are relatively uniform where mafic rocks dominate, with most of the more highly anomalous values being correlated with the presence of ultramafic rocks, typically komatiites.

The regional distribution of chromium is very similar to that of nickel, with the most conspicuous anomalies being in the vicinity of Kellojärvi (Figure 2.3.5b). The Juurikko area is also notably anomalous. However, the chromium anomaly pattern differs from nickel in that there is also a prominent anomaly trend along the western margin of the surveyed area, from north of Arola to Moisiovaara. Exceptionally high chromium values are encountered within this anomalous zone, the highest values exceeding 2 000 ppm.

The Ni/Cr ratio can be used as a discriminant between anomalies due to nickel mineralization and those associated with background concentrations in ultramafic rocks and this approach should be used to a greater extent in future studies. High Ni/Cr ratios were found for example, north of Näätäniemi, west of Kellojärvi, south from Vuosanka and to the east of Moisiovaara (Figure 2.3.5c).

Anomalous lead abundances are typical throughout the central part of the Kuhmo greenstone belt, between Näätäniemi and Moisiovaara (Figure 2.3.5c). In contrast, there is an extensive area near Vuokkijärvi characterized by remarkably low lead concentrations. There is also a local, sharply defined lead anomaly in the northwestern part of Ontojärvi. In general however, the distribution of lead is reminiscent of that of zinc.

During the localt scale sampling, four samples were found to have Cu concentrations greater than 1000 ppm, of which the highest value (13 900 ppm) was obtained from till to the east of Moisiovaara (Figure 2.3.5d). More detailed sampling was then undertaken in the vicinity of the Sauna-aho target (Figure 2.3.5d, Appendix 2). Even though an additional 84 samples were analyzed, no significant results were obtained, the highest Cu value being only 177 ppm. The other three significantly anomalous Cu till analyses were located to the north of Moisiovaara, to the southwest of Arola and at Matalansuo; at the latter site, an additional detailed survey, with 166 samples was later undertaken (Figure 2.3.5d). The gold anomalous zone to the north of Vuokkijärvi is also mirrored by elevated Cu concentrations, although the highest value, of 666 ppm, was recorded about 1.5 km to the east of the highest gold concentrations. Elevated Cu abundances were also reported from Näätäniemi and the eastern shores of Ontojärvi.

A prominent zinc anomaly is present in the Juurikkajoki area, (Figure 2.3.5d, Appendix 2). Towards the southern end of this anomaly zone, a value of 3 480 ppm was obtained, which is potentially of significance as this sample site is located directly south of the Härmänkangas zinc occurrence. The highest Zn value recorded from this sampling survey was 5 130 ppm, from a site immediately southwest of the Pyyliönniemi occurrence. High zinc abundances are also present at the northwestern end of the lake Ontojärvi, where the highest concentrations were 1 460 ppm and 1 120 ppm, respectively. This area is also characterized by anomalous lead concentrations, as noted above.

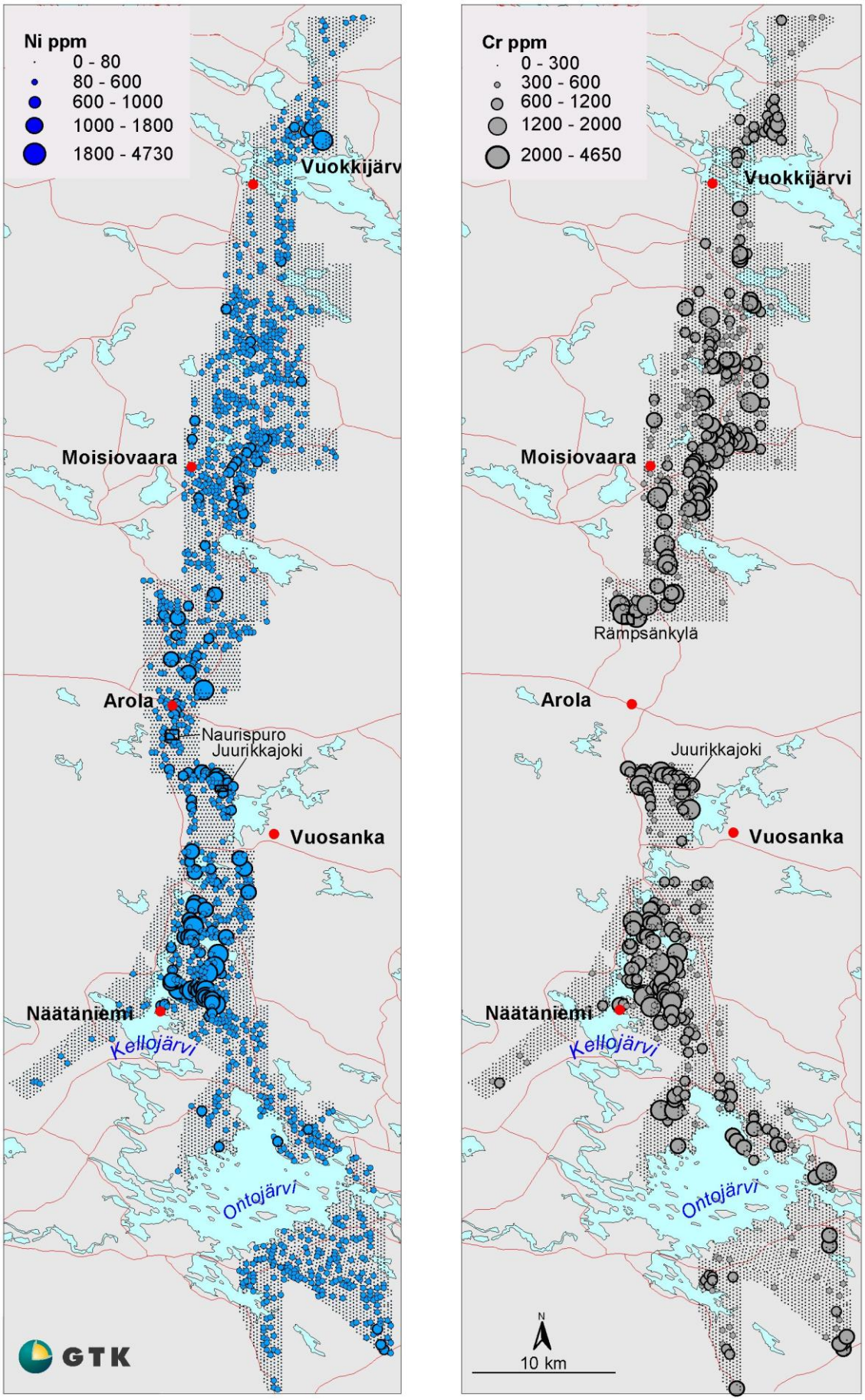


Fig. 2.3.5b. Nickel and chromium concentrations in till samples taken at local scale (16 samples/1 km^2), Kuhmo greenstone belt.

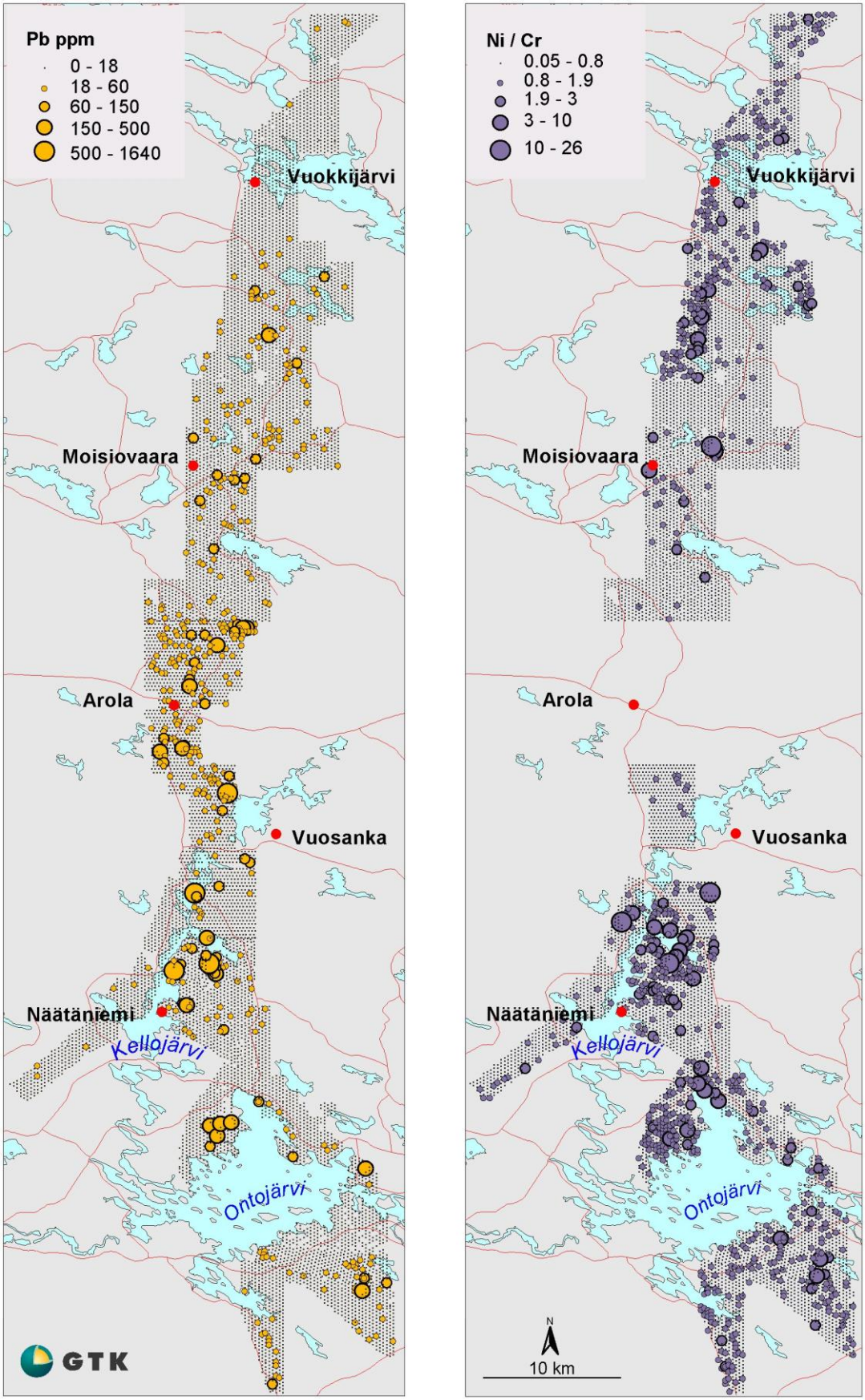


Fig. 2.3.5c. Lead concentrations and the values of Ni/Cr in till samples taken during local scale surveys (16 samples/1 km^2), Kuhmo greenstone belt.

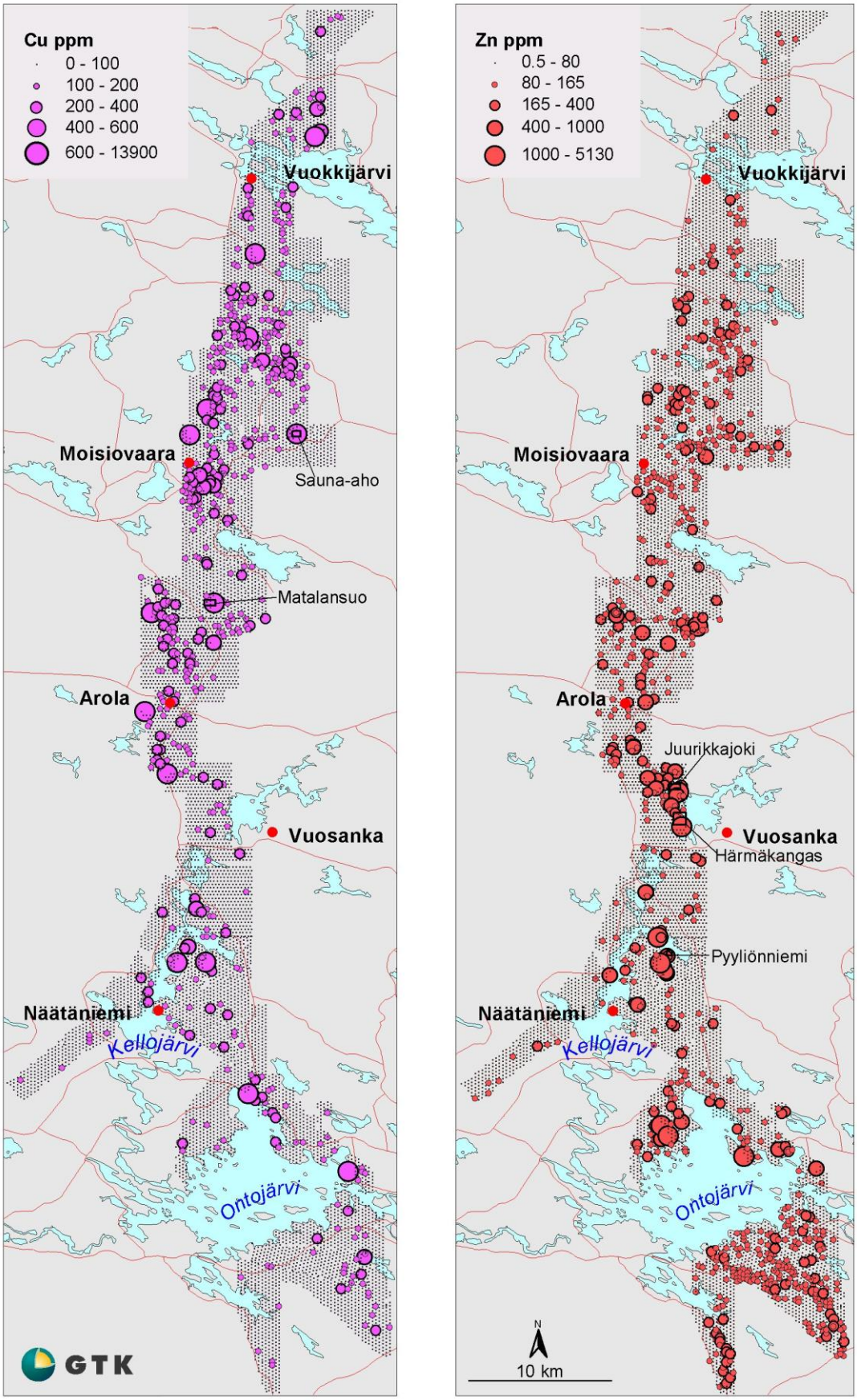


Fig. 2.3.5d. Copper and zinc concentrations in till samples taken during local scale surveys (16 samples/1 km^2), Kuhmo greenstone belt.

A number of detailed, target scale till geochemical surveys were undertaken throughout the Kuhmo greenstone belt, on the basis of results obtained during local scale investigations. Summary data for these fourteen detailed surveys are presented in tabular form in Appendix 2. Most of these targets are related to gold exploration, and are accordingly indicated on the map of gold distribution (Figure 2.3.5a). The other targets relate to zinc (Härmäkangas and Pyyliönniemi, Figure 2.3.5d), copper (Sauna-aho and Matalansuo, Figure 2.3.5d) and nickel (Juurikkajoki and Naurispuro, Figure 2.3.5b). The locations of these targets are also shown on maps for the respective elements.

2.4. SAMPLES SUBMITTED BY THE GENERAL PUBLIC AND GLACIAL BOULDER INVESTIGATIONS

During the project, a total of 613 rock samples from various parts of the study area were submitted to GTK by amateur prospectors and other interested members of the public. Of these, 592 samples were analyzed and 98 were archived. The high proportion of analyzed (97%) and archived samples is an indication of a relatively high awareness on behalf of the general public, in being able to recognize potentially mineralized samples. There was a steady decline over the course of the project in the number of people actively submitting samples (from 8 to 5) but the overall quality of samples remained high, such that 1-2 people were consistently among the recipients of the annual awards presented by GTK for samples that lead to promising follow-up investigations. Samples submitted that were of direct significance to the project include those from Kuikkapuro, Seipelä and Laukkasenniemi in the Suomussalmi greenstone belt, Timola, Mujesuo and Louhiniemi in the Kuhmo greenstone belt, and Ruunaa, southeast of Lieksa. During the project, effective and valuable collaboration was established between GTK staff and amateur prospectors and local communities, such that interested members of the general public were informed of the more common rock types and features associated with potential mineralization, while the significance of submitted samples was rapidly assessed by follow-up investigations in the field.

In addition to field-checking of these samples, GTK technical and research support staff were involved in identifying glacial erratics and tracing potential sources of mineralized boulders, and in searching for bedrock outcrops. These investigations were directed at reconnaissance scale assessment of mineral potential, for example in searching for nickel-anomalous boulders in areas where airborne magnetic data indicated the presence of ultramafic bedrock, and in follow-up investigations in areas where there were already some indications of mineralization potential, based on previously known mineralized boulders or bedrock, or till geochemical anomalies. The Vaara nickel and palladium prospect near Saarikylä, in the Suomussalmi greenstone belt, is an excellent example of how geological and geophysical data interpretation, in combination with focused and systematic boulder investigations, led to the discovery and delineation of a significant mineral occurrence.

Nearly 200 mineralized boulders were examined and analyzed throughout the course of the project. Mineralized boulders are of importance in revealing information on rock type, hydrothermal alteration assemblages and indicator minerals that provide vectors to mineralization. Moreover, they always represent a direct indication of mineralized bedrock, even if the source is now buried beneath glacial deposits.

2.5. DEEP DIAMOND DRILLING

2.5.1. General background

During the course of the project, a total of 897 holes were drilled (with a combined length of 81 554.89 m). Of these, 669 holes (equal to 59 419.34 m) were located within or in close proximity to the Kuhmo and Suomussalmi greenstone belts; of the remaining holes, most were drilled within the Ilomantsi region. Reconnaissance exploratory drilling was generally done with GTK drilling rigs; any subsequent follow-up drilling required at prospective targets was however, submitted to a competitive tendering process amongst private drilling contractors. During the project drill diameter also changed, from T46 to T56, which was particularly useful in the case of gold investigations. Reverse circulation (RC) drilling was also carried out on a trial basis at the Pahkalampi, Pahkosuo and Timola gold prospects in the Suomussalmi greenstone belt. Usually results compared favourably with those from diamond drilling, indicating little gold loss; at Pahakasuo for example, RC gold analyses were similar to those from conventional diamond drilling through the same mineralized intervals (GM-100, using drill bit sizes T46 and T56) The biggest disadvantage with RC drilling is the loss of potentially useful information concerning rock type, alteration assemblages and microstructure, all of which are readily discernible from conventional drill core. A further practical problem is the handling of a mixture of wet crushed rock and finer-grained material during the Finnish winter, in subzero conditions.

Drilling capacity in the project area increased markedly in 1998 and 1999 due to the fortuitous and timely reallocation of funds that had been designated for regional development programs in northern Finland. This enabled significant amounts of drilling (total 259 holes, corresponding to 25 470.40 meters length) at the Vaara-Kauniinlampi nickel-palladium prospect, and at the Kuikkapuro gold target in the Suomussalmi greenstone belt. Both these occurrences were initially taken up by Outokumpu Mining after public tendering arranged by the then Ministry of Trade and Industry. It became clear on the basis of drilling at these prospects that in general, considerable time and effort can be saved by comprehensive drilling as early as possible, once a prospective target has been defined.

Within the gold-prospective Hattu schist belt in the Ilomantsi greenstone belt, a total of 504 deep drill holes and shallower POKA holes were drilled, as indicated according to respective drilling target in Table 3.3.1.4.3. The POKA holes were primarily intended for rapid delineation of the distribution of potentially prospective rock units and structures, with a total of 171 holes being drilled in 1986 and 1987. A total of 333 deep diamond drill holes were drilled, using both T46 mm and T56 mm diameter equipment. Most of the deep holes were drilled in locations that had been identified as anomalous and potentially prospective on the basis of detailed till geochemical surveys, as well as in preliminary delineation of the Pampalo gold deposit. Detailed information on drilling in the Hattu schist belt can be found in Damstén (1990), Damstén et al. (1994a; 1994b), Hartikainen and Niskanen (2001) and Heino et al. (1995a; 1995b).

2.5.2. Processing and analysis of drill core

Drill core was generally analyzed in meter intervals, while also taking into account natural transitions in rock type and alteration style and intensity, or structural discontinuities. Samples selected for analysis were either mechanically split or sawn. One half of the sample was then crushed with a manganese steel jaw crusher, separated into two subsamples, ground to powder in a manganese steel mill and finally separated into two fractions. Apart from a few exceptions, all analyses were made at the geochemical laboratories of the Geological Survey of Finland.

Concentrations of As, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Ni, P, Pb, S, Sb, Sr, Ti, V and Zn were determined by inductively coupled plasma emission spectrometry (ICP-AES) of 0.2 g separates after digestion in aqua regia (90° C), according to the procedures and specifications described by Niskavaara (1995). Measured abundances of many of these elements must be regarded as minimum estimates, for many silicate and oxide phases only partially dissolve in hot aqua regia. In contrast, sulfide phases dissolve readily in aqua regia, so that concentrations of chalcophile elements are considered to be more accurate.

Determination of Au and Te concentrations, or alternatively Au, Pd and Pt, or Pd alone, was done by dissolution of 5 g aliquots in aqua regia at room temperature, co-precipitation with mercury, vaporization in a graphite furnace and analysis by atomic absorption spectrometry (GFAAS), as specified by (Kontas 1981, 1993a,b, Kontas et al. 1987, Niskavaara 1990). Where Au concentrations exceeded 1000 ppm, analyses were repeated with 20 g weighing aliquot.

In order to ascertain the analytical reliability of 5 g aliquots and the potential influence of the nugget effect, 138 drill core samples, each weighing 2 kg, were selected and analyzed. Similar samples were also analyzed from Pahkalampi and Pahkasuo, as well as RC-samples from Timola. Sample preparation was carried out as described above for routine analyses. Subsamples weighing 0.5 kg were separated and then leached in a cyanide solution for 24 hours. Leachates were then diluted with aqua regia and analyzed with GFAAS. Results of this comparative analytical study indicated that the nugget effect is in general negligible and can be ignored, although it may be sporadically significant (Pietikäinen et al., 2000).

Petrological (whole-rock) analyses were performed on pressed powder pellets with wavelength dispersive XRF spectrometry, analytical code 175X (Sandström et al., 1989). Some of these samples were also analyzed separately for carbon. Results of the pressed powder pellet analyses were compared against major element data from fused beads analyzed according to GTK laboratory code 713X (see Section 2.6.2.2).

For the purpose of nickel investigations at the Vaara-Kauniinlampi occurrence, 20 REE analyses were made (see Section 2.6.3), which involved dissolution in hydrofluoric and perchloric acid, followed by lithium metaborate – sodium perborate fusion and analysis with ICP-MS (Rautiainen et al., 1996).

A further 17 PGE-total analyses were performed on samples from the Vaara-Kauniinlampi area (see Section 2.6.4), based on 15 g aliquots. Samples were co-precipitated with tellurium and Au and platinide abundances were determined using nickel sulfide enrichment with ICP-MS, according to the method and specifications described by Juvonen (1999).

2.6. SEPARATE STUDIES

2.6.1. Isotopic age determinations

The radiometric dating of geological events in the Archean of eastern Finland have been particularly useful. The following generalizations can be made:

1. The U-Pb system in zircons generally records primary crystallization age, except where subsequent processes have resulted in partial or complete lead loss or exchange, in which cases analyses are discordant, or where zircons are derived from multiple sources
2. Monazite and titanite U-Pb zircon ages tend to record thermal events younger than magmatic crystallization
3. Whole-rock Sm-Nd analyses provide estimates of crustal residence ages of source

materials of igneous rocks and sediments. When combined with U-Pb zircon data, it is possible to determine the time at which protoliths to intrusive and extrusive rocks were originally extracted from the mantle, as well as the age of magmatic crystallization and relative proportion of reworked crustal material. Nevertheless, the whole-rock Sm-Nd method is susceptible to disturbances by processes that mobilize rare earth elements.

4. The Rb-Sr whole-rock method is also susceptible to disturbance by thermal processes and fluid-rock interaction but when data are used in conjunction with age determinations based on other isotopes, useful information can be obtained. In undisturbed rocks, the strontium initial ratio Sr_i is an important parameter for constraining age and provenance of igneous source materials in particular.
5. The K-Ar system is highly susceptible to resetting by successive thermal events and moreover, different minerals release argon at different temperatures, so that care is needed in interpretation of cooling histories. However, when constrained by data from more robust systems, the K-Ar data can be used to map the distribution of, for example, Paleoproterozoic thermal overprinting throughout the Archean of eastern Finland (cf. Kontinen et al., 1992).

One of the principal objectives of isotopic dating was to constrain and confirm the lithostratigraphic relationships and structural and intrusive events deduced during mapping in the Suomussalmi and Kuhmo greenstone belts. Isotopic age determinations were carried out at the GTK isotope laboratory in Otaniemi, and at the NORDSIMS ion probe facility in Stockholm, Sweden. Some of the data obtained during the project have been published in the explanatory notes to the Lentiira 1: 100 000 mapsheet. However, the results reported here have not yet been published elsewhere. The following text is largely based on unpublished reports and personal communication with Hannu Huhma, Olavi Kouvo, Irmeli Mänttäri and Matti Vaasjoki.

Suomussalmi greenstone belt and surrounding granitoids

Aittojärvi molybdenite occurrence

During the project additional samples were taken for isotope analysis from granitoid rocks hosting the Aittojärvi molybdenite occurrence (Figure 2.6.1a, samples A996a, b, c, d; KKJ 20 000 mapsheet 451402, grid reference FIN_KKJ4 4467.500E, 7262.00N). It was hoped that the age of mineralization could be constrained by U-Pb zircon dating of the host granitoids and by Re-Os dating of molybdenite.

The previously analyzed granitoid sample (A996a) was considered to be representative of the molybdenite mineralization. All seven zircon fractions were discordant and the provisional calculated age of 2 575 ± 35 Ma (Figure 2.6.1b) was interpreted as an estimate of the age of crystallization of the Aittojärvi granitoid and possibly also the minimum age of molybdenite mineralization.

Sample A996b, collected in 1994, is from a relatively dark granitoid variant within the mineralized zone. Seven of the eight fractions analyzed lie along a reference chord, with an upper intercept at 2630 Ma and lower intercept at 345 Ma. The remaining fraction is nearly concordant and appreciably older, with a $^{207}Pb/^{206}Pb$ age of 2 676 ± 2 Ma (Figure 2.6.1c).

Sample A996c represents a leucocratic migmatite adjacent to the Mo-mineralization, which comprises older migmatitic paleosomes and enclaves of amphibolite, as well as veins containing

molybdenite. Analyzed zircon fractions show considerable scatter and tend to lie above the reference chord defined by the A996b sample, and hence suggesting a somewhat younger age (Figure 2.6.1d).

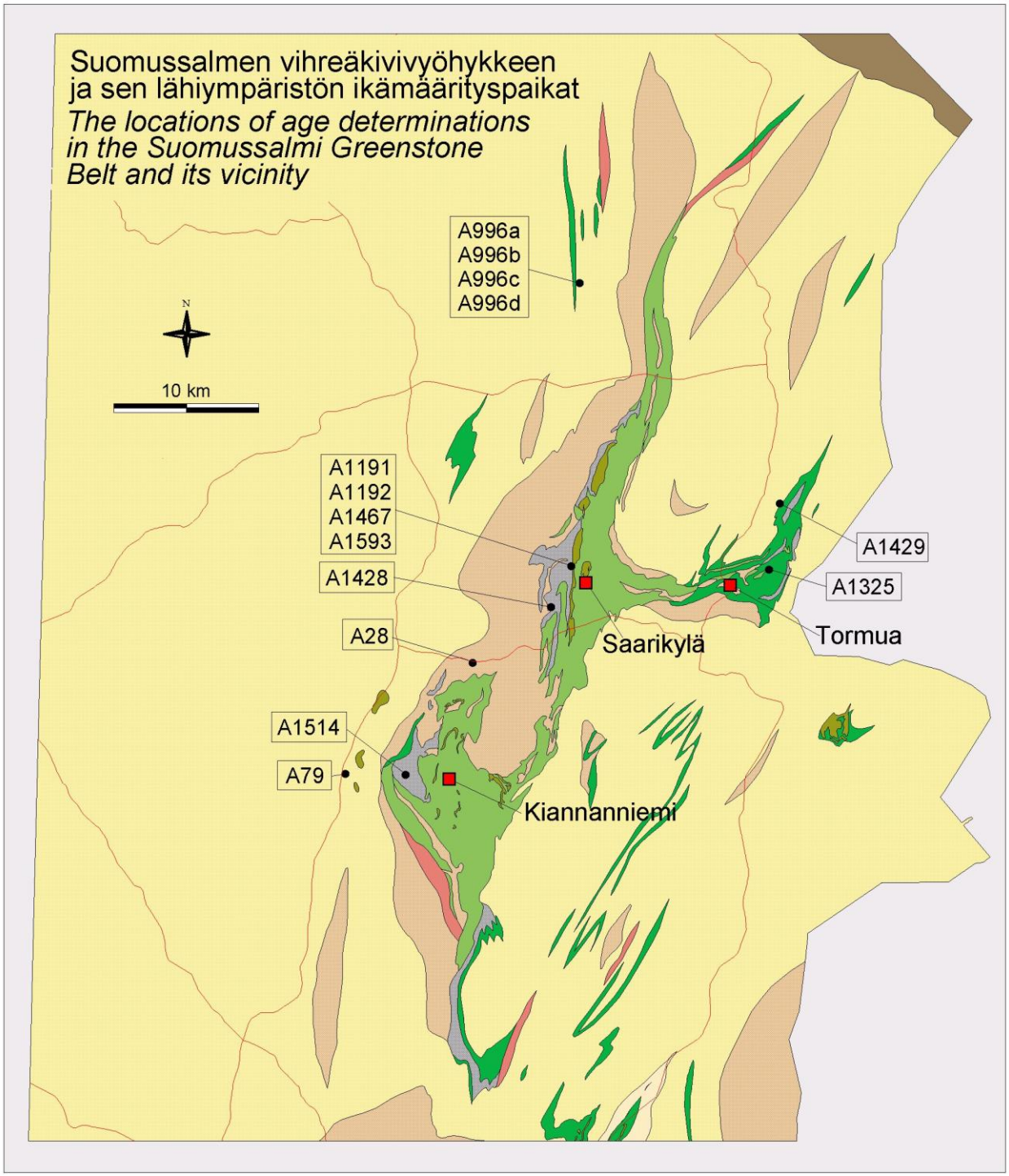


Fig. 2.6.1a. Locations of isotopic age determinations in the Suomussalmi Greenstone Belt and its surroundings.

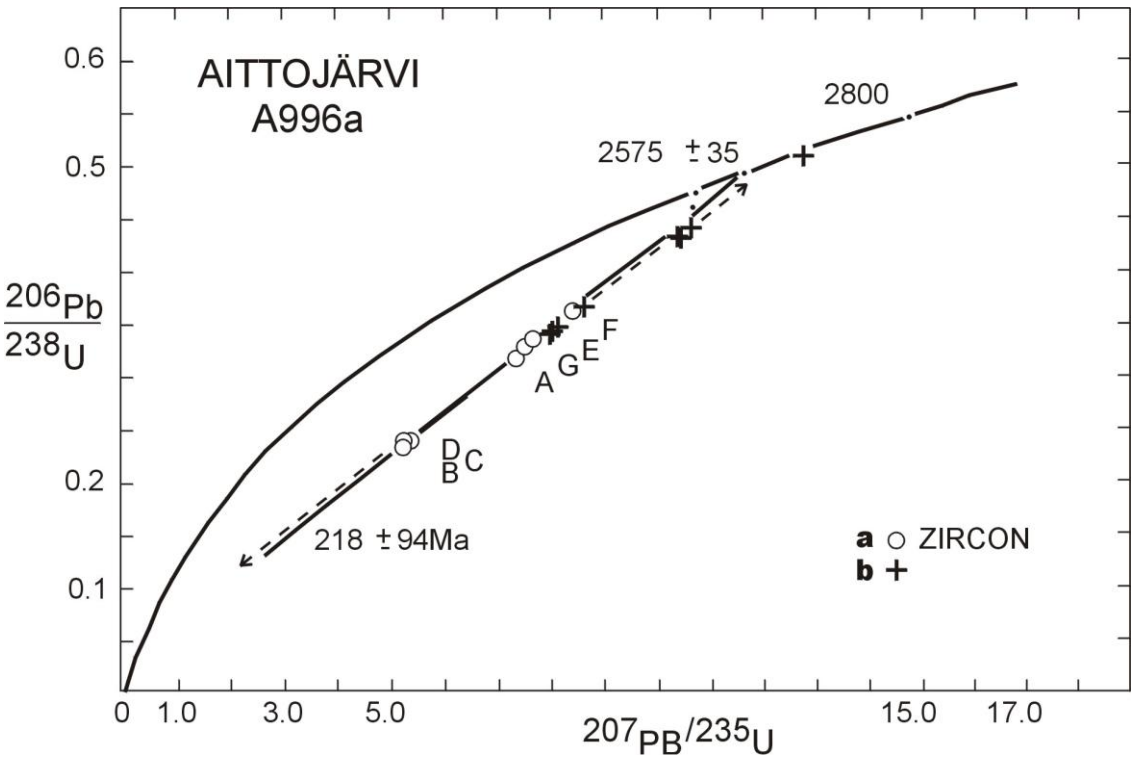


Fig. 2.6.1b. U-Pb concordia plot for zircons from Aittojärvi granitoid samples (A996a).

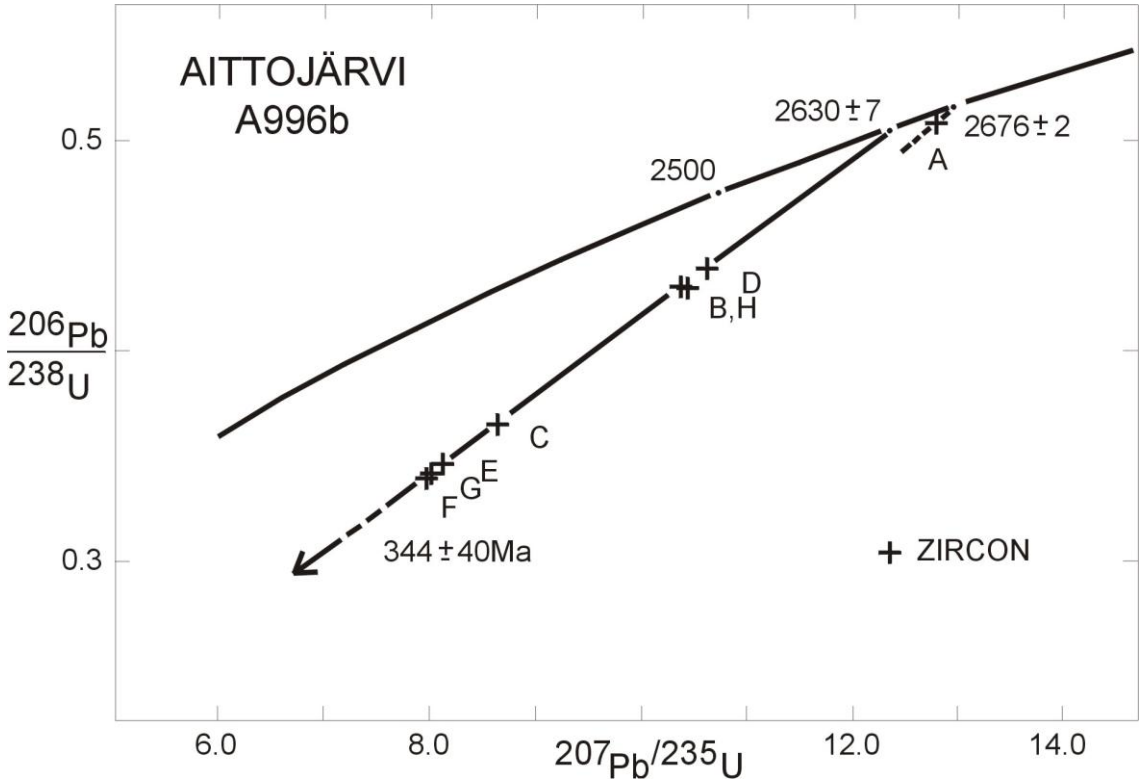


Fig. 2.6.1c. U-Pb concordia plot for zircons from the darkish granitoid sample (A996b), Aittojärvi.

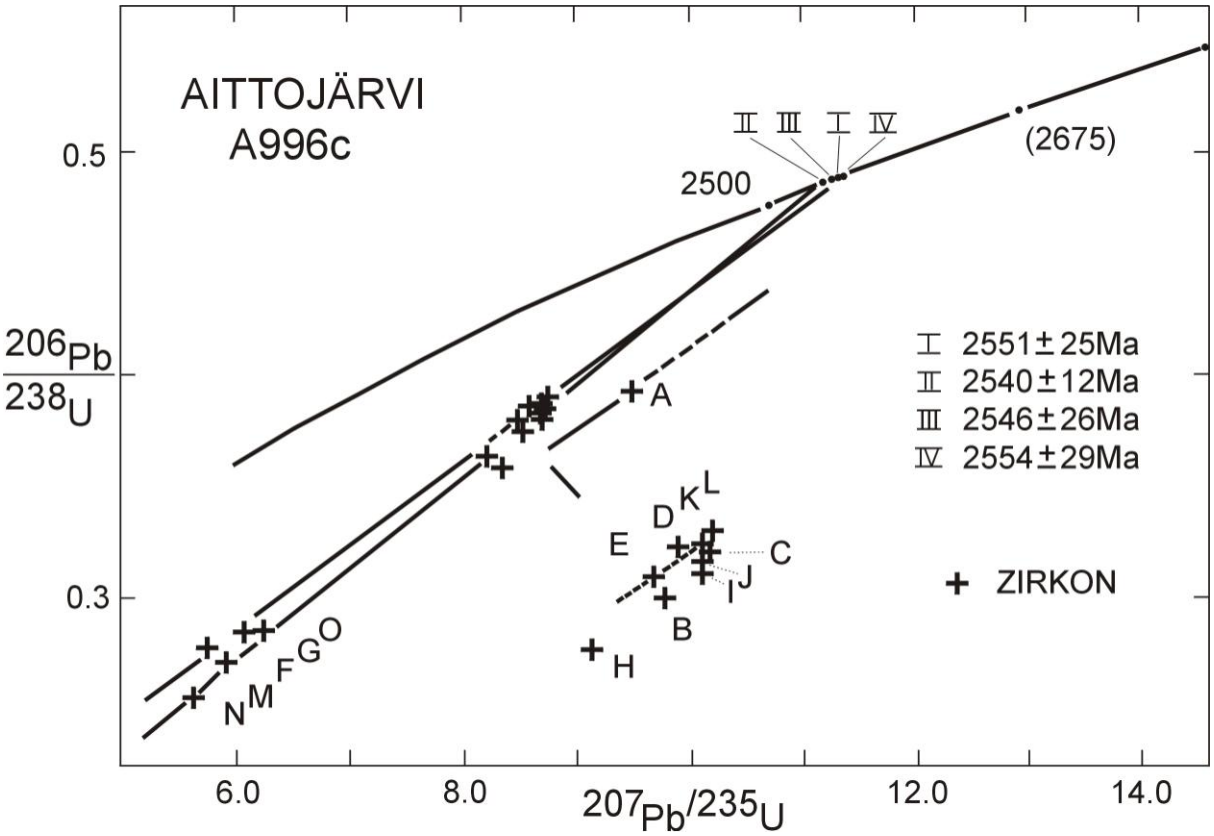


Fig. 2.6.1d. U-Pb concordia plot for zircons from the leucocratic Aittojärvi granitoid sample (A996c).

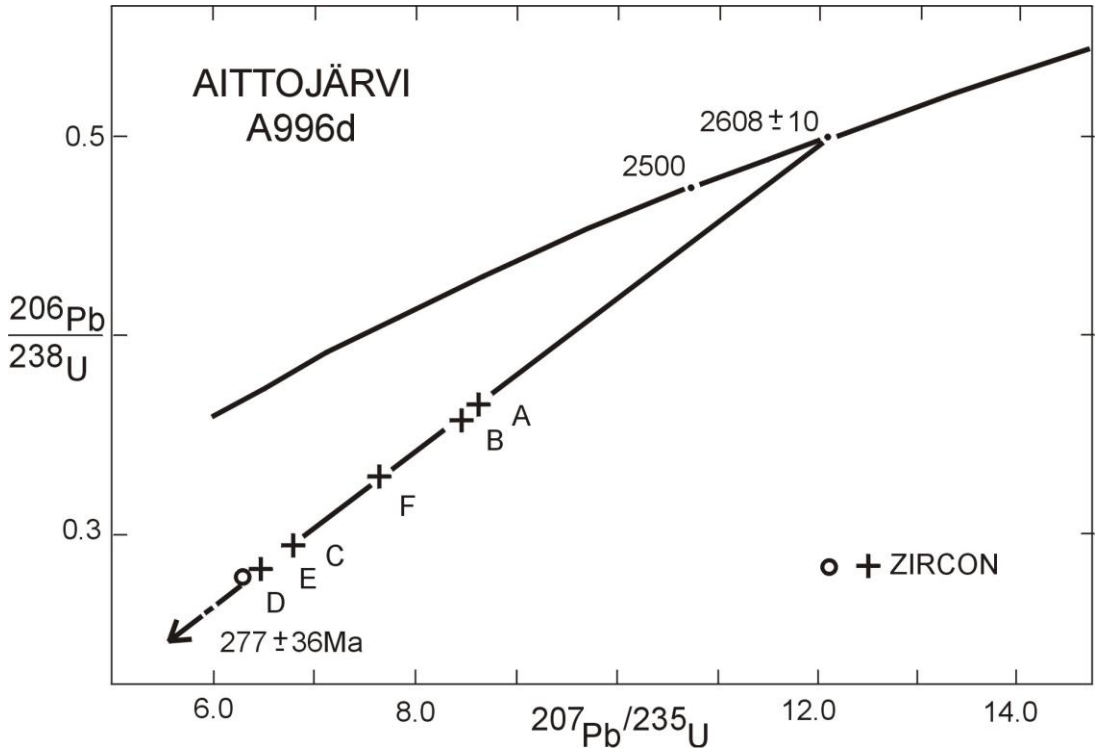


Fig. 2.6.1e. U-Pb concordia plot for zircons from sample (A996d), taken in 1995 from the mineralized part of Aittojärvi.

Sample A996d, collected in 1995 (Figure 2.6.1.e) represents the same type of rock as A996a, namely the host rock to the mineralization; the six analyzed fractions lie close to the reference chord defined by sample A996b.

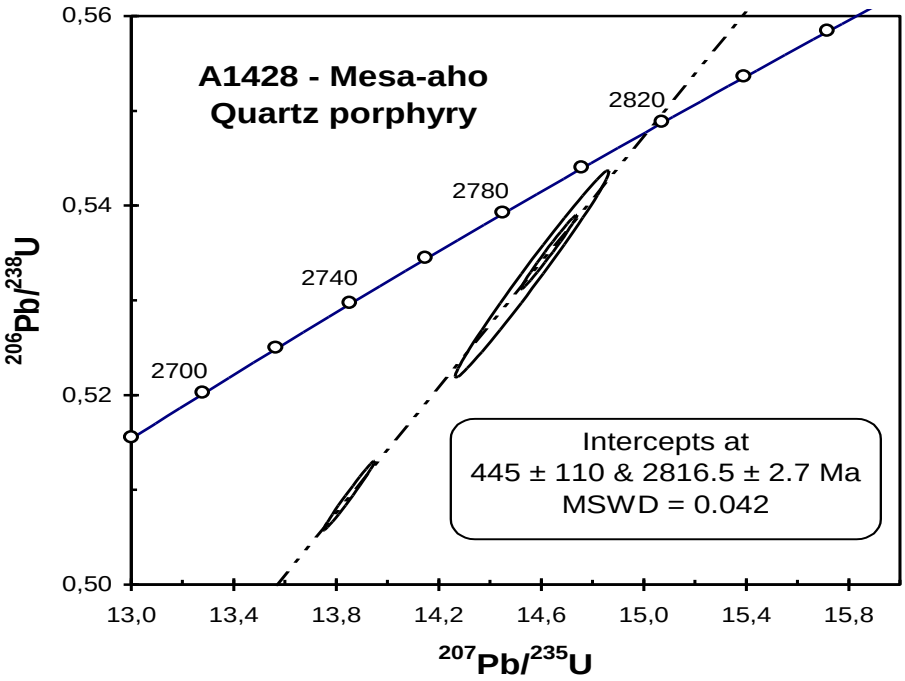
All four Aittojärvi samples are characterized by high abundances of uranium (1 300 – 4 100 ppm) and lead (460 – 1 480 ppm) and a relatively low density for zircon fractions (< 4.2 g/cm^3). Experience has shown that such zircons are typically metamict, having suffered lattice damage and are consequently more susceptible to post-crystallization diffusion. Diffusion could thus be responsible for the observed broad scatter and it may also be noted that the nearly concordant fraction A996bA is in fact one of the densest measured (4.0-4.2), has the lowest uranium content of any sample (1 297 ppm) and has a distinctive $^{208}Pb/^{206}Pb$ ratio of 0.04, compared to the other samples, which have values in the range 0.012 - 0.021. Moreover, the $^{207}Pb/^{206}Pb$ age of 2 676 ± 2 Ma is very typical of granitoids bracketing the Archean D_3 - D_4 deformation events and may therefore provide a reliable constraint on the timing of magmatism with respect to both deformation and mineralization. The upper intercept of the A966b reference chord could accordingly provide an approximation to the age of Mo-mineralization.

Molybdenite from Aittojärvi has also been studied with the Re-Os method by Dr Holly Stein and colleagues at the Colorado State University, USA. The first data set obtained from the Aittojärvi samples indicated an age range from 2 835 ± 8 Ma to 2 851 ± 8 Ma (Stein et al. 1995), which was unexpectedly high. Technical refinements and recalibration of decay constants led to revised age estimates between 2 798 ± 3 Ma and 2 810 ± 4 Ma, (Markey et al. 1999). These dates are clearly still much older than U-Pb zircon ages of granitoids intruding the Suomussalmi greenstone belt, although they coincide on the other hand with age estimates for volcanic rocks in the Kuhmo greenstone belt. An additional notable aspect of Aittojärvi molybdenite is the uniformity of the $^{187}Re/^{187}Os$ ratio, which makes it suitable as a laboratory standard.

At the time that these analyses were made, applications of the Re-Os technique were still relatively new and there was little opportunity for comparisons with age estimates based on other isotopic systems, with the exception of ultramafic rocks. Therefore, it is not possible to make definitive conclusions about the significance of the disparity between U-Pb zircon and Re-Os molybdenite data from Aittojärvi. However, given the discordance shown by the zircon data, the Re-Os data may indeed prove to be a more reliable estimate of the age of crystallization.

Age determinations from the Tormua segment of the Suomussalmi greenstone belt

The central and marginal parts of the northern end of the Tormua schist belt contain a distinctive suite of intermediate volcanic rocks, intercalated with banded amphibolites and tholeiitic uralite porphyry, which correlate with other mafic rock types in the Suomussalmi greenstone belt. Field observations indicate that the Tormua uralite porphyry may actually be somewhat older than the Saarikylä tholeiitic basalts and associated sills and hypabyssal uralitic porphyry intrusions. A representative sample of intermediate volcanics from Kilpasuo (A1429; KKJ mapsheet = 4513 09, KKJ4 grid coordinates 4481.340E and 7248.830N) yielded small brownish, though clear and euhedral zircon crystals that were dated both by TIMS and ion microprobe. Analytical results are rather discordant, as might be expected from the relatively high uranium content, but define a regression chord with an upper concordia intercept at 2 774 ± 8 Ma and lower intercept at 439 ± 180 (MSWD = 1.8, Figure 2.6.1f). However, the fact that this chord is effectively defined by only two points, the apparent precision of this result should be treated with caution. This age estimate for the Kilpasuo sample is nevertheless consistent with other data from the Saarikylä tholeiites and may therefore help constrain the timing of the earlier phases of volcanism in the Suomussalmi greenstone belt.



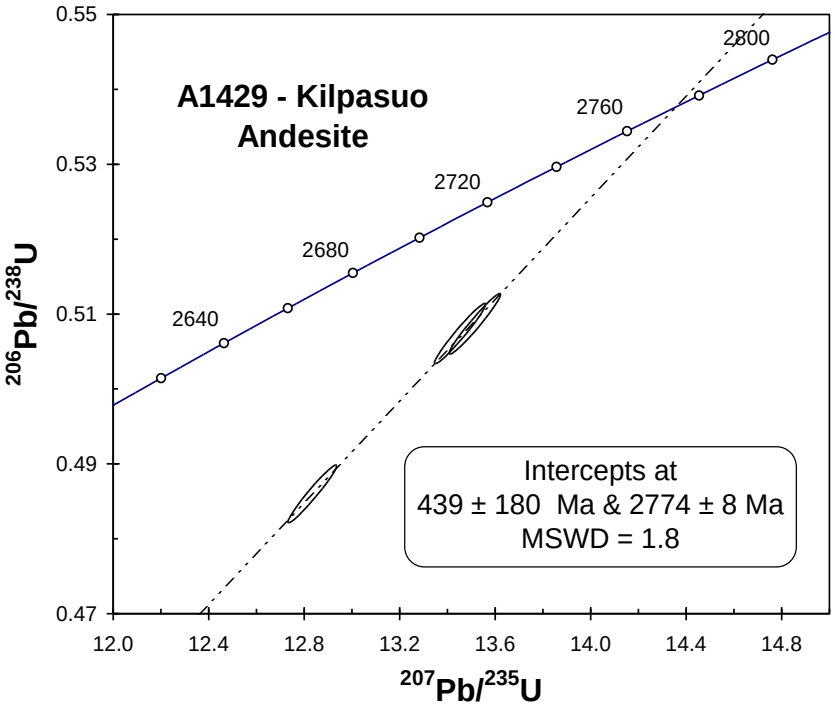


Fig. 2.6.1f. U-Pb concordia plot for zircons from the Kilpasuo intermediate volcanic rock (A1429) and the Mesa-aho quartzporphyry dyke (A1428).

An attempt to date gold mineralization in the Tormua belt by Sm-Nd analysis of scheelite was firstly delayed due to maintenance work on the GTK mass spectrometer, and then abandoned, due to concerns over the general accuracy of the method. However, samples collected from a deformed uralitic porphyry dyke adjacent to the Moukkori gold occurrence (A1325; KKJ 20 000 mapsheet = 4513 09, grid reference FIN_KKJ4 7243.960N, 4480.900E) yielded separates of both scheelite and titanite. The titanite may belong to the hydrothermal mineral assemblage

relating to gold mineralization and was dated by the U-Pb method to 2 676 ± 20 Ma. Because the results are somewhat discordant, this is best interpreted as a minimum age, with the age of mineralization being somewhere between 2650 – 2700 Ma. This is consistent with inferences based on regional scale structural interpretations throughout the Kuhmo and Suomussalmi greenstone belts, in which gold mineralization is linked with the transition between D_3 and D_4 deformation events.

Lead isotopic compositions were also determined from two samples of galena from mineralization at Moukkori (G480 and G481; KKJ 20 000 mapsheet = 4513 09, FIN_KKJ4 grid reference = 7243.960N, 4480.900E). The results classify Moukkori within the so-called higher Archean group in Figure 2.6.1g, as defined by Vaasjoki (1989) and Vaasjoki et al. (1999), contrasting with the lead isotopic results for the Taivaljärvi Ag-Zn-Pb deposit and gold occurrences in the Ilomantsi greenstone belt. The data from Moukkori are thus highly significant in understanding the Archean crustal evolution of eastern Finland, especially given that they closely resemble the results obtained for the Saarikylä Pb-Ag-Zn mineralization in the Suomussalmi greenstone belt. Such values are only possible if lead has evolved in an environment with a relatively high U/Pb ratio, for example in the upper crust. By inference then, the Moukkori and Saarikylä Pb data indicate the presence of, or interaction with much older crust, potentially as old as 3600 Ma, at some stage in the evolution of the Suomussalmi greenstone belt.

Saarikylän - Kiannanniemen alueen ikämääritykset

The western margin of the Suomussalmi greenstone belt includes the so-called Luoma Group, which mostly comprises mafic, intermediate and felsic volcanics and volcaniclastic sediments (Figure 2.6.1a; A1191-1593 and A1514). Deformed medium-grained porphyritic intrusions that are typically concordant or slightly discordant with respect to lithological layering are also present. Both the dykes and the supracrustal rocks of the Luoma Group are considered to be stratigraphically older than the tholeiitic and komatiitic volcanics of the Saarikylä Group (Luukkonen & Lukkarinen 1986, Taipale 1983b).

Samples from the Luoma Group (A1191, KKJ 20 000 mapsheet = 4513 03, grid reference = 7242.760N, 4465.800E) , originally considered to be lavas but later reinterpreted as stratified and graded volcaniclastic sediments have previously been dated by the U-Pb method as 2 966 ± 6 Ma (Vaasjoki et al. 1999). This somewhat anomalously old date seemed reliable from a technical and analytical perspective and subsequent Sm-Nd analysis gave a model age (T_{DM}) of around 3 200 Ma. Zircons from this sample were therefore dated individually at the joint Nordic ion microprobe facility (NORDSIMS) in Stockholm, which allows analyses to be focused with a beam width of less than 30 microns. Scanning electron microscopy (SEM) at GTK revealed that zircon crystals are typically somewhat rounded, which is consistent with limited detrital reworking and transport. Most grains show some degree of fracturing and weak oscillatory zoning, while some contain metamict domains. On the concordia diagram (Figure 2.6.1i), the analyzed zircons clearly define two discrete populations, with age estimates of 2 959 ± 12 Ma and 2 825 ± 27 Ma.

Felsic volcanics from Saarikylä had previously been dated from a sample (A1192) collected in collaboration with Kajaani Oy. Four highly discordant zircon fractions were analyzed and fitted to a chord through the concordia origin that provided an age estimate of 2 804 ± 42 Ma. When combined with whole rock lead isotope data obtained from powder crushed from the same rock, it was concluded that a provisional age estimate for the Saarikylä Group volcanism was around 2790 Ma (Vaasjoki et al., 1999). To resolve this uncertainty, further samples were collected,

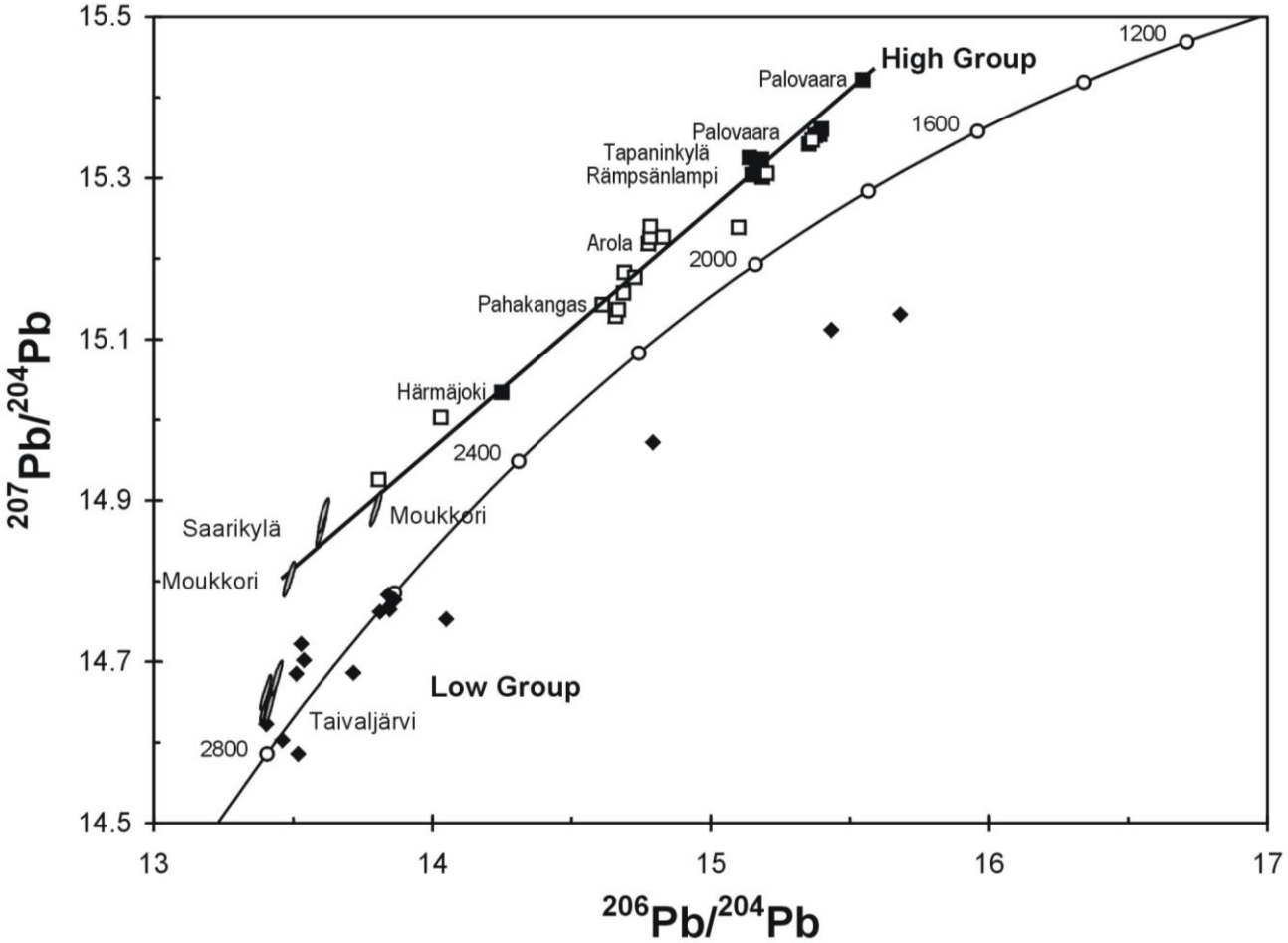


Fig. 2.6.1g. Archaean lead isotope compositions of galena from eastern Finland; solid squares from the area covered by FIN_KKJ 1: 100 000 map sheet 4412, open squares from various other places. The solid diamonds represent samples leached from drill cores of various gold occurrences in the Hattu schist belt, Ilomantsi.

from some felsic volcaniclastic deposits (A1467; KKJ 20 000 mapsheet = 4513 03 C, FIN_KKJ4 grid reference = 7242.680N, 4466.560E) and a quartz porphyry dyke (A1593; KKJ 20 000 mapsheet 4513 03 C, FIN_KKJ4 grid reference = 7242.550N, 4466.540E); sample A1467 yielded zircons but the dyke sample contained very little zircon, although sufficient monazite was obtained for analysis.

The zircons in sample A1467 were principally brownish and rather turbid, and elongate prismatic in shape, suggestive of a magmatic origin, without significant sedimentary reworking. However, there was also a large proportion of more irregular, variably sized grains in which prism faces were less developed or absent. The five analyzed zircon fractions show considerable scatter (Figure 2.6.1j), indicating that the populations are highly heterogeneous, either due to derivation from multiple and diverse sources, or that individual grains have older cores. Closer inspection of the data shows that fractions B and E, which have higher $^{208}Pb/^{206}Pb$ ratios and lower uranium concentrations, define a somewhat younger trend than the other fractions. Therefore it is unlikely that the heterogeneity is a consequence of inheritance of older zircon cores, since fraction E in particular was subjected to prolonged abrasion. A regression chord based on all fractions provides an upper intercept of 2 945 Ma. In this connection it is noteworthy that the nearly concordant monazite from the quartz porphyry dyke (A1593) has a $^{207}Pb/^{206}Pb$ age of 2 942 ± 3 Ma, which lie along on the same chord. This monazite incidentally also represents the oldest phosphate mineral so far found in Finland.

Because this quartz porphyry dyke is a nearly concordant intrusion within felsic volcanics, it also constrains the minimum age for eruption and deposition of the Saarikylä Group. Accordingly, the simplest interpretation for sample A1467 is that the felsic volcanics were erupted around 2950 Ma and that the zircons contain some older inherited cores, in fractions A, C and D. The NORDSIMS analyses support this interpretation in that five concordant U-Pb analyses give an age estimate of 2 943 ± 20 Ma, with one grain being considerably older. This age is virtually the same as the monazite U-Pb age from the quartz porphyry dyke (A1593).

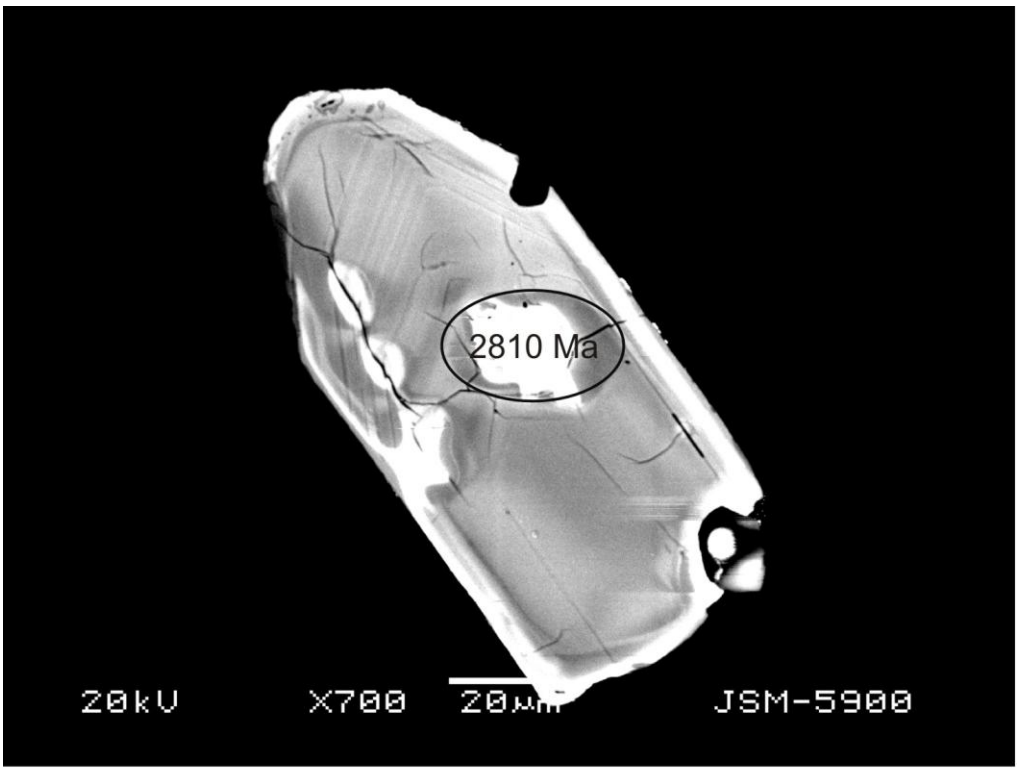
Another typical quartz porphyry dyke intruding Luoma Group rocks was sampled at Mesa-aho, near Saarikylä (KKJ 20 000 mapsheet = 4513 03, FIN_KKJ4 grid reference = 7240.420N, 4464.880E). Zircon was relatively abundant and grains were mostly short (typically about 200 μm in length) and reddish in color, and euhedral with clearly discernible prismatic and pyramidal facets (unlike most Archean zircons). Three of the analyzed fractions were only slightly discordant, and gave a calculated upper intercept of 2 816.5 ± 2.7 Ma (lower intercept 445 ± 110 Ma, MSWD = 0.04; Figure 2.6.1f), which is regarded as a reliable estimate of the age of crystallization. NORDSIM analytical data support this interpretation, as a pooled estimate from eight grains was 2 818 ± 15 Ma (Figure 2.6.1k). This age is also in agreement with the results obtained for the Polvilampi quartz-feldspar schist in the Kuhmo greenstone belt (Hyppönen 1983), even though the latter analyses were highly discordant. Both ages are representative of a period of felsic to intermediate volcanism that occurred prior to the main stage of tholeiitic mafic and komatiitic ultramafic volcanism in both the Suomussalmi and Kuhmo greenstone belts. Although slightly younger, the Katerma felsic volcanics in the southern part of the Kuhmo greenstone belt (Hyppönen, 1983) and the Taivaljärvi felsic volcanics in the Tipasjärvi greenstone belt (Papunen et al., 1989) are likely to be broadly stratigraphically correlative with the Saarikylä felsic volcanics.

A further volcanogenic sample from the Luoma Group, representing a proximal intermediate eruptive facies displaying pillow structures, was obtained from Huurunvaara near Kiannanniemi (A1514; KKJ 20 000 mapsheet 4511 11C, FIN_KKJ4 grid reference = 7230.140N, 4455,720E). Unfortunately, however, the separates from this sample yielded no zircon, monazite or titanite.

A rather extensive area of granitoids, known as the Lamminkylä granodiorite, occurs along the western margin of the Suomussalmi greenstone belt. These granitoids are clearly discordant with respect to greenstone belt lithologies and also the earlier migmatic tonalitic and trondhjemitic rocks. Based on regional structural mapping, the Lamminkylä granitoids belong to the late D_3 stage of deformation. The first isotopic age determination (A28) was made in the 1960's on these rocks by borax fusion of a 600 mg sample, from an outcrop located near the Lamminkylä road junction. Another sample was subsequently collected from a nearby road cutting (A44; KKJ 20 000 mapsheet = 4513 02; grid reference = 7239.300N, 4466.960E). Both samples gave results that are identical within error limits, of 2 718 ± 6 ja 2719 ± 4 Ma, which is therefore interpreted as the age of emplacement and crystallization of the Lamminkylä granodiorite. It is also notable that the titanite age for sample A44 is exactly the same as for zircon.

Isotopic studies on the Päivärinta migmatites

Stromatic migmatites exposed in a road cutting at Päivärinta, on the main highway between Suomussalmi and Kuusamo (A79; KKJ 20 000 mapsheet = 4511 10, grid reference = 7228.900N, 4450.500E; Figure 2.6.1a), were sampled, ensuring that material was obtained from both paleosomes (which may also be described as mesosomes in this case) and neosomes. Due to the extreme scatter, it was not possible to define a precise age for the paleosomes but when the most discordant sample is excluded, a reference chord is obtained with an upper concordia intercept of around 2820 Ma. The analyses from the neosome zircons provide a more reliable



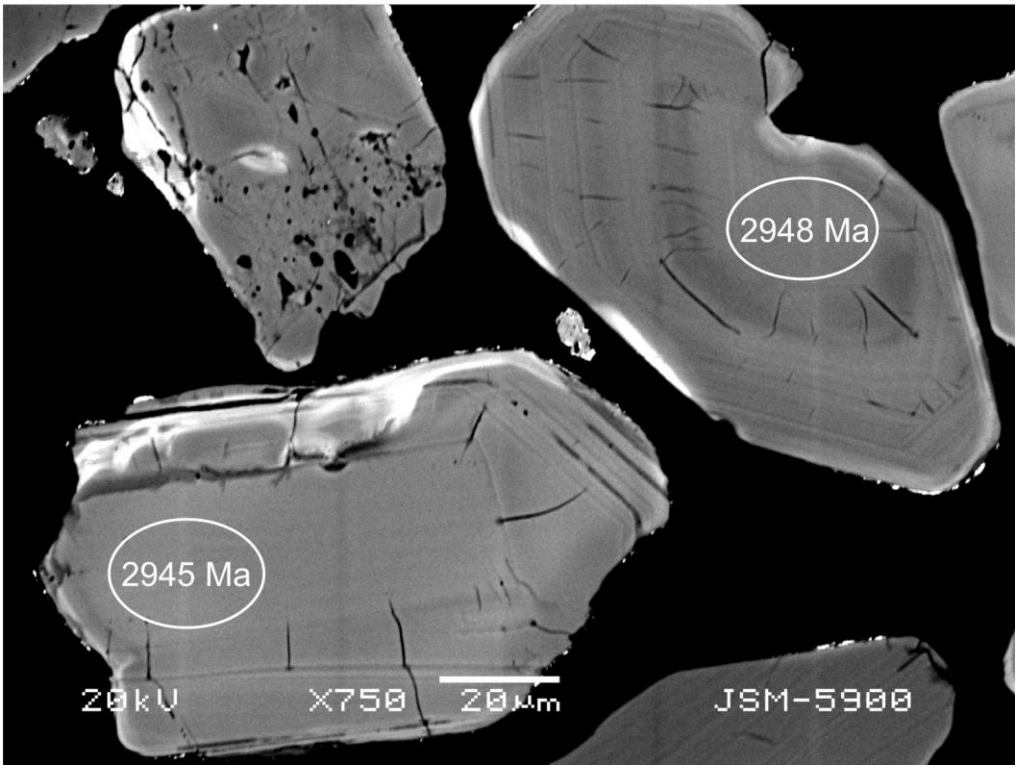


Fig. 2.6.1h. Back scattered SEM images of sample A1191 (Ala-Luoma). The zircon crystals 1 (above), 4 and 5 (below) have been analysed by secondary ion-mass-spectrometry, using NORDSIM, with analysed areas indicated by ellipsoids; $^{207}Pb/^{206}Pb$ ages in millions of years (Ma) are shown inside the ellipses Photo by M. Vaasjoki.

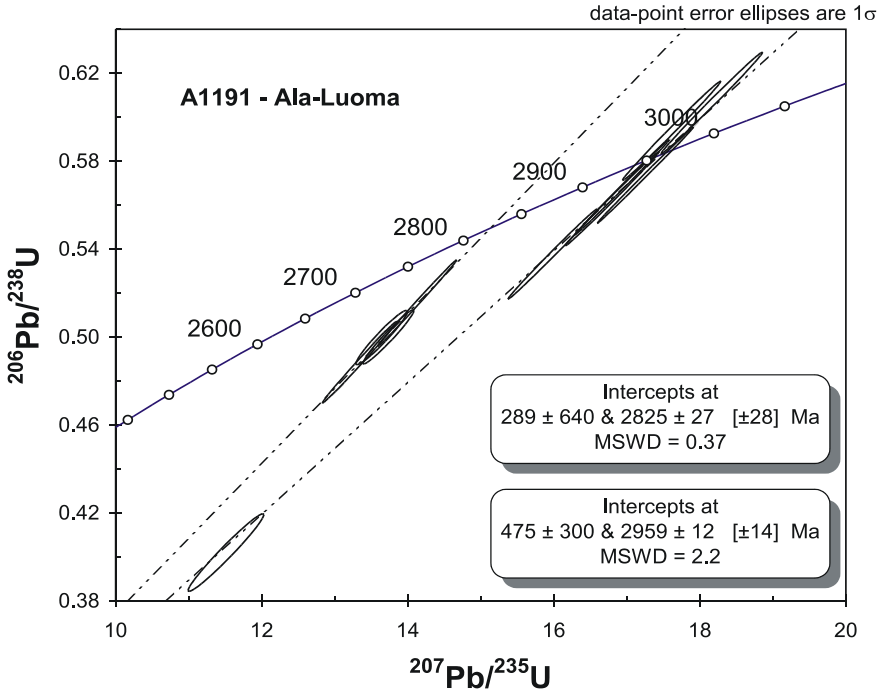


Fig. 2.6.1i. Two age populations of zircon crystals from the metasedimentary sample A1191, Ala-Luoma, Suomussalmi. The analyses were carried out by secondary ion-mass-spectrometry, using NORDSIM.

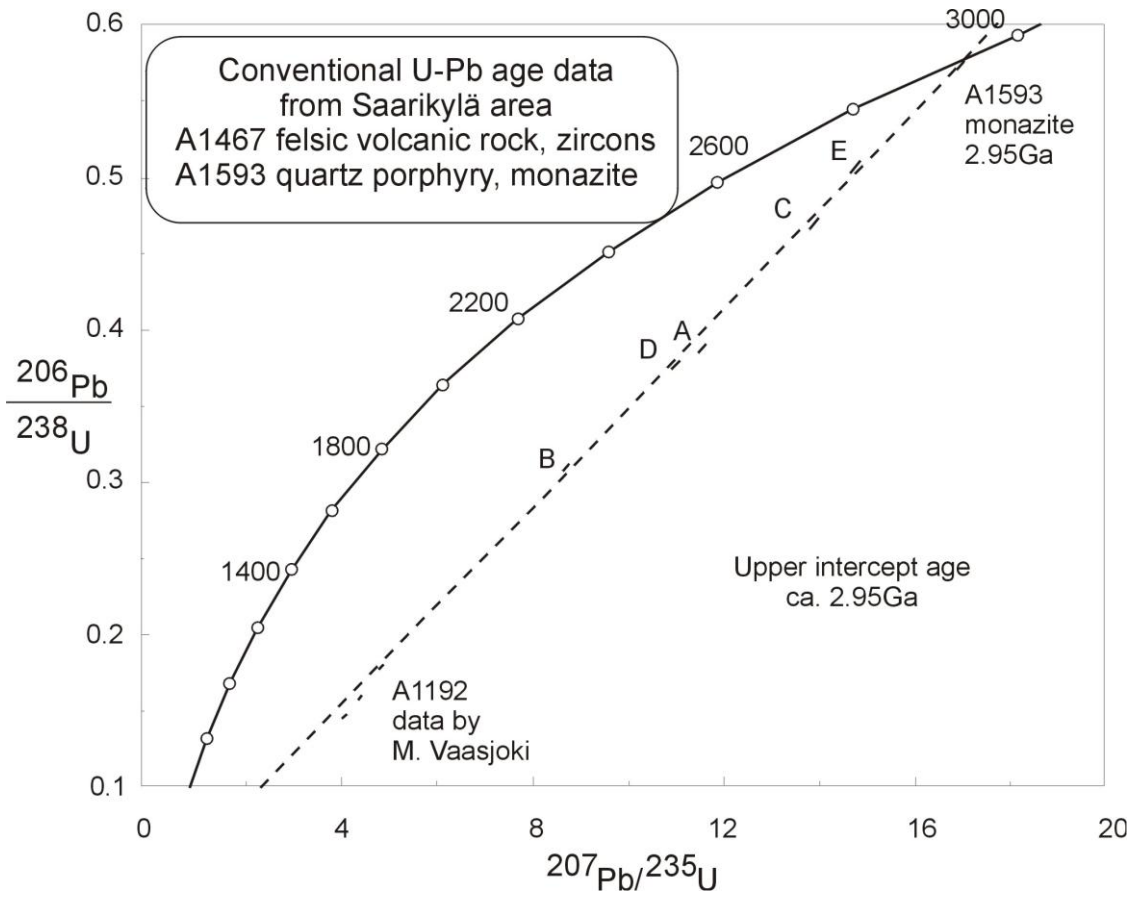


Fig. 2.6.1j. U-Pb concordia plot for zircons (A1467) and monazite (A1593) from Saarikylä felsic and intermediate volcanics.

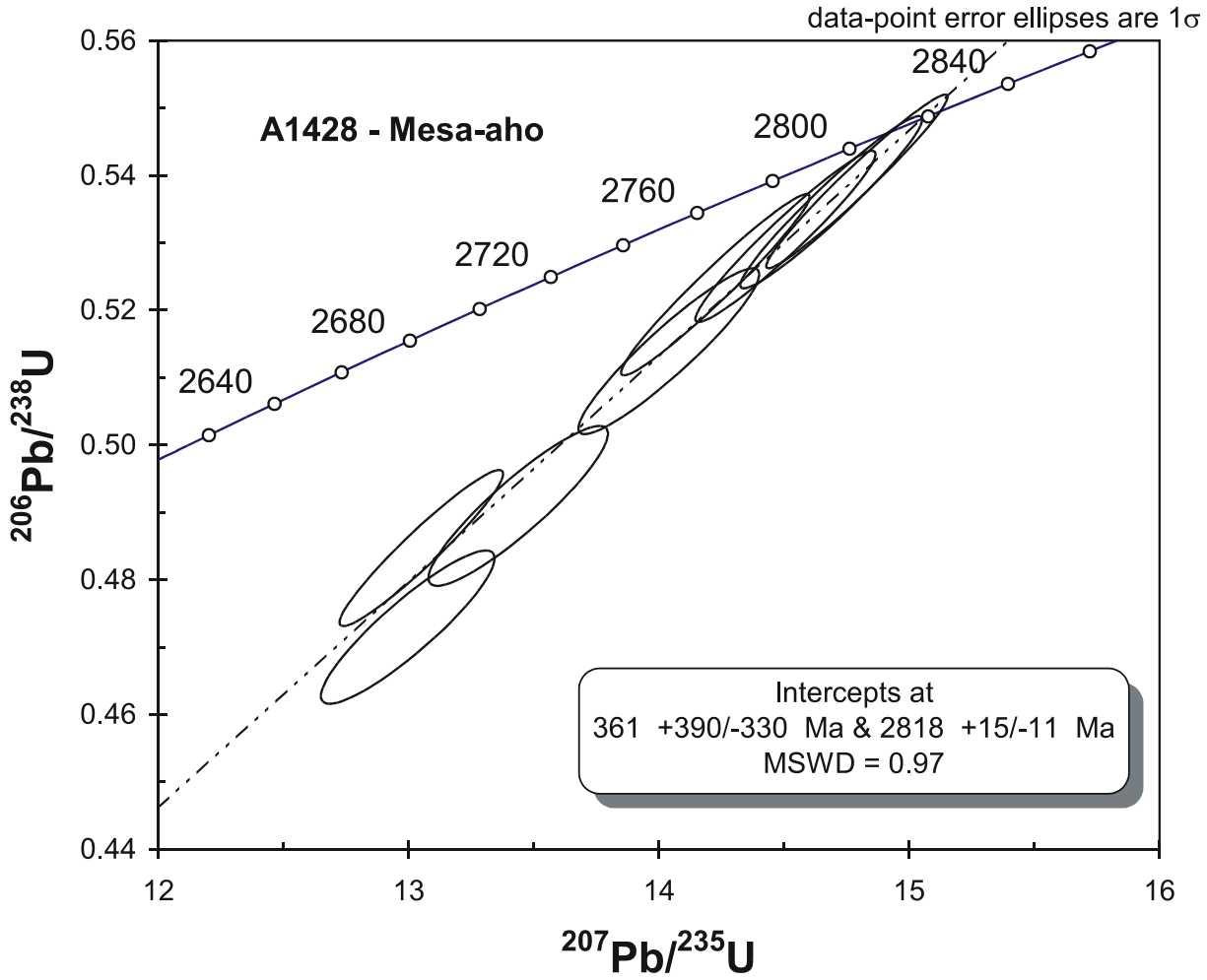


Fig. 2.6.1k. Age spectrum of zircon crystals from the quartz porphyry dyke sample A1428, Mesa-aho, Suomussalmi greenstone belt. The analyses were made by secondary ion-mass-spectrometry, using NORDSIM.

2 763 ± 16 Ma. The paleosome date nevertheless agrees well with other published results for banded stromatic migmatites from the Archean of eastern Finland (cf. Martin 1989, Luukkonen, 1985). Conversely, the leucotonalitic neosome date from the Päivärinta road cutting is older than most other neosomes dated from the region.

The paleosome age obtained from Päiväranta could represent a mixture of zircon populations of different ages, which may also be the case for other migmatitic paleosomes in the Archean of eastern Finland. Irrespective of whether this is the case or not, the paleosome ages clearly record a widespread thermal event that occurred prior to the mafic and ultramafic volcanism preserved in the Kuhmo and Suomussalmi greenstone belts. This thermal event has been associated with D_2 deformation and metamorphism, whereas neosomes and discrete granitoid plutons in the age range 2.76-2.69 Ga coincided with the protracted D_3 event, which is recognizable throughout the Archean terrains of eastern Finland and adjacent Russian Karelia. Further clarification of the timing and origin of these magmatic events is required, preferably analysis of individual grains with secondary ion mass spectrometry.

The Päivärinta samples have also been analyzed at GTK with the Sm-Nd technique and a model age (T_{DM}) of about 3 500 Ma was obtained which indicates that the paleosome is significantly

older than the zircon ages, and was subjected to intense thermal reworking after 2800 Ma. Further refinement of these issues requires ion microprobe analysis.

In summary, the Sm-Nd and Pb-Pb data from the Suomussalmi greenstone belt and surrounding migmatites indicate the presence of earlier crust that is significantly older than the greenstone belt volcanism. The oldest Sm-Nd model ages obtained are between 3.7-3.9 Ga and moreover, because these samples are not anomalous with respect to REE abundances, it is unlikely that they have been disturbed by hydrothermal processes. The isotopic compositions of galena defining the uppermost of the Archean trends do however, show some disturbance related to Paleoproterozoic Svecofennian orogenic processes, as well as indicating the existence of crustal source material as old as 3.6 Ga.

Kuhmo greenstone belt and its surroundings

One of the most important issues in the Kuhmo greenstone belt was to better constrain the age of the felsic to intermediate volcanic rocks that lie stratigraphically beneath the dominant mafic to ultramafic sequence, as well as the surrounding plutonic units and the anorthositic components of the Kellojärvi ultramafic complex, which would thus provide a direct estimate of the age of komatiitic volcanism (Figure 2.6.1l). A number of additional U-Pb zircon age determinations were undertaken on plutonic rocks to the east of the Kuhmo greenstone belt and results have been published in the explanatory notes to the Lentiira 1: 100 000 (FIN_KKJ 4414 + 4432) mapsheet (Luukkonen 2001).

Moisiovaara – Jumaliskylä region

Felsic clastic volcanic rocks representing the eastern part of the Kuhmo greenstone belt are exposed on the eastern shores of the lake Ruokojärvi, near Jumaliskylä. In outcrop they appear to be pyroclastic deposits, with diverse angular mafic fragments in a felsic matrix, suggesting eruption through a substrate of earlier mafic volcanics (komatiitic clasts have not however been identified). The analyzed sample (A120, mapsheet KKJ 4423 02B; FIN_KKJ4 grid reference = 7178.980N, 4464.500E) was taken from a more homogeneous felsic unit immediately east of an exposure of clastic breccia (cf. Luukkonen 1988a).

Zircons are morphologically dominated by elongated prismatic crystals, of which 1-2 % show reddish pigmentation. Small zircons, with short prismatic faces are also common and the small grain size may be a general feature of the host rock. The lower density fraction also contains sporadic large crystals with cloudy metamict cores, surrounded by clear rims, as is typical of metamorphic reworking or magmatic rocks derived from older material.

Four zircon fractions yielded a result of 3 007 ± 7 Ma (Figure 2.6.1m). Although this age has not been corroborated with ion probe SIMS analyses, it nevertheless indicates that the Ruokojärvi felsic rocks, or at least their source regions, are considerably older than the mafic and ultramafic volcanism of the Kuhmo greenstone belt. Moreover, the diffusion model age obtained by Hyppönen (1983) from sericitic quartzites in the central part of the greenstone belt is similar within error limits. These sericitic quartzites are considered to represent sedimentary reworking of penecontemporaneous felsic volcanics, which is also consistent with this interpretation. An Sm-Nd model age of 2900 Ma from the Ruokojärvi sample is somewhat younger than expected but this may be attributed to Paleoproterozoic hydrothermal and metamorphic processes that have elsewhere been shown to cause fractionation of REE (Gruau et al. 1992). Ion probe analyses on individual zircons are clearly necessary to resolve these uncertainties.

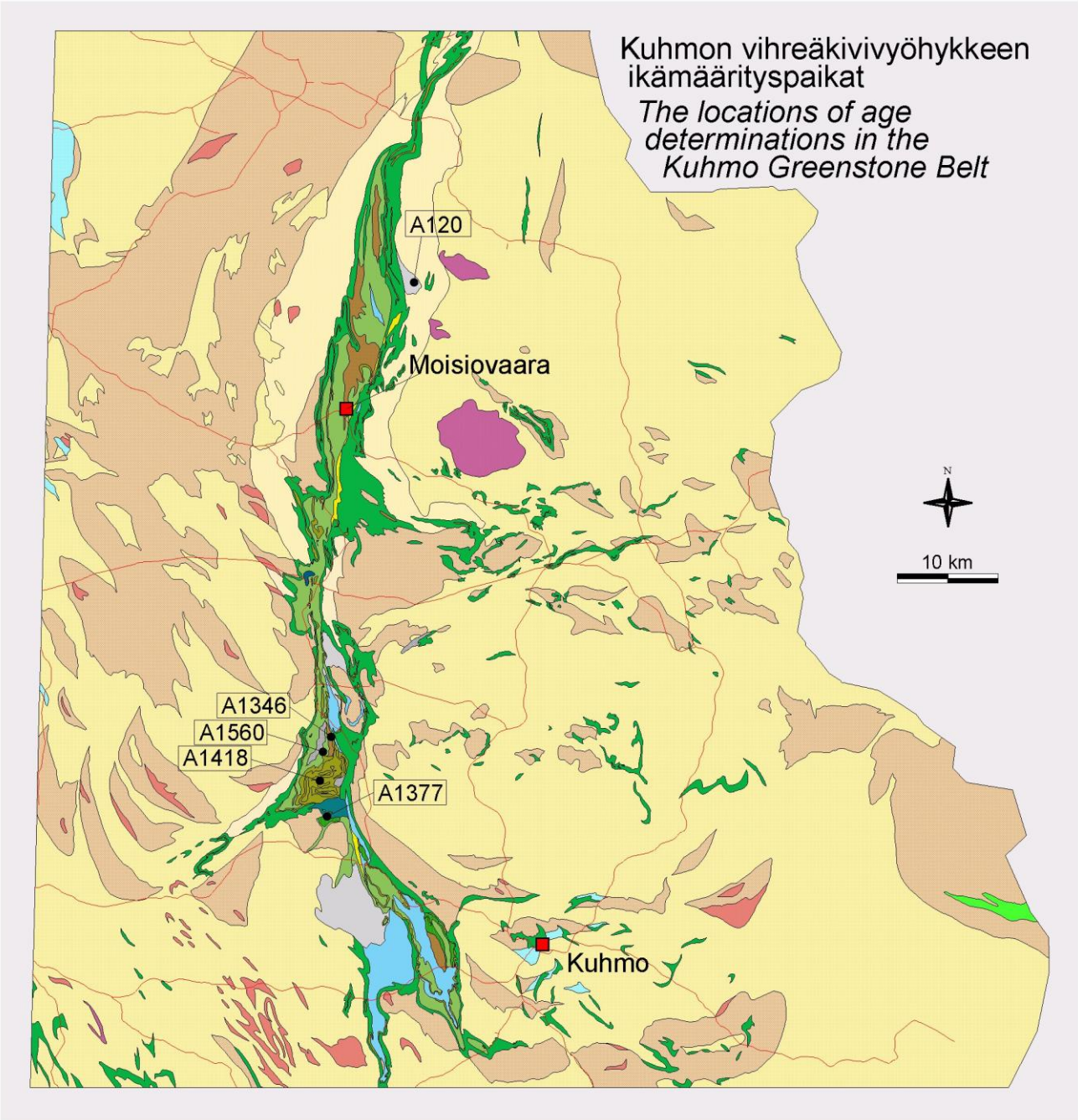


Fig. 2.6.1l. Locations of isotopic age determinations from the Kuhmo Greenstone Belt.

Arola – Ontojärvi area

The central part of the Kuhmo greenstone belt, in the area between Lampela and Kellojärvi, includes intermediate lavas, pyroclastic deposits and lahars which are considered on the basis of field relationships to be younger than the tholeiitic and komatiitic volcanics. Sample A1346 (KKJ 20 000 mapsheet 4412 10, grid reference = FIN_KKJ4 7134.720N, 4456.070E) yielded only a small number of zircon grains, which were mostly small, stubby and anhedral, and very pale in color, lacking the reddish tinge characteristic of many zircon populations. All five analyzed fractions, of which two were microanalyses, were discordant, and yielded a regression chord with an upper intercept of 2 794 ± 26 Ma (MSWD = 8.3). However, considering the highly discordant nature of the analyses and the poor precision of the resultant regression curve, as well

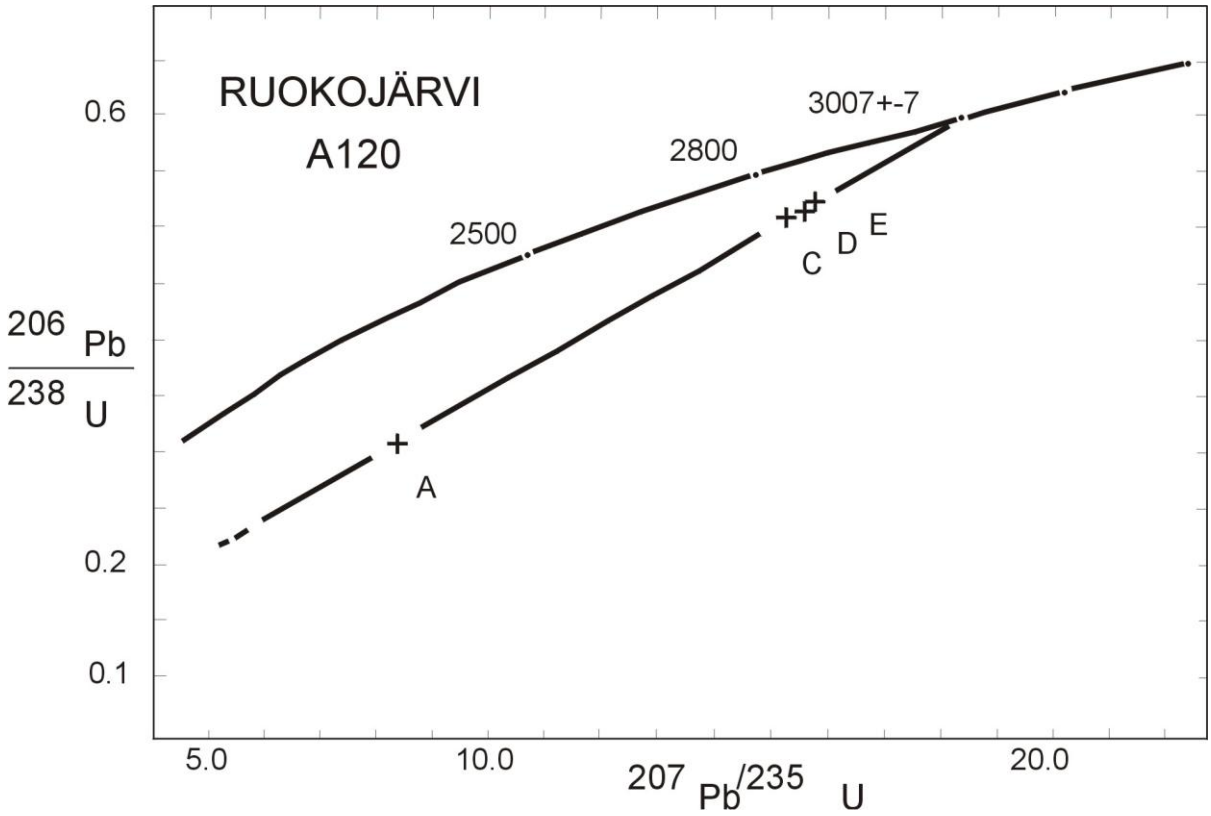


Fig. 2.6.1m. U-Pb concordia diagram showing data from the felsic volcanic at Ruokojärvi (A120).

as the possible presence of inherited zircons amongst the largest (ca. 4 mg) size fraction, this result is not regarded as a reliable or robust age estimate.

Three samples from the Kellojärvi area were analyzed between 1995 – 1999; sample A1418 from Niittylahti is a gabbroic anorthosite phase that is considered to represent the youngest fractionated magma within the ultramafic complex (Figures 2.6.1n, 2.6.1o and 2.6.1p). According to Hannu Huhma (personal communication, 1995), the sample yielded a moderate amount of turbid and anhedral zircon. The five fractions analyzed lie along a rather well-defined chord (MSWD = 2.2) with an upper concordia intercept at 2 757 ± 6 Ma and a lower intercept, which is unusually high, at 1 398 ± 22 Ma (Figure 2.6.1q). The Niittylahti gabbro is therefore clearly Archean in age, and provides a minimum age estimate for the Kellojärvi ultramafic complex.

Sample A1377, from the Siivikko area, represents a felsic enclave from within a NW-SE trending lenticular komatiitic mesocumulate body, some 650 m in length and 120 m wide, which is interpreted as a ponded accumulation of a channelized komatiitic lava flow (cf. Halkoaho et al., 1996). The mesocumulate body is now serpentinized, but at the eastern margin, outcrops of more tremolitic rock contain five separate felsic enclaves, varying in size from several decimeters to 3.5 meters (Figures 2.6.1n, 2.6.1r and 2.6.1s). The enclaves are roundish and ovoid, somewhat oblate and aligned within the inferred orientation of magmatic layering, and surrounded by a selvage of chlorite some 5-10 cm wide. Texturally, both in outcrop and microscopically, the enclaves appear to represent a medium-grained plutonic rock. Major minerals are albite, K-feldspar, quartz and biotite, with accessory cummingtonite, which has so far not been found in any other rocks within the Siivikko – Kellojärvi area. Although the enclaves resemble plutonic rocks texturally, thermal metamorphism caused by entrainment in komatiitic magma has likely caused thorough annealing and recrystallization and they may equally represent penecontemporaneous felsic volcanics rather than older granitoid basement lithologies. Although

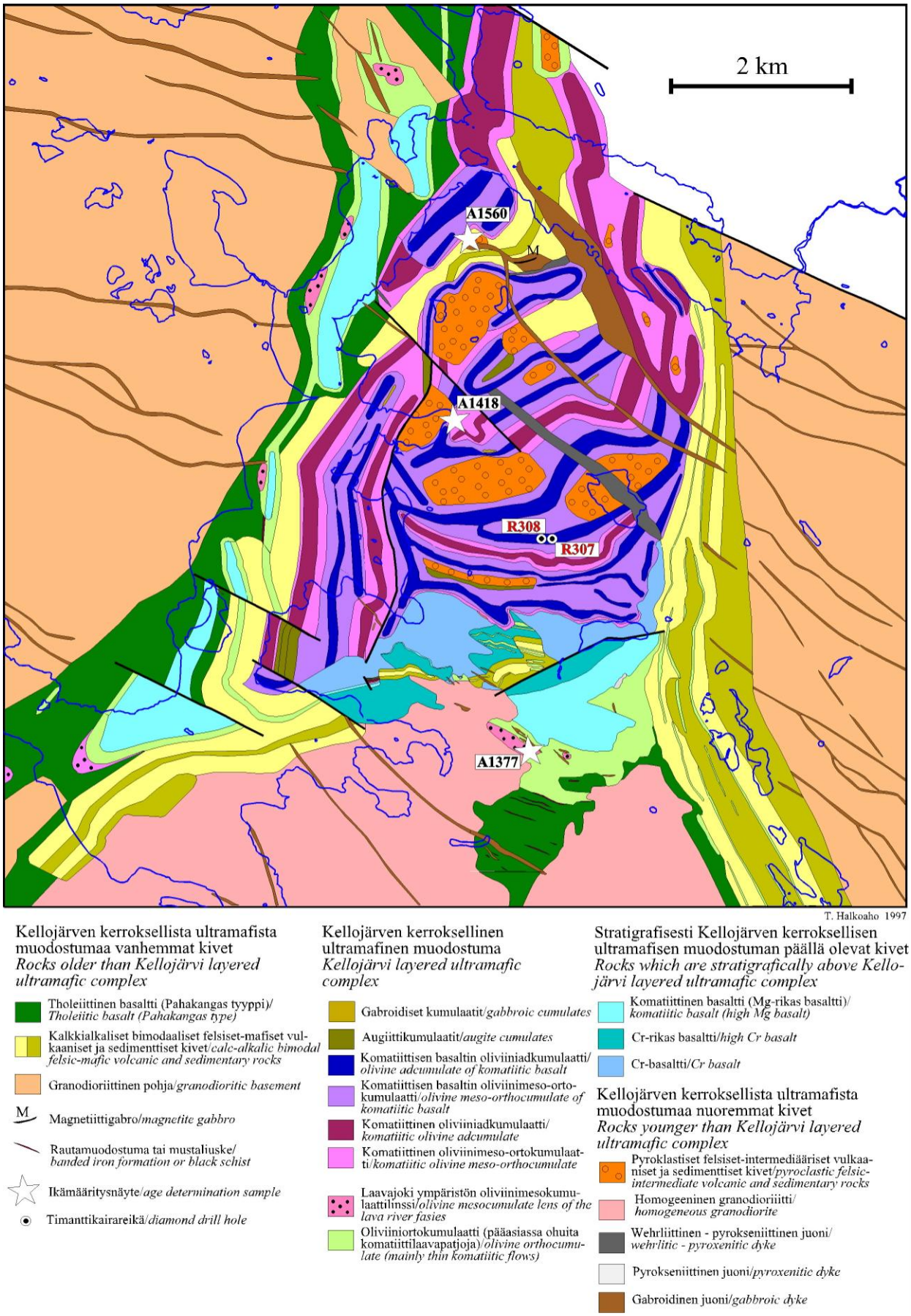


Fig. 2.6.1n. Generalized geological map of the Kellojärvi area, showing locations of samples collected for isotopic age determinations.

their origin has been a matter for debate (cf. Halkoaho et al. 1996), there is at least agreement that they were spalled off from marginal wallrocks during at a time when lava flow had momentarily slowed and ceased. A subsequent flow, commencing with a rather thin lava lobe, which represents an unfractionated komatiitic cumulate at the base of the flow channel, then incorporated and partially assimilated the felsic enclaves, causing pervasive recrystallization and annealing, resulting in the observed texture resembling a granitoid. The spatial association between the presence of enclaves and the tremolitic unit, and in particular its lower part, is also consistent with this scenario. These enclaves were therefore sampled because it was expected that they would provide a maximum age constraint on the age of komatiitic volcanism and also indicate the age of the inferred substrate to Kuhmo greenstone belt volcanism. Zircons were extracted from the sample, and the < 4.3 g/cm^3 fraction consisted principally of brownish, turbid crystals of variable size. The fraction with density > 4.3 g/cm^3 consisted of relatively clear grains with elongate prismatic faces; both large and small grains were present. Three analyses were made, each of which was highly discordant (Figure 2.6.1q). The resultant ^{207}Pb/^{206}Pb age of around 2660 Ma can be considered as a minimum estimate for the age of the felsic enclaves (and also the komatiitic volcanism), but it is not possible at this stage to be more precise.

Sample A1560 is from the Ensilä area (Grid reference = FIN_KKJ4 7132.480N, 4455.190E) (Figure 2.6.1.n) and represents a quartz dioritic lithology near the margins of the Kellojärvi complex. The sample was chosen in order to ascertain whether the rock represented a younger intrusive event (cf. Luukkonen, 1992) or possibly relict basement, older than the greenstone belt volcanism. The latter possibility is supported by the presence of reaction selvages between the Kellojärvi ultramafic rocks and the granitoid (Heikki Papunen, personal communication 1998). According to Hannu Huhma (personal communication, 1999), zircons in this rock tend to be euhedral and are typically transparent, although some turbid and fractured grains are also present. Some crystals were also transparent with a reddish tinge. The dense, though fine-grained fraction also contains small clear and colorless crystals (F in Figure 2.6.1t). The results for six fractions are dispersed throughout the concordia diagram, indicating the heterogeneous nature of the zircon populations. This may also be attributed to the effects of metamorphic disturbance (Hannu Huhma, personal communication, 1999) but the least discordant analyses A and E define a ^{207}Pb/^{206}Pb age of 2 780 Ma, which may be interpreted as a minimum age estimate for the magmatic crystallization of zircon. If we assume that the euhedral zircon grains in sample A1560 are principally of magmatic origin, rather than inherited from an older source, then the intrusive age of this quartz diorite would be significantly older than that of the 2740 Ma orogenic granitoids intruding and surrounding the Kuhmo and Suomussalmi greenstone belts. If, as Hannu Huhma (personal communication, 1999) notes, fractions A and E contain a metamorphic component, then the true age is in fact potentially much greater than 2780 Ma. The minimum age constraint of 2780 Ma is nevertheless older than the 2 757 ± 6 Ma age estimate for the Niittylahti gabbro (A1418). Therefore, it is most likely that it provides evidence for the existence of an older basement substrate.

In addition to the above U-Pb analyses, a total of 12 Sm-Nd analyses were made from dyke samples obtained during research into the Kellojärvi cumulate complex by Tulenheimo (1999). Of these, 8 samples represent pyroxenitic wehrlite dykes and 3 represent gabbroic dykes, all of which are discordant with respect to the Kellojärvi rock units. One sample was also collected from serpentinites belonging to the Kellojärvi cpomplex itself, from near the Näätäniemi trigonometric tower. While the ages of the dykes could not be precisely determined, all samples were clearly Paleoproterozoic in age and according to Tulenheimo (1999), represent fractionation from a single differentiated intrusion with an age between 2 100 and 2 200 Ma.

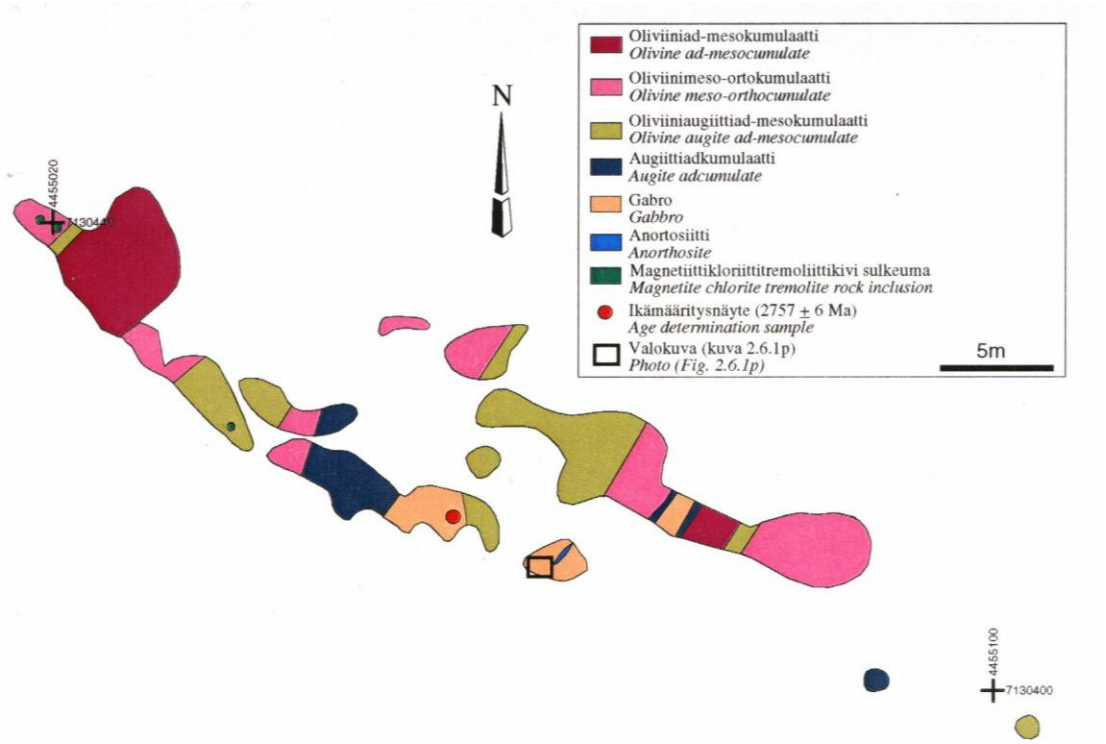


Fig. 2.6.1o. Detailed geological map of the areas surrounding the Niittylahti age determation sampling site in the Kellojärvi ultramafic complex.

Fig. 2.6.1p. Anorthositic part of the gabbro-pyroxenitic "dyke" which intersects the Kellojärvi ultramafic rocks. Age of the gabbro is 2757 ± 20 Ma (A1418, H. Huhma, pers. comm. 1995, Figure 2.6.1q) and it is supposed to represent the last products of the Kellojärvi ultramafic magma. Note large "hopper-like" pyroxene crystals; diameter of coin is about 2.5 cm. Niittylahti, Kellojärvi ultramafic complex, Kuhmo greenstone belt. Photo by T. Halkoaho.

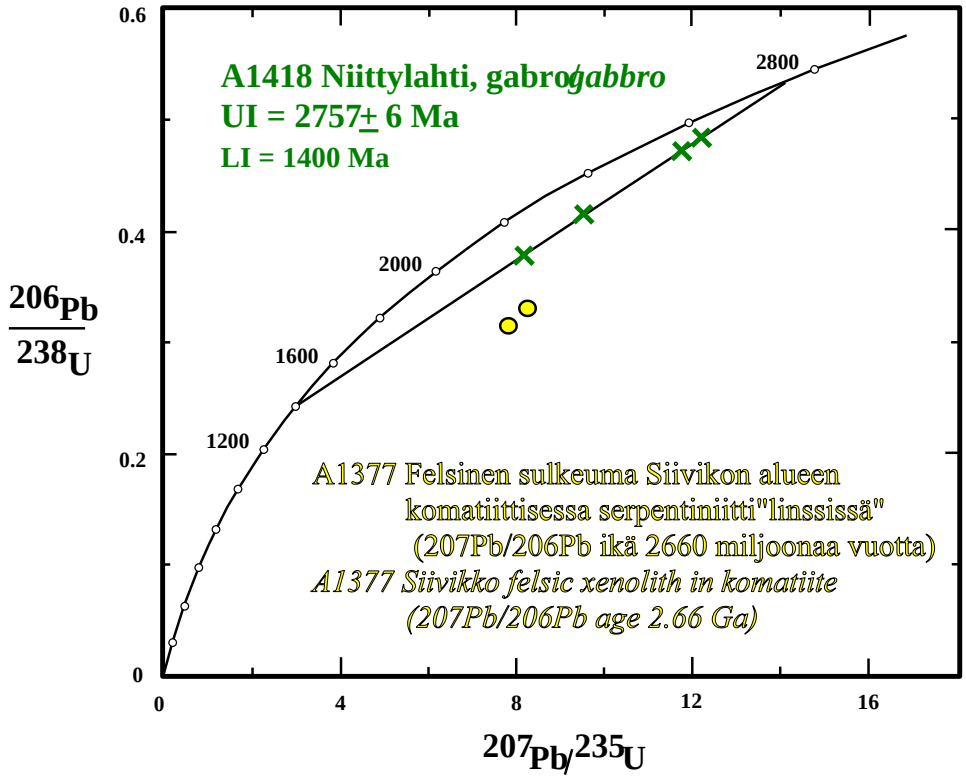


Fig. 2.6.1q. Pb-U concordia diagram showing data for gabbro from Niittylahti, within the Kellojärvi ultramafic complex and a felsic enclave from Siivikko, within a komatiitic serpentinite "lens" (Hannu Huhma 1995, pers. comm).

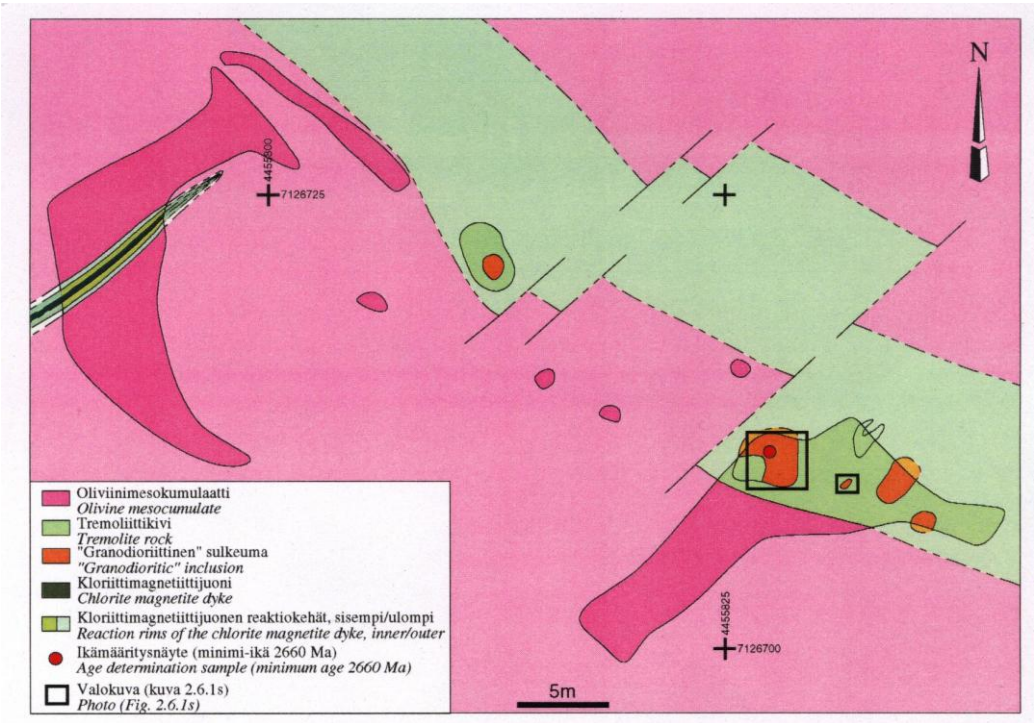


Fig. 2.6.1r. Detailed map of the eastern part of the small serpentinite lens in the Siivikko area (see also Figure 2.6.1n).

Fig. 2.6.1s. Eastern part of the small serpentinite lens in the Siivikko area contains a tremolitic rock unit about 10 m thick, with 0.2 - 3.0 m felsic enclaves in its lower part (see Figures 2.6.1n and 2.6). In the lower picture the longest side of compass is perpendicular to inferred primary magmatic layering. Siivikko, Kuhmo greenstone belt. Photo by T. Halkoaho.

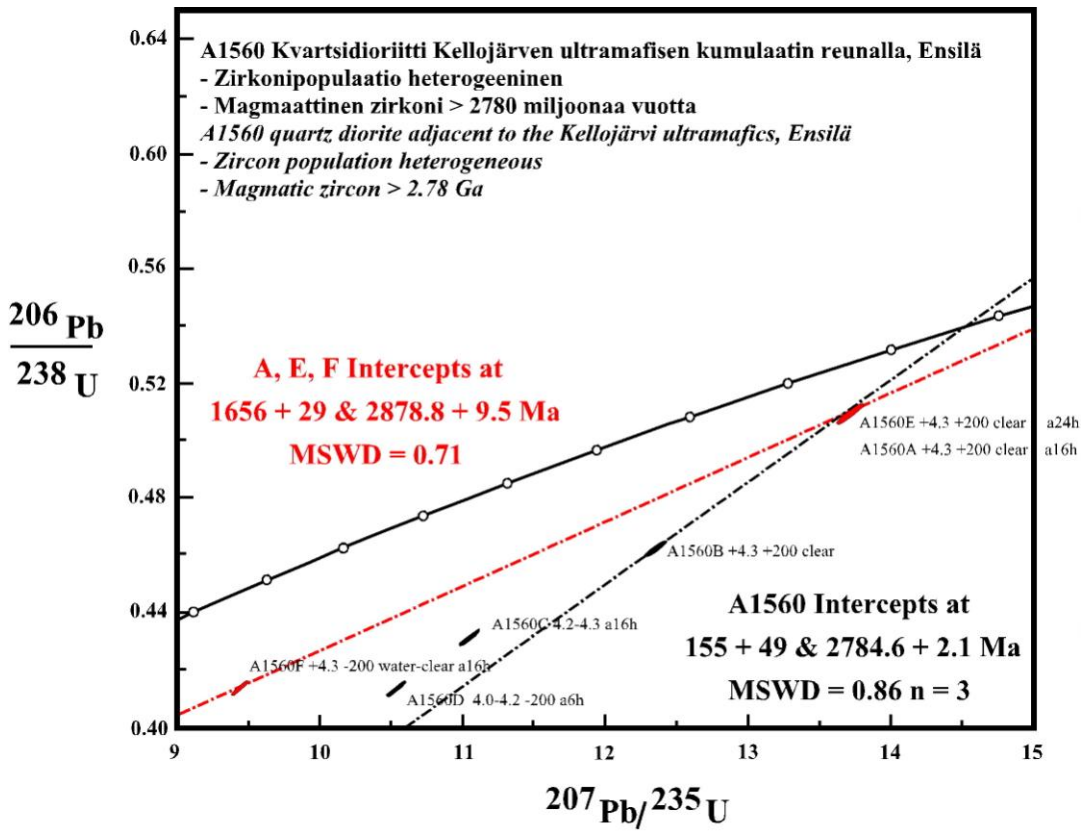


Fig. 2.6.1t. Pb-U concordia diagram showing data from a quartz diorite adjacent to the Kellojärvi ultramafic complex, Ensilä, Kuhmo greenstone belt (Hannu Huhma 1999, pers. comm.).

Table 2.6.1. Data on the age determination samples from the Archaean terrain.

Sampe no.	Location	Map no.	northing	easting	206/204	mswd	207/204	mswd	208/204	mswd	corr.
G149 T	Tapaninkylä	4412	7157400	3600700	15.139	0.12	15.325	0.12	34.969	0.12	0.9
G334	Arola	4412	7151210	3598903	14.776	0.12	15.219	0.12	34.450	0.12	0.9
G335	Tapaninkylä	4412	7153350	3599660	15.182	0.12	15.323	0.12	34.824	0.12	0.9
G341	Pahakangas	4412	7127500	3601300	14.611	0.12	15.143	0.12	34.431	0.12	0.9
G393A	Rämpsänlampi	4412	7156180	3597370	15.164	0.12	15.307	0.12	34.826	0.12	0.9
G393B	Rämpsänlampi	4412	7156180	3597370	15.168	0.12	15.318	0.12	34.863	0.12	0.9
G393C	Rämpsänlampi	4412	7156180	3597370	15.149	0.12	15.304	0.12	34.818	0.12	0.9
G394A	Palovaara	4412	7154040	3600050	15.376	0.12	15.353	0.12	35.013	0.12	0.9
G394B	Palovaara	4412	7154040	3600050	15.353	0.12	15.342	0.12	34.972	0.12	0.9
G394C	Palovaara	4412	7154500	3600015	15.398	0.12	15.361	0.12	35.041	0.12	0.9
G433	Rämpsänlampi	4412	7156180	3597370	15.186	0.12	15.301	0.12	34.824	0.12	0.9
G441	Härmäjoki	4412	7146590	3598400	14.248	0.12	15.034	0.12	34.139	0.12	0.9
G459	Palovaara	4412	7154500	3600015	15.392	0.12	15.354	0.12	35.026	0.12	0.9
G479	Palovaara	4412	7154500	3600015	15.546	0.12	15.422	0.12	35.238	0.12	0.9

In 1987, indications of spahelerite and galena were found in a road cutting northeast of Rämpsänlampi, within a highly sheared banded amphibolite. According to the published 1: 100 000 geological map (Hyppönen, 1983), quartzofeldspathic schists occur immediately to the southwest, which were interpreted by Taipale (1983) as felsic volcanics. During the same year, further narrow felsic units, in places including cherty horizons, were found associated with mafic volcanics at the eastern margin of the Kuhmo greenstone belt; the easternmost of these occurrences can be traced for several hundred meters along strike and contains pyrite, sphalerite and galena.

At both these localities, deformation is intense; at Palovaara the shearing is subparallel to the N-S trend of the greenstone belt, whereas at Rämpsälampi the main deformation zone trends NW-SE. Likewise, in both cases, the sulfides are aligned within the foliation associated with the shearing and may therefore represent either remobilization or introduction of mineralization during a Paleoproterozoic brittle-ductile tectonic event.

Mineralized samples were collected for lead isotopic studies; sample locations and analytical data are shown in Table 2.6.1, while galena isotopic compositions are plotted in Figure 2.6.1g According to Matti Vaasjoki (personal communication, 1999), $^{207}Pb/^{204}Pb$ ratios for these samples are higher than those for the Archean Taivaljärvi Pb-Zn-Ag deposit, which otherwise has the highest ratios so far reported from the Archean of eastern Finland. This is most readily interpreted as a consequence of lead remobilization from surrounding Archean bedrock and sulfide precipitation around 1 850 ± 50 Ma, during Svecofennian orogenic overprinting.

2.6.2. Petrological and mineralogical investigations

2.6.2.1. Determination of greenstone belt pressure/temperature conditions and evolution

Metamorphic conditions and P-T-t evolution, based on studies of mineral assemblages, were determined for selected localities in the Kuhmo greenstone belt and in the area between Kuhmo and Nurmes. However, due to allocation of research priorities elsewhere, there was less opportunity than originally intended for undertaking comprehensive metamorphic studies.

Provisional investigations by Matti Pajunen, based in the GTK Otaniemi office, nevertheless indicated that amphibolites in the area to the east of the Kuhmo greenstone belt generally record growth of garnet porphyroblasts over earlier microstructures (although examples showing opposite relationships have also been found). This reaction is attributed to increasing pressure, with maximum temperature estimates of (610° C - 670° C) and pressures of (5.5 - 8.0 kb) being determined for garnet amphibolites in the central part of the Lentiira (4414 + 4432) mapsheet area, between Pitkäsuo and Isosuo. Relatively high maximum P-T conditions (p = 5.0 - 6.5 kb and T = 690° C – 730° C) have also been inferred from pyroxene-bearing granitoids and banded garnet amphibolites in the Murhijärvi – Hietajärvi area, some 40 km to the east of the Kuhmo greenstone belt, near the Russian border (KKJ mapsheets 4441 02 and 4441 03). However, in close proximity to the Kuhmo greenstone belt, peak metamorphic conditions occurred at significantly lower pressures and temperatures (Figure 2.6.2.1).

In the area between Nurmes, Kuhmo and Sotkamo, garnet porphyroblasts tend to overprint tectonic foliations and mineral parageneses generally comprise garnet-biotite-muscovite, indicating equilibration at relatively low pressures and temperatures.

More detailed investigations were carried out in the Hiltuspuro area between Kuhmo and Nurmes (mapsheet KKJ 4324 08, x = 7070.510, y = 4485.250), where an Archean deformation zone was intensely overprinted by Paleoproterozoic deformation and metamorphism. Pajunen and Poutiainen (1999) established that xenotime, dated at 1850 Ma, crystallized as part of this overprinting mineral assemblage and further demonstrated the existence of intense structurally controlled hydrothermal alteration within Archean basement during Proterozoic orogenesis; so far there is however, no evidence that this thermal overprint resulted in anatexis of Archean crust in eastern Finland.

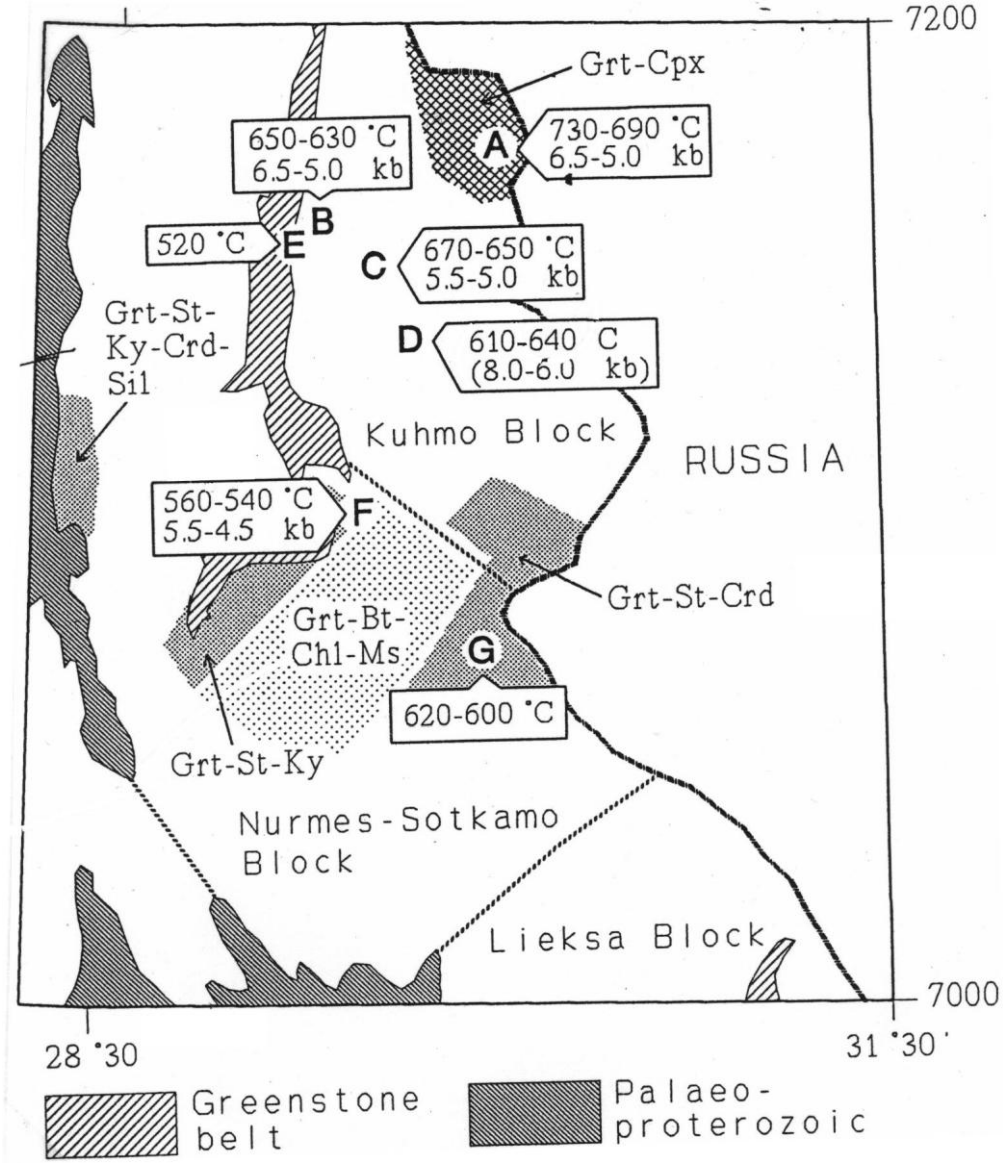


Fig. 2.6.2.1. Preliminary results of metamorphic pressure-temperature determinations in the Suomussalmi, Kuhmo, Sotkamo and Nurmes areas. Map compiled by Matti Pajunen in 1999.

2.6.2.2. Whole rock geochemistry

2.6.2.2.1. General background

Major element geochemistry for samples from the Suomussalmi and Kuhmo greenstone belts was performed using the GTK analytical procedure 175X on pressed powder pellets, rather than the 713X fused bead procedure; this was because comparative calibration studies showed that carbon analyses (based on GTK analysis procedure code 811L) show remarkably good correlation for samples analyzed with the two methods (Figure 2.6.2.2). Results will not however, be considered here, but are discussed instead in subsequent sections dealing with specific stratigraphic units and potentially prospective mineral occurrences.

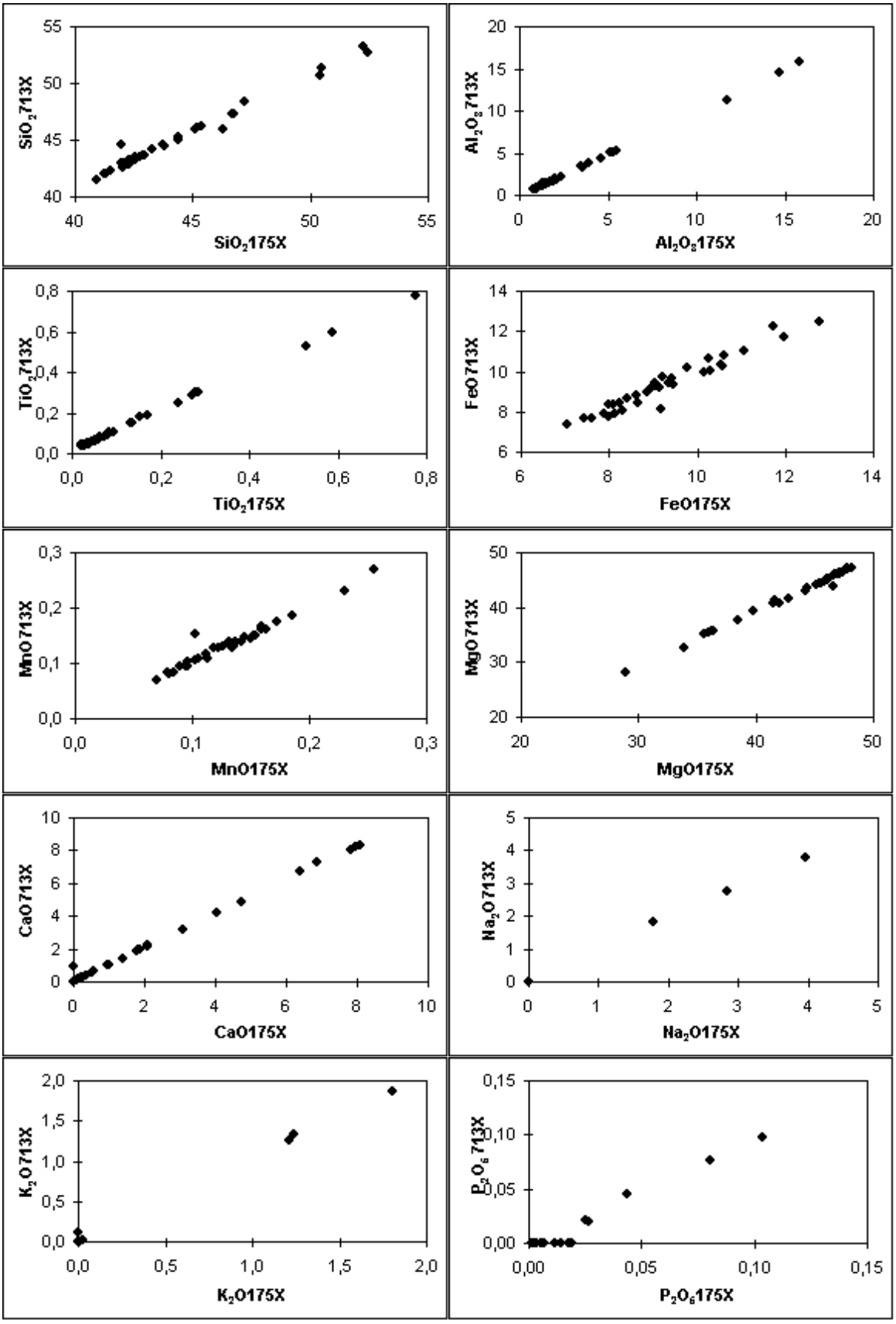


Fig. 2.6.2.2. Comparisons of major element data results using GTK whole rock analytical methods 175X and 713X.

2.6.2.2.2. Use of whole-rock lithogeochemistry in bedrock mapping

While it is relatively straightforward to distinguish between felsic, intermediate, mafic and ultramafic rocks using geochemistry, whole rock data proved to be extremely useful in discriminating between eruptive mafic volcanic rocks and mafic dykes. On the basis of whole rock geochemistry it is also possible to discriminate between four types of mafic volcanic rocks in the Kuhmo and Suomussalmi greenstone belts that are virtually indistinguishable in outcrop: tholeiitic basalt, komatiitic basalt, Cr-basalt and high-Cr basalt (Halkoaho et al., 1997, 2000). The tholeiitic basalts relate to an early eruptive event, prior to komatiitic volcanism, whereas the other three basaltic rock types post-date the komatiites and represent progressively fractionated variants of a single parent magma type. The recognition of these distinct rock compositions has been of value in defining and mapping regional lithostratigrapy. It is more difficult to classify felsic and intermediate rocks on the basis of chemical composition however, because it is usually uncertain as to how much material is actually of sedimentary rather than eruptive origin. It is generally possible to discriminate chemically between komatiitic lavas and ultramafic cumulates formed from komatiitic basalts because the MgO content of the latter seldom exceeds 35% by weight and Al_2O_3/TiO_2 ratios and Ni abundances tend to be lower. Paleoproterozoic mafic dyke swarms that were emplaced into the greenstone belts can be subdivided into four compositional groups, corresponding to an age progression, from boninitic through gabbroic wehrlitic to Ti-rich Fe-tholeiitic and finally Mg-tholeiitic.

2.6.2.2.3. Regional indicators of nickel potential

Komatiitic lavas generally show a gently increasing trend with atomic number on REE diagrams, reflecting a slight enrichment in komatiitic magmas of heavy rare earth elements (HREE) with respect to light rare earths (LREE). If a komatiitic rock has a REE pattern that is either smooth, or decreasing with atomic number (LREE enriched), this is usually a consequence of assimilation of felsic material, through contamination by older continental crust, or by penecontemporaneous felsic volcanics. If the assimilated felsic material lacks sulfide minerals, then it is unlikely that a sulfide melt will form within the komatiitic magma. However, where the REE data also show significant Eu depletion, it is possible that a sulfide melt has at some stage been extracted from the komatiitic magma. Lodders (1996) showed through experimental investigations that the partition coefficient between sulfides and silicate melt for europium favours incorporation into the sulfide phase, when compared to adjacent REE (Sm and Gd). Relatively low concentrations of nickel and other chalcophile elements in komatiitic lavas or their differentiates is not necessarily an indication of extraction of a sulfide melt and is therefore only useful as a regional guide to nickel potential. However, where a komatiitic lava sequence shows an absence of nickel (plotted on an Ni-MgO diagram), there is a stronger possibility that a sulfide melt has separated at some stage. Even so, this information is not sufficient to form a reliable vector to potential sulfide mineralization. An essential requirement for the accumulation of significant massive sulfide mineralization is the presence of some kind of “trap”, such as a topographic depression, or channeling, which generates turbulence or some other disruption to the lava flow and allows sulfide melt droplets to segregate and coalesce. Therefore, evaluation of nickel sulfide potential requires detailed field mapping, with particular emphasis on recognition of komatiitic volcanic facies relationships and evidence for flow dynamics.

2.6.2.3. Mineralogical and petrographical characteristics of komatiites

A total of 241 thin sections and 168 polished thin sections were prepared for mineralogical and petrographical studies of the lenticular komatiitic cumulate bodies in the Vaara – Kaunislampi area, mostly from drill core. Of these, 164 thin sections and 83 polished sections were prepared from samples from the Kaunislampi cumulate lense, 43 thin sections and one polished section from the Hoikkalampi cumulate, 36 thin sections and 4 polished sections from the Rytys lense

and 80 polished thin sections from the Vaara cumulate lense. A total of 58 polished thin sections were made from samples from the Kaunislampi cumulate body and 37 from the Vaara cumulate for the purpose of determining ore mineralogy, of which four from Kaunislampi and three from Vaara (including one sample subjected to ore enrichment), were analyzed in detail. Olivine was also analyzed from a polished section from Kaunislampi.

2.6.2.3.1. Olivine

Olivine is very rare in the **Suomussalmi greenstone belt**, being almost invariably serpentinized. As a consequence, only four samples have been analyzed for olivine, from the Kaunislampi cumulate (6 analyses from drill hole R565 at 132.70 m), the Hoikkalampi cumulate (6 analyses from drill hole R354 at 179.20 m) and from two roadside exposures within the Huutoniemi cumulate (1 analysis from thin section KU23358 and 3 analyses from thin section KU23359). The Kaunislampi and Hoikkalampi olivines appear to be relict magmatic in origin, whereas the olivine within the Huutoniemi cumulate is most likely metamorphic. Relict magmatic olivine was also identified in the Rytys cumulate body, but has not been analyzed.

The Kaunislampi magmatic olivines have a forsterite composition of $Fo_{87,1}$ and contain 0.20% NiO, whereas comparable values for the Hoikkalampi olivines are $Fo_{90,2}$ and 0,35 % NiO respectively (Table 2.6.2.3.1). The two inferred metamorphic olivines from the Huutoniemi cumulate have forsterite values of Fo_{82} and $Fo_{75,1}$, with NiO-concentrations of 0,21 and 0,16 % respectively.

Olivine was not analyzed from the Kuhmo greenstone belt during the present project. However, Tulenheimo (1993) has compiled all of the olivine compositional data acquired from the Kellojärvi ultramafic complex during komatiite-related research undertaken by the University of Turku, with an additional 3 olivine analyses from the Arola wehrlitic dyke and 43 olivine analyses obtained from Kellojärvi by Eero Hanski. Most of the relatively colorless olivine analyzed from the Kellojärvi complex is considered to be metamorphic in origin, with very high forsterite contents (Fo_{95} - Fo_{96}) and NiO-concentrations between 0,24 - 0.49 %. Hanski interpreted brownish olivine grains from two Kellojärvi samples as being of possible relict magmatic origin, with forsterite contents of Fo_{83} (olivine mesocumulate) ja Fo_{89} (olivine adcumulate) and NiO-concentrations of 0,24 -0,30 % and 0,37 - 0,44 % respectively. Piquet (1982) and Blais (1989) have also analyzed olivines from the Kellojärvi ultramafic complex, from three samples, obtaining forsterite compositions with the range Fo_{94} - $Fo_{98.}$ In addition they analyzed olivines from two cumulate samples from north of the Kellojärvi complex, with forsterite contents between Fo_{74} - Fo_{79}. The forsterite contents of olivine from the Arola wehrlitic dyke vary between Fo_{68} - Fo_{73} , while NiO-concentrations are around 0,25 %.

2.6.2.3.2. Chromite

Compositions of chromites from the Haaponen and Kivikangas ultramafic bodies in the Saarikylä segment of the Suomussalmi greenstone belt have previously been determined by Liipo et al. (1994) and Liipo (1999). During this project, attention was focused on chromites from other ultramafic cumulates in the Saarikylä area, notably the Kaunislampi, Hoikkalampi and Vaara cumulate bodies, as well as the Huutoniemi cumulate lense at Kiannanniemi. Analyses from the Kaunislampi cumulate body have also been reported by Pakkanen and Luukkonen (1995).

Chromite grains from the northern part of the Kaunislampi occurrence exhibit zoning but are somewhat corroded (Figures 2.6.2.3.2a ja 2.6.2.3.2b). Moreover, magnetite veins are disrupted and patchily preserved, indicating that these rocks were affected by interaction with reducing fluids. On the basis of mineral chemistry, it appears that the Kaunislampi chromites did not crystallize in the presence of base metal sulfide phases, since the latter have relatively high

Fe_2O_3-contents (7 - 9 weight %) compared to those of the chromite grains (Figure 2.6.2.3.2a). In contrast, chromite at the Vaara Ni-occurrence has evidently crystallized in equilibrium with sulfides (Figure 2.6.2.3.2d). Further evidence for metamorphic infiltration by reducing fluids at Vaara includes the presence of thin, irregular and discontinuous graphitic veins within serpentinized olivine cumulates (Figure 2.6.2.3.2c).

Table 2.6.2.3.1. Olivine analyses from the Suomussalmi area.

Sample	Target	SiO2	FeOt	MnO	MgO	NiO	Total	NiO (aver.)
KU23361	Hoikkalampi	41.27	9.05	0.14	47.78	0.35	98.59	0.35
KU23361	Hoikkalampi	41.38	9.21	0.13	47.97	0.35	99.04	
KU23361	Hoikkalampi	41.56	9.19	0.11	48.22	0.35	99.43	
KU23361	Hoikkalampi	41.49	9.41	0.15	48.41	0.35	99.81	
KU23361B	Hoikkalampi	41.33	8.8	0.18	47.61	0.36	98.28	0.36
KU23361B	Hoikkalampi	41.17	9.21	0.15	47.79	0.36	98.68	
KU23358	Huutoniemi	39.92	16.1	0.51	42.51	0.21	99.25	0.21
KU23359	Huutoniemi	38.92	23.14	0.47	37.77	0.14	100.44	0.16
KU23359	Huutoniemi	39.17	21.9	0.44	38.71	0.17	100.39	
KU23359	Huutoniemi	39.10	21.64	0.41	38.44	0.16	99.75	
R565-132.7	Kauniinlampi	39.92	12.28	0.18	47.35	0.18	99.90	0.20
R565-132.7	Kauniinlampi	39.90	12.72	0.19	46.17	0.17	99.15	
R565-132.7	Kauniinlampi	40.01	12.40	0.18	47.09	0.21	99.89	
R565-132.7	Kauniinlampi	39.24	11.81	0.17	46.56	0.20	97.98	
R565-132.7	Kauniinlampi	40.10	11.69	0.17	47.17	0.20	99.33	
R565-132.7	Kauniinlampi	39.67	11.97	0.17	46.63	0.21	98.64	
		Si	**Fe2+**	**Mn**	**Mg**	**Ni**	**Fo**	**Fo (aver.)**
KU23361	Hoikkalampi	1.021	0.187	0.003	1.762	0.007	90.3	90.2
KU23361	Hoikkalampi	1.019	0.190	0.003	1.762	0.007	90.2	
KU23361	Hoikkalampi	1.019	0.189	0.002	1.763	0.007	90.2	
KU23361	Hoikkalampi	1.016	0.193	0.003	1.766	0.007	90.0	
KU23361B	Hoikkalampi	1.024	0.182	0.004	1.759	0.007	90.4	90.3
KU23361B	Hoikkalampi	1.018	0.191	0.003	1.762	0.007	90.1	
KU23358	Huutoniemi	1.015	0.342	0.011	1.612	0.004	82.0	82.0
KU23359	Huutoniemi	1.011	0.503	0.010	1.462	0.003	74.0	75.1
KU23359	Huutoniemi	1.012	0.473	0.010	1.490	0.003	75.5	
KU23359	Huutoniemi	1.015	0.470	0.009	1.488	0.003	75.7	
R565-132.7	Kauniinlampi	0.992	0.255	0.004	1.754	0.004	87.1	87.1
R565-132.7	Kauniinlampi	1.000	0.267	0.004	1.725	0.004	86.4	
R565-132.7	Kauniinlampi	0.995	0.258	0.004	1.745	0.004	87.0	
R565-132.7	Kauniinlampi	0.993	0.250	0.004	1.756	0.004	87.4	
R565-132.7	Kauniinlampi	0.999	0.244	0.004	1.751	0.004	87.6	
R565-132.7	Kauniinlampi	0.997	0.252	0.004	1.747	0.004	87.3	

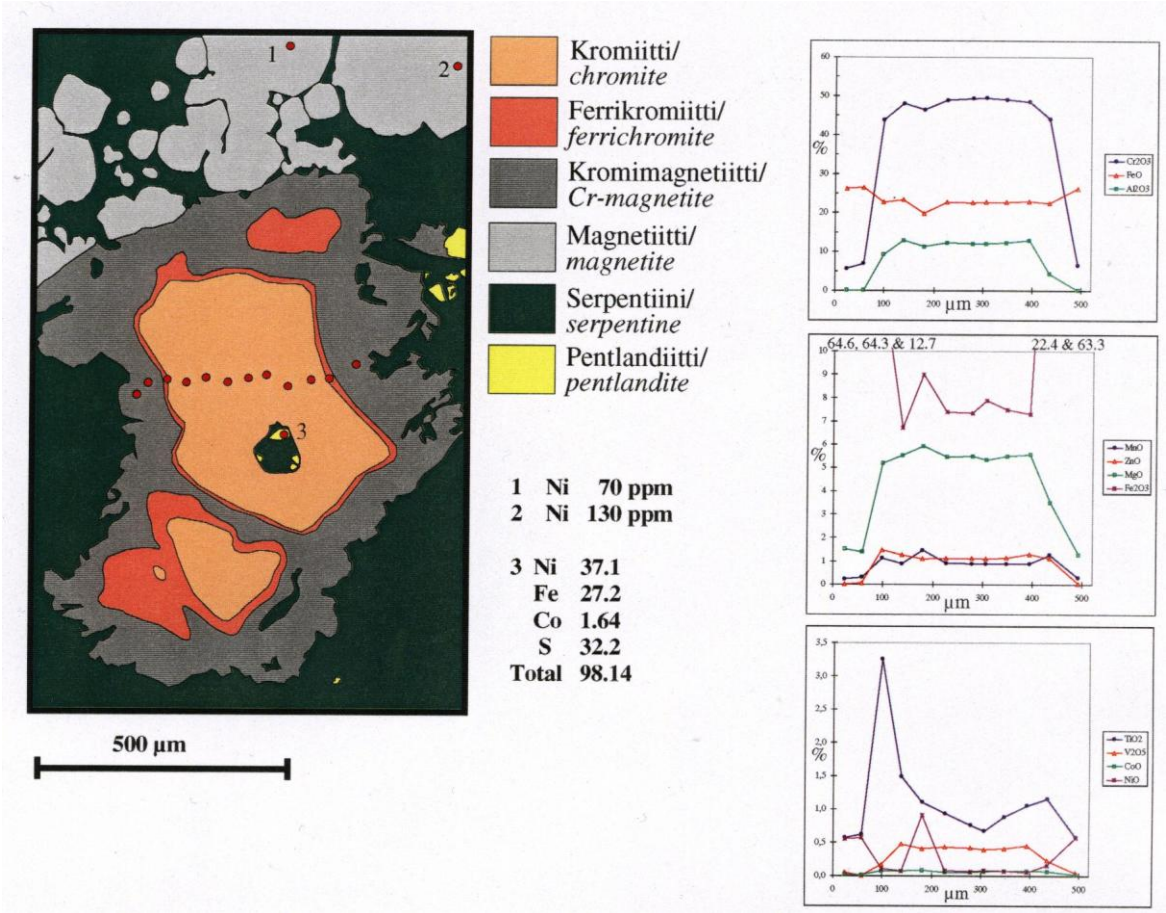


Fig. 2.6.2.3.2a. Zoning and compositional variation within chromite from the Kauniinlampi komatiitic cumulate lens.

The presence of elevated ZnO concentrations in komatiites has been interpreted as an indicator of potential Ni-enrichment (cf. Groves et al., 1983); chromites at Kaunislampi have ZnO contents exceeding 1 weight % (Figure 2.6.2.3.2a).

Chromites from the Vaara cumulate body had not previously been described but differ markedly from those in the Haaponen, Kivikangas, Kaunislampi and Hoikkalampi cumulates. Vaara chromites are very fine-grained, with a mean diameter of 0.1 mm (Figure 2.6.2.3.2d) and apart from a relatively narrow rim of magnetite, are unzoned and show little evidence of metamorphic recrystallization or deformation. Such an exceptional state of preservation has not previously been found in komatiites from Finland; mineral chemical data, revealing high MgO (4.5 – 5.0 weight %) and Al_2O_3 (ca. 14 weight %) contents are also consistent with a relict magmatic composition. It is also evident that the Vaara chromites crystallized in equilibrium with a sulfide melt phase, as deduced from their relatively low Fe_2O_3 contents (1.8 - 2.5 weight %). Vaara chromites have ZnO concentrations between 1.2 – 1.8 weight % and unusually high MnO (ca. 3.4 weight %).

A total of 12 spinel analyses were made from thin sections KU23358 ja KU23359, representing samples from a road cutting within the Huutoniemi ultramafic cumulate (Rautio, 2000). The Huutoniemi chromites are, like the Kaunislampi, Hoikkalampi, Haaponen and Kivikangas cumulates, strongly zoned, having cores with relatively high Fe_2O_3 contents (12.5 -19,5 weight %), indicating that they have not equilibrate with sulfides. Cores also have ZnO contents between 1.3 – 1.8 weight %.

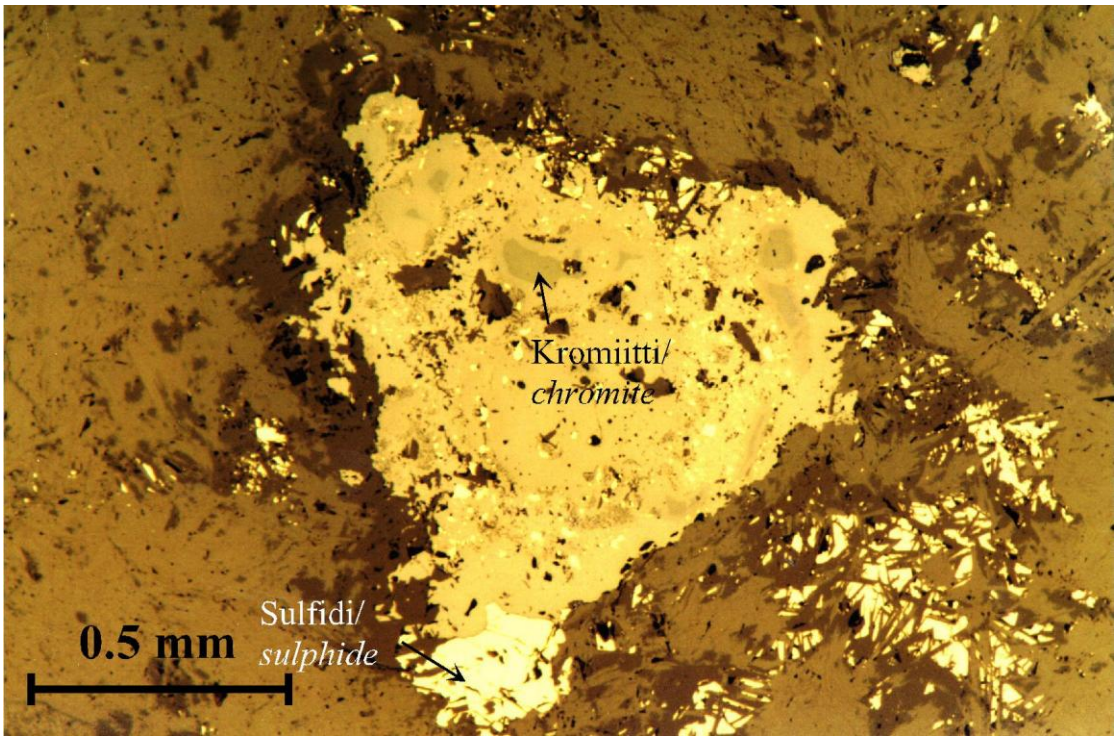


Fig. 2.6.2.3.2b. Photomicrograph (reflected light) of zoned and corroded chromite from the Kauniinlampi komatiitic cumulate lens. Photo by T. Halkoaho.

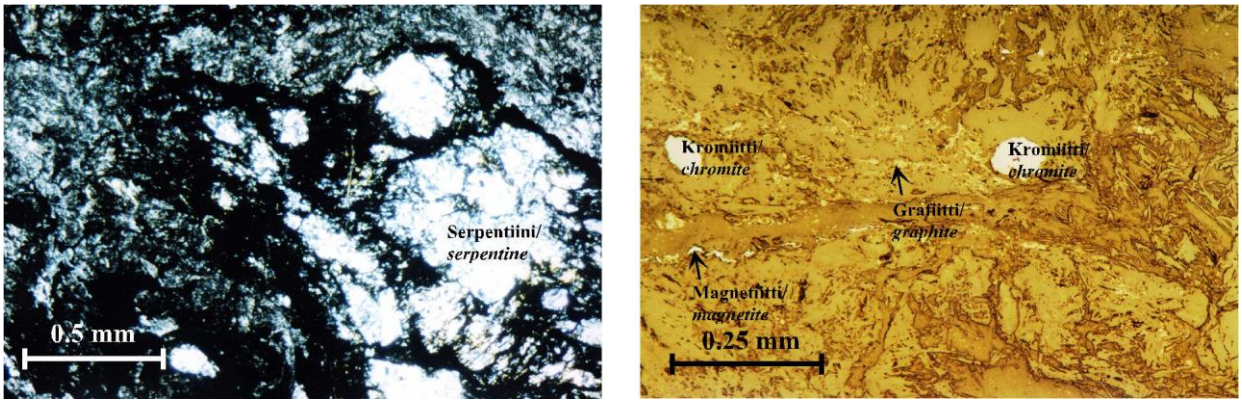


Fig. 2.6.2.3.2c. Graphite-bearing serpentinite, Kauniinlampi-N Ni deposit (R321 - 62.00). Image at left taken with crossed nicols and at right under reflected light. Photo by T. Halkoaho.

No analyses were made on chromites from the Kuhmo greenstone belt during this study, but previously published data provide some basis for comparison with analytical data from the Suomususalmi greenstone belt. According to Liipo et al. (1994, 1995) and Liipo (1999), chromites from the Kellojärvi ultramafic complex are zoned in the same way as those from Suomussalmi (with the exception of the Vaara cumulate), with a maximum of three distinct zones discernible (Figure 2.6.2.3.2e). Liipo et al. (1995) also found that the chromites have Fe_2O_3-abundances between 2 – 8 weight % and ZnO contents between 3 – 4.4 weight %.

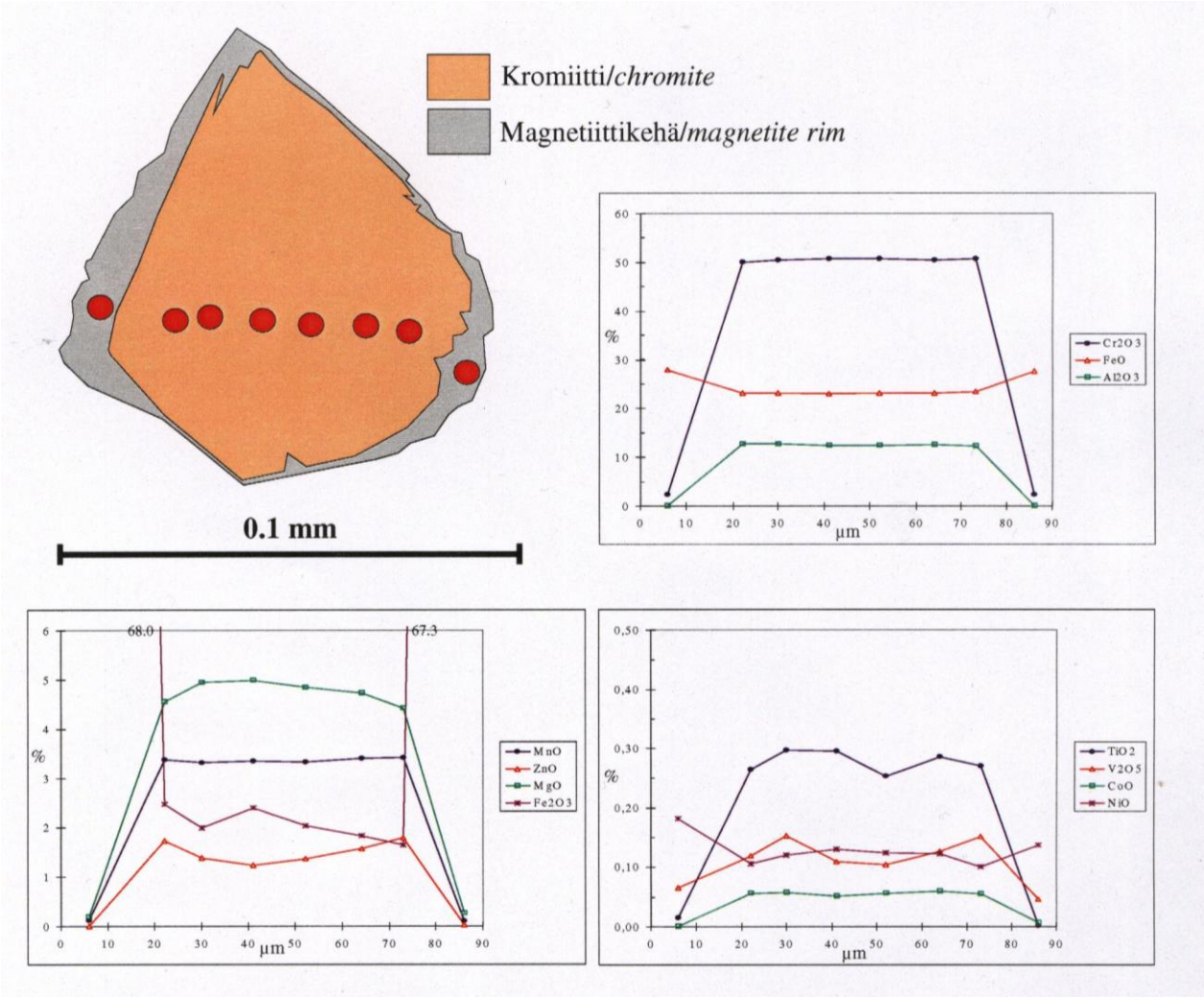


Fig. 2.6.2.3.2d. Zoning and compositional variation within chromite from the Vaara komatiitic cumulate lens.

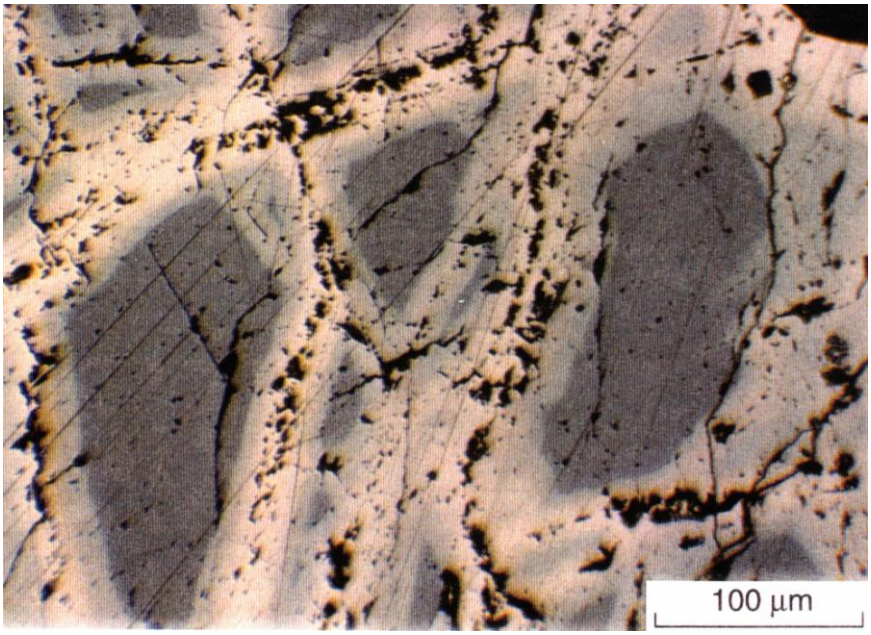


Fig. 2.6.2.3.2e. Photomicrograph (reflected light) of zoned chromite from the Kellojärvi ultramafic complex (R307 - 192.50). Photo by T. Halkoaho.

2.6.2.3.3 Sulfides

Three separate nickel occurrences have been found within the Kaunislampi olivine cumulate lenses, designated here as the Kaunislampi South, Central and North occurrences, respectively. The Kaunislampi Central occurrence is rather less coherent than the other two and is dominated by pyrrhotite; while sulfur content approaches 2 %, nickel concentrations are < 0.5 %. Nevertheless, the mineralization still falls within the typical field for nickel deposits on the Fe-S-Ni plot, being comparable with a number of Archean komatiite-hosted nickel deposits in Western Australia. Calculated mean sulfide phase compositions for two samples (R565) are S = 34.9 %, Fe = 53 % , Ni = 10.5 %, Cu = 0.9 % and Co = 0.5 %. Sulfide mineralogy comprises pyrrhotite and Ni-poor pentlandite (Figure 2.6.2.3.3a).

The Kaunislampi North mineralization has been studied in more detail and differs significantly from the Kaunislampi Central in that it shows evidence of nickel mobilization. Disseminated sulfide mineralization consists principally of intergrowths of Ni-rich pentlandite (37.5 % Ni on average) and heazlewoodite (Figures 2.6.2.3.3a ja 2.6.2.3.3b) and narrow veinlets of heazlewoodite, whereas neither pyrrhotite nor pyrite have been found. As a consequence, sulfide Ni-contents are exceptionally high; calculated mean sulfide compositions based on two samples are S = 31.3 %, Fe = 20 %, Ni = 47.5 %, Cu = 0.05 % and Co = 1 %.

Pakkanen and Luukkonen (1995) reported a wide variety of sulfides and other minerals from outcrops within the Kaunislampi South cumulate lense, including metallic nickel and copper and Ni-Cu layering/lejeerinkiä, cuprite (Cu_2O), tenorite (CuO) ja malachite ($Cu_2(CO_3)(OH)_2$), as well as sporadic orcelite (Ni_2As), heazlewoodiittia (Ni_3S_2), chalcopyrite, bornite and galena.

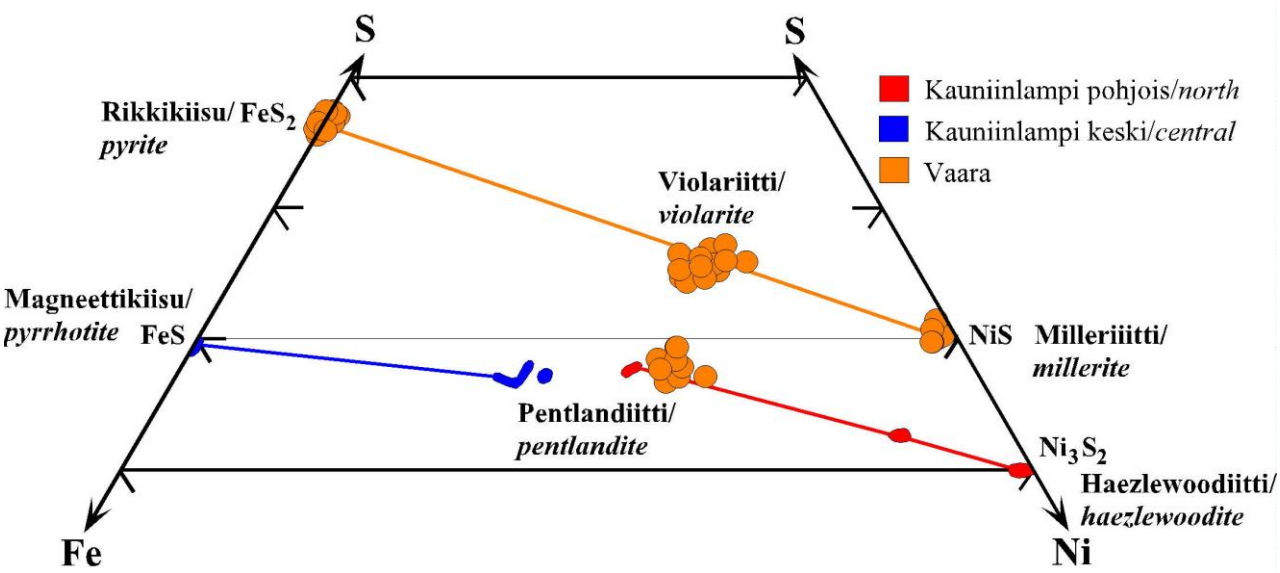
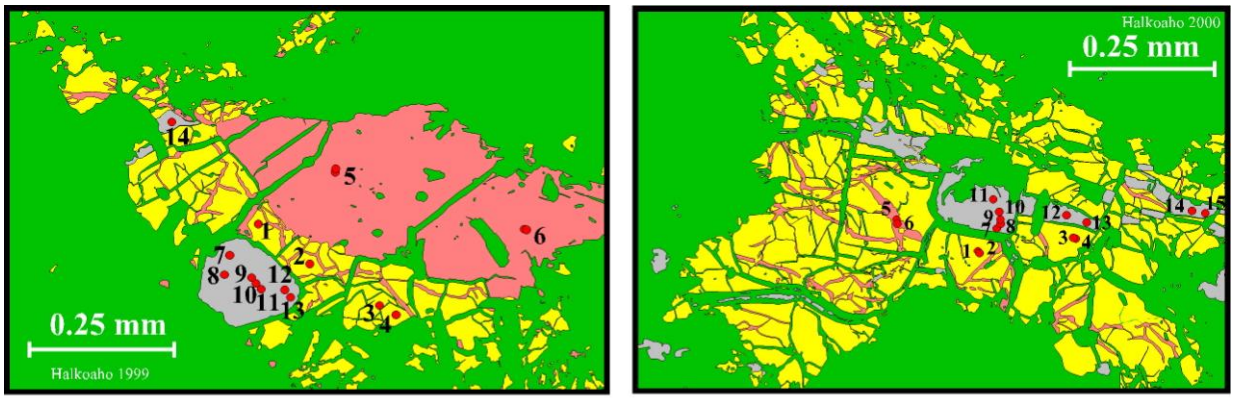


Fig. 2.6.2.3.3a. Ni-Fe sulfides from the Kauniinlampi and Vaara Ni-deposits.



Silikaatti, pääasiassa serpentiini/ *silicate, mainly serpentine* | Heazlewoodiitti/ *heazlewoodite* | Magnetiitti/*magnetite* | Pentlandiitti/ *pentlandite*

	S	Fe	Co	Ni	Total	Mineral
1	32.67	27.94	0.94	37.65	99.20	Pentlandite
2	32.38	27.98	0.86	37.69	98.91	Pentlandite
3	32.94	27.91	0.98	37.53	99.36	Pentlandite
4	32.69	28.17	0.96	37.71	99.53	Pentlandite
5	26.41	<0.01	<0.01	72.39	98.80	Haezlewoodite
6	26.90	<0.01	<0.01	72.27	99.17	Haezlewoodite

	S	Fe	Co	Ni	Total	Mineral
1	32.83	27.89	0.90	37.29	98.91	Pentlandite
2	32.64	27.88	0.83	37.30	98.65	Pentlandite
3	32.92	28.28	0.89	37.55	99.64	Pentlandite
4	32.69	27.87	0.87	37.34	98.77	Pentlandite
5	26.40	1.00	<0.01	71.73	99.13	Haezlewoodite
6	26.34	0.95	0.02	71.30	98.61	Haezlewoodite

	Cr (ppm)	Ti (ppm)	Ni (ppm)	Co (ppm)	
7	3010	2458	3374	70	Magnetite
8	3216	2338	3124	<100	Magnetite
9	6226	2998	3214	110	Magnetite
10	1095	2758	3054	40	Magnetite
11	1026	2638	3174	50	Magnetite
12	2942	2398	3515	100	Magnetite
13	3010	1918	3915	100	Magnetite
14	<100	<100	4035	40	Magnetite

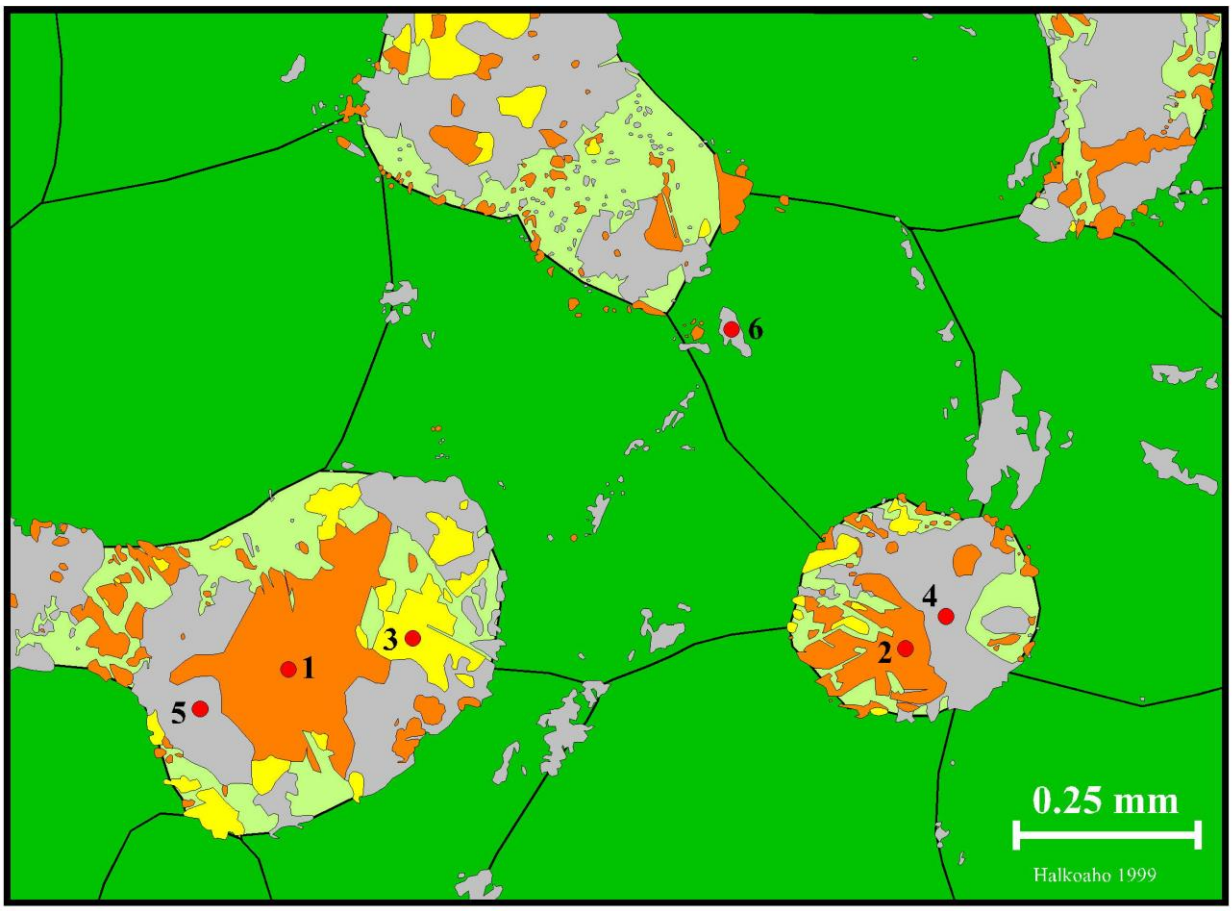
	Cr (ppm)	Ti (ppm)	Ni (ppm)	Co (ppm)	
7	3010	1619	3475	70	Magnetite
8	684	2278	3114	70	Magnetite
9	753	1739	3204	50	Magnetite
10	1710	2338	3065	30	Magnetite
11	12795	2938	3365	50	Magnetite
12	<100	<100	2543	150	Magnetite
13	<100	<100	7569	230	Magnetite
14	68	<100	2132	110	Magnetite
15	137	<100	1943	100	Magnetite

Fig. 2.6.2.3.3b. Sulfides from the Kauniinlampi-N Ni-deposit, showing mineral textures.

The Vaara mineralized zone can be traced for at least 450 m along a nearly north-south trend and consists of 1 – 3 distinct mineralized lenses or layers that vary in thickness from 2-3 m in the northern part, to a maximum of nearly 50 m in the south. Sulfides in the Vaara occurrence have Ni-contents varying between 0.25 – 1.4 weight %, with mean values, depending on choice of cut-off grade, between 0.35 – 0.8 weight %. In contrast to the Kaunislampi North mineralization, chalcophile elements in the Vaara occurrence show a strong mutual positive correlation. According to Hintikka et al. (1999), Ni-contents of sulfide minerals, including those from bulk samples selected for enrichment and processing, vary between individual sampling profiles, but lie within the range 34 – 48 %, while palladium contents vary from 20 – 32 ppm.

Aggregates of sulfide grains in the Vaara cumulates sometimes occur as well-formed roundish ”droplets” between 0.5 – 1. 0 mm in diameter (Figure 2.6.2.3.3c) but more commonly as irregular intergrowths, in some cases resembling intercumulus textures. One sample (R651-75.40 m) showed distinct layering defined by sulfide inclusion trails within serpentinized olivine grains (Figure 2.6.2.3.3d), thus indicating that olivine phenocrysts had nucleated on paragenetically early sulfide droplets. This type of rhythmic layering indicates that subtle variations in physical and chemical processes between silicate and sulfide melt phases at the crystallizing interface: in some places olivines and sulfides crystallize simultaneously, resulting in droplet-like sulfide textures, while elsewhere olivine crystallized somewhat earlier, with sulfides displaying intercumulus features and in some cases sulfides crystallized first, such that they were overgrown

by olivine. In addition to disseminated sulfides, nickel mineralization at Vaara is characterized by locally remobilized, massive sulfide veins and banding. In outcrop disseminated sulfide grain aggregates are typically discernible as brownish spots (Figures 2.6.2.3.3c ja 3.1.1.2.5.5n) consisting of millerite, pyrite and magnetite (Figure 2.6.2.3.3c). Based on studies to date, millerite (50 – 75%) and pyrite (15 – 35 %) are evidently the most common sulfide phases at the Vaara Ni-occurrence. Samples analyzed for processing and enrichment tests by Hintikka (1999) were also found to contain up to 12% of Ni-rich pentlandite, (40.8 % Ni) and violarite (38.3 % Ni). Chalcopyrite comprises some 13 % of sulfides on average and sporadic grains of galena and sperrylite ($PtAs_2$) have also been identified. Cobalt occurs predominantly within pyrite, which has Co-contents of nearly one percent (Figure 2.6.2.3.3c).



	S	Fe	Co	Ni	Total	Mineral
1	35.32	1.24	0.17	62.83	99.56	Milleriitti/*millerite*
2	35.34	1.62	0.17	62.73	99.86	Milleriitti/*millerite*
3	52.49	45.66	0.93	0.03	99.10	Rikkikiisu/*pyrite*

	Cr (ppm)	Ti (ppm)	Ni (ppm)	Co (ppm)	
4	<100	300	2353	50	Magnetiitti/*magnetite*
5	<100	180	1912	<100	Magnetiitti/*magnetite*
6	547	180	1142	40	Magnetiitti/*magnetite*

Serpentiniittiytynyt oliviini/ *serpentinitized olivine*
Serpentiini/*serpentine*
Milleriitti/*millerite*
Rikkikiisu/*pyrite*
Magnetiitti/*magnetite*

Fig. 2.6.2.3.3c. Sulfides from the Vaara Ni-deposit, displaying “droplet” textures.

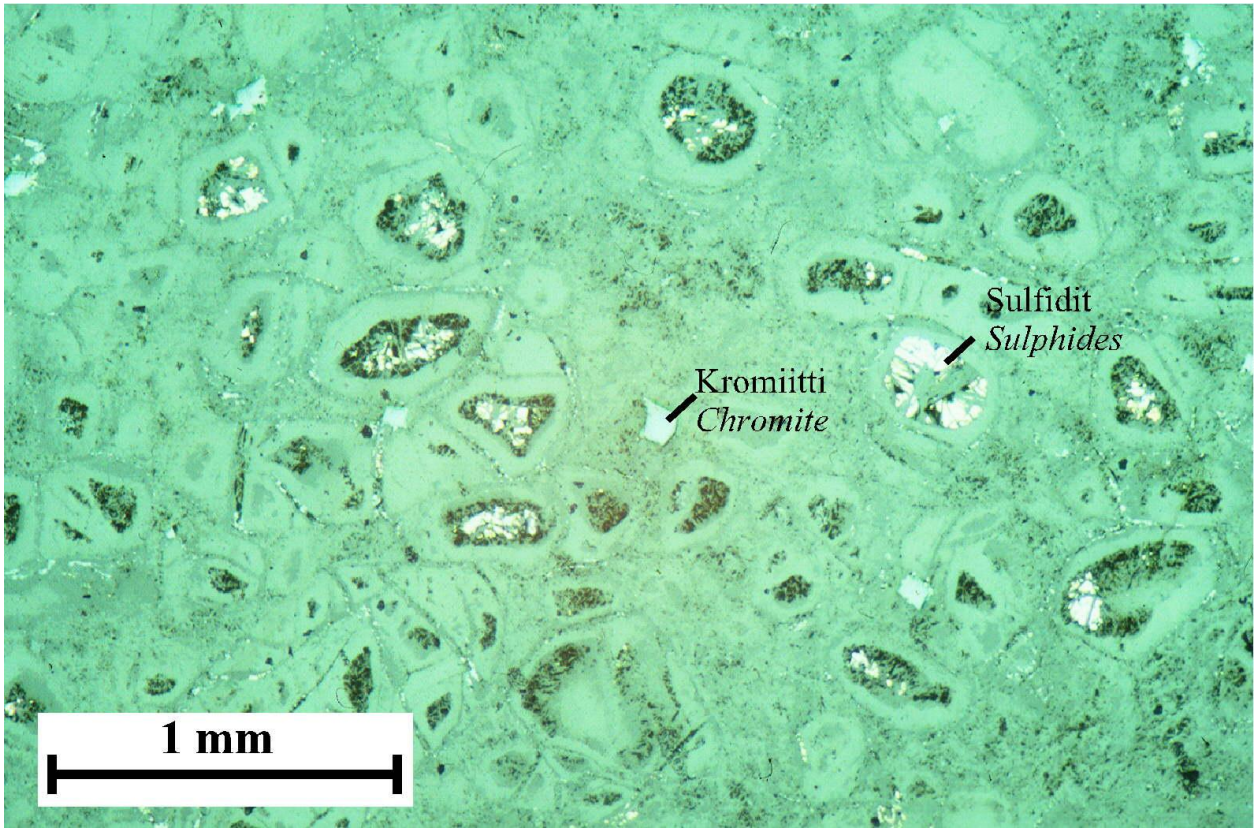


Fig. 2.6.2.3.3d. Photomicrograph (reflected light) from a banded cumulate horizon in which sulfides occur within the central parts of the serpentinized olivine grains, Vaara cumulate lens (R651 - 75.40 m). Photo by T. Halkoaho.

2.6.3. REE-investigations

2.6.3.1. Petrogenesis of Archean and Paleoproterozoic granitoids

Studies of the character, origin, evolution and geodynamic affinities of granitoids in the project area involved collaboration with Professor Tapani Rämö and graduate student projects at the Helsinki University. The first group of intrusions to be investigated were the Paleoproterozoic plutons of A-type affinity and resembling rapakivi granites (Figure 2.6.3.1), outcropping at Iso Kyllönen (mapsheet KKJ 4423 02, 03), Iso Kikonvaara (mapsheet KKJ 4423 02), Tuliniemet (mapsheet KKJ 4423 01) and Rasimäki (mapsheet KKJ 4322 04). Provisional Nd-Sm whole rock isotopic results indicate that these granitoids have slightly negative initial εNd (2440 Ma) values, in the range -2.5 to -1.5, which overlaps with those obtained from the mafic layered intrusions of the Koillismaa region, located to the north and northeast of the present study area (cf. Rämö and Luukkonen, 2001). Investigations into the nature and origin of the Archean granitoids intruding the greenstone belts, and migmatitic granitoids that may represent the substrate to the greenstone belts are the subject of further research projects (cf. Käpyaho, 2007).

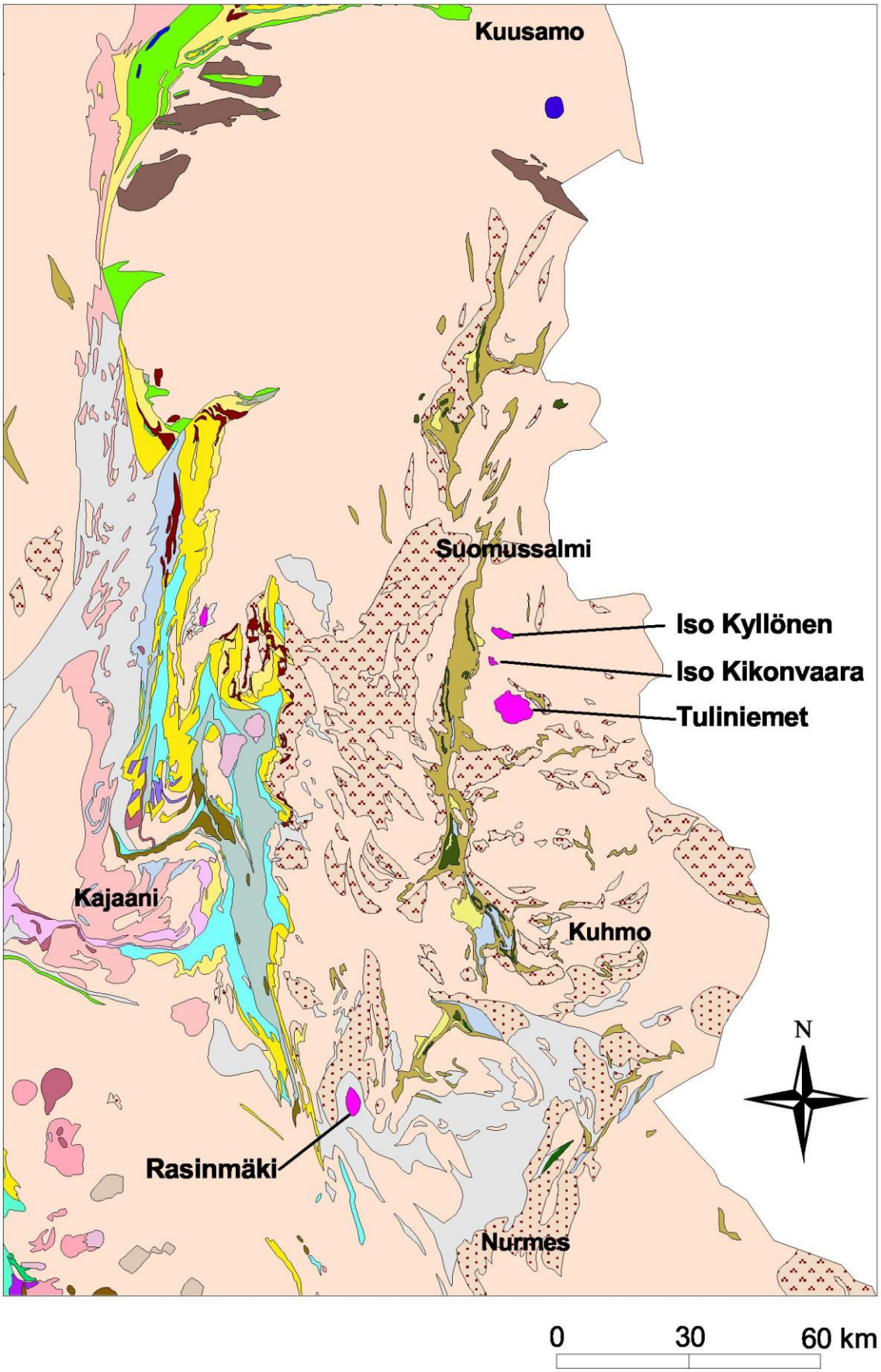


Fig. 2.6.3.1. Paleoproterozoic A-type granites in the Archean terrain of Eastern Finland.. Map is compiled by E. Luukkonen 2001.

2.6.3.2. REE data for the Vaara – Kaunislampi komatiitic cumulates

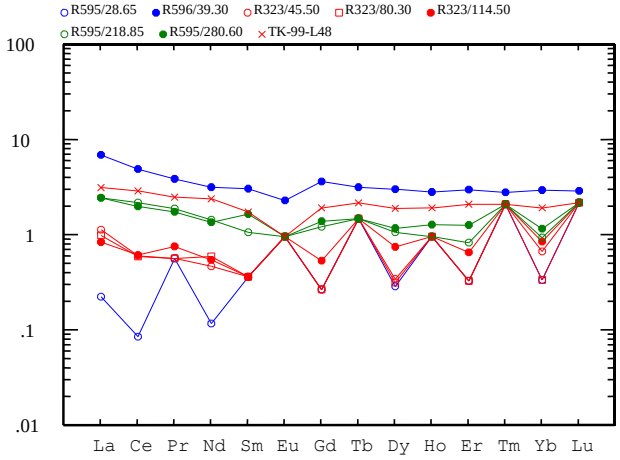
A total of 20 REE analyses were made from representative samples of the Vaara and Kaunislampi komatiitic cumulates, of which with 7 analyses are from the Kaunislampi cumulate body, 3 from the Rytys cumulate lense, and 9 from the Vaara cumulate body, with 5 samples representing the western part (R631, R632 and R628), 2 samples from the central part (R634) and 2 analyses from the eastern part (R654), as shown in Figure 3.1.1.2.5.1a. A single analysis was also made from a mineralized boulder found to the east of Hoikkalampi.

Of the Kaunislampi analyses, four samples (R595/28.65, R323/45.50, R323/80.90 and R323/114.50) have extremely low REE abundances, as do the three samples from Rytys, with LREE and HREE ratios of 0.09 – 1.2 and 0.3 – 2.3 respectively when normalized against chondritic abundances (Figures 2.6.3.2A ja 2.6.3.2B). This gently upward sloping trend on REE plots is characteristic of the so-called komatiitic trend. Three of the samples from Kaunislampi, as well as the Hoikkalampi boulder sample, have almost horizontal or slightly negative slopes on the REE diagrams, with LREE being from 2.5 – 7.0 times greater, and HREE from 1.0 – 3.0 times greater than chondritic abundances (Figure 2.6.3.2a). The sample showing greatest enrichment in LREE is R596/39.30, for which La is 7 times greater and Lu 3 times greater than chondritic values. This sample is from a presumed komatiitic basaltic cumulate located somewhat to the east of the main Kaunislampi ultramafic cumulate body. Both this sample, and the boulder sampled to the east of Hoikkalampi, show slight negative europium minima in their respective REE plots.

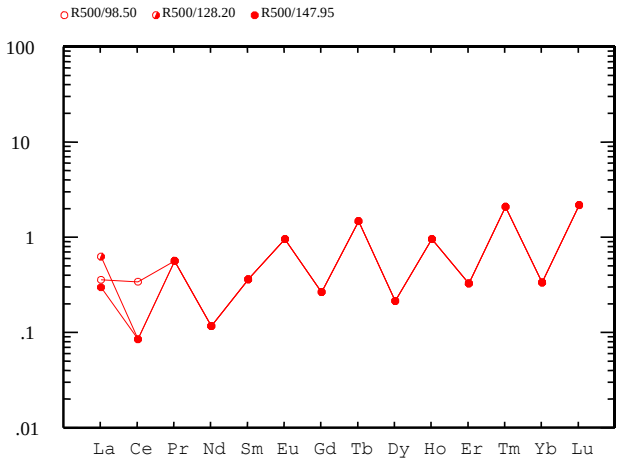
Comparison of the REE data for the Vaara cumulate samples reveals the existence of three distinct compositional groups (Figure 2.6.3.2c). Most of the samples (6 analyses) coincide along a nearly flat REE trend, with LREE abundances of 1.2 – 3-5 times greater than chondritic values and HREE abundances 1.5 – 2.2 times greater than mean chondritic abundances. The next group comprises a single sample (R364/86.20), which shows slight LREE enrichment, while generally resembling the previous group, apart from having a distinct negative europium anomaly. The third group comprises the westernmost sample from the mineralized cumulate lense (R632/60.15) and the westernmost sample from the eastern cumulate body (R654/112.00), as shown in Figure 2.6.3.2c. Both of these samples show distinct LREE enrichment, with abundances from 8 – 11 times greater than chondritic, while HREE abundances are enriched about 4 -5 times over mean chondritic abundances. The most distinctive feature in this group is however the prominent depletion in Eu, with values close to mean chondritic, while adjacent elements Sm and Gd are enriched by a factor of five over mean chondritic values.

Enrichment of komatiitic magmas in LREE can occur through contamination by felsic material, either from older continental crust or contemporaneous volcanics. The presence of a negative Eu anomaly can indicate separation and extraction of plagioclase, either by crystal fractionation or selective removal of plagioclase during melt extraction. However, this is unlikely to be the case for komatiitic magmas, in which plagioclase contents are inherently low. Experimental studies by Lodders (1996) showed that Eu exhibits distinctive behaviour compared to other rare earth elements in that partitioning between silicate melts and sulfide phases (FeS or CaS) favours incorporation into the latter. Lodders (1996) also found that the partition coefficient between sulfides and silicates is significantly greater for europium than for the nearby elements Sm and Gd. In this case, an alternative explanation for depletion in Eu is the preferential sequestration within the sulfide melt phase. Accordingly, if a sample shows signs of contamination with felsic material and a distinct Eu-minimum on REE diagrams, this may be a more reliable indication of sulfide melt fractionation and separation than the presence of samples showing Ni-depletion. A negative Eu anomaly may alternatively be a consequence of metamorphic processes.

KAUNIINLAMPI JA/*AND* HOIKKALAMMEN LOHKARE/*BOULDER*



RYTYS



VAARA

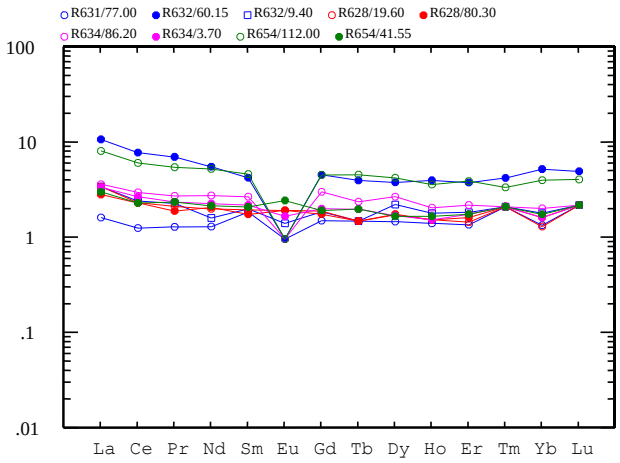


Fig. 2.6.3.2. Average chondrite-normalized REE patterns of the komatiitic cumulates in the Vaara - Kauniinlampi area (average chondrite values after Nakamura (1974): La, Ce, Nd, Sm, Eu, Gd, Dy, Er, Yb and Lu, and after Sun (1980): Pr, Tb, Ho and Tm).

2.6.4. PGE investigations of the Vaara - Kaunislampi komatiites

The komatiitic cumulates of the Vaara – Kaunislampi were analyzed for PGE-total abundances, on the basis of 17 samples. Of these, 9 were from the Kaunislampi cumulate lenses (4 from Kaunislampi North, 3 from Kaunislampi Central and 2 from Kaunislampi South), 3 were from the Rytys cumulate, and 5 from the Vaara cumulate body. Each of these samples were analyzed for six platinum group elements and Au (with the exception of one of the Vaara samples, for which Os was not measured), at the GTK chemical laboratories, using the ICP-MS (Inductively Coupled Plasma Mass Spectrometry) analytical package 714M.

For eight of the analyzed samples, PGE_{tot} + Au abundances were between 0.94 – 1.81 ppm, while four further samples had corresponding values within the range 0.13 – 0.52 ppm, with the remaining five samples having abundances less than 0.1 ppm. The highest abundances of platinides were found at Vaara, at the Ni-PGE mineralization at Kaunislampi North, and in one of the samples from the Rytys cumulate body. Platinum and palladium concentrations in particular are appreciably greater than in the other samples (Figure 2.6.4). When normalized against mantle values for PGE elements, the Vaara Ni-mineralization is clearly seen to be the most enriched. Other element distribution diagrams are very similar, with the exception of the Kaunislampi North Ni-PGE occurrence. Within the epigenetically remobilized part of the Kaunislampi North occurrence, platinides show enrichment within a discrete zone separate from the main Ni- and Cu-mineralization, in which PGE concentrations are conversely, relatively low.

2.6.5. Fluid inclusion studies

Fluid inclusion studies were undertaken in collaboration with Dr Matti Poutiainen of the Department of Geology at Helsinki University, with the aim of assessing the composition and evolution of fluids associated with structurally-controlled gold mineralization in the Kuhmo and Suomussalmi greenstone belts. The Moukkori Au-prospect in the Suomussalmi greenstone belt and the Aittojärvi occurrence in the Kuhmo greenstone belt were selected for detailed investigation.

On the basis of the fluid inclusion studies (Poutiainen and Luukkonen, 1994), auriferous quartz veins have inclusions containing mixtures of CO_2 - CH_4 (less than 10 mol % CH_4), CH_4 alone (only in the Kuhmo greenstone belt), H_2O - CO_2 ± CH_4 (typically 1,5 - 4 moĺ % CO_2 and less than 10 mol % CH_4 in the CO_2 phase) and H_2O alone (although occasionally with small amounts of CO_2 and traces of other gas components in the vapor phase). Some inclusions (although not those consisting of CH_4) contain crystals of carbonate, mica, halite, opaques and other unidentified mineral phases. The earliest fluids were evidently in equilibrium with CO_2 ± CH_4 (primary/secondary) and H_2O - CO_2 ± CH_4. Fluid inclusion trails within paragenetically late fractures are doubtless secondary (especially CH_4 and H_2O inclusions). Salinities of H_2O - CO_2 ± CH_4 inclusions are low in samples from the Moukkori Au-prospect but higher in samples from the Aittojärvi occurrence; salinities of H_2O-dominated fluids are however similar in both gold occurrences. Homogenization temperatures under stable conditions for the H_2O - CO_2 ± CH_4 inclusions range between 235° C - 195° C for the Moukkori samples and 305° C - 145° C for the Aittojärvi samples. Corresponding homogenization temperatures for the H_2O-dominant fluids are 315° C - 100° C for Moukkori and 235° C - 95° C for Aittojärvi.

The source and origin of the fluids has not been established, although the low salinities of the Moukkori H_2O - CO_2 ± CH_4 inclusions and the high salinities of the Aittojärvi samples are typical for mesothermal Au and Au + base metal mineralization styles. Likewise, the association between CO_2 ± CH_4 fluids and deformation zones is well-documented from gold deposits elsewhere. It is therefore probable that the high-strain zones within the Suomussalmi and Kuhmo

greenstone belts have been the loci of significant transport of $CO_2 \pm CH_4$ ja H_2O - CO_2 fluids, capable of transporting Au in solution. The high salinities of the $H_2O \pm CO_2$ inclusions is presumably a consequence of retrogressive fluid-rock interaction and equilibration. The observed variation in $CO_2 \pm CH_4$ fluid inclusion densities (0,22 – 1,16 g/cm^3) may be attributed to fluid pressure fluctuations accompanying episodic stress release within deformation zones. In summary, the data from fluid inclusions in auriferous quartz veins are consistent with precipitation of gold from late orogenic fluids, post-dating peak metamorphism and within a tectonic regime spanning the brittle-plastic transition. Gold precipitation was evidently facilitated at least in part by sulfidation of suitably mafic host rocks.

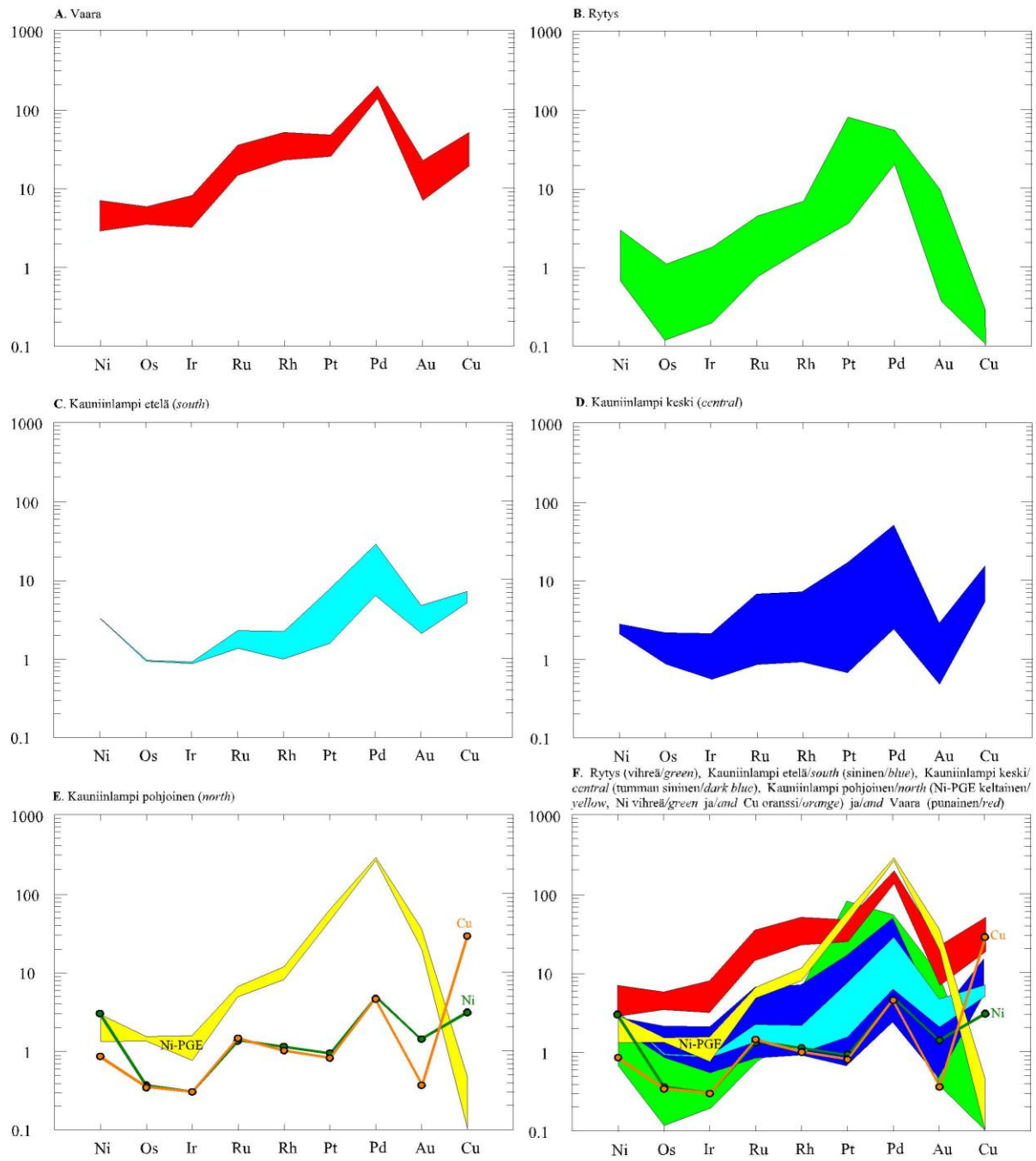


Fig. 2.6.4. Average mantle-normalized platinum-group element, Au, Ni and Cu data for the komatiitic Vaara - Kauniinlampi Ni occurrences. Mantle values after Sun (1982) and Barnes et al. (1988).

2.6.6. Geophysical investigations of the deep crust

Deep crustal properties and architecture in the Archean of eastern Finland, including the Kuhmo greenstone belt, were the focus of joint investigations undertaken by the University of Oulu and GTK as part of the Global Geoscience Transects (GGT) program (Figure 2.6.6a). These studies included a continuation of the SVEKA seismic refraction survey line towards the northeast, using blasting operations at the Lahnaslampi talc quarries and Kostamus iron mine (in adjacent Russian Karelia) as energy sources (Yliniemi 1986 and Yliniemi et al. 1996). In combination with the earlier SVEKA interpretations and gravity survey data, it was possible to intepret the Kuhmo greenstone belt as being from 1.0 – 4.5 km thick, with an eastwards dipping enveloping surface. Moreover, there appears to be a significant change in Moho thickness either side of the Kuhmo greenstone belt, from 57 km on the southwestern side, to 46 km on the eastern side. This prominent deep crustal feature is potentially of significance with respect to large scale structural controls on orogenic gold mineralization, especially since it coincides with deformation zones and mineralized structures mapped at the present erosion surface.

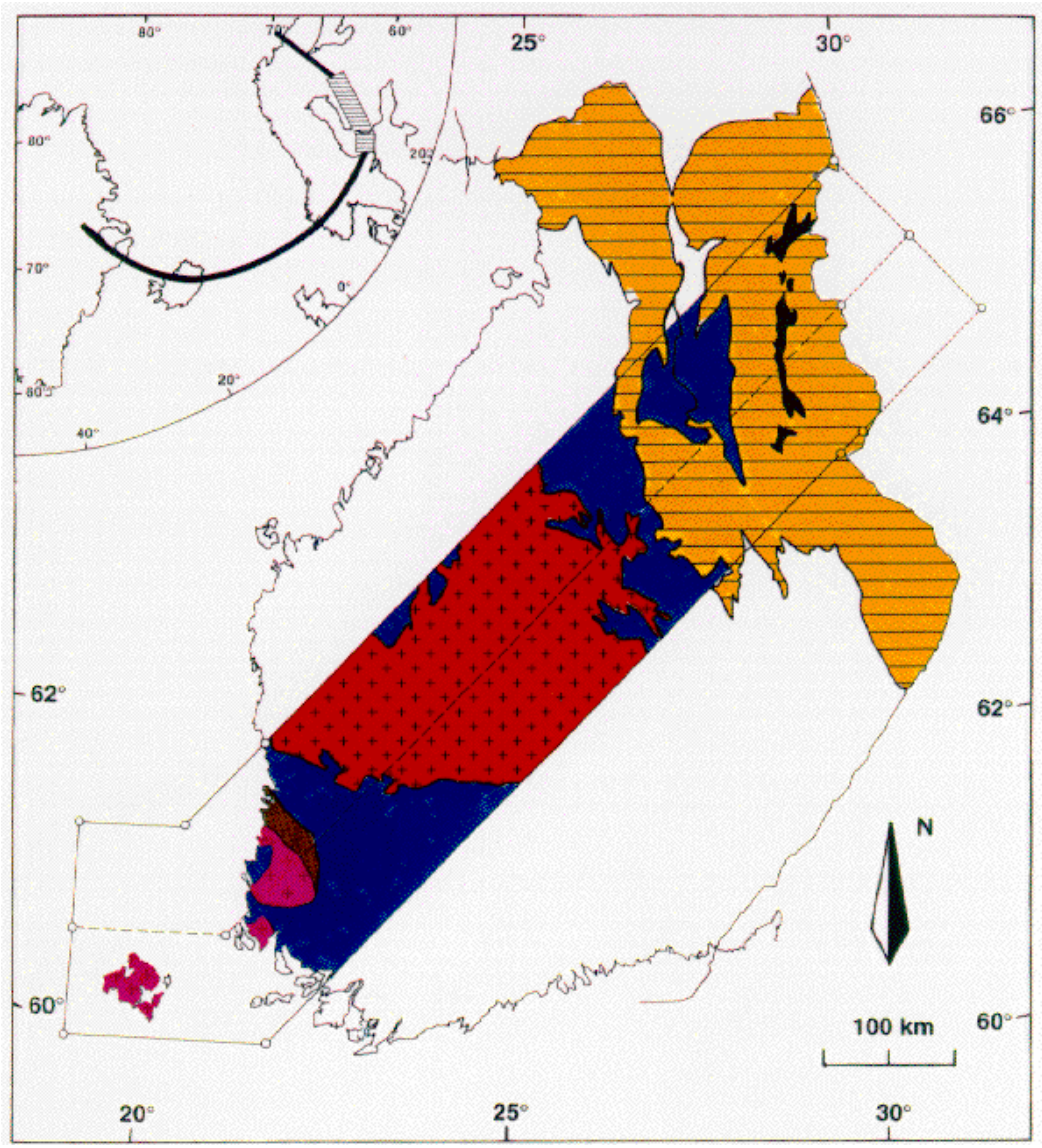


Fig. 2.6.6a. Location of GGT-transect.

Gravity modeling by Elo (1997) across the Kuhmo greenstone belt indicated that the observed change in crustal thickness, assuming a Moho density contrast of 400 kg/m^3, should generate a surface anomaly of 170 mGal, contrasting with the measured Bouguer anomaly, which is only 12

mGal. Moreover, because the amplitude gradient of the observed anomaly is attributed primarily to upper crustal density contrasts, a denser lower crustal layer is required to the west of the greenstone belt. The effect of the calculated Bouguer anomaly due to the presence of such an anomalous mass in the lower crust is shown (thinner line) in Figure 2.6.6b. This anomaly has been corrected for in the upper crustal model.

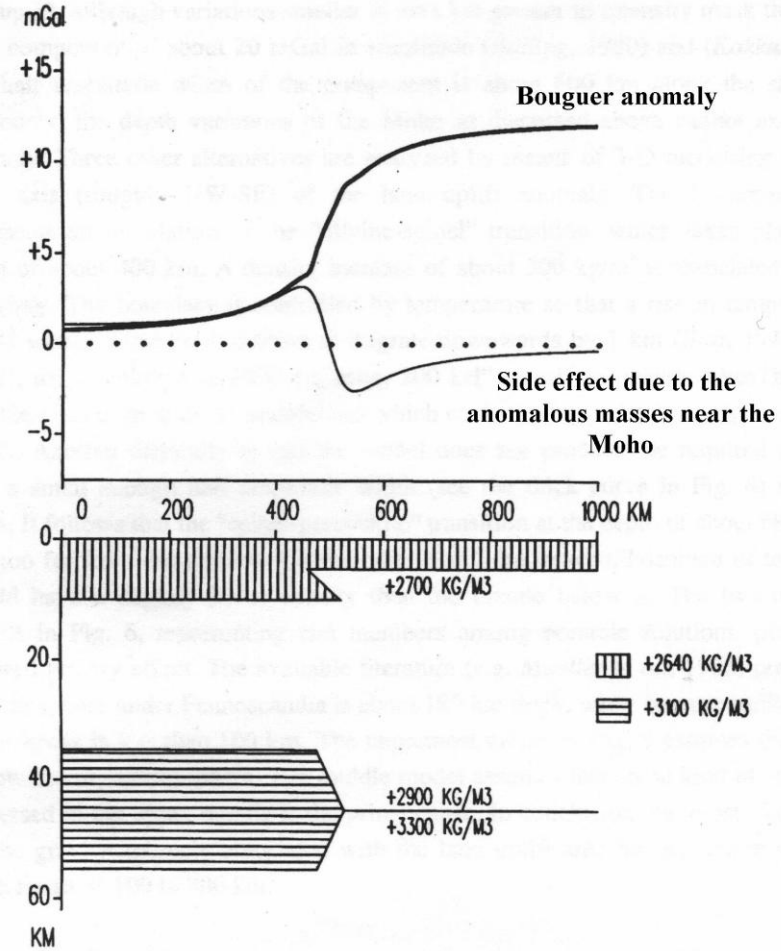


Fig.2.6.6b. Crustal model and Bouguer anomaly over the Kuhmo Greenstone Belt (Elo, 1997).

The seismic profile and gravity data were reinterpreted by Kozlovskaya et al., 1999, making use of the non-linear dependency of P- and S-waves with respect to density. This revised interpretation further confirmed the earlier conclusions concerning an anomalously dense lower crustal layer (Figure 2.6.6c). This dense layer, with high seismic impedance velocities, most probably represents mafic to ultramafic mantle-derived material, underplated during Paleoproterozoic time.

Those domains within the gravity anomaly data that correlated poorly with the density structure model were interpreted as residual gravity anomalies; the positive residual anomaly coinciding with the Kuhmo greenstone belt can thus be explained by a wedge-shaped body close to the surface (anomaly on the right side in Figure 2.6.6d).

The SVEKA seismic refraction data have not revealed many insights into compositional structure of the upper crust, but the results of the FIRE seismic reflection surveys, conducted between 2003-2004 provide more information on upper crustal architecture (Kontinen and Paavola, 2006).

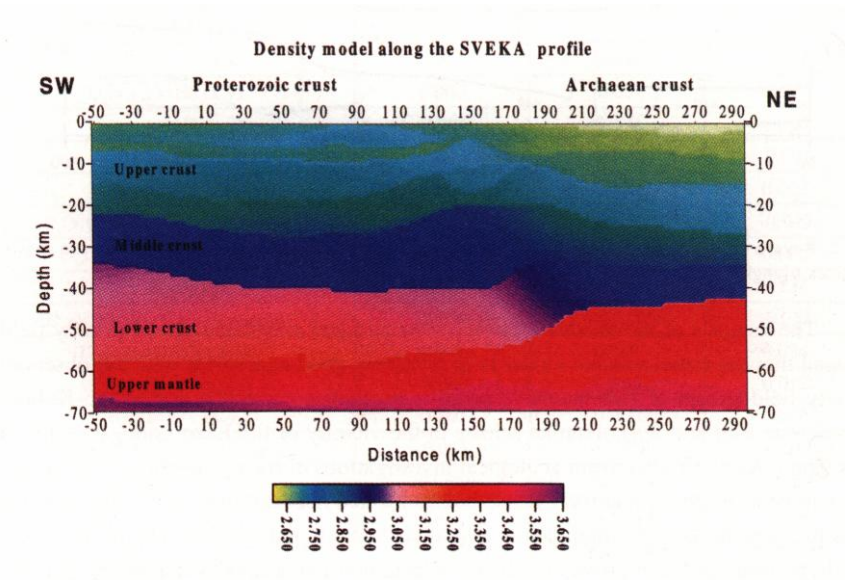


Fig. 2.6.6c. Density model of the extended SVEKA-profile. (Kozlovskaya et al, 1999).

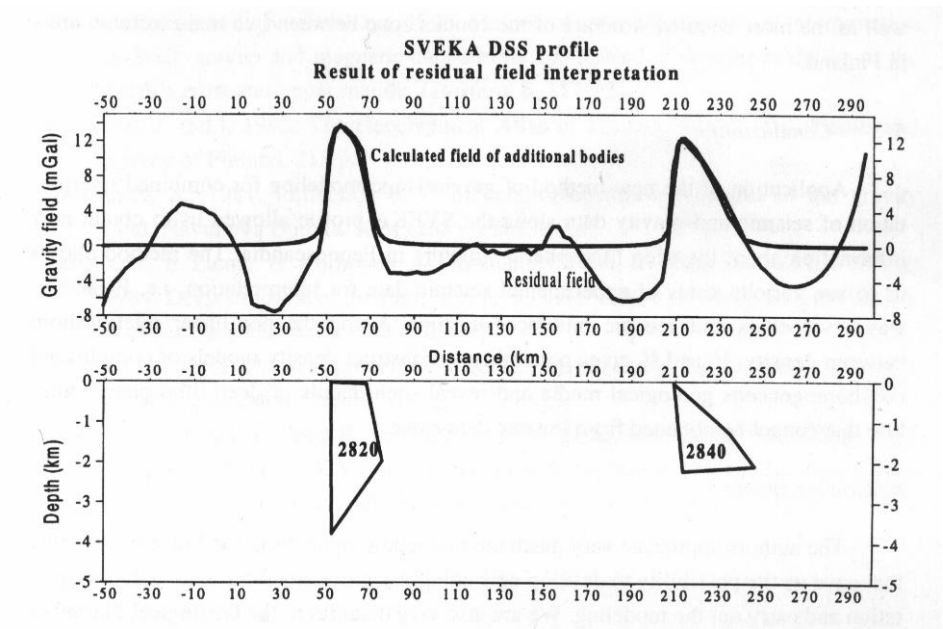


Fig. 2.6.6d. Gravity-density model of the uppermost crust and residual Bouguer anomaly (Kozlovskaya et al, 1999).

3. GEOLOGICAL BACKGROUND AND MINERAL POTENTIAL IN THE ARCHEAN OF EASTERN FINLAND

The Archean cratonic nucleus of the Fennoscandian Shield comprises much of eastern and northern Finland, the Kola Peninsula and the Russian Republic of Karelia (Figure 3a). The total area of this craton is comparable to that of the Yilgarn Craton in Western Australia and in global terms, represents a median-sized Archean domain.

Gaál and Gorbatschev (1987) subdivided the Archean rocks of Fennoscandia into the Karelian, Belomorian and Kola provinces and proposed two major crustal forming episodes, namely the Saamian (3100-2900 Ma) and Loppian (2900-2600) orogenic events. The Archean terrain investigated here covers an area of 26 913 km^2, comprising part of the Karelian Province, most of which occurs in the adjacent Karelian Republic of the Russian Federation. The Karelian Province in eastern Finland is also characterized by granitoids and greenstone belts with low- to medium-pressure metamorphic assemblages and is bounded to the south, west and north by the Paleoproterozoic North Karelian, Kainuu and Kuusamo schist belts respectively. In contrast to better exposed Paleoproteroic bedrock of southern and western Finland, the Archean of eastern Finland was rather poorly understood, and until as recently as the 1960's, had only been mapped at reconnaissance scale. This was a consequence, not only of the relative scarcity of bedrock outcrops – the proportion of bedrock exposed is only 6-8% - but also the absence of detailed topographic maps and high-resolution airborne geophysical data. Moreover, most of the strongly hydrothermally altered and sulfide-bearing shear zones are buried beneath till or esker deposits several meters in thickness. For these reasons, the Archean of Eastern Finland can still be considered as substantially underexplored.

The Meso- and Neoarchean bedrock of eastern Finland can be subdivided lithogically into four main types: Archean orthomagmatic migmatites and discrete granitoid bodies (about 60% by area), Archean greenstone belts (20% by area), Archean paragneisses and derivative biotite-rich phlebitis migmatites (about 10% by area), with the remaining 10% represented by Paleoproterozoic mafic dykes, A-type granitoids, and the Saari-Kiekki greenstone belt. Figures 3e-3h illustrate the more typical rock types found within the Kuhmo and Suomussalmi greenstone belts.
On the basis of structural relationships and isotopic age determinations, the orthomagmatic migmatites (tonalitic – trondhjemitic – granodioritic migmatites = TTG gneisses) and some of the discrete intrusive granitoids are older than 2800 Ma. Some granitoids from the Suomussalmi and Ilomantsi areas have Nd-Sm model ages and inherited zircons indicating derivation from source material greater than 3000 Ma in age. In total, these older orthomagmatic plutonic rocks represent about half of the exposed granitoid bedrock in the area investigated, the other half consisting of younger (2760-2690 Ma) tonalites, quartz diorites, granodiorites and granites *sensu stricto*, all of which show cross-cutting intrusive relationships with both the older granitoids and the greenstone belts.

On the basis of rock type and isotopic ages, the greenstone belt assemblages of eastern Finland can be subdivided into three main groups:

1) the Luoma association, which consists of 3000-2800 Ma intermediate, felsic and mafic volcanic; this association is restricted to a relatively small area in the northern parts of the Suomussalmi and Kuhmo greenstone belts (Appendix 5).
2) the Kuhmo association, which is dominated by 2800-2750 Ma mafic and ultramafic volcanic units, with minor amounts of felsic and intermediate volcanics and derived volcaniclastic sediments, as well as sporadic banded iron formations and immature clastic quartzites. The Kuhmo-type greenstones are found in all greenstone belts with the exception of the Ilomantsi greenstone belt

3) the 2760-2700 Ilomantsi area, in which resedimented intermediate to felsic volcaniclastic deposits predominate, with minor oxide-facies banded iron formations and sporadic intercalations of mafic and ultramafic volcanics. In this respect the Ilomantsi-type resembles the upper part of the stratigraphical sequence defined in the Kostamuksha greenstone belt in Russian Karelia and it is conceivable that the two areas represent a formerly contiguous supracrustal terrain, subsequently disrupted by granitoid intrusions.

Numerous geodynamic interpretations have been presented for the Archean greenstone belts of eastern Finland, including a back-arc basin (Taipale, 1983), oceanic island arc system ((Sokolov and Heiskanen 1985, Jahn et al., 1980, Sorjonen-Ward 1993a) and a rift-related setting (Luukkonen 1988b, 1992). Although geochemical data are to some extent compatible with each of these interpretations, caution should be exercised in comparing terrains and inferring geodynamic setting based on lithogeochemical criteria alone. It is however, likely, that the Archean greenstone belts of eastern Finland represent the deep-level disrupted remnants of an extensive essentially submarine volcanic system; within this context, variations in composition could be attributed to the original primary location within a single differentiated magmatic complex, rather than to a change in tectonic setting.

An extensive area of strongly deformed paragneisses and associated migmatites occurs to the south and west of the Tipasjärvi greenstone belt, known as Nurmes-type paragneisses, while similar rock types are also abundant to the east of the Paleoproterozoic Kainuu schist belt, from Sotkamo to north of Hyrynsalmi. According to Kontinen (1990, 1991), the protoliths to the Nurmes-type paragneisses were derived in part from weathering and erosion of Archean granitoids, and in part from greenstone belt rocks. Lithological and lithogeochemical similarities between the metasediments in the Ontojärvi synform in the Kuhmo greenstone belt and those in the Tipasjärvi greenstone belt also indicate that a volcaniclastic origin is possible.
Subsequent to cratonization, the Archean crust of eastern Finland was subjected to tectonic reactivation and thermal overprinting at various times during the Paloeproterozoic and possibly Mesoproterozoic. The first of these events was around 2450 Ma, associated with the emplacement of the Koillismaa mafic layered intrusions, and is represented by predominantly E-W trending and NE-SW trending mafic dykes, as well as the emplacement of A-type rapakivi granites to the east of the Kuhmo greenstone belts. The Saari.Kiekki greenstone belt is also considered to represent volcanic expression of this mafic magmatism (Luukkonen, 1992). Further dykes swarms were emplaced after a hiatus of some 250 Ma, with a predominant NW-SE trend, although E-W trending and NE-SW trending dykes are also present. Several NNW-SSE trending diabase dykes dated at 1970 Ma (Vuollo, 1994) are attributed to magmatism during initial cratonic breakup. The fourth overprinting event was related to emplacement of ophiolites and overthrusting along the western margin of the Karelian Province with widespread thermal overprinting culminating around 1850 Ma; this event also generated hydrothermal activity along reactivated fault zones, as recorded for example by the kyanite-phlogopite assemblages in the Hiltuspuro area between Kuhmo and Nurmes. The final event recorded in the Karelian Province was the emplacement of ultra-alkaline lamproitic dykes to the east of the Kuhmo greenstone belt. Although these have not been dated directly, by analogy with similar dykes elsewhere in Finland and Russian Karelia, they are likely to be of Mesoproterozoic age, around 1300-1100 Ma.

Overall, the Archean of eastern Finland represents a mosaic of deeply eroded Meso- and Neoarchean granitoids, greenstone and paragneisses of different age and composition, as is indeed typical of Archean cratons worldwide. Tectonic juxtaposition of formerly disparate terranes and crustal units is possible, but difficult to demonstrate quantitatively. Nevertheless an overall coherent picture is emerging for the evolution of the Archean bedrock of eastern Finland, over the period from 3100 – 2650 Ma, as well as the role of subsequent Paleoproterozoic reactivation, granitoid emplacement and hydrothermal activity. More detailed investigations are in progress.

Although greenstone belts represent less than 40% of exposed Archean terrains, they contain the vast majority of known Archean precious and base-metal reserves. Globally, greenstone belts account for some 25-30% of total historical nickel production, about 20% of all gold mined and they contain in addition some 20% of known VHMS deposits. Nickel is characteristically associated with komatiites and commonly occurs as polymetallic Ni-Cu-PGE occurrences, whereas gold typically forms “gold-only” structurally controlled deposits. Volcanic-hosted massive sulfide (VHMS) deposits occur within distinct facies associations in the proximal parts of submarine volcanic complexes. Other more unusual, but nevertheless significant Archean mineral deposits include PGE- and chromite deposits, volcanogenic Cu-Mo deposits, porphyry Au-Cu deposits and a variety of other Au deposits (Galley, 2001).

A number of komatiite-related Ni-Cu ± PGE occurrences have already been identified in the greenstone belts of eastern Finland, including Kauniinlampi (3 separate Ni occurrences), Vaara, Peura-aho and Hietaharju in the Suomussalmi greenstone belt and Sika-aho and Arola in the Kuhmo greenstone belt. In addition, smaller supracrustal remnants outside the main greenstone belts are also prospective for nickel, such as Riihilampi at Kuhmo and Tainiovaara near Lieksa (Figure 3c). Several tens of structurally controlled Au occurrences have been identified in the Suomussalmi, Kuhmo and Ilomantsi greenstone belts, the most significant being Moukkori, Kuikka, Valkeasuo (Hosko) and Pampalo. Figure 3b indicates the various greenstone belts and target areas delineated during the investigations reported here.

Intensely hydrothermally altered felsic pyroclastic units in the inferred stratigraphically lowermost parts of the Tipasjärvi greenstone belt contain the Taivaljärvi Ag-Pb-Zn deposit (Papunen et al., 1989). According to Kopperoinen and Tuokko (1988) the mineralization formed as a result of hydrothermal processes associated with submarine phreatomagmatic eruptions. In addition, the Tipasjärvi pyritic ore was mined on a small scale during the early part of the twentieth century for the purpose of supplying sulfuric acid and sulfur dioxide for the paper industry (Laitakari, 1937).

In the Kuusijärvi segment of the Kiihtelysvaara greenstone belt, the Otravaara Formation contains extensive stratiform occurrences of pyritic ore in hydrothermally altered felsic volcanics (Saksela 1923, Männikkö et al. 1987). The most significant of these deposits, at Otravaara, was also mined for the manufacture of sulfuric acid and sulfur dioxide (Laitakari, 1937).

The Ilomantsi greenstone belt had long been regarded as being propsective for banded iron formation although grade and tonnage of currently known occurrences appears subeconomic. Similar, more modest iron formations are also widespread in other greenstone belt. At Huhus, in the western part of the Ilomantsi greenstone belt, a small Pb occurrence has been found in association with the banded iron formations.

Hydrothermal alteration and carbonation of olivine cumulates associated with komatiitic complexes in several greenstone belts has resulted in the formation of high-quality and economically significant soapstone deposits for the natural stone industry. At the time of writing, industrial operations were active at Kivikangas in the Suomussalmi greenstone belt, Verikallio in the Kuhmo greenstone belt, and Nunnanlahti, at Juuka, where the main dressing and manufacturing facilities are located (Figure 3d).

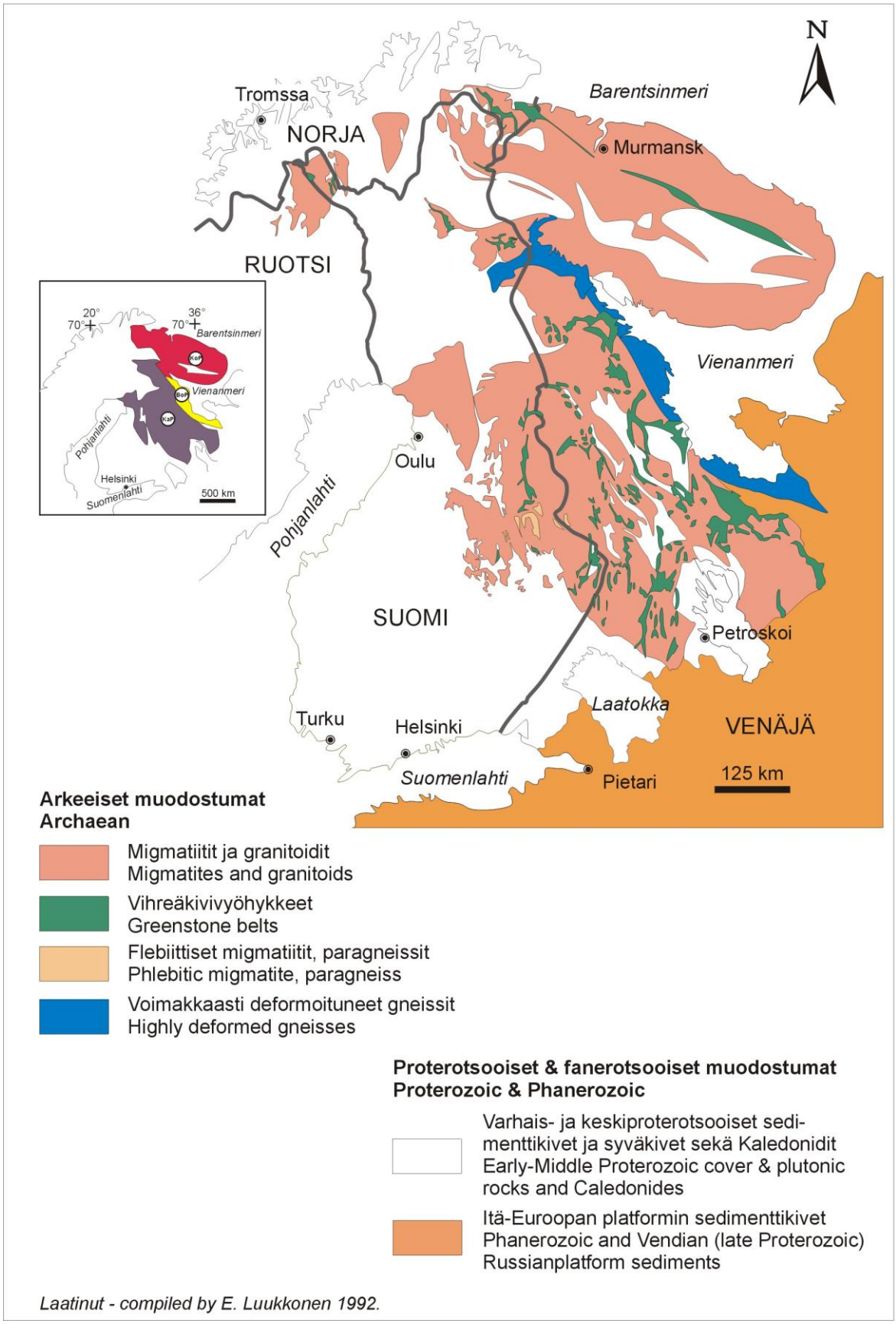


Fig. 3a. Major Archean crustal subdivisions in the Fennoscandian Shield (compiled by Luukkonen 1992). KoP = Kolan Province, BeP = Belomorian Province and KaP = Karelian Province.

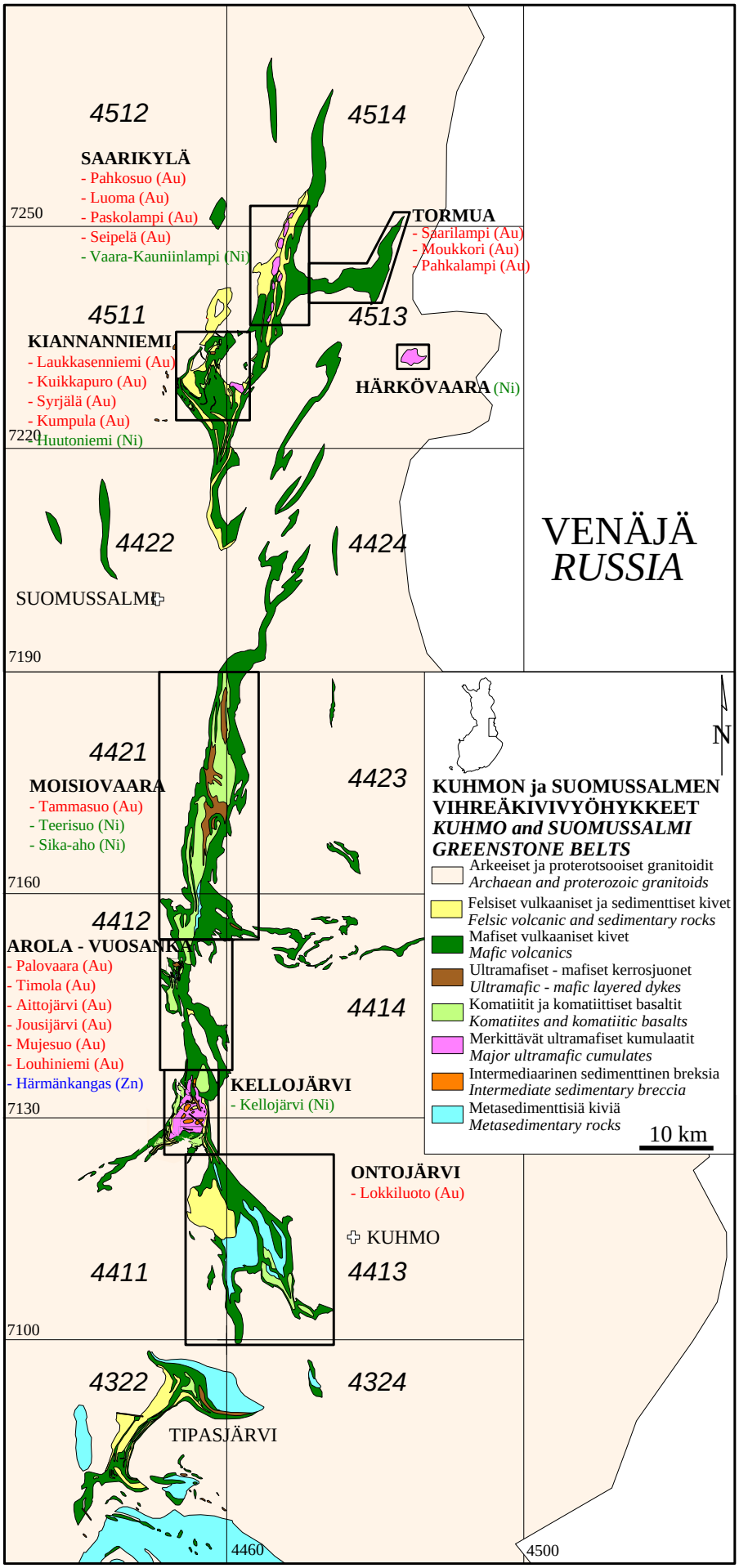
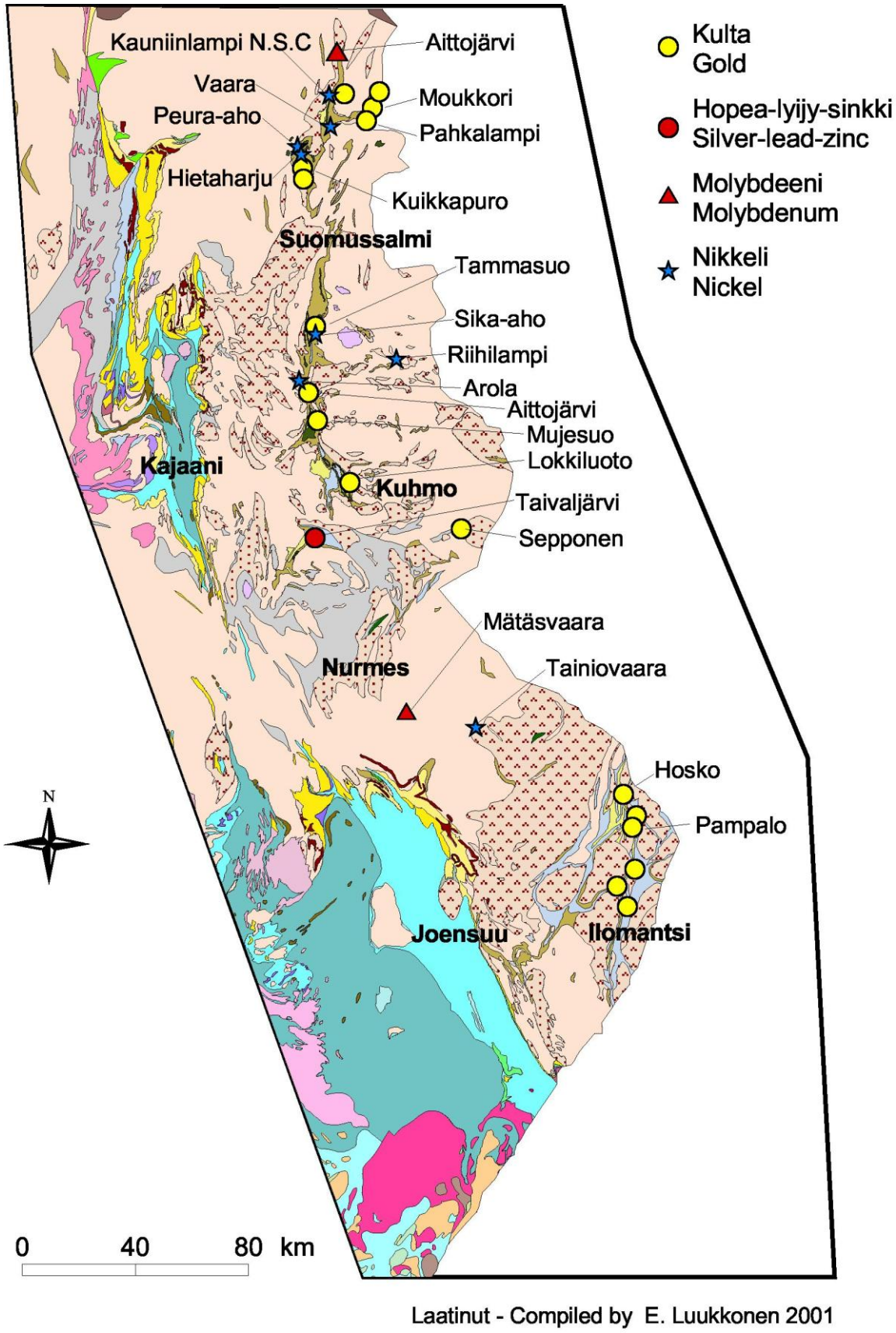


Fig. 3b. Generalized geological map of the Suomussalmi, Kuhmo and Tipasjärvi Greenstone Belts, showing exploration areas and targets investigated during the GTK project "Archean Terrains of Eastern Finland".



Laatinut - Compiled by E. Luukkonen 2001

Fig. 3c. Metallic mineral occurrences, deposits and mines within the Archean terrain of Eastern Finland.

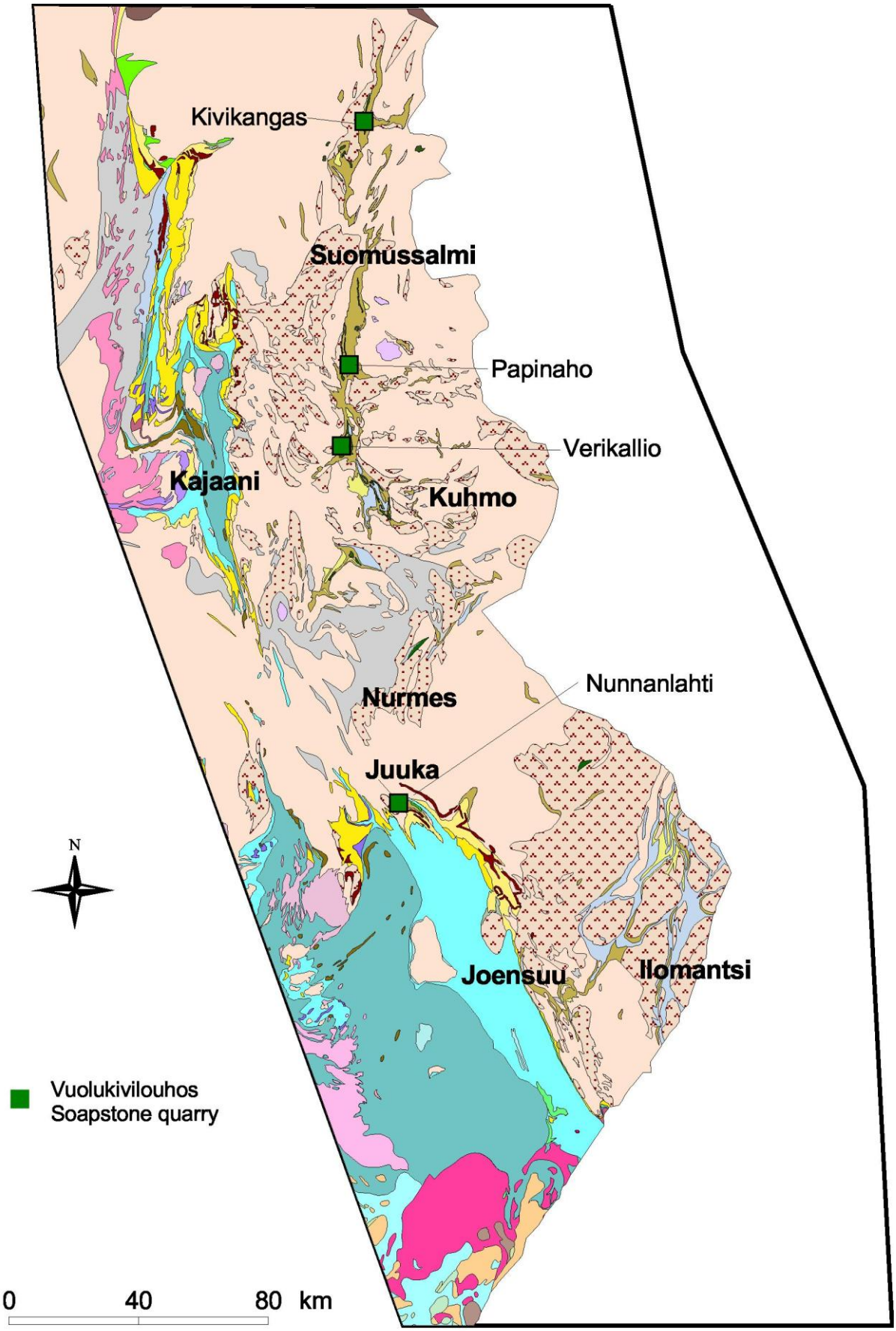


Fig. 3d. Soapstone quarries in eastern Finland.

Based on comparisons with other mineralized Archean terrains, and the currently known mineral occurrences, the Archean greenstone belts are considered to remain highly prospective for metallic and non-metallic mineral resources. In contrast, the granitoid-dominated areas in eastern Finland have been regarded as having less potential. Nevertheless, younger Archean granitoids and sheared, hydrothermally altered older migmatites are associated with economically significant Mo mineralization, at Aittojärvi, east of the Suomussalmi greenstone belt (Kurki, 1980, 1989)., and at Mätäsvaara, near Lieksa, which was mined during the Second World War as a source of molybdenum for the German steel industry (Kranck, 1945; Zeidler, 1949). In recent years, the areas underlain by Archean granitoids have also received more attention in the course of exploration for kimberlite pipes. A number of small gold occurrences have also been found, as well as numerous localities that have potential for providing suitable material for the natural stone industry. On the other hand, Archean paragneisses and post-Archean rock types have received less attention, although mafic dykes and intrusions, where not affected by hydrothermal recrystallization, and where they retain primary magmatic olivine or pyroxene, maybe of suitable quality for the natural stone industry.

3.1 Suomussalmi greenstone belt

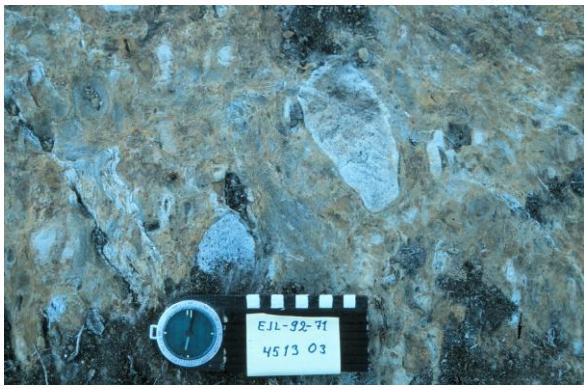
The Suomussalmi greenstone belt, which is the most northerly of the greenstone belts of eastern Finland, is located within the central and northern part of the rural municipality of Suomussalmi (Figures 3a and 3b and Appendix 5). The belt extends for about 60 km from north to south and has a maximum width of about 10 km. Two supracrustal, predominantly volcanic, successions of different age have been recognized, in tectonic contact with one another. The older succession occurs along both the western margin of the greenstone belt and in the east, where it is referred to as the Tormua belt, and consists of 3000 – 2850 Ma mafic, intermediate and felsic volcanic and volcaniclastic rocks, defined as the Luoma Group; these rocks were evidently erupted and deposited within shallow marine or subaerial environments. Variably sized enclaves of banded amphibolites and intermediate granofels are common within granitoids surrounding the Suomussalmi greenstone belt and probably represent isolated and disrupted remnants of Luoma Group volcanics.

The central part of the Suomussalmi greenstone belt is characterized by the younger komatiitic olivine (± pyroxene) cumulates and tholeiitic and komatiitic basalts of the Saarikiylä Group. These are interpreted as the deeply eroded remnants of extensive submarine fissure eruptions which formed within either a mid-ocean ridge or shield volcano setting. The komatiitic olivine (± pyroxene) cumulates presumably represent the deformed and disrupted remnants of extensive channeled lava flows. The komatiitic and tholeiitic basalts display both massive and pillowed flow structures and evidently represent eruption at greater water depths than the Luoma Group volcanism, although primary textures have commonly been obscured by intense deformation. Differentiated mafic dykes, tens of meters in thickness are also relatively abundant within the Saarikylä Goup.

The mafic volcanism of the Saarikylä Group was succeeded by intermediate and felsic volcanics, volcaniclastic sediments and graphitic pelitic schists although at the present erosion level these are only locally preserved, occurring typically as tectonically bounded domains within zones of high strain. Both the Luoma and Saarikylä Group greenstones are intruded by younger Archean granitoids and massive, ophitic Paleoproterozoic mafic dyke swarms. Representative examples of rock types present in the Suomussalmi greenstone belt are shown in Figures 3e and 3f.

A

B



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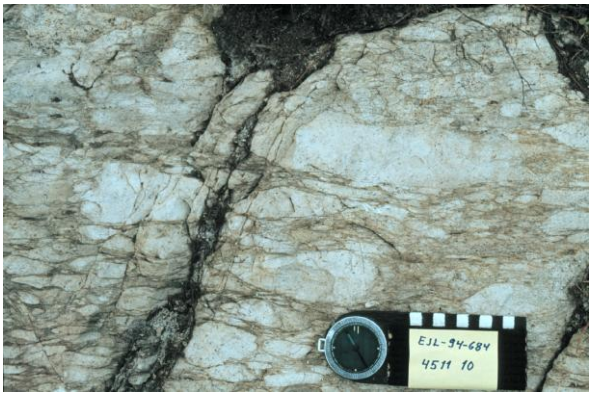

D

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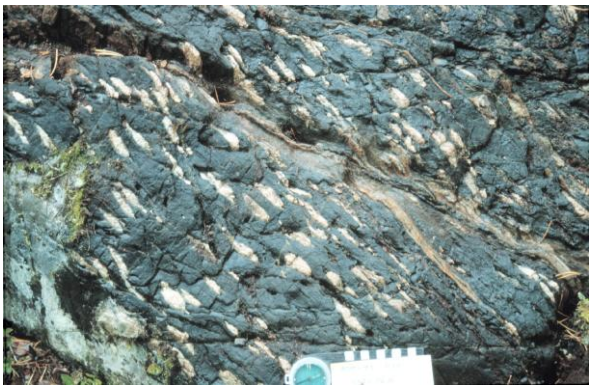


F

Fig. 3e. Images from outcrops in the Suomussalmi area.

A. Intermediate tuffite of the Luoma Group. Photo E. Luukkonen.

B. Felsic pyroclastic rock of the Luoma Group, Suomussalmi. Photo E. Luukkonen.

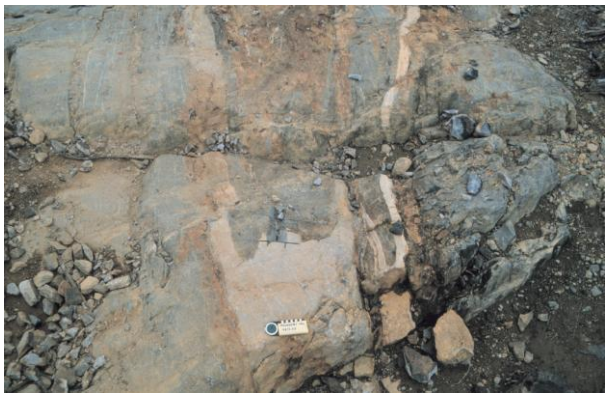
C. Deformed felsic pyroclastic rock of the Luoma Group, Suomussalmi. Kuva E. Luukkonen.

D. Tholeiite-pillow lava, Kiannanniemi, Suomussalmi. Photo E. Luukkonen.

E. Tholeiite-amygdaloid lava, eastern side of Saarijärvi, Suomussalmi. Photo E. Luukkonen.

F. Komatiitic ”harrisite” layer, Rytys, Suomussalmi. Photo E. Luukkonen.

A



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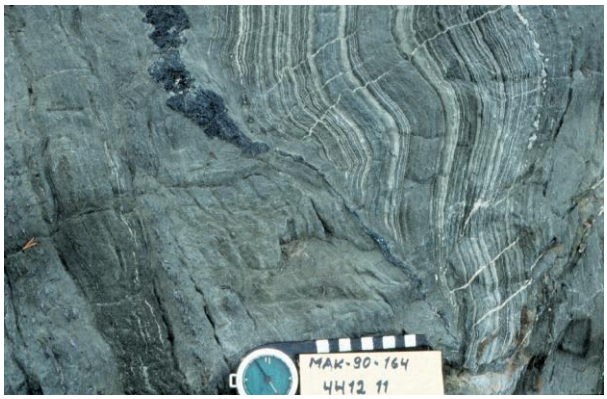


E

F

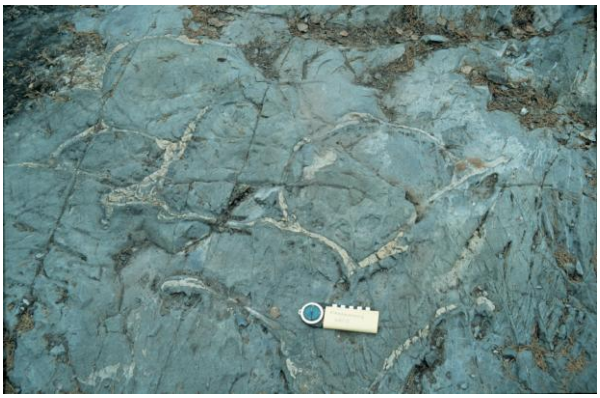


Fig. 3f. Images from outcrops in the Suomussalmi and Kuhmo areas.

A. Granodiorite dyke cutting banded amphibolite, Moukkori gold mineralization. Photo E. Luukkonen.

B. Outcrop of Moukkori gold mineralization, Suomussalmi. Gold bearing quartz dyke in the middle and highly altered rocks on both sides. Photo E. Luukkonen.

C. Gold bearing bluegrey quartz dyke samples from the Moukkori gold mineralization, Suomussalmi. Photo E. Luukkonen.

D. Komatiitic dyke intersecting banded amphibolite, Tervalampi, Kuhmo. Photo E. Luukkonen.

E. Felsic dyke intersecting intermediate tuffite, Jousijärvi, Kuhmo. Photo E. Luukkonen.

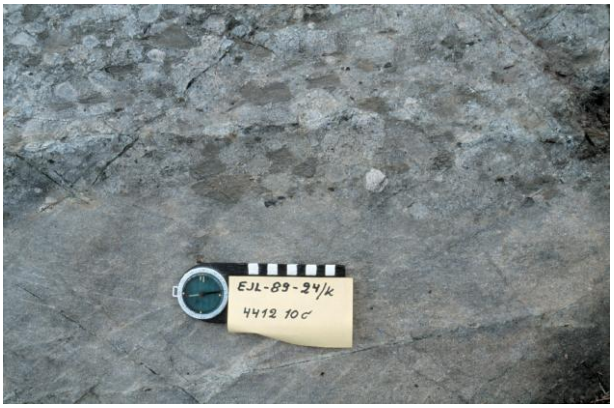
F. Tholeiitic pillow lava, Pahakangas, Kuhmo. Photo E. Luukkonen.

A

B

C

D



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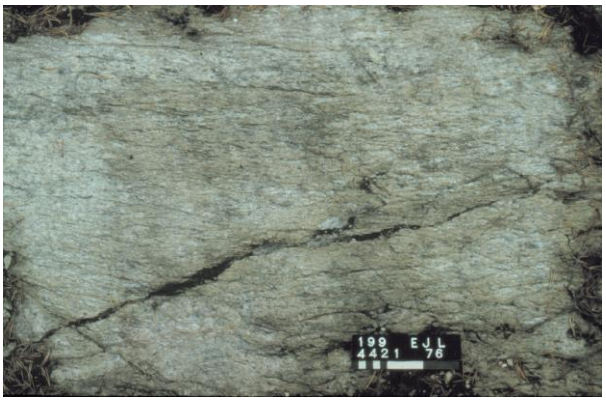


Fig. 3g. Images from outcrops in the Kuhmo and Hyrynsalmi areas.

A. Banded iron formation between tholeiitic lava layers, Pahakangas, Kuhmo. Photo E. Luukkonen.

B. The contact between intermediate volcanic konglomerate and basalt, Lampela, Kuhmo. Photo E. Luukkonen.

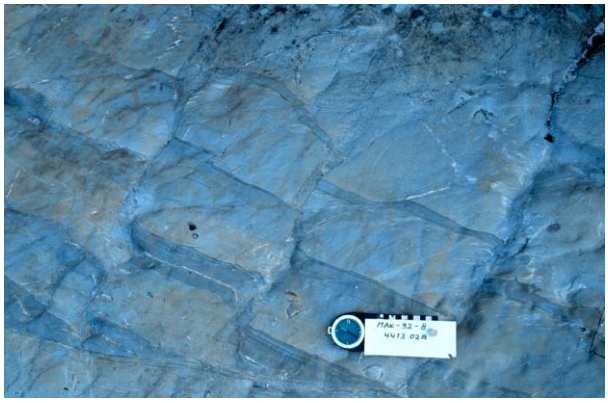
C. Intermediate volcanic conglomerate, Lampela, Kuhmo. Photo E. Luukkonen.

D. The contact between intermediate volcanic conglomerate and tuffite, Lampela, Kuhmo. Photo E. Luukkonen.

E. Quartz pebble conglomerate, Moisiovaara, Hyrynsalmi. Photo E. Luukkonen.

F. Sericite quartzite, Moisiovaara, Hyrynsalmi. Photo E. Luukkonen.

A



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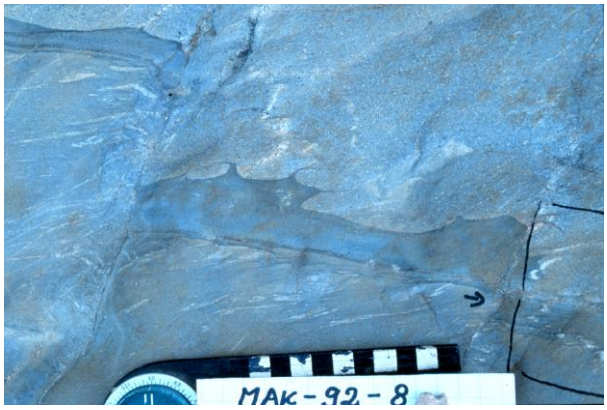

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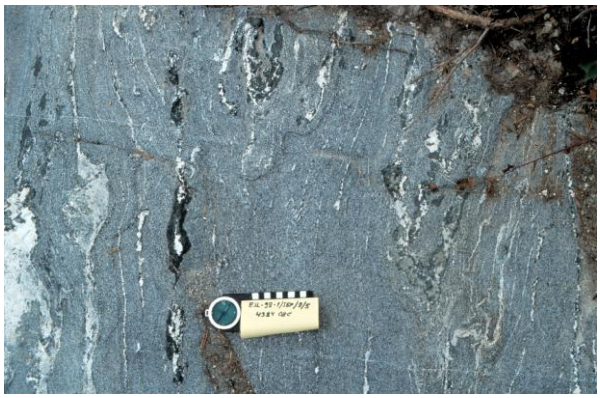


F

Fig. 3h. Images from outcrops in the Kuhmo area.

A. Volcanogenic graded bedding in greywacke-mica schist of Ontojärvi basin, Petäjäniemi, Kuhmo. Photo E. Luukkonen.

B. Volcanogenic graded bedding in greywacke-mica schist of Ontojärvi basin, Petäjäniemi, Kuhmo. Photo E. Luukkonen.

C. Deformed and graded bedding in mica schist of Ontojärvi basin, Petäjäniemi, Kuhmo. Photo E. Luukkonen.

D. Proterozoic metadiabase dyke containing late Archaean mylonite fragment, Jousijärvi, Kuhmo. Photo E. Luukkonen.

E. Highly altered banded amphibolite, Sepponen, Kuhmo. Photo E. Luukkonen.

F. Outcrop of the Sepponen gold mineralization, Sepponen, Kuhmo.

3.1.1. Exploration targets and areas studied in the Suomussalmi greenstone belt

Because of remote location and in the past, limited road access, the Suomussalmi greenstone belt had not been mapped in detail, although the results of reconnaissance bedrock mapping were published in the Geological Survey of Finland 1: 400 000 geological map series by Matisto (1958). More detailed lithological maps, of the greenstones in particular, were produced in 1981 by the Kuhmo Ore Geology Project, undertaken by the University of Oulu and based to a large extent on exploration mapping by Kajaani Oy (Taipale and Tuokko, 1981). Nevertheless, it was considered necessary for the purposes of the present research project to thoroughly revise earlier studies, by detailed outcrop mapping at 1: 20 000 and in some area, 1: 10 000 scale. Of the 2472 outcrop observations recorded from the Suomussalmi greenstone belt and surroundings granitoids, 2119 observations were made during the course of the current project, between 1992 and 2000. In areas of poorer exposure, or of potential mineralization, supplementary shallow POKA and deeper diamond drilling was undertaken. Geophysical surveys were also carried out in a number of areas. The areas investigated, including exploration targets, are indicated in Figures 2.2.2.1a, 2.3.4a and 3b.

It had long been known that the nickel sulfide mineralization at Hietaharju and Peura-aho, discovered by Outokumpu Oy in the 1960's, were associated with basaltic komatiitic cumulates. More detailed study of the Suomussalmi greenstone belt during this project resulted in the delineation of a further zone some 15 km in length and 0.5 km wide, containing komatiitic olivine cumulates and passing through Portti, Vaara, Rytys, Hoikkalampi and Kauniinlampi (Figure 3.1.1a). The first indications of disseminated nickel sulfide mineralization were found within this komatiitic zone during the first POKA and deep diamond drilling investigations. Further drilling led to the discovery of three separate nickel occurrences within cumulate lenses at Kauniinlampi and also the mineralized cumulate lense at Vaara. Despite this encouraging start, no massive sulfide lenses were discovered at this stage of the project. At the same time, the nickel potential of the Huutoniemi and Härkövaara komatiitic olivine-pyroxene cumulate bodies was assessed, with essentially negative results.

Exploration for gold in the Suomussalmi greenstone belt had already commenced in 1990, on the basis of a mineralized sample containing arsenopyrite, sphalerite and galena from the Iso Housuvaara area, which had been found and submitted to GTK by Väinö Kemppainen, a district forestry manager and amateur prospector. Investigations were at first focused entirely on the Tormua branch of the Suomussalmi greenstone belt, but later expanded to cover the whole belt. The gold occurrences identified by GTK are all located within or proximal to prominent high-strain zones (Figure 3.1.1b).

3.1.1.1. Tormua schist belt

Due to its remote location and rather poor road access, the Tormua schist belt had not previously been studied in detail; results of reconnaissance geological surveys had been published in the Geological Survey of Finland 1: 400 000 bedrock geological map series (Matisto 1954, 1958) and the somewhat more detailed lithological map prepared during the Oulu University Kuhmo Ore Geology Project only extended as far west as the village of Tormua (Taipale and Tuokko, 1981). On the basis of high-altitude airborne geophysical data, it was inferred that the Tormua schist belt continued eastwards across the national border into adjacent Russian Karelia.

The supracrustal rocks of the Tormua schist belt have either intrusive or tectonically defined contacts with the surrounding granitoids and migmatitic gneisses. The area which appears to be most prospective for gold, near the village of Tormua, has an E-W strike trend and is nearly 3 km wide. The Tormua belt continues eastwards as far as Lauttalampi (refer to geological map in Ap-

pendix 3) before a sharp change in trend, just before the restricted border zone at the Russian frontier. From here the schist belt trends northwards, gradually tapering to a width of about 1.5 km; some 10 km further north, near Matalajoki, the belt narrows even further, and is difficult to identify in outcrop. Low-altitude airborne magnetic surveys flown by GTK in 1996 nevertheless indicate that greenstone belt lithologies occur within a narrow belt extending northwards as far as Näränkävaara.

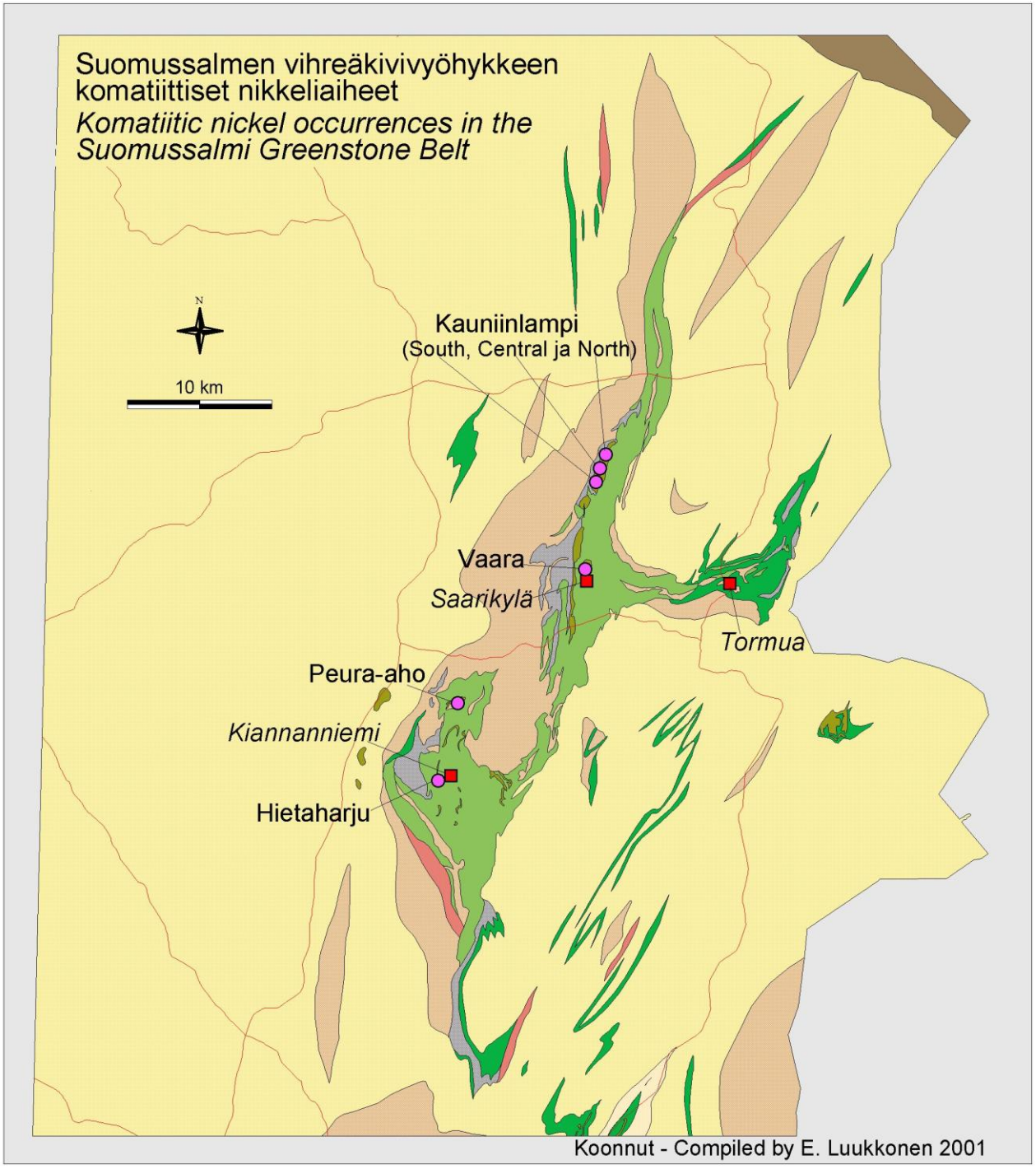


Fig. 3.1.1a. Komatiitic Komatiitic-hosted nickel mineralization occurrences in the Suomussalmi Greenstone Belt.

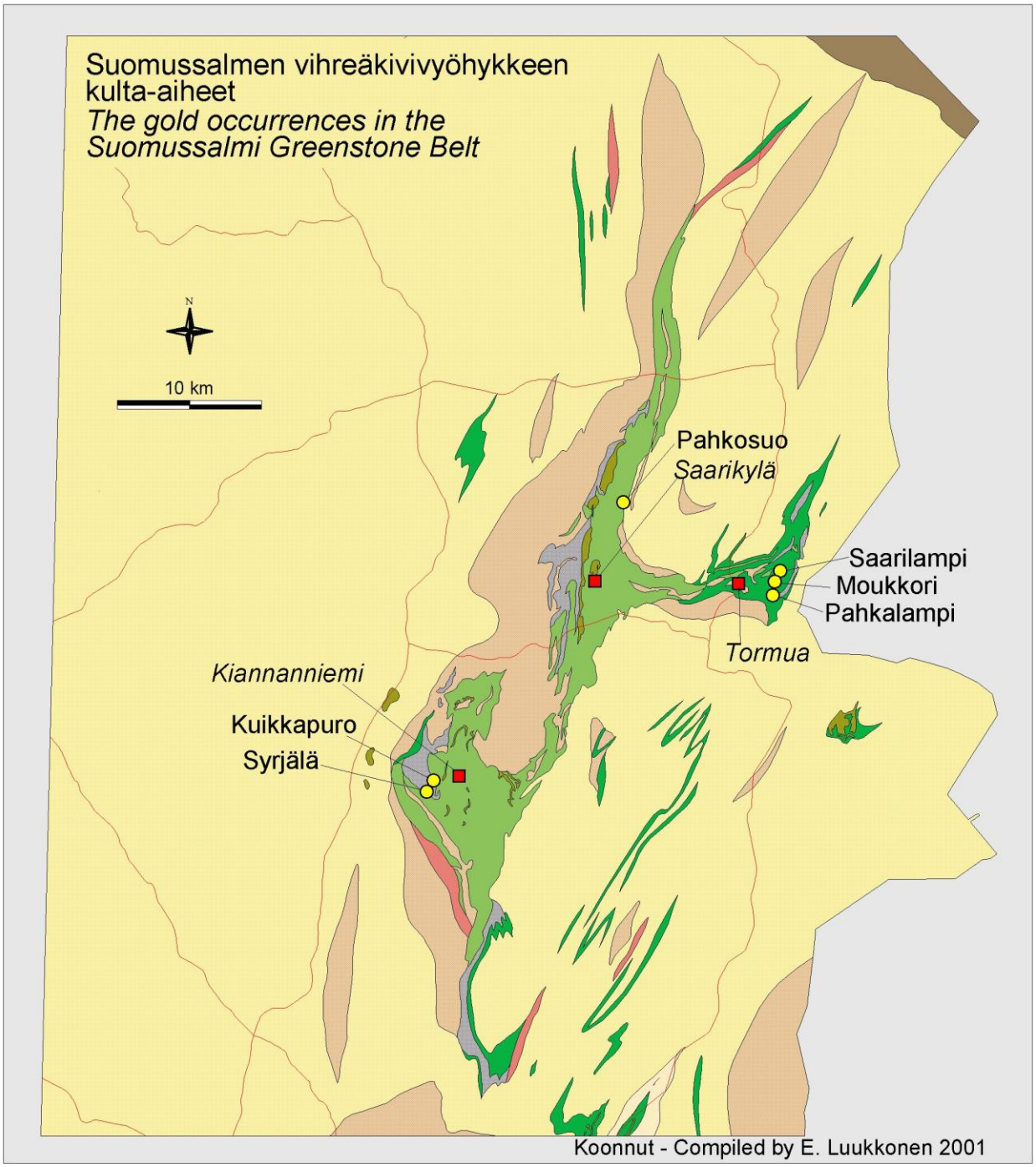


Fig. 3.1.1b. Occurrences of gold mineralizations in the Suomussalmi Greenstone Belt.

The Tormua belt is both lithogically diverse and structurally complex. Much of the belt consists of rocks correlated with the Luoma Group, which are older than the main tholeiitic and komatiitic volcanics of the Suomussalmi greenstone belt. Tholeiitic banded amphibolites and intermediate and felsic volcanics predominate but due to intense deformation and high grade metamorphism, primary textures are only seldom discernible. Sporadic relict features in the banded amphibolites indicate that they were probably massive and pillowed tholeiitic basalt flows while the banded intermediate and felsic rocks were probably stratified volcaniclastic deposits.

Less abundant rock types include uralitic porphyries, metapyroxenites and serpentinites that may be correlated on the basis of geochemistry with the tholeiites and komatiites of the main part of the Suomussalmi greenstone belt. The uralitic porphyries may represent either a laminar flow

regime in tholeiitic lava flows or disrupted segments of differentiated sills; the latter interpretation is favoured by the presence of deformed intrusive contact relationships and the absence of features typical of lavas, such as amygdales and hyaloclastic textures. The serpentinites and associated metapyroxenites are most probably the deeply eroded and fragmentary remnants of channelized komatiitic flows. Intercalated metasediments and graphite- and sulfide-bearing amphibolites are presumably products of erosion of intermittently emergent volcanic edifices.

Granitoids, including leucotonalites, granodiorites, plagioclase porphyries and quartz porphyries, accompanying the 2 700 Ma D_3 tectonic event, intrude the older supracrustal association (predating the main tholeiitic and komatiitic volcanism) in many places but demonstrably intrusive contacts between the granitoids and the uralite porphyries, metapyroxenites and serpentinites have not been recorded. However, elsewhere in the Suomussalmi greenstone belt the komatiites and tholeiites are clearly truncated by D_3 granitoids.

The Tormua schist belt was intensely deformed during the Neoarchean D_3 – D_4 tectonic events, which commenced with the formation of ductile structures, including predominantly dextral sense folding and a pervasive N-S trending axial planar foliation, except in the area between Tormua and Lauttalampi, where trends are nearly E-W. Similarly, intense strain partitioning expressed as N-S shear zones in much of the belt curve into an E-W orientation between Tormua and Lauttalampi; these discrete deformation zones are considered to have been the loci of hydrothermal fluid flow during later stages of deformation, resulting in alteration expressed by the formation of K-feldspar, biotite and sericite.

The P-T conditions recorded by the garnet-bearing amphibolites of the Tormua schist belt have been determined, although interpretation is complicated by the occurrence of several phases of garnet growth. Maximum pressures for D_3 garnet-amphibolite mineral pairs were estimated at 5 kbar, at temperatures of 600º C but it was not possible, due to the intense D_3 overprint, to establish earlier P-T conditions (Matti Pajunen, personal communication). The D_3 structures are overprinted and truncated by predominantly NW-SE trending D_4 structures that typically show dextral sense (with sporadic conjugate NE-SW foliation and sinistral fold trends), and tend to be more brittle-ductile in character than the D_3 structures. At outcrop scale the D_4 structures may form interference patterns with D_3 structures are often deflected into the more intense D_3 deformation zones, and, thus explaining why the latter sometimes seem to be show uncharacteristic brittle features and thus making it difficult to distinguish between D_3 and D_4 structures. The D_4 event evidently represented retrograde conditions with respect to the D_3 metamorphic peak and is commonly associated with chlorite and epidote. It is most likely that gold was introduced during this transition from predominantly ductile D_3 to the more brittle regime characteristic of D_4 deformation. Younger, weakly expressed brittle D5 an D6 deformation events are unlikely to have been significant with respect to gold introduction or mobilization.

An E-W trending Paleoproterozoic mafic dyke abruptly truncates rock units and foliations of the Tormua schist belt at Pieni Housuvaara, demonstrating that Proterozoic tectonic overprinting is minimal and that there is no significant reactivation and remobilization of gold in the Suomussalmi greenstone belt.

Titanite from the Moukkori gold occurrence has been dated with the U-Pb method to 2680 Ma (refer to Section 2.6.1), which is typical for Archean gold mineralization in eastern Finland.

The Tormua schist belt and its surroundings were mapped at 1: 10 000 scale during the current project, and extensive ground geophysical surveys (MaxMin, Slingram and total magnetic intensity) were undertaken throughout the area (Figure 2.2.2.1a and Table 2.2.2.1a). The lack of comprehensive airborne coverage at the time of mapping necessitated additional ground surveys,

in particular the IP (Induced Polarization) method, which was very effective in delineating zones of disseminated sulfides. Systematic IP measurements were accordingly undertaken at the Maaselänvaara, Pahkalampi and Moukkorinaho gold prospects and more generally in the Housuvaara and Saarilampi areas (Figure2.2.2.1a and Table 2.2.2.1a).

Reconnaissance (16 samples/km2) geochemical sampling of basal till and bedrock was also undertaken over the schist belt, revealing a number of distinct anomaly patterns with respect to Au, Te and As, each of which corresponded to deformation zones defined by either bedrock mapping or ground-based geophysics. Therefore, detailed follow-up geochemical surveys were made during several stages of investigation at over the more interesting anomalies at Isosuo, Housuvaara/Saarilampi, Moukkori, Lahna-aho and Pahkalampi/Lauttalampi. The results of analysis of gold from till are shown in Figure 3.1.1.1.1, while further selected data are presented in tables in Appendix 1. The locations of the individual targets are indicated in Figure 2.3.4a.

The abundance and distribution of detrital placer gold grains in till was also evaluated by panning. Together with integration of geophysical data with geological interpretations based on detailed outcrop mapping, this resulted in an improved picture of the structures controlling mineralization the Tormua schist belt.

3.1.1.1.1. Saarilampi gold occurrence

Anomalous gold concentrations were found during till geochemical surveys in the Saarilampi area (Figure 3.1.1.1.1). The highest gold value obtained (8210 ppb) was from a sample retrieved from the weathered bedrock interface to the northeast of Saarilampi. More detailed analytical results are shown in Appendix 1.

The till anomalies were subsequently tested with POKA bedrock drilling, with a total length of 1 106 m, from 18 holes (Luukkonen et al., 1997). However, because T46 drilling equipment was used, the relatively small sample sizes makes interpretation of analytical results somewhat uncertain. Drill hole locations are indicated on the map showing gold distribution.

Despite the promising till indications, the highest gold values analyzed from drill core were only 337 ppb over a one meter interval. If the basal till and weathered bedrock anomalous values are truly in situ, then it appears that there may have been some supergene enrichment in the regolith or fractured bedrock (Nikkarinen, 1991).

3.1.1.1.2. Moukkori gold occurrence

The impetus for investigations in the Moukkorin area was the finding of a mineralized glacial erratic by Väinö Kemppainen, a regional manager of forestry operations who has also been an enthusiastic amateur prospector. The sample submitted to the GTK by Kemppainen in 1989 was from the Iso Housuvaara area and contained arsenopyrite, sphalerite and galena. Subsequent fieldwork in this area by GTK staff during 1990 led to the fortuitous discovery of the Moukkori prospect in outcrop along the Moukkorikangas forestry road. Gold mineralization at Moukkori is associated with blue-gray quartz veins and epidote-quartz-biotite-sericite alteration within an mafic uralitic porphyry (Figures 3f A-C). An systematic VLF-R survey was undertaken in 1,5 km^2 area surrounding the mineralized outcrop in order to better delineate the structural geometry and the trend of the quartz veins. The possible continuation of the mineralized zone was also traced with detailed IP surveys.

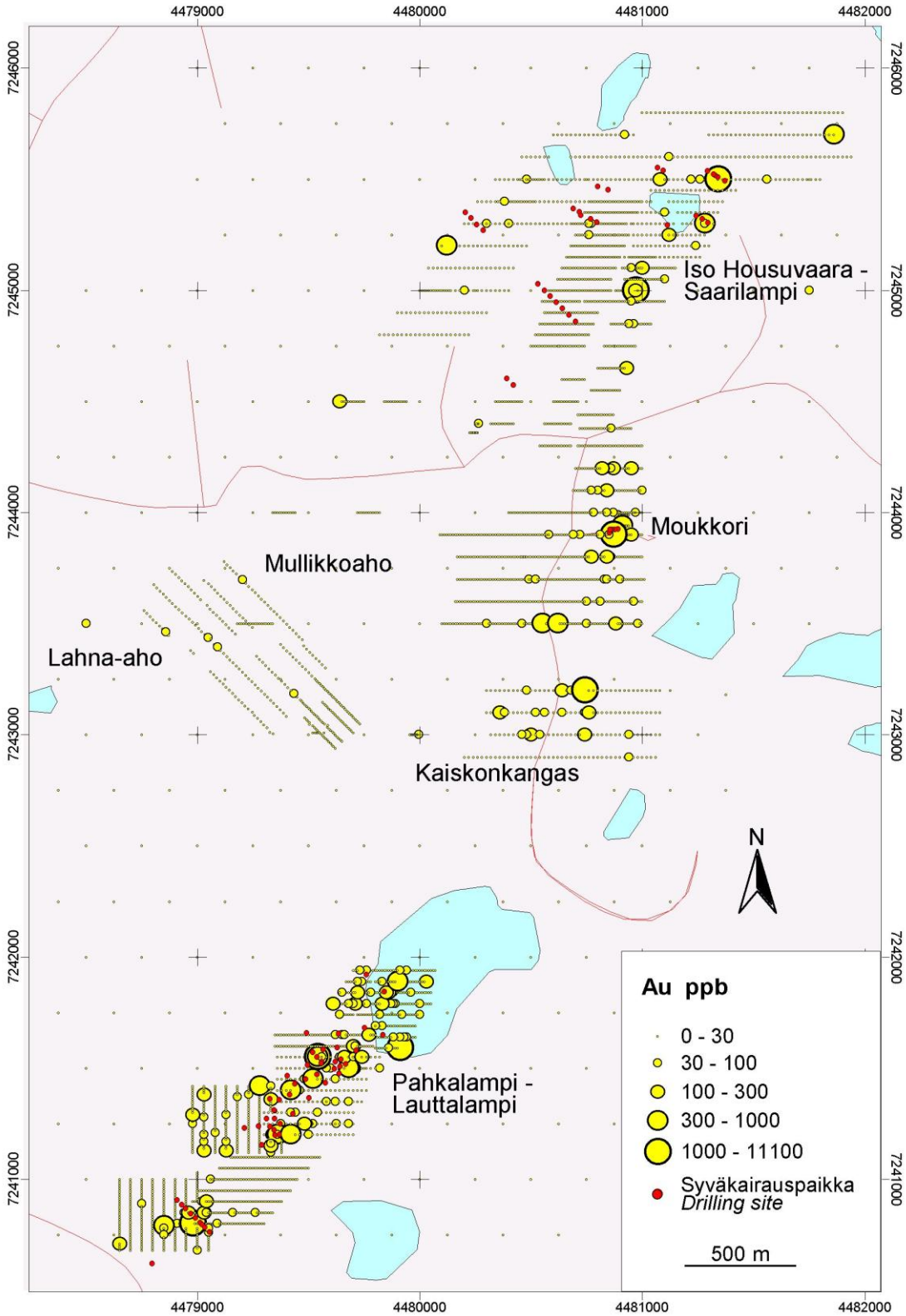


Fig. 3.1.1.1.1. Gold concentrations in till and weathered bedrock samples taken during detailed scale surveys between Lauttalampi and Saarilampi areas, Tormua schist belt, Suomussalmi.

Extensive till sampling was carried out at the Moukkori, Kaiskonkangas and Lahna-aho occurrences (Figure 3.1.1.1.1) and delineated an anomalous zone, with the highest value of 1960 ppb being located directly over the mineralized Moukkori outcrop. Selected analyses of basal till fine fractions and material from the weathered bedrock interface are reported in Appendix 1.

Bedrock drilling at Moukkori revealed three distinct parallel auriferous quartz vein systems that are aligned parallel to a second order (Riedel-R) fracture network and chevron fold sets within a generally N-trending D_3 deformation zone. Mineralized quartz veins also tend share the regional steeply plunging mineral lineation. Outcrop measurements and drill core observations both constrain the geometry of the mineralized zone, with a dip of 42º - 45º towards the south. However, orientations may well change over short distances, as the Archean D3 structures in this area have been strongly overprinted by NW-SE trending (and less commonly, conjugate NE-SW trending) D_4 structures. At present there is insufficient information to verify this possibility due to the paucity of outcrop and the lack of drill holes to the north and south.

In outcrop, as in drill core, gold is paragenetically associated with pyrrhotite, marcasite, pyrite, sphalerite, galena and chalcopyrite, all occurring within dark blue-gray vein quartz and to a lesser extent, in hydrothermally altered fracture zones and felsic veins (Luukkonen et al., 1997). Intense alteration is characterized by quartz, sericite, biotite, chlorite and epidote, while carbonate minerals are only observed in close proximity to gold-bearing veins. Accessory minerals found sporadically with gold include a number of telluride phases containing bismuth, lead, silver and silver-gold alloys, as well as ilmenite, scheelite, rutile and goethite (cf. Chernet, 1994).

Approximately 80% of gold observed is as free grains or fracture fill, with Ag contents varying between 6 –13 %. The remaining 20% of gold analyzed contains 18 –22 % Ag, and occurs principally as inclusions within pyrhhotite, galena, pyrite, tellurides and chalcopyrite. Gold grains typically range in size from 1 µm - 1 mm, the mean diameter being 25 µm. Larger nuggets occur almost exclusively within quartz veins or pervasively silicified host rocks, whereas most of the smaller grains occur as inclusions within pyrite and other sulfides, or in fractures and at grain margins. Microstructural paragenetic studies indicate that pyrrhotite and pyrite formed early, followed by sphalerite, galena, a younger generation of pyrite and mono- and sub-tellurides. Gold crystallized or exsolved latest, together with monotellurides (cf. Chernet, 1994).

Preliminary fluid inclusion studies on mineralized quartz veins from Moukkori were made in collaboration with Dr Matti Poutiainen of the Department of Geology, Helsinki University and in indicate that fluids precipitated and equilibrated at various stages under a range of conditions. From oldest to youngest, the following sequence has been defined (cf. Poutiainen and Luukkonen, 1994):

1. CO_2 –rich fluid inclusions (ca. < 20 volume % H_2O, > 50 mol % CO_2 and 10 mol % CH_4; no daughter phases; homogenization temperature ca. 160º - 300º C , generally between 220º - 280º C).
2. $H_2O \pm CO_2$ –rich fluid inclusions (< 35 mol % CO_2; daughter phases include carbonate, mica and opaque minerals; homogenization temperature 160º - 315º).
3. Saline H_2O –fluid inclusions (daughter phases halite and 1 - 2 unidentified anisotropic minerals; homogenization temperatures 30º - 90º C; unrelated to mineralization processes).

The evolutionary trend inferred for fluid compositions under decreasing temperature conditions is as follows:

a) Decrease in CO_2 – and CH_4 -concentration (= transition from reducing to oxidizing environment >>> destabilization and exsolution of gold complexes from solution ??).

b) Increase in salinity, which is apparently unrelated to gold mineralizing processes.

All of the above evidence suggests that the gold mineralization at Moukkori formed after regional peak metamorphism, under thermally retrograde conditions, probably near the transition from amphibolite to greenschist facies conditions, corresponding to a stress regime consistent with oscillating brittle and ductile behaviour.

3.1.1.1.3. Pahkalampi gold occurrence

The Pahkalampi gold occurrence was found on the basis of systematic local and detailed till geochemical surveys, after which detailed follow-up sampling was undertaken (Figure 3.1.1.1.1). The area was considered to be highly anomalies with respect to gold, for concentrations exceeded 1000 ppb in many samples. Selected analytical results are reported in Appendix 1.

Drilling was undertaken at various stages, using the T46 POKA equipment for shallow exploratory holes and T56 and reverse circulation rigs for deeper holes (Luukkonen et al., 1997). Correlation of results from different profiles and using the different drilling equipment was surprisingly good. A total of 42 holes were drilled with a combined length of 4 249 m; locations are indicated on the map displaying gold concentrations of till samples.

Gold at Pahkalampi tends to be fine-grained (diameter < 15 µm, commonly < 5 µm) and either pure or mixed with silver (Ag content 6 – 30 %). Some gold is also intergrown with tellurides and both may occur as inclusions within pyrite, albite and K-feldspar, or at the margins of pyrrhotite grains (Kojonen et al., 1996).

Gold mineralization occurs typically within dark blue-gray quartz veins but is also common within altered, sericitic and strongly epidotized amphibolites, granitic veins and highy fractured tourmaline leucogranodiorite and leucogranite. Auriferous zones are typically associated with weak disseminations of pyrrhotite, chalcopyrite and pyrite, as well as ilmenite, sphalerite, galena and cobaltite. Other minerals include different types of tellurides, arsenopyrite, löllingite, tourmaline, scheelite, rutile and titanite.

Mineralization at Pahkalampi appears to resemble that at Moukkori in having formed after the metamorphic peak, under lower amphibolite facies conditions. At Pahkalampi however, the mineralization is evidently aligned within several pipe-like bodies showing metasomatic alteration and sulfide dissemination. On the basis of drill core and outcrop observations, the pipes plunge at about 52º - 60º towards the NE.

3.1.1.1.4. Other gold prospects in the Tormuan schist belt

Drilling in the Iso Housuvaara, Kaiskonkangas and Mullikkoaho areas was restricted to several shallow POKA holes, using T46 drill bits, so that the interpretation of analytical data, based on small sample sizes, should be treated as qualitative and subject to uncertainty (Luukkonen et al., 1997). Locations of gold occurrences are shown in Figure 2.3.4a, and POKA drill hole locations are marked on the map showing regional gold concentrations (Figure 3.1.1.1.1).

A single POKA hole was drilled at Iso Housuvaara and gold concentrations remained below detection limits throughout, although telluride concentrations were as high as 1630 ppb over a one meter interval. At Mullikkoaho, gold concentrations of 908 ppb and 818 ppb averaged over one

meter intervals were obtained, with maximum tellurium values of 7900 ppb and arsenic values of 1080 ppm. Corresponding maximum gold abundances at Kaiskonkangas were 138 ppb, with tellurium values reaching 354 ppb.

3.1.1.2. Saarikylä area

The Saarikylän area (Figures 2.3.4c and 3b) is about 65 km north of the town of Suomussalmi and lies within the northern part of the N-S trending Suomussalmi greenstone belt, which has a total length of about 50 km and maximum width of nearly 10 km.

Mapping during the present project indicated that the oldest rocks in the Saarikylä area represent the lowermost stratigraphic succession within the Suomussalmi greenstone belt, consisting of 3 000 Ma – 2 800 Ma felsic, intermediate and mafic volcanics and volcaniclastic sediments, in many places containing sulfides. These rocks were overlain by 2 800 Ma – 2 760 Ma komatiitic volcanics, which consist principally of komatiitic olivine meso- and adcumulate lenses (refer to Section 3.1.1.2.5). Komatiitic volcanism was followed by the eruption of komatiitic basalts and a distinctive basalt suite that is exceptionally enriched in Cr (450 – 900 ppm). The youngest stratigraphic unit consists of felsic to intermediate volcanics and volcaniclastic deposits, with sporadic graphitic slate intercalations. However, this stratigraphic sequence has been significantly disrupted by N-S trending deformation zones, resulting in isolated stratigraphic segments and intervening high-strain zones in which rock units are strongly transposed, rotated and faulted. The youngest significant fracture trend observed appears to be NW-SE in orientation.

Previous studies in the Saarikylä area include those of Engel and Diez (1989), which focused on lithogeochemistry and stratigraphic relationships, and Luukkonen and Halkoaho (1998), which was concerned with the Rytys komatiitic olivine cumulates. Geological and technical assessments of soapstone resources in the area were made by Leinonen (1992), Pekkala and Niemelä (1997) and Vauhkonen and Leinonen (1998). Chromite compositions of the Haaponen and Kivikangas ultramafic occurrences were reported by Liipo et al. (1994) and Liipo (1999), as described further in Section 2.6.2.3.2. The Zn-Pb-Ag-Au mineralization in the Ala-Luoma area has been investigated by Kopperoinen (1987), Kopperpinen and Tuokko (1988) and Diiez and Engel (1989) and the komatiitic olivine cumulate lenses in the Kaunislampi area were documented by Pakkanen and Luukkonen (1995) and Halkoaho et al. (1999).

3.1.1.2.1. Pahkosuo gold occurrence

Pahkosuo is situated within an extensive gold anomaly, to the north of Saarikylä and was discovered through local scale till geochemical surveys. Subsequent detailed till sampling was made at 10 m intervals with a 50 m line spacing (Tenhola et al., 2001), resulting in a total number of 783 samples. Of these, 65.6 % represented weathered and fresh bedrock material (Appendix 1), which thereby allowed accurate delineation of bedrock composition. The survey revealed an extensive anomalous zone, with numerous samples having Au values in excess of 1000 ppb (Figure 3.1.1.2.1a). Highest gold abundances were obtained from weathered bedrock samples, indicating that the anomalies are indeed *in situ*.

Low-altitude airborne geophysical coverage of the Pahkosuo area included total magnetic intensity, and Slingram EM measurements, as well as radiometric surveys with total gamma radiation, and uranium, thorium and potassium components. Ground-based IP surveys were made with Scintrex IPR-10/IPC-8 and SGU RIPS-2/RIPT-30 equipment and some 4 line kilometers of electromagnetic VLF-R measurements were carried out on a trial basis. Petrophysical properties, including density, susceptibility and remanence were recorded from selected drill core material; more detailed descriptions of geophysical techniques are presented in Tenhola et al. (2001).

The IP survey results are shown in Figure 3.1.1.2.1b, revealing an intense anomaly that coincides with the distribution of anomalous gold in weathered bedrock. Geochemical and geophysical interpretations were thus useful in determining drilling targets. A total of 62 holes were drilled in the Pahkosuo area between 1995 and 1998, with a total length of 4732 m (Tenhola et al., 2001). Apart from 19 reverse circulation holes, most holes were drilled with POKA equipment using T46 and T56 drill bits and results using both sizes seem to be comparable. Locations of drill holes are shown on the IP map (Figure 3.1.1.2.1b).

Elevated gold abundances were found in many different rock types, all of which are characterized by intense hydrothermal alteration and deformation. In mafic volcanic rocks, gold occurs within silicified shear zones that contain abundant biotite, sericite and carbonate; chlorite and epidote alteration is also typical. Sulfidation is intense at the margins of mineralized quartz veins and alteration zones, with sulfide phases including pyrrhotite, pyrite and to a lesser extent, arsenopyrite.

Leucogranitoid and quartz porphyry dykes are abundant throughout the Pahkosuo area and are also sporadically associated with elevated gold abundances, in which case they are also intensely sericitic and contain disseminated pyrite. Fine-grained felsic dykes are also common, transecting both mafic volcanics and granitoids, with sharp, though strongly sheared contacts; these dykes may represent textural variants of the leucogranitoid and quartz porphyry dykes, but in some cases may be hydrothermal in origin, representing high-strain alteration zones. It is of interest to note that the area containing abundant dykes coincides closely with that of anomalous gold concentrations.

Gold grades in excess of 1 ppm were recorded from 31 drill holes, although in most cases anomalous intervals are less than one meter. In several holes, elevated gold was found over 1 – 5 m sections, the highest mean value being 1.7 ppm over 5 m, with a maximum value of 2.81 ppm. Potential resources at Pahkosuo were estimated at 97 785 t Au, with a mean grade of 1.55 ppm, assuming a cut-off limit of 0.5 ppm (Heino, 2001).

3.1.1.2.2. Ala-Luoma gold occurrence

The Ala-Luoma gold occurrence is also located near Saarikylä, within the central part of the Suomussalmi greenstone belt (20 000 mapsheet FIN_KKJ 4513 03). Attention was primarily drawn to the area after regional and local till geochemical mapping, although visible gold had previously found in quartz veins outcropping on the shores of the lake Ala-Luomajärvi. Drill hole R522 was subsequently drilled at this latter location.

The Ala-Luoma area is situated at the western margin of the greenstone belt, in an area dominated by 3 000 Ma – 2 800 Ma felsic and mafic volcanics and volcaniclastic sediments assigned to the Luoma Group (Luukkonen 1992, Luukkonen and Lukkarinen 1986, Taipale 1983b). However, in a profile drilled from west to east across the Ala-Luoma area, the Luoma Group is represented by phyllitic and graded turbiditic sediments, whereas the eastern part of the profile intersected tholeiitic lavas and komatiites of the Saarikylä Group, as well as soapstones, belonging to the younger phase of greenstone belt volcanism. The contact between these two rock units is a zone of high strain, which was intersected in drill hole R525, towards the eastern margin of the drilling profile (Figure 3.1.1.2.2). All Archean rock units have been strongly deformed, being intensely foliated and folded, with N-S trending high strain zones disrupting and obscuring primary stratigraphic relationships.

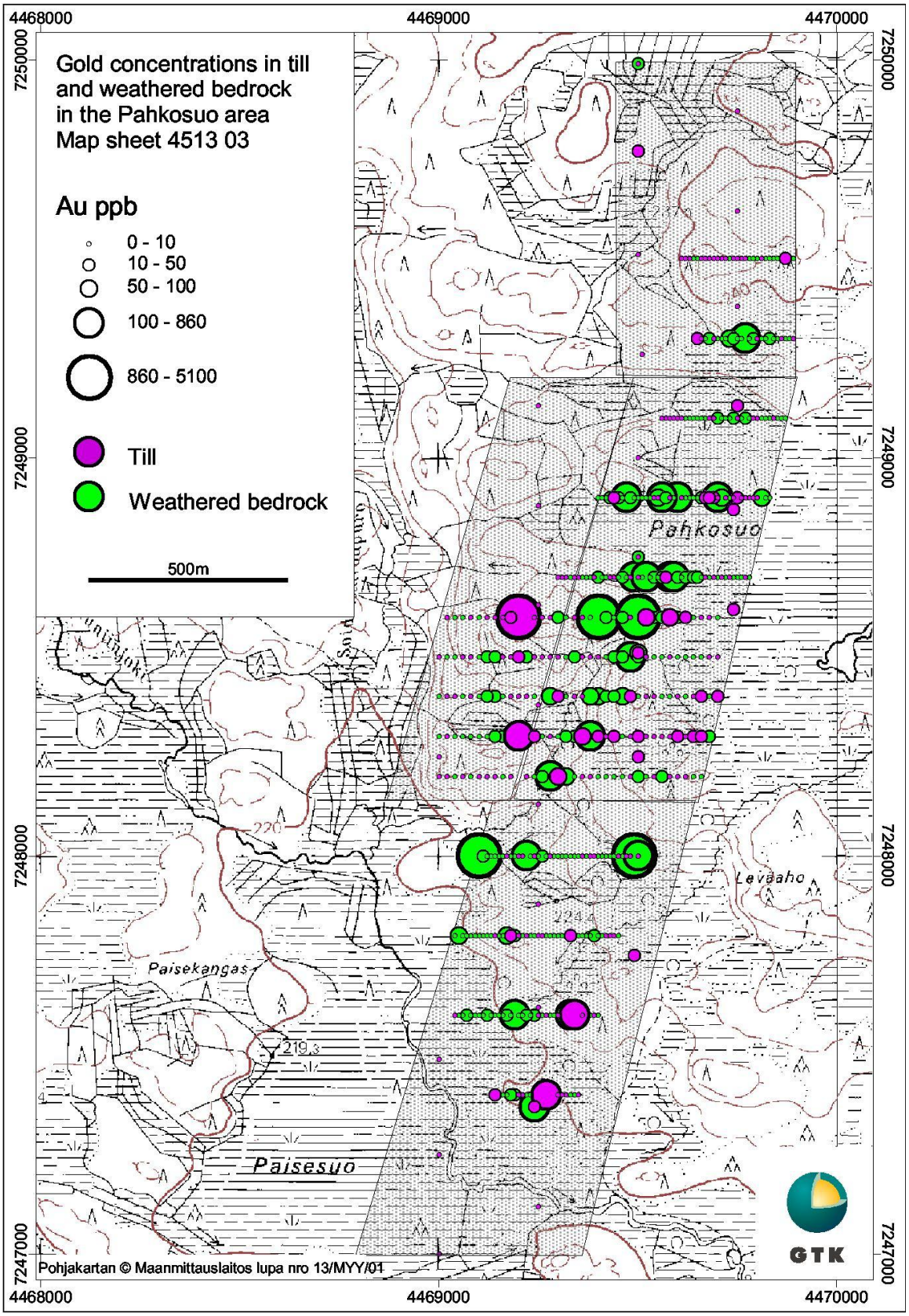


Fig. 3.1.1.2.1a. Gold concentration in till and weathered bedrock samples taken during detailed scale surveys in the Pahkosuo area, Suomussalmi.

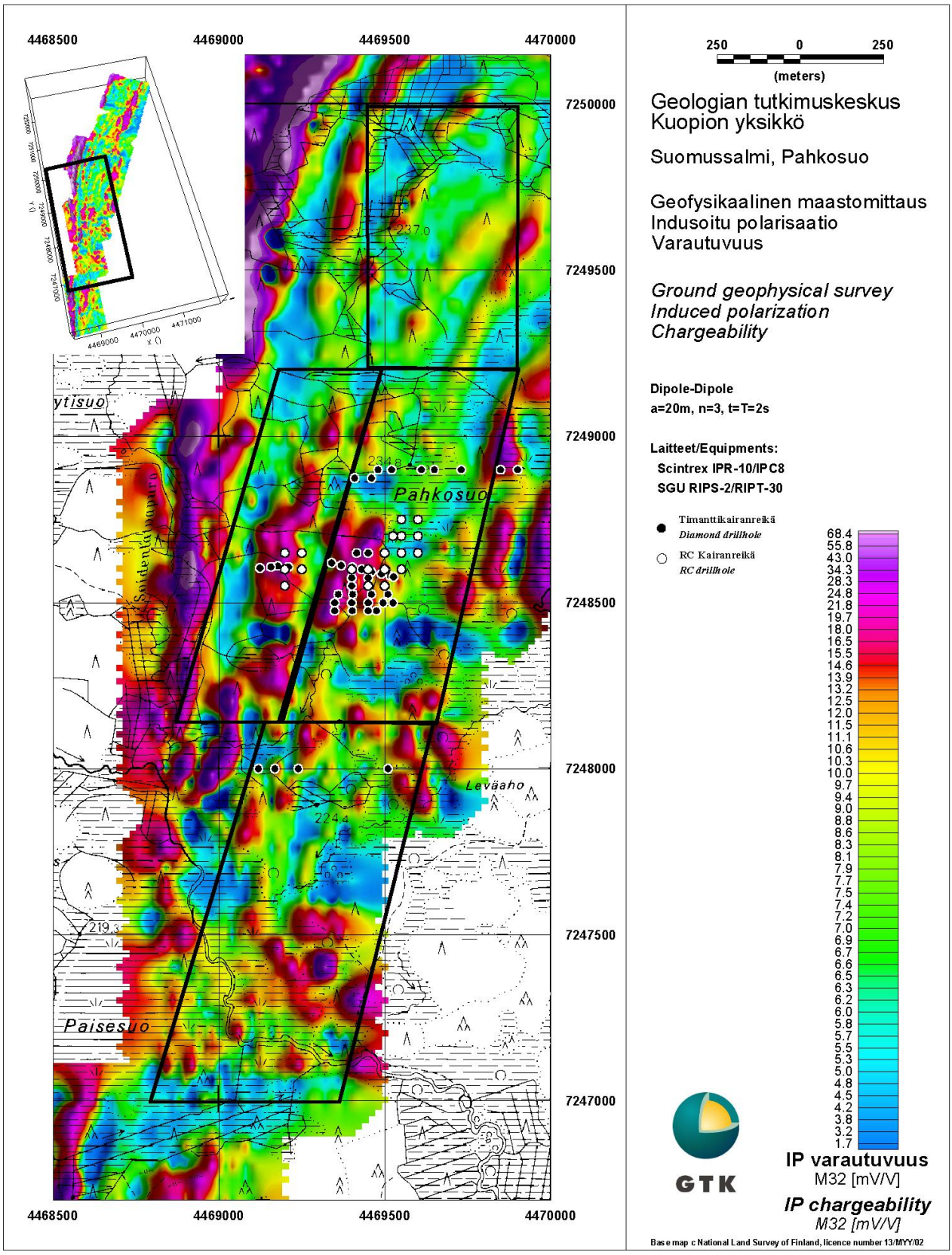


Fig. 3.1.1.2.1b. IP-chargeability anomalies in the Pahkosuo area, Suomussalmi.

A swarm of undeformed Paleoproterozoic mafic dykes transects all Archean rock units, with a NW-SE or E-W trend readily discernible from their signatures in airborne maganetic data; dykes have also been observed on outcrop on the shores of the lake Ala-Luomajärvi.

The Ala-Luoma area has been surveyed extensively. Airborne geophysical surveys, flown in 1977, included magnetics, Slingram EM and total gamma radiation, along E-W profiles, spaced at 200 m, with a recording interval of 28 m. Results of glacial boulder prospecting, till geochemical surveys and detailed outcrop mapping have been reported elsewhere, so that this summary relates primarily to the results of drilling surveys.

Petrophysical properties (density, remanence magnetism, susceptibility and electric conductivity, at 3 frequencies) from a total of 63 samples from drill holes R522 – R525 were measured in the laboratory. This permitted petrophysical characterization of Luoma Group rock types, with results being shown in Table 3.1.1.2.2.

A total of four holes with a combined length of 275.0 m were drilled using GTK POKA equipment, with a T56 diameter drill bit. Drill core was analyzed for gold using a graphite absorption spectrometry (GFAAS), with a total of 233 analyses, with an additional 118 ICP-AES base metal determinations. The first hole (R522) was drilled at an angle of 45°, some 10 m to the east of the outcrop containing visible gold, in order to intersect the mineralized quartz veins. After logging and splitting the core, Au and base metal analyses were made, mostly from one meter intervals and using 5 g sample fractions. Gold concentrations were below 0.3 ppm, generally around 0.01 ppm, except for the interval between 118.40 – 19.40 m, in which the first analysis gave a mean value of 1.36 ppm. However, subsequent analysis with a 20 g fraction failed to replicate this anomalous value, the mean value being only 0.02 ppm. The drill core consisted almost entirely of distinctly banded and sometimes graded fine-grained phyllitic sediments, varying from dark green to pale gray, depending on the grain size and relative proportions of chlorite and sericite. These latter sericitic and chloritic zones were also characterized by the presence of sphalerite, galena and small amounts of chalcopyrite, as well as pyrite, occurring as weak disseminations or within fractures and quartz veins. Sulfide minerals were more abundant in the interval between 17.40 – 32.40 m although Zn concentrations, for example, did not exceed 0.75 % and were generally in the range 0.13 – 0.31 %.

An E-W trending profile defined by three holes was drilled 50 m to the south of drill hole R522 (Figure 3.1.1.2.2). Drill holes R523, R524 and R525, from a depth of 31.00, all intersected phyllitic sediments similar to those in drill hole R522, thereby establishing the continuity of this rock type with some degree of confidence in the western part of the area. Sphalerite and galena were observed in drill hole R523 between 30.20 – 33.20 m (with Zn concentrations over respective one meter intervals of 0.15 %, 3.29 % and 0.20 %) and between 54.20 – 60.20 m, for which the mean Zn value was 0.28 % Zn, ranging from 0.16 – 0.65 %. Gold abundances in the phyllitic rocks were generally less than 10 ppb, except between 9.00 – 10.00 m in drill hole R524, where the mean value was 0.39 ppm (based on a 5g sample fraction).

The western part of the profile (between 14.90 – 31.00 m in R525) consisted of sheared mafic volcanics, while the remainder of the hole intersected soapstone, which is evidently the same lense that has intermittently been quarried some 200 m to the south of the drilling profile. The western margin of the soapstone is highly sheared and the mafic volcanics include a single anomalous interval averaging 1.39 ppm (based on a 5g sample fraction) between 24.90 – 25.90 m. Again, replication of this analysis using a 20 g fraction resulted in a much more modest anomalous value of only 0.02 ppm.

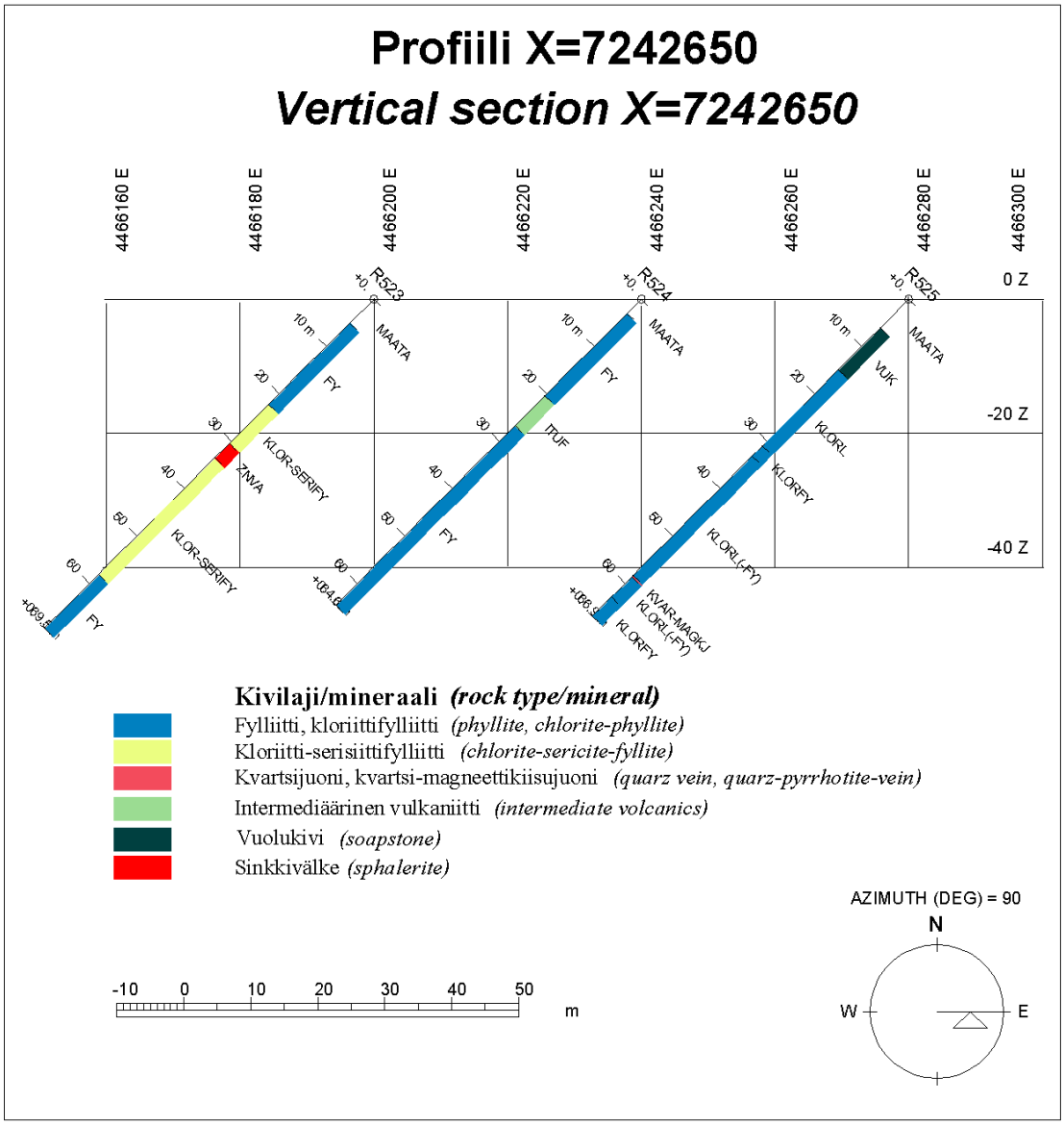


Fig. 3.1.1.2.2. Vertical section based on the drilled profile R523 - R525 at the Ala-Luoma gold exploration target,, Suomussalmi.

Of these drill hole intersections, only the upper part of R525 revealed any potential economic interest, since the soapstone is likely to be contiguous with outcrops further south, and this is only one kilometer from the active soapstone quarrying and processing operations. A report of the Ala-Luoma investigations was formally lodged with then Ministry of Trade and Industry in 2001 (Pietikäinen and Niskanen 2001b).

Table 3.1.1.2.2. Petrofysical properities of the Luoma group.

	Average value	***Standard deviation***	***Range***
*Susceptibility (SI*10^6)*	530	710	100 - 4940
Density (kg/m^3)	2770	65	2646 - 3049
Remanence (mA/m)	210	670	10 - 4720
Resistivity 0.1 Hz (ohm m)	4000	3000	542 - 17300

3.1.1.2.3. Paskolampi gold occurrence

The Paskolampi gold occurrence is also situated in the northern part of the Suomussalmi greenstone belt near Saarikylä, to the south of Saarijärvi (FIN_KKJ mapsheet 4513 03). Initial indications of gold potential came from regional and local till geochemical surveys. Anomalous gold concentrations were both found to be both higher and more extensive than those in the Moukkori and Pahkalampi areas in the Tormua schist belt, which were already known to be associated with gold in outcrop. Moreover, previous exploration activity by Otanmäki Oy in the 1960's and later by Kajaani Oy had provided some indications that the area might be prospective for gold.

The area has been investigated using a variety of methods, including airborne geophysical surveys, glacial boulder studies, till geochemistry and detailed outcrop mapping, the results of which can be obtained from the Geological Survey of Finland upon request. Ground geophysical surveys were undertaken in two stages, beginning with systematic induced polarization (IP) measurements, in order to delineate the potential distribution of rock units containing disseminated sulfides. However, due to the presence of strongly conductive horizons, the results of the IP surveys were not considered reliable. The next stage of investigations involved Slingram and magnetic surveys, which were successful in delineating conductive horizons and magnetically responsive rock units.

Slingram surveys were done using a GTK system with a coil separation of 60 m and a frequency of 14 kHz, with a line spacing of 50 m and measurements at 20 m intervals. The total area measured was 0.72 km^2 (780 points). Magnetic surveys were done with a proton magnetometer using the same profile spacing and as for the Slingram surveys, but with a point spacing of 10 m, resulting in a total of 1500 measurements.

The magnetic colored pixel images of magnetic anomalies proved particularly effective in delineating pyrrhotite-bearing horizons. The in-phase electromagnetic data are shown in the colored pixel image in Figure 3.1.1.2.3a; negative anomalies correspond to pyritic or pyrrhotitic and graphite-bearing conductors.

A total of 8 holes and 506.90 m of core was drilled during two separate drilling programs, using GTK POKA drilling equipment (Commando and GM100). A total of 264 gold analyses were made (GFAAS with aqua regia) as well as 67 base metal analyses (ICP-AES with aqua regia).

Rock types intersected during drilling fall into three broad categories and a representative profile section, based on drill holes R526 – R528, is shown in Figure 3.1.1.2.3b. The western part of the profile consists predominantly of mafic volcanics (basalts), the central part of fine-grained laminated and graded sediments (phyllites) and the eastern part, of ultramafic olivine cumulates that have been hydrothermally altered and metamorphosed to soapstone. All of these rock units are intensely deformed, generally with N-S trending foliations and are in places mylonitic, especially in the central part of the profile.

The mafic volcanics in the western part of the profile are intensely deformed, with a pervasive foliation and in the zones of highest strain, they may be described as chloritic phyllonites. The foliation is oblique to dilational carbonate vein arrays with an orientation suggesting, at least in the vicinity of R434, that the western side has slipped downwards with respect to the eastern side. Gold concentrations mostly remained below the detection limit (10 ppb), except in R526, in which the intervals from 41.30 – 42.30 m and 42.30 – 43.30 m contained 0.55 ppm and 0.13 ppm Au respectively, and in R432 between 41.00 – 42.00 m, where Au concentrations of 0.02 ppm were recorded. Each of these intervals was characterized by intense fracturing and loss of drill

core, suggesting that gold may have been introduced into these brittle deformation zones at a relatively late stage.

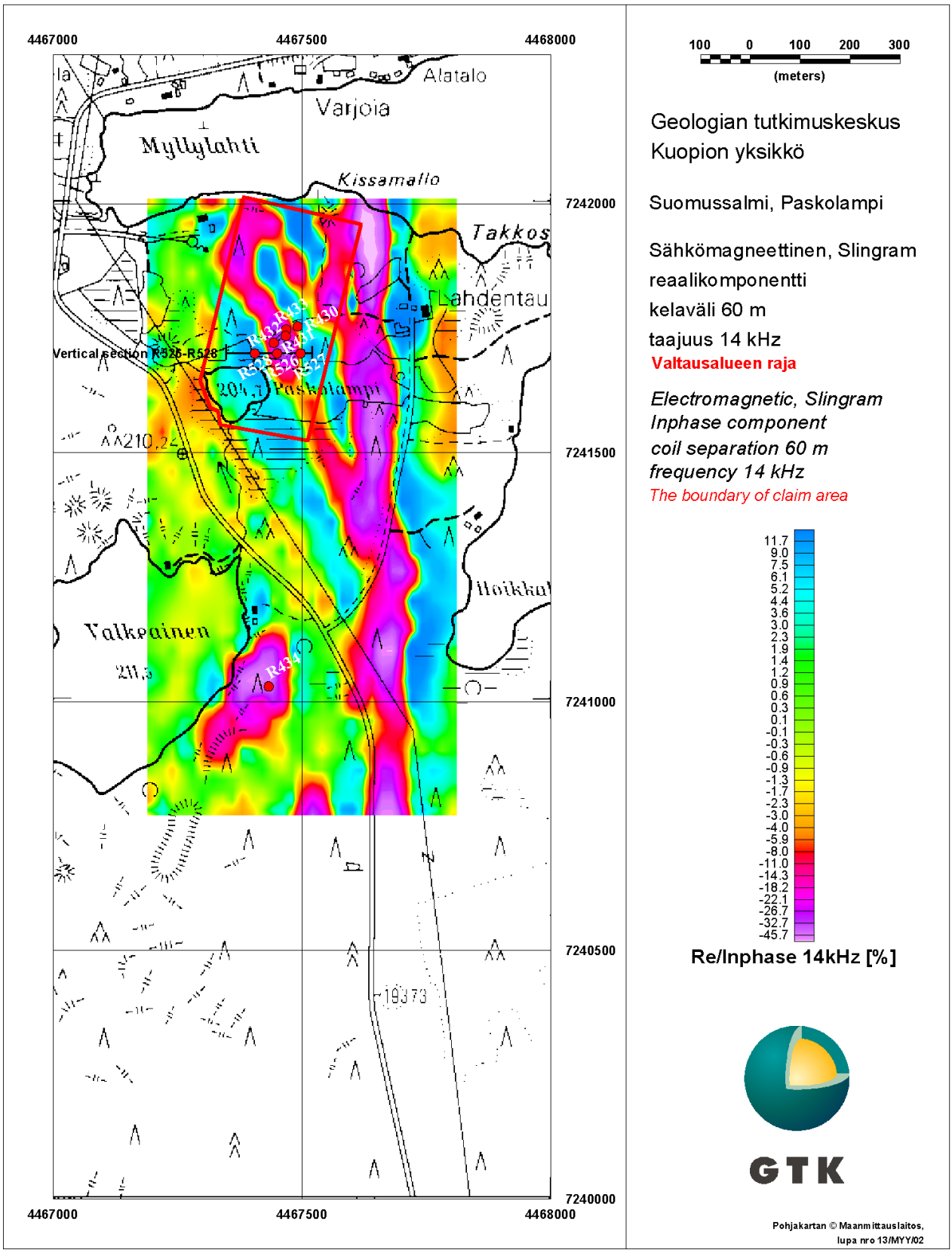


Fig. 3.1.1.2.3a. Slingram ground measurements, real (in-phase) component, Paskolampi, Suomussalmi.

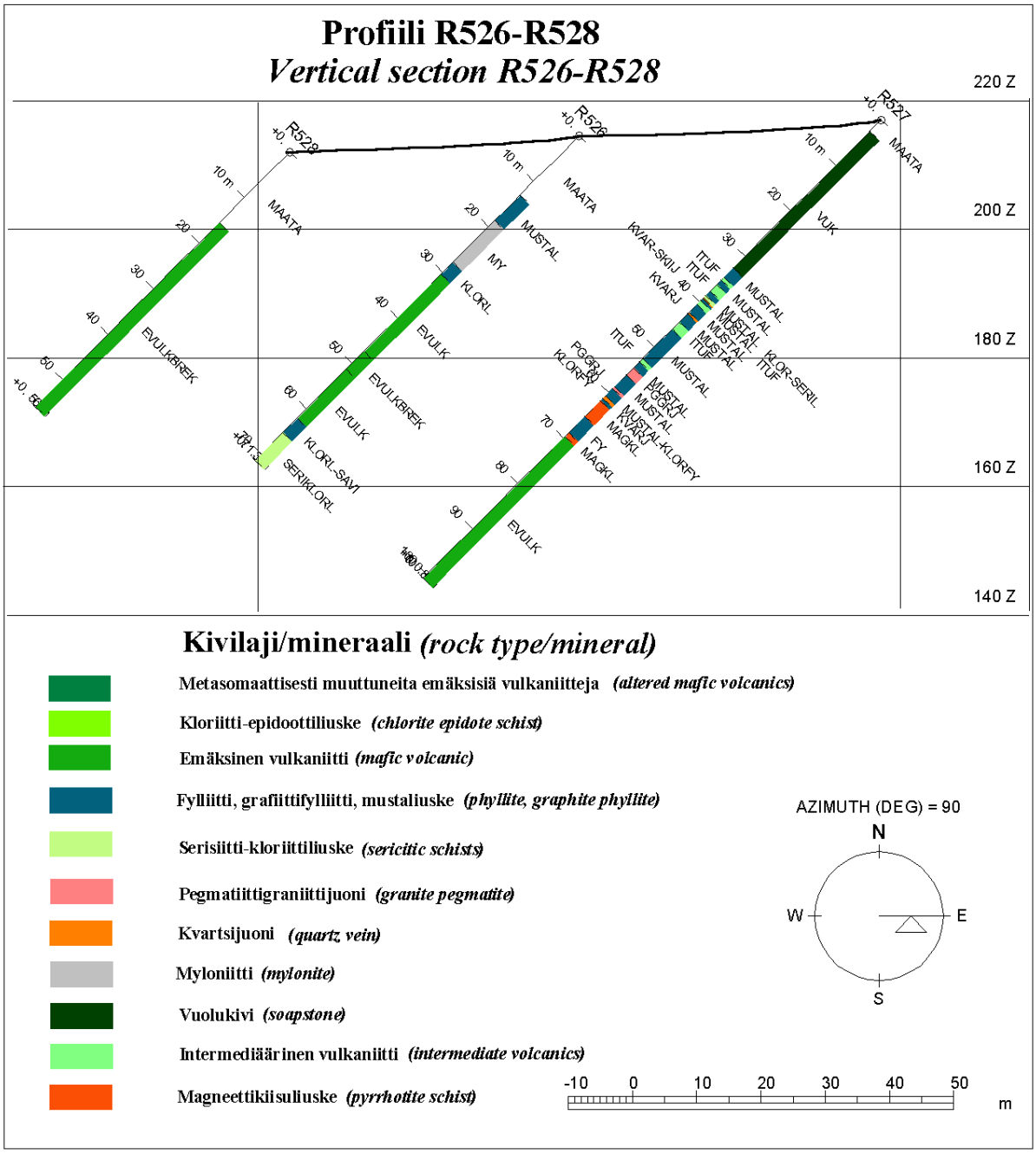


Fig. 3.1.1.2.3b. Vertical Vertical section based on drilling profile R526 - R528, Paskolampi, Suomussalmi.

The central part of the drilling profile intersected strongly deformed rocks with alternating phyllitic sediments containing graphite, iron sulfides and arsenopyrite, sheared mafic volcanics, granitoid dykes and sporadic pyrite-bearing quartz veins. Highest gold values in this section were found in the western part, in mafic volcanics between 40.60 – 41.60 m in R430 (0.10 ppm Au) and between 18.00 – 19.20 m in R431, in graphitic phyllites (0.10 ppm Au). Elsewhere, gold concentrations tended to be below detection limits, nor was any meaningful correlation observed between gold and relatively weak arsenic and tellurium anomalies. Similarly, there was no obvious correlation between abundance of sulfides and gold concentration in quartz veins; for example, in the interval 39.10 – 39.30 m in R527, which contains 11.9 % S and 16.7 % Fe, gold contents remained below detection limit.

The eastern part of the profile appears to have some economic potential, though for unusually pale-colored soapstone rather than for gold. Soapstone was intersected in R527, which was drilled at an angle of 45º to the west, to a depth of 32.50 m. Moreover, the drill hole is located about 0.5 km from an operating quarry and processing plant. A report summarizing investigations at Paskolampi was submitted in 2001 to the then Ministry of Trade and Industry, for the purposes of public tendering of the exploration rights to the area (Pietikäinen and Niskanen, 2001a).

3.1.1.2.4. Seipelä gold occurrence

Seipelä is situated in the Saarikylä area, to the south and southeast of the lake Saarijärvi (FIN_KKJ mapsheets 4513 02, - 03, - 05 and - 06). The first indication that the area might have gold potential was from regional and local till geochemical surveys, the results of which showed more extensive anomalies and higher gold concentrations than those obtained from the areas associated with known mineralization in the Tormua schist belt, such as Moukkori and Pahkalampi. During detailed bedrock mapping in the Seipelä area, quartz veins and silicified rocks containing pyrite, arsenopyrite and tourmaline had also been found, although they were not accompanied by elevated gold concentrations.

For the purpose of follow-up investigations, GTK took out exploration leases in the area in 1997, partly based on the results of ground geophysical surveys undertaken in 1995 (Figure 3.1.1.2.4). Several holes were drilled in 1997 – 1998, to determine rock types, structural trends and the possible existence of mineralized alteration zones.

Systematic IP surveys were carried out in the Seipelä area (Figure 3.1.1.2.4). The source of the IP anomaly in the eastern part of the area is pyrrhotite in graphitic and sulfide-bearing schists. Pyrrhotite is likewise responsible for the anomaly in the profile drilled between R518 and R521, within the Siikaselänne 1 exploration lease area (Figure 3.1.1.2.4). Anomalies in the southwestern part of the area are less coherent, partly due to lower water content in surficial deposits overlying the bedrock, which tend to cause increased background noise. However, IP anomalies in the section between R598 and R601 are attributable to pyrite and arsenopyrite disseminations.

A total of 21 POKA (GM100) holes were drilled using a T56 drill bit, with a combined core length of 1 239.60 m, from which 1185 gold assays were made (GFAAS) and 261 analyses for base metals (ICP-AES). The first profile (R513-517) was drilled along a N-S trend (Zone FIN_KKJ4 grid at easting 4471.250E, between northings 7241.070N and 7241.270N), with holes drilled at an angle of 45° to the south (Figure 3.1.1.2.4). These drill hole thus provided bedrock information from an area lacking surface exposures, enabling correlation to be made with geophysical anomalies. The only significant anomalous gold values were 0.37 ppm and 0.23 ppm obtained from two separate one meter intervals in intermediate volcanics in R516.

The second profile (R518 – R521) was drilled in at the northern end of the study area along a N-S profile (Zone FIN_KKJ4 grid at easting 4471.025E, between northings 7241.550N and 7241.670N). Holes were drilled to the south and mostly intersected mafic volcanics. The highest gold value obtained was 0.58 ppm Au, in R520.

Mafic volcanics in the southern part of the study area are intruded by leucotonalite – leucogranite that contains finely disseminated pyrrhotite and chalcopyrite. The volcanics also contain sulfide-bearing granitic dykes and quartz veins and lenses with tourmaline and arsenopyrite.

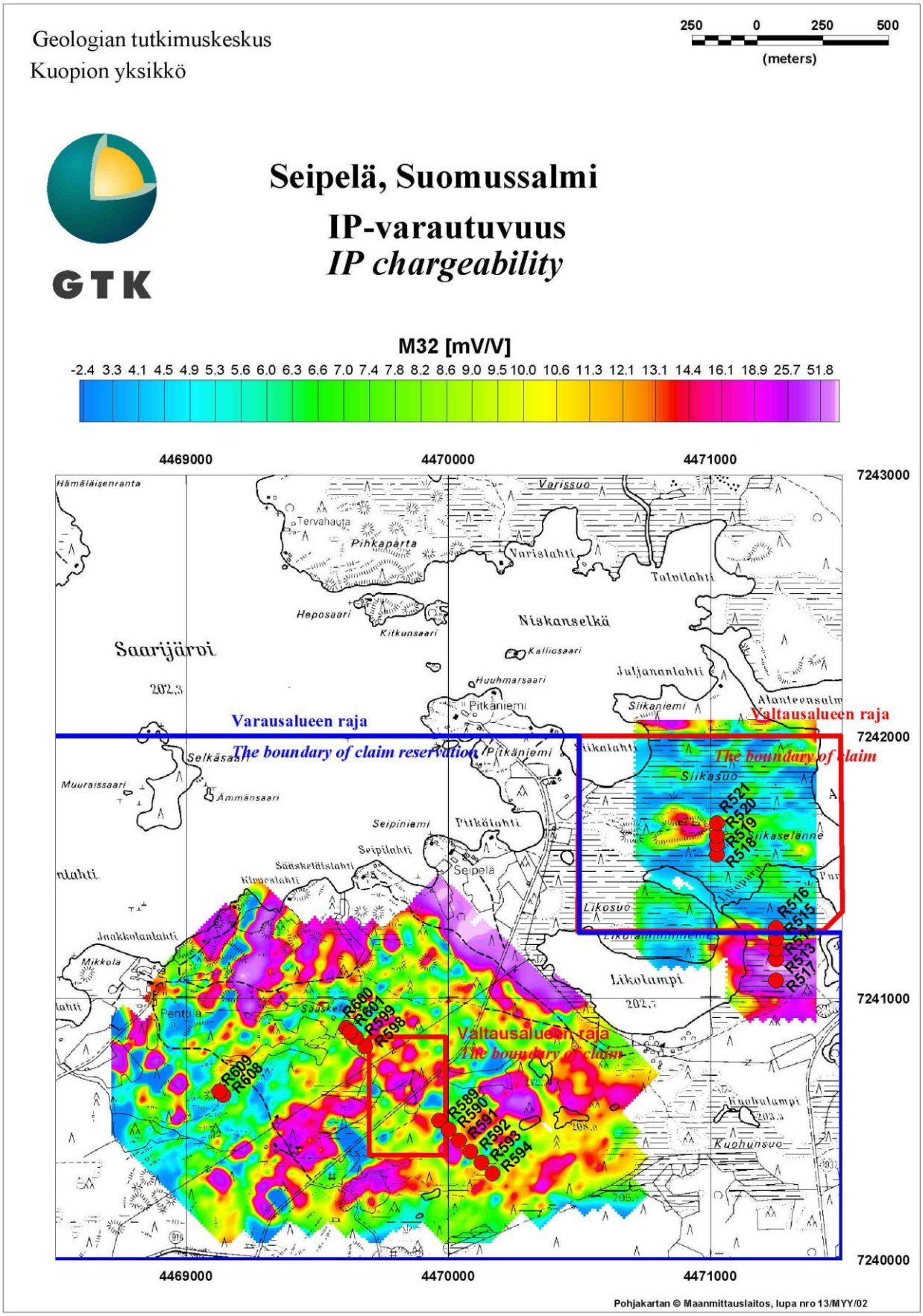


Fig. 3.1.1.2.4. Locations of exploration claims, claim reservation areas, IP-chargeability and the points of drill holes at the Seipelä gold exploration target area, Suomussalmi.

The third profile (R589 – R594) was drilled along a NW-SE trend, with individual holes drilled at an angle of 45° towards 135° (between FIN_KKJ4 grid coordinates 7240.332N, 4470.168E and 7240.535N, 4469.965E). The main reason for drilling this profile was to ascertain the gold potential across the greenstone contact. Rock types intersected were largely as anticipated, except for the presence of abundant mafic dykes. Although there was abundant quartz, tourmaline, arsenopyrite and iron sulfides, as well as sporadic scheelite, gold contents proved on assaying to be surprisingly low, being mostly below the detection limit of 0.01 ppm. Some intervals had Au abundances in the range 0.3 – 0.5 ppm, and an exceptional value of 1.33 ppm Au was obtained between 15.40 – 16.40 m in R592. However, visual inspection of this interval showed no obvious difference between this interval and adjacent weakly mineralized or unmineralized core.

On the basis of results obtained from till geochemical surveys, the third profile was continued further to the southeast by drilling four more holes (R598 - R601), between FIN_KKJ4 grid coordinates 7240.818N, 4469.682E and 7240.888N, 4469.611E. The same rock types were intersected as in the previous drill holes, and no anomalous gold intervals were found.

During field work in 1998, an additional outcrop was found, somewhat to the west of the drilled profile, consisting of intensely sheared and sericitized tonalite in contact with greenstones, which also contained deformed quartz veins with abundant arsenopyrite and pyrite. Taking into account the local glacial transport direction, this outcrop would be a likely source for the gold anomalies found in till. Drill holes R608 (FIN_KKJ4 grid coordinates 7240.633N, 4469.141E) and R609 (FIN_KKJ4 grid coordinates 7240.647N, 4469.127E) were both drilled at an angle of 45° towards 135° and intersected the altered tonalite and adjacent greenstones. However, no anomalous gold was present.

A more detailed report was prepared in 2001 for the then Ministry of Trade and Industry (Pietikäinen and Niskanen, 2001c).

3.1.1.2.5. Vaara – Kauniinlampi komatiitic cumulate complex and associated nickel deposits

The Vaara – Kaunislampi komatiitic cumulate complex is situated in the Saarikylä area, in the northern part of the Suomussalmi greenstone belt, some 50 km north of the Suomussalmi town center (FIN_KKJ mapsheets 451303 and 4514 01). It comprises five discrete serpentinized komatiitic olivine cumulate lenses that dip rather steeply to the east; from south to north, over a distance of nearly 15 km, these lenses have been named Portti, Vaara, Rytys, Hoikkalampi and Kauniinlampi. The Portti cumulate body has been extensively affected by talc-carbonate alteration and is currently the focus of soapstone mining operations by Tulikivi Oy.

The results of mapping undertaken during the current study indicate that in the Saarikylä area, the western margin of the greenstone belt succession consists of the 3 000 Ma – 2 800 Ma felsic to mafic volcanics and volcaniclastic sediments of the Luoma Group, which represent the oldest known supracrustal rock units in the Suomussalmi greenstone belt. The next lithostratigraphic unit recognized is a tholeiitic basalt sequence, although this is absent in many places and rocks of the Luoma Group are directly juxtaposed against komatiitic rocks that are between 50 –200 Ma younger. The tholeiitic basalts have been observed in outcrop and intersected in drill core in numerous localities including the southern part of the Vaara area, to the southeast of Rytys, between the Rytys and Hoikkalampi komatiitic cumulate lenses, at the western margin of the Hoikkalampi lens, between the Hoikkalampi and Kauniinlampi komatiite cumulate lenses and at the northern end of the Kauniinlampi lens. The majority of the komatiitic cumulates in the Saarikylä area are olivine mesocumulates and adcumulates formed from turbulent channelized lava flows. In contrast, the proportion of orthocumulates and particularly thin eruptive komatiite lavas is relatively small. The komatiitic units are in turn stratigraphically overlain by komatiitic

basalts and a distinctive suite of basalts that contain exceptionally high chromium concentrations (Cr = 450 –900 ppm). The youngest stratigraphic unit recognized consists of volcaniclastic sediments and finer-grained phyllites and locally graphitic pelitic schists.

3.1.1.2.5.1. Geophysical investigations

Systematic Slingram EM surveys, with a profile spacing of 50 m and a measurement interval of 20 m, were undertaken at Hoikkalampi and Kauniinlampi (Figure 3.1.1.2.5.1b). Surveys were made using GTK 14 kHz Slingram system except in the northern part of the Kauniinlampi area (north of FIN_KKJ4 grid northing 7250.000N), where a MAXMIN1-10 system was used, with a coil separation of 60 m and at frequencies of 880, 3 520 and 14 080 Hz. Total magnetic intensity was measured along the same profiles but with a smaller measurement interval of 10 m (Figures 3.1.1.2.5.1a and 3.1.1.2.5.1c). Results were corrected by calibration against a base-station. More detailed profiles were measured, with a line spacing of 10 m and measurement spacing of 5 m, over the central and northern parts of the Kauniinlampi komatiitic cumulate body. A total of 9 400 Slingram and 18 500 magnetic measurements were recorded. Sampo soundings (300 measurements, using a coil separation of 150 – 750 m) were used to delineate deeper conductive horizons although the effectiveness of this technique was hampered by the presence of highly conductive graphitic phyllites at the margins of the komatiitic cumulate bodies.

Five gravimetric profiles were measured across the Hoikkalampi and Kauniinlampi komatiitic lenses using a 20 m measurement spacing (total of 350 readings). Interpretation of potential field (combined magnetic and gravimetric) data for the Kauniinlampi cumulate body gave a an estimate of 350 m for its depth extent.

Petrophysical parameters measured *in situ*, at 5 cm intervals, from drill holes included susceptibility (from 26 drill holes representing a total length of 3 175 m) and apparent Wenner resistivity (from 24 holes, representing a total length of 2 830 m). Laboratory measurements on selected drill core samples (264 samples, from 16 drill holes) included susceptibility, density and remnant magnetism; electrical conductivity was also measured on 67 samples.

The mise-a-la-masse electrical resistivity technique was used to delineate the geometry of conductive rock units in the central and northern parts of the Kauniinlampi cumulate bodies. The potential array was designed with a measurement spacing interval of 10 m for ground surface readings and 2 m for down-hole measurements and a total of 1 900 measurements were made from surface electrodes and 1 300 from drill holes.

The central part of the Kauniinlampi mineralization was also selected as a site for testing the spectral IP system developed with the BriteEuram Geonickel project, a research program aimed at improving nickel exploration techniques, funded by the EU and consisting of a consortium of industrial and research partners from four EU countries, comprising Softeco Sismat (Italy), IGME and NCRS (Greece), BRGM and Iris Instruments (France) and Outokumpu Mining Oy and GTK (Finland).

Slingram surveys at Rytys were made with the Apex MAXMIN I-10 system using frequencies of 880, 3 520 and 14 080 Hz, with a coil separation of 60 m, line spacing of 100 m and measurement interval spacing of 20 m. More closely spaced measurements (50 m line spacing) were made over distinctly anomalous areas. A total of 4 100 measurements were made. Total magnetic intensity was also recorded from the same profiles, but with a smaller spacing interval of 10 m, with the total number of measurements being 8 100 (Figures 3.1.1.2.5.1b and 3.1.1.2.5.1c).

Five gravimetric profiles with a 20 m spacing between measurements were made over the Rytys komatiitic cumulate lens (total of 300 points).

Drill hole R435 (95 m) was logged with a variety of methods to test their effectiveness, including Wenner, single-point and lateral resistivity, IP, susceptibility, natural gamma radiation and gamma-gamma density.

Slingram measurements over the Vaara cumulate body were made using the GTK 14 kHz system with a coil separation of 60 m, profile spacing of 50 m and point separation of 20 m, corresponding to a total of 1 200 measurements. Total magnetic intensity was surveyed in the central part of the area with a 25 m line spacing and 10 m measurement interval, resulting in a total of 4 000 measurements (Figures 3.1.1.2.5.1b and 3.1.1.2.5.1c).

Down-hole measurements of susceptibility (32 holes, total length of 3 000 m) and Wenner resistivity (31 holes, total length of 2 800 m) were made at 5 cm intervals. Laboratory measurements on drill core (from 120 samples, representing 11 holes) included density, susceptibilty and remnant magnetism. Remanence vector components were also measured from a single oriented sample (R632, depth of 10.1 m; remanence inclination I = 7° and declination D = 27°).

Petrophysical properties of drill holes and core from the Kauniinlampi and Vaara mineralizations have been correlated with nickel abundance by comparing mean values of respective parameters over the same intervals as those used for chemical analysis, which usually comprised one meter sections of core. Accordingly, averaged petrophysical data are based on about 20 measurements per meter of drill core. Down-hole *in situ* measurements consisted of resistivity and susceptibility, while laboratory measurements also included density. Therefore, density values are more sparse and usually based on a single measurement for each one meter length of drill core. It should also be noted that the minimum Wenner resistivity value recorded by the equipment used in down-hole measurements was 1Ohm.m so that rock units that are more conductive plot on the correlation diagrams within the range of one to several ohm-meters.

Results for the Kauniinlampi Ni-mineralization have been calculated by combining the data from the central and northern mineralizations; measurements from the southern mineralized body were not available (Figures 3.1.1.2.5.1b and 3.1.1.2.5.1c). The most highly conductive parts of the mineralization correlate with Ni contents < 0.5 % (Figure 3.1.1.2.5.1d). Higher nickel contents correlate with higher resistivities, varying either side of 1000 Ohm.m. Susceptibilities vary within the range 0.05 –0.20 SI for Ni values < 0.4 % (Figure 3.1.1.2.5.1e), which agrees well with values obtained from unmineralized serpentinites in the surrounding area. With increasing Ni contents, susceptibility values fall below 0.1 SI and are in many places remarkably low. The higher nickel abundances tend to be mostly from the northerly mineralization. The low susceptibilities are likely to reflect partial destruction of magnetite by metamorphic and hydrothermal alteration processes (refer to Sections 2.6.2.3.2 and 3.1.1.2.5.5). Densities in the Kauniinlampi mineralization are relatively low and rather similar to those of the surrounding serpentinites; even at nickel concentrations of1 %, densities are only around 2 550 kg/m^3.

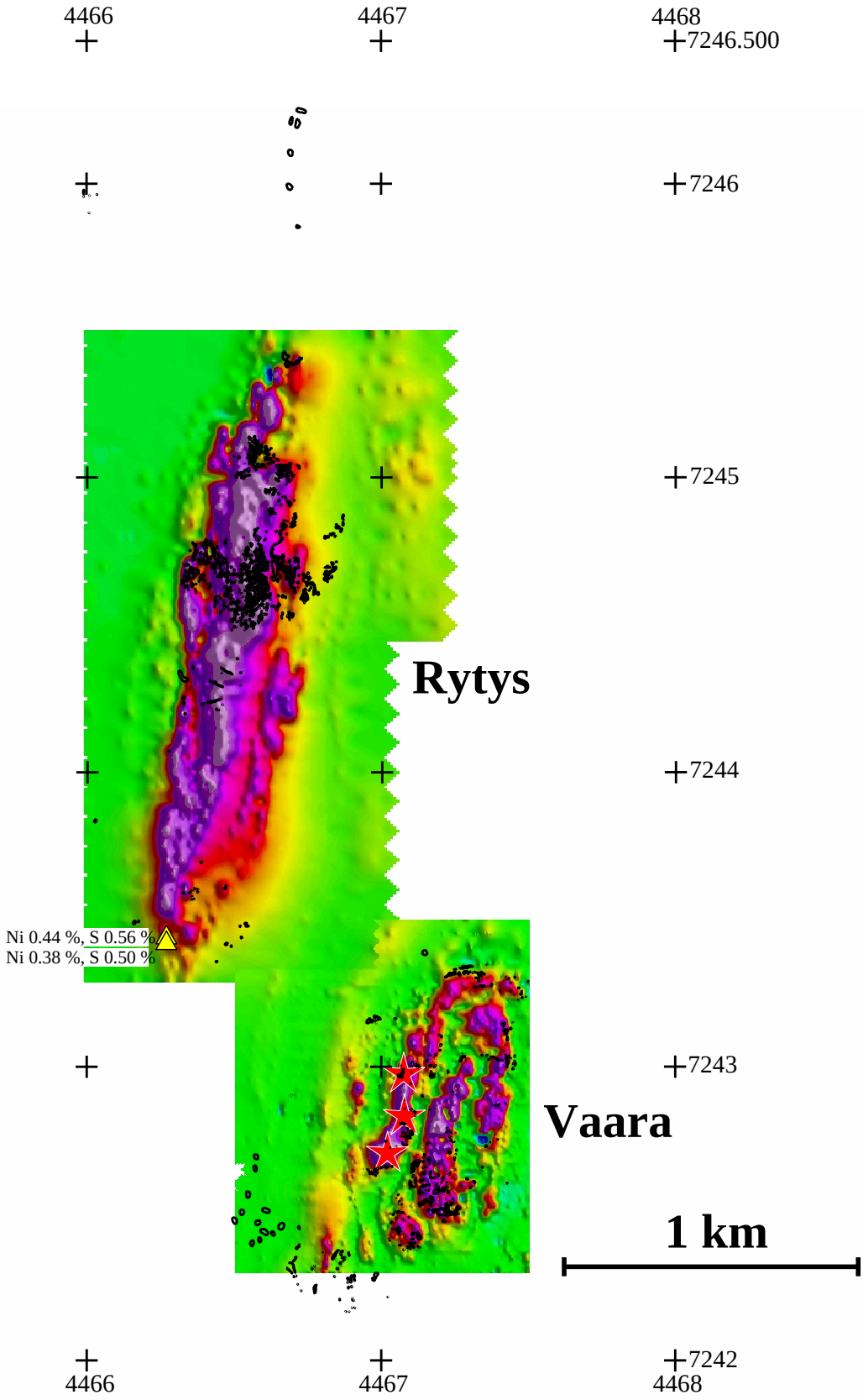


Fig. 3.1.1.2.5.1a. Location of outcrops in the Vaara - Kauniinlampi complex. Base map represents total magnetic total intensity from ground-based surveys (see Figure 3.1.1.2.5.1c). Locations of nickel occurrences (red stars) and Ni-bearing boulders (yellow triangles) also shown..

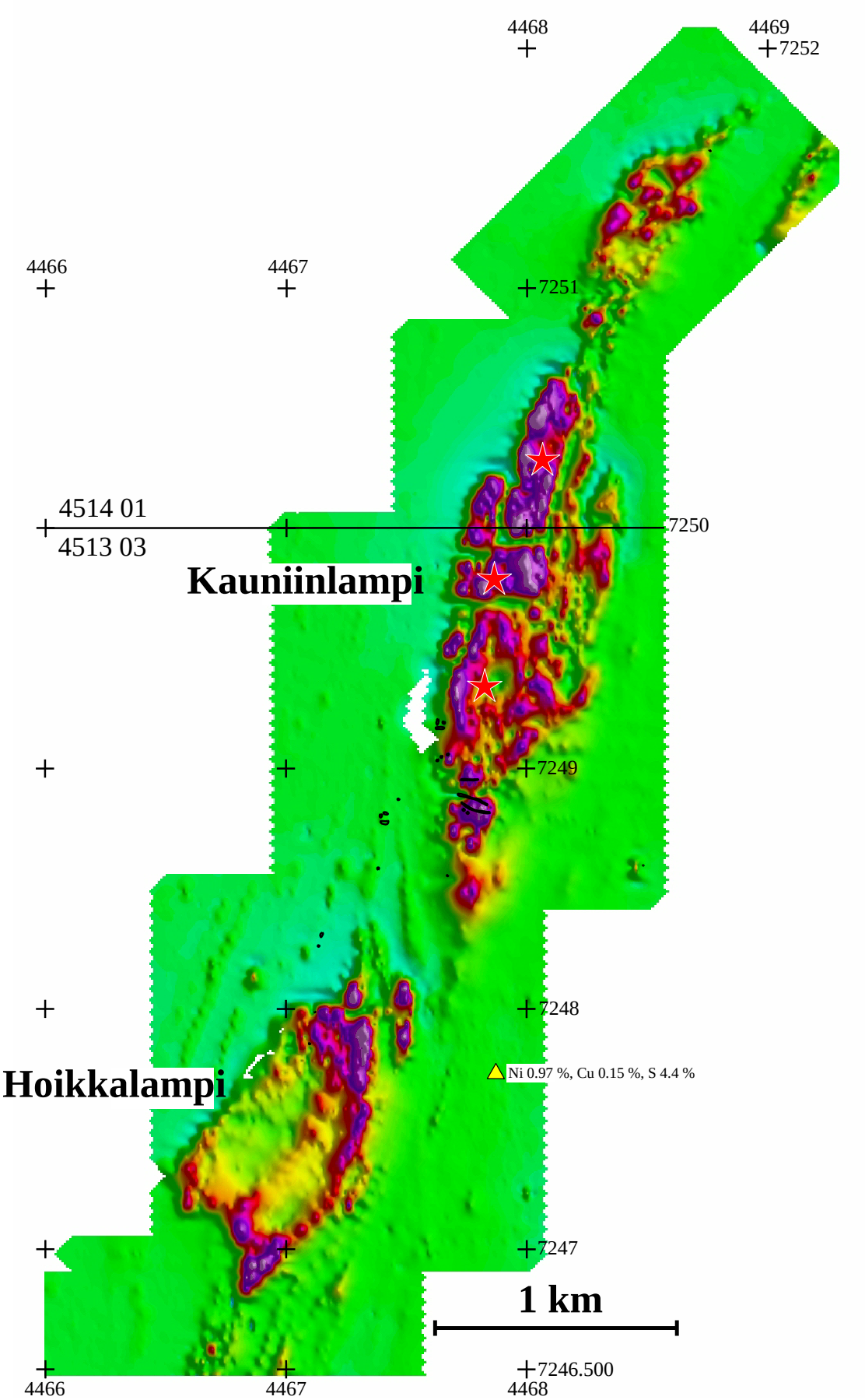


Fig. 3.1.1.2.5.1a. Continued

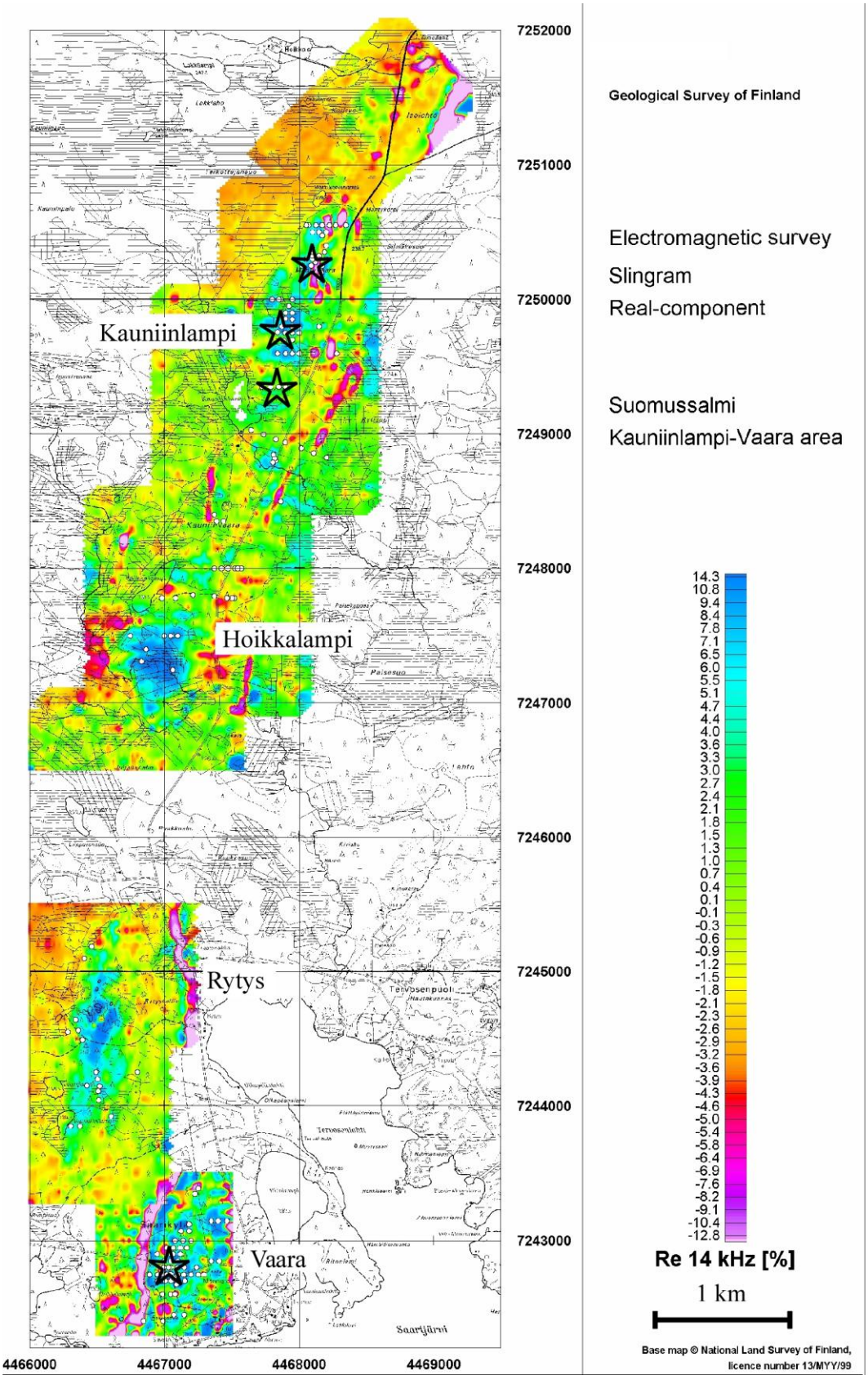


Fig. 3.1.1.2.5.1b. Ground electromagnetic Slingram real (in-phase) component map of the Vaara - Kauniinlampi complex. Cumulate lenses, from south to north: Vaara, Rytys, Hoikkalampi and Kauniinlampi. Locations of diamond drill holes (white circles) and nickel mineralization (black open stars) also shown.

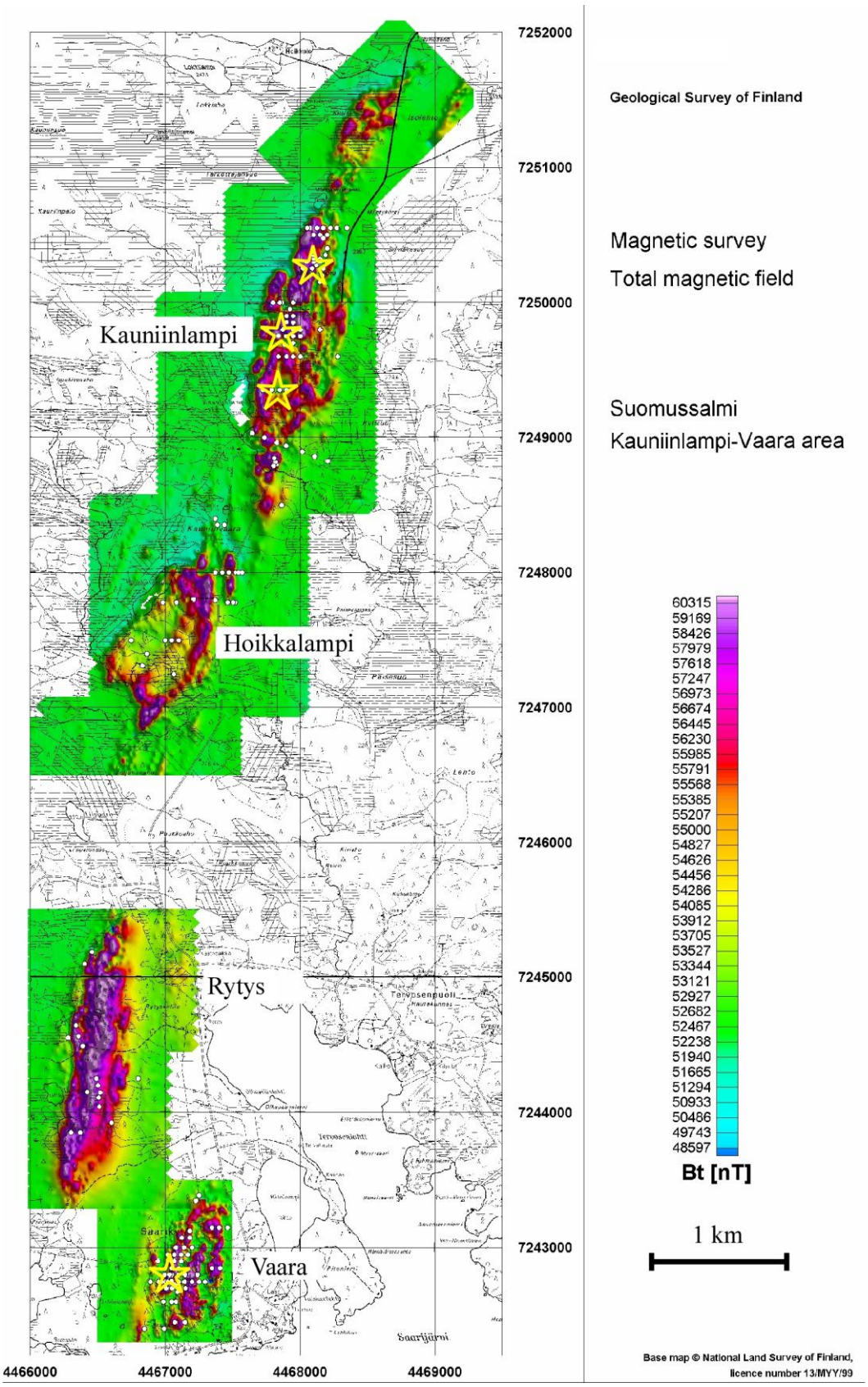


Fig. 3.1.1.2.5.1c. Ground magnetic total intensity map of the Vaara - Kauniinlampi complex. Cumulate lenses, from south to north: Vaara, Rytys, Hoikkalampi and Kauniinlampi. Locations of diamond drill holes (white circles) and nickel mineralization (yellow open stars) also shown.

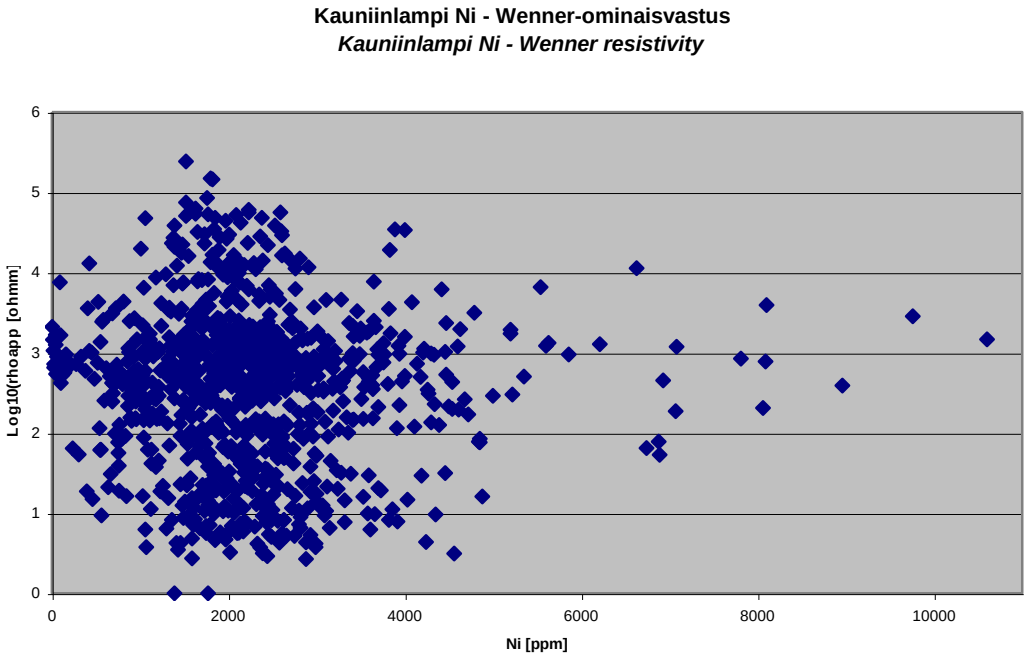


Fig. 3.1.1.2.5.1d. Logarithmic Wenner resistivity versus Ni-content, Kauniinlampi.

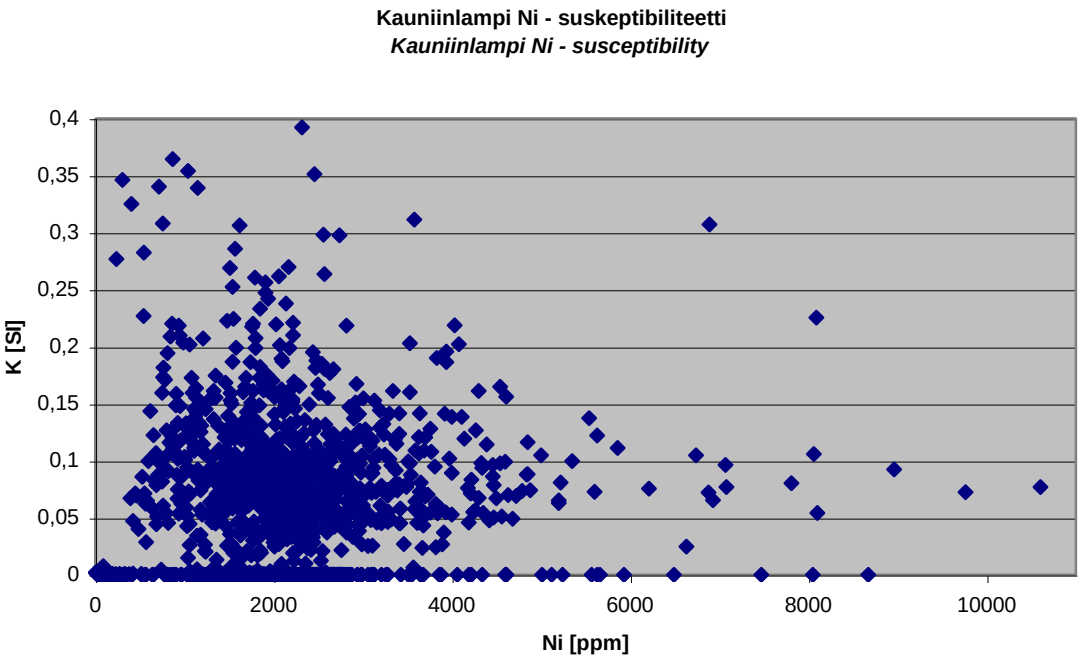


Fig. 3.1.1.2.5.1e. Susceptibility versus Ni-content, Kauniinlampi.

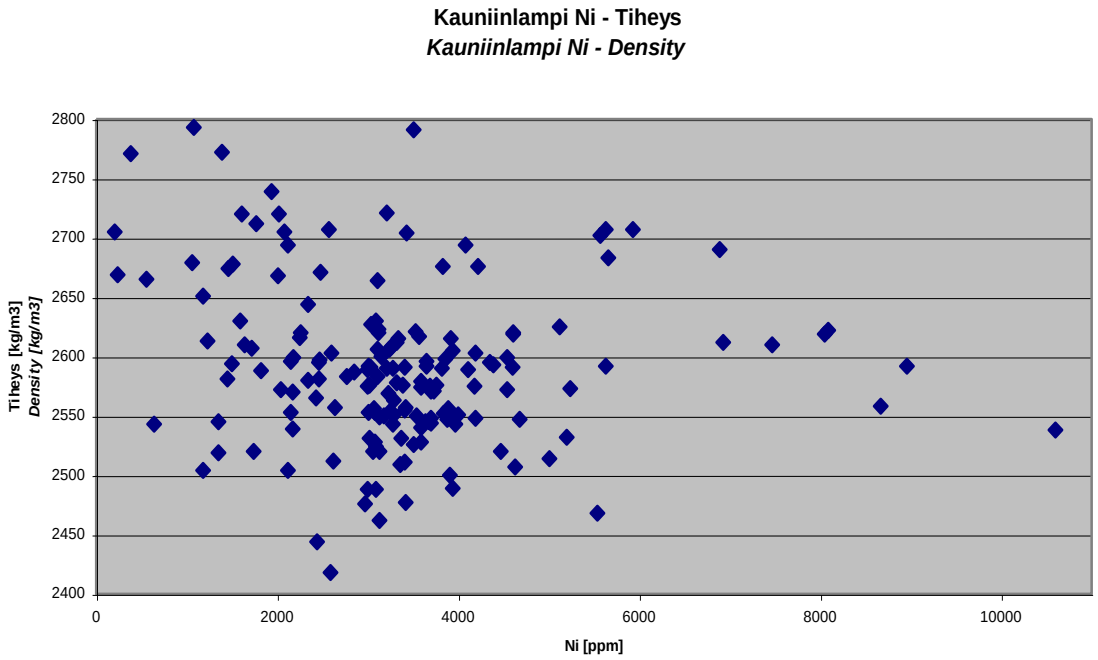


Fig. 3.1.1.2.5.1f. Density versus Ni-content, Kauniinlampi.

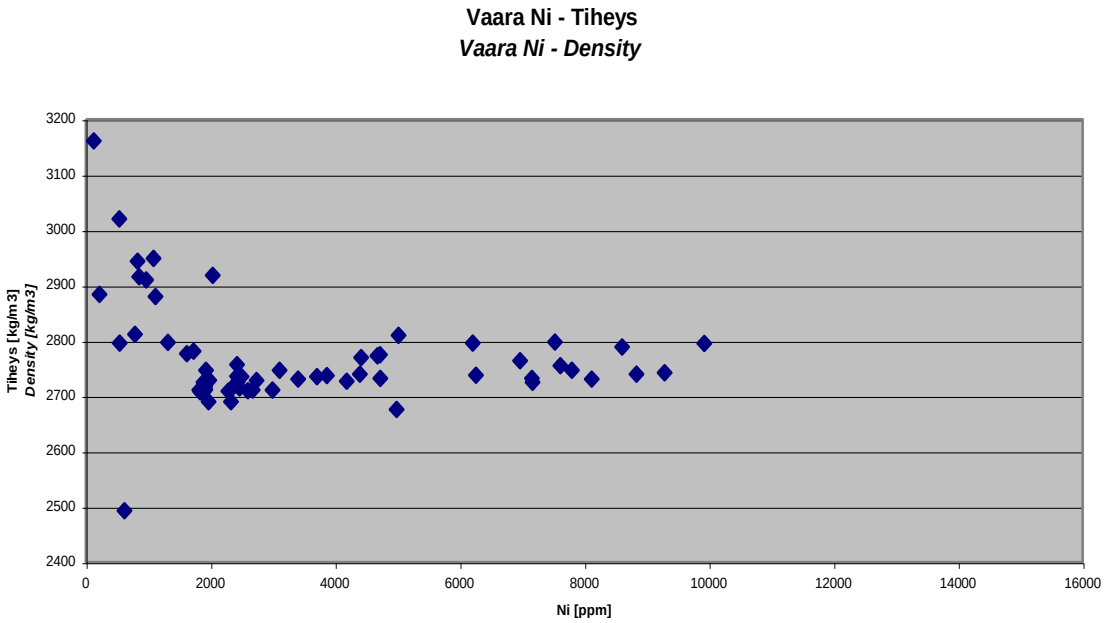


Fig. 3.1.1.2.5.1g. Density versus Ni-content, Vaara.

The density of the Vaara Ni-mineralization is rather uniform between 2 700 – 2 800 kg/m^3 for mean nickel concentrations between 0.2 - 1.0 %, which provides and indication of the relatively homogeneous nature of the mineralization (Figure 3.1.1.2.5.1.1g). The density contrast with surrounding unmineralized serpentinites is slightly positive (< 40 kg/m^3), with the higher densities at relatively low nickel concentrations in Figure 3.1.1.2.5.1.g being due to the presence of pyroxenites. The susceptibilities at the Vaara mineralization are somewhat greater than those at Kauniinlampi (Figure 3.1.1.2.5.1.h), ranging between 0.1 – 0.2 SI, even for nickel concentrations as high as 1.2 %. Electrical conductivities at Vaara are conversely less, with resistivities varying from tens to thousands of ohm-meters (Figure 3.1.1.2.5.1i). Near the surface, resistivities are even higher, up to tens of thousands of ohm-meters.

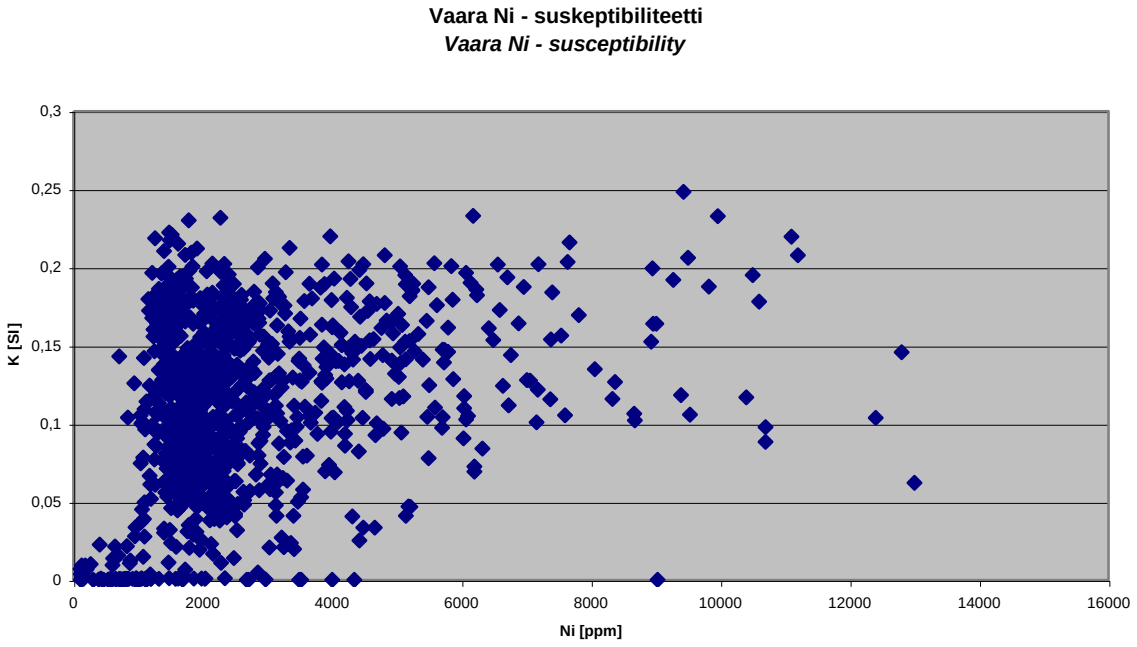


Fig. 3.1.1.2.5.1h. Susceptibility versus Ni-content, Vaara.

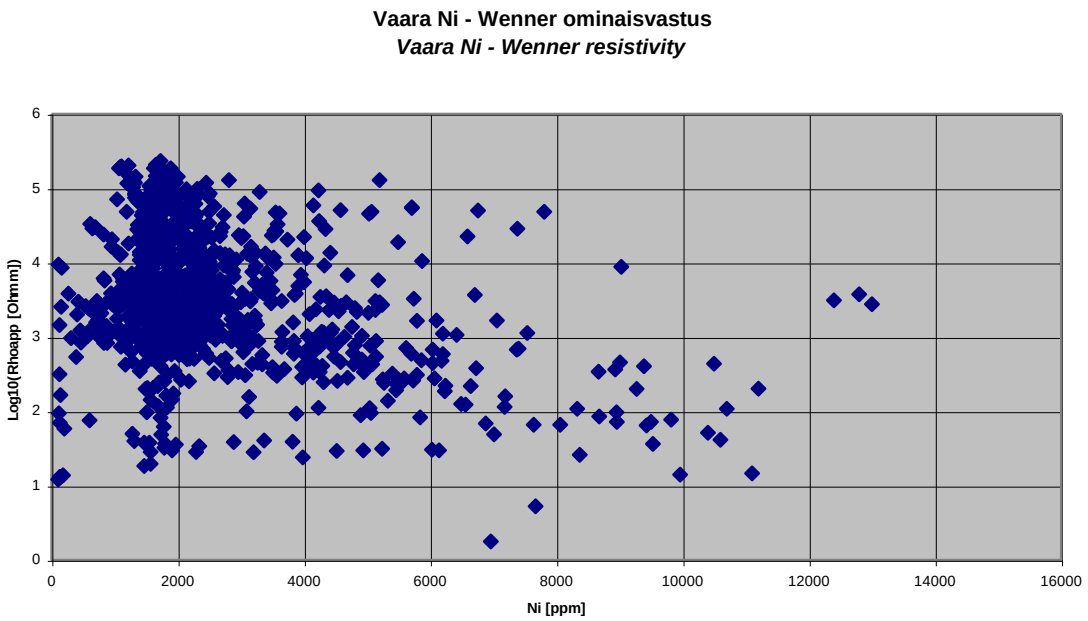


Fig. 3.1.1.2.5.1i. Logarithmic Wenner resistivity versus Ni-content, Vaara..

In some parts of the Suomussalmi greenstone belt, serpentinite resistivity shows a tendency to decrease with depth. This phenomenon is particularly clear for the Hoikkalampi serpentinite body (Figure 3.1.1.2.5.1c). The serpentinite is associated with a prominent real Slingram anomaly (Figure 3.1.1.2.5.1j) which however, cannot be entirely explained by the high susceptibilities of the rocks themselves (refer also to Section 2.2.5). Accordingly, the preferred interpretation is that an additional, buried conductor is present, at a maximum depth of 90 m. Sampo survey results also indicate that resistivity decreases with depth. Nevertheless, drilling showed that the Hoikkalampi serpentinite lens consists essentially of homogeneous olivine adcumulates, which makes it difficult to understand the ultimate source of the conductivity anomaly.

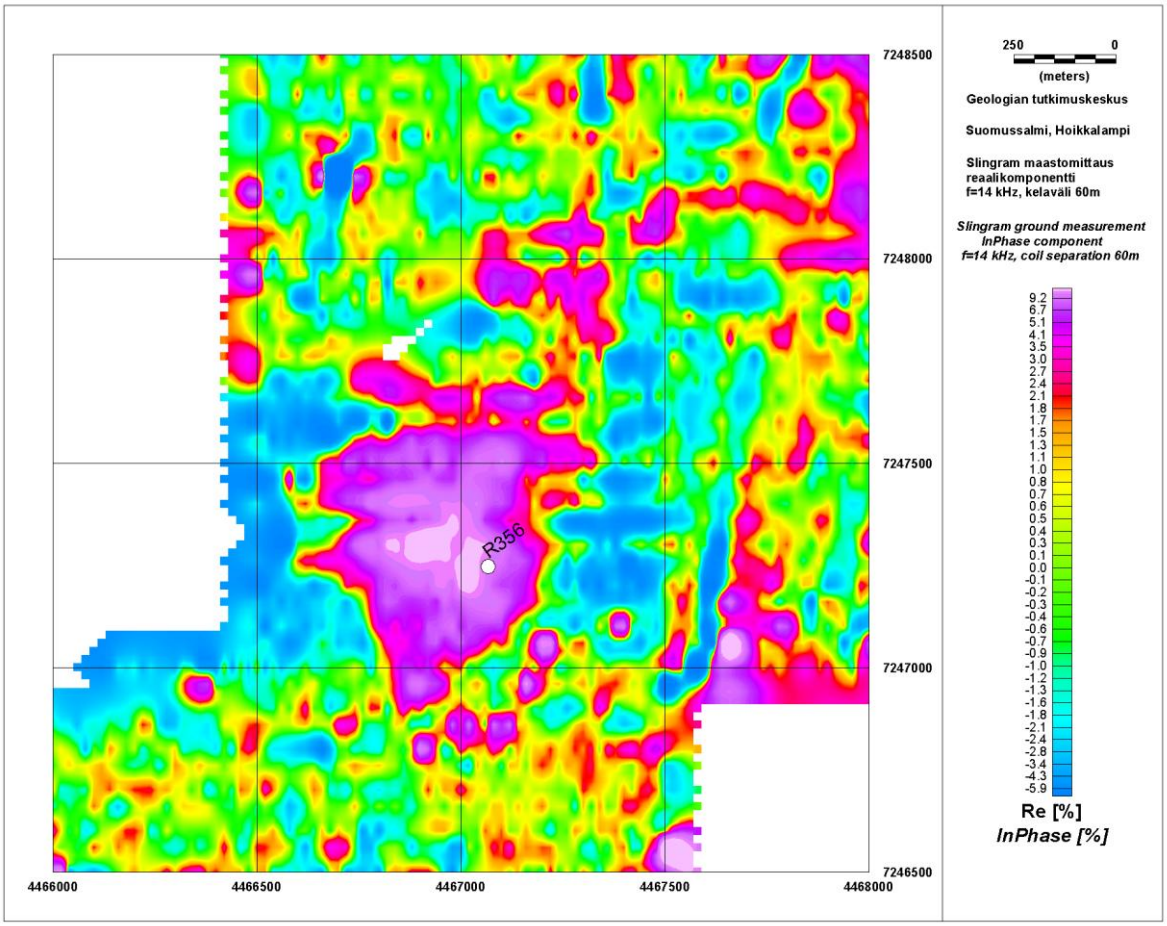


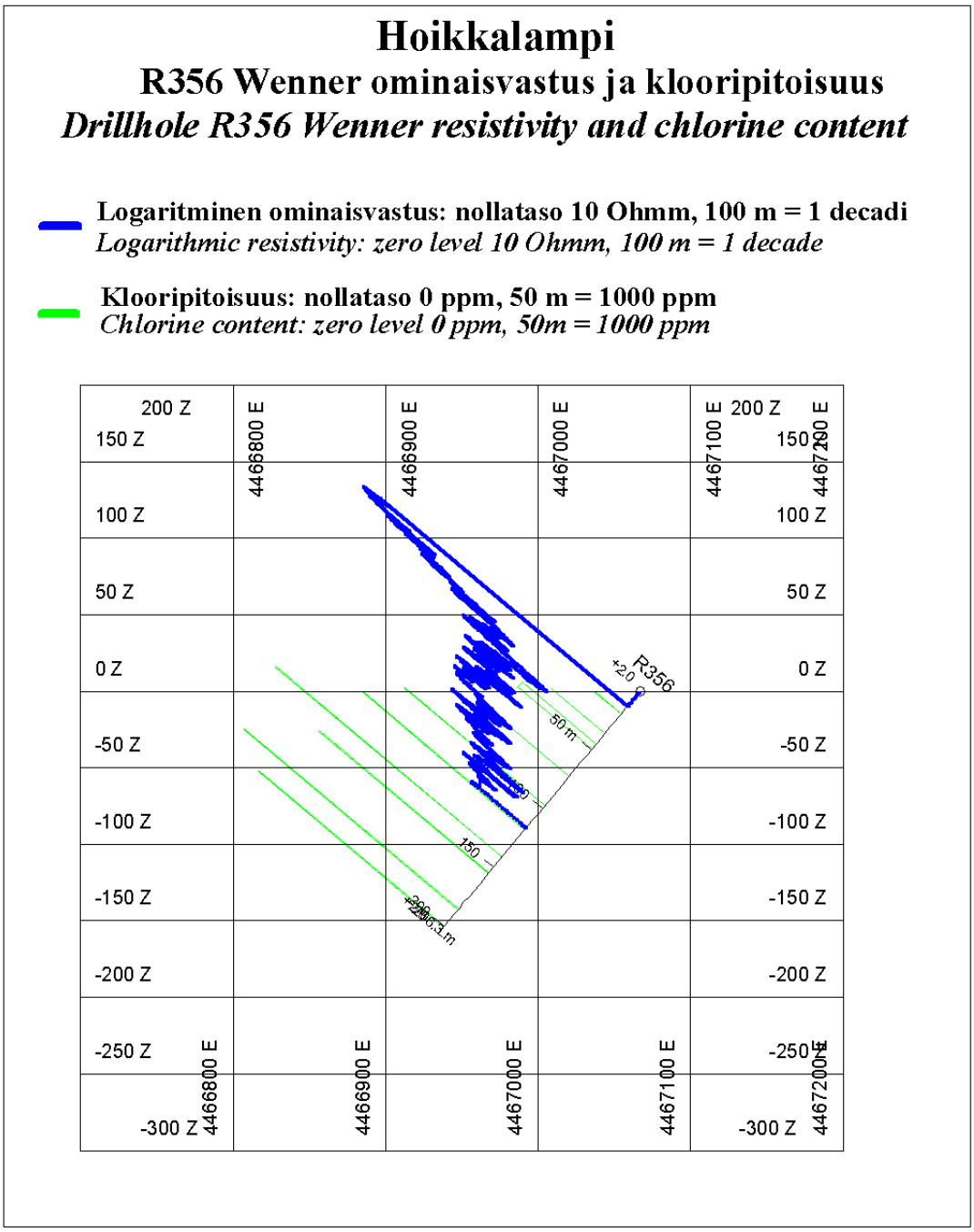
Fig. 3.1.1.2.5.1j. Slingram real (in-phase) component anomalies from ground survey measurement over the serpentinite lens at Hoikkalampi.

Down-hole measurements in R356 indicate that electrical resistivity decreases downwards during the first 30 m from about 2 000 Ohm.m to 100 Ohm.m (Figure 3.1.1.2.5.1k). The same trend continues at greater depths, though with a slightly lower gradient, such that at 90 m depth, resistivity is only 20 Ohm.m. According to the results of XRF analyses, the chlorine content of the serpentinites increases significantly with depth, from 500 ppm near the surface, to 2 800 ppm at depth of 90 m. The decrease in resistivity may therefore be attributed to variations in salinity of pore fluids within the serpentinites.

Detailed magnetometry was used to define detailed geometry of rock units at a number of targets, owing to the fact that surficial deposits and overburden in much of the study area are only several meters in thickness. In areas of exposed bedrock, increasing the density of survey grids (typically with 10 m profile spacing and 5 m point separation) was an effective way of improving the characterization of rock types in terms of magnetic properties.

Detailed magnetic surveys in the Kauniinlampi area were made with a profile spacing of 20 m and point spacing of 5 m, except in the central part of the area, where profiles were 10 m apart (Figure 3.1.1.2.5.1l). For comparison, Figure 3.1.1.2.5.1m shows results for a more sparse survey, with a profile spacing of 50 m and point separation of 10 m, both data sets having been interpolated onto a 5m x 5m grid. It is apparent that the more detailed survey reveals more information on internal structure and the location of high-strain deformation zones. The detailed grid (Figure 3.1.1.2.5.1l) also compares well with the detailed geological map of the northern part of the Kauniinlampi occurrence, which is constrained by additional information from drill core (Figure 3.1.1.2.5.5a).

Fig.



3.1.1.2.5.1k. Wenner resistivity logging and XRF analyses of chlorine content from diamond drillhole R356, Hoikkalampi.

3.1.1.2.5.2. Geological mapping

The Vaara – Kauniinlampi komatiitic cumulate complexes were systematically mapped at 1: 10 000 scale between 1992 and 1994. The Kauniinlampi and Hoikkalampi areas are poorly exposed but outcrops are abundant at Vaara and in the central part of the Rytys area (Figure 3.1.1.2.5.1a). The latter areas were mapped in even greater detail, at a scale of 1: 1 000, Rytys in 1996 and Vaara in 1999. Mapping in poorly exposed areas has been supplemented by information from drill core and detailed ground geophysical surveys, which have been effective in delineating the highly magnetic komatiitic cumulate lenses (Figures 3.1.1.2.5.1a and 3.1.1.2.5.1c).

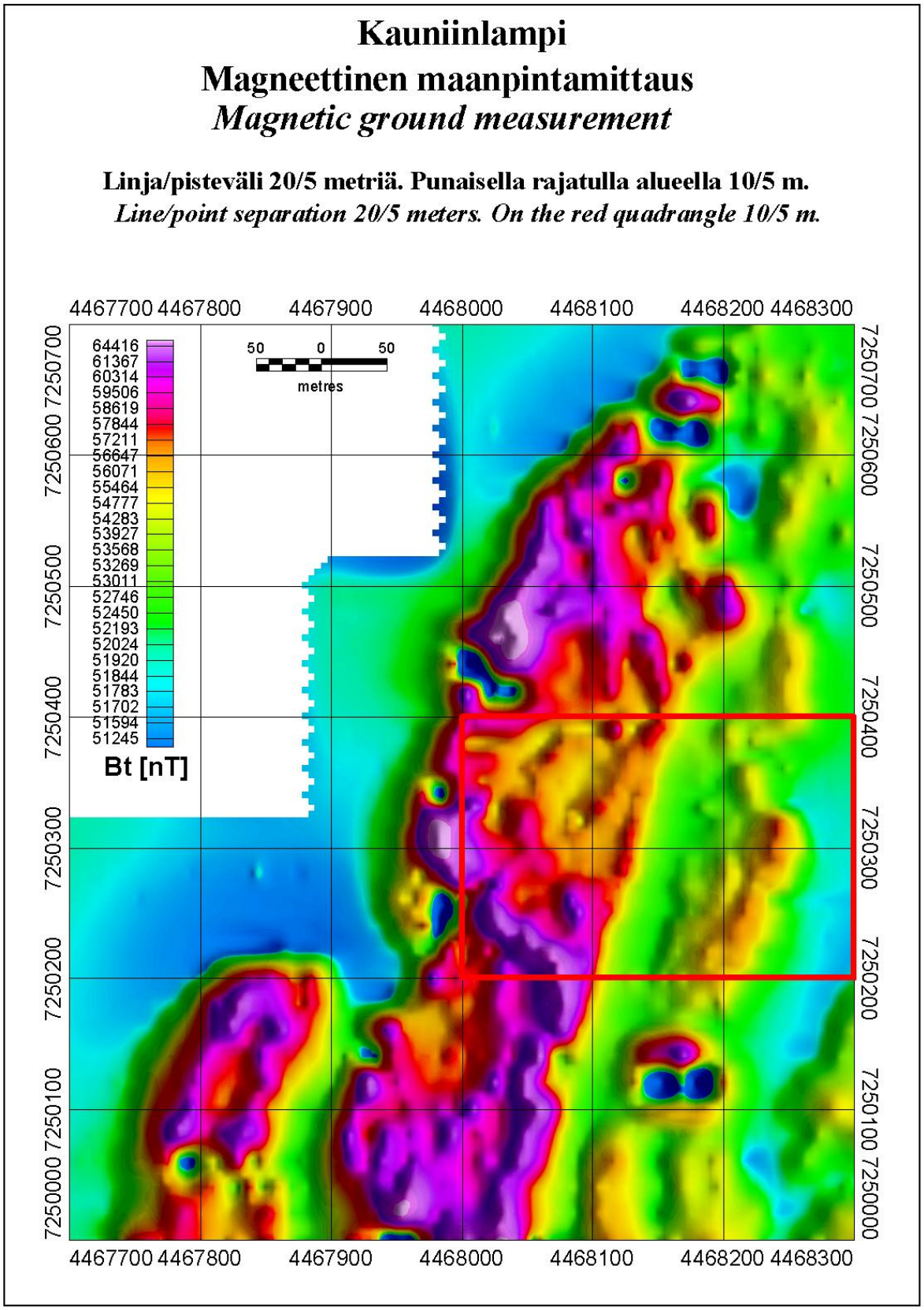


Fig. 3.1.1.2.5.1l. Detailed ground magnetic survey, Kauniinlampi.

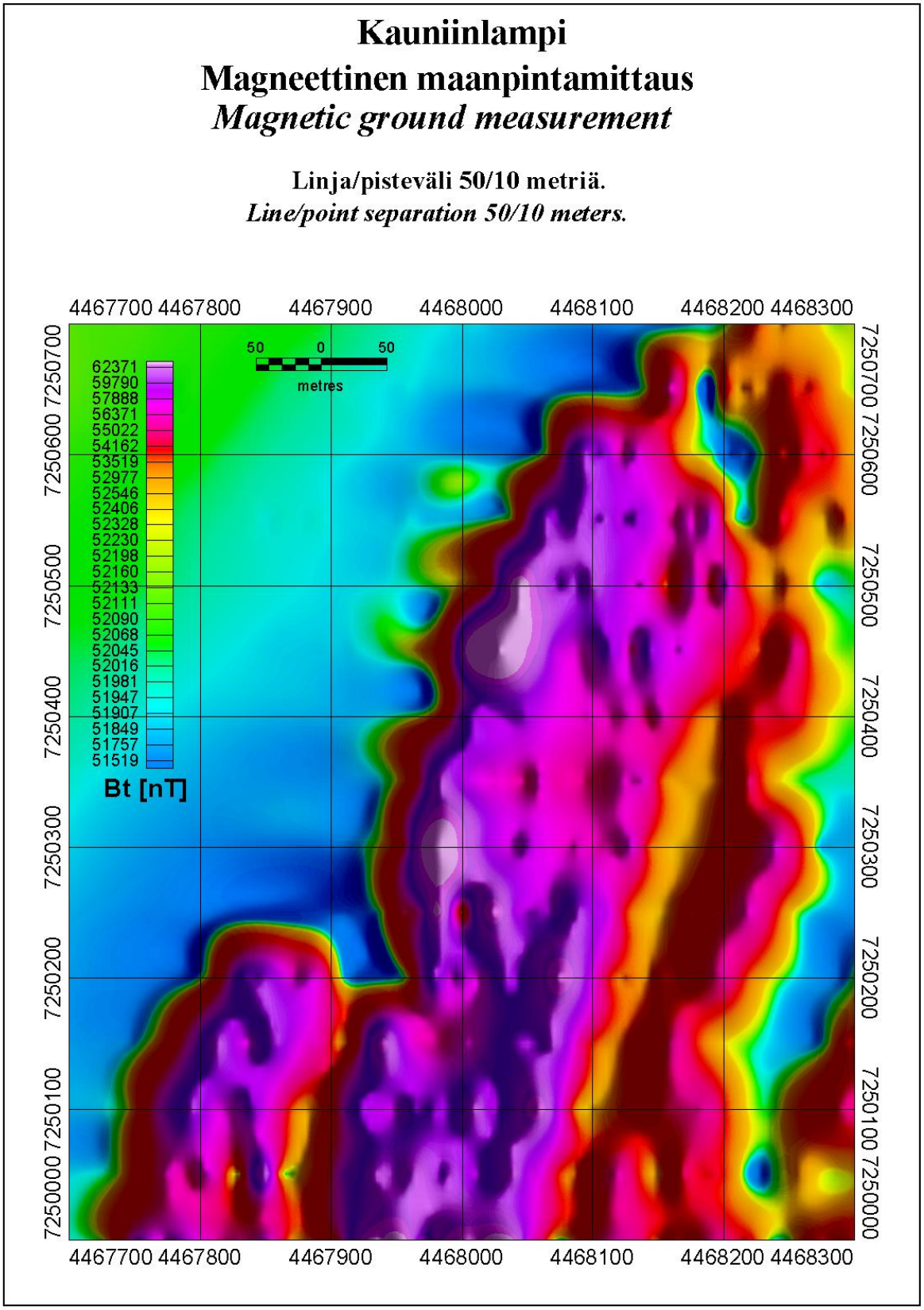


Fig. 3.1.1.2.5.1m. Ground magnetic survey measured with 50 meters line spacing and 10 meters point separation.

3.1.1.2.5.3. Till geochemical surveys

Figure 2.3.4c shows the detailed distribution of nickel anomalies throughout the Saarijärvi region and has been extracted and enlarged from Figure 2.3.4b, which shows local results based on till sampling survey, conducted on a 250 m grid. Elevated nickel concentrations clearly coincide with the Vaara, Rytys, Hoikkalampi and Kauniinlampi komatiitic units, as well as the mafic volcanics in the Saarilampi area. The Kivikangas soapstone quarry is also close to a prominent nickel anomaly. However, ore grade nickel abundances were not during these surveys, the highest values being 2 180 ppm at Vaara, 3 000 ppm at Rytys, 2 420 ppm at Hoikkalampi and 2 200 ppm at Kauniinlampi. Fan-shaped nickel anomalies within the adjacent granitoid area are attributed to glacial dispersion from west to east (refer to Section 2.3.4).

3.1.1.2.5.4. Bedrock drilling studies

GTK has drilled a total of 164 bedrock drillholes within the area surrounding the Vaara - Kauniinlampi komatiitic cumulate bodies, corresponding to a total length of 17 894, 35 m. Drill hole locations are shown in Figures 3.1.1.2.5.1b and 3.1.1.2.5.1c. Distribution of drilling within each of the cumulate bodies is as follows: Kauniinlampi, 69 holes (7 979.65 m); Hoikkalampi, 23 holes (2 362.70 m); Rytys, 16 holes (1 655.90 m) and Vaara, 56 holes (5 896.10 m). At Kauniinlampi, 19 holes intersected nickel mineralization, compared to 32 holes at Vaara. Most drilling (147 holes) were drilled with a 46 mm diameter drill bit, with only 18 holes drilled with a diameter of 56 mm.

3.1.1.2.5.5. Geological context, structural evolution, metallogeny and mineralogy of the Vaara - Kauniinlampi komatiitic-hosted nickel mineralization

Results of drilling indicate that the geological settings of the Hoikkalampi and Kauniinlampi occurrences are very similar to one another. Pelitic schists, intermediate volcanics and volcaniclastic sediments, amphibolites and tholeiitic basalts occur to the west of Hoikkalampi, with the latter being exposed in outcrops between Hoikkalampi and Kauniinlampi (Figure 3.1.1.2.5.1a). Towards the eastern margin of both the Hoikkalampi and Kauniinlampi cumulates is 25 – 50 m wide deformation zone consisting of heterogeneous breccias, chlorite-biotite schists, mafic volcanics, felsic rocks and rock assemblage containing relatively thick phyllitic units (Figures 3.1.1.2.5.5a and 3.1.1.2.5.5b). Immediately to the east of this deformation zone is a komatiitic olivine mesocumulate unit, at most 100 m in thickness, which is in tune followed by a lithologically diverse rock package consisting primarily of intermediate volcanics and volcaniclastic sediments. The Hoikkalampi and Kauniinlampi komatiitic cumulate lenses are both transected by a number of E-W trending Mg-tholeiitic dykes that cause segmentation of the magnetic response of the cumulates. In addition to these discordant E-W trending Mg-tholeiitic dykes, outcrops of gabbro were mapped on the eastern shores of the Kauniinlampi lake, which form part of a nearly concordant Mg-tholeiitic intrusion that can be traced along the western margin of the cumulate body.

The Hoikkalampi komatiitic cumulate body is about 1500 m in strike length and 500 m wide but is extremely poorly exposed. A total of 23 holes (amounting to 2 363 m) have been drilled in the Hoikkalampi area but the cumulate body is still poorly known. Lithologically it is relatively homogeneous, consisting primarily of rather coarse-grained (though serpentinized) olivine adcumulates. The Hoikkalampi cumulate body nevertheless seems prospective for nickel, as there is an extensive nickel anomaly in till parallel to the eastern margin of the lense (see Figure2.3.4c). Moreover, a mineralized glacial boulder (0.97 % Ni) was found in 1999, also to the east of Hoikkalampi (Figure 3.1.1.2.5.1a). Drilling in the northern part of the lense also delineated a 30 m wide zone the eastern margin, in which komatiites show conspicuous nickel depletion.

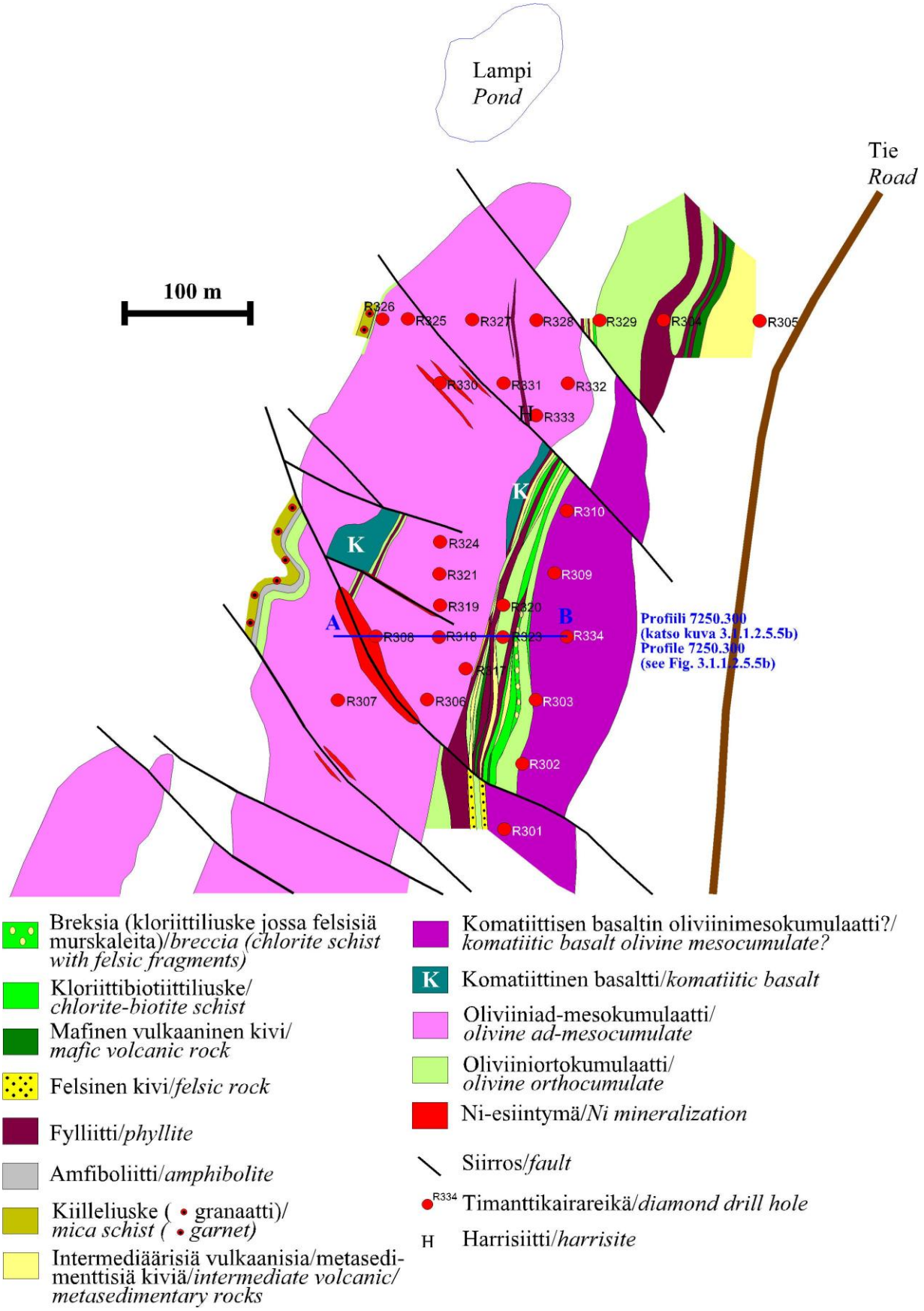


Fig. 3.1.1.2.5.5a. Geological map of the northernmost part of the Kauniinlampi cumulate lens, showing location of the Kauniinlampi North nickel occurrence.

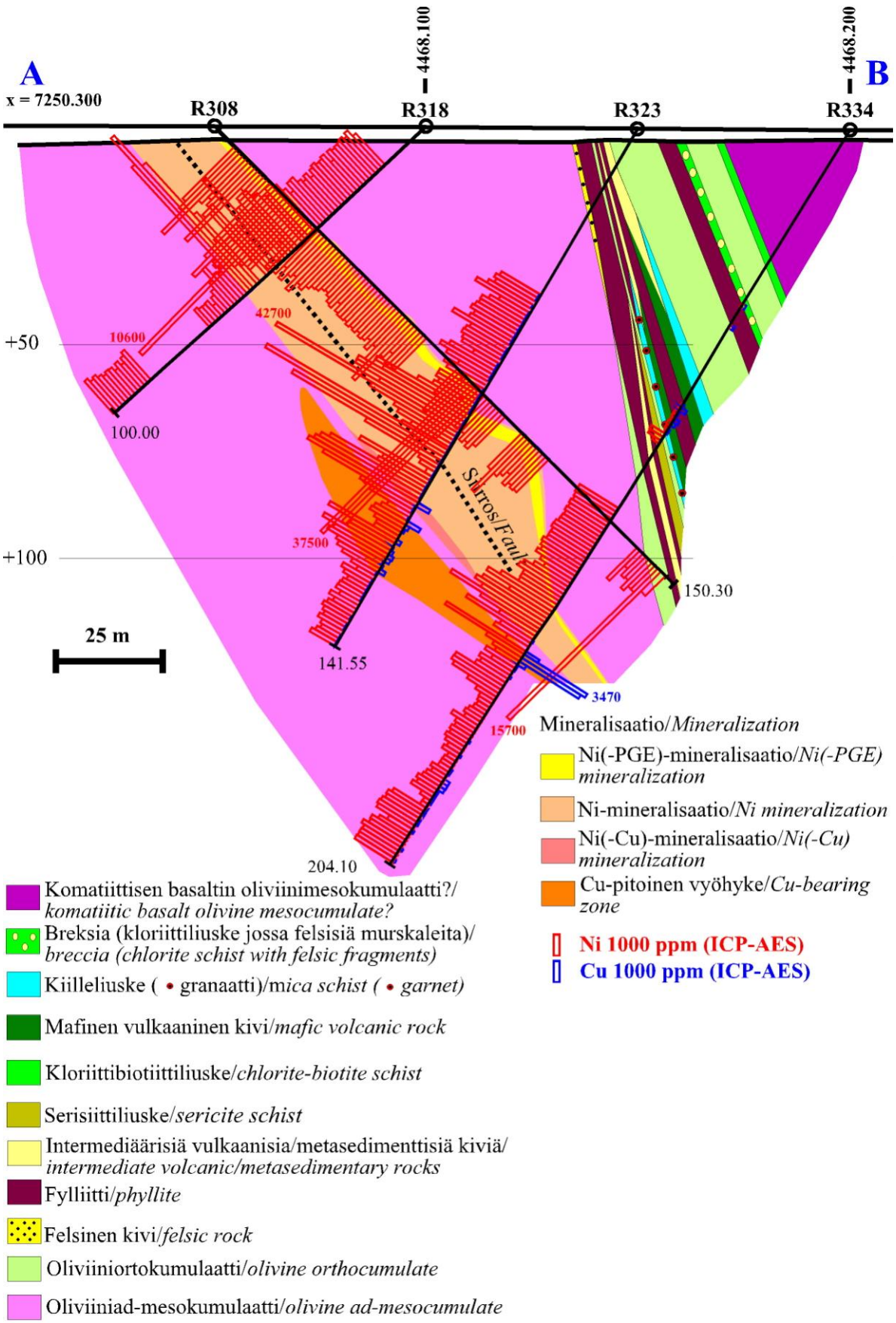


Fig. 3.1.1.2.5.5b. Cross-section profile of the Kauniinlampi North nickel occurrence for the interval A-B (blue line) in Figure 3.1.1.2.5.5a, showing variations in Ni and Cu content.

The Kauniinlampi komatiitic olivine cumulate lense is between 200 – 500 m in width and about 2 300 m in strike length, although if a northerly extension is included, the total length is about 3 400 m. The Kauniinlampi body is also poorly exposed, apart from a few outcrops and old exploration trenches (excavated by Kajaani Oy) in ultramafic rocks towards its southern end. A total of 70 holes (amounting to about 7 890 m) have been drilled in the Kauniinlampi cumulate body, as a result of which three separate nickel mineralizations were identified (Figures 3.1.1.2.5.1a, 3.1.1.2.5.1b and 3.1.1.2.5.1c). The Kauniinlampi cumulate body consists mostly of olivine mesocumulates and adcumulates in which the MgO content is somewhat lower when compared with the Hoikkalampi adcumulates. Harrisite has been recognized in the northern part of the main Kauniinlampi cumulate lense (Figure 3.1.1.2.5.5a), which allows an eastwards younging stratigraphic orientation to be deduced. Isolated occurrences of komatiitic basalts have also been found within this northern part of the cumulate body (Figure 3.1.1.2.5.5a). Graphitic shear zones are also sometimes observed in the olivine cumulates (Figure 2.6.2.3.2c).

The southernmost of the Ni-occurrences in the Kauniinlampi olivine cumulate lenses was also the last to be found, in April 1999, and has only been drilled in two places. The central Ni-occurrence is somewhat discontinuous and dispersed and was found in May 1996. This occurrence is dominated by pyrrhotite such that even though sulfur contents attain values of almost 2 %, nickel concentrations remain below 0.5 %. This is nevertheless quite typical for metal distribution in komatiites and the Kauniinlampi sulfide phases plot within the same field as Australian Archean nickel deposits on the Fe-S-Ni diagram (Figure 3.1.1.2.5.5c). The calculate mean sulfide phase composition for two samples from R565 was S = 34.9 %, Fe = 53 %, Ni = 10.5 % , Cu = 0.9 % and Co = 0.5 %. Sulfides occur principally as pyrrhotite and Ni-poor pentlandite (refer to Figure 2.6.2.3.3a). Relict magmatic olivine grains have also been found from this central mineralization.

The most thoroughly studied of the Kauniinlampi Ni-occurrences is the mineralization in the northern part of the cumulate lense, which was discovered in April 1997. This mineralization differs in style from the central occurrence in that it shows textural evidence for significant remobilization. Instead of being aligned within magmatic banding, which trends roughly N-S and dips subvertically eastwards at about 85° (Figures 3.1.1.2.5.5a and 3.1.1.2.5.5b), the nickel mineralization appears to be controlled by a NW-SE trending shear zone that dips at about 45° towards the NE. The highest nickel contents were obtained from drill core intersecting highly strained and altered olivine mesocumulates and adcumulates. Nickel contents in the sulfide mineralization range between 0.2 – 1.0 %, with a mean value of 0.45 %. Chalcophile elements (Ni, Co, Cu and platinum group elements) have been mobilized into different zones; at the + 40 m level below ground surface, copper is absent but at the + 80 m level there is a Cu-enriched zone (maximum Cu = 0.08 %) below the nickel mineralization (Figure 3.1.1.2.5.5d). Cobalt concentrations in the cumulates invariably correlate closely with those of nickel, although maximum values do not exceed 800 ppm. Platinum group elements, namely Pd and Pt are always associated with the uppermost part of the nickel mineralization; the highest value analyzed for total PGE was 2.9 ppm.

Sulfides in the disseminated part of the mineralization principally comprise intergrowths of Ni-rich pentlandite (mean Ni value of 37.5 %) and heazlewoodite (Figures 2.6.2.3.3a and 2.6.2.3.3b), with the latter mineral also occurring as narrow sulfide veinlets; neither pyrrhotite nor pyrite have been found. The nickel content of the sulfide phase is exceptionally high (Figure 3.1.1.2.5.5c) and the mean calculated sulfide phase composition is S = 31,3 %, Fe = 20 %, Ni = 47,5 %, Cu = 0,05 % and Co = 1 %.

If chalcophile elements have been mobilized and transported by metamorphic hydrothermal fluids, then the presence of corroded chromite grains (refer to Figure 2.6.2.3.2b) and almost complete destruction or dissolution of magnetite veins suggest that such fluids would have been

reducing. Chromite mineral chemistry suggests that they did not react or equilibrate with sulfide phases during crystallization since they have higher Fe_2O_3 contents than would be the case if they had crystallized coevally with sulfides within a magma. Further evidence for interaction with reducing fluids may be seen in the presence of thin graphitic veins within the serpentinized olivine cumulates.

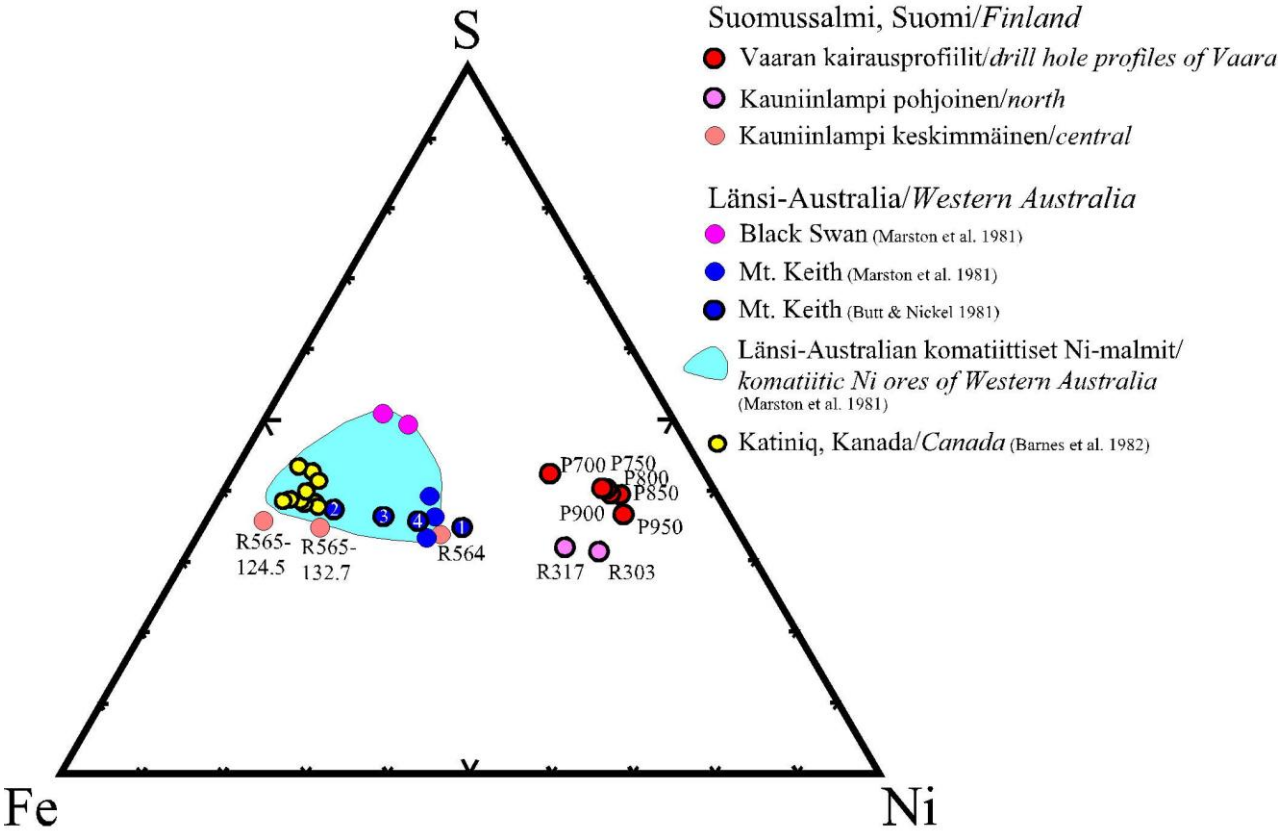


Fig. 3.1.1.2.5.5c. Compositions of sulfide fractions from Western Australia Ni sulfide ores (Marston et al. 1981, Butt & Nickel 1981), Katiniq in Canada (Barnes et al. 1982) and Ni mineralizations in the Vaara - Kauniinlampi area, Suomussalmi.

If this nickel occurrence is not in fact of primary magmatic origin, then longer in its original position with respect to magmatic processes, then the most likely sources for mobilized nickel (and other chalcophile elements) are 1) nearby cumulates; 2) primary magmatic nickel sulfide mineralization, or 3) both of these. Nickel could in principle be leached from surrounding komatiitic cumulates but the high PGE contents in the upper part of the nickel occurrence and the anomalous Cu-enriched zone below the mineralization indicate that the cumulates could not have been the only source. On the other hand, a sulfide melt within a komatiitic magma will likely preferentially sequester chalcophile elements from the surrounding silicate melt; later hydrothermal processes may then leach chalcophile metals that will be precipitated again under appropriate conditions.

Outcrops of ultramafic rocks are in general scarce in the Vaara – Kauniinlampi area (Figure 3.1.1.2.5.1a) but exceptions to this are the Vaara nickel occurrence, described later, and the Rytyskallio area, some 2.5 km north of the Saarikylä primary school, where the Rytys cumulate body is relatively well exposed over an area about 30 m in width and 2 000 m along strike. The Rytyskallio outcrops provide an excellent cross-section through an olivine cumulate sequence that formed within a rather extensive channelized komatiite flow system. The Rytyskallio section will be

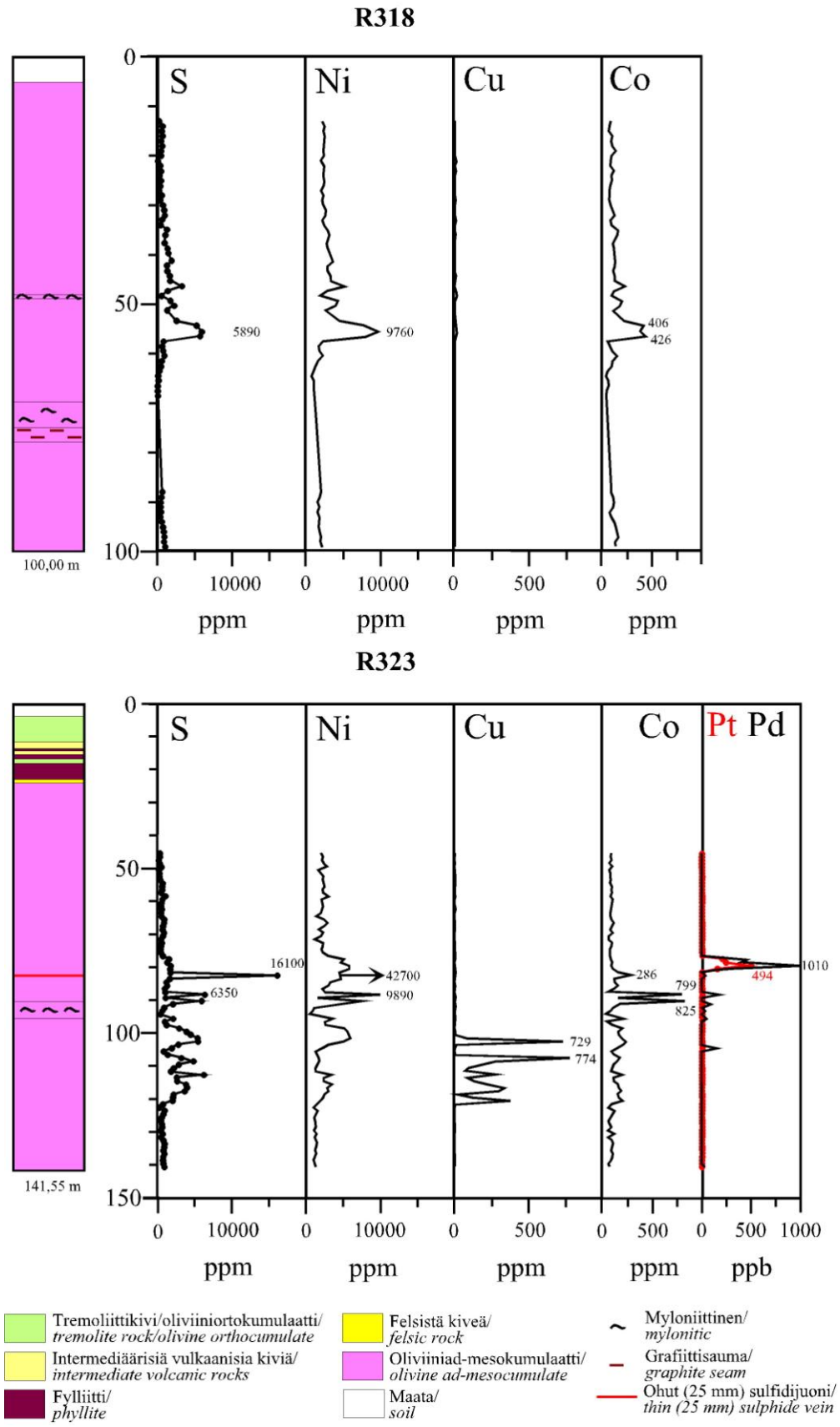


Fig. 3.1.1.2.5.5d. Variation in chalcophile element abundances in diamond drill holes R318 and R323 at the Kauniinlampi North nickel occurrence (see Figure 3.1.1.2.5.5b).

described in some detail, so as to provide further insights into the Hoikkalampi and Kauniinlampi cumulates, although Rytyskallio resembles the latter more than the former, which consists predominantly of coarse-grained olivine adcumulates.

Figure 3.1.1.2.5.5e is a geological map of the Rytyskallio area and Figure 3.1.1.2.5.5f depicts lithostratigraphical units as well as chemical variations in cumulate composition. At the western margin of the Rytyskallio outcrops, which represents the footwall, schistose, banded and locally mica-rich felsic metasediments are exposed and cut discordantly by a fine-grained massive and leucocratic feldspar porphyry dyke. An exploration trench excavated across the contact between these felsic rocks and the cumulates exposed a zone about 10 m thick consisting of chloritic and tremolitic schists. Irregular patches of chloritic and tremolitic rock are also found in the basalmost outcrops of the olivine cumulates, suggesting mechanical mixing and partial assimilation of felsic material, resulting in hybrid compositions.

As shown in Figures 3.1.1.2.5.5e and 3.1.1.2.5.5f, the topographically highest outcrops in the Rytyskallio area consist predominantly of komatiitic olivine mesocumulates with MgO contents between 39 – 46 %. The stratigraphic column in Figure 3.1.1.2.5.5f distinguishes three separate thicker units – two olivine adcumulates and a single “harrisitic” unit (Figure 3.1.1.2.5.5g). Recognition of olivine adcumulates is based on their MgO contents; as can be seen in Figure 3.1.1.2.5.5f, the MgO content of the lower adcumulate unit, which is nearly 60 m thick, is between 46.2 – 50.9 %, whereas the upper adcumulate unit, which is about 40 m thick, has MgO contents between 46.0 – 47.4%. The so-called “harrisitic” horizon varies in thickness from 5 –35 m and on weathered outcrop surfaces this rock is very pale in comparison to the grayish and rusty brown colors which are typical of cumulate outcrops. Diagnostic and convincing harrisitic textures, such as elongate prismatic olivine crystals have only been observed in a few exposures. Coarser pegmatitic textures have also been observed in several places.

The highest outcrops on Rytyskallio also include another unit that is reminiscent of harrisite, with well preserved textures in one outcrop in particular suggesting that this horizon indeed represents a flow hiatus within the komatiitic lava (Figure 3.1.1.2.5.5h). The uppermost sample from this unit also has the highest chromium value recorded in the entire sequence, of nearly 1.2 %. This “harrisitic” layer, with its distinctive pale color in outcrop, is readily distinguished from the overlying upper olivine adcumulate, which weathers to a characteristic rusty brown color. About 10 m stratigraphically above the olivine adcumulate is a series of darkish bands, each about 5 cm thick, representing alternating augite-olivine adcumulate layers (Figure 3.1.1.2.5.5i). Some 50 m further east is a tectonic boundary, juxtaposing the cumulate body against felsic metasedimentary rocks (Figure 3.1.1.2.5.5e).

The unit considered to have the greatest nickel potential is the lower olivine adcumulate layer. It is evident from Figure 3.1.1.2.5.5f that the chromium content of the lower (western) part of this adcumulate is distinctly lower (1 000 – 3 000 ppm) than in the upper (eastern) part (2 500 – 2 700 ppm, with a maximum value of 12 974 ppm). This is an important feature to recall when considering the variation in chromium abundances in the Vaara Ni-occurrence as well. This olivine adcumulate layer is also strongly depleted in nickel (Ni = 1 200 – 1 600 ppm, despite MgO contents greater than 46 wt %), at precisely the point where chromium concentrations increase markedly, from 1 120 ppm to 6 234 ppm. This location also coincides with the maximum recorded copper abundance of 413 ppm.

Drill hole R439 (FIN_KKJ4 grid coordinates = 7244,254N, 4466,495E) intersected a two meter interval that contained 0.51% Ni and 0.19 % S, as well as having anomalous palladium (141 –209 ppb) and platinum (56 – 1 040 ppb) abundances. This interval corresponds to the “harrisitic” unit outcropping on the highest exposures on Rytyskallio and apparently relates to the separation of

localized sulfide melt droplets during melt crystallization. A till sample from the eastern shores of the lake Kuivattulampi, in the southern part of the Rytys cumulate body, had a nickel concentration of 4120 ppm and subsequently, in 1999, several nickeliferous serpentinite boulders (0.44 % and 0.38 % Ni, refer to Figure 3.1.1.2.5.1a) were found some 450 m south of this till sample, at the extreme southern end of the Rytys cumulate body.

Parhaiten tutkitun Vaaran kumulaattilinssin geologia ja nikkeliaihe esitetään yksityiskohtaisesti. Vaaran kumulaattilinssi on n. 900 m pitkä ja enimmillään n. 500 m leveä. Suomussalmen vihreäkivijakson alueelliseen kartoitukseen liittyviä paljastumahavaintoja serpentiniitistä on muutamia. Engelin & Diezin (1989) julkaisussa Saarikylän alueelta, Luoman tienvarren serpentiniittipaljastumat on huomioitu. Kesällä 1998 GTK:n lohkare-etsintä Saarikylän Vaaran serpentiniittilinssin alueella johti sulfidipitoisten lohkareiden ja niiden lähtöpaikan paljastuman löytymiseen. Nopean kohteellisen selvityksen jälkeen aloitettiin tutkimuskairaukset, joiden yhteydessä tehtiin yhteensä 56 syväkairausreikää. Detaljikartoitus tehtiin vuonna 1999 mittakaavassa 1:1 000. Kartoituksen tuloksena syntynyt geologinen kartta on kuvassa 3.1.1.2.5.5j.

The Vaara lense is the best known of the cumulate lenses and therefore geological context and the nature of nickel mineralization will be described in detail. The Vaara cumulate body is nearly 900 m in length and has a maximum width of about 500 m. There are only a few exposures known, including outcrops of serpentinite adjacent to the road between Saarikylä and Luoma, already noted by Engel and Diez (1989). Glacial boulder investigations by GTK in 1998 in the Vaara area led to the discovery of serpentinite boulders containing sulfides and ultimately the outcrop from which they were derived. A total of 56 diamond drill holes were subsequently drilled in this part of the cumulate lense and the area was mapped in detail at a scale of 1: 1 000 (Figure 3.1.1.2.5.5j).

The ultramafic komatiitic cumulates represent crystallization from komatiitic magma within a turbulent flow regime. Under these conditions, the normal sequence of crystallization is olivine, chromite, clinopyroxene (augite) and possibly sulfides and orthopyroxene. Where subsequent hydrothermal alteration and deformation is less intense, cumulus textures are clearly discernible. Definitions and characteristic attributes of different types of cumulates are as follows:

Olivine orthocumulates (oOC) have more than 25 % intercumulus melt and whole rock chemical attributes as follows: MgO < 32 wt %, CaO > 5 wt %, Al_2O_3 > 5 wt % and TiO_2 > 0.4 wt %.

Olivine mesocumulates (oMC) have between 5 – 25 % intercumulus melt with the following chemical compositions: MgO = 32 – 45 wt %, CaO = 1 – 5 wt %, Al_2O_3 < 5 wt % and TiO_2 < 0.4 wt %.

Olivine adcumulates (oAC) have < 5% intercumulus melt and whole rock chemical compositions of MgO > 45 wt %, CaO < 1 wt %, Al_2O_3 < 1 wt % and TiO_2 < 0.2 wt %.

Cumulus nomenclature firstly assigns the dominant mineral phases (olivine = o, augite = a, chromite = c) in order of decreasing abundance, followed by textural style (orthocumulate = OC, mesocumulate = MC, adcumulate = AC) and finally intercumulus minerals, if present, denoted by an asterisk (for example, intercumulus augite = a*).

Cumulates that contain pyroxenes, such as olivine-augite mesocumulates (oaMC) or poikolitic olivine mesocumulates (oMCa*) and orthocumulates (oOCa*), in which poikilitic augite is the intercumulus phase, have somewhat higher abundances of CaO, Al_2O_3 and TiO_2 than olivine cumulates. The relatively rare harrisitic texture forms when there is a temporary hiatus in lava flow, which promotes rapid growth of already nucleating olivine crystals.

The serpentinized komatiitic olivine cumulates of the Vaara cumulate body include olivine orthocumulates (oOC), olivine mesocumulates (oMC), olivine-augite adcumulates (oaAC), pokilitic olivine-augite mesocumulates (oMCa*), poikilitic olivine orthocumulates (oOCa*) and harrisite. There are also some cumulates whose original textures have been obliterated by deformation, metamorphism and hydrothermal processes, such as soapstones and weakly magnetic massive serpentinites, that have nevertheless been classified on the basis of whole-rock geochemical composition (typically olivine mesocumulates). In addition to the above rock types, the komatiitic sequence can include pyroxenitic and gabbroic cumulates, for example in the upper parts of lava flows and where lava has mingled with and assimilated wall rock material.

Other primary textural features observed in the Vaara komatiitic cumulates include:

1. *Bimodal olivine grain size distribution*; olivine is present as both platy crystals favourable for buoyant transport in the melt (Figures 3.1.1.2.5.5k and 3.1.1.2.5.5l) and as equant euhedral grains that represent static, *in situ* crystallization;
2. *Fine-grained olivine cumulates* ; the western margin of the westernmost cumulate unit at Vaara comprises a fine- and even-grained olivine orthocumulate and mesocumulate lacking pyroxene. The intercumulus material is compositionally the same type of serpentine as in the pseudomorphed olivine grains, which are about 0.5 mm in diameter (Figure 3.1.1.2.5.5m). This rock type also contains most of the sulfide disseminations observed in outcrop in the Vaara cumulate body. Such textures are attributed to abundant crystal nucleation but relatively slow growth rates.

Ultramafic komatiitic lavas typically crystallize from magma within a laminar flow regime and form relatively thin sheet flows or flanking the margins of thicker cumulate systems. Original magmatic mineral phases have been replaced by metamorphic and hydrothermal tremolite, talc and chlorite. Primary flow-related features include pillow lavas, polygonal jointing and spinifex textures, as well as basal and flow-top breccias. Deformation and hydrothermal alteration have obscured these features in many places in the Vaara cumulates, an in addition to intense foliation development, such rocks are typically relatively pale in color and characterized by low susceptibilities.

Rocks with compositions corresponding to high-Mg basalts (MgO contents of 10 – 18 wt %) are rare in the Vaara area, having been found in only two dykes, one being gabbroic and the other a finer grained dolerite. Both dykes intrude the ultramafic cumulates. Tholeiitic mafic lavas are present in both the northern and southern parts of the Vaara area; outcrops in the south are of medium-grained gabbroic amphibolite, possibly representing the slowly cooled basal part of a thick lava flow, while those in the north have only been intersected in drillcore and consist of schistose fine-grained basalt.

Felsic volcanogenic rocks, including lavas and volcaniclastic deposits have been identified in drill core in the Vaara area, but so far have only been found in a single outcrop. An extensive area of heterogeneous felsic volcanics and volcaniclastic sediments occurs to the west of the Vaara cumulate lense but the predominant rock type found in drillcore consists of dark phyllitic sediments, with abundant mica and chlorite. Pyrrhotite and pyrite are sporadically present but graphite is not common. In the southern part of the area, one sedimentary section included a 35 m thick sericitic schist containing iron sulfide disseminations.

Mafic dykes at Vaara occur mostly in the central part of the cumulate lense, with discordant contacts against felsic volcanics and serpentinites. The relatively high TiO_2 abundances indicate that the dykes are not consanguineous with the komatiitic magmatism. In the lower part of drill hole R687, in the northern part of the Vaara area, a gabbroic unit showed a gradual transition to

tremolitic serpentinite, which may indicate an ultramafic component, originally as olivine pyroxenite, within the gabbroic dyke.

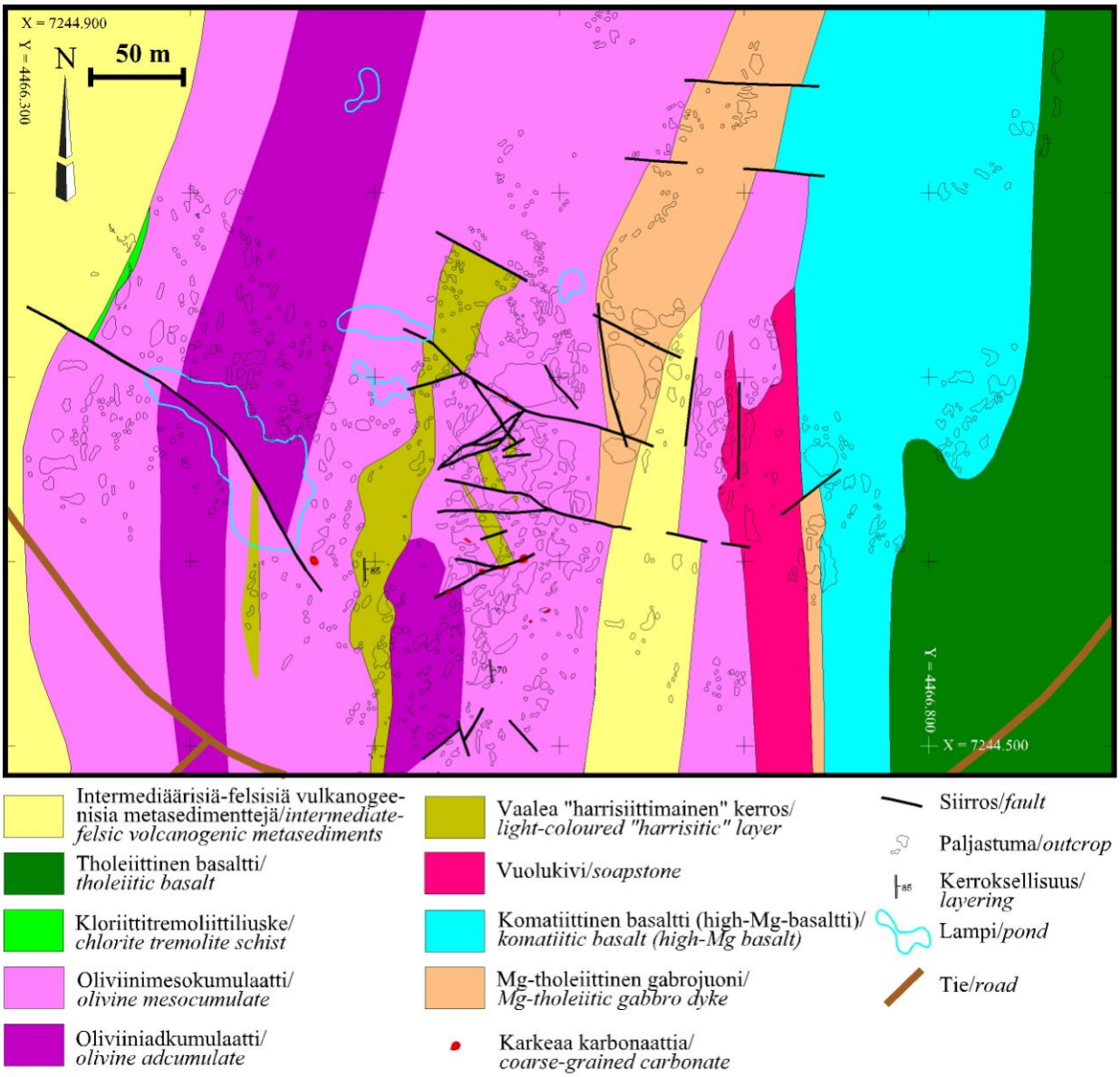


Fig. 3.1.1.2.5.5e. Geological map of the Rytyskallio area.

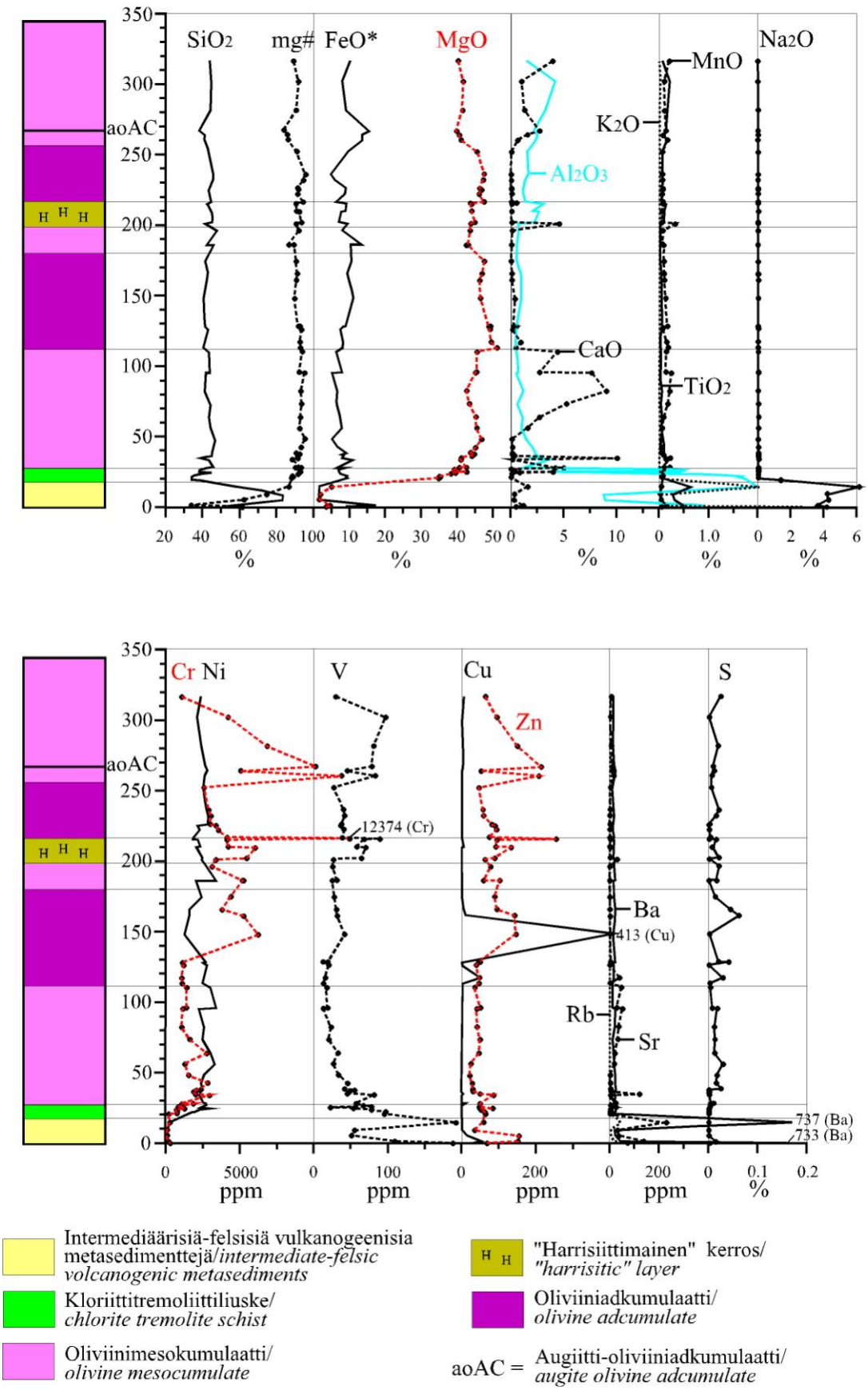


Fig. 3.1.1.2.5.5f. Stratigraphic sequence and elemental variations in komatiitic cumulates of the Rytyskallio area. Mg# = 100(MgO/40.3044)/((MgO/40.3044)+0.9(FeO/71.8464)).

Fig. 3.1.1.2.5.5g. Serpentinized olivine adcumulate, Rytyskallio. The length of the knife is about 20 cm. Photo by T. Halkoaho.

Fig. 3.1.1.2.5.5h. Serpentinized harrisite, Rytyskallio. The length of the knife is about 20 cm. Photo by T. Halkoaho.

Fig. 3.1.1.2.5.5i. Dark-coloured augite olivine adcumulate layers in serpentinized olivine mesocumulate, Rytyskallio. The length of the knife is about 20 cm. Photo by T. Halkoaho.

An almost N-S trending zone of nickel enrichment has been intersected in each of the eleven profiles drilled across the Vaara cumulate lense, thus delineating a mineralized zone some 450 m in strike length. Mineralization has also been observed in outcrop, at the initial site of discovery (FIN_KKJ4 grid coordinates 7242.995N, 4467.073E), at the location from which bulk samples were taken for processing tests (FIN_KKJ4 grid coordinates 7242.970N, 4467.067E), in exploration trenches (FIN_KKJ4 grid coordinates 7242.808N, 4467.073E) and in another natural outcrop (FIN_KKJ4 grid coordinates 7242.727N, 4467.030E). Abundant disseminated sulfides are present in both the discovery outcrop (Figure 3.1.1.2.5.5n) and at the site of sampling for enrichment tests.

The mineralized zone consists of from one to three distinct horizons, the richest being located at the interface between the Cr-poor and Cr-enriched cumulate layer (Figure 3.1.1.2.5.5o). Drilling in the northern part of the area showed that this interface also coincides with the presence of harrisitic texture. If a cut-off grade of 0.3 % for Ni is chosen to define the margins of the mineralization, then the ore grade resource varies in width from 2-3 m in the north to a maximum of about 50 m in the south (Figure 3.1.1.2.5.5p). The mineralization has been intersected in each profile, at a depth of greater than 50 m, and in the southernmost profile, at a depth of 170 –180 m below ground surface. It is considered unlikely that the disseminated type of mineralization characterizing the northernmost part of the occurrence would continue further northwards to any great extent. However, there is still a possibility that isolated massive sulfide lenses could be present in the basal parts of lava flows, even in the absence of disseminated sulfides or significant cumulates. It is difficult to constrain the likely depth extent of the mineralization since the enveloping surface and plunge of the ore intersections has not been established with certainty. Interpretation is further complicated by the abundance of faulting, although it appears that mineralization is aligned obliquely with a dip of about 30° to the southwest, meaning that correlation within and between profiles is not straightforward. For example, it was not possible to trace the best nickel intersection in drill hole R656, in the southern part of the field (Profile 7242.700 in Figure 3.1.1.2.5.5p) to the adjacent hole in the same profile, nor directly along strike to drill hole R696 in the next profile (7242.675). Moreover, the Ni/S ratio (0.5 – 1.0) of the best

mineralized zone in R656 differs significantly from that in the other holes (Ni/S > 1). At this stage the most interesting target for further investigation is the area associated with a weak EM real anomaly (FIN_KKJ4 grid coordinates 7242.600N, 4466.940E), which appears to be aligned with the best known mineralized zone.

Whole-rock nickel in sulfide contents for the Vaara mineralization generally vary within the range 0.25 – 1.40 wt %, with mean nickel contents between 0.35 – 0.80 wt %, depending on cut-off grade. In contrast to the northern mineralization occurrence at Kauniinlampi, all chalcophile elements at Vaara occur together (Figure 3.1.1.2.5.5q). Based on 432 samples from the mineralized zone, with Ni contents varying between 0.40 – 1.99 % (mean Ni= 0.62 %), the concentrations of other metals in sulfides area as follows: S 0.09 – 2.83 % (mean = 0.57 %), Cu 0.006 – 0.25 % (mean = 0.055 %), Co 88 - 399 ppm (mean = 155 ppm) and Pd 84 - 1 180 ppb (mean = 350 ppb). The Ni/S ratio is almost constant, varying between 0.5 –2.0 (mean= 1.2) and if the analyses from R656 (Ni/S < 1) and R647 (Ni/S > 2) are excluded, then Ni/S ratios are essentially in the range 1- 2. Despite this relatively uniform Ni/S ratio, Ni/Cu ratios vary widely from 2 – 64 (mean = 13.5). The Ni/1000*Pd ratio also shows considerable variation, from 7 – 60 (mean = 19). When the cumulate palladium and nickel abundances are compared, it is apparent from Figures 3.1.1.2.5.5r and 3.1.1.2.5.5s that the Vaara Ni-occurrence contains significantly more Pd at a given Ni value than the komatiitic-hosted nickel deposits of the Archean Yilgarn Craton in Western Australia. The same contrast is also apparent when data are compared with the Katiniq deposit in Canada.

Figures 3.1.1.2.5.5r and 3.1.1.2.5.5s show that the sulfide phase abundances for both metals are higher than in Western Australian Archean Ni-deposits. At Vaara however, this enriched value is likely to be a secondary phenomenon. The nickel contents of the sulfide phase can increase during metamorphism in two ways:

1. through liberation of nickel from the breakdown of olivine and
2. by consuming iron from the sulfide phase during the formation of magnetite (refer to Figure 2.6.2.3.3c).

However, enrichment in platinum group elements cannot be explained in the same way. The Katiniq deposit in Canada has a similar Pd/Ni ratio as at Vaara, yet Barnes et al. (1982) noted that these ratios are anomalous, being 5 –10 times higher than for other komatiitic nickel deposits and offered three possible explanations:

1. the original magma was exceptionally rich in PGE
2. partition coefficients were unusually large, or
3. the silicate/sulfide ratio was very high.

Barnes et al. (1982) argued that the original magma was indeed higher in Pd and Pt than typical Archean komatiitic magmas, and also have somewhat elevated Ti-, Zr- and Y- concentrations compared to komatiites at equivalent MgO compositions. According to Barnes et al. (1982), the Katiniq magma represents either a small degree of mantle melting, or melting of a mantle source less depleted than that from which most Archean magmas were derived. The komatiitic magma from which the Vaara cumulates crystallized was thus inherently richer in PGE than the sources for Western Australian Archean komatiites. Similar characteristics are also evident elsewhere within the Suomussalmi greenstone belt, in the Kiannanniemi area. For example the ultramafic cumulates at Peura-aho and Hietaharju both plot along the same trend as the Vaara population on the Ni vs Pd diagram in Figure 3.1.1.2.5.5r. Moreover, because the magma from which the Kiannanniemi cumulates crystallized was evidently poorer in MgO than the magma which formed the Vaara cumulates, the elevated PGE concentrations must be of mantle origin.

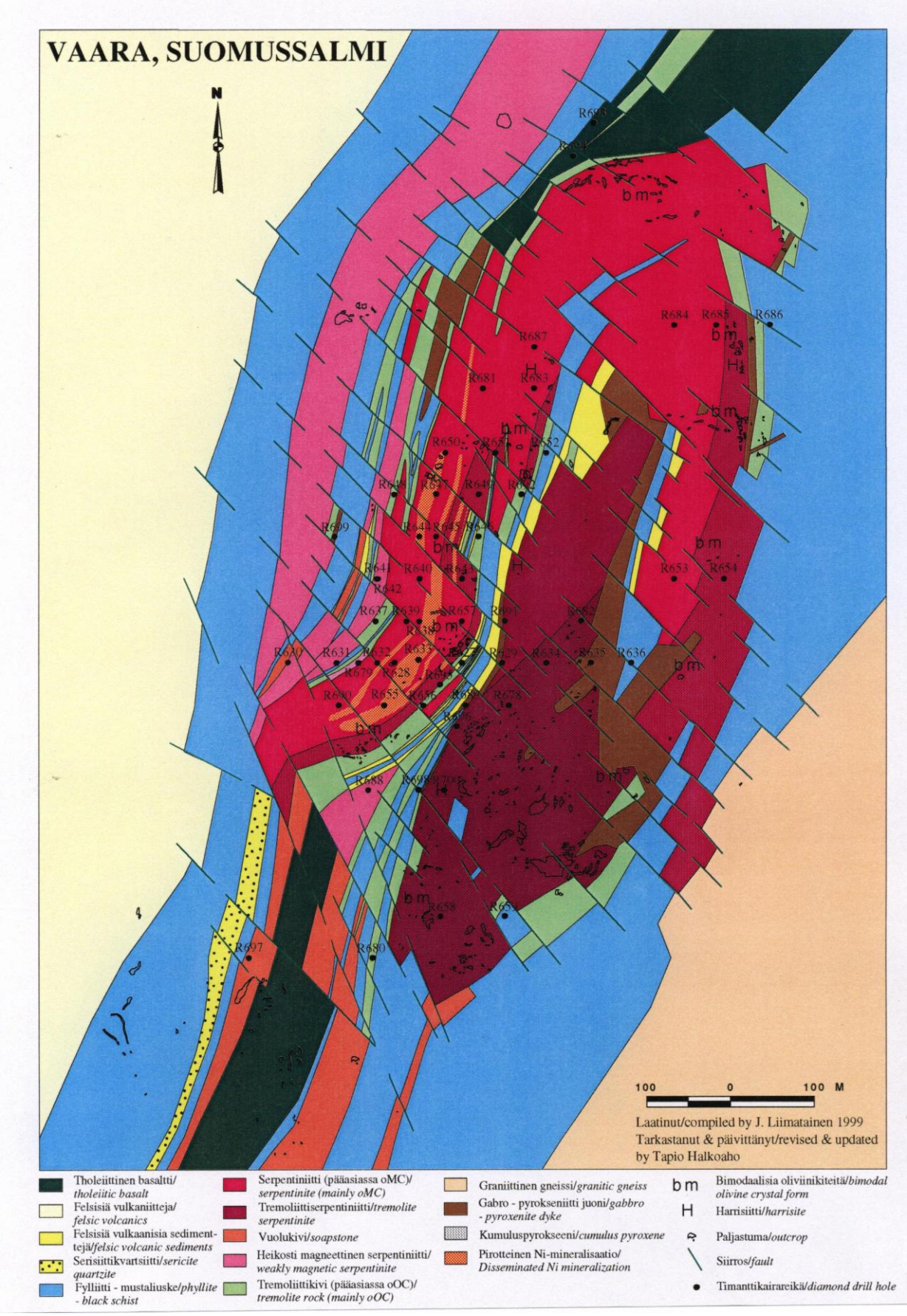


Fig. 3.1.1.2.5.5j. Geological map of the Vaara komatiitic cumulate lens, showing location of the Vaara nickel occurrence.

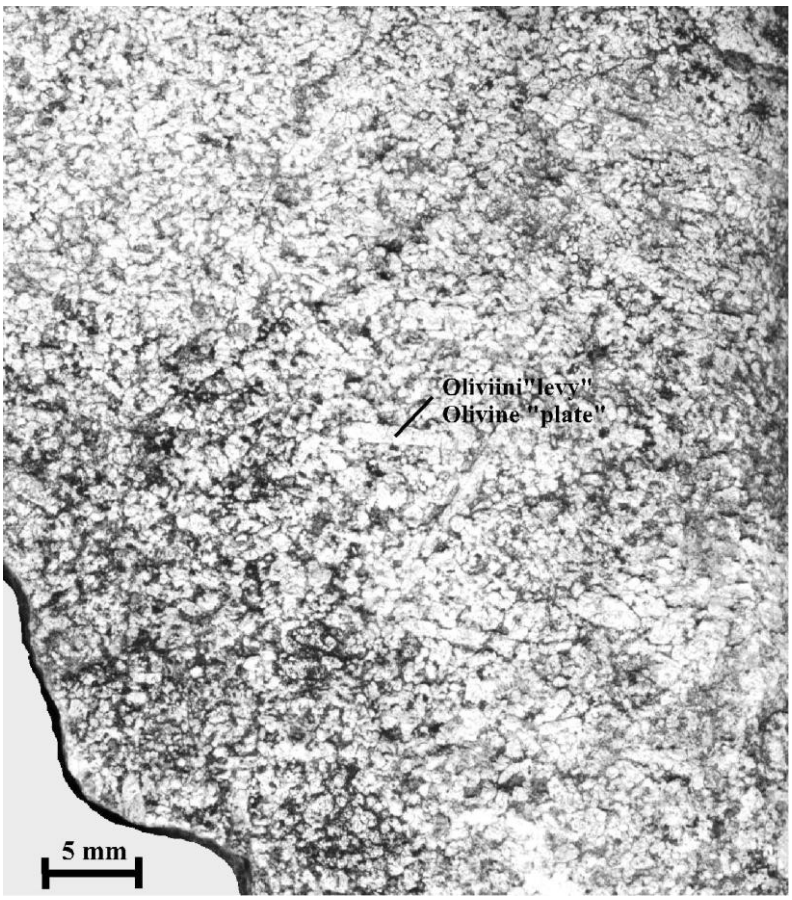


Fig. 3.1.1.2.5.5k. Serpentinized olivine orthocumulate, Vaara cumulate lens.

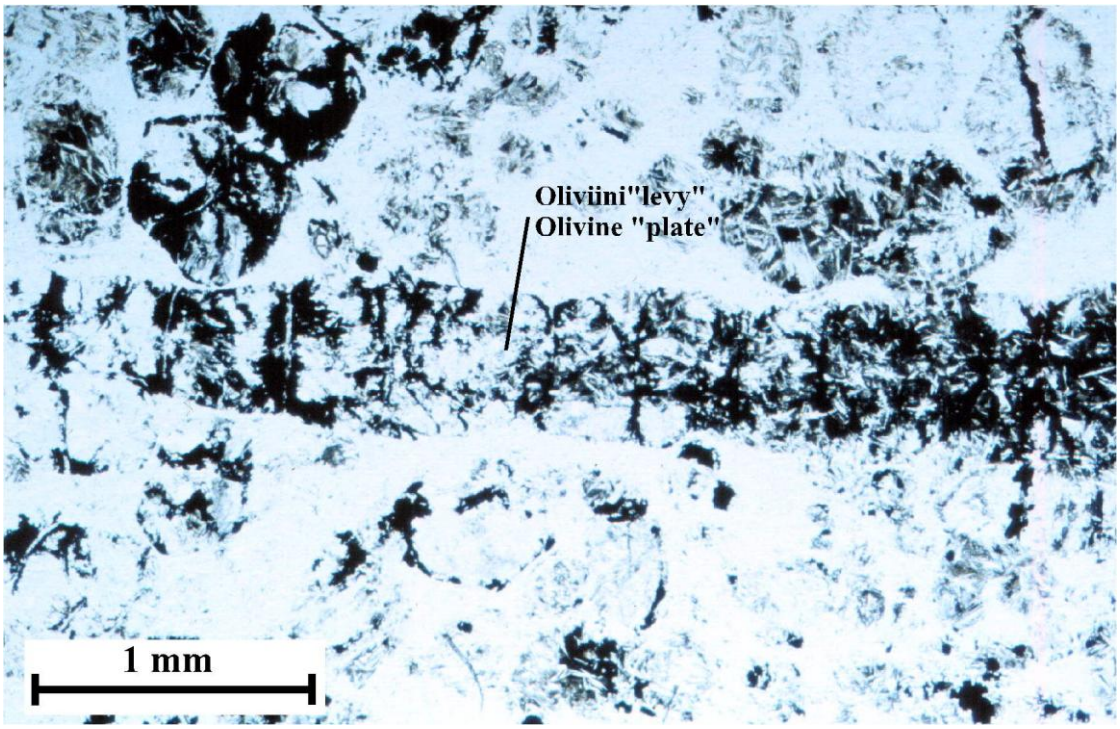


Fig. 3.1.1.2.5.5l. Platy olivine grain in serpentinized olivine orthocumulate, Vaara cumulate lens. Plane polarized light. Photo by T. Halkoaho.

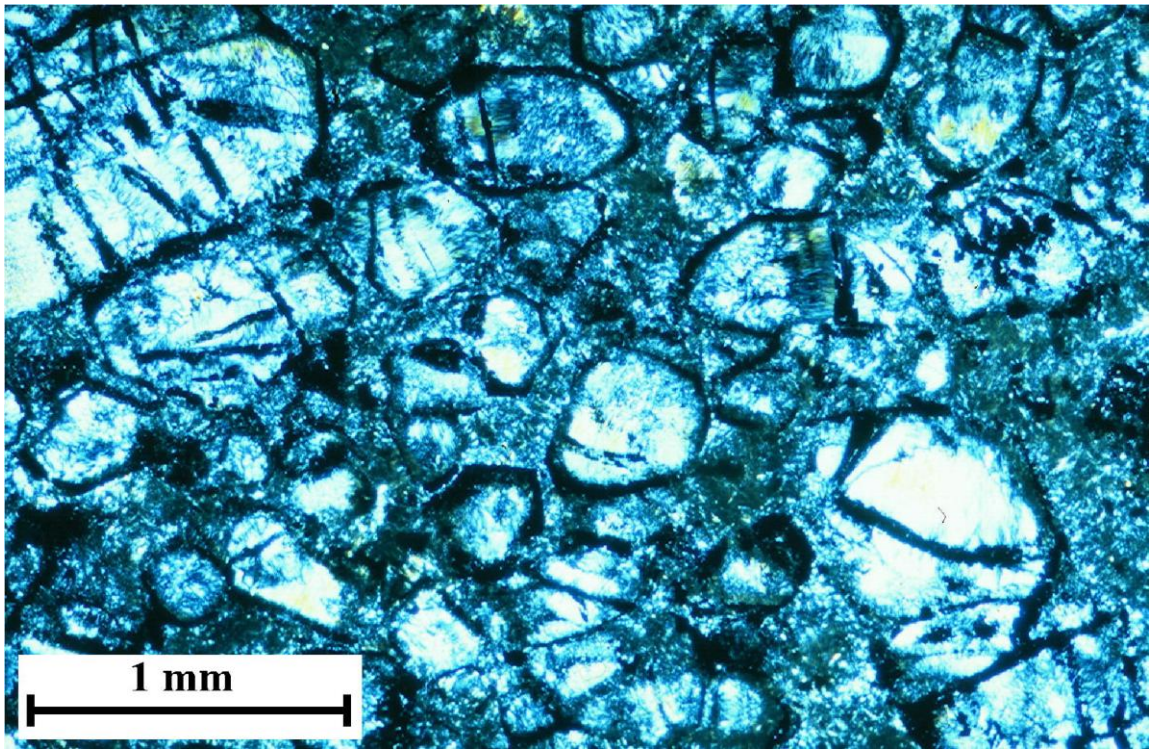


Fig. 3.1.1.2.5.5m. Serpentinized olivine orthocumulate, Vaara cumulate lens. Crossed nicols. Photo by T. Halkoaho.

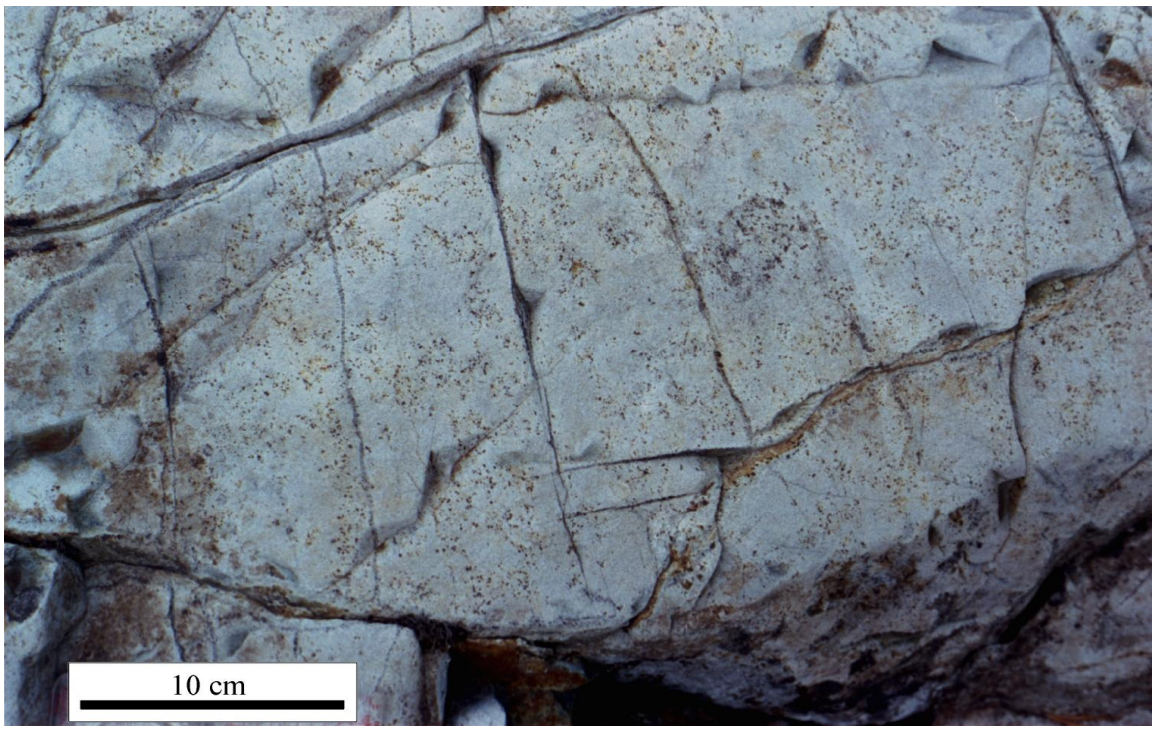


Fig. 3.1.1.2.5.5n. Outcrop of the Vaara nickel occurrence. Brown spots are millerite-pyrite-magnetite ”droplets” (see also Figure 2.6.2.3.3c). Photo by J. Liimatainen 1999.

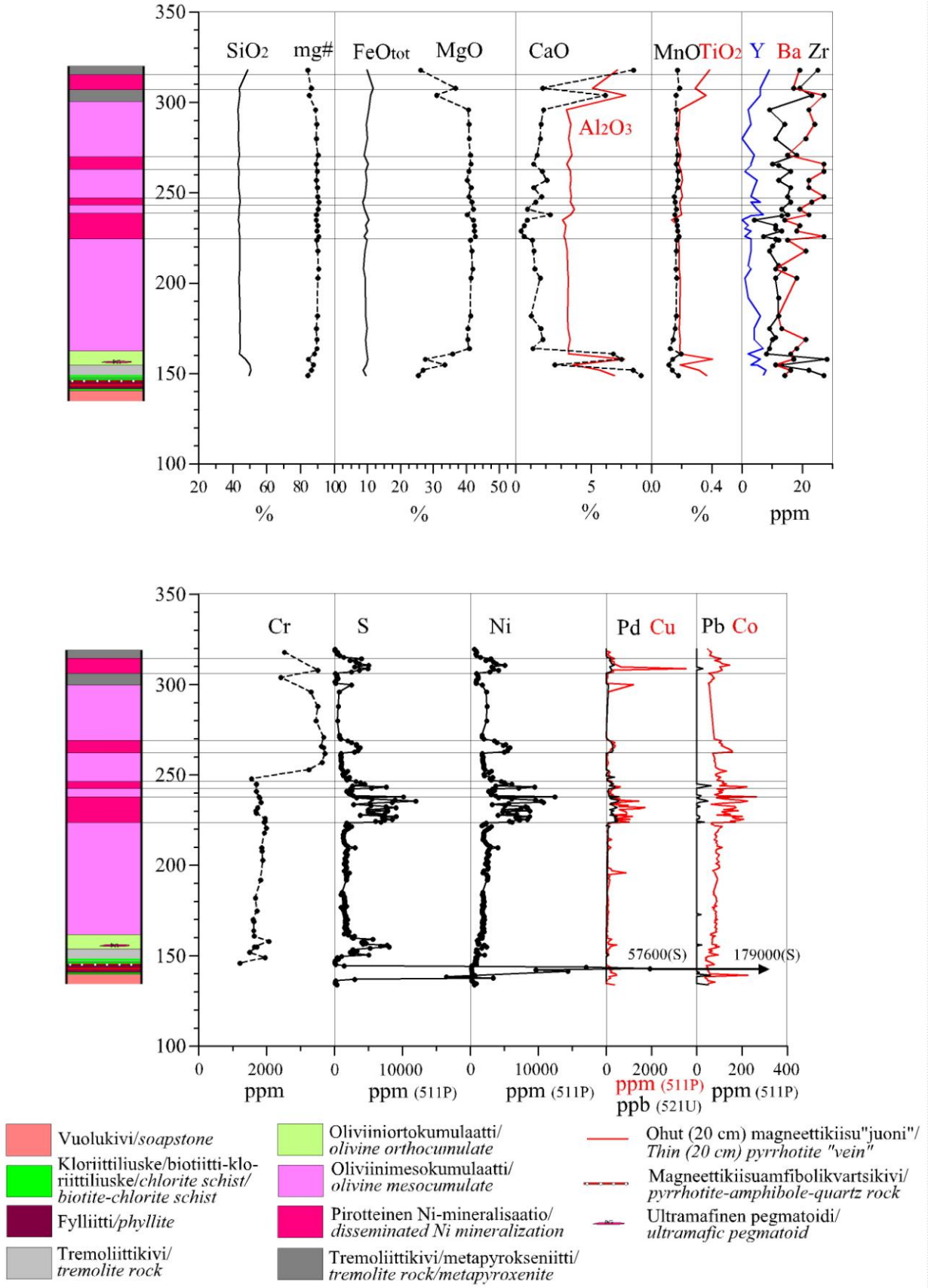


Fig. 3.1.1.2.5.5o. Elemental variations in the mineralized Vaara cumulate unit. Mg# = 100(MgO/40.3044)/((MgO/40.3044)+0.9(FeO/71.8464)).

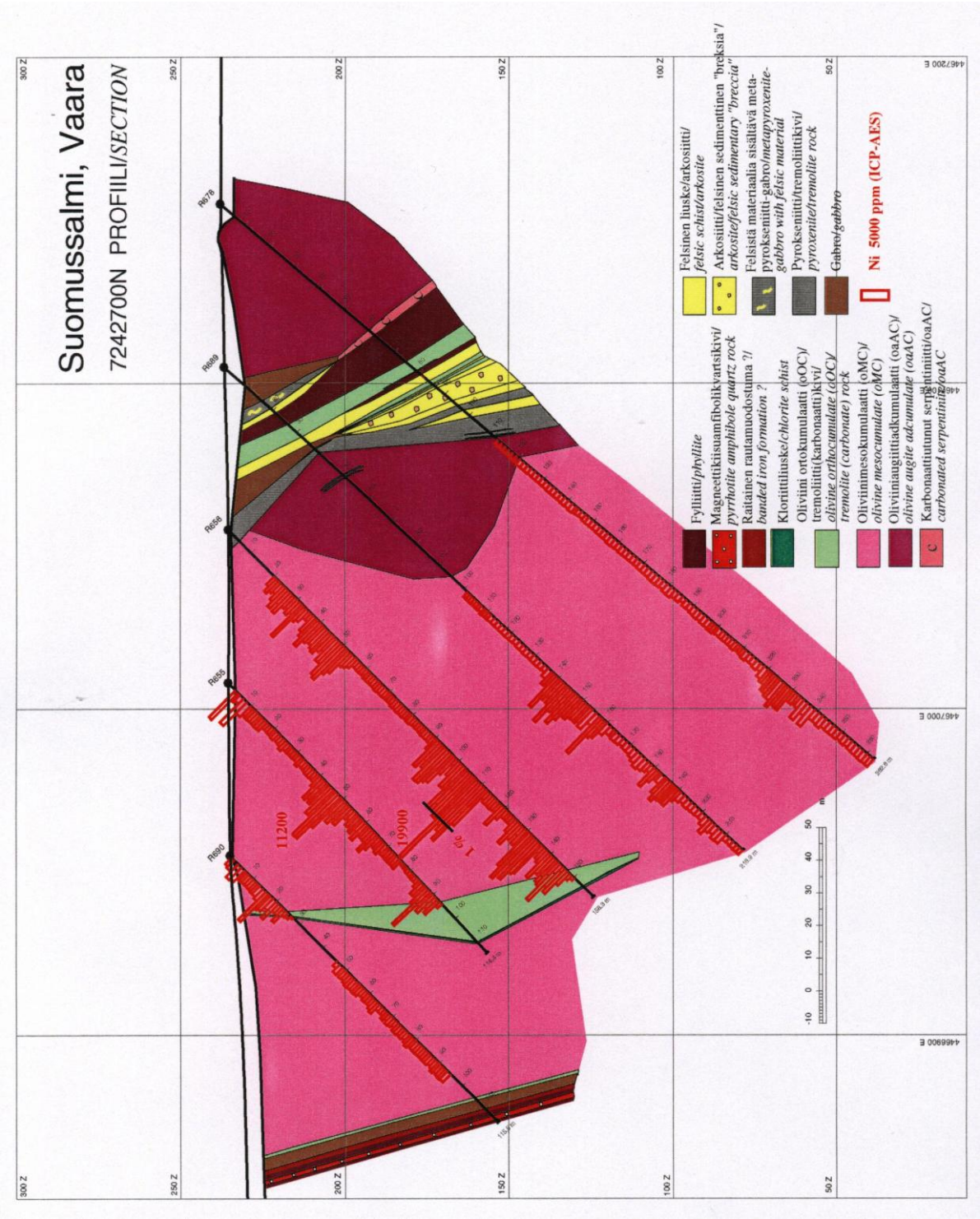


Fig. 3.1.1.2.5.5p. Southernmost diamond drill hole profile through the Vaara nickel occurrence, showing variations in Ni content.

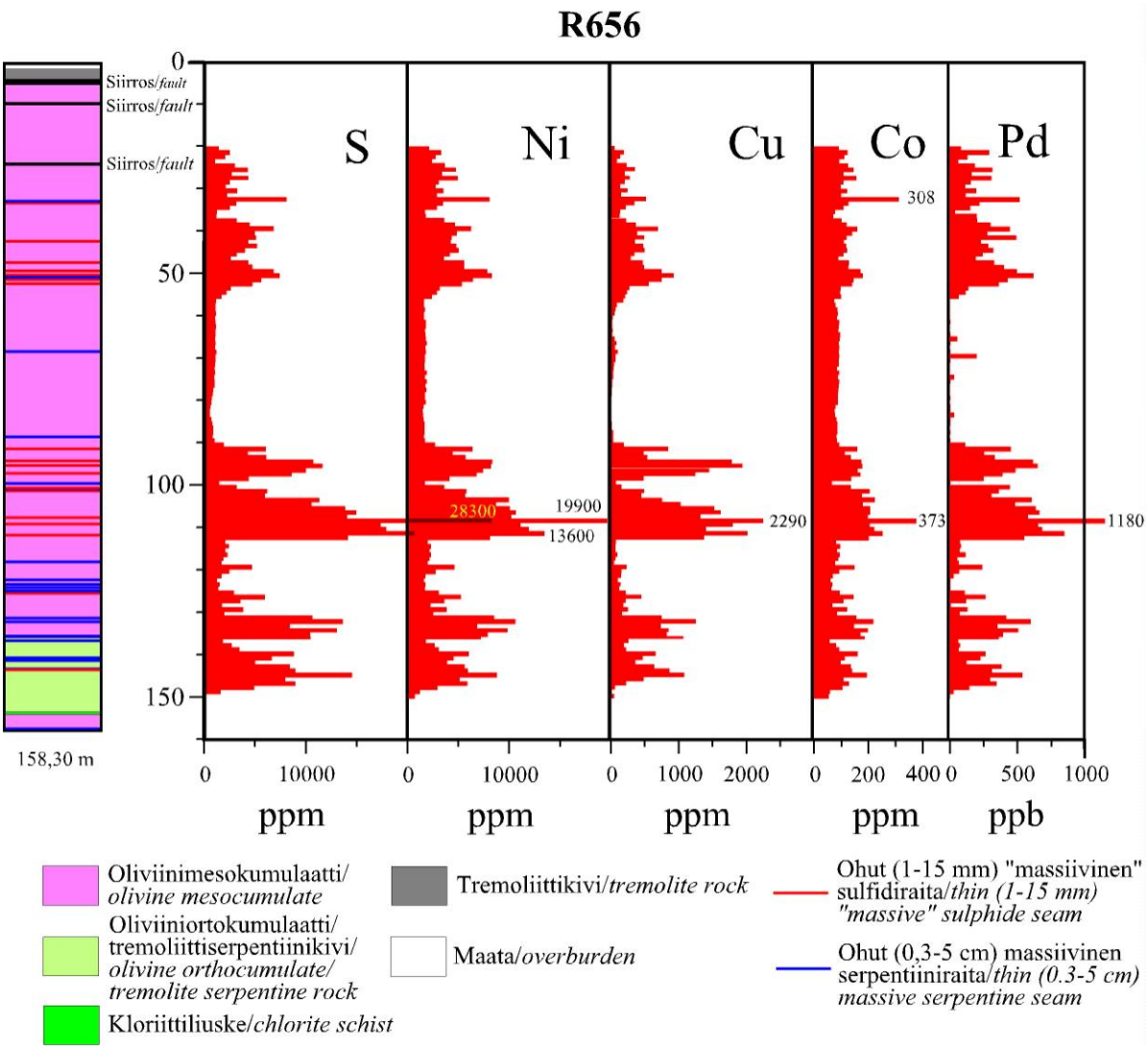


Fig. 3.1.1.2.5.5q. Variations in chalcophile element abundances in diamond drill hole R656 at the Vaara nickel occurrence (see Figure 3.1.1.2.5.5p).

There is still some uncertainty with respect to stratigraphical relationships – at present the felsic volcanics and phyllitic and graphitic sulfide-bearing sediments to the west of the Vaara cumulate lense are considered to stratigraphically below the serpentinites. On this basis, the lowermost unit in the ultramafic sequence consists fine-grained serpentinite that has low Cr contents in its basal part and is somewhat mineralized in its upper part. This unit passes upwards into a bimodal olivine mesocumulate and then to a pyroxene-bearing olivine mesocumulate and possibly komatiitic lava flow (now tremolite rock). The serpentinite is then overlain by fine-grained sediments. The entire sequence is intruded by gabbroic dykes that may be Paleoproterozoic rather than Archean in age.

Results of investigations in the Vaara – Kauniinlampi area were reported and submitted to the then Minsitry of Trade and Industry (Hintikka et al. 1999, Koistinen and Halkoaho 2000, Halkoaho et al. 2000). As a result of the subsequent tendering process, the exploration rights to the area were acquired by Outokumpu Mining Oy in 2000.

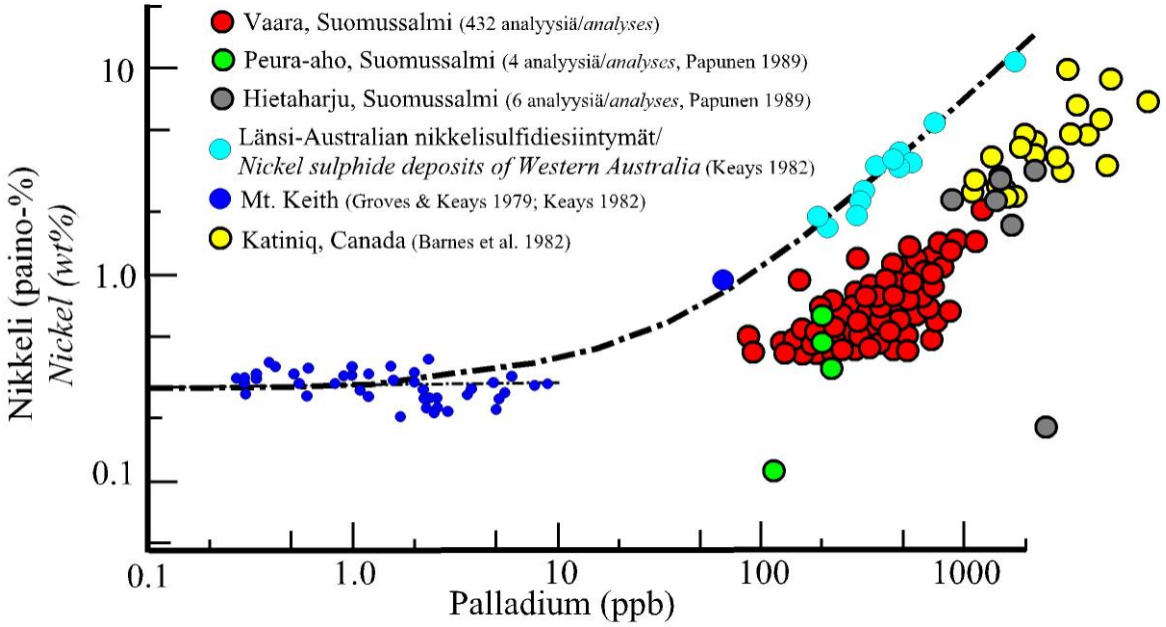


Fig. 3.1.1.2.5.5r. Plot of Ni and Pd contents for Suomussalmi nickel deposits (modified after Keays 1982). Note that all Vaara samples contain ≥ 0.4 wt% nickel.

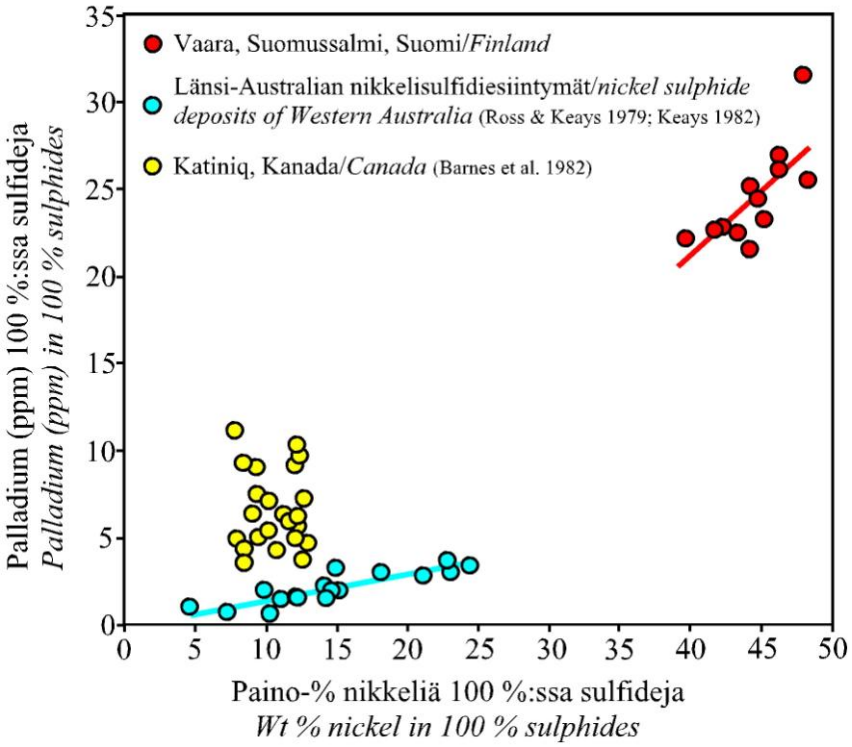


Fig. 3.1.1.2.5.5s. Variation of Pd as a function of the nickel contents of the mineral occurrences, calculated to 100% sulfides. In the case of the Vaara nickel deposit red circles represent average contents for different profiles across the mineralized zone.

3.1.1.3 Kiannanniemi area

The Kiannanniemi area (Figures 3b and 3.1.1.3a) also lies within Suomussalmi greenstone belt and thus contains felsic and intermediate volcanics and sedimentary units assigned to the 3 000 - 2 800 Ma Luoma Group and the younger phase of greenstone belt volcanism assigned to the

Saarikylä Group (Figure 3.1.1.3b). Despite intense deformation, primary eruptive and depositional features are well-preserved in the Kiannanniemi area, as for example the pillowed tholeiitic basalts shown in Figure 3.1.1.3c. The tholeiitic lavas are sometimes separated by intervals of cherty and sulfidic and graphitic sediments and are overlain by a felsic-dominated volcanic and sedimentary sequence with locally abundant sulfides. These felsic units were in turn followed by ultramafic volcanism, including the komatiitic cumulate host rocks to the Hietaharju and Peura-aho nickel occurrences. The komatiites were followed by a thin sequence felsic volcaniclastic deposits, prior to eruption of the uppermost volcanic unit, which consists of a distinctive suite of Cr-rich basaltic lavas. The entire greenstone sequence was deformed and intruded by granitoids relatively soon afterwards, with the main phase of granitoid emplacement being between 2710 – 2690 Ma, which gave rise for example, to the extensive domal patterns around the northern part of Kiantajärvi.

All of the above rock types were intruded by dyke swarms that fall into three distinct groups (cf. Vuollo, 1994), which are from oldest to youngest:

1. The oldest dykes, with chemical characteristics (though not tectonic setting) affine with boninites, are presumably 2440 Ma in age
2. Ti-rich Fe-tholeiites
3. Mg-tholeiites

On the basis of structural geometry and stratigraphic younging observations, the Kiannanniemi area is interpreted as a tightly folded synclinorium with numerous subsidiary synclines having fold hinges plunging towards the southeast. Younger deformation events have caused more complicated fold interference patterns and disruption by faulting, making it difficult, though not impossible, to resolve original stratigraphical relationships.

3.1.1.3.1. Gold exploration at Laukkasenniemi

During 1998, a number of mineralized rock samples containing gold were submitted to GTK from Laukkasenniemi, which is situated on the shores of the lake Kiantajärvi, to the north of the village of Kiannanniemi. As a result of these finds, the area was investigated in detail, leading to the discovery of further mineralized samples. The tendency for boulders to occur in small clusters in close proximity to one another and their irregular shapes suggested the possibility of fracturing in situ, or with only minimal transport, possibly involving alternating freezing and thawing in the Kiantajärvi basin, after deglaciation. Therefore, a local provenance was considered likely. Boulders all showed silicification, sericitic alteration and weak pyrite and arsenopyrite disseminations, all of which are characteristic features of hydrothermal alteration in proximity to gold mineralization.

An EM and IP ground survey was conducted at Laukkasenniemi in the area inferred to be the likely source of the boulders. An IP chargeability anomaly was delineated, and subsequent drilling showed that the eastern part of this anomaly coincides with bedrock pyrite disseminations; the western part of this anomaly remains unresolved as the drilling profile did not extend that far west. Ice cover on lake Kiantajärvi was sufficiently thick during March 1999 to provide access for drilling at Laukkasenniemi, with an E-W profile consisting of four holes being drilled, with a total length of 310.70 m, between FIN_KKJ4 grid coordinates 7235.500N, 4460.600E and 7235.510N, 4460.750E. Holes were drilled at an angle of 45° towards 270° and using T56 drill bits.

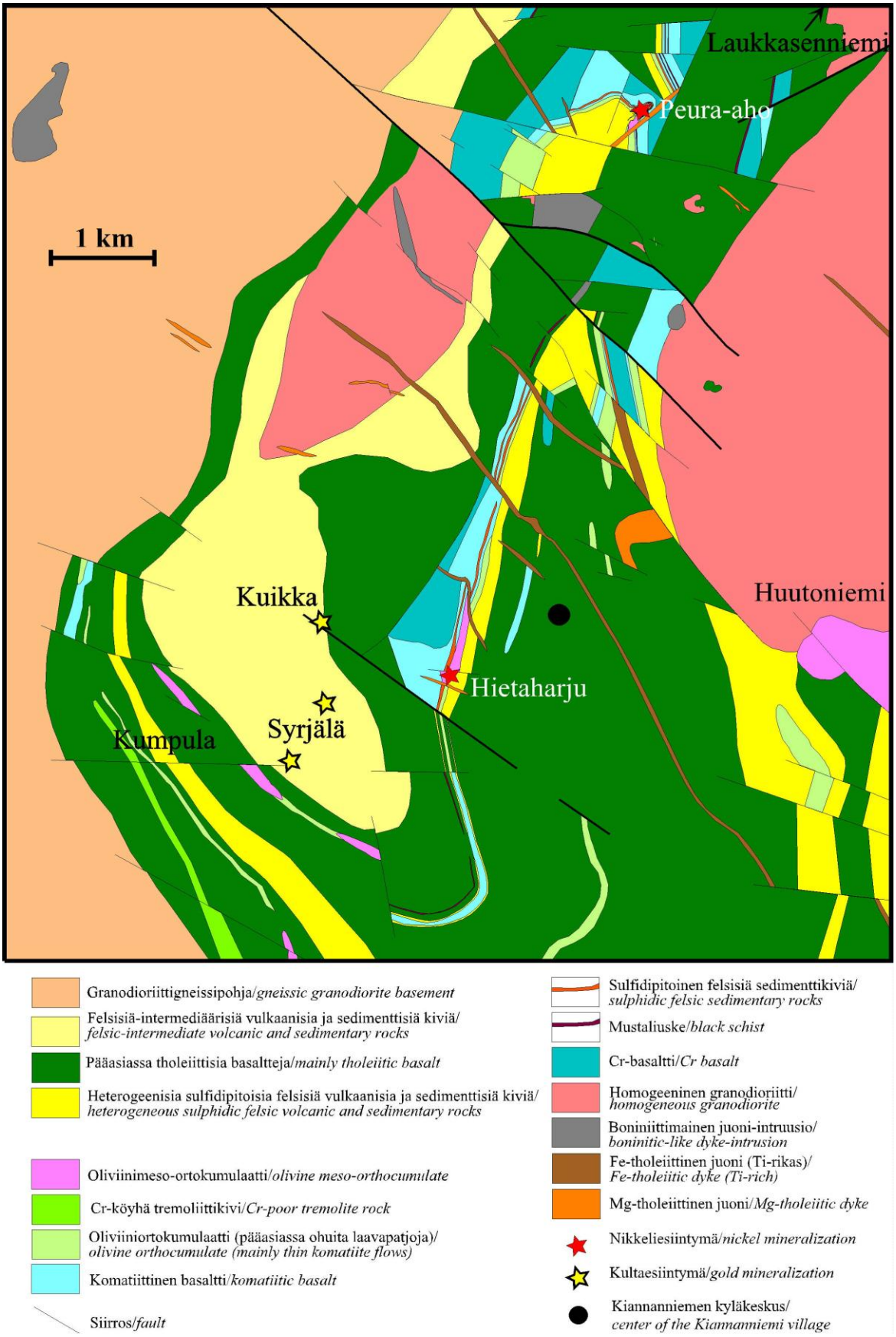


Fig. 3.1.1.3a. Generalized geological map of the Kiannanniemi area, Suomussalmi Greenstone Belt, showing gold and nickel occurrences.

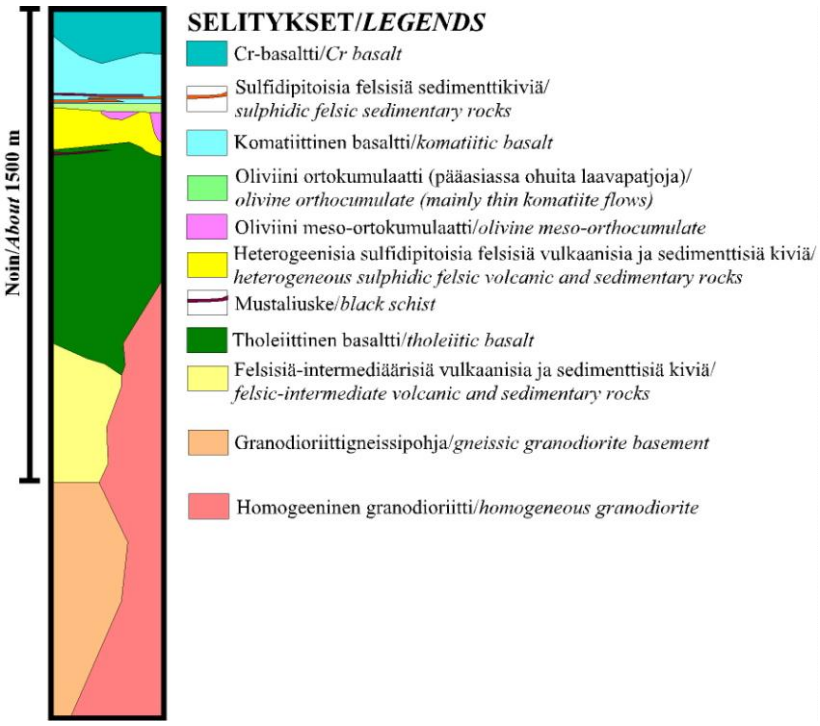


Fig. 3.1.1.3b. Generalized stratigraphy of the Suomussalmi Greenstone Belt in the Kiannanniemi area.

Fig. 3.1.1.3c. Tholeiitic basalt pillow lava in which light-colored gas vesicles occur mainly at pillow margins. The outcrop is situated in the southern part of Suottakangas area about 4 km north of the village of Kiannanniemi. The length of the knife is about 20 cm. Photo by T. Halkoaho.

A total of 231 Au and Te analyses were made from split core samples, representing continuous one meter intervals. Results were exceedingly modest, the maximum Au value being only 66 ppb and the majority of the core had values below detection limit of 10 ppb. Rocks intersected in drilling were predominantly plagioclase- and amphibole-bearing intermediate volcanics, occasionally with relict primary textures, and discordant granitic veins. The rocks are also highly strained such that in some places their original nature is no longer discernible. Associated silicification, sericitization and sporadic pyrite dissemination were not found to be more anomalous with respect to gold than less deformed and altered rock types.

3.1.1.3.2. Kuikka gold occurrence

Investigations into the gold prospectivity of the Kiannanniemi area began in 1995, following detailed bedrock mapping which commenced in 1994 and continued through 1997 to 1999. Investigations at first focussed on the area surrounding the Syrjälä farmstead, which is described in Section 3.1.1.3.3. However, in 1998, emphasis shifted to the Kuikkapuro area, where Väinö Kemppainen, an enthusiastic amateur prospector had found a number of auriferous glacial boulders, for which he subsequently received due recognition and a reward from GTK. Geophysical surveys and drilling commenced in the area soon after.

Systematic Slingram and magnetic surveys were made, with a more detailed magnetic survey over the contact zone between the alteration zone and mafic volcanics. Key petrophysical parameters (density, susceptibility, remanence and resistivity, at three frequencies) were determined from three of the mineralized samples submitted by Kemppainen. Down-hole geophysical logging was also undertaken, measuring natural total gamma radiation (from 3 holes), susceptibility (from 13 holes) and Wenner resistivity (from 12 holes).

The susceptibilities of mafic volcanics is rather uniform (0.0025 SI) but in the mineralized alteration zones, values range considerably, between 0.002 – 0.003 SI, with anomaly maxima corresponding to variations in the abundance of pyrrhotite. Down-hole resistivities varied from several hundred to several thousand ohm meters and the observed resistivity distribution can be understood to correlate with high strain deformation zones and variations in the amount of quartz. However, laboratory measurements also indicated some degree of dependence between orientation and resistivity. Total gamma radiation results were not particularly informative; it would have been more useful to measure the entire spectra, so that the proportions due to different components could be assessed and better correlated with rock types and structures.

Detailed magnetic surveys were made to follow the mineralized zone, using a 10 m line spacing and 5 m point spacing. This enabled the recognition of a number of discrete small, if variable susceptibility anomalies that could be traced with the aid of careful ground surface measurements (Figure 3.1.1.3.2a).

Between December 1998 and September 1999 a total of 52 holes were drilled, with a total length of 4 359 m, using a T56 drill bit and drilling rigs operated by both GTK and commercial contractors. The first hole drilled, R361, intersected mineralization with visible gold (Figures 3.1.1.3.2b and 3.1.1.3.2c), to which the name Kuikka was applied. Drill core was logged and sawn, with halved sections submitted for chemical analysis. In general analyses were made from one meter sections, with some degree of flexibility to accommodate significant changes in rock type, alteration or structural breaks.

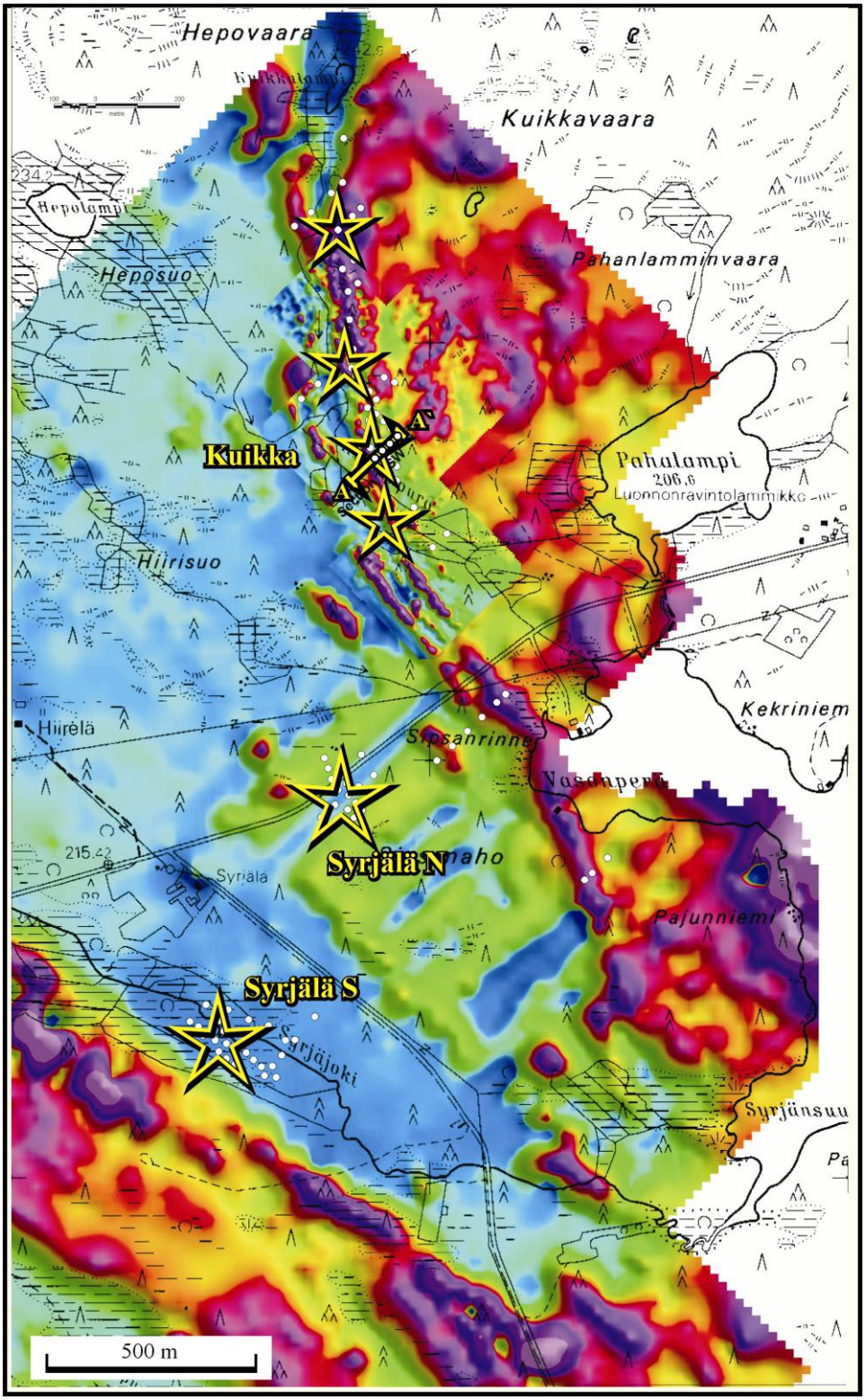


Fig. 3.1.1.3.2a. Ground magnetic map of the Kiannanniemi area, Suomussalmi, with drill hole locations indicated by white dots.

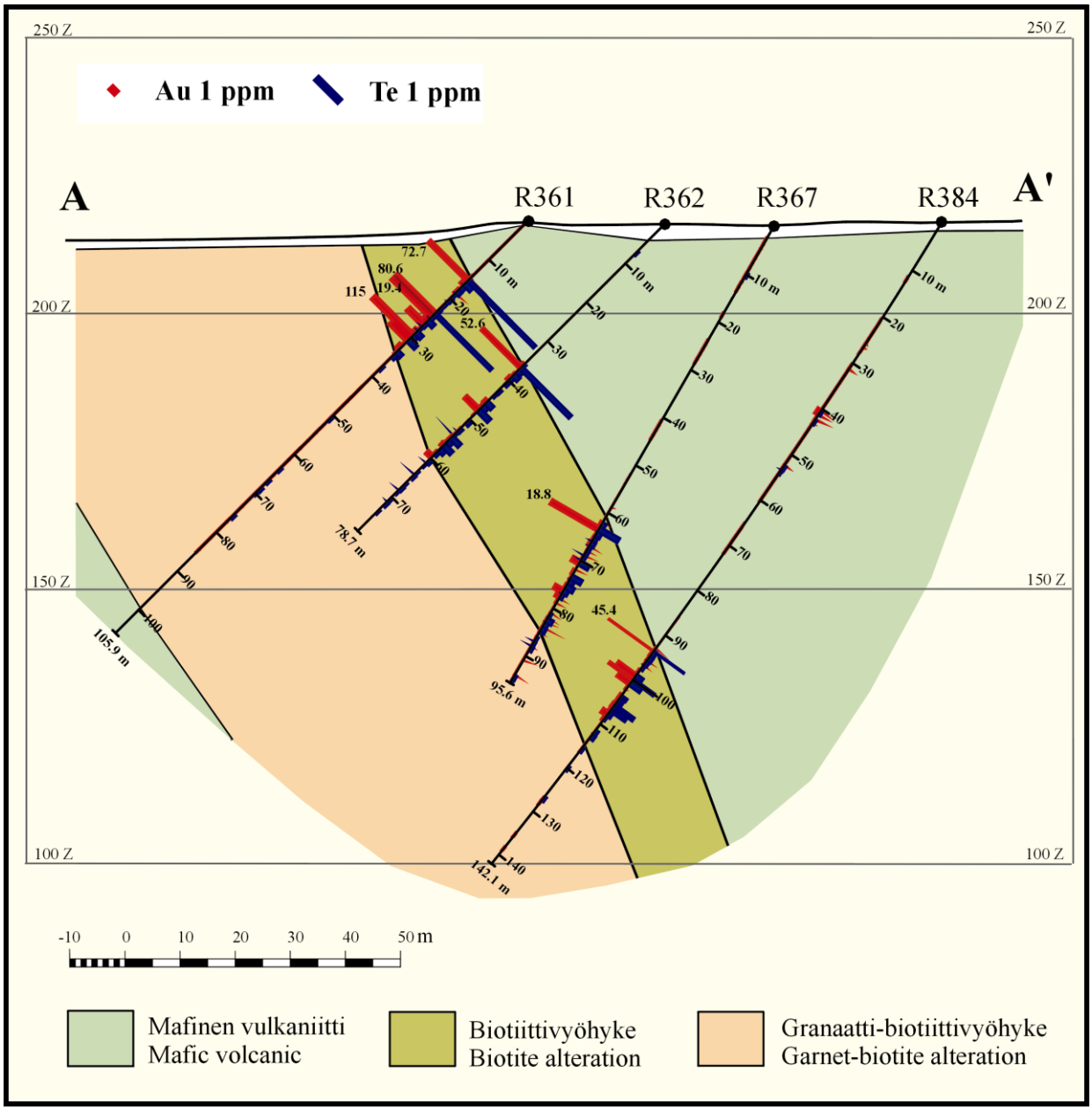


Fig. 3.1.1.3.2b. Drilled section at '10 SW' through the Kuikka mineralization, showing the zones of alteration zones and abundances of gold and tellurium.

A total of 1 231 ICP-AES analyses were obtained for the elements As, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Ni, P, Pb, S, Sb, Sr, Ti, V and Zn, while Au and Te were analysed from 2 441 samples by GFAAS. Figure 3.1.1.3.2b illustrates the strong positive correlation between Au and Te. Arsenic and gold do not show such good mutual correlation, even though arsenopyrite is usually present to some extent in mineralized rocks (Figure 3.1.1.3.2c). A total of 15 whole-rock XRF analyses were done and 29 thin sections were prepared from drill core.

To optimize the value of drill core, orientations were measured routinely and results of down-hole geophysical measurements were used to correlate anomalies recorded from different rock types in ground geophysical surveys. It proved possible to trace the gold-anomalous zone, which is associated with deformed, highly altered rocks, within a discrete zone, nearly 2 km long, confirmed by drilling along its entire length.

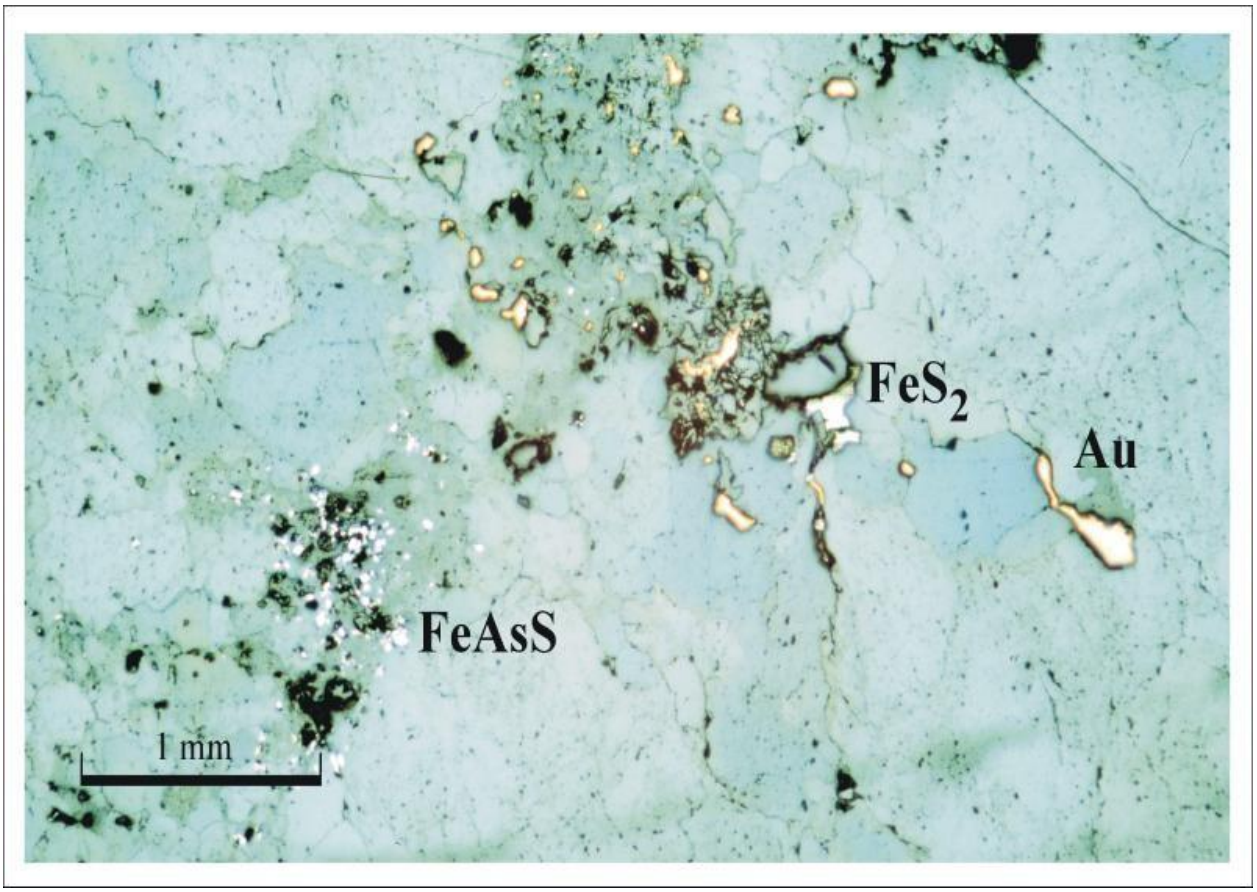


Fig. 3.1.1.3.2c. Gold (Au), arsenopyrite (FeAsS) and pyrite (FeS_2) in quartz vein from drill core R361/24.20m, Kuikka gold mineralization, Suomussalmi. Note that gold occurs as discrete metallic grains separate from arsenides and sulfides.

The hanging wall sequence to the east of the mineralized zone at Kuikka consist of fine-grained green amphibole- and plagioclase-bearing mafic volcanics, with sporadically preserved volcanic and pyroclastic textures; in these rocks there is little evidence of hydrothermal alteration, with very little biotite or sulfides.

The contact with the mineralized zone to the west, which is from 10 –20 m thick, is rather abrupt, and the most strongly mineralized rocks are characterized by intense silicification and biotite formation. The highest gold contents tend to occur within deformed, bluish or brownish quartz veins immediately beneath the hanging wall, varying from several centimeters to nearly one meter in thickness. The abundance of quartz veins varies considerably but appears to generally diminish downwards, subparallel to drill hole direction, towards the southwest. Sulfide minerals, both pyrite and pyrrhotite, are common in this zone and disseminated arsenopyrite is also present in variable amounts (Figure 3.1.1.3.2c). Gold concentrations vary considerably, as is evident from Figure 3.1.1.3.2b.

The biotite-altered zone in general shows a gradual transition to garnet-biotite rock, with a steadily increasing proportion of garnet. The proportion of sulfides and arsenopyrite conversely diminish but they are still more abundant than in unaltered mafic rock. Although the garnet-biotite alteration zone contains quartz veins that superficially resemble those in the gold mineralized zone, gold and tellurium concentrations nevertheless fall sharply, though the latter is still somewhat anomalous.

The alteration zones at Kuikkapuro are strongly deformed, foliated and folded; quartz veins in particular are tightly folded. The deformed structures are truncated by ophitic dolerite dykes, demonstrating that the alteration and deformation are of Archean age. Moreover, the country rock foliation, which is slightly oblique to the alteration zone may predate the discrete regional scale shear zones that can be discerned in the airborne magnetic images. It is therefore possible that hydrothermal alteration at Kuikka, and gold mineralization, predate some of the major late orogenic deformation events that affected the Kuhmo and Suomussalmi greenstone belts.

The alteration zones at Kuikka include a diverse range of minerals that have been used to deduce P-T evolution and peak metamorphic conditions. According number of microprobe studies were made at the GTK Otaniemi laboratories of mineral pairs in different alteration zones. Results indicated however, that the minerals assemblages did not represent stable metamorphic equilibration, and that calculated pressure and temperature estimates are unreliable; pressures in particular were overestimated and would have implied extensive partial melting, which is inconsistent with the observed mineral assemblages and textures.

A report of investigations carried out at Kuikka was submitted to the then Ministry of Trade and Industry in 2000 (Pietikäinen et al., 2000) and after a due tendering process, the exploration rights were transferred to Outokumpu Mining Oy.

3.1.1.3.3 Gold occurrences at Syrjälä

A number of mineralized boulders containing gold were found in the Syrjälä area in 1995, while till geochemical investigations revealed the presence of anomalous Au, As and Te in the same area. A total of five targets were drilled, known as Syrjälä S, Syrjälä N, Tupakkiloma, Kumpula and Kuikka; the last two of these are described separately in Sections 3.3.1.3.4 and 3.3.1.3.2. The Syrjälä gold occurrences have been described in a report submitted in 2000 to the then Ministry of Trade and Industry (Pietikäinen et al. 2000).

Bedrock in the Syrjälä area is typically buried beneath a thin (< 5 m) blanket of till, which had already been sampled during local scale geochemical surveys (16 samples / km^2), indicating some potential with respect to gold prospectivity. During detailed follow-up studies, chip samples from the bedrock interface were collected using a percussion drill, using a 10 m profile spacing (Figure 3.1.1.3.3a). These studies were supplemented by detailed magnetic (Figure 3.1.1.3.2a) and IP surveys (Figure 3.1.1.3.3b).

Bedrock in the Kiannanniemi area consists principally of intermediate and mafic volcanic rocks that have been strongly deformed, with a prominent lineation and abundant mylonitic and cataclastic textures (refer to Section 3.1.1.3). Hydrothermal alteration is common in proximity to gold mineralization, over distances up to 70 m wide. Table 3.1.1.3.3 summarizes the number and length of drill holes, chemical analytical data and methods used and thin sections prepared for each of the mineralization targets in the Syrjälä area. Drilling was done with a T56 drill bit, and holes were inclined at angle of 45° or 60° towards the southwest.

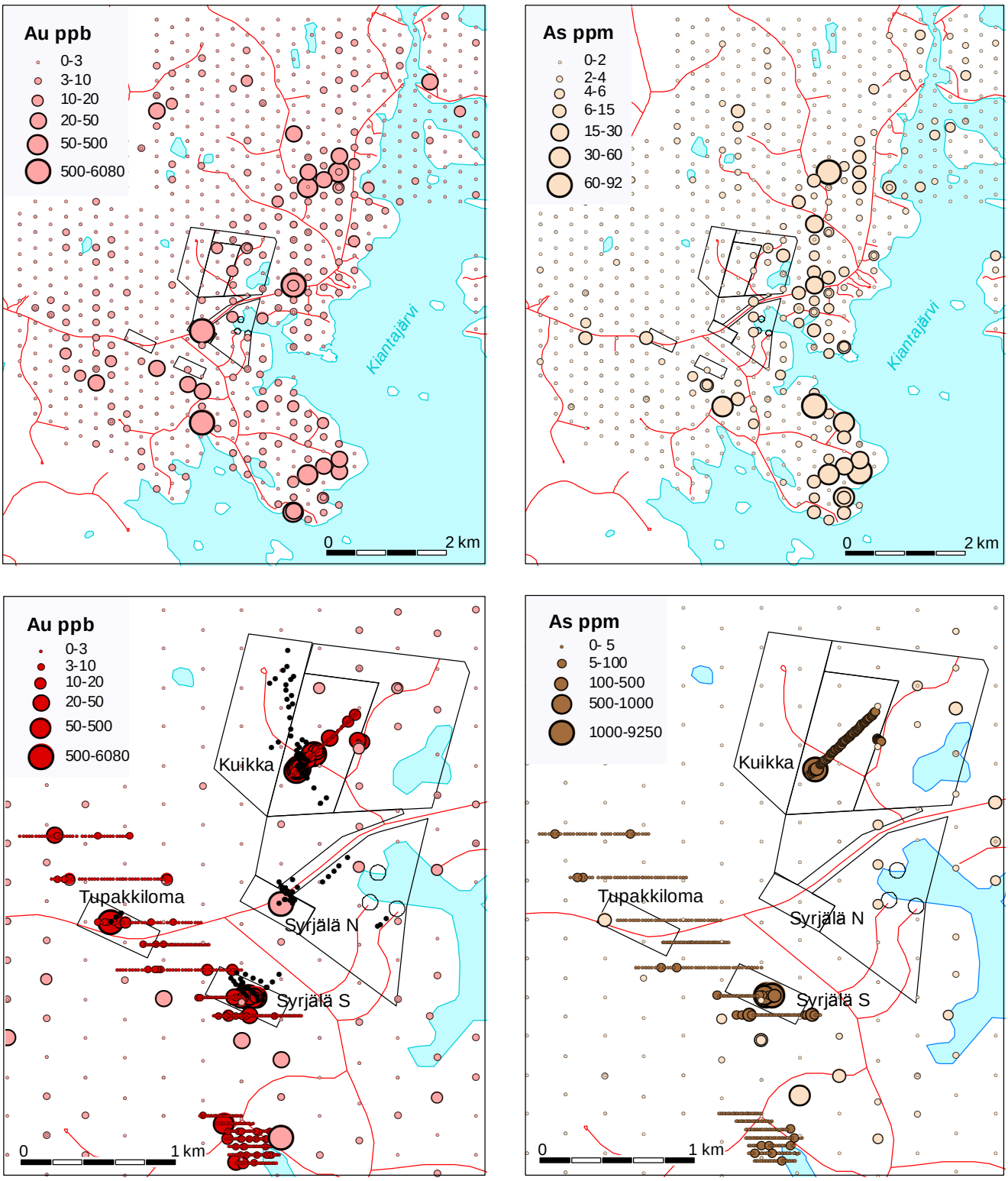


Fig. 3.1.1.3.3a. Gold and arsenic contents in till based on local geochemical soil sampling (two upper maps) and gold and arsenic contents in till representing both local (light color) and target scale (darker color) geochemical soil sampling (two lower maps) at Kiannanniemi, Suomussalmi.

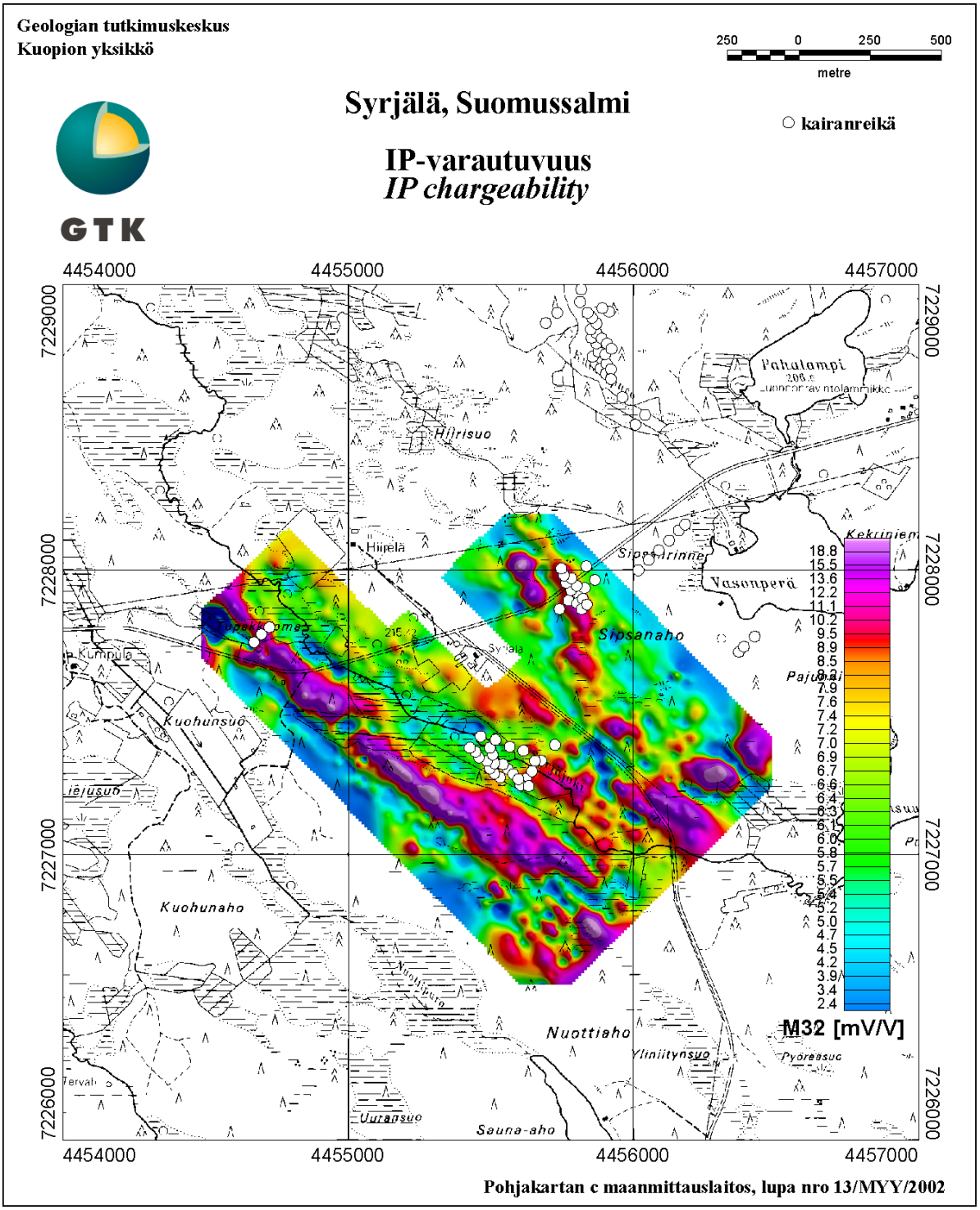


Fig. 3.1.1.3.3b. IP-chargeability and the location of diamond drill holes (white circles), Syrjälä-Tupakkiloma.

Table 3.1.1.3.3. Number of drill holes, their total length, the number of ICP-, GFAAS- and XRF-analyses and the number of thin sections at the targets of Syrjälä, Kiannanniemi, Suomussalmi. ICP = inductively coupled plasma emission spectrometry, GFAAS = absorption spectrometry with a graphite furnace technique and XRF = X-ray fluorescence spectrometry.

Target	Drill holes	Total lenght, m	ICP analyses	GFAAS analyses	XRF analyses	Thin sections
Syrjälä S	25	1 992.70	497	1 408	5	25
Syrjälä N	16	1 140.70	-	898	-	16
Tupakkiloma	3	232.50	216	216	3	3
Total	44	3 365.90	713	2 522	8	44

Mineralization at Syrjälä S is situated in the contact zone between intermediate and mafic volcanics and is buried beneath from 3 –11 m of till. Individual relict lithic banding dips at an angle of 65° towards the NE. Felsic clasts in agglomeratic units are strongly linear and also oriented towards the NE, though plunging at a slightly gentler angle. The predominant rock types are mafic volcanics, amphibolites, uralitic porphyries and typically fragmentary, commonly sericitic intermediate volcanics and volcaniclastic deposits (Figure 3.1.1.3.3c). In some places deformation has been so intense that it is difficult to discriminate between clasts and matrix. Numerous, though volumetrically minor veins consisting entirely of carbonate, or of quartz + carbonate, quartz + chlorite, or albite, from 1 – 20 mm thick, and much thicker white quartz veins that show little effect of deformation; the latter veins have very low gold contents. The most interesting rock units with respect to gold are two distinct quartz-sericite zones, both varying from 1 –3 m in thickness and spaced about 20 –30 m apart, and almost concordant with respect to the dominant foliation and lithological layering (Figure 3.1.1.3.3c). The degree of alteration in these zones varies considerably and the protolith, which is usually an intermediate volcanic rock, is usually recognizable. Alteration has also taken place to a lesser degree in the intervening rocks between the quartz-sericite schists. The most important alteration minerals are quartz, sericite, biotite, chlorite and saussurite, with significant accessory minerals being pyrite, arsenopyrite (As = 100 – 2000 ppm), tourmaline and scheelite.

Gold is typically associated with the quartz-sericite rocks but elevated gold abundances are also found sporadically at distances of several meters from the altered rocks, in relatively unaltered rock. Conversely, in many places the quartz-sericite rocks are barren. Gold concentrations are generally < 2 ppm and there were 19 separate one meter intervals in which Au exceeded 1 ppm.

The highest values analysed (Au >2 ppm) were as follows:
M52/4511/96/R311/11.00 - 12.00 m: Au 2.1 g/t
M52/4511/97/R321/32.30 - 33.30 m: Au 2.8 g/t
M52/4511/97/R321/33.30 - 34.30 m: Au 12.7 g/t
M52/4511/98/R335/28.00 - 29.00 m: Au 85.7 g/t
M52/4511/98/R343/94.80 - 95.80 m: Au 3.9 g/t

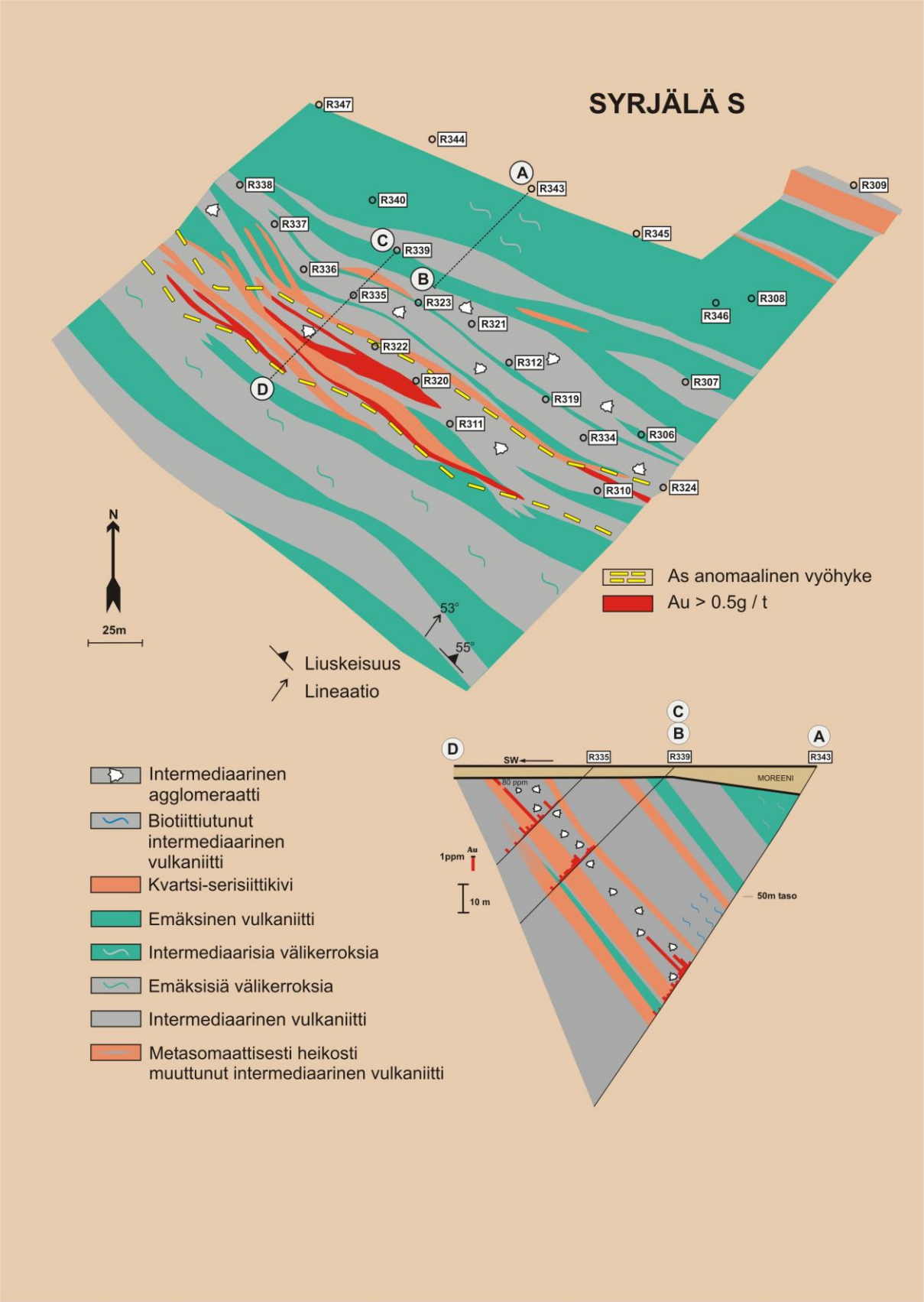


Fig. 3.1.1.3.3c. Bedrock geology and locations of drilling sites at the Syrjälä S occurrence, Suomussalmi (upper Figure), showing gold contents within the profile M52/4511/97/R335, R339 and R343 (A - B, C - D) (lower Figure).

It appears that the distribution of elevated gold (> 1 ppm) defines two gently undulating, nearly NW-SE trending sheets, tens of meters in width, nearly 200 m in length and 1-2 m thick (Figure 3.1.1.3.3c). The abundance of Au and As and the intensity of hydrothermal alteration seem to decrease both to the NW and the SE. However, this was only observed in a few holes, so it is still conceivable that mineralization is more extensive. Visible gold was found in only one drill hole, tellurides seem to be absent (Te < 50 ppb), and sulfur contents are generally < 1 %. Preliminary resource estimates based on drilling results indicate that Syrjälä S contains some 90 000 t of mineralized rock, with a grade of 1.15 ppm, assuming a cut-off value of 0.5 ppm (Pietikäinen et al. 2000).

The Syrjälä N mineralization is located either side of the Kiannanniemi road, beneath a thin (1 – 4 m) cover of till. Lithological layering dips towards the NE at 50° - 60° and the predominant rock types are intermediate volcaniclastic deposits, including agglomerates and lapilli tuffs. Mafic volcanics and uralitic porphyries are present too, particularly in the footwall to mineralization. Deformation is intense, and clasts are highly elongate. As at Syrjälä S, barren quartz veins are abundant (Figure 3.1.1.3.3d). Hydrothermal alteration has also produced similar mineral assemblages to those at Syrjälä S, typically comprising quartz, biotite, chlorite, saussurite, and sericite, with minor amounts of carbonates and sulfides. In general however, the intensity of alteration is somewhat less than at Syrjälä S.

The main alteration zone is about 60 m wide, concordant with the dominant foliation, and is interpreted as a shear zone that has focussed hydrothermal fluids transporting gold. Highest gold concentrations are found in the area between two subparallel, light colored quartz-sericite rock units (inferred to be highly permeable fluid pathways) some 50 m apart (Figure 3.1.1.3.3d). The gold-enriched zone is somewhat more magnetic than the enclosing unaltered rocks, possibly due to the greater abundance of biotite and sulfide (Figure 3.1.1.3.2a). The main gold-enriched zone is 1 –4 m in width and defines an undulating sheet or lode dipping towards the NE and E with a dip of 50° - 60° to a depth of at least 70 m. One smoky quartz vein some 20 cm thick had a gold content of 57 ppm (R318, 25.10 – 25.30 m).

The gold anomalous zone (> 100 ppb) is sometimes difficult to identify qualitatively, as alteration is rather weak and the abundance of sulfides is not much greater than in the unmineralized country rocks. Tellurium is also weakly anomalous in the gold-enriched zone, as is arsenic, which defines a weak aureole around the mineralization (Figure 3.1.1.3.3d). Tourmaline and scheelite are sporadically present, the latter being distributed patchily but locally abundant (particularly in drill holes R348 and R349).

Gold concentrations > 1 ppm were present in 15 one meter intervals, the highest values being as follows (> 2 ppm, 20 g fractions analysed, except in one case, which was 5g):
M52/4511/96/R318/24.00 - 25.00 m: 5.2 g/t
M52/4511/96/R318/25.00 - 26.00 m: 2.9 g/t
M52/4511/97/R325/52.50 - 53.50 m: 0.25g/t (5 g sample analysis = 25.3g/t);
M52/4511/97/R328/17.10 - 18.10 m: 2.5 g/t
M52/4511/97/R329/36.80 - 37.80 m: 2.0 g/t
M52/4511/98/R348/92.00 - 93.00 m: 2.3 g/t (5 g sample analyzed)

Resource estimates based on drilling results indicated the presence of 57 000 t of mineralized rock with a grade of 1.57 ppm, using a cut-off value of 0.5 ppm (Pietikäinen et al. 2000).

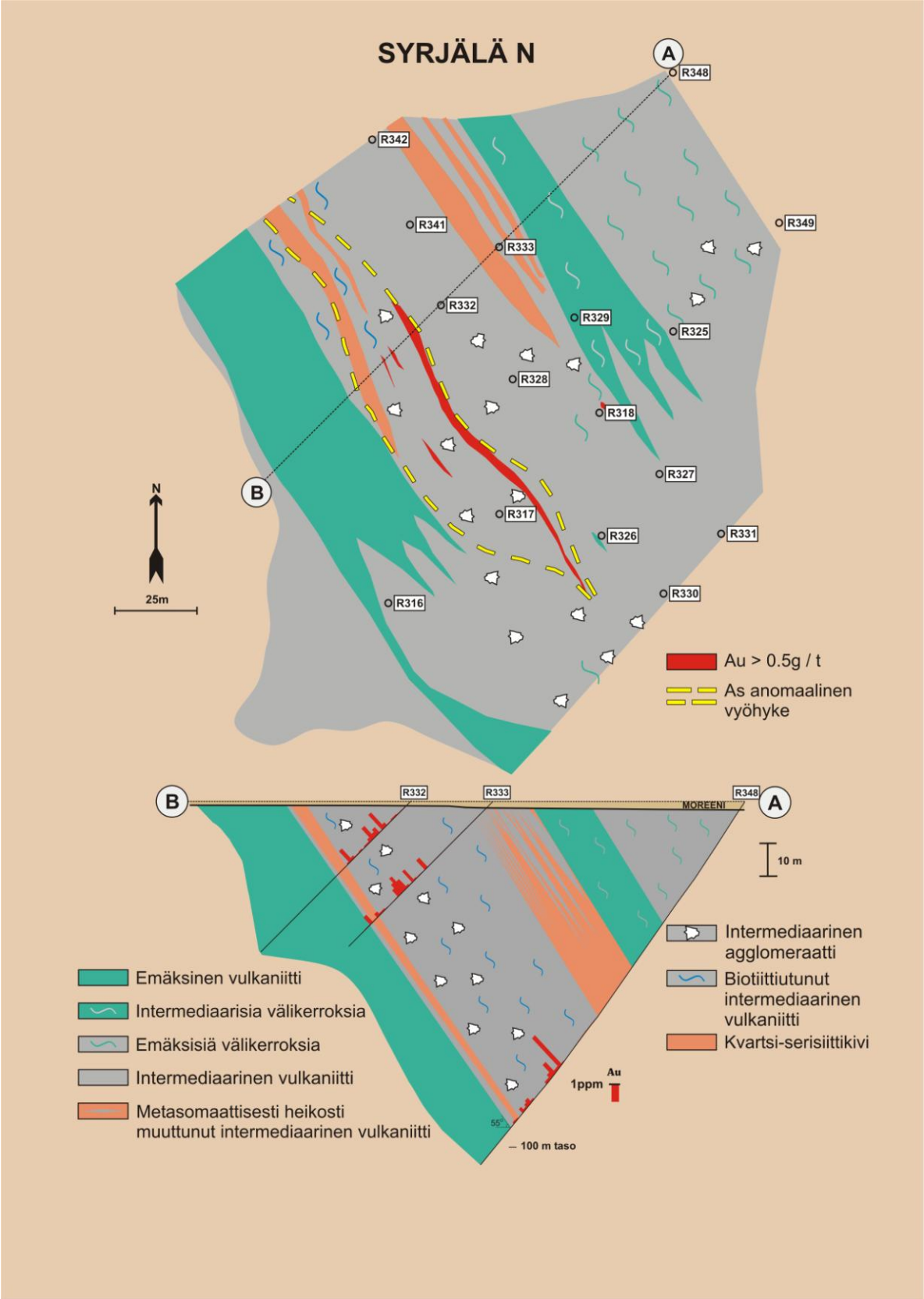


Fig. 3.1.1.3.3d. Bedrock geology and locations of drilling sites at the Syrjälä N occurrence (upper Figure) and the gold contents within the drilling profile M52/4511/97/R332 - R333 ja R348 (A - B) (lower Figure).

The Tupakkiloma mineralization is located by the main road to Kiannanniemi, within the same NW-SE trending shear zone as Syrjälä S. Bedrock is concealed beneath a thin (2 –4 m) cover of till, but consists predominantly of mylonitic, generally weakly altered mafic rocks that dip towards the northeast. The intensity of alteration seems a little more in the northeast than the southwest.

Results from three holes drilled along a profile across Tupakkiloma indicate the followijng rock sequence: 1) >37 m of banded amphibolite, mafic volcanics and uralitic porphyry (tholeiitic basalt); 2) 1 m of intermediate volcanics; 3) 42 m of banded amphibolite; 4) 6 m of talc-chlorite schist (altered komatiite) and 5) > 100 m of garnet amphibolite and banded amphibolite.

A pegmatite dyke 1.5 m thick containing country rock enclaves truncates the amphibolites and is moderately anomalous in gold (< 100 ppb). In contrast, medium-grained felsic porphyry dykes contain neither gold nor scheelite; similarly, albitic, quartz, and quartz-carbonate veins are not anomalous in gold.

The contact zone between the intermediate rocks and banded amphibolite is marked by a 10 – 20 cm thick horizon consisting almost entirely of compact pyrite and pyrrhotite, which is responsible for the prominent IP chargeability anomaly (Figure 3.1.1.3.3b). Cataclastic, biotite-rich intermediate volcanics also contain abundant pyrite. Layers subjected to sulfidation contain moderate amounts of tellurium (503 and 439 ppb) but no gold, nor are scheelite, arsenopyrite or tourmaline present.

Some gold enrichment to the northeast of Tupakkiloma is possible, as intensity of alteration seems to increase in this direction and mineralization analogous to that at Syrjälä S may well be present in the contact zone between intermediate and mafic rocks.

3.1.1.3.4. Gold investigations at Kumpula

The Kumpula area, to the west of the village of Kiannanniemi was studied during the years 1995 – 1998. A total of 16 holes were drilled, with a combined length of 1 065.8 m. Analysis of drill core was done using GTK laboratory procedures, with 189 Au + Te analyses (GTK 521U), 60 As analyses (GTK 111E), 11 S analyses (GTK 810L), 22 ICP analyses (GTK 511P and 511A) and 32 XRF analyses (GTK 175X).

Bedrock in the Kumpula area is poorly exposed but because of the strong contrasts in magnetic (Figure 3.1.1.3.4a) and EM responses in ground geophysical surveys, the decision was made to drill three systematic profiles across the main felsic to intermediate volcanic sequence, the first being on the eastern and northeastern side and the other two on the western and southwestern side. An overall NW-SE lithological trend is evident from inspection of the magnetic images, with a change towards a more N-S trend in the northern part of the area. The whole sequence dips moderately 45° towards the NE. Bedrock consists predominantly of mafic and felsic to intermediate volcanics and volcaniclastic deposits, with ultramafic rocks having been found in only three outcrops, including serpentinite in the central part of the area and a single outcrop of soapstone in a roadside exposure in the southern part of the area. This latter occurrence is apparently contiguous with a zone of ultramafic rocks that was intersected in both of the western drilling profiles. Komatiitic basalts have only been found in outcrop in the northwestern part of the area.

The eastern profile commences in rather homogeneous mafic volcanics (Figures 3.1.1.3.4a and 3.1.1.3.4b) which are separated form the adjacent intermediate volcanics and sediments by a thick sulfide-bearing quartz vein. The eastern end of the profile is more diverse lithologically, with a

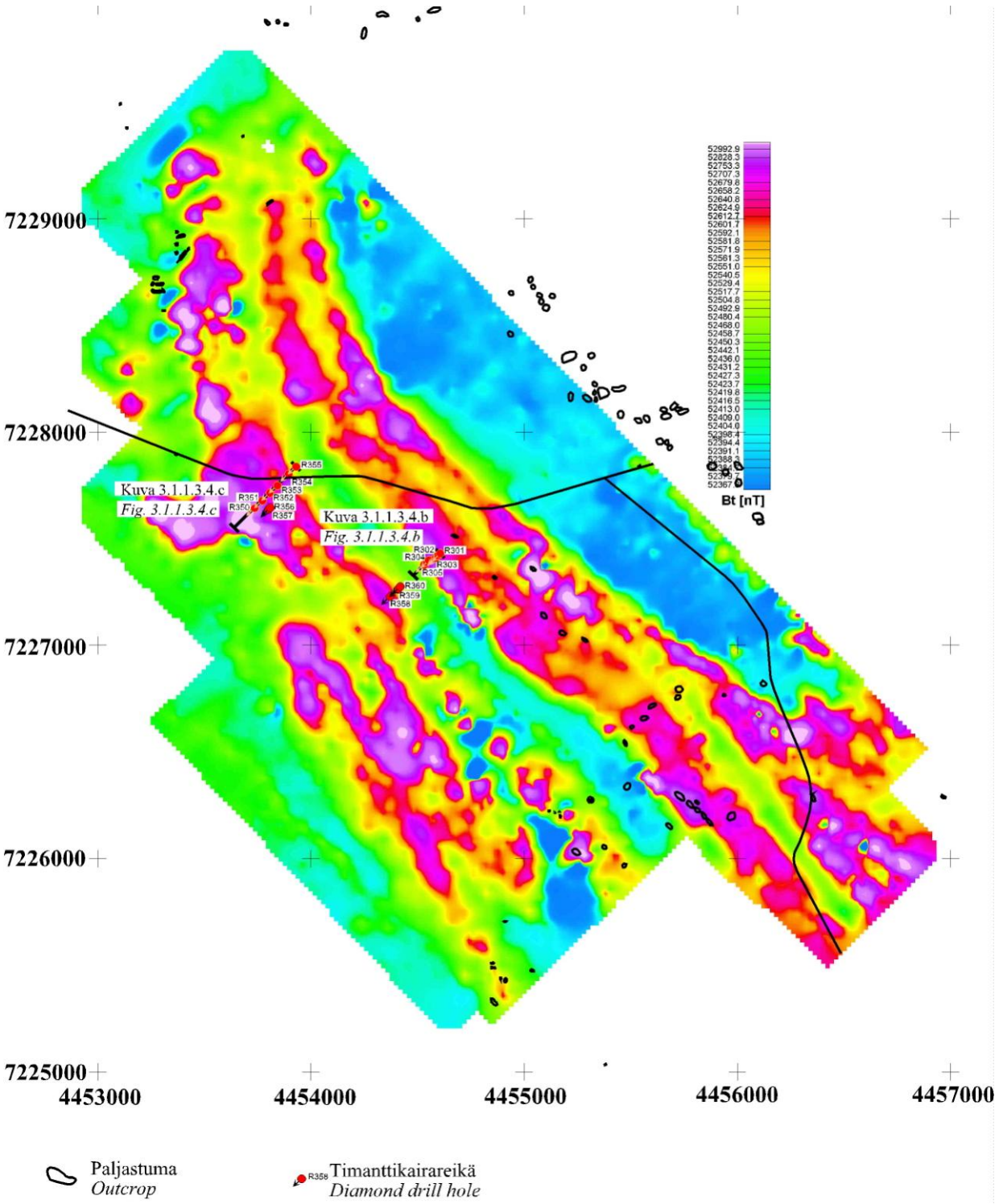


Fig. 3.1.1.3.4a. Ground magnetic total intensity map of the southwestern part of Kiannanniemi area. Outcrops and locations of diamond drill holes in Kumpula area also shown.

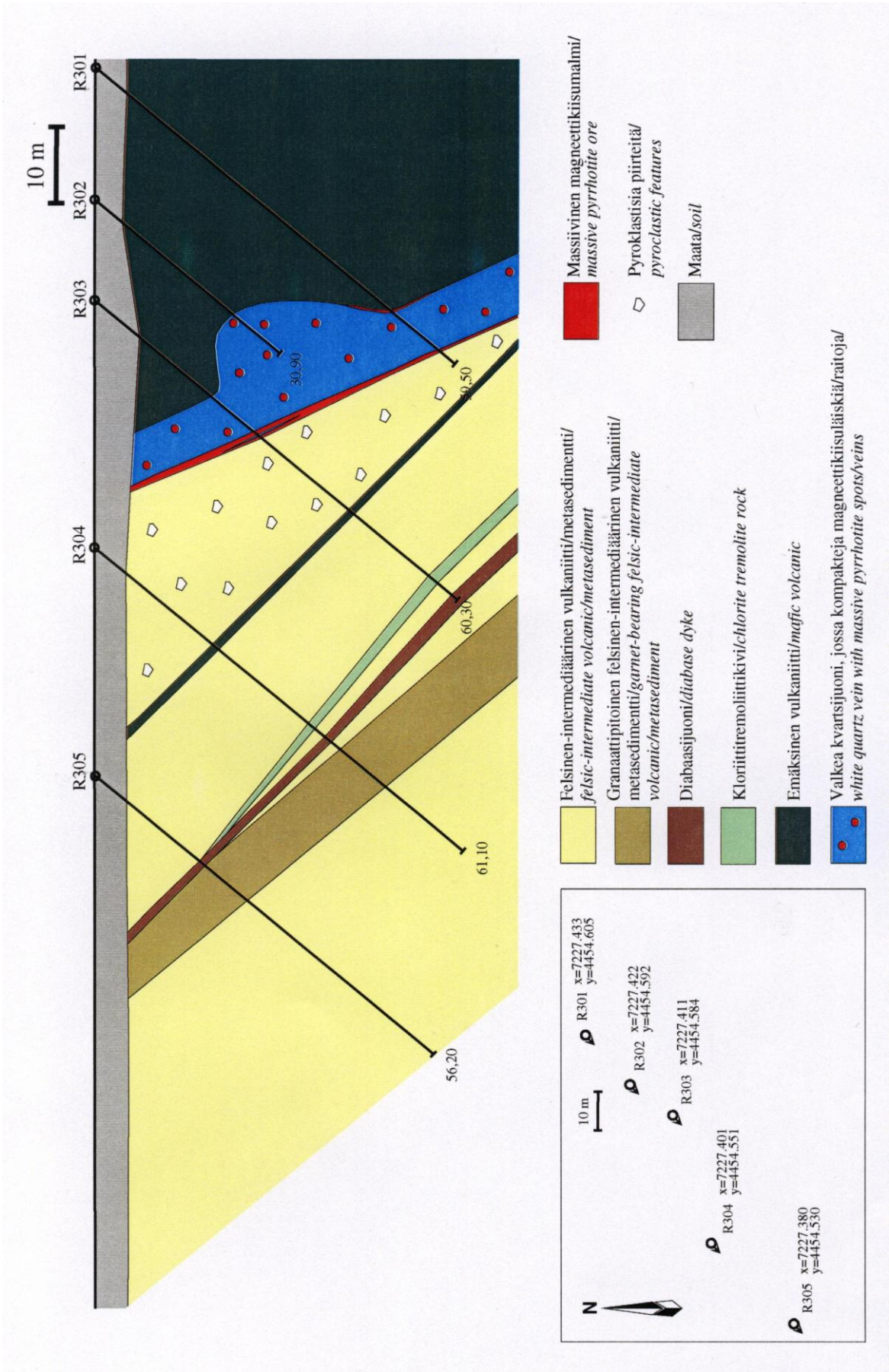


Fig. 3.1.1.3.4b. Cross-section profile of the Kumpula-E area (see Figure 3.1.1.3.4a).

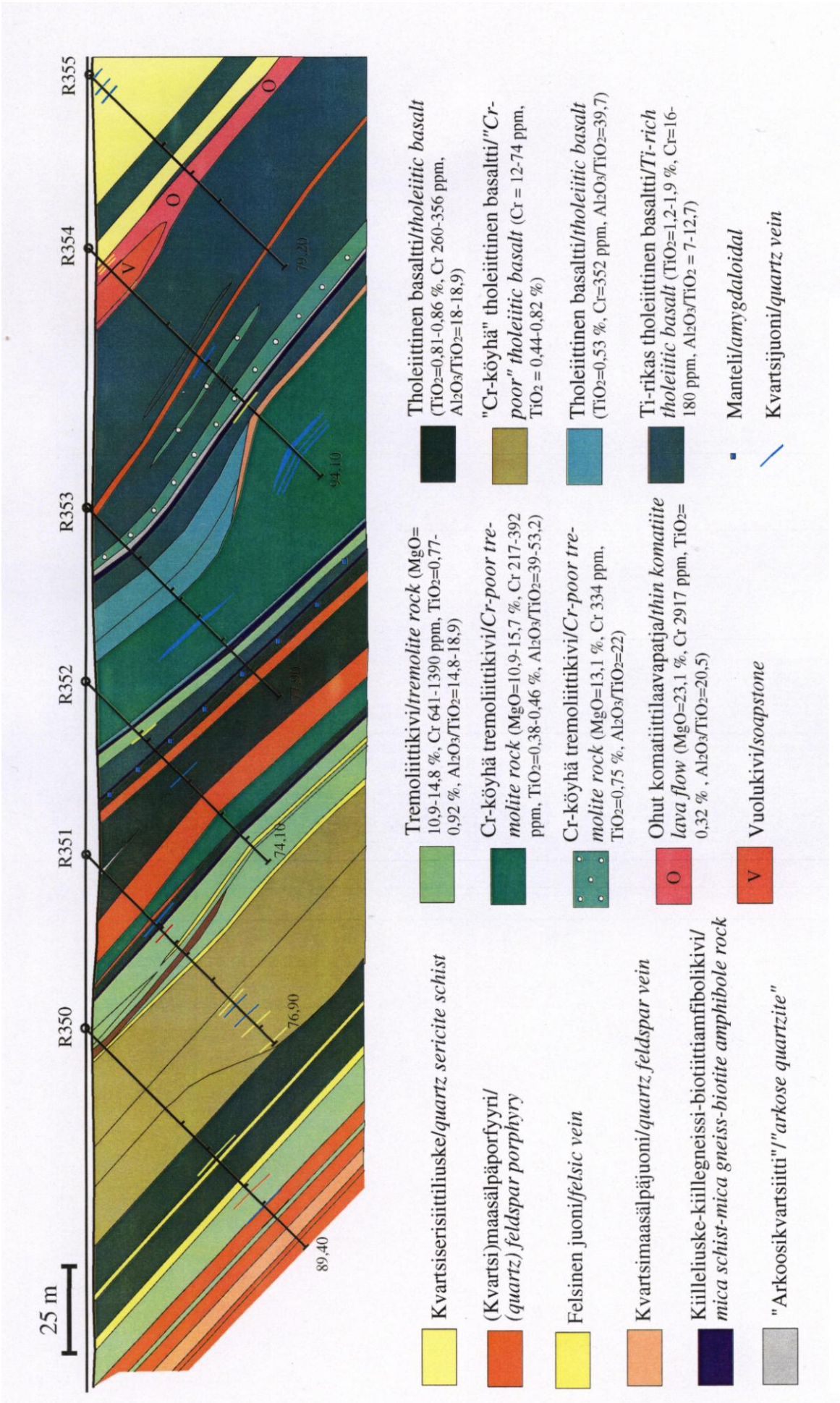


Fig. 3.1.1.3.4c. Cross-section profile of the Kumpula-W area (see Figure 3.1.1.3.4a).

thin mafic volcanic horizon, a chlorite-tremolite rock unit, and a mafic dyke, witin the predominant intermediate pyroclastic sequence. Metamorphic garnet has also developed preferentially in some layers (Halkoaho et al., 2001.

The western profile located to the southwest of the felsic volcanic and sedimentary sequence intersected predominantly mafic volcanics that have a very distinctive composition (Figures 3.1.1.3.4a and 3.1.1.3.4c). An ultramafic rock unit was present at the northeastern end of the profile and can be traced for a distance of at least 2 km towards the southeast. However, the most distinctive mafic volcanic unit consists of Cr-poor tremolite rocks, which are also found in outcrops at Jokiniemi, some 2.5 km to the southeast, and a suite of Cr-poor tholeiitic basalts and Ti-rich tholeiitic basalts; the latter two rock types have not so far been recognized elsewhere in the Kuhmo and Suomussalmi greenstone belts.

The most significant intersections with respect to mineralization were in drill hole R351 at 31.40 – 31.50 m, which contained S = 14.9 wt %, Cu = 0.17 wt %, Ni = 0.09 wt %, and Zn = 4.14 wt %, with Au = 0.23 ppm, Te = 2.6 ppm and Pb < 10 ppm.

Despite the generally low gold tenors, the area is still considered prospective, not only for gold but also for komatiite-hosted PGE-rich Ni mineralization (cf. Hietaharju Ni-occurrence). Gold mineralization is more likely to be found at the northwestern and northeastern margins of the area, whereas nickel prospectivity is likely to be greater in the intensely magnetic areas in the northwestern, southwestern and northeastern parts of the area.

3.1.1.3.5. Nickel investigations in the Huutoniemi area

Exploration-related investigations in the southern part of the Suomussalmi greenstone belt had previously been focused on the area around Kiannanniemi and Vasoniemi whereas the ultramafic complex Huutoniemi area, owing to its poor exposure, had been largely ignored. The first observations of the Huutoniemi ultramafic complex were made during the 1: 400 000 scale reconnaissance mapping by Matisto (1958). A more detailed map, in part based on exploration in the area by Kajaani Oy, was prepared by the University of Oulu Kuhmo Metallogeny Project in 1981 and clearly distinguishes serpentinites and ultramafic volcanics (Taipale and Tuokko 1981).

Investigations began at Huutoniemi in 1993, after petrographic and microprobe studies showed that that the ultramafic rocks were in fact komatiitic olivine (± pyroxene) cumulates. In addition, several XRF analyses indicated significant nickel depletion, which is a typical feature of komatiites in proximity to nickel mineralization.

During the current project the Huutoniemi area was mapped in detail at a scale of 1: 10 000 and magnetic, EM and gravimetric geophysical surveys were made, in addition to till geochemical sampling of till and the weathered bedrock interface (= 16 samples/km^2). The scarcity of outcrops was an impediment to bedrock mapping but this was compensated for in part by selective POKA drilling. Master of Science thesis on the Huutoniemi area was also submitted at the University of Turku (Rautio 2000).

The Huutoniemi komatiitic cumulate is located near the margin of the southeastern branch of the Suomussalmi greenstone belt, where komatiitic olivine (± pyroxene) cumulates are most prominent (Figure 3b and Appendix 5). To the east, the greenstone belt is juxtaposed against tonalitic and trondhjemitic migmatites and granitoids, with tectonic or intrusive contacts. To the west of Huutoniemi, rocks of the greenstone belt are concealed beneath the waters of Kiantajärvi lake so that interpretations are largely based on airborne magnetic data.

The major part of the Huutoniemi area lies within a tholeiitic and komatiitic sequence correlated with the Saarikylä Group and includes massive and pillowed tholeiitic lavas, hypabyssal and extrusive uralitic porphyries and uralitic gabbros, komatiitic basalts and komatiitic olivine (± pyroxene) cumulates. The tholeiitic and komatiitic units are in some places separated by intermediate tuffs and sediments containing metamorphic andalusite, garnet and sulfides. The whole sequence has been variably affected by hydrothermal alteration and intense deformation, so that primary textural features are only rarely recognizable.

The komatiitic olivine (± pyroxene) cumulates represent the deeply eroded and tectonically disrupted remnants of channelized komatiite flows which were erupted onto the seafloor, blanketing a substrate including tholeiitic and intermediate volcanics and related volcanogenic sediments. The petrographical and geochemical attributes of the Huutoniemi ultramafic cumulates have been compared with those of the Hietaharju and Peura-aho nickel occurrences by Rautio (2000), who examined core of the six drill holes defining the profile across Huutoniemi.

The nearly NW-SE trending Huutoniemi cumulate complex is more than 3 km in length and up to 500 m in width, with a felsic to intermediate rock unit dividing it into southwestern and northeastern parts. According to Rautio (2000), the southwestern part consists of serpentinized olivine orthocumulates, with a narrow rim of pyroxenite. The somewhat thinner northeastern part contains in addition to olivine orthocumulates and mesocumulates, olivine-augite cumulates and augite cumulates.

According to Rautio (2000), the Huutoniemi olivine (± augite) cumulates are chemically similar to the host rocks to the Hietaharju and Peura-aho Ni-mineralizations. Each of these cumulates is characterized by low Al_2O_3/TiO_2 ratios, around 15, which indicate that the parent magmas were komatiitic basalts. Rautio (2000) derived a theoretical MgO content of 16 wt % for the source magma for the Huutoniemi serpentinite. The Huutoniemi cumulate is also somewhat depleted in nickel when compared to the Hietaharju and Peura-aho cumulates. Moreover, because the Huutoniemi cumulates are stratigraphically underlain by sulfide-bearing felsic to intermediate volcanics and sediments, it has potentially been a favourable environment for the formation of sulfide melt phases. Therefore, the Huutoniemi cumulates may be considered highly prospective for nickel.

The southern part of the Suomussalmi greenstone belt was particularly strongly affected by the late Archean D_3 and D_4 deformation events. The early stages of D3 were characterized by dextral folding (with some lesser sinistrally folded domains) and the formation of a pervasive, nearly N-S trending axial planar foliation, with progressive development of discrete N-S trending shear zones. It is most likely that during this later stage of deformation, fluid generation and transport through shear zones resulted in the intense structurally controlled hydrothermal alteration, recorded by K-feldspar, biotite and sericite.

Detailed till geochemical sampling in 1993 was undertaken in the area east of Kiantajärvi lake, near the margin of the greenstone belt. Nickel and chromium abundances from till and weathered bedrock chip samples were generally at background levels, although three anomalous analyses, with maximum Ni and Cr values of 635 ppm and 1510 ppm respectively were recorded.

Systematic Slingram EM and magnetic (total intensity) surveys were made at Huutoniemi over an area of 9.0 km^2. On the basis of results from these surveys, a smaller (4.4 km^2) area was selected for detailed gravimetric surveys, the aim of which was to assist in structural interpretation and site selection for POKA and deep bedrock drilling. Between 1995 and 1997, a total of 1895.05 m was drilled in the Huutoniemi area; the lack of encouraging signs of nickel mineralization during this drilling survey led to the decision to not continue with further investigations.

3.1.1.4. Nickel investigations in the Härkövaaran area

The Härkövaara ultramafic complex is located about 16 km to the east of the Suomussalmi greenstone belt but shows many lithological similarities with rocks of the greenstone belt. Due to poor exposure and difficult of access, the Härkövaara complex was not well known at the commencement of investigations; in the regional 1: 400 000 mapping survey by Matisto (1954, 1958), the Härkövaara serpentinite was actually interpreted as a Paleoproterozoic (Karelian) intrusive complex with ophiolitic affinities. However, airborne magnetic surveys flown in 1976 and subsequent bedrock mapping indicated that the complex represents serpentinized olivine cumulates formed in a channelized komatiitic lava system.

Detailed investigations in the Härkövaara area began in 1994, following the discovery of elevated concentrations of Ni, Cr and Zn during till geochemical surveys. Outcrops were mapped in detail, together with ground geophysical surveys during the following year, providing a more accurate understanding of bedrock geology (Figure 3.1.1.4).

The Härkövaara ultramafic complex is juxtaposed against tonalitic and trondhjemitic migmatites and granitoids, with inferred tectonic or intrusive contacts. Because the contact itself has not been observed in outcrop, the extent of the ultramafic rocks is largely deduced from the distribution magnetic anomalies. In particular, the inferred northerly and northwesterly continuations of the Härkölampi complex are based on interpretation of airborne surveys flown within the restricted frontier zone in 1996.

The Härkövaara ultramafic complex consists predominantly of totally serpentinized komatiitic olivine (± pyroxene) cumulates and tholeiitic lavas. The komatiites and tholeiites can be correlated on the basis of lithogeochemistry with the Saarikylä Group in the Suomussalmi greenstone belt. Primary cumulus textures in the komatiites have been almost entirely obliterated during serpentinization and carbonation, although some examples of highly strained komatiitic pillow lavas and lavas with spinifex and harrisitic textures were found. Komatiitic olivine (± pyroxene) cumulates represent channelized lava flow facies, whereas the pillows and spinifex and harrisitic structures represent more distal aspects of the same flow system. The Härkövaara ultramafic rocks can be correlated with serpentinized komatiitic olivine (± pyroxene) cumulates of the southern part of the Suomussalmi greenstone belt, including the Peura-aho, Hietaharju and Huutoniemi cumulate complexes.

The Härkövaara area has been strongly deformed, with tectonic transport towards the east and southwest and the likelihood of significant rotation and repetition of rock units by tectonic imbrication. It is therefore difficult to define original stratigraphical units with confidence. The ultramafic rocks are usually in contact with banded, in places garnet-bearing amphibolites. Thin, strongly deformed intercalations of felsic and intermediate volcanics are also present but sulfide-bearing intermediate volcaniclastic rocks also form more extensive units, alternating with banded amphibolites and Fe-tholeiitic basalts and occasionally forming the substrate to komatiitic olivine (± pyroxene) cumulates. The amphibolites and felsic to intermediate volcanics are likely to correlated with the Luoma Group, which is the oldest supracrustal succession in the Suomussalmi greenstone belt.

The Härkövaara ultramafic complex was intensely disrupted and deformed by the late Archean D_3 and D_4 deformation events. The early D3 event was characterized by the formation of ductile structures, typically dextral folding, though some sinistral domains are present, and a pervasive foliation that in the Härkövaara area trends E-W. It is likely that S-vergent and SW-vergent overthrusting accompanied this stage of deformation.

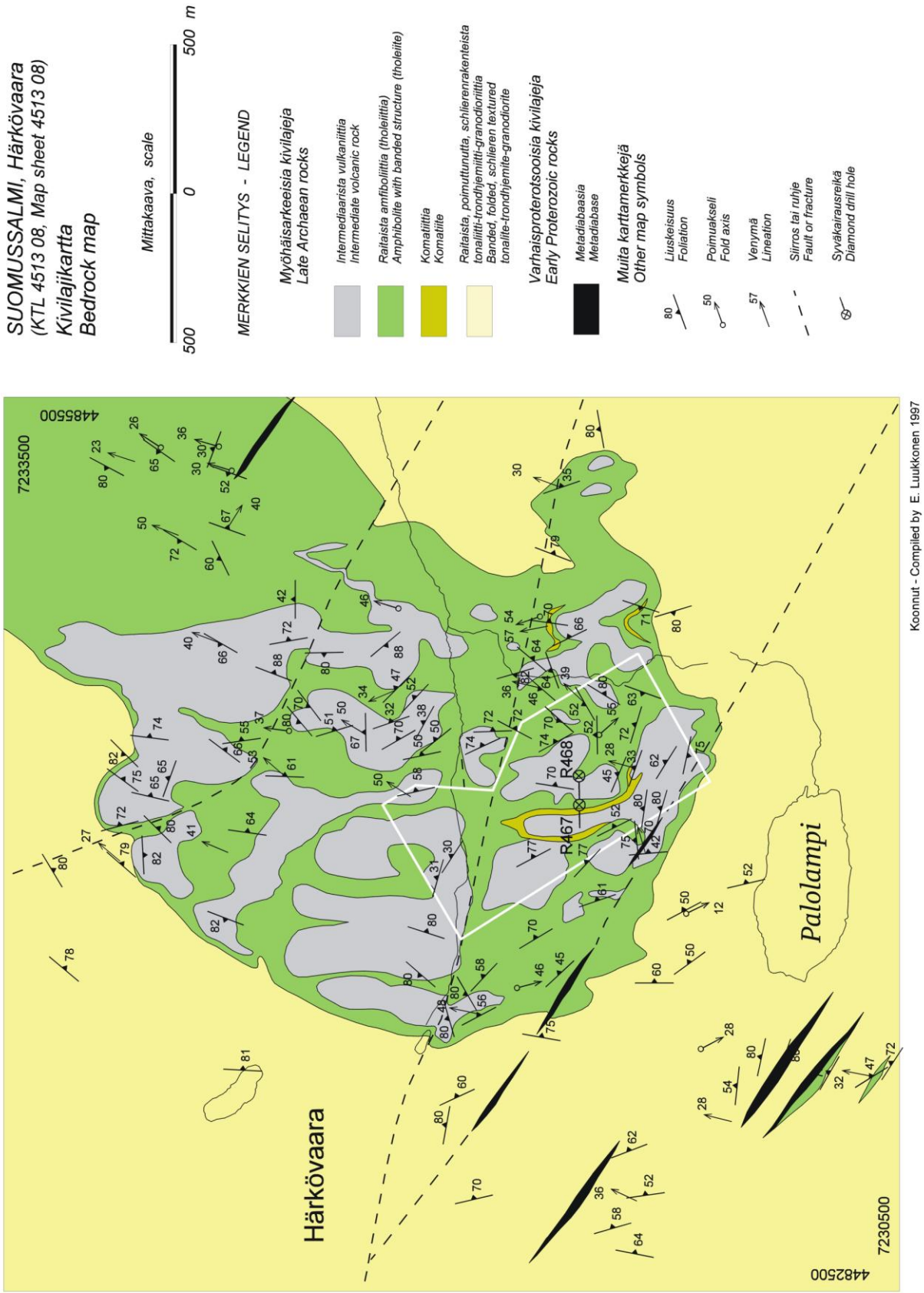


Fig. 3.1.1.4. Bedrock geology of the Härkövaara area, Suomussalmi. The claim reservation area is indicated by the white line.

The D_3 structures are overprinted by distinctly younger and somewhat more brittle than ductile NW-SE trending D_4 structures, although dextral folds and foliation asymmetry (with local conjugate NE-SW trends) are rather common.

Paleoproterozoic NW-SE trending mafic dykes truncate the Archean structural trends and rock units, from which it is inferred that the Proterozoic tectonic overprint on the Härkövaara ultramafic complex is negligible.

Local scale till geochemical surveys using percussion drilling for sampling were conducted over the Härkövaara area in 1991. Because the glacial deposits are relatively thin, most samples represent the weathered bedrock interface. Analysis of Co, Cu, Ni, Zn and Ag was with AAS and Au and Te with GFAAS. In general, concentrations of these elements are relatively low; the highest Ni concentrations were in the range 1 190 – 1 750 ppm, which can nevertheless be attributed to the inherently high background concentration in komatiitic olivine (± pyroxene) cumulates and enrichment during weathering.

Systematic EM (MAXMIN) and magnetic (total intensity) measurements were made at Härkövaara over an area covering 7.5 km^2 (Figure 2.2.2.1a), in order to investigate the internal structure of the ultramafic complex. It was also hoped to define the northern limits of the complex, since that area had not been covered by airborne surveys

Deeper penetrating SAMPO EM soundings were also made along a total of 7 line kilometers and gravimetric data were measured along 9.7 km of profiles. These surveys provided some constraints on the depth extent of the ultramafic complex and sought to identify anomalous conductors at depths down to 400 m.

A total of 244.60 m was drilled from two POKA holes in the southern part of the Härkövaara complex in 1995.

So far there is little direct evidence for nickel mineralization within the Härkövaara ultramafic complex, although results must be regarded as very preliminary. Further drilling is clearly warranted, given the poor exposure of bedrock in the area. Attention should also be given to the potential for industrial quality soapstone in hydrothermally altered and carbonated ultramafic rocks.

3.1.2. Summary of significant results

3.1.2.1. Bedrock geology and metallogeny

One of the major outcomes of the project has been to improve understanding of the Suomussalmi greenstone belt such that the general level of information is comparable to that which previously had only been available for the Kuhmo greenstone belt. Through these investigations, an awareness of the prospectivity of the Suomussalmi greenstone belt has been obtained, with a number of potential targets having been found, particularly for gold and nickel and natural stone. The soapstone industry has already been active for a number of years, with quarrying and processing operations in several places, and exploration for komatiite-hosted nickel deposits has been increasing, with the recent acquisition of a number of claims by Vulcan Resources.

During the project, the whole of the Suomussalmi greenstone belt was mapped at 1: 20 000 scale and critical areas at 1: 10 000 or in even greater detail. Mapping resulted in the generation of 2 119 bedrock observations, in addition to previous records, making a total of 2 472 database entries. As a result, a much more refined understanding of greenstone belt stratigraphy has

emerged. For example, the age difference between the Luoma Group and Saarikylä Group was confirmed with detailed SIMS zircon dating. At the same time, the regional context of the Luoma Group and stratigraphical relationships within the Group were extensively revised.

Another major focus of the project was to use a combination of outcrop mapping, detailed ground geophysical surveys and targeted POKA- and deep bedrock drilling to determine the overall morphology and internal structure of Ni-prospective komatiitic cumulate complexes.

On the basis of lithogeochemical studies, it is possible to classify the komatiitic cumulte complexes of the Suomussalmi greenstone belt into two distinct types:

1. The Portti - Vaara - Rytys - Hoikkalampi - Kauniinlampi –type, which are characterized by olivine adcumulates, mesocumulates and orthocumulates. Lithogeochemistry confirms that these are indeed komatiitic cumulates and they typically contain disseminated Ni-Cu + PGE mineralization. Despite many promising features, massive sulfide mineralization and ore bodies have not yet been recognized.
2. The Peura-aho - Hietaharju - Huutoniemi - Härkövaara – type, which is typified by olivine (± pyroxene) mesocumulates and orthocumulates. Lithogeochemical studies indicate that these cumulates probably crystallized from komatiitic basalt magmas. These cumulates are known to be associated with Ni-Cu + PGE mineralization, including the disseminated and massive sulfide deposits at Peura-aho and Hietaharju, originally discovered by Outokumpu Oy Malminetsintä (OKME).

Moroever, both of these cumulate types are demonstrably prospective for soapstone; the Kianta Stone operations at Saarikylä are for example, already extracting and processing soapstone derived from a Type 1 komatiitic olivine mesocumulate.

Geological mapping during the project also delineated a number of regional scale deformation zones that have evidently been significant in controlling metamorphic and hydrothermal fluid flow, and which may also defined structurally favourable sites for precipitation of mesothermal gold deposits, typically in second- and third order fault splays and arrays. Further study of these deformation zones will be no doubt critical in assessing gold prospectivity.

3.1.2.2. Geophysical investigations

Geophysical data, acquired and applied at different scales, have been particularly important in the current project, especially in poorly exposed terrain. The most important technique in the Suomussalmi greenstone belt has been airborne magnetic data which, in addition to facilitating regional bedrock mapping, enables targeting of potential ultramafic cumulate complexes, owing to their intensely positive magnetic signatures (for example the Vaara – Kauniinlampi cumulate complex, described in Section 3.1.1.2.5.

Ground geophysical surveys were also highly effective in delineating and discriminating between different rock types, due to their respective differences in petrophysical properties. Detailed magnetometry was very useful in refining geological interpretations at a number of targets and was equally applicable to gold and nickel investigations. The optimum line spacing for effectively delineating rock units and mineralization with such surveys was 10 m, with a point spacing of 5 m.

One of the most remarkable features of the various Ni-occurrences discovered so far in the Suomussalmi greenstone belt is that even at relatively high nickel concentrations (≥ 1 %), the mineralization is not strongly conductive. The petrophysical properties of the Kauniinlampi and Vaara Ni-occurrences in the Saarikylä district are described in some detail in Section 3.1.1.2.5.1.

At gold prospects, such as those in the Tormua schist belt and Syrjälä at Kiannanniemi, induced polarization (IP) surveys proved very useful in delineating mineralization, especially where associated with finely disseminated pyrite. On the other hand, while arsenopyrite is commonly present where gold is anomalous, it is usually not sufficiently abundant to generate an IP response. It is recommended that future studies make further use of different IP survey configurations.

3.1.2.3 Geochemical investigations

Geochemical investigations, involving sampling of till, bedrock and weathered bedrock material, were very effective and important in locating gold mineralization, or areas of gold potential. As a direct or indirect result of till geochemical studies, numerous anomalous zones and gold occurrences were identified in the northern part of the Suomussalmi greenstone belt, in the Moukkori area (Section 3.1.1.1) and in the area between Saarikylä and Selkoskylä (Section 3.1.1.2). Although these investigations did not lead directly to the discovery of economic gold deposits, the detailed mapping and analytical data provide a stronger basis for future exploration. In this respect the Pahkosuo area is of interest, where numerous small gold occurrences have been found, aligned along the contact (300 – 400 m wide) between greenstones and granitoids. The results of till geochemical studies indicate that this contact zone is anomalous and hence prospective for several kilometers both to the north and south.

Further south at Kiannanniemi, the initial discovery of the Kuikka (3.1.1.3.2) and Syrjälä (3.1.1.3.3) gold occurrences was to a large extent the result of tracing glacial boulders. However the finding of anomalous gold in till during detailed geochemical surveys revealed additional targets and provided the main impetus for follow-up investigations. Some of the anomalies in the Kiannanniemi area, such as Soidinvaara were, during the later stages of the project, within exploration leases held by Outokumpu Mining Oy, and therefore it was not possible or practical for GTK to continue investigations.

The 250 m sampling grid proved to be sufficiently dense to reveal the more extensive gold anomalous zones, which include “pathfinder” aureoles, defined by elevated Te and As in particular, which in many cases proved to be reliable vectors to mineralization. The presence of scheelite, especially in the Pahkosuo area, was also an important pathfinder mineral. The 10 m grid spacing used in detailed follow-up sampling surveys was appropriate for delineating gold distribution, in conjunction with ground geophysical surveys, in planning drilling targets.

Where glacial till cover was relatively thin, it was possible to sample the basalmost till, which contains a larger proportion of weathered and fresh material from the immediately underlying bedrock (such as Moukkori and Pahkosuo, Appendix 2). Recovery and microscopic examination of chip samples and fragments of bedrock and detrital clasts from till also provide insights into bedrock composition. However, in areas where soil cover was thicker, samples are less likely to represent the immediately underlying bedrock and coinsequently, anomaly zones may be somewhat diffused, obscured or even truncated in such areas (Figures 2.3.1 ja 2.3.4b).

One of the main advantages of till sampling in gold exploration is that till represents a larger area than weathered or fresh bedrock chip samples. In many cases, highest gold concentrations are recorded from till rather than weathered bedrock samples, although sample size of 100 – 200 g are generally too small for representative geochemical analysis (Harris 1981, Nichol et al., 1992). However, small sample size can be compensated for by increasing sampling density, particularly at more detailed surveys. Increasing the sample aliquot size for analysis from 1 g to 5 g during the current project also had an impact on how representative the sample was, and reproducibility of results.

3.2. Kuhmo greenstone belt

The Kuhmo greenstone belt is the largest Archean greenstone belt in Finland, being up to 10 km in width and more than 100 km from north to south, within the rural municipalities of Suomususalmi, Hyrynsalmi and the city of Kuhmo.

Based on isotopic and structural evidence, the felsic, intermediate and mafic volcanic rock units at the margins of the Kuhmo greenstone belt may correlate with the 3 000 – 2 800 Ma Luoma Group of the Suomussalmi greenstone belt. In contrast to the Suomussalmi greenstone belt however, the oldest rocks in the Kuhmo succession are predominantl tholeiitic basalts that have been metamorphosed to banded amphibolites (Figure 3fD). Felsic and intermediate volcanics are associated with these early stage volcanics in the Ruokojärvi and Vuosanka areas. Contacts with surrounding granitoids and younger units of the greenstone belt are tectonic or intrusive.

The central part of the Kuhmo greenstone belt consists of 2 800 – 2 750 Ma tholeiitic basalts, tholeiitic layered sills, komatiitic olivine (± pyroxene) cumulates and lavas, komatiitic basalts and Cr-basalts. The most complete and best-preserved stratigraphic sequence is in the Siivikkovaara and Ronkaperä area; elsewhere it is more difficult to correlate rock sequences due to the effects of intense deformation.

Tholeiitic basalt flows are commonly separated by thin banded iron formations (Figure 3gA) and pelitic sedimentary intervals, indicating the intermittent and episodic nature of volcanism. This contrasts with komatiitic and komatiitic basalt sequences, which rarely have sedimentary intercalations and likely represent the eroded, deformed and disrupted remnants of an extensive submarine komatiitic and tholeiitic volcanic complex characterized by relatively gentle topographic relief. The komatiitic olivine (± pyroxene) cumulates are interpreted as lava flows (± large lava tubes) and possible lava lakes formed in a proximal vent setting. Spinifix-textured komatiites and pillowed or massive komatiitic basalt flows may represent the more distal facies of the same eruptive events.

Intermediate and felsic volcanics and volcaniclastic deposits are significant though minor components in the central part of the Kuhmo greenstone belt, erupted and deposited in a somewhat shallower environment than the ultramafic and mafic volcanics and possibly even in a subaerial setting in some cases. This may be explained in terms of felsic to intermediate volcanic edifices becoming intermittently emergent.

A very distinctive feature of the Kuhmo greenstone belt is a persistent, though tectonically disrupted sequence of conglomerates and sericitic quartzites that transect the greenstone belt from Hietaperä in the south to Viitivaara in the north, and which appear to be controlled by major fault systems. The quartzites are commonly feldspathic and poorly sorted and are likely to represent reworking of felsic volcanic rocks.

The well-preserved volcaniclastic graywackes of the Ontojärvi Synform have not been dated isotopically. However, lithogeochemical similarities with the youngest intermediate volcanics suggest that they maybe distal facies variants, for example of the Lampela-type intermediate volcanism. Conversely, they are also compositionally similar to the metagraywackes of the Tipasjärvi and Ilomantsi greenstone belts and the more strongly metamorphosed Nurmes paragneisses. Accordingly, the Ontojärvi metasediments may be as young as 2 740 – 2 700 Ma. Examples of these rock types are shown in Figures 3f and 3g.

Homogeneous, massive, NW-SE trending mafic dykes transect the Archean rocks of the Kuhmo greenstone belt with sharply discordant contacts, which thus constrain the deformation of the

greenstones to late Archean time. The wehrlitic gabbro dykes within the komatiitic olivine (± pyroxene) cumulates of the Kellojärvi complex are also similar in truncating Archean structures, although Paleoproterozoic regional metamorphic thermal overprinting is sometimes evident in outcrop as reaction selvages between rocks of contrasting composition.

The Arola and Sika-aho Ni-occurrences are spatially associated with komatiitic volcanic rocks (Figure 3.2.1a) whereas gold occurrences throughout the Kuhmo greenstone belt are structurally controlled, occurring within or adjacent to major deformation zones and moreover, gold mineralization is found in almost all rock types and at all stratigraphic levels (Figure 3.2.1b). Talc-carbonate alteration of the Kellojärvi komatiitic olivine cumulates has also provided high-quality soapstone resources for the natural stone industry.

3.2.1. Key areas and exploration targets in the Kuhmo greenstone belt

Prior to the commencement of this project there had already been a number of mapping and research projects in the Kuhmo greenstone belt, commencing with 1: 400 000 scale reconnaissance mapping (Wilkman 1921, 1924) and subsequently more detailed studies for the Geological Survey of Finland 1:100 000 bedrock mapping program (Hyppönen 1973, 1976, 1978, Luukkonen 1986, 1987, 1988a). Outokumpu Malminetsintä (OKME) carried out exploration-oriented mapping during the 1960's and 1970's and Suomen Malmi Oy discovered the Arola nickel occurrence in 1962. The University of Oulu conducted a research program into the geology and metallogeny of the Archean terrain of eastern Finland, focusing on the greenstone belt in the Kuhmo area, as well as surrounding granitoids (Piirainen, 1985). There was also a considerable amount of research into the petrogenesis of mafic volcanics and Archean granitoids by a postgraduate students and staff from the University of Rennes (cf. Martin et al., 1984). Luukkonen (1992) presented a structural and tectonic synthesis of the area and at the time of commencement of the current project, Professor Heikki Papunen and students from the University of Turku were conducting research into the ultramafic rocks of the Kellojärvi complex in particular, which formed the basis for very valuable collaboration.

The main objective of the current project in the Kuhmo area was revision and refinement of bedrock mapping, in order to provide a more robust framework for exploration, and resulted in the identification of a number of new mineralizations and delineation of potential areas for follow-up exploration. Two nickel occurrences had previously been know from the Kuhmo area, at Arola, and at Riihilampi, in the easterly branch of the greenstone belt. During the project, additional mineralization was found in the Moisiovaara area at Sika-aho (Figure 3.2.1a) and additional nickel-related investigations were carried out within the Teerisuo and Naurispuro claim areas as well as in the Kellojärvi ultramafic complex. Apart from Sika-aho however, no significant nickel mineralization was found.

The only gold mineralization known when the project began was the Lokkiluoto occurrence discovered by Kajaani Oy but during the course of the project a number of new occurrences were found and investigated, including Tammasuo, Palovaara, Timola, Iso Aittojärvi, Pieni Aittojärvi, Jousijärvi, Mujesuo and Louhiniemi. Each of these are described in following sections, as is the Kajaani Oy Lokkiluoto prospect (Figure 3.2.1b).

Although the main focus of the project was on nickel and gold prospectivity, there were a number of zinc-bearing samples found that justified follow-up investigations, at Palovaara, at Härmänkangas near Vuosanka and in the Kangaslampi area (refer to Figures 3b and 3.2.2.2a and b).

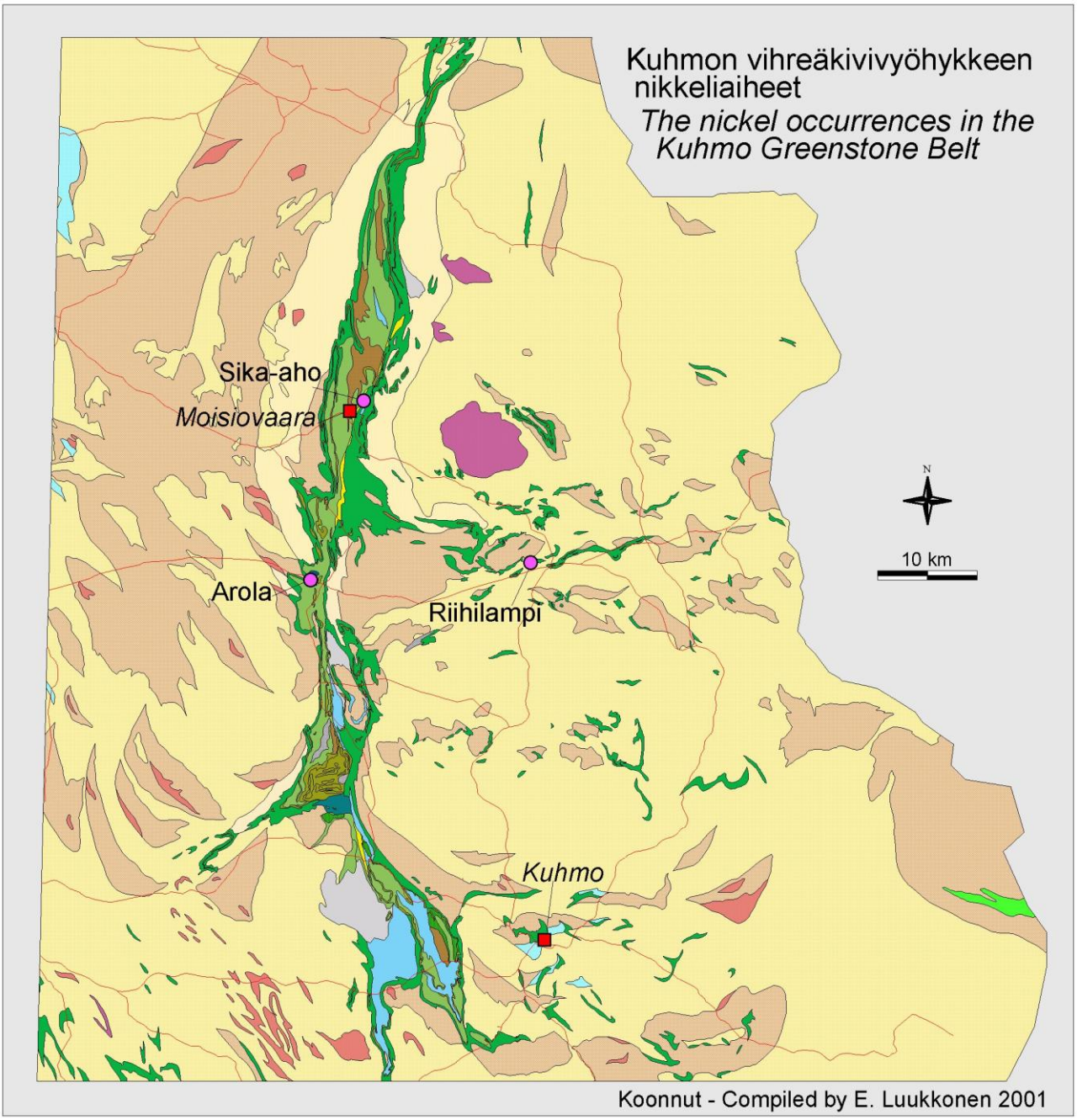


Fig. 3.2.1a. Distribution of nickel occurrences in the Kuhmo Greenstone Belt.

During the project, some 50 km^2 of systematic ground geophysical surveys were done in selected parts of the Kuhmo greenstone belt and are detailed, according to type of method used, in the index map in Figure 2.2.2.1a. In addition, numerous profiles and specialized surveys were undertaken, include down-hole geophysical measurement. Petrophysical parameters were also measured in the laboratory and used to constrain interpretations of rock types in the field, which assisted further in defining drilling targets. A summary of geophysical methods and areas surveyed in the Kuhmo greenstone belt is given in Table 2.2.2.1b.

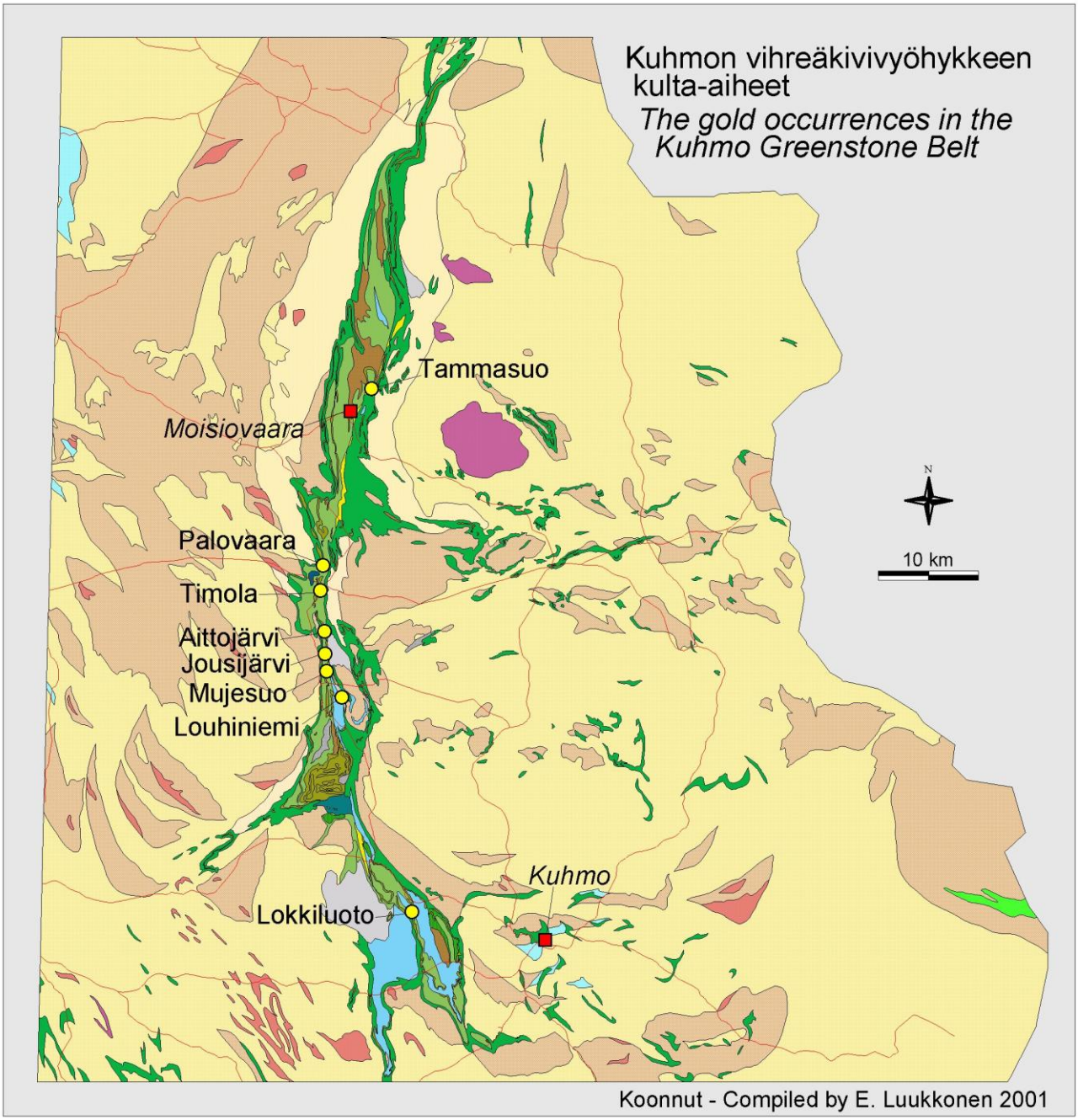


Fig. 3.2.1b. Distribution of gold occurrences in the Kuhmo Greenstone Belt.

3.2.1.1. Moisiovaaran area

The Moisiovaara area is located within the center of the northern part of the Kuhmo greenstone belt (Figure 3b and Appendix 4), where the greenstone belt is about 6 km wide and bounded to both east and west by intense high strain deformation zones that juxtaposed greenstones against granitoids and migmatites.

The oldest known rocks in the Kuhmo greenstone belt occur along the margins of the belt in the Moisiovaara area and are correlated with the 3 000 – 2 800 Ma Luoma Group in the Suomussalmi greenstone belt, consisting of banded tholeiites and strongly altered amphibolites, with sporadic intercalations of more felsic, presumably also volcanogenic, rock types.

This older rock sequence is overlain, presumably after a considerable hiatus, by massive and pillowed mafic to ultramafic lavas which are the predominant rock types in the greenstone belt. There is a general progression from more tholeiitic to komatiitic compositions upwards through the greenstone sequence. Felsic and intermediate volcanics and sedimentary rock units are also present, but only a few outcrops exist in the Moisovaaara area. Drilling indicates that individual felsic units can be traced for considerable distances, either between tholeiitic lava flows, and within the transition zone between tholeiitic and komatiitic units. The most extensive unit of felsic and intermediate sedimentary and volcanic rocks is within a tectonically bounded domain of the so-called Tammasuo shear system and is considered to represent the stratigraphically youngest rock unit in the Kuhmo greenstone belt.

Both outcrop and drill core evidence indicate a submarine setting for the eruption of the Moisiovaara komatiites, on a variable substrate including not only the older rocks correlated with the Luoma Group but also the Fe-tholeiitic volcanics belonging to the younger (< 2830 Ma) phase of greenstone belt evolution. The Fe-tholeiites and komatiites are usually separated by a sulfide- and oxide-facies banded iron formation sequence of variable thickness, or by pelitic sediments and felsic volcanics. In this respect, the stratigraphical sequence defined in the Siivikkovaara area, where the Siivikkovaara Formation komatiites overlie pillowed tholeiitic basalts of the Pahakangas Formation (cf. Halkoaho et al., 1997, 2000).

The bedrock geology of the Moisiovaara area was mapped in detail at 1: 10 000 scale during the years 1993 –1996 and key areas were surveyed with ground-based geophysical methods (EM and magnetic total field), as shown in Figure 2.2.1a. Detailed geochemical sampling (16 samples/km2) of till and weathered bedrock was done with a profile spacing of 50 – 100 m and sample interval of 10 –20 m. Exploration trenches, modal analyses and panning were done to define till stratigraphy and assess the distribution, provenance and morphology of detritally transported gold grains. All of these sources of information were valuable in selecting drilling targets, which in turn provided new insights into the nature of the bedrock, leading to a more comprehensive understanding of regional geology and providing a stronger basis for future nickel and gold exploration.

3.2.1.1.1. Tammasuon gold occurrence

The Tammasuo shear system, to the east of the Sika-aho Ni-occurrence, is in some places anomalous in gold (maximum values 0.5 – 2.0 ppm). Preliminary evaluation, based on POKA drilling, suggests that gold enrichment is structurally controlled and restricted to narrow and discontinuous zones that are characterized by cataclastic textures and intense silicification, carbonation and sericitization; felsic dykes are also commonly associated.

The first indications of gold potential at Tammasuo were obtained from till geochemical surveys (Figure 2.3.5a), which led to systematic IP surveys and more detailed geochemical sampling in 1993 (Figure 3.2.1.1.1),with POKA drilling carried out intermittently between 1994 – 1996. The most significant till geochemical analyses are presented in tables in Appendix 2.

Many of the till geochemical gold anomalies were tested by POKA drilling, with analyses yielding numerous anomalous intervals with Au > 0.5 ppm, and several one meter intervals in which maximum gold values were between 2.0 – 2.5 ppm. Analyses showed a strong correlation between Au, As and S and to some extent with tellurium. Some exceptionally high gold contents in till and weathered bedrock (as much as 2.3 – 8.8 ppm) are suspected as being at least in part due to gold enrichment by supergene processes.

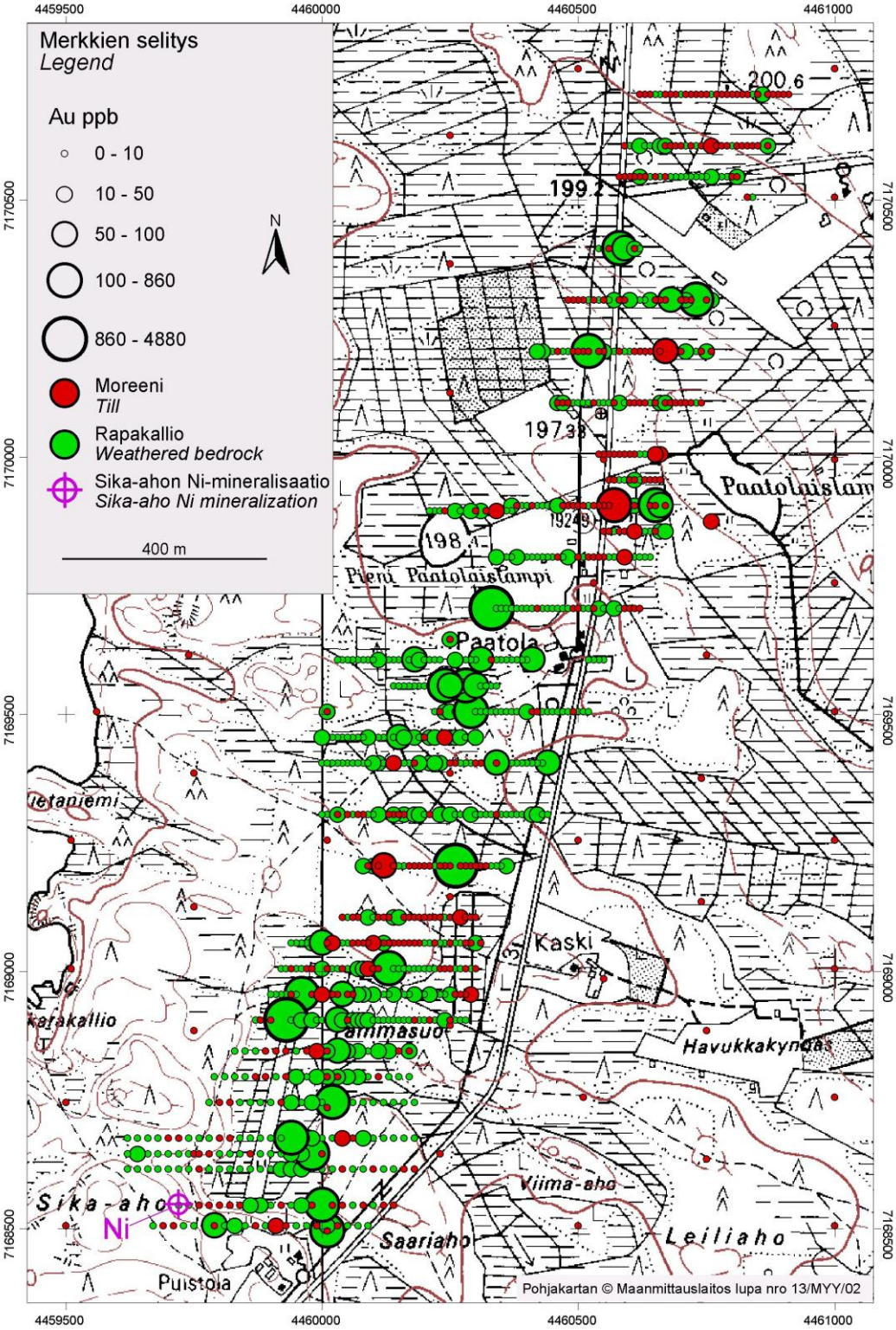


Fig. 3.2.1.1.1. Gold concentration in till and weathered bedrock samples taken during local stage sampling surveys in the Sika-aho and Tammasuo areas, Hyrynsalmi.

3.2.1.1.2. Nickel investigations in the Teerisuo area

In 1997, a chlorite schist glacial boulder containing pentlandite, found to the east of Teerisuo, near Jumaliskylä (FIN_KKJ mapsheet 4421 11D), was submitted to Outokumpu Malminetsintä Oy. A subsequent search at the time failed to identify any potential source outcrops from which the boulder may have been derived, so during the current project, renewed boulder investigations and outcrop mapping were undertaken (Figure 3.2.1.1.2), together with detailed ground geophysical surveys (EM and magnetic) and POKA drilling.

Geophysical surveys revealed the presence of two conductive horizons beneath till, both to the east and west of Teerisuo, and either of which could have been the source of the mineralized boulder. Six POKA holes were drilled into these conductive horizons, intersecting tholeiitic basalts (± basaltic komatiitic cumulates) and sheared sulfide-bearing schists; no chlorite schists or pentlandite was found however.

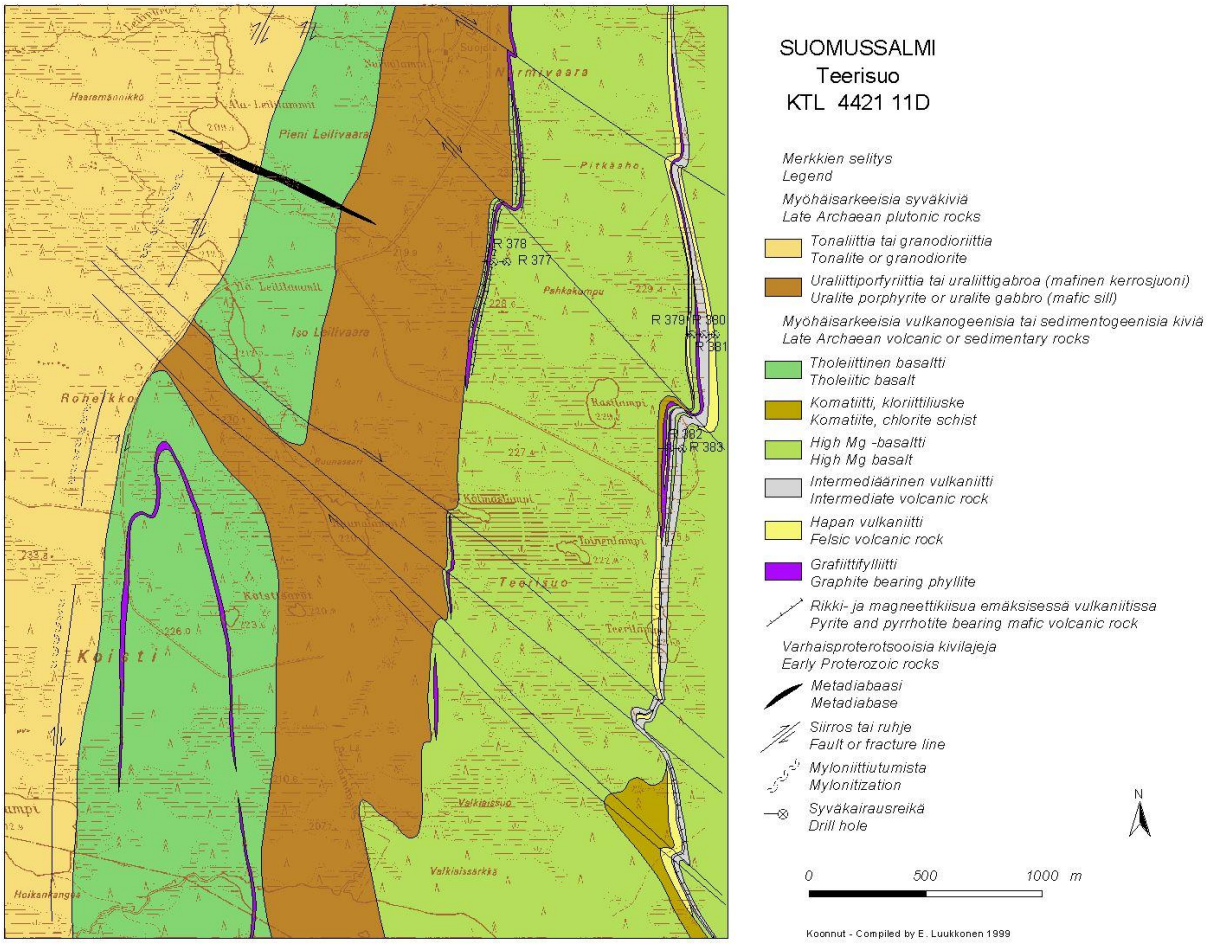


Fig. 3.2.1.1.2. Bedrock geology of the Teerisuo area, Suomussalmi.

3.2.1.1.3. Nickel mineralization at Sika-aho

During 1993 –1995, Au and Co geochemical anomalies that had been found during earlier local till surveys were resampled in more detail (Appendix 2), followed by ground geophysical surveys and POKA bedrock drilling. Early in 1994, a single sample along a till geochemical profile (Figure 3.2.1.1.1) revealed anomalous nickel; this was the first indication of the existence of nickel mineralization at Sika-aho, and by the end of the same year, mineralized bedrock had been

intersected in POKA drill hole R306 (refer to Figure 3.2.1.1.3a). During 1995 and 1996, further drilling was done to trace the mineralized zone and Ni-critical komatiitic unit along strike, in the absence of bedrock exposures.

The Sika-aho Ni-mineralization is located about 1 km north of the village of Moisiovaara, near the western edge of the Tammasuo shear system, and towards the western margin of a sequence of sheared and carbonate-altered komatiitic (olivine ± pyroxene) cumulates (Figure 3.2.1.1.3a). The host rock to the mineralization is usually a quartz-rich, commonly strongly carbonated chlorite schist, which is interpreted as the intensely hydrothermally altered pyroxenitic basal part of a komatiitic lava flow. On the basis of XRF analyses the MgO content of the komatiitic protolith (MgO = 23.9 wt % - 18.5 wt % anhydrous normalized) is consistent with the more distal parts of a komatiitic lava channel.

The positioning of the mineralization at the margin of the komatiitic cumulate body throughout its entire known length is characteristic of Archean Kambalda-type komatiite-hosted nickel mineralization, although the overall location within a major deformation zone also admits the possibility of tectonic remobilization. On the basis of outcrop observations, deep drilling and geophysical interpretations, it thus appears probable that the mineralized komatiite unit (= Sika-aho komatiite and host rock and the mineralization) has been translated along a dextral Archean D3 fault within the Tammasuo shear system and is now juxtaposed alongside another, almost compositionally identical komatiitic unit. Komatiites that match the Sika-aho mineralized komatiite both lithologically and chemically have also been intersected during drilling elsewhere in the Moisiovaara area, some being traced over strike lengths of several kilometers and forming arcuate, lenticular bodies up to hundreds of meters in thickness. The main Ni-critical Sika-aho komatiitic unit can be traced, despite being rather tightly folded, from Kaivolampi through Sika-aho to Paatola, to the east of Moisiovaara. From Paatola the komatiite unit curves towards the northeastern end of the lake Honkajärvi, then changes trend again towards the south, along the eastern shore of the lake. The western continuation of the komatiite unit is evidently rather narrow and discontinuous and passes to the east of Moisiovaara near Kaivolampi, after which it trends parallel to the eastern branch of the unit, for some distance further southwards.

Though geometrically complex, the overall structure represents a north-plunging, upward younging synform (possibly interference between Archean D_3 and D_4 structures), with the core consisting of komatiitic basalts and Cr-rich basalts that lie stratigraphically above the main komatiite succession. Structural observations and SAMPO soundings indicate that the limbs of the synform dip steeply and that the hinge zone is at depths greater than 500 m, consistent with a steep plunge.

The sulfide mineralization at Sika-aho shows tectonic remobilization into highly strained serpentinized komatiitic rocks that also experienced pervasive silicification and carbonation. Nevertheless, the Ni/Cu ratio and Ni content of the sulfide phase are both typical of Archean komatiitic-hosted nickel deposits. Despite the high strain and its position within one of the most prominent deformation zones in the Kuhmo greenstone belt, it is considered unlikely that there has been substantial displacement from its primary environment of formation.

The dimensions of the Sika-aho mineralization at the present erosion level are approximately 80 m measured along strike, with a width of from 1 – 9 m. A provisional resource estimate by Heino (1998), to a depth of 150 m, indicated the presence of 175 085 t of mineralized rock, assuming a Ni cut-off value of 0.35 % and a mean Ni concentration of 0.665 %. An additional, less mineralized extension towards the northeast was also delineated, based on intersections in several POKA drill holes; this mineralization has a strike length of about 150 m and a width of 2 – 10 m.

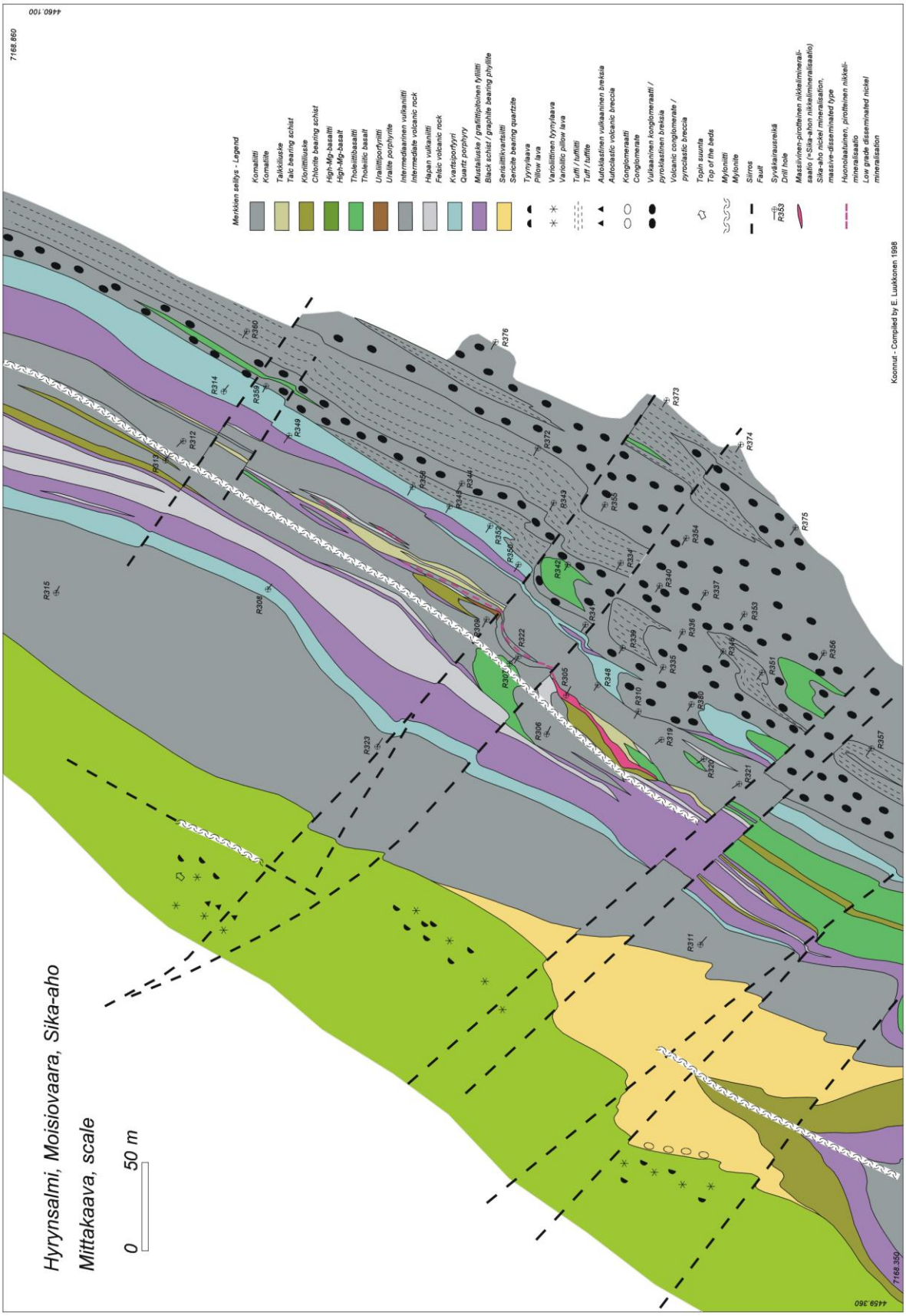


Fig. 3.2.1.1.3a. Bedrock geology of the Sika-aho area, Hyrynsalmi..

The most important sulfide minerals at Sika-aho are pyrrhotite, pentlandite (± Ni-arsenides) and pyrite; arsenopyrite and chalcopyrite are only sporadically present. Petrographical observations indicate that pentlandite tends to occur both as a discrete mineral phase, intergrown with pyrite, and as inclusions or exsolution lamellae in pyrrhotite.

Petrophysical properties of the Sika-aho Ni-mineralization have been correlated against nickel content; resistivity and susceptibility were measured in situ in drill holes, whereas density was measured from drill core samples in the laboratory. Mean values for petrophysical parameters were calculated for each corresponding analyzed section of drill core, which was generally one meter in length; in practice this means that for each one meter section of core, there were twenty measurements of resistivity and susceptibility, but in most cases, a single density measurement is assumed to be representative of the corresponding meter long section of core. It should also be noted that the sensitivity of the equipment used for down-hole Wenner resistivity measurements had a minimum threshold value of 1 Ohm.m. More conductive rock units plot on the resistivity profile between one and several Ohm.m.

The Sika-aho nickel mineralization has a relatively low susceptibility, below 0.005 SI (Figure 3.2.1.1.3b), which is attributed to pyrrhotite in chlorite-sericite schists rather than to magnetite. Densities vary generally between 2 700 – 3 100 kg/m^3 (Figure 3.2.1.1.3d) but there is no perceptible correlation between Ni content and increasing density. Density contrasts between mineralization and surrounding rocks range between +100 ± 300 kg/m^3 but despite this, gravity modeling of the Bouguer anomaly due to the mineralization yields a value of only 0.05 – 0.08 mGal. The Sika-aho mineralization also contains some narrow conductive horizons (RhoApp << 10 Ohm-m) and some of these conductors in drill holes were used for earthing in misé-a-la-masse surveys to determine mineralization dimensions.

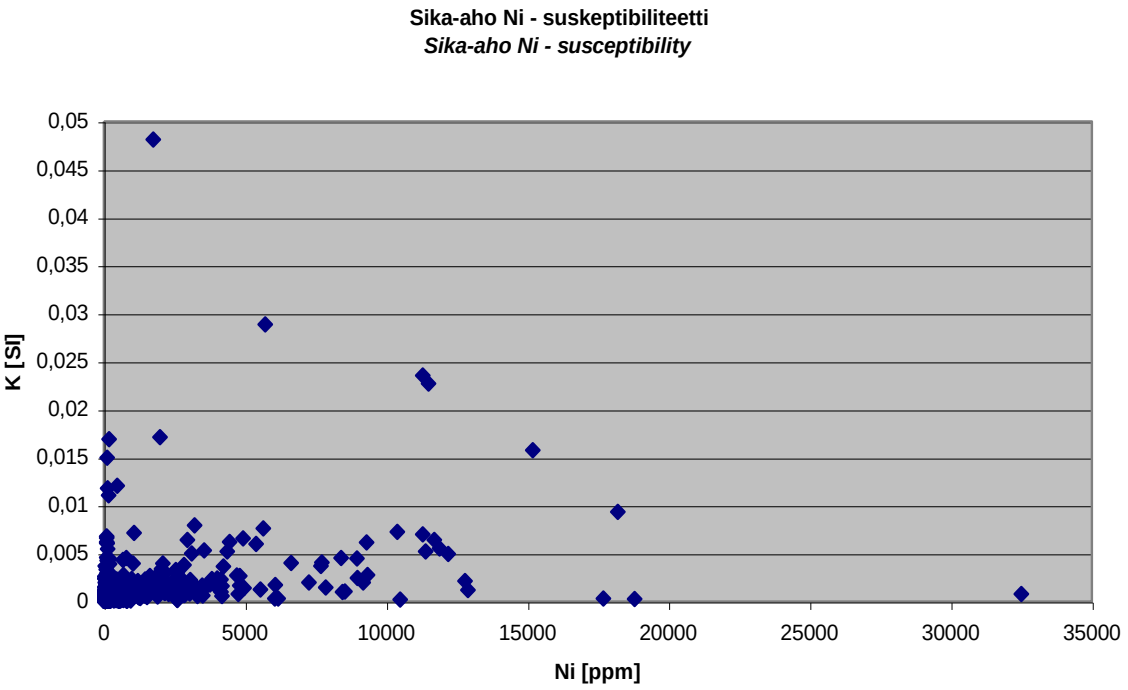


Fig. 3.2.1.1.3b. Susceptibility versus Ni-content, Sika-aho, Hyrynsalmi.

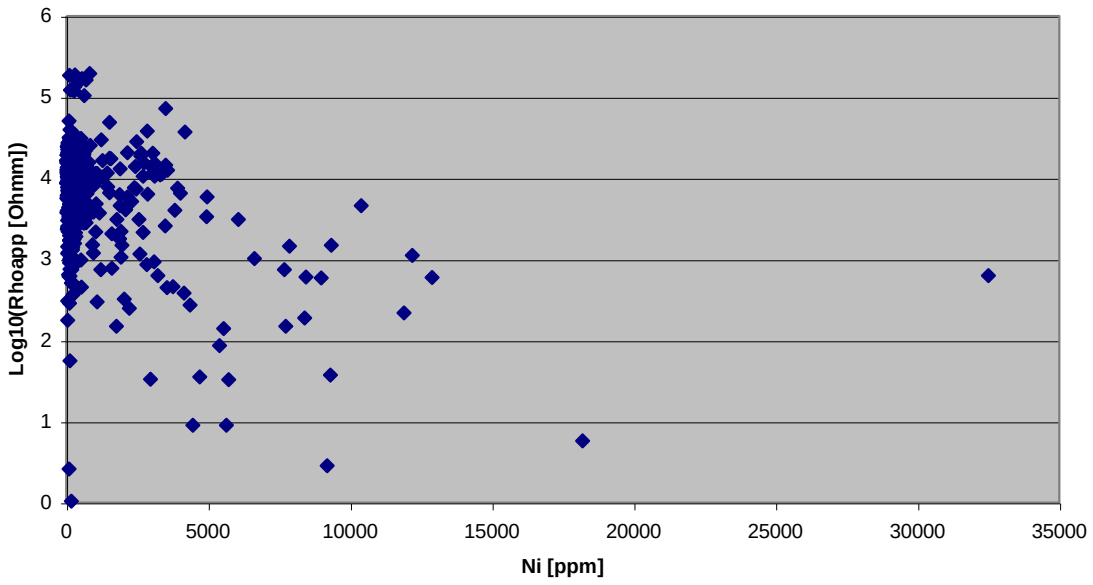


Fig. 3.2.1.1.3c. Apparent (logarithmic) resistivity versus Ni-content, Sika-aho, Hyrynsalmi.

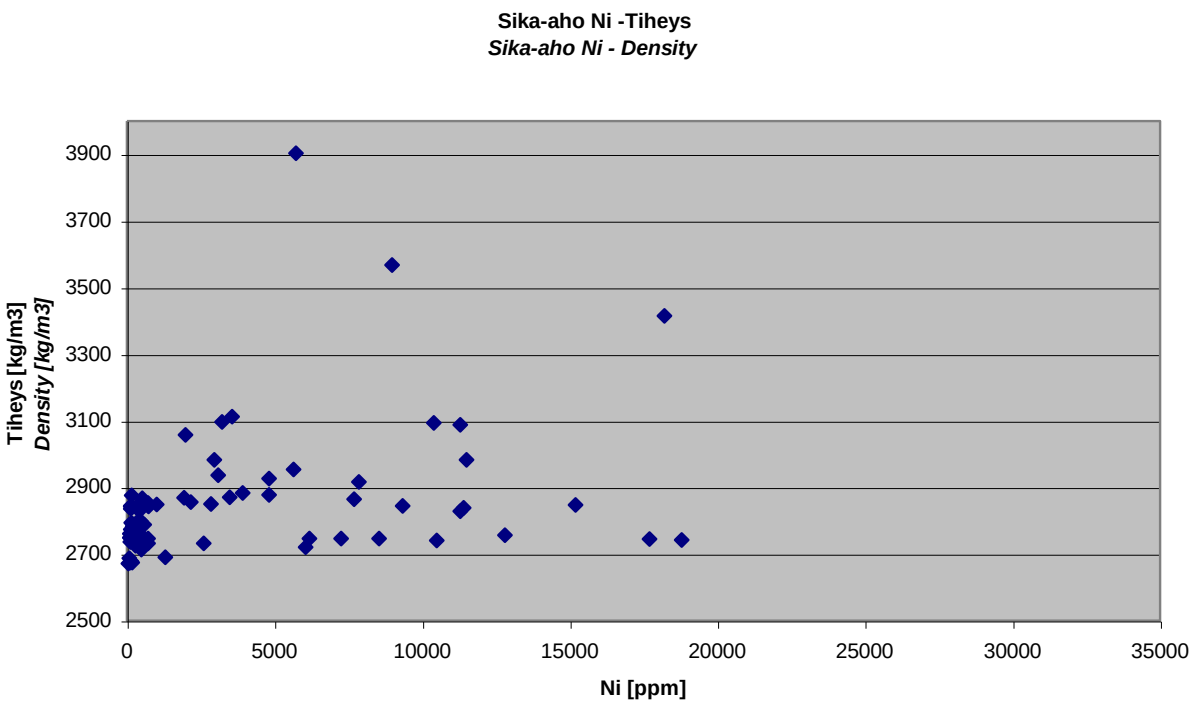


Fig. 3.2.1.1.3d. Density versus Ni-content, Sika-aho, Hyrynsalmi.

Figure 3.2.1.1.3e shows the misé-a-la-masse survey data for the northeasterly continuation of the mineralization. Earthing was in drill hole R345 and the charge potential measured at the surface continued further towards the northeast as far as R349, after which it diminished rapidly. The mineralization was intersected in R349 and again as a much narrower layer in R359, after which it apparently terminates; this corresponds to a steep gradient in the charge potential plot.

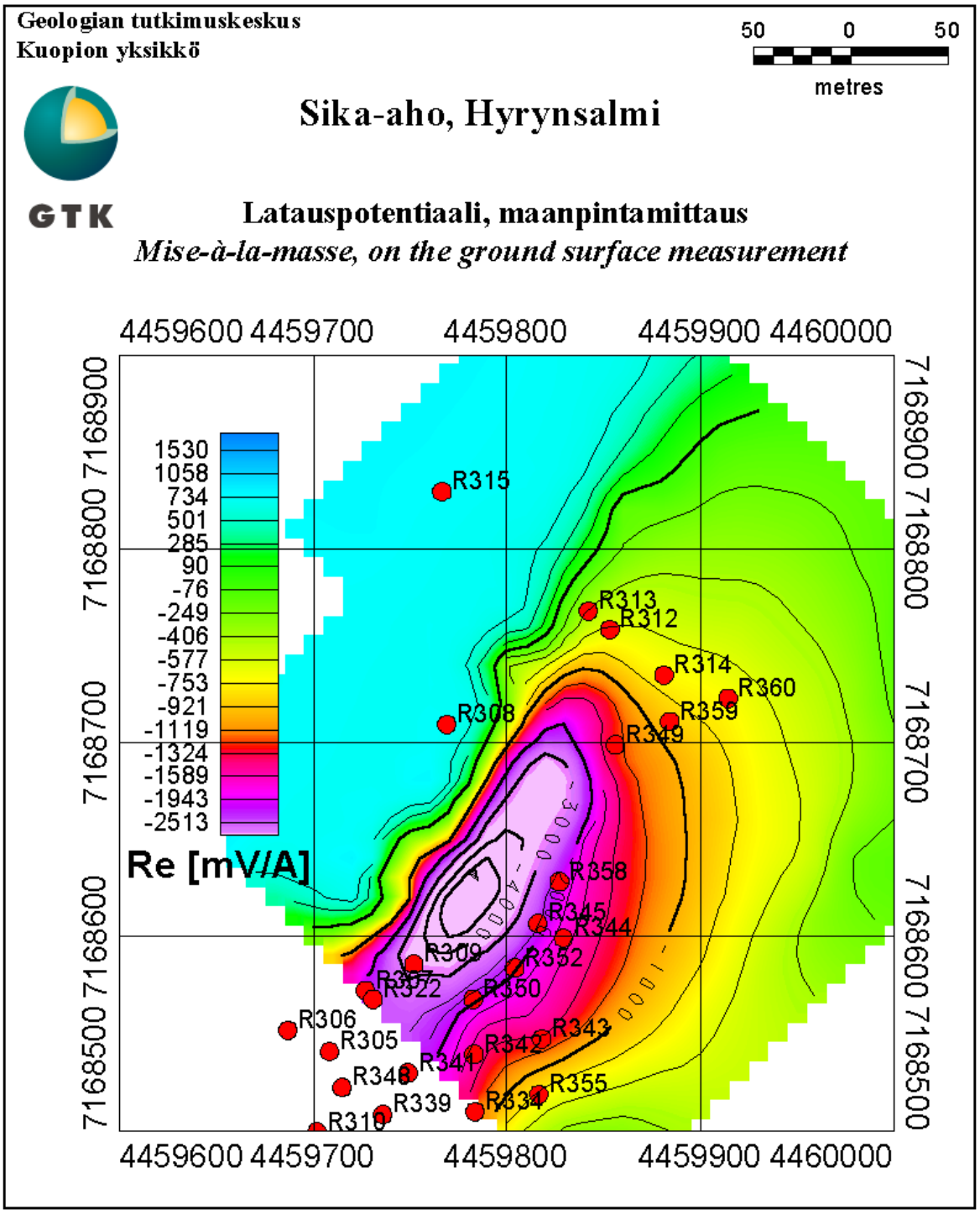


Fig. 3.2.1.1.3e. Mise-á-la-masse measurements at the NE-extension of the Sika-aho mineralization, Hyrynsalmi.

3.2.1.2. Palovaaran - Vuosanka area

The Arola area (refer to Figures 3.2.1.2a and 3.2.1.2b), contains the most significant known mineralization in the Kuhmo greenstone belt and is located near the village of Vieksi, some 40 km northwest of the city of Kuhmo. The older bimodal felsic and mafic volcanic rocks that occur along the eastern margin of the greenstone belt in the Vuosanka and Siivikkovaara areas have not been found at Arola. A robust minimum age constraint for the volcanism at Arola is provided by U-Pb

zircon age of 2 734 ± 2 Ma from a porphyritic granodiorite intrusion defining the western and northern margin of the greenstone belt (GTK Annual Reports 1977, 1978, and Lehtinen 1983).

The lowest stratigraphical unit identified in the Arola area is a highly deformed dark green and massive or banded tholeiitic basalt. The basalts are strongly foliated and folded, with mylonitic textures in places, and therefore primary eruptive features have not been recognized in outcrop. The tholeiitic basalts are overlain by komatiitic lavas but the banded iron formation that occurs at this stratigraphical level in the Palovaara area is not well represented at Arola, apart from several isolated exposures in the southwestern part of the area. Komatiitic lavas and associated cumulates occur as three nearly N-S trending units. At the eastern margin of the Arola area there is komatiitic cumulate lense about 1300 m in length and 300 m in width which is interpreted as an example of a channelized komatiitic lava flow. The komatiitic (high-Mg)basalts that overlie the komatiites in other areas are only sporadically found at Arola and generally absent entirely. The next eruptive unit consists of highly distinctive dark green and massive basalts that are exceptionally enriched in chromium (Halkoaho et al., 2000). The high-Cr-basalts are overlain by a somewhat lighter colored pillowed lava flows alternating with massive Cr-basalts. The Arola Ni-occurrence is hosted by a deformed variolitic pillow basalt in the upper part of this sequence, which also includes some garnet-bearing schists for which Perttula (1983) obtained, using XRD and refractive index determinations, obtained garnet compositions of pyrope (45.4 %), grossular (9.2 %) and spessartine (9.2 %).

The Arola mineralization is aligned within the predominant nearly N-S trending foliation and is associated with chlorite schists, and garnet and tourmaline, indicating that the area has been affected by hydrothermal processes. The stratigraphic position is also rather unusual for komatiitic Ni-mineralization, which further suggests the possibility of some hydrothermal mobilization of nickel from adjacent komatiitic units. Immediately to the east, overlying the Cr-basalts and the Ni-mineralization, is a transition to a sedimentary sequence including metagraywackes, mica schists, graphitic and sulfidic schists and clastic sericitic quartzites, the latter being the uppermost rocks represented. Three types of mafic dyke have been found in the Arola area, the oldest of which is a dark, in places banded, Ti-rich gabbro with uralitic porphyritic texture and which has been observed to discordantly cut across the tholeiitic basalts. The second type is an extensive NW-trending dyke in the northern part of the area which is of wehrlitic composition (Hanski 1984, 1986). The third, and youngest type of dyke is tholeiitic in composition.

The Arola area has been intensely disrupted by faulting and folding, with the main fold plunge trend being 50° - 70° to the south. As a result, repetition of the stratigraphic sequence is apparent in different parts of the area.

Bedrock mapping and investigations were carried out in the Vuosanka area over an extended period from1992 – 1999, with particular emphasis on the gold occurrences at Louhiniemi, Iso Aittojärvi, Pieni Aittojärvi, Mujesuo and Jousijärvi, and the Zn occurrence at Härmänkangas (refer to Figures 3.2.1.2a and b). Systematic EM and magnetic surveys were also made over key areas and additional detailed IP surveys over gold targets. A summary of the geophysical profiles and petrophysical parameters measured in situ and in the laboratory is given in Table 2.2.2.1b and results of surveys have been reported by Tenhola and Niskanen (2001a,b).

The Vuosanka area has been strongly affected by N-S trending deformation zones, and the Aittojärvi and Jousijärvi Au-occurrences are controlled by faulting within one such zone. Faults with NW-SE trends are also prominent, resulting in a distinct network of faults separating isolated domains of less strained rock, which are difficult to correlate. Lithologically the Vuosanka rocks resemble those of the Arola area, except that along the contact zone with the surrounding granitoids, there is an additional sequence that underlies the tholeiitic basalts, comprising sulfide-bearing felsic to intermediate volcanics and sediments (Figure 3.2.1.2c) and

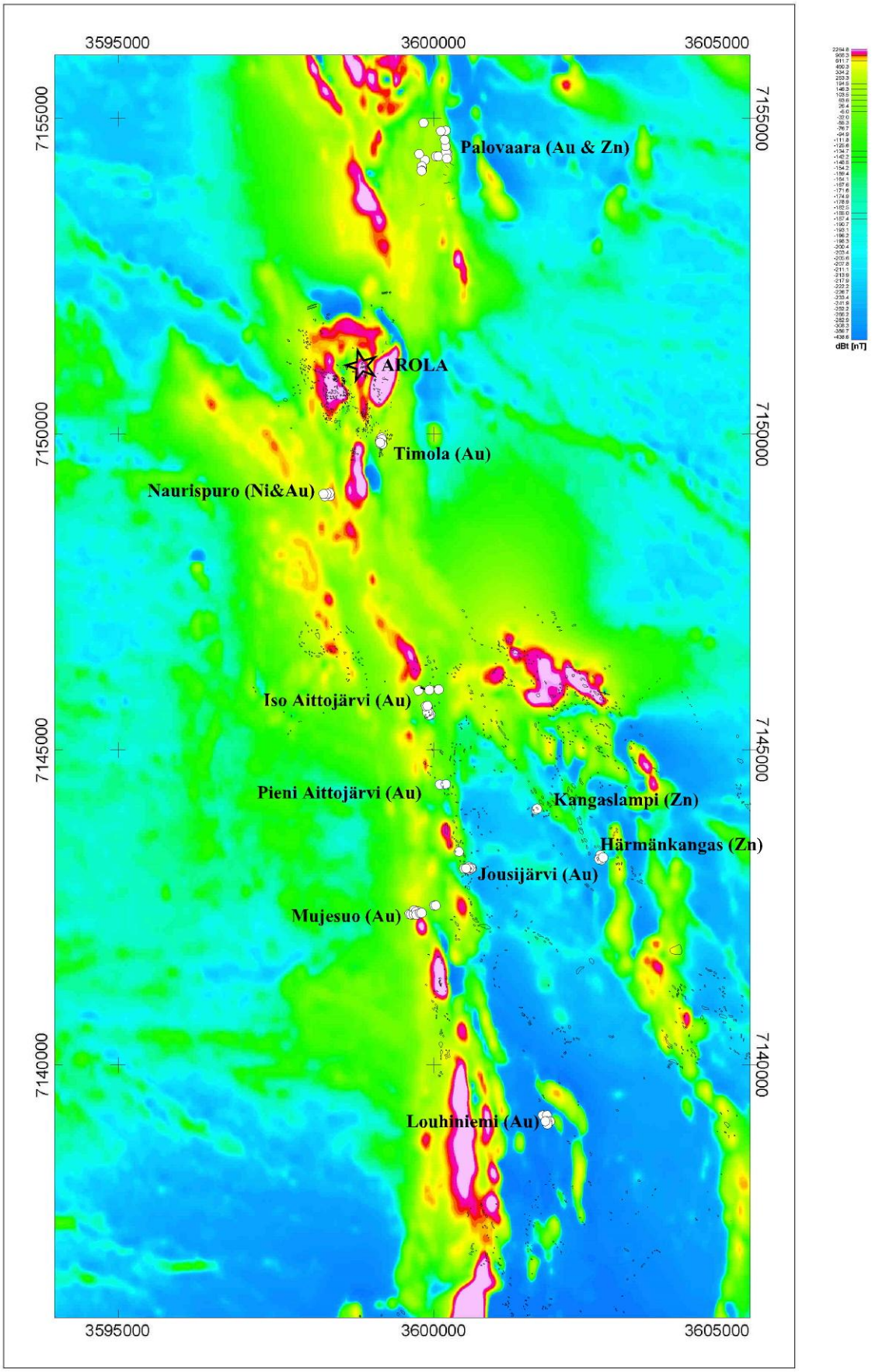


Fig. 3.2.1.2a. Aeromagnetic total intensity map of the Palovaara - Vuosanka area. Locations of exploration targets with diamond drill holes (white circles) and outcrops/trenches also shown.

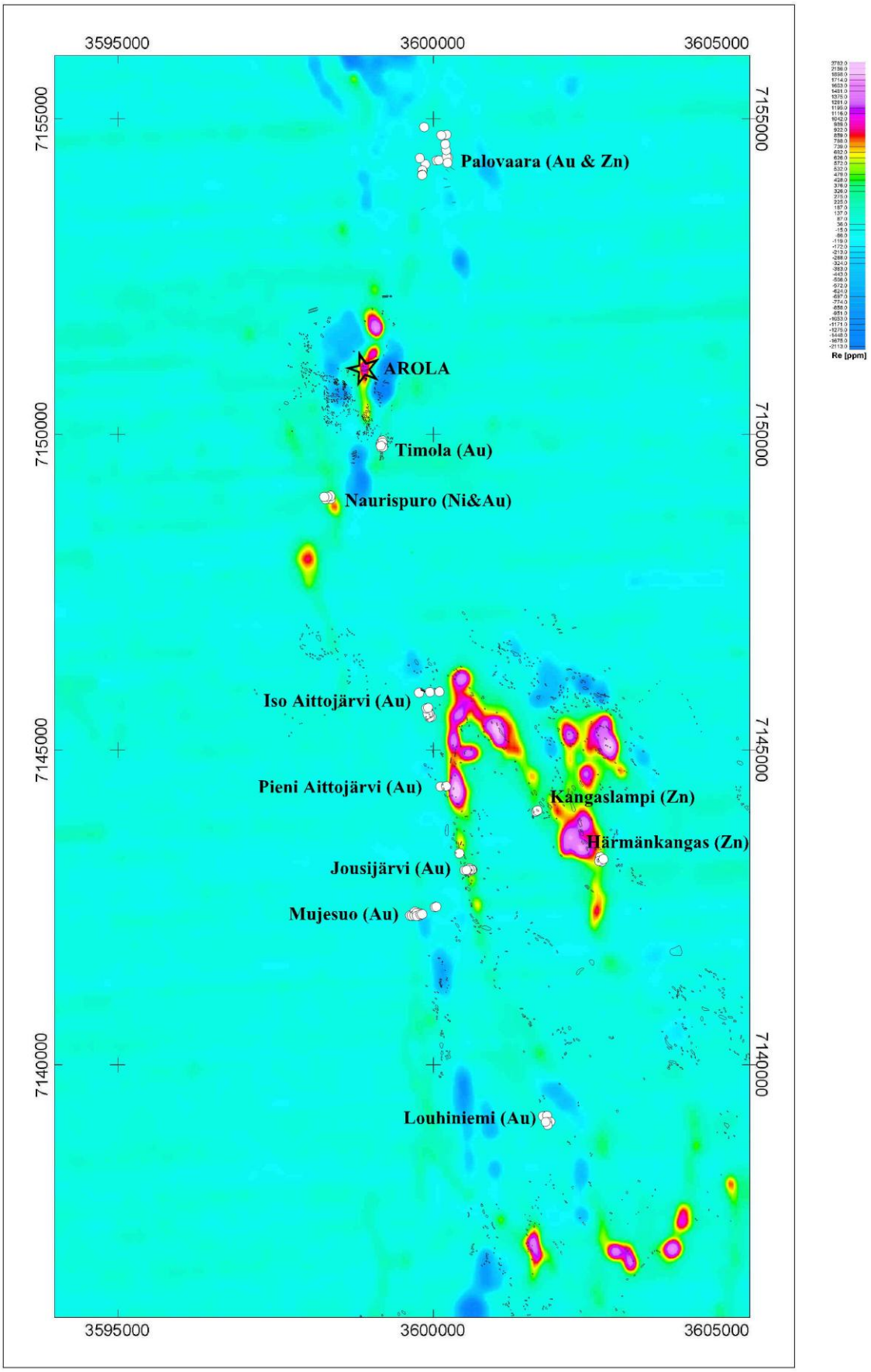


Fig. 3.2.1.2b. Airborne electromagnetic real (in-phase) component map of the Palovaara - Vuosanka area. Locations of exploration targets with diamond drill holes (white circles) and outcrops/trenches also shown.

banded amphibolites (Figure 3.2.1.2d). It is uncertain whether the banded amphibolites are merely highly strained equivalents of the tholeiitic basalts, or belong to an older succession, for example correlatives of the Luoma Group. The tholeiitic basalts are intruded by komatiitic dykes and overlain by komatiitic lavas and cumulates which attain maximum thicknesses on the western shores of the lake Kuivajärvi and to the south of Juurikkajärvi. The komatiitic cumulates are overlain by komatiitic basalts, which are apparently the youngest rocks preserved in the area; the distinctive high-Cr basalts and Cr-basalts found in the Arola area have not been met at Vuosanka.

Airborne magnetic pixel images reveal that the Vuosanka "domal"structure is flanked by two continuous strongly magnetic zones associated with komatiitic cumulate horizons (Figure 3.2.1.2a). The western zone can be traced from north of Iso Aittojärvi and trends almost N-S from Korpijärvi to Kellojärvi. The eastern zone begins at the southwestern shore of the lake Juurikkajärvi and continues along the western shore of the lake Vuosanganjärvi to the southeast of Halmevaara (as far as FIN_KKJ4 grid northing 7134.00N). In addition, there is a magnetic anomaly almost 1.5 km in length beneath the lake Vuosanganjärvi and another, nearly 2.5 km long, at Louhiniemi; both anomaly zones are from 100 –300 m in width.

The airborne EM pixel images over the Vuosanka granitoid "domal" structure (Figure 3.2.1.2b) reveal a number of prominent conductive anomalies. The most northerly of these conductive horizons begins on the northwestern shores of lake Vuosangajärvi and can be traced southwards for about 3 km towards the Vuosanka River, before turning to the northwest, continuing as far as the eastern side of the lake Iso Aittojärvi. From there it again trends southwards, past the lake Jousijärvi to the northern part of the lake Kuivajärvi. Only in the section along the eastern shores of Iso Aittojärvi does a prominent magnetic anomaly coincide with this EM anomaly and is probably attributable to felsic and intermediate sulfide-bearing volcaniclastic deposits.

Fig. 3.2.1.2c. Felsic-intermediate agglomerate about 700 m south from the lake Juurikkajärvi, Vuosanka, Kuhmo. The length of the knife is about 20 cm. Photo by T. Halkoaho.

The Härmänkangas Zn occurrence also lies within this anomaly zone. A significantly weaker anomaly zone can be discerned further west (Figure 3.2.1.2b) starting from the Vuosanka road junction and continuing southwards for about 3 km , to the northern shores of the lake Korpijärvi. This EM anomaly is located to the west of a prominent magnetic anomaly but also locally coincides with intense magnetic responses that suggest the presence, at least locally, of banded iron formations. The third EM anomaly zone, which is about 100 – 200 m wide and 5 km in length commences at the village of Koskenmäki, trending eastwards as far as Halmevaara, where it turns towards the north. This EM anomaly is not associated with any magnetic anomalies. The most easterly of the EM anomaly zones is 100 –200 m in width and can be traced from the northeastern part of the Halmevaara area for at least 3 km towards the south. In contrast to the preceding anomalies, this zone coincides with a strong magnetic anomaly. Outcrops are very scarce in this area so it has been impossible to ascertain what rock types generate these anomalies. Nevertheless, the abundance of sulfide-bearing boulders of felsic to intermediate composition indicates that these rock types are likely to be present in the area.

Fig. 3.2.1.2d. Banded amphibolite and cross-cutting ultramafic dyke, along the southwestern shore of the lake Juurikkajärvi, Vuosanka, Kuhmo. The length of the knife is about 20 cm. Photo by T. Halkoaho.

3.2.1.2.1. Zinc and gold investigations in the Palovaara area

The first indications of zinc potential in the Palovaara area were found in 1987, when disseminated sphalerite was noted in felsic volcanic intercalations within a predominantly mafic volcanic sequence. At the same time, compact pyritic horizons with elevated gold concentrations were discovered within banded iron formations in the same general area.

Local till geochemical surveys were undertaken from 1987 – 1989 after which, in 1990 and 1991, more detailed sampling was carried out at Härmänkylä and in the area between Palovaara and

Kelosuo, as shown on the map of gold distribution in till (Figure 2.3.5a). Further sampling was done on a more closely spaced grid and individual profiles, the results of which have not previously been published. Therefore, analytical data for Ni-, Zn-, Pb-, Fe-, Cu- and Au are presented here, and shown in Figure 3.2.1.2.1a and b, with the more significant results given in tables in Appendix 2.

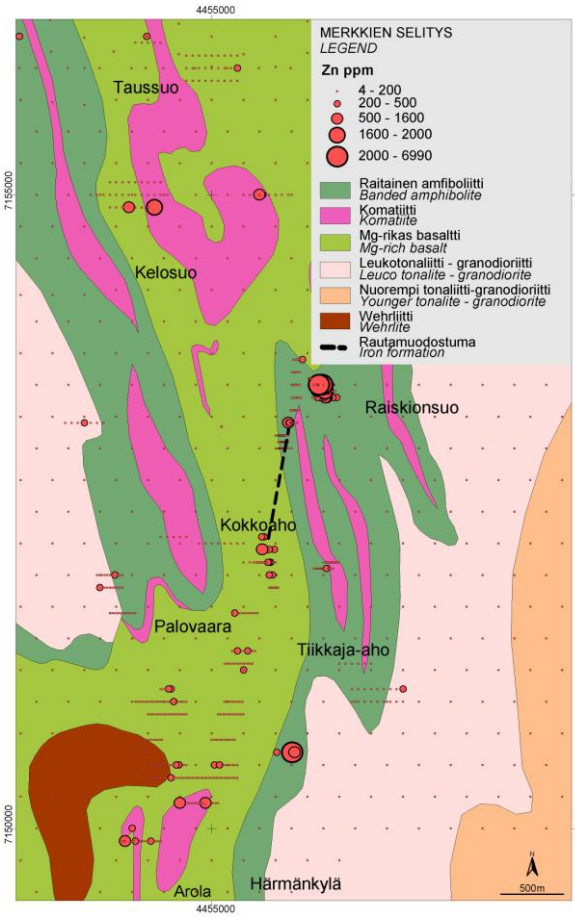
Zinc abundances form a prominent NW-SE trending anomaly terminating at the northwestern end of Raiskiopää, where the highest Zn values from weathered bedrock samples were obtained, namely 1 880 ppm, 3 390 ppm and 6 990 ppm (Figure 3.2.1.2.1a). High zinc abundances are also present at Kelosuo and in the area between Tiikkaja-aho and Härmänkylä, where the maximum value analyzed was 2 200 ppm. Iron is rather uniformly distributed throughout both mafic volcanic and ultramafic bedrock areas (Figure 3.2.1.2.1a), with anomalously high values (6.0 – 13.9 %) being characteristic of the entire region. A banded iron formation, found in outcrop to the west Raiskionsuo and extending for about a kilometer along strike (Timo Heino, personal communication, 2001) is clearly evident as a discontinuous chain of anomalies. The same horizon may continue further south towards Kokkoaho, where high iron contents are also present.

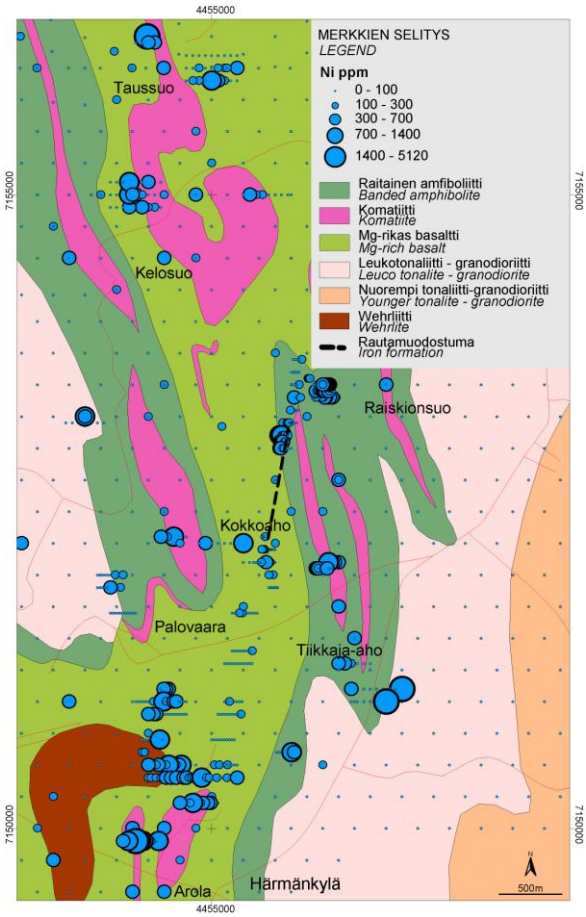
Elevated nickel abundances are also found in till between Arola and Palovaara (the highest value being 2 110 ppm), at Tiikkaja-aho (maximum Ni value = 1 820 ppm) and in the Kelosuo – Taussuo area (Figure 3.2.1.2.1a). Anomalous copper abundances were similarly found to the northwest of Raiskionsuo, with a maximum value of 2 940 ppm (Figure 3.2.1.2.1b). Anomalous copper is also present at Kokkoaho, Kelosuo and north of Arola. Slightly elevated copper concentrations are also common in a zone that extends from north of Härmänkylä to the northwest beyond Raiskio, converging upon the northern end of the banded iron formation horizon. This zone also exhibits weak and discontinuous anomalies with respect to gold (Figure 3.2.1.2.1b). Sporadic elevated gold abundances are also apparent within the transition zone between banded amphibolites and Mg-rich basalts. Lead anomalies are also conspicuous in the northern end of Raiskionsuo, with a maximum value of 3 340 ppm (Figure 3.2.1.2.1b)

Magnetic, EM, IP and VLF surveys were undertaken in the Palovaara area in 1988 and 1989 (Figure 2.2.2.1a). The IP results indicated that at least one horizon anomalous in zinc can be traced for more than a kilometer. The banded iron formations are also readily discernible in the magnetic data (Heino, 1995).

Four separate drilling programs were undertaken in the area, beginning in 1987 with four holes having a combined length of 432.4 m. Seven holes, totaling 212.8 m were drilled in the northern winter of 1989 –1990, in order to determine the extent of the zinc-enriched horizon and to ascertain the range of zinc abundances. In 1990, four holes were drilled, with a total length of 289.1 m, with the aim of determining the extent of anomalous gold contents in banded iron formations (Heino, 1995). The last drilling phase was in 1993, when five holes with a combined length of 593.9 m were drilled, three of which were to test the northern continuation of the banded iron formation, while the remaining two were to assess whether the zinc-mineralized horizon also continued northwards.

The highest gold contents analyzed from drill core (4.6 ppm and 3.1 ppm) were within the banded iron formation, which contained grünerite as well as pyrrhotite breccias. The best mineralized intersection contained 1.3% Zn over a 3 meter interval. The banded iron formation does not appear to contain any economically significant gold mineralization, although the anomalous horizon can be traced by its geophysical signatures for a distance of more than 10 km. Zinc and lead abundances are also rather modest, well below economic ore grade concentrations (Heino, 1995).





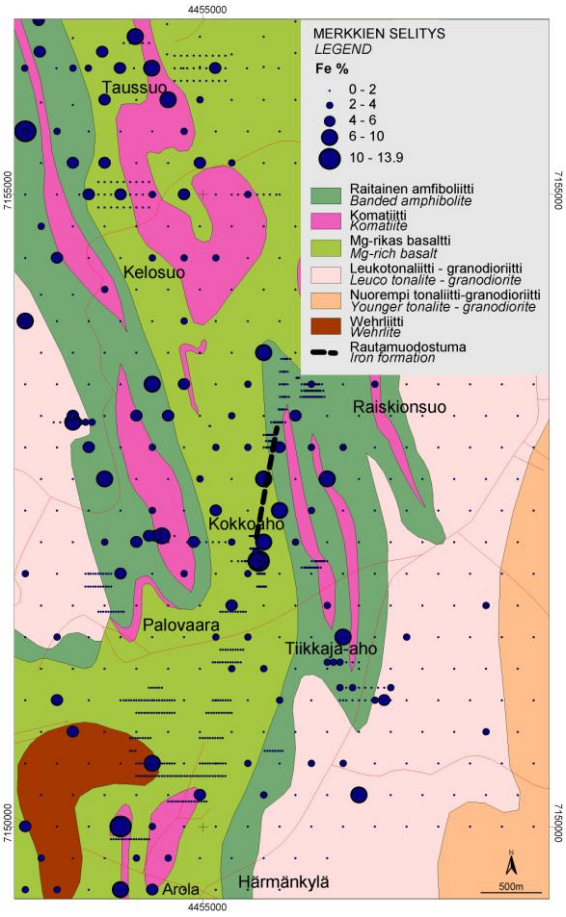
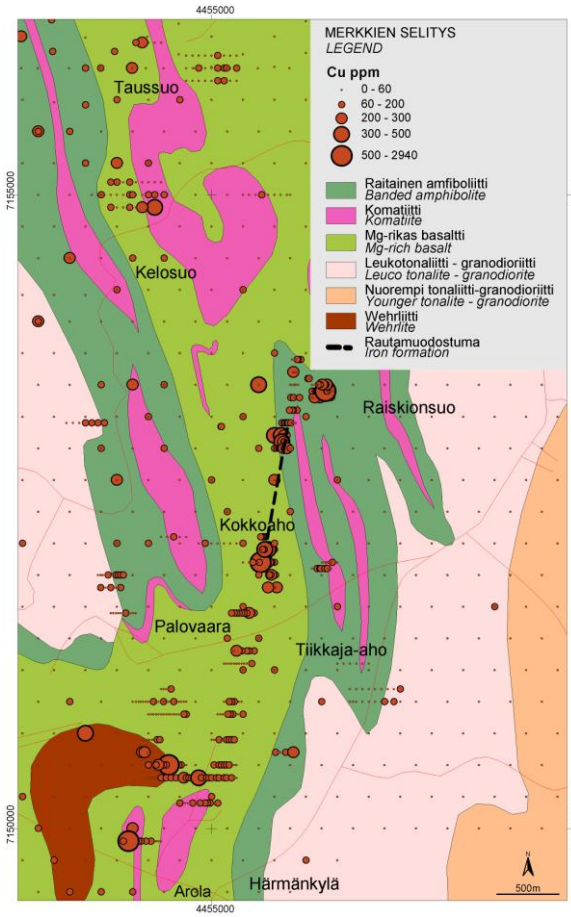
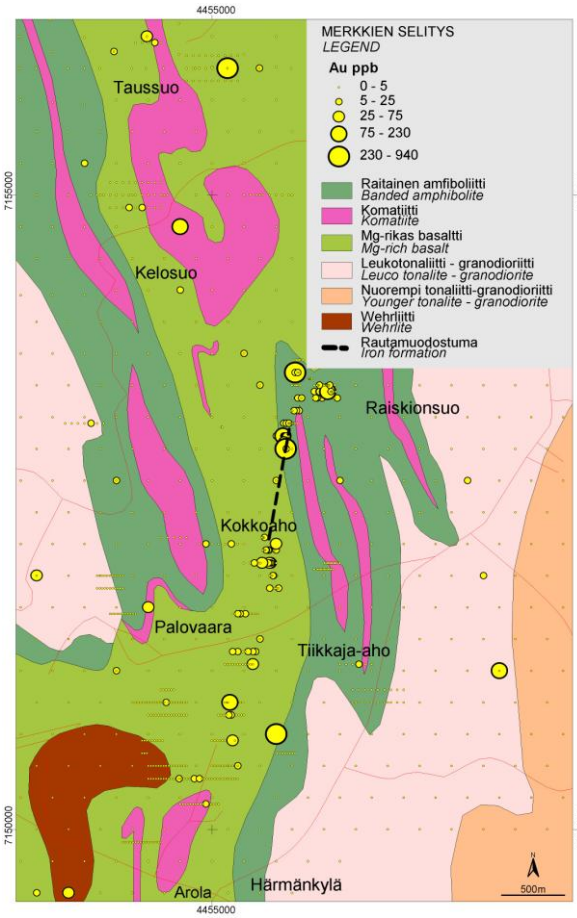


Fig. 3.2.1.2.1a. Zinc, nickel and iron concentrations in till and weathered bedrock samples taken during detailed scale surveying in the Palovaara area, Kuhmo.





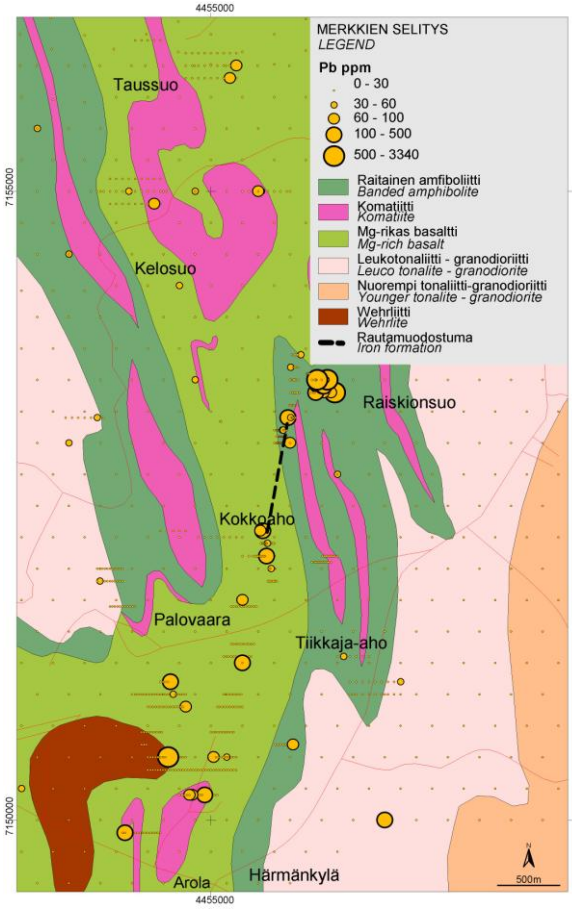


Fig. 3.2.1.2.1b. Copper, gold and lead concentrations in till and weathered bedrock samples taken during detailed scale sampling in the Palovaara area, Kuhmo.

3.2.1.2.2. Timola Au-occurrence

The Timola gold occurrence is situated northwest of the city of Kuhmo, a kilometer south of Härmänkylä, to the east of the main road from Kuhmo to Hyrynsalmi. Tholeiitic volcanics dominate in this area and are strongly deformed, commonly mylonitic, with a foliation trend almost N-S (010º - 190º), which is subparallel to the general trend of the greenstone belt. Outside the exploration lease covering the Timola mineralization, a greater diversity of rock types is present, including serpentinites, soapstones, mica schists and quartz-feldspar gneisses.

Nine POKA holes were drilled in 1995 (GM 100, T46 mm, holes R356 – R364), totalling 582.50 m in length. A further twelve holes (R374 – R385), totalling 915 m were drilled with the RC technique in 1997 (Table 3.2.1.2.2). Specific details for each of the 21 holes drilled were presented in an earlier report by Hartikainen (2001).

Table 3.2.1.2.2. Amount of drill hole, total length of drillings, the amount of ICP-analyses and gold analyses (GFAAS and syanidization+GFAAS), the amount of XRF analyses and thin sections in the drillings in Timola, Kuhmo. ICP=Inductively Coupled Plasmaspectrometer, GFAAS = Flameless absorption spectrophotometer with graphite furnace, POKA=GM100-drilling, RC=Reverse Circulation drilling.

	Drill holes	***Total length, m***	***ICP analyses***	***GFAAS analyses***	***Syanidization + GFAAS analyses***	***XRF analyses***	***Thin sections***
POKA drilling	9	582.50	497	497	0	2	2
RC drilling	12	915.00	0	0	905	0	0
Altogether	21	1497.50	497	497	905	2	2

The dominant rock type hosting the mineralization is a mylonitic tholeiitic basalt which usually shows evidence of intense hydrothermal alteration in the form of biotite, chlorite, quartz, carbonate, sericite and less commonly, epidote. The more highly strained rocks tend also to be more strongly altered, containing abundant biotite. Tourmaline is very common within fracture networks and at the margins of quartz veins but also within the tholeiitic basalts. Scheelite and fuchsite also occur sporadically within the altered rocks, though have not been observed in direct association with gold.

The highest gold content analysed from drill core was 2.82 ppm and five one meter intervals had mean Au concentrations > 1 ppm. However, there was no obvious visible correlation between gold concentration and rock type, intensity of deformation or degree of alteration. Arsenopyrite is nevertheless almost always present where gold is anomalous. Arsenic also forms a distinct geochemical halo around the mineralization (Figure 3.2.1.2.2) and the Timola area is clearly anomalous with respect to arsenic in the till geochemical survey data (Hartikainen, 2001). The sulfur content of gold mineralized samples, despite the apparent abundance of sulfide minerals, is almost always < 1 % (varying between 0.06 – 1.01 %).

In conclusion, the gold anomalous zone at Timola has rather low gold grades, and the overall dimensions of the mineralization are relatively small. There is still however, potential for exploration within the cataclastic and mylonitic deformation zone, both to the north and south of Timola.

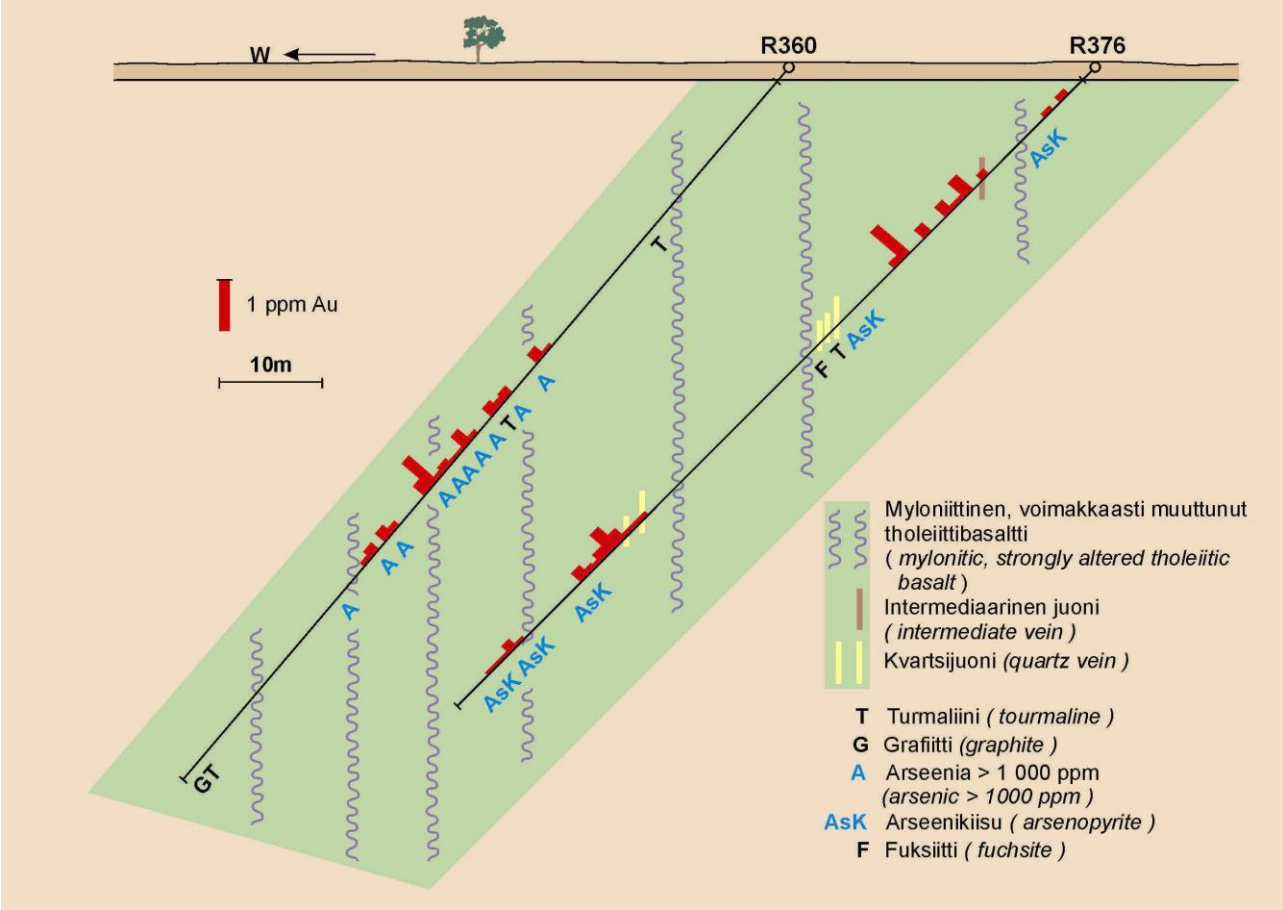


Fig. 3.2.1.2.2. Drilling profiles M52/4412/95/R360 and M52/4412/97/R376 at the Timola prospect, Kuhmo.

3.2.1.2.3. Gold and nickel investigations at Naurispuro

During the present project, investigations were carried out into gold potential in the highly sheared tholeiitic basalts of the Timola area, immediately south of the Härmänkylä road junction (Figure 3.2.1.2.2), as described by Hartikainen (2001) and in Section 3.2.1.2.2. The Naurispuro area is situated further south again, some 2.5 km south of the Arola Ni-mineralization and the purpose of investigations in this area was to obtain a better understanding of the nickel mineralization and also to assess whether the gold mineralization at Timola was indeed part of a more extensive mineralized zone (Halkoaho et al., 2001b).

During detailed geochemical surveying in 1996, 344 samples were obtained from the Naurispuro area, including 122 samples from till, 210 samples of weathered bedrock and 12 samples of weathered material in till. The highest metal abundances analyzed were Ni = 1 580 ppm, Cr = 2 760 ppm, Zn = 1 390 ppm and Au = 956 ppb (Appendix 2). A number of other samples yielded Au concentrations of several hundreds of ppb or more, suggesting that the Timola anomalous zone may indeed continue for several kilometers southwards to Naurispuro.

The five holes drilled at Naurispuro (total length 355.5 m) intersected mafic volcanics for the most part, with sporadic intercalations of sulfidic and graphitic phyllites and cherts. The phyllitic units are generally less than 5 m thick, with one exceptional unit at the bottom of one hole being 15 m. Thin felsic units, possibly volcanic in origin, were also locally present. A single 2 m interval of carbonated ultramafic rock was present in the upper part of one hole. The entire rock sequence is dipping steeply eastwards (85°) or vertical. The prominent EM anomalies and the

western magnetic anomaly trend may both be attributed to sulfidic and graphitic phyllites. The eastern magnetic anomaly is more likely to represent the continuation of the komatiitic cumulate body that is known to outcrop north of the local primary school. Although no whole-rock geochemistry has been done on the mafic rocks at Naurispuro, by analogy with the Arola area, phyllitic sediments only occur stratigraphically above the and to the east of Cr-basalts (which belong to the komatiitic series). Therefore, it is inferred that the mafic volcanics intersected during drilling at Naurispuro are Cr-basalts. The rocks surrounding the eastern magnetic anomaly are also thus likely to be tholeiitic basalts. Although the proposed stratigraphic sequence correlates well with that described for the area surrounding the Arola Ni-occurrence, no evidence of nickel enrichment was found at Naurispuro. The highest Ni abundance measured in till sampling was 1 580 ppm but the same sample also had 2 760 ppm Cr, which means that the sample is likely to have been weathered serpentinite.

3.2.1.2.4. Iso Aittojärvi and Pieni Aittojärvi gold occurrences

Investigations in the gold potential of the Iso Aittojärvi area began in the early 1990's, when a mylonitic deformation zone was found on the eastern shores of the lake, characterized by quartz – tourmaline breccias in strongly sheared chloritic schists, with locally abundant arsenopyrite. Two exploration trenches were excavated by GTK across this zone, with detailed sampling. Three holes were drilled at the northeastern end of the lake and a further two to the southeast of the nearby lake Pieni Aittojärvi (Tenhola and Niskanen 2001b).

Till geochemical surveys were conducted in 1994; of a total of 233 samples, 112 represented till and 119 were from weathered bedrock and weathered till material (Appendix 2). Anomalous gold values were distributed extremely erratically and the highest value obtained was 174 ppb (Figure 3.2.1.2.4). In contrast, arsenic abundances defined a distinct, sharply defined anomaly along the eastern shore of lake Iso Aittojärvi (Figure 3.2.1.2.4). Arsenic contents exceeded 80 ppm in many samples, the highest value being 10 800 ppm.

Magnetic total intensity measurements were made with a proton magnetometer along profiles spaced 50 m apart. Slingram EM ground surveys were made with a GTK system using a coil separation of 60 m and 14kHz frequency, with the same profile and point spacing as for the magnetic surveys (Tenhola and Niskanen 2001b).

Six deep diamond holes were drilled in 1993 and demonstrated the extensive nature of the hydrothermal alteration, characterized by biotite, chlorite and tremolite in mafic volcanic rocks and an abundance of talc-carbonate veins typically 1-5 cm wide. Tourmaline was present in the mafic volcanics as well as in the quartz breccias. Arsenopyrite was found both erratically and abundantly in almost all rock types intersected. The drilling to the southeast of Pieni Aittojärvi revealed that felsic volcaniclastic rocks predominate in that area, alternating with carbonated ultramafic rock intercalations. Arsenopyrite and tourmaline were also relatively common. Gold and tellurium contents in drill core were however generally low, the highest values analysed being Au = 395 ppb and Te = 262 ppb. Arsenic concentrations were high throughout the entire section drilled, the highest value obtained being 26 400 ppm. The highest Cu value analyzed, of 4 580 ppm also occurred within this anomalous arsenic zone.

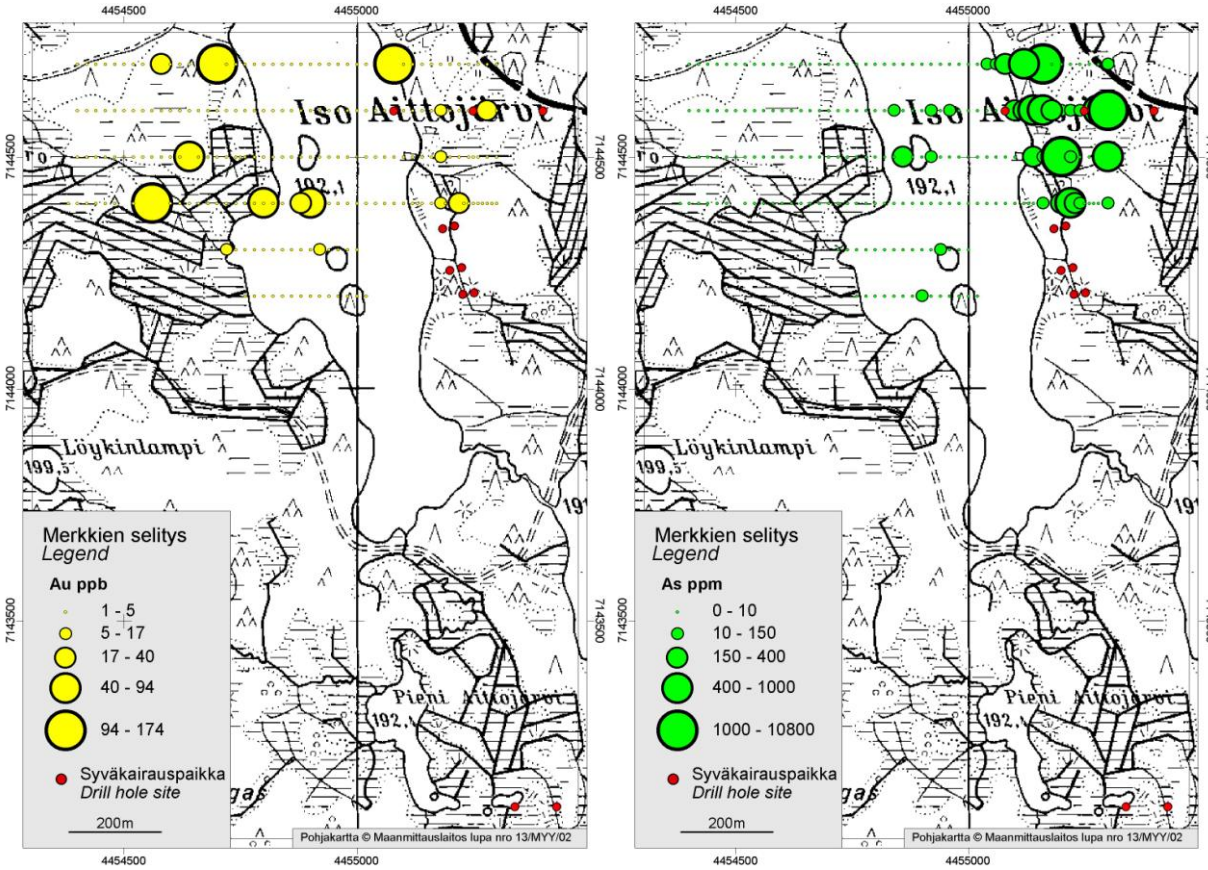
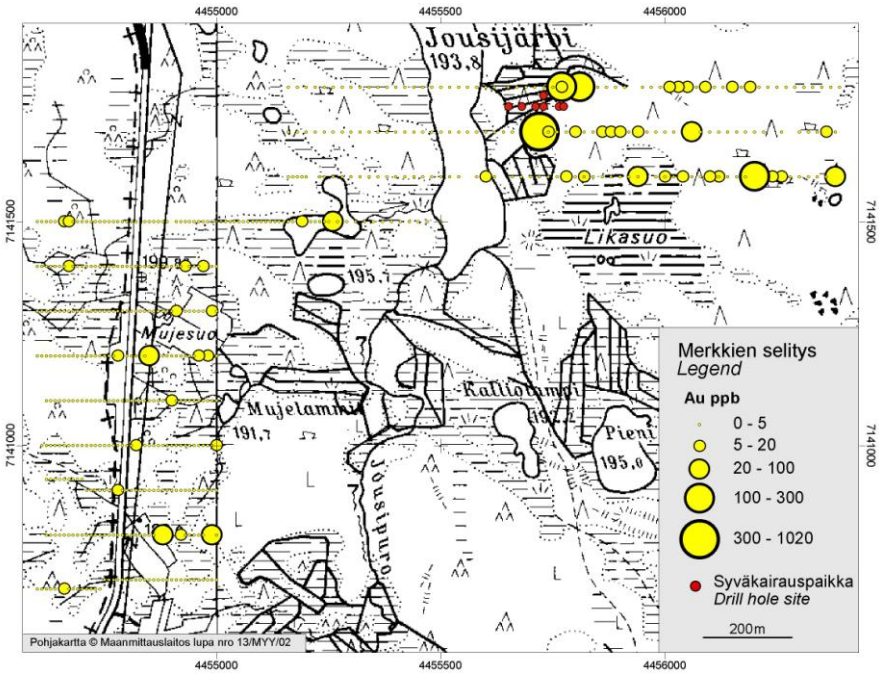


Fig. 3.2.1.2.4. Gold and arsenic concentrations in till and weathered bedrock samples taken during detailed scale sampling surveys and at drill hole sites in the Iso Aittojärvi area, Kuhmo.

3.2.1.2.5. Jousijärvi gold occurrence

The Jousijärvi area seems likely to represent a continuation of the Iso-Aittojärvi As and Au anomalous zone, especially given the similarities in rock types and the continuous nature of geophysical anomalies between the two areas. A single hole was drilled beneath the lake (Pajunen 1990) and intersected chlorite-biotite schists, amphibolites and more felsic schists and gneisses. As at Iso-Aittojärvi, intervals several meters thick of carbonated ultramafic rocks, and talc schists were present. Tourmaline was widespread in quartz breccias as well as in both felsic and mafic rocks. It is therefore apparent that a continuous anomalous zone extends from Iso Aittojärvi through Pieni Aittojärvi to Jousijärvi. Because the drilling was originally planned for clarifying lithological relationships, no analytical data are available.

Till geochemical sampling was done in two stages, to the east of Jousijärvi in 1991 and to the west in 1994. The total number of samples obtained was 254, of which 188 were till samples, 58 were from fresh and weathered bedrock (Appendix 2). Metal abundances were abnormally low, which is partly due to the relatively small proportions of bedrock and weathered bedrock (only 22.8 % of the total number of samples). This in turn was due to the stony and compact nature of the till in this area, which made sampling from the bedrock interface technically demanding. Despite this, there is a clearly discernible N-S trending arsenic anomaly between Iso Aittojärvi and Jousijärvi (Figure 3.2.1.2.5). The highest arsenic concentration analyzed was 6 180 ppb (Appendix 2). Gold abundances also define a distinct anomaly to the east of Jousijärvi, with the highest value measured being 1 020 ppb (Figure 3.2.1.2.5).



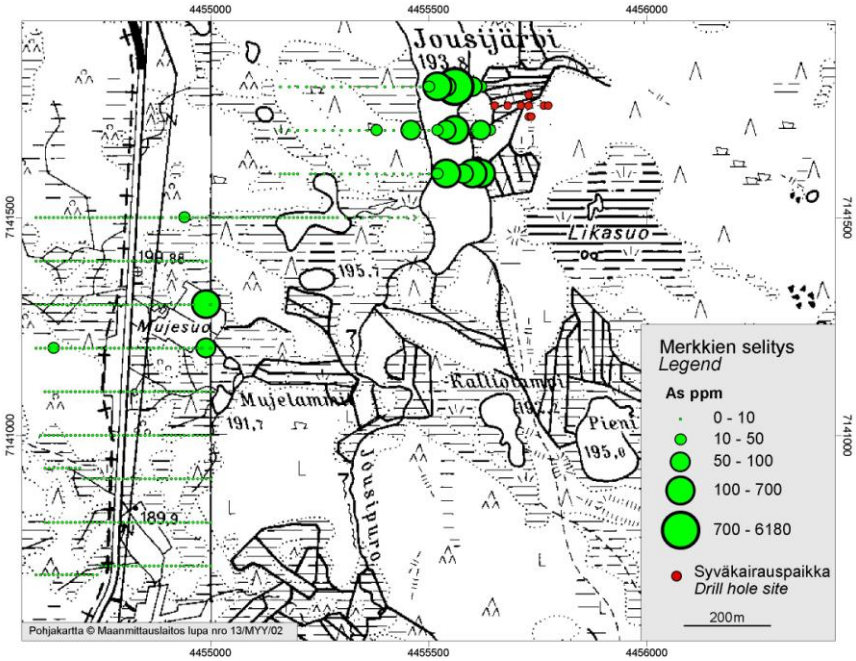


Fig. 3.2.1.2.5. Gold and arsenic concentrations in till and weathered bedrock samples taken during detailed scale sampling surveys and at drill hole sites in the Jousijärvi and Mujesuo areas, Kuhmo. Arsenic has not been analysed in the area east of lake Jousiiärvi.

During 1993, five holes were drilled and in 1996, four holes, making a total drilled length of 382 m. The holes were sited to the east of the main arsenic anomaly that passes through Jousijärvi, with the aim of intersecting the gold anomalies identified in till sampling (Figure 3.2.1.2.5). The main rock types intersected were tonalite and felsic to intermediate volcanics, with occasional garnet-bearing mica schist intercalations. Disseminated iron sulfides are common, but compact sulfide bands are also present. Arsenopyrite is however only occasionally present (Tenhola and Niskanen, 2001b).

In one drill hole there was a 3 m intersection, in garnet-bearing intermediate volcaniclastic rocks with a weak sulfide dissemination, in which gold abundances varied from 1 440 – 3 820 ppb. The highest arsenic content in this interval was 1 300 ppm.

3.2.1.2.6. Mujesuo gold occurrence

The impetus for gold investigations in the Mujesuo area came from a mineralized sample submitted to GTK by Viljo Heikura in early 1993. The rock was a tremolitic quartz vein which not only had an exceptionally high Au content, of 850 ppm, but also anomalous Ag (25.4 ppm), Cu (1 500 ppm) and Pb (911 ppm). Visible gold was present in the sample, especially along fractures (Tenhola and Niskanen, 2001b).

Geochemical surveys were made in 1993 and 1994, with a total of 381 samples collected, of which 261 represented till and 120 were from bedrock and weathered bedrock (Appendix 2). Till stratigraphy and clast transport and provenance was studied in detail in 1994, concluding that the till was particularly sandy, and extremely compacted, and in places was formed as ablation moraines. Gold abundances were very low, the maximum value being only 51.7 ppb (Figure 3.2.1.2.5, Appendix 2). Arsenic values were also low (Figure 3.2.1.2.5). Nickel abundances define a prominent and continuous anomaly trend along the eastern edge of the survey area, with a maximum value obtained of 2 050 ppm.

Magnetic surveys were done with the same instruments and grid spacing as at Iso Aittojärvi, whereas IP measurements (a total of 20 line km) were made with a dipole-dipole configuration using a Scintrex IP system with measurement parameters a = 20 m and n = 3 (mid-point distance between dipoles was 60 m).

During 1994 and 1995, 17 holes were drilled at Mujesuo, with a total length of 996.7 m. The main rock types intersected were intensely chloritized mafic volcanics and amphibolites, and some granitoids in the western parts of the area. Talc-carbonate schist intercalations within the mafic volcanics were common, especially in the eastern part of the area. Tremolitic chlorite schists were present in many drill holes, but no tremolitic quartz rock, equivalent to the gold-bearing sample which had originally been submitted to GTK, was found. Both pyrite and pyrrhotite were abundant and chalcopyrite was sporadically present; arsenopyrite was however absent.

Gold abundances in drill core at Mujesuo were generally low, although a single one meter interval in one hole had a mean value of 9 060 ppb. This mineralized section consisting of radiating crystal of tremolite and actinolite with chlorite and disseminated iron sulfide and chalcopyrite, as well as rare grains (0.1 x 0.5 mm) of visible gold. Arsenic and tellurium abundances were low throughout; the deformation zone containing abundant arsenopyrite and tourmaline that can be traced from Iso Aittojärvi to Jousijärvi does not pass through Mujesuo itself, but is located some 700 m to the east.

3.2.1.2.7. Härmäkangas and Kangaslampi zinc occurrences

Investigations into zinc potential at Härmänkangas commenced after the discovery of mineralization, with a maximum content of 8 % Zn, in outcrop in 1995 by GTK field operations manager, Tarmo Kemppainen. Although no detailed till geochemical surveys were made, drilling at the site commenced in 1996, with six holes having a combined length of 395 m (Tenhola and Niskanen, 2001b).

No ore grade intersections were found in drill core although elevated abundances between 1 000 – 9 000 ppm were present over one 40 m interval. Arsenic was also distinctly anomalous, with a maximum value of 1.3 % As but gold concentrations were consistently low.

A limited geochemical survey was conducted over the Kangaslampi area in 1994, with a total of 28 samples (Appendix 2). Metal abundances were low, the highest Au value being 148 ppb and Zn 353 ppm. A total of 122 m was drilled in two holes at Kangaslampi; metal abundances were likewise low and devoid of significant anomalous concentrations.

3.2.1.2.8. Louhiniemi gold occurrence

The stimulus for investigations in the Louhiniemi area came from several gold anomalous samples submitted to GTK by Väinö Kemppainen in late 1997, with Au concentrations of 5 060 ppb, 4 500 ppb and 2 800 ppb. Arsenic values were also highly anomalous, corresponding concentrations being 16 000 ppm, 15 900 ppm and 42 000 ppm. The samples consisted of strongly deformed and rather silicified amphibolite, with disseminated pyrite and pyrrhotite as well as arsenopyrite. All samples were found within a relatively small area to the east of the Korkealehto farmstead and were of particular interest in that this area is located along the same trend that contains the Iso Aittojärvi, Jousijärvi and Mujesuo gold occurrences. Although the mineralized boulders were of the same rock type as that found in outcrop on a nearby lakeshores, sampling of the latter did not reveal anomalous gold concentrations.

Geochemical surveys were done in the northern winter of 1998, so that sampling could be undertaken beneath frozen lakes. Samples were collected with a Terri percussion drill rig along profiles with a line spacing of 100 m and sample spacing of 10 m. A total of 459 samples were obtained, of which 212 were of till, 212 from weathered bedrock, 29 represented weathered bedrock material in till and 6 were chip samples from the underlying bedrock (Appendix 2).

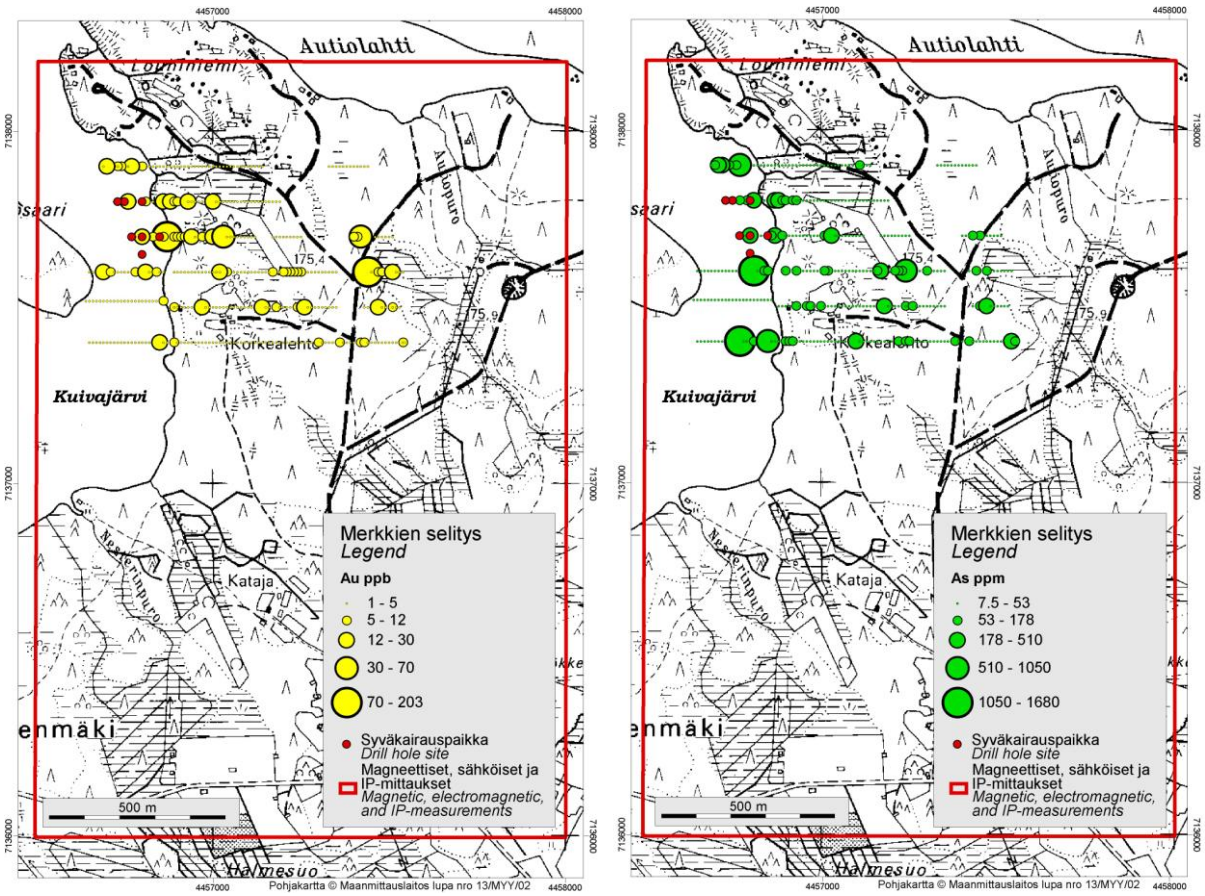


Fig. 3.2.1.2.8a. Gold and arsenic concentrations in till and weathered bedrock samples taken during the detailed stage of sampling in the Louhiniemi area, Kuhmo.

Gold concentrations were low throughout, although a weak NW-SE trending anomaly was discernible to the north of the Korkealehto farm, extending as far as the adjacent lake (Figure 3.2.1.8a). In contrast, arsenic abundances were highly anomalous, the maximum value being 1 680 ppm and a prominent anomaly trend was defined along the eastern shores of the lake Kuivajärvi (Figure 3.2.1.8a).

Extensive geophysical surveys were made in 1998 and 1999, with the technical data for EM, magnetic and IP surveys summarized in Table 3.2.1.2.8. Slingram measurements were done with GTK equipment using a coil separation of 60 m and a frequency of 14 kHz, with a line spacing of 50 m and measurement spacing of 20 m (Tenhola and Niskanen 2001a). The primary purpose of the survey was to delineate conductive horizons and brittle-ductile deformation zones.

Magnetic surveys were done as total intensity measurements with a proton magnetometer, using a profile spacing of 25 m and measurement point spacing of 10 m. The survey was effective in delineating the distribution of serpentinite, which has a strong magnetic signature. Dyke rocks and deformation zones containing (or devoid of) magneticminerals, in particular pyrrhotite were also identified on the basis of total intensity anomalies. Petrophysical properties of the mineralized boulders were also measured, with susceptibility being (S 0.002 SI) and remanence magnetism (S 840 mA/m); these values are consistent with the gold anomalous zone being associated with a modest magnetic anomaly.

Induced polarization (IP) dipole to dipole surveys were made with a Scintrex IPR/10-IPC/8-system along profiles spaced 50 m apart and 20 m intervals between measurements (Figure 3.2.1.2.8b). Measurement constants were a = 20 and n = 3 (midpoint distance between dipoles was 60 m). The main purpose of the IP survey s was to detect polarizing rock units and structures, particularly those containing disseminated pyrite.

A total of 7 holes were drilled at Louhiniemi, with a combined length of 507 m, using a POKA (GM 100) rig with T56 drill bit (Tenhola and Niskanen, 2001a). The water depth beneath the frozen lake, up to 10 m, hindered the drilling to some extent. Drill hole locations are marked on the map of Au and As distribution and on the IP chargeability maps (Figures 3.2.1.2.8a and b).

Table. 3.2.1.2.8. Geophysical measurements in Louhiniemi, Kuhmo

Method	Number of points	Area (sq km)	Line kilometres (km)
Slingram (HLEM)	3 300	3.17	64
Magnetic (total field intensity)	13 000	3.23	127
Induced polarization	3 300	3.24	62.5

The highest gold concentration, of 6 200 ppb, with As = 16 600 ppm in the same sample interval, was in intensely sheared mafic volcanics, containing disseminated arsenopyrite and chalcopyrite as well as pyrrhotite. However, it is not possible to confirm that this represents the same rock unit or structural zone from which the mineralized samples were derived. The next highest anomalous value, of 938 ppb (with As = 11 200 ppm) was in a quartz porphyry dyke impregnated with pyrrhotite and arsenopyrite. Elevated gold abundances were found throughout the drill core, in many places being in the range 20 –100 ppb.

On the basis of drilling, it is evident that the rock units that can be traced through Kuivajärvi are consistently enriched in arsenic, and sporadically contain high gold concentrations. Gold anomalies are nevertheless restricted to narrow intervals (< 1 m). The occurrence at Louhiniemi

can be regarded as demonstrating the southwards extension and continuity of the anomalous Au and As zone trending through Jousijärvi and Mujesuo. The limited amount of drilling did not allow the significance of the magnetic and IP anomalies that can be traced as far as Kuivajärvi to be adequately assessed. Therefore, a priority for future studies would be the anomalies to the south of the Louhiniemi.

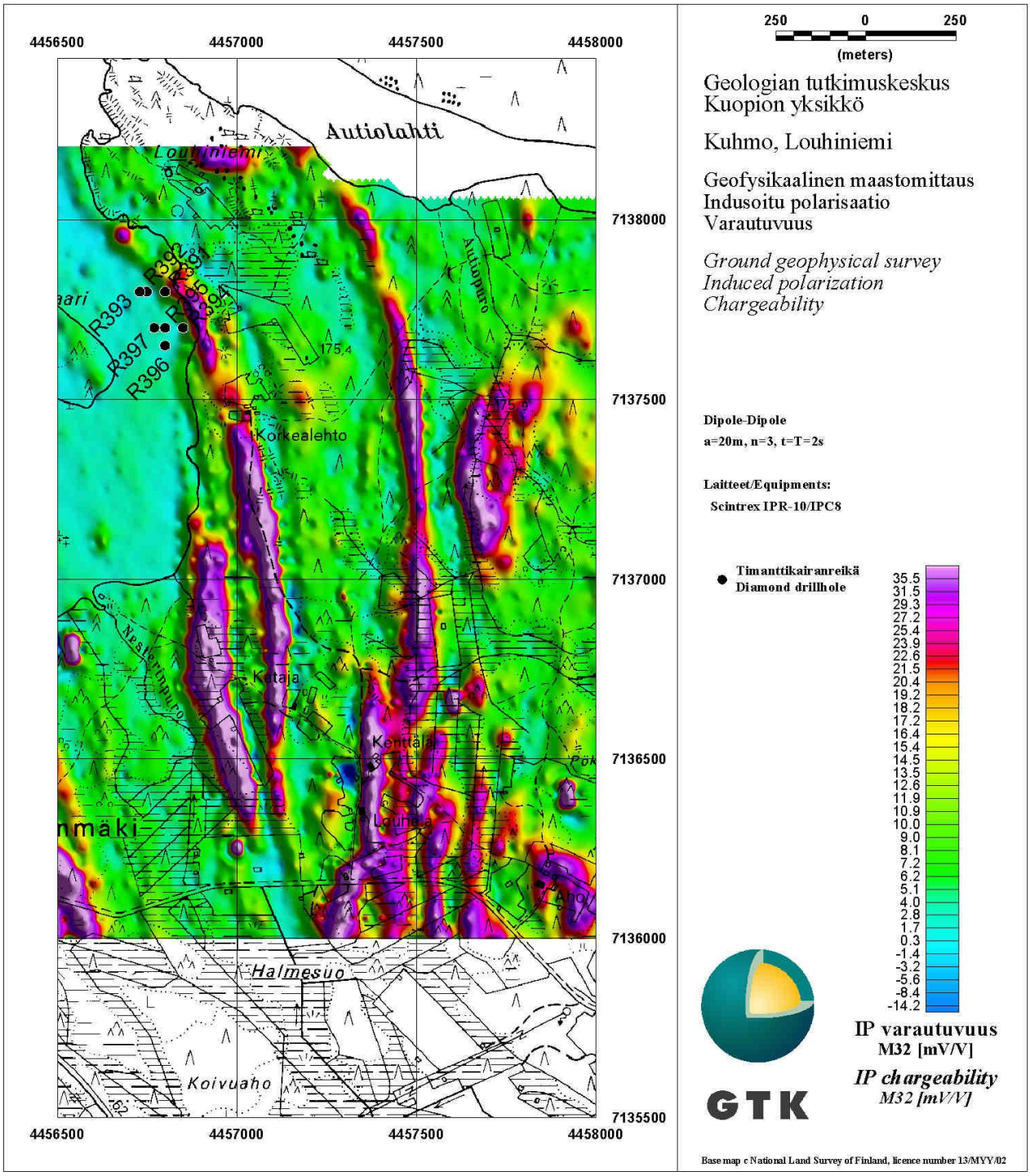


Fig. 3.2.1.2.8b. IP-chargeability in the Louhiniemi area, Kuhmo.

3.2.1.3. Kellojärvi ultramafic complex

The Kellojärvi ultramafic complex is an exceptional, roughly triangular shaped area of komatiitic cumulate bodies, about 24 km^2 in extent, situated in the southern part of the Kuhmo greenstone belt. The southern margin of the complex in the Siivikkovaara area lies between FIN-KKJ4 northing coordinates 7128.100 - 7128.400 and in the Näätäniemi area between 7127.300 - 7127.700. The complex has a maximum width of about 4 km and at its northern end (FIN_KKJ4 northing coordinate 7132.000) the complex branches into two northerly trending segments, of which the western belt is more prominent and continuous (Figure 2.6.1n). Airborne surveys were flown over the Kellojärvi complex (FIN_KKJ 1: 20 000 scale mapsheets 4411 12 and 4412 10) with a closer line spacing of 100 m, instead of the usual 200 m, in 1994, which considerably improved the resolution and discrimination of bedrock units and structural features. Modeling of magnetic anomalies indicates that the vertical extent of the complex varies from 3 –5 km. The complex is subdivided into four domains, namely northwestern and southwestern domains and northeastern and southeastern domains (Halkoaho et al., 1996).

According to IUGS rock type classifications (Streckeisen, 1976), the Kellojärvi ultramafic rocks belong to the dunite – wehrlite - olivine clinopyroxenite - clinopyroxenite series but in this context the cumulus terminology of Wager et al. (1960), Wager and Brown (1968) and Irvine (1982) will be used in preference. Apart from the northeastern domain, the most common rock types are olivine adcumulates and mesocumulates, with lesser amounts of olivine orthocumulates, olivine – augite adcumulates and augite adcumulates (= clinopyroxenites). The northeastern block contains, in addition to olivine ad cumulates and mesocumulates, abundant olivine orthocumulates and olivine – augite adcumulates (Figure 3.2.1.3) and augite adcumulates. Gabbroic rocks are present, but rare, and also include a solitary occurrence of anorthosite (Figure 2.6.1p). Although the Kellojärvi ultramafic complex shares many features in common with layered intrusive complexes, the petrological and geochemical affinity with eruptive komatiites in the area is very evident (Halkoaho et al., 1996, Tulenheimo, 1999). This relationship is also supported by isotopic dating of the gabbroic unit at Niittylahti, which yielded a U-Pb zircon age of 2757 ± 20 Ma (Figure 2.6.1q). The Kellojärvi ultramafic complex was recently the subject of a very comprehensive University of Turku *pro gradu* study (Tulenheimo, 1999), which concluded that the extensive komatiitic magmatism at Kellojärvi produced an unusually thick layered ultramafic complex, with an inferred original thickness of300 –500 m and lateral dimensions of 10 x 15 km^2. The total estimated volume of the complex is thus about 60 km^3 (Halkoaho et al., 1996, Tulenheimo, 1999).

The Kellojärvi ultramafic complex was intruded by at least two groups of mafic dykes, the most prominent of which is a layered and fractionated wehrlitic gabbro, with a mean Al_2O_3/TiO_2 ratio of six. Outcrops of these dykes are present on the eastern and northern shores of Likosenlampi, to the north of Niittylahti and east of Ensilä farmstead, which is the most informative exposure. The lowermost cumulates are wehrlitic olivine orthocumulates, olivine mesocumulates, olivine – augite adcumulates and augite adcumulates, with Cr contents in the range 1 800 –3 000 ppm. The augite adcumulates are overlain by gabbroic cumulates with low Cr abundances (< 100 ppm), firstly a medium-grained augite orthocumulate with intercumulus plagioclase and then a more “spotted” or “blotchy” augite orthocumulate, which still has plagioclase as an intercumulus phase. The “spotty” or “blotchy” appearance results from the presence of aggregates of cumulus pyroxene crystals up to 1 cm in diameter. The “blotchy” gabbro is overlain by magnetite gabbro unit about 20 m thick, which also has intercumulus plagioclase. Above this magnetite gabbro horizon is a medium-grained plagioclase – augite adcumulate at least 50 m thick. The total thickness of these differentiated wehrlitic gabbro intrusions is 200 –300 m and Tulenheimo (1999) reported Sm-Nd model ages of 2 100 – 2 200 Ma for intrusions in the Kellojärvi area.

Fig. 3.2.1.3. Serpentinized olivine augite adcumulate-mesocumulate (oaAC-oaMCa). The crystallization of cumulus pyroxene has been irregular and heterogeneous. Hyttimäki, Kellojärvi, Kuhmo. Photo by T. Halkoaho.

The second group of dykes is not very common and shows compositional affinities with tholeiites, having an Al_2O_3/TiO_2 ratio of about 15 and Cr content somewhat higher (about 250 ppm) than the wehrlitic gabbro intrusions (Halkoaho et al., 1996, Tulenheimo, 1999).

3.2.1.3.1. Nickel investigations in the Kellojärvi ultramafic complex

In addition to geological mapping and local till geochemical surveys, nickel exploration in the Kellojärvi ultramafic complex included the drilling of two deep holes to the northwest of Likosenlampi (total length 648.70 m). The first hole (R307, FIN_KKJ4 grid coordinates 7129.073N, 4456.030E) was vertical and 324.40 m deep, while the second hole (R308, FIN_KKJ4 grid coordinates 7129.073N, 4455.915E) was drilled eastwards at an angle of 70° towards R307 and had a length of 324.40 m. The site for R307 was chosen on the basis of a conductive anomaly detected during SAMPO soundings. However, neither hole intersected significant conductors, with only a few weakly conductive zones identified in the upper part of R307, at 80 m (2 000 Ohm.m) followed by a 20 m thick zone with resistivity of about 700 Ohm.m. The rocks in these intervals were devoid of visible sulfides and rather homogeneous, being predominantly olivine mesocumulates and adcumulates, which is reflected geochemically in major element variations (Figure 3.2.1.3.1). The only other distinctive feature on R307 was the presence of augite as an additional cumulus mineral with olivine, between 191.20 – 198.30 m. Similar intervals were found within the otherwise homogeneous olivine mesocumulates and adcumulates in R308, at depth intervals 210.40 – 234.70 and 243.40 – 258.00 m. These relatively coarse-grained units, which are locally pegmatitic, with pyroxene grains up to 1 cm in size, may possibly be harrisitic layers. About a kilometer to the west of the drilling site, serpentinite outcrops contain E-W trending relict magmatic banding, defined by augite-rich layers, with very steep dips (88°) towards the north; it is highly probable that the rocks intersected in both drill holes represent the same lithic unit.

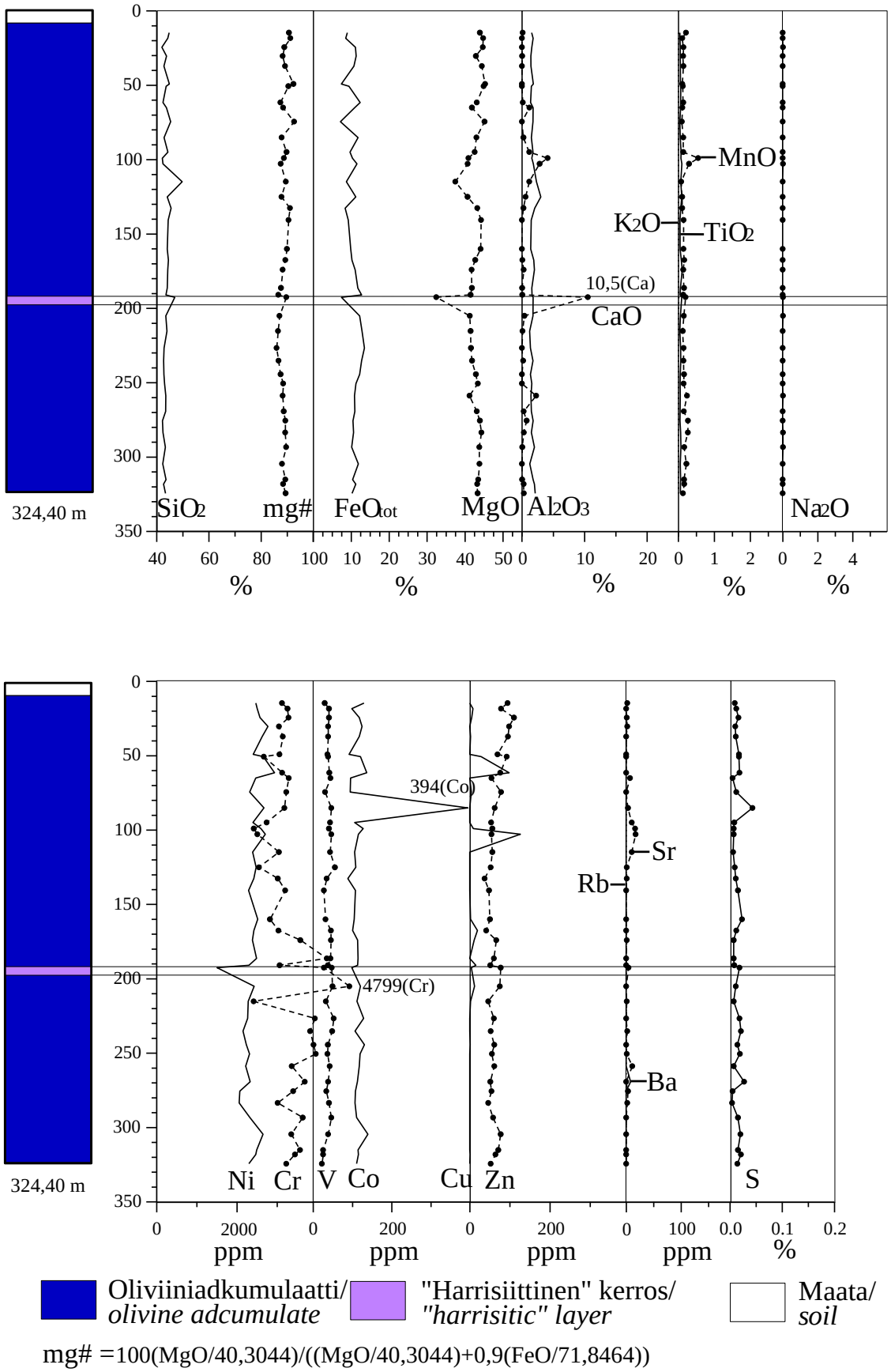


Fig. 3.2.1.3.1. Elemental variations in the komatiitic cumulates in drill hole R307, Kellojärvi area. Mg# = 100(MgO/40.3044)/((MgO/40.3044)+0.9(FeO/71.8464)).

3.2.1.4. Ontojärvi area

The southwestern branch of the Kuhmo greenstone belt, around the lake Ontojärvi, to the west of Kuhmo, and from north to south between Hietaperä and Raiskio, is variably known as the Ontojärvi basin or Ontojärvi synform. The area had been investigated by Suomen Malmi Oy in the 1960's, the Geological Survey of Finland, during the 1960's and 1970's, Kajaani Oy (1970's) and in two University of Oulu research projects ("Metallogeny of the Kuhmo region" and "Metallogeny of the Kuhmo and Kittilä greenstone belts") between 1977 –1984. An overview of these investigations is given Report 47 of the "Metallogeny of the Kuhmo and Kittilä greenstone belts" project (Taipale and Tuokko, 1981). Because the area had been studied extensively in the past, the area was addressed only briefly in the current project, with revisionary or detailed work in several key areas, including the Lokkiluoto gold occurrence and its immediate surroundings, the Petäjäniemi area in the northeast part of Ontojärvi, and in the south, near Ruunakangas and Raiskio. GTK activity in the area was primarily during the years 1989, 1992 and 1993.

Taipale and Tuokko (1981) assigned the Archean metasediments and volcanics of the Ontojärvi area to the Ontojärvi Group, which was further subdivided into the Juurikkaniemi Formation and the Petäjäniemi Formation. Taipale and Tuokko (1981) interpreted the Ontojärvi Group as having been deposited on the Kellojärvi Group, thus being the youngest Archean rocks preserved in the Kuhmo greenstone belt. One of the key exposures justifying this interpretation was an outcrop of conglomerate at Hietaperä (Taipale and Tuokko, p. 26), which has since been destroyed during realignment of the road between Hietaperä and Heinälahti.

Only a limited amount of fieldwork and geophysical interpretation was done during this project but it is nevertheless apparent that the "Ontojärvi Basin" is structurally more complex than previously thought, consisting of several en echelon, antiformal – synformal pairs, separated by nearly N-S trending high strain zones, making regional stratigraphical correlation less straightforward.

Felsic volcanics along the western shore of of Ontojärvi,corresponding to the Juurikkaniemi Formation of Taipale and Tuokko (1981) were previously interpreted as stratigraphically overlying the komatiitic and mafic volcanics of the Kellojärvi Group. However, isotopic age determinations from the felsic volcanics of the Ontojärvi group and correlative units elsewhere, indicate that they may be older, with U-Pb zircon ages in the range 3 006 Ma – 2 790 Ma (refer to Section 2.6.1). Although the possibility of zircon inheritance form an older substrate should be considered, this interpretation is nevertheless consistent with lithostratigaphical interpretations elsewhere, including the Moisiovaara and Vuosanka areas of the Kuhmo greenstone belt, as well as the Tipasjärvi greenstone belt. Accordingly, the felsic volcanics of the Ontojärvi Group are considered more likely to be older than, or representing the earliest stages of the magmatic event that generated the Kellojärvi Group ultramafic and mafic volcanics, for example through melting of the lower crust following plume impingement.

The Petäjäniemi Formation is dominantly metasedimentary but includes an ultramafic and mafic sequence some 50 –200 m thick that generates a prominent magnetic anomaly which can be traced around much of the "Ontojärvi Synform". This ultramafic and mafic unit thus forms an important marker horizon that would also be more appropriately correlated with the Kellojärvi Group; lithogeochemical differences between the two can be attributed to the fact that the Petäjäniemi Formation rocks represent a more distal depositional and eruptive environment and that they were more susceptible to contamination by crustal material. To the south of Ontojärvi, in the Karankavaara area, a medium-grained blasto-ophitic gabbroic mafic rock unit is exposed inthe core of an antiformal structure, which possibly dips gently beneath the metasediments of the Petäjäniemi Formation. This mafic unit resembles the Moisiovaara layered tholeiitic sill in terms

of both chemical composition and general appearance. If this inferred correlation is correct, then it would be consistent with its structural and stratigraphic position beneath the mafic and ultramafic rocks of the Ontojärvi Group.

The central part of the "Ontojärvi Synform" consists predominantly of variably deformed intermediate volcanics and metasediments, many of which are turbiditic graywackes, assigned by Taipale and Tuokko (1981) to the Petäjäniemi Formation. Depositional younging determinations from outcrops on islands within Ontojärvi, and at Petäjäniemi, indicate that these metasediments are stratigraphically younger than the ultramafic and mafic volcanics and therefore represent some of the youngest Archean rocks in the Kuhmo greenstone belt.

Further north in the Kuhmo greenstone belt, in the Kellojärvi – Koskenmäki area, volcanogenic polymictic conglomerates have been found, analogous to the outcrop at Hietaperä that was destroyed, associated with intermediate volcanics, that stratigaphically overlie the tholeiitic basalts, komatiites and high-Mg basalts. Some of the coarse clastic deposits in the Koskenmäki – Lampela area have been interpreted as lahars formed in a terrestrial setting (Nieminen 1998). The intermediate volcanics of the Kellojärvi – Koskenmäki area are chemically very similar to those in the "Ontojärvi Synform" and both units may belong to a distinct intermediated volcanic episode younger than the komatiitic volcanism. The pelitic sediments and graywackes of the Ontojärvi Group may therefore be interpreted as distal and reworked volcaniclastic deposits (Figures 3h A-C). Moreover, the mica schists and graywackes in the "Ontojärvi Synform" are geochemically similar to metasediments in the Tipasjärvi greenstone belt, the Nurmes-type paragneisses and the volcaniclastic deposits and turbiditic graywackes of the Hattu schist belt in the Ilomantsi greenstone belt. Such correlation, if substantiated, indicates extensive intermediate to felsic volcanism and sedimentation throughout what is now the Archean craton of eastern Finland, in the time interval bracketed by 2 750 – 2720 Ma.

3.2.1.4.1. Lokkiluoto gold occurrence

During GTK investigations in 1990, 11 samples were collected from outcrops at Lokkiluoto, a small island in the lake Ontojärvi (Figures 2.3.5a and 3.2.1b), which had previously been examined by Kajaani Oy. Gold abundances in the samples varied between 30 – 9 040 ppb, as a result of which further samples were taken with a hand-held drill in early 1991; conditions for sampling were unusually favourable in that the level of water in the lake was exceptionally low. Lokkiluoto and surrounding islands were also mapped in detail during 1991 and 1992 and 8 holes were drilled during the northern winter in 1992, with a combined length of 3422.55m. A more detailed account of the investigations is presented in the report on the Lokkiluoto exploration lease, submitted to the then Ministry of Trade and Industry (Heino and Kilpelä, 1995).

Drilling intersected a single one meter thick interval with elevated gold contents between 1 – 9 ppm which can be traced for a distance of about 80 m. The host rock is an intermediate volcanic unit with a nearly N-S strike trend and which shows the effects of hydrothermal alteration, in particular silicification, potassium alteration, indicated by the abundance of biotite and carbonation, and also contains disseminated sulfides. Gold occurs as small inclusions in arsenopyrite and chalcopyrite or at grain margins. Other accessory minerals include pyrrhotite, ilmenite, pyrite, and sporadic telluride minerals and molybdenite. Because the concentrations of precious metals were low, and the location would make access and exploitation difficult, no further investigations were made.

3.2.2. Summary of significant results

3.2.2.1. Bedrock and mineral potential

A total of 662 bedrock observations were made in the Kuhmo greenstone belt during the project. When combined with all previous observations from 1: 100 00 scale regional bedrock mapping 100 000 in the GTK database archives, this makes a total of 9619 data entries.

One of the most significant outcomes of the project investigations was the recognition and delineation of a major deformation zone transecting the greenstone belt from north to south, accompanied by hydrothermal alteration and associated with numerous gold prospects including, from north to south, Tammasuo, Palovaara, Timola, Iso Aittojärvi, Pieni Aittojärvi, Jousijärvi, Mujesuo and Louhiniemi. The Lokkiluoto Au-mineralization in the Ontojärvi area had previously been examined by Kajaani Oy and was investigated in further detail during this project. In addition to the occurrences listed above, extensive carbonation and weak sulfide disseminations within a NW-SE trending deformation zone passing through Petäjäniemi, Poukama, Katajalahti and Hietaperä indicate significant structurally focused fluid flow and gold mineralization potential.

The main focus of research into komatiite-hosted nickel mineralization during the project was the Saarikylä area in the Suomussalmi greenstone belt. In the Kuhmo greenstone belt, only the Teerisuo and Naurispuro exploration leases and the areas surrounding Sika-aho at Moisiovaara and Kellojärvi were studied in some detail. However, particular attention was given to the recognition of komatiitic cumulates and lava flows during bedrock mapping. Additional observations in the Kellojärvi area demonstrated that this area too could be prospective for nickel, particularly given that the Arola occurrence, already discovered during the 1960's, and the mineralization at Sika-aho, which was found during this project, occur in analogous rock units.

On the basis of airborne geophysical data interpretation and field checking, a more detailed understanding of the "Ontojärvi Synform" was obtained. Nevertheless, further studies are needed to establish the stratigraphic sequence and depositional environment with confidence. Resolving these issues should be tractable, given that many outcrops retain well-preserved primary depositional features.

3.2.2.2. Summary of geophysical investigations

Various types of geophysical techniques have been effective in delineating rock units, structures and hydrothermal alteration associated with mineralization. Airborne magnetic data have been particularly important in defining the major deformation zone transecting the Kuhmo greenstone belt, which has a distinct spatial association with gold anomalies identified from till geochemical surveys; combining the two sources of information provides a more confident basis for targeting detailed exploration.

More detailed airborne surveys, with a line spacing of 100 m, were flown over the Kellojärvi area in 1994 (FIN_KKJ 1: 20 000 mapsheets 4411 12 and 4412 10), to obtain better resolution of the more intensely magnetic ultramafic units. Results compared very favourably with measurements from ground surveys (Lohva et al., 1996). Surveys in the Kittilä area in 2001, with a line spacing of 75 m also demonstrated not only the effective discrimination of rock units but also that a brief airborne survey (of several days for example) can be very cost-effective compared to ground surveys over the same area (Kurimo and Airo, 1991).

Although the density contrast between the Sika-aho nickel mineralization and surrounding rocks is quite marked, gravity measurements are not necessarily a practical or economic technique in exploration. The Sika-aho occurrence is only 10 m thick or less and accordingly generates a very modest Bouguer anomaly that is difficult to discriminate from background values, even with detailed surveys. Petrophysical parameters relevant to the Sika-aho occurrence are considered in more detail in Section 3.2.1.1.3.

3.2.2.3 Summary of geochemical investigations

Systematic geochemical surveys in the Kuhmo greenstone belt delineated a conspicuous, sharply defined arsenic anomaly zone and more diffuse and discontinuous gold anomalies which can be traced from north to south along the entire greenstone belt. This anomalous trend was previously recognized in several places, namely Vuosanka, Palovaara and Näätäniemi, as a result of investigations by Outokumpu Mining Oy, and at Lokkisaari in the lake Ontojärvi. Geochemical mapping showed the continuity of this anomalous zone from Palovaara through Moisiovaara to Vuokkijärvi. The eastern part of the Ontojärvi area also appears to be of potential interest, warranting further investigation. The most intense gold anomalies were found in the northern part of the greenstone belt, which is geologically less well understood than the southern part. Geochemical sampling and interpretation of this area is made even more difficult by the greater thickness of well-sorted and stratified surficial deposits, especially to the north and south of Vuokkijärvi.

As in the Suomussalmi greenstone belt, the effectiveness of till geochemical sampling is controlled by the nature of till materials and the depth of sampling. Investigations in the Mujesuo, Jousijärvi and Iso Aittojärvi areas were hindered by the thickness and stony and well-sorted nature of surficial deposits and the presence of hummocky ablation moraines. In the Louhiniemi area, detailed geochemical sampling was restricted to a relatively small part of a more extensive area of interest; the prominent magnetic and IP anomalies in the area south of Kuivajärvi require further study, including systematic geochemical surveys.

The detailed till geochemical surveys in the Kuhmo greenstone belt revealed numerous areas that are potentially prospective for gold (Appendix 2) , which need to be assessed in future studies.

Another important ouctome from the geochemical investigations is the availability of a comprehensive, standardized analytical database covering the entire greenstone belt. Analyses exist for a wide range of elements and data are readily accessible. Specific areas can be selected and element concentrations can be correlated against dominant lithology, which can also be used in environmental studies and in regional and urban planning.

3.3. Ilomantsi greenstone belt

3.3.1. Areas investigated

3.3.1.1. Introduction

During the period 1983 – 1995 the Geological Survey of Finland (GTK) undertook an extensive research and exploration program along some 40 km of strike length within the Hattu schist belt, which forms the northerly trending, eastern part of the Ilomantsi greenstone belt. This was one of the first areas in Finland, together with Kuusamo, Kittilä and Sodankylä, to be studied systematically with respect to gold. The original incentive for gold exploration was from prominent arsenic anomalies found over an area of more than 300 km^2 in the eastern part of the Ilomantsi region, as a result of till geochemical surveys undertaken in 1976-1977, but analysed for as not before 1982. Heavy mineral panning in 1983 and 1984 revealed the presence of

scattered small grains of gold. Above mentioned Regional till geochemical samples from the FIN_KKJ 1: 100 000 mapsheet 4244 (Ilomantsi) were combined and analyzed for gold in late 1983, which revealed anomalous abundances throughout much of the Hattu schist belt and adjacent areas.

Geological investigations (outcrop mapping, geophysical surveys and deep bedrock drilling) were initially (1984 – 1985) focused on the Kuittila – Leppärinne area after which the entire western margin of the Kuittila Tonalite was systematically explored during the years 1984 -1987. The northern parts of the Hattu schist belt were studied more intensively from 1987 to 1995.

Till geochemical surveys were important in the discovery of 13 of the gold occurrences subsequently confirmed in outcrop (Viinivaara, Kelokorpi, Kuittila, Korvilansuo, Kivisuo, Elinsuo, Muurinsuo, Palosuo, Sivakko, Korpilampi, Kuivisto, Valkeasuo and Iso Kivijärvi: Figure 3.3.1.1). Two other occurrences (Rämepuro and Pampalo) were delineated after anomalous samples and visible gold were found in outcrop. Gold was typically associated with highly deformed and altered supracrustal rocks but was also found in tonalitic intrusions, as at Kuittila and Rämepuro. Exploration leases held by GTK during the research program were relinquished upon submission of technical reports to the then Ministry of Trade and Industry (Damstén 1990, Damstén et al. 1994a, 1994b, Heino et al. 1995a, 1995b), who then released them for public tender.

Gold-related research and exploration involved close collaboration between researchers from the Kuopio and Otaniemi units of GTK and results of investigations were published in a comprehensive volume as GTK Special Paper 17 (Nurmi and Sorjonen-Ward, 1993). When the operational activities of the Kuopio unit were restructured in 1992, research was coordinated so as to effectively complete the surveying and documentation of the Hattu schist belt during 1994 – 1995, with the intention of making staff and resources available for investigations in the Kuhmo and Suomussalmi greenstone belts.

3.3.1.2. General geological features

The Neoarchean Hattu schist belt, which forms the eastern branch of the Ilomantsi greenstone belt, spans FIN_KKJ 1: 100 000 scale mapsheets 4244 and 4333. The schist belt is about 80 km from north to south and varies in width from less than 1km to over 5 km, with the segment studied in detail being some 40 km along strike and typically 1-2 km wide (Figures 3.3.1.4.4, 3.3.1.5, 3.3.1.6a and 3.3.1.6b). The southern part of the schist belt consists predominantly of rather monotonous mica schist and metagraywackes, whereas to the north of Hattuvaara coarser grained felsic volcaniclastic rocks predominate, with some intermediate, mafic and ultramafic volcanic units. Syntectonic tonalite plutons and porphyritic dyke swarms intruded the supracrustal rocks, which are metamorphosed to lower amphibolite facies (Lavikainen 1973, Ojala et al. 1988, Sorjonen-Ward 1993a, 1993b).

Isotopic studies have shown (Vaasjoki et al., 1989, Vaasjoki et al., 1993) that deposition of sediments and eruption of volcanics, and intrusion of granitoids and deformation, took place within a relatively brief time span between 2.76 – 2.72 Ga. However, zircons inherited from older crustal material, up to 3.32 Ga in age, are present in both sediments and granitoids (Sorjonen-Ward 1993a, Sorjonen-Ward & Claoué-Long 1993).

3.3.1.3 General overview of surficial deposits

A summary of the surficial deposits of the Ilomantsi region were provided by Nenonen and Huhta (1993), while Rainio (1990) investigated the glacial deposits at Hattujärvi, which form a narrow

marginal formation across the Hattu schist belt, coeval with the main Salpausselkä ice-marginal formations. Glaciofluvial deposits are also present as a distinct esker, nearly 100 m wide, transecting the Kuittila Tonalite. Elsewhere, the bedrock of Hattu schist belt is covered by till only several meters thick, although even this has been somewhat reworked by wave action when the area was inundated by the transient Ilomantsi ice-dammed lake. The Hattu schist belt is characterized by undulating terrain in which elevated areas have been shaped by glacial processes to form *roche moutonnée* with variable development of NW-SE trending drumlins and in which deglaciation trends are also prominent between 325º - 340º. This is also the direction of numerous striations and the direction of gravel fragments of basal till.

Boulders within the upper levels of till have travelled for many kilometers, whereas gravel-sized material sampled from depth of two meters with in the stratigraphic profile are clearly of more local origin. Geochemical anomalies in the finest till fraction (< 0.06 mm) are demonstrably proximal (0 – 500 m) to bedrock sources (Salminen and Hartikainen 1985).

Some 300 pits were excavated in the deposits overlying the Hattu schist belt by GTK for the purpose of defining till stratigraphy and investigating clast composition. Observations have been systematically archived, recording stratigraphy, fabric orientation, pebble counts and various physical properties of till (moisture content, degree of compaction, abundance of stony clasts, clast size and degree of roundedness). About 500 samples (approximately 12 kg each) were also collected for heavy mineral investigations (Huhta 1989, 1993).

3.3.1.4. Overview of research methods and strategies

3.3.1.4.1. Bedrock mapping

Prior to the present project, regional geological mapping had been carried out at 1: 400 000 reconnaissance scale during the early part of the twentieth century (Frosterus and Wilkman, 1924). The Ilomantsi KKJ 1: 100 000 mapsheet (KKJ 4244) was published by Lavikainen (1973). Exploration for banded iron ore mineralization in the Hattu schist belt was summarized thoroughly by Niiniskorpi (1975), while during the years 1986 - 1989, the University of Oulu North Karelia Exploration Research Project undertook mapping of selected areas in the Archean greenstone belts of North Karelia, together with assessment of mineral potential (Piirainen and Vuollo (editors) 1991).

A more detailed 1: 50 000 scale map of the Hattu schist belt and its surroundings was prepared and reported by Sorjonen-Ward (1993 a,b), based on more than 1000 bedrock observations made between 1986 - 1992. The remaining areas of the Naarva 1: 100 000 mapsheet (KKJ 4333) were mapped by GTK during the 1996 field season.

3.3.1.4.2. Ground-based geophysical surveys

Geophysical surveys were mainly used for delineating buried rock units and tracing lithological boundaries, and in some cases, mineralization. Low-altitude airborne surveys have also been flown over the area (Figure 2.2.1.1a). In addition to magnetic, EM and electrical surveys, ground surveys included measurement of induced polarity (IP) over extensive areas. Areas surveyed are shown, according to method used, in Figure 2.2.2.1b. Profile spacing was generally 100 m (Slingram, magentic and IP), although this was reduced to 50 m in areas that were already defined as prospective on the basis of till geochemical studies. Measurement point spacing was 20 m for Slingram and IP surveys and either 20 m or 10 m for magnetic surveys. A summary of available digital survey data is given in Table 2.2.2.1.c.

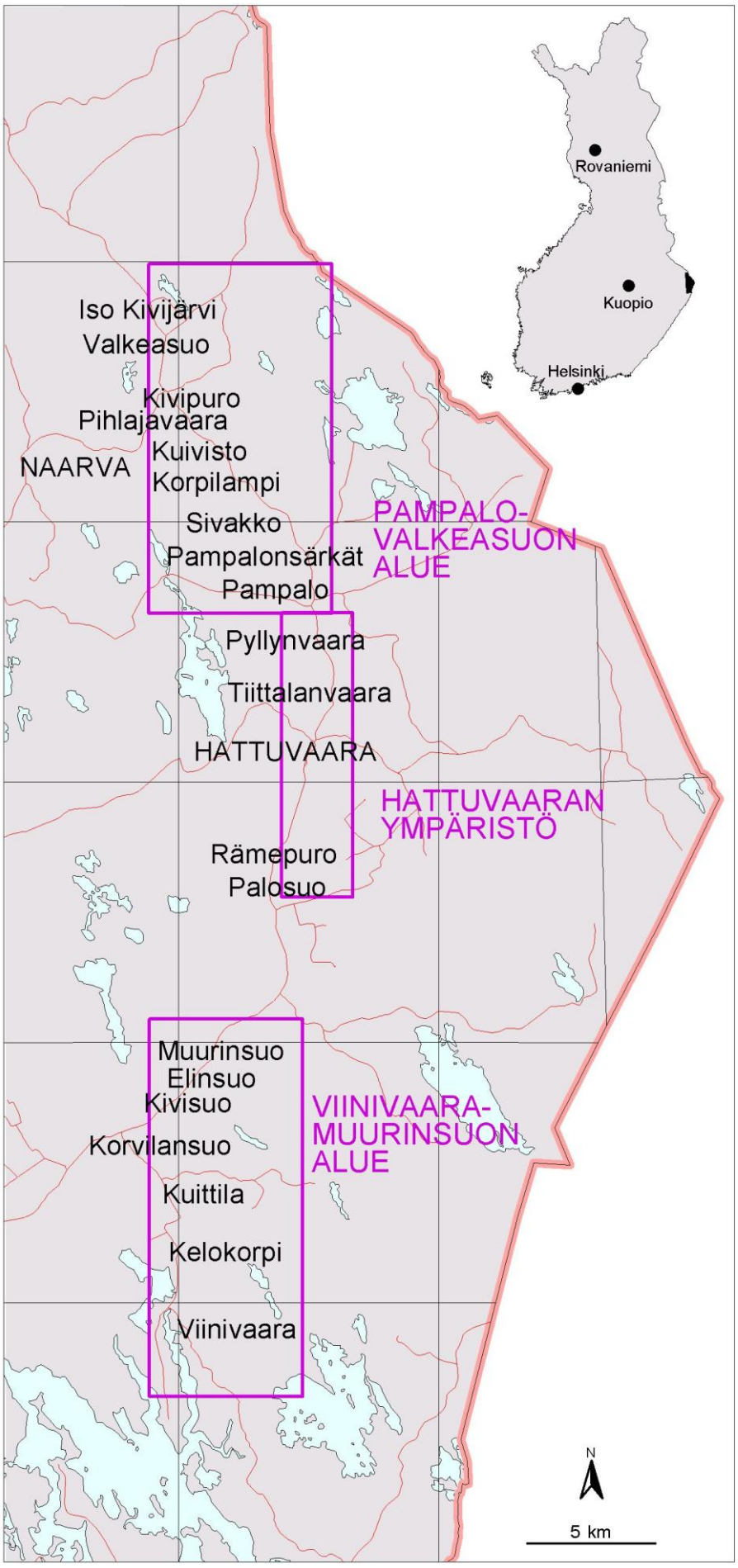


Fig. 3.3.1.1. Locations of exploration targets mentioned in the text on FIN_KKJ 1: 100 000 map sheets Ilomantsi (4244) and Naarva (4333).

The most effective technique for tracing and delineating zones anomalous in gold was IP surveying, for rock units and shear zones with disseminated sulfides tended to generate strong responses in IP chargeability parameters (Figure 3.3.1.4.2a). The Rämepuro gold prospect south of Hattuvaara also generated a prominent positive anomaly in the IP surveys made by Outokumpu Oy (Pekkarinen, 1989). Some detailed misé-a-la-masse surveys were undertaken at the Pampalo gold prospect.

Slingram surveys were the principal EM technique used in discriminating between rock units and in tracing conductive horizons, while VLF-R surveys were only done along several selected profiles. Variation in conductivity was relatively small in the area around Pampalo and to the northwest of Pampalo, where Slingram surveys, with a frequency of 3600 Hz, generated only weak responses from comparatively poor conductors.

Magnetic surveys were effective in discriminating between rock units and tracing key horizons in poorly exposed terrain. The main parameter measured during the early stages of investigations was the total magnetic intensity vertical component. Most of the areas with digitally recorded data were total intensity surveys using a proton magnetometer (Figure 3.3.1.4.2b).

Representation of both IP chargeability and magnetic total intensity data on the same map proved to be an effective way of discriminating and visualizing different lithic units and structures (Figure 3.3.1.4.2c). Magenta shades (as in the sulfide-bearing sericite schists in the northern part of the area) generally correspond to polarized but non-magnetic lithologies, whereas magnetic, poorly polarized rock units, typically containing weakly disseminated magnetite, are shown by cyan colors. Areas that are both magnetic and polarized remain white, as in the iron formations in the southern part of the region, whereas neutral areas, lacking geophysical anomalies, are indicated by dark blue.

3.3.1.4.3 POKA and deep bedrock drilling

A total of 171 shallow POKA holes were drilled at 10 – 100 m intervals along several profiles on FIN-KKJ 1: 20 000 mapsheets 4244 05, 4244 08, 4333 04 and 4333 07 during 1986 and 1987. (Table 3.3.1.4.3). Almost a third of the 328 deeper drillholes, using both T46 and T56 diameter equipment, were in the Pampalo area. Drill core was generally split mechanically and analuzed in one meter intervals using GFAAS and FAAS assay techniques. Most of the drilling was focused on anomalies that had been identified during detailed till geochemical surveys and in preliminary assessment of potential reserves at the Pampalo deposit.

Detailed information concerning drilling in the Hattu schist belt is contained in reports by Damstén (1990), Damstén et al. (1994a, 1994b) and Heino et al. (1995a, 1995b). Till geochemistry reports for the Hattu schist belt also contain additional information including bedrock drilling parameters (Hartikainen and Niskanen, 2001; Appendix 1) and site locations (Hartikainen and Niskanen, 2001; Appendices 16 – 31).

3.3.1.4.4 Till geochemical surveys

3.3.1.4.4.1 Sampling strategies

Sampling strategies were designed separately for each successively more detailed stage of investigations. A light percussion drilling rig was used in sampling (Atlas Copco Cobra 248 and148 with 30 mm drill sampler) , allowing retrieval of about 100 – 150 g of sample material. Sampling surveys were generally done in winter time, as snow and ice cover allow better

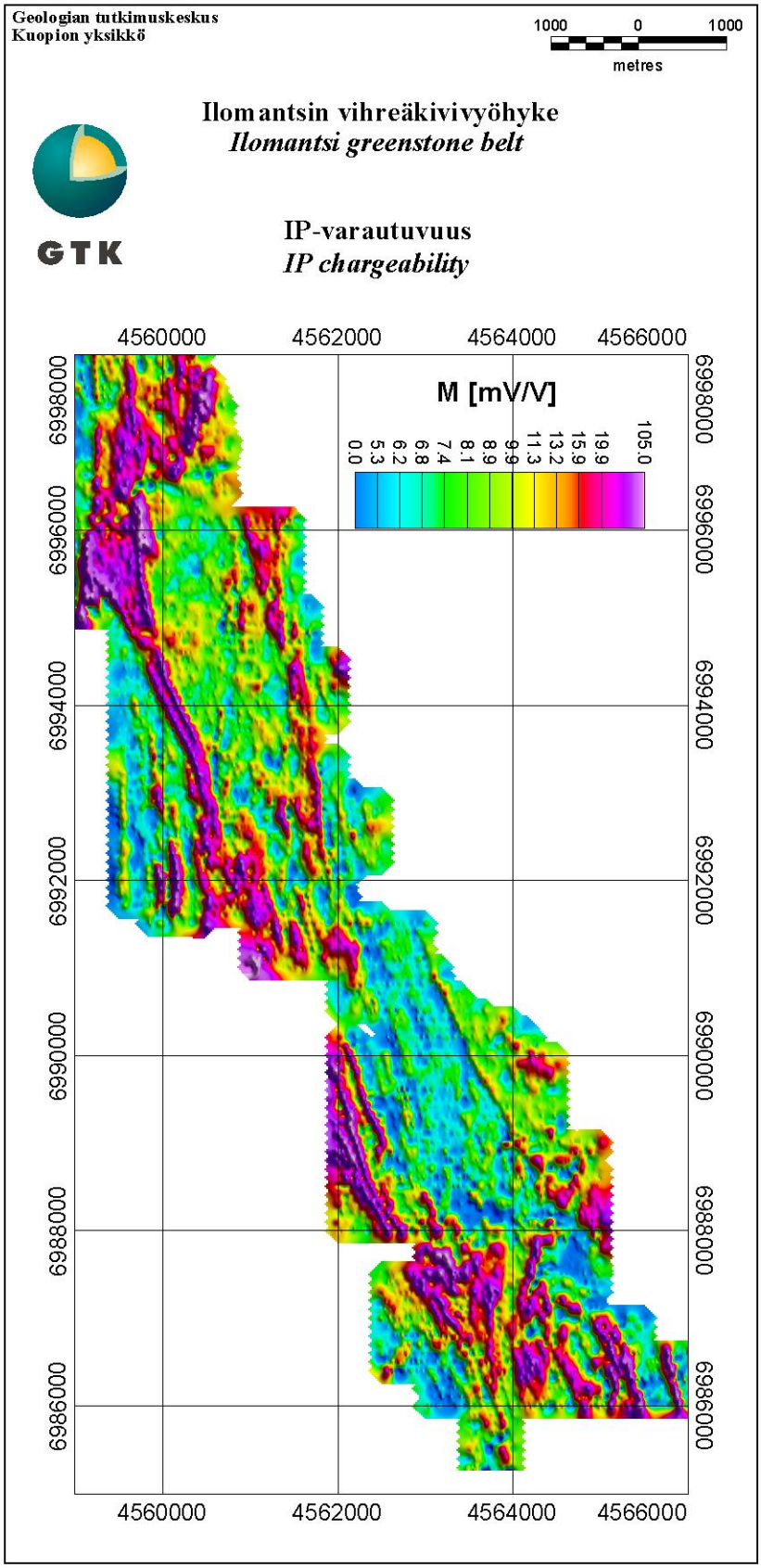


Fig. 3.3.1.4.2a. Induced polarization, chargeability, Ilomantsi.

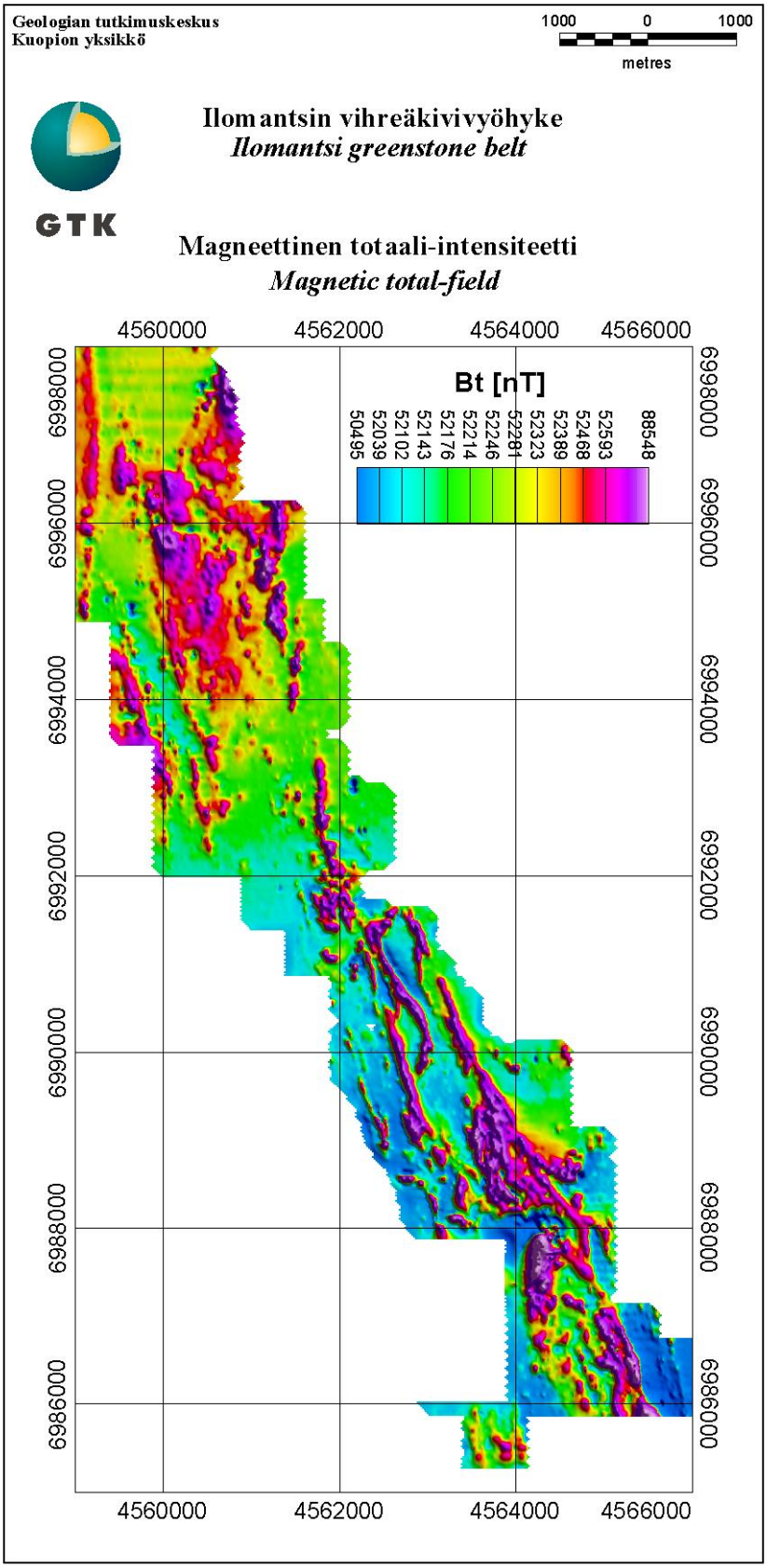


Fig. 3.3.1.4.2b. Magnetic ground measurement, total-field, Ilomantsi.

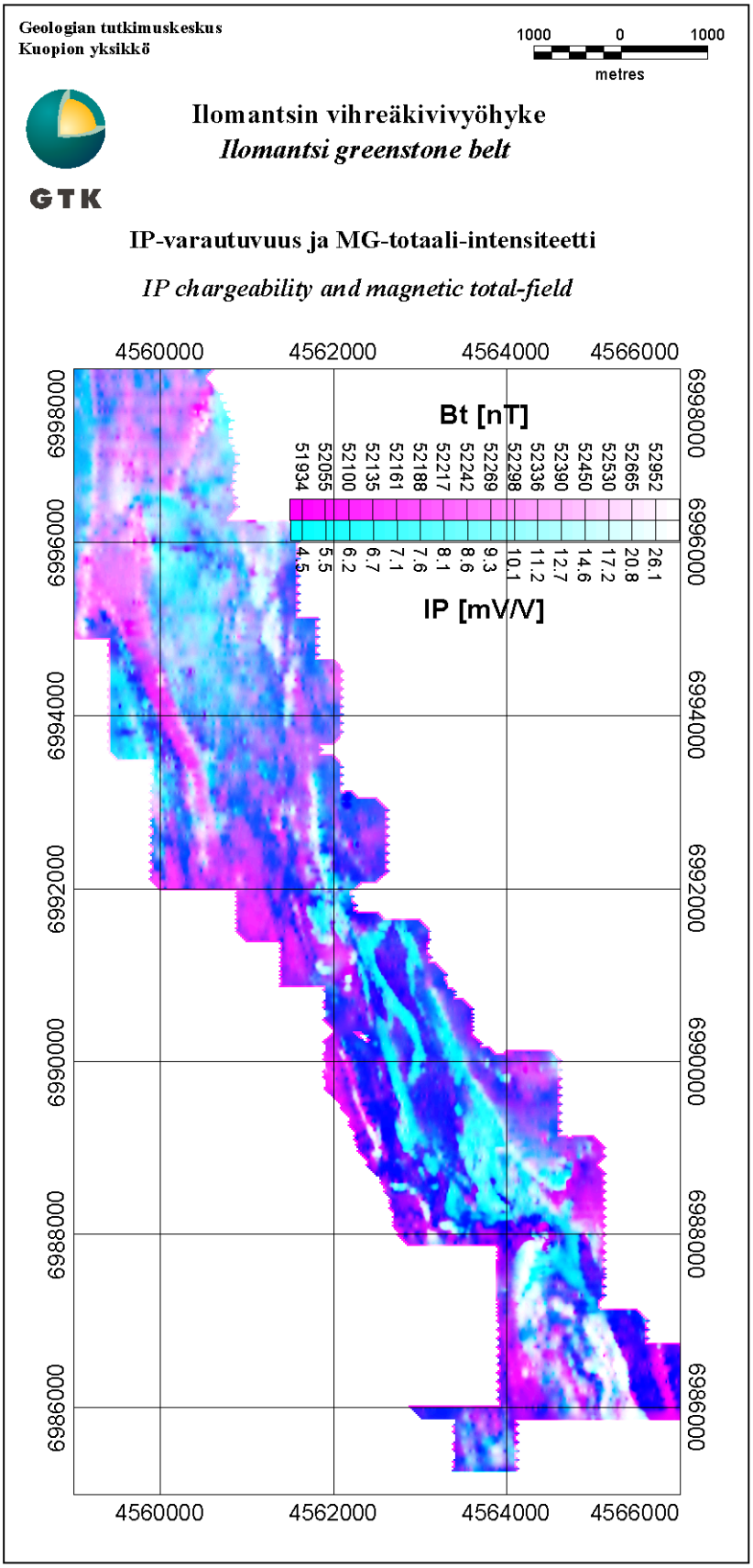


Fig. 3.3.1.4.2c. Combined map of IP chargeability and magnetic total-field, Ilomantsi.

Table 3.3.1.4.3. Amount of drill holes, the drilling meters and best intersections (Au g/t) at targets drilled in the years 1984-1995 in the Hattu schist belt, Ilomantsi (Damstén et al. 1994a, 1994b, Heino et al. 1995a).

Target	***Map sheets***	***Amount of holes***	***Total, m***	***Best intersection***
Viinivaara	4244 07B	5	665.60	4.7 g/t / 1.0 m
Kelokorpi	4244 08A	1	150.00	2.5 g/t / 5.0 m
Kuittila	4244 08A	18	2445.70	4.5 g/t / 4.0 m
Korvilansuo	4244 05D, 4244 08B	15	2201.90	5.1 g/t / 2.5 m
Kivisuo	4244 08B	12	1644.00	4.0g/t / 4.9 m
Elinsuo	4244 08B	3	396.10	3.1 g/t / 2.0 m
Muurinsuo	4244 08B, 4244 09A	30	2838.30	2.6 g/t / 6.0 m
Palosuo	4244 09 D	5	141.70	2.7 g/t / 1.2 m
Tiittalanvaara	4333 07C	2	53.60	< 0.5 g/t
Pyllynvaara	4333 07D	7	299.00	< 0.5 g/t
Pampalo	4333 07B	103	12569.45	4-30 g/t / 3-21 m
Pampalonsärkät	4333 07B	17	1220.50	1.2 g/t / 1.0 m
Sivakko	4333 08A	25	2079.90	4.2 g/t / 2.0 m
Korpilampi	4333 08A	12	1055.80	1.7 g/t / 1.0 m
Kuivisto	4333 05D, 4333 08A	45	3318.75	3.6 g/t / 12.0 m
Kivipuro	4333 08B	10	1071.20	0.8 g/t / 1.0 m
Valkeasuo	4333 05D	19	2223.50	19.8 g/t / 1.0 m
Iso Kivijärvi	4333 05D	4	452.50	< 0.5 g/t
POKA drilling, 1986	4244 05D,08A,B	115	1433.85	< 0.5 g/t
POKA drilling, 1986	4333 07A,B,C	56	825.30	< 0.5 g/t
Total		**499**	**37086.65**	

mobility of drilling equipment. Sampling was done at three scales: regional or reconnaissance scale (1 sample / 4 km^2); local scale targeting (16 samples / km^2) and detailed prospect scale surveys (100 – 400 samples / km^2). Detailed information concerning methods, sampling parameters, sample preparation, analytical procedures and the range of elements analyzed can be found in the report by Hartikainen and Niskanen (2001).

Sampling during the regional phase survey was apparently already sufficiently dense to broadly delineate gold prospective zones in North Karelia (cf. Hartikainen and Nurmi, 1993, Salminen, 1995a). Samples during this phase were collected from the uppermost till (mean sampling depth 1.7 m). During the next stage, designed to target and delineate gold-critical alteration zones, samples were collected from basal till, at a mean depth of 4.9 m. During the most detailed survey phase, designed to define individual prospects, sampling was aimed at both the basalmost till at the bedrock interface, and wherever possible, on retrieving chips of bedrock, with a mean sampling depth of 5.2 m (cf. Hartikainen 1987, Nurmi et al. 1989, Hartikainen and Nurmi 1993, Hartikainen and Niskanen 2001) (Table 3.3.1.4.4a).

During the district scale targeting (16 samples / km^2), a total of 6 260 samples were obtained, the main purpose being to delineate zones of hydrothermal alteration within the Hattu schist belt, which tend to be coincide spatially with elevated gold concentrations. The concentrations of gold in till, based on sampling during these surveys, are shown in Figure 3.3.1.4.4.

The purpose of the more detailed till sampling (100 – 400 samples / km^2) was to get an indication of individual occurrences. Sampling grids were usually designed with a line spacing of 100 – 300 m with a sampling interval of 5, 10 or 20 m (10 m was most common). A total of 20 028 samples were collected between 1981 – 1995 (Table 3.3.1.4.4b). Comprehensive information on these

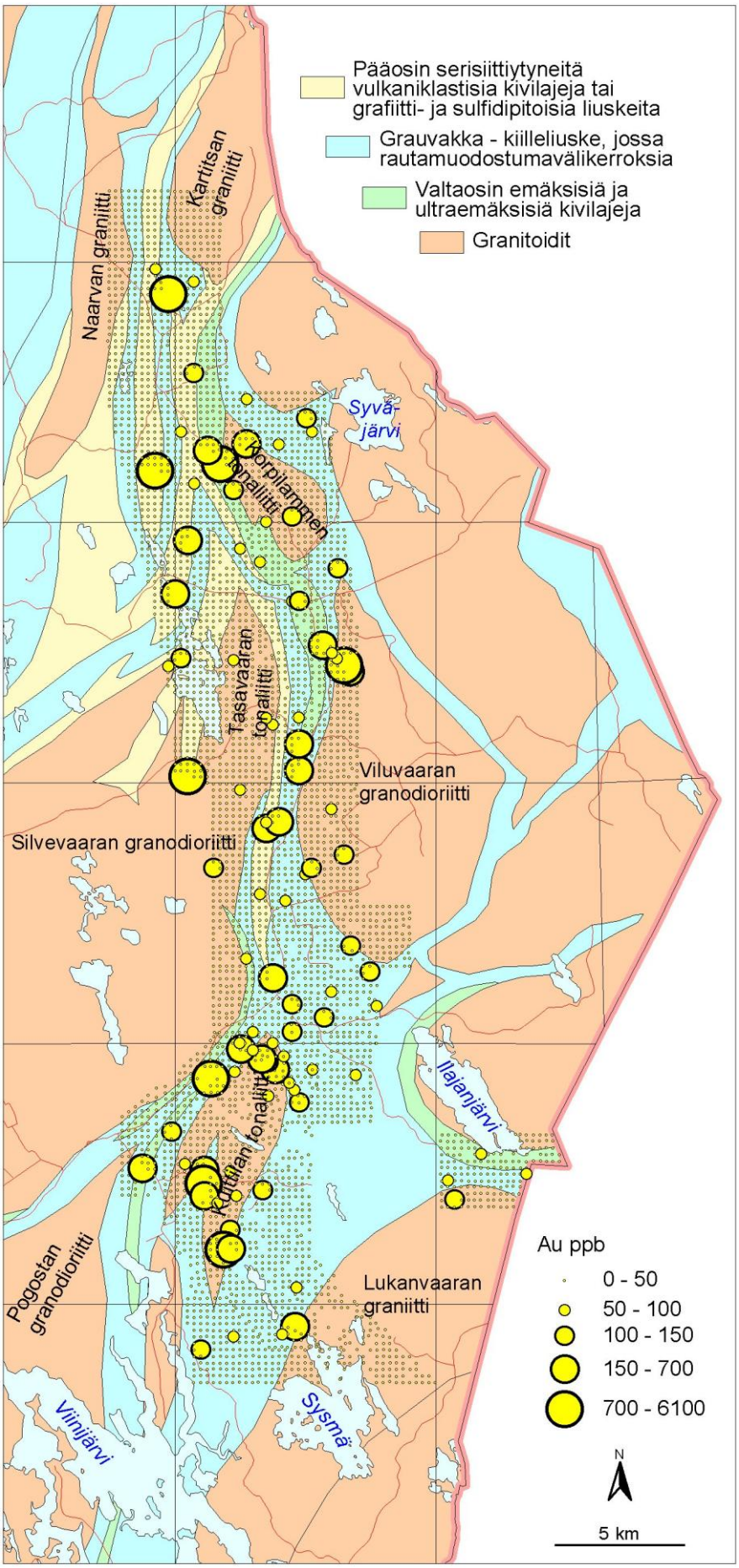


Fig. 3.3.1.4.4. Gold contents in till from local scale geochemical sampling in the Hattu schist belt, Ilomantsi. Bedrock geology from Lundqvist et al. (1996), simplified from Sorjoen-Ward (1993b), with names of granitoids according to Sorjonen-Ward (1993b).

Table 3.3.1.4.4a. Parameters concerning different stages of geochemical soil sampling in gold exploration in Hattu schist belt, Ilomantsi.

Sampling stage	Strategy	Density pieces/km^2	Material	Average sampling depth	Analyzed fraction (mm)
Regional	Even grid	0.25-0.40	Till	1.7 m	< 0.06 mm
Local	Even grid	16	Till	4.9 m	< 0.06 mm
Detailed scale	Lines	100-400	Till and/or bedrock	5.2 m 5.4 m	< 0.5 mm Powdered sample

Table 3.3.1.4.4b. Amount of samples of different soil types collected at a detailed scale sampling in the Hattu schist belt, Ilomantsi.

Target area	Total	Bedrock	Weathered bedrock	Till	Gravel	Sand	Silt	Clay
Iknonvaara (4244 01)	229	17	26	182	0	0	4	0
Viinivaara-Muurinsuo sequence	7619	843	1777	4883	13	89	6	8
Surroundings of Hattuvaara	2602	521	791	1290	0	0	0	0
Pampalo-Valkeasuo sequence	9578	1965	3370	4236	1	6	0	0
Total	20028	3346	5964	10591	14	95	10	8

surveys, including sample locations, are presented in a report by Hartikainen and Niskanen (2001; Appendices 16 – 32).

3.3.1.4.4.2 Sample preparation and analyses

Samples underwent a preliminary stage of drying at room temperature during temporary storage in the field, by leaving sample bags opened. Potential sources of external contamination were carefully and systematically avoided, including for example, not wearing gold rings (Hartikainen et al., 1983; Kontas, 1991). Samples were squeezed to cause natural contamination of “big” nuggets. Samples were then finally dried in the GTK laboratories, with bags opened, at a temperature of 70º C and then sieved. The regional and local scale till samples were separated into three fractions (< 0.06 mm, 0.06 - 0.5 mm and > 2.0 mm), while samples from detailed surveys were sieved into two size fractions through a 0.5 mm mesh. The finest sieved fractions were analyzed without further treatment in the case of the regional and local scale sample material, but samples collected during the more detailed prospect scale surveys were ground to powder prior to analysis. A part of chip samples from bedrock and weathered bedrock clasts were washed and examined visually, under a binocular microscope where necessary, in order to ascertain rock type, before being crushed and analyzed.

An extensive range of elements were analyzed, varying depending upon the nature and geographical location of the samples. For example, the use of pathfinder elements associated with anomalous gold was most relevant to the regional and local scale surveys. Analytical methods and documentation of the number of analyses made for each of the different survey types were presented in the report ”Maaperägeokemialliset kultatutkimukset Hatun liuskejaksolla Ilomantsissa vv. 1983 - 1995” (Till geochemical investigations related to gold exploration in the Hattu schist belt, Ilomantsi, during years 1983 – 1995) by Hartikainen and Niskanen (2001, Table 4). Surveys in the Ilomantsi area also provided an ideal opportunity for systematic testing of

optimum sampling methods and strategies and ranges of pathfinder elements, including those that only sporadically show strong correlation with gold (cf. Hartikainen and Nurmi, 1993).

Analytical techniques used for samples collected during the regional scale sampling were ICP-AES (Inductively Coupled Emission Plasma Spectrometry), AAS (Atomic Absorption Spectrometry), GFAAS (Flameless Atomic Absorption Spectrometry with graphite furnace) (Kontas 1981, Kontas et al. 1987) and NA (Neutron Activation). During the more focused local scale investigations, analyses were made using AAS-, GFAAS-, NA-, OES- (Optical Emission Spectrometry), DCP- (Direct Current Plasma Atomic Emission Spectrometry); loss on ignition was also routinely determined. At the more detailed prospect scale, AAS-, GFAAS-, NA-, Leco-ja Spectrometer-methods were used. Some of the above-mentioned tecniques were however, only used on a small proportion of samples analyzed.

Duplicate analyses for gold were performed on some samples, demonstrating that the so-called nugget effect (Harris, 1981; Nichol et al., 1992) has a significant effect on reproducibility of analytical results. Nevertheless, the overall anomaly pattern was very similar when the results of duplicate analyses were plotted on gold distribution maps. Comparison of analytical data from different size fractions showed that the mean gold concentrations in the < 0.06 mm size fractions were about three times greater than in the 0.06 – 0.5 m fraction (Hartikainen and Nurmi, 1993). This observation is consistent with the conclusions based on microscopic analyses of gold in thin section (Kojonen et al., 1993), which showed that gold inclusions and free grains are generally less than < 15 μm in diameter in gold mineralized rock.

3.3.1.4.5 Data capture, processing and storage

Since 1989, all data relating to drilling has been reported using the GTK KAIRA program and entered into the GTK Kairaus database, which is an Oracle-based system. At the time of reporting, earlier data were in the process of being transferred to the Kairaus database. Drill core is housed at the GTK national drill core library at Loppi, along with duplicate hardcopies of all drilling reports.

A total of 1213 bedrock observations from the Hattu schist belt by Peter Sorjonen-Ward (1213 mapping have been transferred to GTK databases and the original field observation datasheets are available as scanned pdf files.

Digital geophysical data are stored as ASCII files in xyz-coordinate space on magnetic tapes in the GTK central archives in Otaniemi.

Till geochemical anomaly maps for individual elements and element ratios were originally plotted using the GTK Alkemia program in a VAX environment (Björklund and Gustavsson, 1987). Later statistical analysis and plotting was done with commercially available software suited to PC applications (SPSS, Excel, ArcView) and stored on CD-ROM. Remaining sample powders are stored , for the present, in plastic ampules at the GTK laboratories in Kuopio.

Data collecting during excavation of pits and profiles in surficial deposits (a total of 243 and 210 observations from FIN_KKJ 1: 100 000 mapsheets 4244 and 4333 respectively) are stored in the GTK Maanhoito database in an Oracle-compatible format, which can also be readily exported to Excel and ArcView.

3.3.1.5 Gold occurrences between Viinivaara and Muurinsuo in the Hattu schist belt

Between Viinivaara in the south, and Muurinsuo, at the northern end of the Kuittila tonalite pluton, the Hattu schist belt has a predominantly northerly trend, though deflected somewhat towards the northeast along the western margin of the tonalite pluton (Figure 3.3.1.5). Metagraywackes and finer-grained pelitic schists dominate, with sporadic intercalations of conglomerates and more mafic volcaniclastic units. The metasediments are intruded by synorogenic tonalites and subparallel porphyritic dykes swarms that compositionally resemble the tonalites, however they fall into two discrete chemical populations (Bornhorst et al., 1993; O'Brien et al., 1993). Rock units tend to be steeply dipping, except along the northwestern margin of the Kuittila Tonalite, where dips are commonly around 60º towards the NW. Three distinct mineralized zones, associated with chloritic and sericitic alteration have been identified along this western margin of the pluton that, from south to north, are known as the Korvilansuo, Kivisuo and Elinsuo – Muurinsuo occurrences. Three other occurrences have also been found: Kelokorpi, at the southeastern margin of the Kuittila Tonalite; Viinivaara, within altered sediments several kilometers further south, and at Kuittila itself, within hydrothermally altered tonalite (Nurmi et al., 1993; Damstén et al., 1994a). Bulk chemical assessments of the signatures of hydrothermal alteration and mass-balance calculations have been done by Bornhorst and Rasilainen (1993) and Rasilainen (1996), while the results of mineralogical and mineral chemical microprobe investigations have been reported by Johanson and Kojonen (1989), Johanson et al. (1991) and Kojonen et al. (1993).

Extensive investigations in the Kuittila area were undertaken by GTK between 1983 and 1990, with technical results reported by Damstén (1990), Damstén et al. (1994a), and Hartikainen and Niskanen 2001, and further summaries and interpretations published by Hartikainen 1993, Hartikainen and Damstén (1991), Nurmi (1993), Nurmi and Sorjonen-Ward 1993 (editors), Nurmi et al. (1993), Salminen & Hartikainen (1986) and Sorjonen-Ward (1997). The following summary of gold mineralization in the Kuittila area is extracted from the above publications (see also Table 3.3.1.4.3). Gold concentrations are expressed as g/m or ppm/m, where g represents grams and ppm parts per million respectively, and m refers to analytical intervals of drill core (or combined intervals) one meter in length.

3.3.1.5.1. Viinivaara

Gold grains were found during panning of till material at Viinivaara, as well as elevated gold concentrations in till samples retrieved during percussion drill surveys. Therefore, five holes were drilled in the area in 1986 - 1987, with a combined length of 665.60 m (Figure 3.3.1.5). The principal rock types intersected were visibly altered mica schists and metagraywackes, intruded by tonalitic dykes and the highest gold content measured was 4.7 ppm/m at the contact between one such dyke and adjacent metasediments. Although gold concentrations were rather erratic (Damstén et al., 1994), it would be necessary to undertake further drilling to more reliably evaluate gold potential.

3.3.1.5.2. Kelokorpi

The Kelokorpi gold occurrence is located at the southeastern margin of the Kuittila Tonalite and was identified as a result of till geochemical surveys. A single hole was drilled in 1987 (Figure 3.3.1.5), intersecting altered metasediments displaying intense sericitic and biotitic alteration and silicification. One interval including quartz-tourmaline vein networks assayed at 2.5 ppm/ 5 m. Elevated gold concentrations in till were restricted to the immediate vicinity of the drill hole site but due to limited resources, the occurrence could not be assessed more thoroughly (Damstén et al., 1994a, Nurmi et al., 1993, p. 206 – 207).

VIINIVAARA-MUURINSUON ALUE

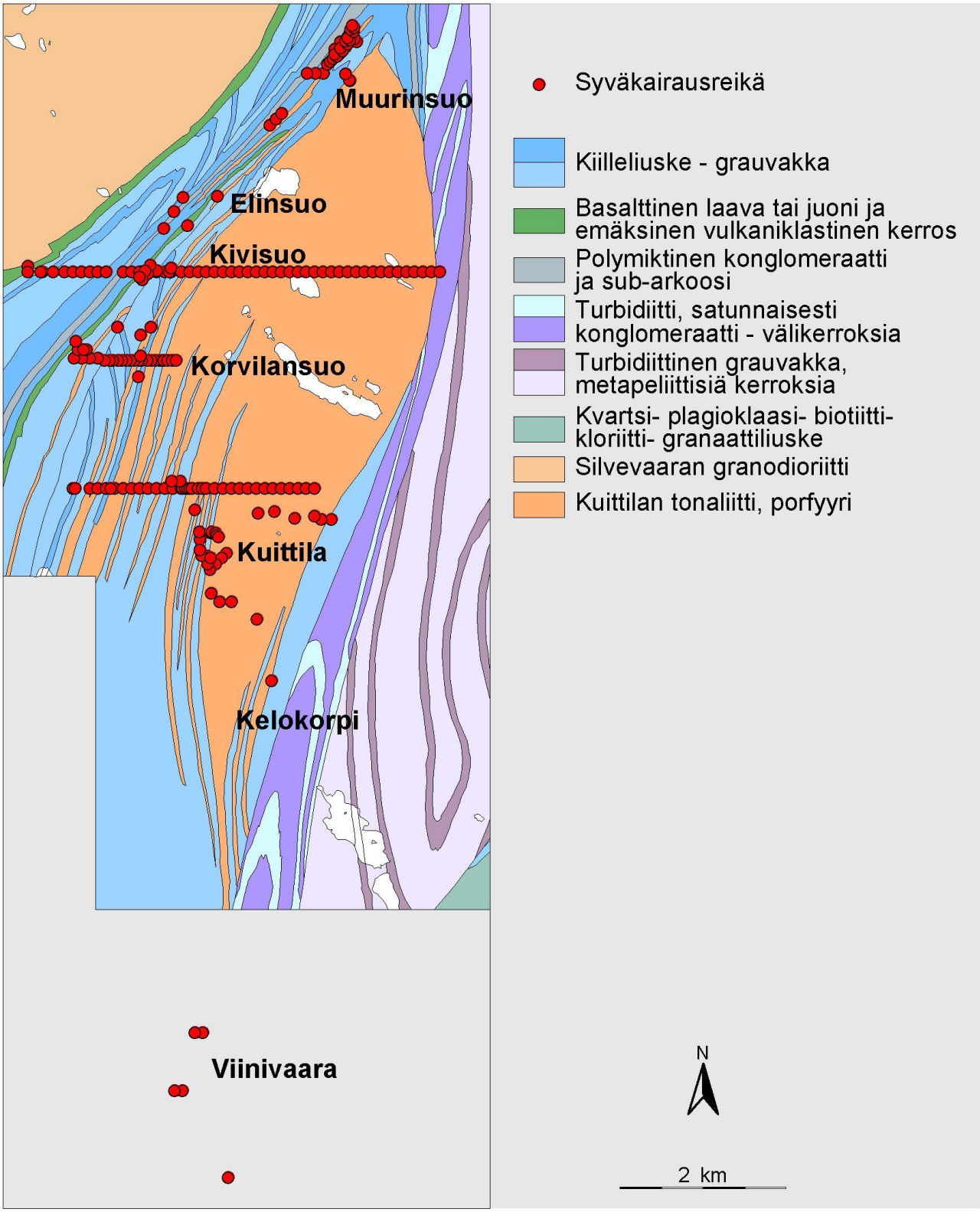


Fig. 3.3.1.5. Simplified bedrock map of the Viinivaara-Muurinsuo area on Hattu schist belt, Ilomantsi, after Sorjonen-Ward (1993b), with locations of GTK drill holes (Damstén 1990, Damstén et al. 1994a).

3.3.1.5.3. Kuittila

Kuittila provided the first indications of gold potential in the Hattu schist belt after elevated gold concentrations were found during investigation, in 1983 and 1984, of anomalous Mo and W in till overlying the Kuittila Tonalite. A total of 18 deep bedrock holes wre drilled at Kuittila with a total recovered core length of 2 445.70 m (Figure 3.3.1.5). The Kuittila occurrence is so far the only mineralization found wholly within the tonalite, although it too is located close to the southwestern margin of the pluton. Alteration is not so pervasive as in the metasediments, being restricted to discrete deformation zones with high strain, intense quartz veining and accompanied by intense carbonate, sericitic and silicic alteration. Numerous significant intersections were recorded during drilling, including Au = 9.4 ppm / 1 m and 4.5 ppm / 4 m (Damstén et al. 1994a; Nurmi et al. 1993, p. 202 – 206, and Hartikainen and Niskanen 2001: Appendix 18).

3.3.1.5.4. Korvilansuo

The Korvilansuo occurrence is situated between the Kuittila Tonalite and a smaller tonalite body, about one kilometer to the northwest of the Kuittila prospect. Mineralization at Korvilansuo was first indicated by gold anomalies in till and as a result, 15 holes were drilled with a combined length of 2201.90 m (Figure 3.3.1.5). The bedrock in this area is characterized by intense hydrothermal alteration, with tonalite altered to fine-grained quartz – tourmaline rock and metasediments to quartz – sericite – chlorite – biotite schists with abundant tourmaline veins and disseminations. The most significant gold intersections drilled were: Au = 5.1 ppm / 2.5 m, 4.75 ppm / 2.0 m and 15.2 ppm / 1.0 m (Damstén et al., 1994a; Nurmi et al., 1993).

The area between Korvilansuo and Kuittila is covered by an extensive ablation moraine complex. Test pits were excavated in moraine unit, to depths of four meters, from which bulk samples were collected for heavy mineral analysis. One sample yielded a gold grain of dimensions 0.5 x 1.0 mm (Huhta 1999) but the potential source of this gold was not tested by drilling.

3.3.1.5.5. Kivisuo

The Kivisuo gold occurrence is situated to the NW of the Kuittila prospect and NNE of Korvilansuo, within a NE-trending zone characterized by anomalous gold concentrations in till, extending from Korvilansuo in the southwest, through Kivisuo to Elinsuo and Muurinsuo. Twelve holes were drilled at Kivisuo with a total length of 1 644.0 m (Figure 3.3.1.5). The area is characterized by mica schists and feldspathic metagraywackes, commonly retaining primary depositional features such as grading, observed both in outcrop and in drill core, with sporadic intercalations of conglomerate and mafic volcaniclastic sediments, and possibly mafic sills. Hydrothermal alteration is present, but not ubiquitous, being restricted to NE-SW trending high-strain zones. The most anomalous gold intersections in drill core were Au = 4.0 ppm / 4.9 m and 4.4 ppm / 2.0 m, with abundances in excess of 1 ppm being quite common (Damstén et al., 1994).

3.3.1.5.6. Muurinsuo - Elinsuo

The Muurinsuo – Elinsuo gold occurrence lies within the same anomalous trend as Kivisuo but is situated near the northern end of the Kuittila Tonalite. A total of 33 holes were drilled at the target, with a combined length of 3 234.4 m (Figure 3.3.1.5). Elevated gold concentrations were widespread, though erratic, and appear to define a number of distinct elongate and lenticular bodies aligned parallel to the prevailing mineral lineation trend, which plunges around 65º towards 315º. The most typical host rocks are altered graywackes and porphyry dykes and in particular, mafic metasedimentary horizons, which commonly contain quartz - tourmaline veins and quartz – siderite veins. Anomalous abundances in excess of 1 ppm are common but the

erratic and dispersed nature of higher concentrations makes it difficult to make reliable resource estimates, despite the fact that drilling profiles were relatively closely spaced (50 m). The best single intersection at Elinsuo was Au = 1.1 ppm / 6 m.

3.3.1.6 Gold investigations in the Hattuvaara area and within the Pampalo – Valkeasuo zone

Gold investigations in the Hattuvaara area and within the Pampalo – Valkeasuo zone were undertaken by GTK between 1986 – 1995, and included district scale and local prospect scale till geochemical sampling, extensive ground geophysical surveys, systematic bedrock geological and structural mapping, bedrock drilling, and detailed geochemical, mineralogical and paragenetic studies of mineralized zones (refer to Nurmi and Sorjonen-Ward (editors), 1993).

The northern part of the Hattu schist belt, from south of Hattuvaara to north of Valkeasuo differs from the southern part (between the Viinivaara and Muurinsuo) in that the abundance of coarse clastic felsic epiclastic and volcaniclastic deposits is greater, with mafic volcanics also being locally abundant, northwards from Pyllynvaara (Figures 3.3.1.6a and 3.3.1.6b). Eruptive komatiitic units are also locally present in a narrow zone northwards from Pampalo and are interpreted as relatively high in the stratigraphic sequence (O'Brien et al., 1993, Sorjonen-Ward, 1993a). In the northernmost part of the schist belt, around Valkeasuo, feldspathic graywackes and felsic to intermediate volcaniclastic rock types dominate.

Drilling was undertaken at 11 different sites in the Pampalo – Valkeasuo zone (Table 3.3.1.4.3), most of which were chosen on the basis of anomalous gold concentrations found during till geochemical surveys. Drilling confirmed that mineralized bedrock is generally accompanied by intense alteration of supracrustal rocks and is commonly localized at contacts between different rock units, with ductile to brittle high-strain zones and locally within quartz-feldspar porphyritic and pegmatitic dykes (Heino et al., 1995a; Nurmi et al., 1993).

A report on investigations and preliminary resource assessment at Pampalo was submitted by GTK to the then Ministry of Trade and Industry in 1994 (Damstén et al., 1994b) and further reports on the gold occurrences in exploration leases between Pampalo and Valkeasuo were submitted in 1995 (Heino et al., 1995a, 1995b). A separate report on geochemical investigations in the area was prepared by Hartikainen and Niskanen (2001) and the geological and structural context of mineralization is dealt within a GTK Special Paper edited by Nurmi and Sorjonen-Ward (1993). A brief summary of the gold occurrences in the Hattuvaara area and within the Pampalo – Valkeasuo zone is given below, based largely on the above-mentioned reports and publications.

3.3.1.6.1 Palosuo

The Palosuo gold occurrence lies to the south of the Rämepuro gold prospect, which was investigated and drilled by Outokumpu Malminetsintä Oy (Ojala 1988, Ojala et al. 1990, Pekkarinen 1989). As at Rämepuro, mineralization at Palosuo is situated within the tectonically modified contact zone between tonalite and metasediments, including graywackes, conglomerates, intermediate biotite schists and iron formations. Five shallow holes were drilled in 1992, with a total length of 141.70 m (Figure 3.3.1.6a); the best intersection was Au = 2.7 ppm / 1.2 m (Damstén et al., 1994a).

3.3.1.6.2. Tiittalanvaara and Pyllynvaara

The Tiittalanvaara and Pyllynvaara occurrences are located a few kilometers to the north of Hattuvaara along the main road between Hattuvaara and Lieksa. Two shallow holes (total length

53.60 m) drilled at Tiittalanvaara intersected dacitic, andesitic and tholeiitic volcanics and also tonalitic dykes (Figure 3.3.1.6a). Gold contents in both holes were low, but further investigation is warranted.

A total of 7 holes were drilled at Pyllynvaara, with a combined length of 299 m, intersecting mainly massive, though locally sheared chloritic tholeiitic basalts; minor felsic to intermediate rocks and sulfidic iron formation were also present. None of the drill core analyses revealed anomalous gold contents, leaving the elevated gold in till unexplained. Therefore, several trenches were excavated and bulk samples collected for heavy mineral analysis. Gold grains were relatively abundant in several samples, in association with intensely weathered boulders of porphyritic tonalite. This rock type closely resembles the porphyritic dykes at the Pampalo deposit, which commonly contain gold contents of 1 – 2 ppm and given that Pampalo and Pyllynvaara lie within the glacial transport vector, it is reasonable to deduce that the gold grains are also derived form Pampalo. A similar auriferous porphyritic tonalite boulder, although unweathered, was found in the uppermost levels of the till sequence immediately east of the Hattuvaara – Lieksa road, near the Pampalo and Poikopää road junction.

3.3.1.6.3 Pampalo

The Pampalo deposit, some 6 km north of Hattuvaara, proved to be the largest of the gold occurrences identified and investigated in the Hattu schist belt. A total of 103 holes were drilled for the purpose of making a provisional ore estimate and to explore for more mineralization in the immediate vicinity. The first five holes were drilled for two reasons, the first being to trace the lateral continuity and depth extent of mineralization zone containing visible gold, which had been found in a porphyritic tonalite outcrop to the southeast of the small lake Lietojanlampi. The second reason was the presence of elevated Au and Te abundances in basal till and weathered bedrock samples taken from geochemical profiles to the north and west of Lietojanlampi.

Gold mineralization at Pampalo lies within a highly strained intermediate clastic rock sequence trending NE – SW, which is highly discordant with respect to regional structural trends. The three main ore lodes plunge somewhat more gently than the regional elongation lineation, at about 35º towards 035º. Ultramafic komatiitic rocks immediately east of the main mineralized zone do not appear to be anomalous in gold, but are pervasively altered to talc – carbonate - chlorite schists with abundant pyrite porphyroblasts. Mafic volcanics immediately to the west of the main mineralization (and stratigraphically below it) are intensely chloritized. The main host rock, apart from porphyritic dykes, is highly strained and pervasively affected by biotite alteration and veining, but is likely to have been a coarse volcaniclastic deposit of intermediate composition. The alteration assemblage is also characterized by quartz, sericite, K-feldspar, tourmaline, epidote, carbonate and scheelite and albite (Damstén et al. 1994b; Nurmi et al. 1993; Rasilainen 1997).

The ore mineralogy at Pampalo is also rather distinctive, with several new telluride species having been identified (Kojonen et al., 1993, 1994, 1995). The best drill core assays in virtually all holes drilled were of ore grade and a preliminary resource estimate was made and then submitted to the Ministry of Trade and Industry in 1994. As a result of a competitive tendering process, rights to the Pampalo claim were subsequently offered to Outoukumpu Mining Oy in 1995. Following limited extraction of ore and further drilling, the ownership of the Pampalo deposit was subsequently transferred to Endomines Oy in 2006.

3.3.1.6.4. Pampalonsärkät

Pampalonsärkät may represent a northwesterly continuation of the Pampalo mineralization, at least in terms of rock types, which include tonalitic porphyry dykes, felsic, intermediate and mafic volcanics and talc-chlorite-tremolite schists derived from ultramafic komatiitic units. However, there was no pervasive hydrothermal alteration nor were gold abundances particularly anomalous, being generally in the range 400 – 500 ppb. The best intersections in the 17 holes drilled, resulting in a combined length of 1 220.50 m (Figure 3.3.3.1.6b), were Au = 1.2 ppm / 1 m and 1.6 ppm / 0.5 m; duplication of the latter yielded a value of 24.4 ppm / 0.5 m (Heino et al., 1995a).

3.3.1.6.5. Sivakko

Still further to the northwest of Pampalo, within the same structural zone, is the Sivakkolampi occurrence, where 25 holes were drilled, totalling 2 079.90 m (Figure 3.3.1.6b). Selection of drilling targets was based to some extent on the results of till geochemical anomalies, and to some extent on the distribution of IP ground geophysical anomalies. Elevated gold concentrations were found in a number of holes, the best intersection being Au = 3.97 ppm / 1.7 m at the contact between ultramafic rocks and a silica-altered porphyritic dyke. More extensive surveys are needed to establish whether there is greater potential in the area (Heino et al., 1995a, 1995b).

3.3.1.6.6. Korpilampi

The Korpilampi occurrence is located at the western contact of the Korpivaara Tonalite pluton and diverse supracrustal rocks, including an altered ultramafic unit. A total of 12 holes were drilled in the Korpilampi area, 3 in 1987 – 1988 and 9 in 1994 – 1995, making a combined length of 1 055.80 m (Figure 3.3.1.6b). As at Sivakko, there were numerous intervals with anomalous gold, although the best assay was only 1.7 ppm / 1.0 m. Elevated gold values were obtained from pegmatitic dykes and silica-altered tonalite, as well as mafic and intermediate rocks, and at the contact between ultramafic rocks and tonalite. The drilling undertaken so far is clearly of a preliminary nature only and further assessment is needed (Heino et al., 1995a, 1995b).

3.3.1.6.7. Kuivisto

The Kuivisto occurrence is within a relatively extensive area of sericitic volcaniclastic schists and was investigated with 45 drill holes, totalling 3 318.75 m in length, during 1993 and 1994 (Figure 3.3.1.6b). Rocks in the western part of the area in particular are intensely sericitized and where pyrite is present, the alteration zone exhibits a prominent IP anomaly which can be traced further north. Sericitic schists in the eastern part of the Kuivisto occurrence contained gold intersections of up to Au = 4.3 / 6 m (or 3.6 ppm / 12 m) and in the western part, maximum values were 2.5 ppm / 2.8 m. There were several sections where drilling was sufficient to allow a preliminary assessment of potential, but in general, further evaluation is needed (Heino et al., 1995a, 1995b).

3.3.1.6.8. Kivipuro

Till geochemical anomalies identified during district scale surveys in the Kivipuro area were checked by drilling 10 holes along two E – W trending profiles, with a combined recovered drill core length of 1 071.20 m (Figure 3.3.1.6b). Predominant rock types intersected were basaltic and intermediate in composition, with locally intense sericitic alteration (Heino et al. 1995a, 1995b, Sorjonen-Ward 1993b). Although assays of Au > 200 ppb were rather widespread, significant enrichment was not found, the best intersection being Au = 0.8 ppm / 1.0 m.

3.3.1.6.9. Valkeasuo and Iso Kivijärvi

Investigations at Valkeasuo were initiated after local and detailed scale till geochemical surveys had revealed anomalous Au and Te. As well was discovered auriferous boulders of sericite schist, which is a characteristic rock type in this area. Between 1992 – 1994 there were 19 deep holes drilled, with a total length of 2 223.50 m (Figure 3.3.1.6b). Sericitic schists were the predominant rock type in each hole, with relict depositional grading and other clastic features being recognizable in much of the drill core, despite the intensity of alteration. Drilling intersected a N – S trending mineralized zone of sericite schists associated with quartz, tourmaline, scheelite and arsenopyrite, which can be traced confidently between profiles with a 100 m spacing. Gold abundances were between 3 – 6 ppm over intervals of 1 – 3 m, with the highest grade assayed being Au = 19.8 ppm / 1.0 m. This mineralized zone also coincides with a significant IP anomaly, which apparently broadens southwards and continues for some distance beyond the area drilled (Heino et al., 1995a, 1995b). Further exploration is warranted in the area but will inevitably be hindered by the relatively thick glaciofluvial deposits.

Elevated tellurium concentration (33 ppm) was found in local scale till sampling in the Iso Kivijärvi area, although gold content in the same samples was low. Duplicate analysis illustrate the significance of the nugget effect, as Au concentrations 6.1 ppm was recorded. To the northof Valkeasuo, in the Iso-Kivijärvi area 4 holes were drilled, with a combined length of 452.50 m (Figure 3.3.1.6b). Intensely sericitized schists were encountered, showing elevated tellurium but gold was not significantly anomalous, maximum concentrations remaining < 1 ppm (Heino et al., 1995a).

3.3.2 Principal outcomes and conclusions

The Hattu schist belt has been one of the most significant areas in Finland for developing an understanding of gold mineralization and for applying and testing exploration techniques. A broad range of investigations was carried out during an extensive research program, and the availability of detailed geological information (Lavikainen, 1973; Sorjonen-Ward, 1993b) was of great value in target selection.

Late orogenic hydrothermal fluid flow affected virtually all rock units within the Hattu schist belt, within a system of high-strain brittle-ductile deformation zones, over a distance of > 40 km. The geochemical signature of the associated hydrothermal alteration is apparent in bedrock, and in till derived from weathered bedrock, even at reconnaissance and regional scale, which represents a sampling density of 1 site per 4 km^2. The more extensive hydrothermally altered deformation zones (50 – 200 m in width) are also clearly discernible as geochemical anomalies in local scale surveys, which have a density of 16 samples per km^2. However, gold is typically widely dispersed within such extensive alteration zones and is seldom enriched to grades of economic interest; the Kivisuo, Elinsuo and Muurinsuo occurrences are representative of this type of mineralization. Where chemical gradients and mechanical contrasts between adjacent rock units are favourable, together with structurally enhanced permeability, there is greater potential for focusing of fluids and fluid-rock interaction, resulting in more extensive ore grade mineralization (Au values > 4 ppm). Pampalo, Rämepuro and Valkeasuo are the best examples of this mineralization style in the Hattu schist belt, although there are clearly a number of other targets with similar characteristics that have not been adequately assessed.

The IP technique was the most useful geophysical method for delineating alteration zones prospective for gold mineralization, for sulfide disseminations in high-strain zones generated strong responses in IP survey chargeability parameters. Total magnetic intensity data were very useful in discriminating between different rock units, which increased reliability of correlation in

HATTUVAARAN YMPÄRISTÖ

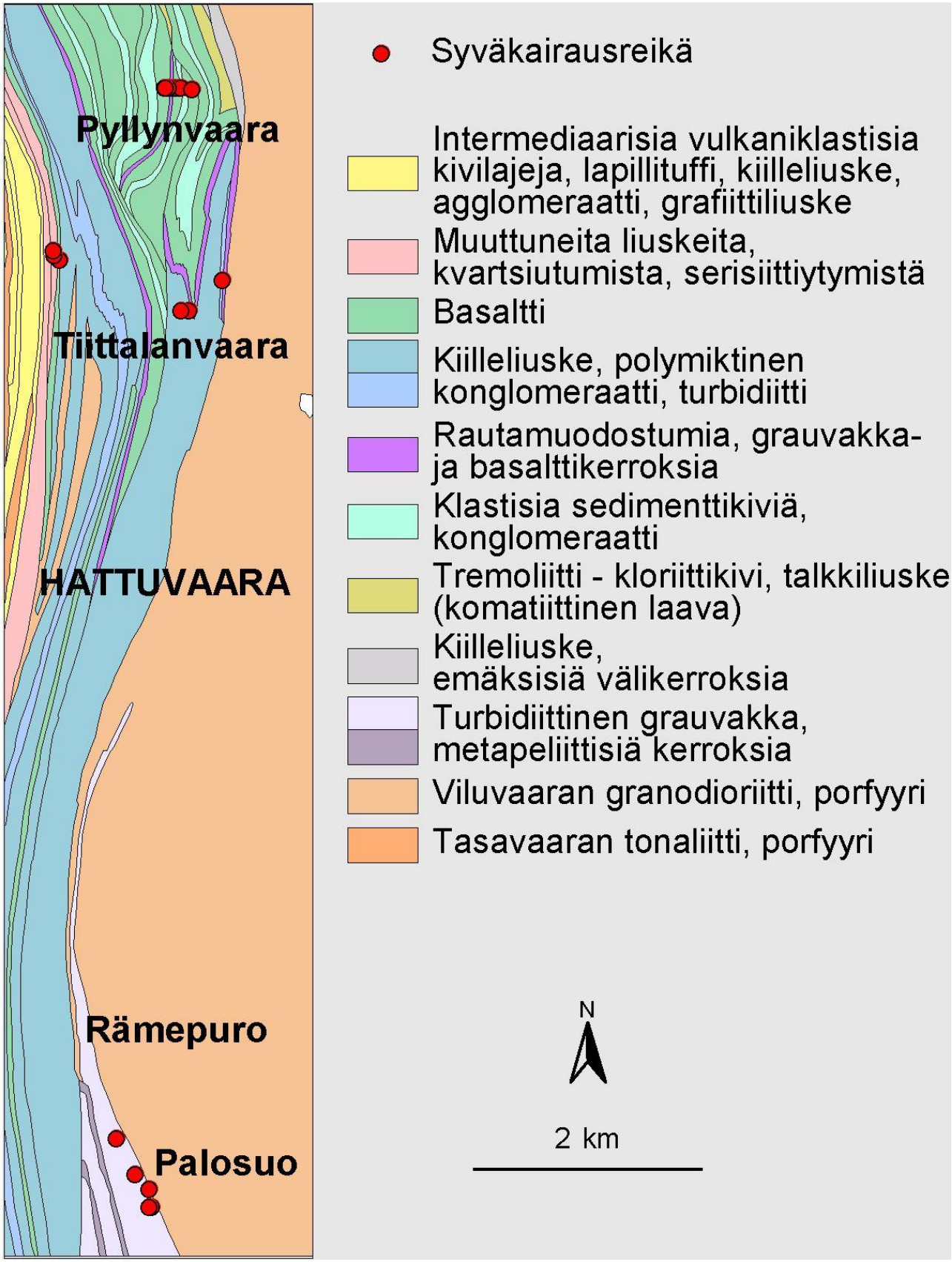


Fig. 3.3.1.6a. Simplified bedrock map of the area around Hattuvaara, Ilomantsi, after Sorjonen-Ward (1993b), with locations of GTK drill holes (Damstén et al. 1994a).

PAMPALO-VALKEASUON ALUE

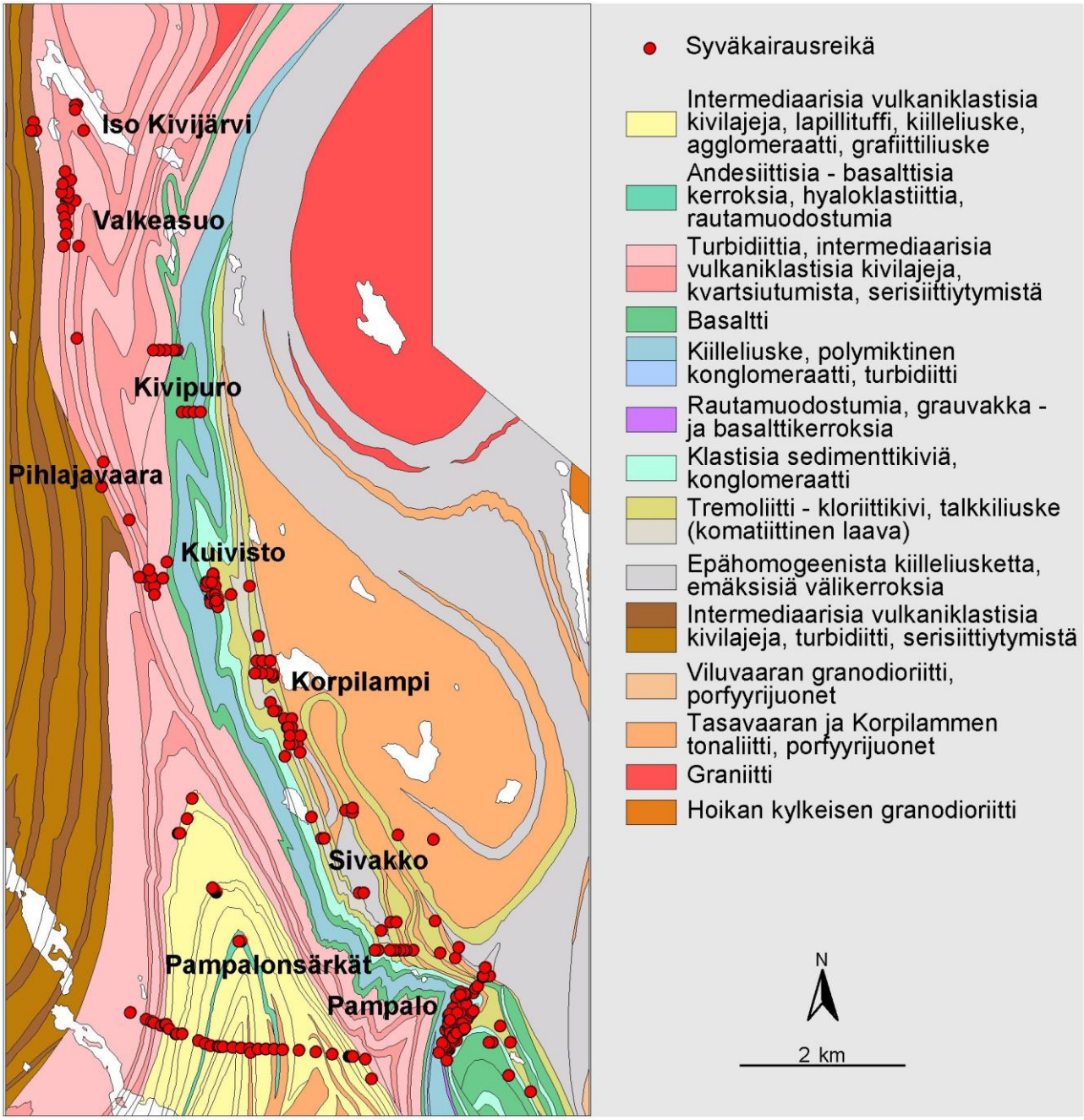


Fig. 3.3.1.6b. Simplified bedrock map of the Pampalo-Valkeasuo area, Hattu schist belt, Ilomantsi, after Sorjonen-Ward (1993b), showing locations of GTK drill holes (Heino et al. 1995a).

poorly exposed areas, and provided a more robust geological framework for interpreting critical structures.

Till in the Ilomantsi region is ideally suited to sampling for geochemical surveys because it is nearly ubiquitous, of relatively uniform thickness and stratigraphically simple, nor has the area been affected by significant glaciofluvial processes. Moreover, glacial transport distances in basal till are comparatively short (50 – 300 m), making it possible to evaluate potential proximal sources with relatively little effort. Geochemical surveys were undertaken at three different scales (regional, scale, local scale and detailed target selection), which can be recommended as a general sampling strategy in gold exploration elsewhere too. However, the nature of the bedrock and surficial deposits ultimately determine which sampling equipment, analytical methods and

range of elements, and sampling grid densities are most appropriate. Comprehensive and systematic sampling at three different scales is also a lengthy process requiring a commitment of resources over several years. In the Hattu schist belt, such a strategy was nevertheless successful in locating more than ten occurrences of interest for follow-up exploration.

3.4 GREENSTONE BELTS IN THE KIIHTELYSVAARA – KOVERO AREA

3.4.1 Introduction

Several areas of supracrustal rocks, variously known as the Kiihtelysvaara, Keskijärvi, Kuusjärvi, Kovero, Sonkaja and Mönni greenstone belts, are present to the southwest of Ilomantsi and are likely contiguous with the Hattu schist belt; together they are generally referred to as comprising the Ilomantsi greenstone belt. Investigations in the Kiihtelysvaara – Kovero area began in 1994, with the primary objective being to assess whether the greenstone belts and surrounding granitoids are prospective for gold, based on lithological, structural and till geochemical comparisons with the Hattu schist belt. The main focus was on the greenstone belts occurring within FIN_KKJ 1: 100 000 mapsheet 4241 (Kiihtelysvaara) and less on the southern extension of the Hattu schist belt due to the comparatively thick overburden (Figure 3.4.1).

Aimo Hartikainen was primarily responsible for coordinating research in the area, with additional field work undertaken by Peter Sorjonen-Ward (2 weeks in 1995) and Kimmo Pietikäinen (2 months in 1996). Technical support, sampling and surveying was provided by Kalle Husso, Hannu Pelkonen, Hannu Repo, Martti Saastamoinen and Kauko Väänänen, while Alpo Eronen undertook technical duties in the office in Kuopio.

The early stages of investigations mostly involved collation and assessment of existing data, including:

1. the results of regional scale till geochemical surveys
2. available bedrock geological information
3. the results of more detailed geochemical surveys
4. mineralized samples submitted to GTK by members of the public
5. regional low-altitude airborne geophysical survey data

The first stage of investigations was analysis of gold and tellurium from stored till samples that had already been collected with and analysed for a range of elements during earlier (1974 – 1975) regional scale till geochemical survey, based on percussion drilling sampling (Salminen, 1980). This earlier survey comprised sampling on the Keskijärvi, Kuusjärvi and Sonkaja greenstone belts (Nykänen 1971a, 1971b) on the FIN_KKJ 1: 100 000 mapsheet 4241 (Kiihtelysvaara) and on the southwards continuations of the Hattu schist belt on the adjoining 4243 (Oskajärvi) mapsheet (Lavikainen 1975, 1986; Sorjonen-Ward 1993a, b). The analytical data obtained were compared with bedrock data and with other pathfinder elements from till. The extensive bedrock geochemical and geological data acquired by the Oulu University project on the geology and mineral resources of North Karelia (Männikkö 1988; Männikkö and Tuukki 1989; Männikkö et al. 1987; Pitkäjärvi 1988; Tuukki 1991a, 1991b; Tuukki and Uusikartano 1988; Tuukki et al. 1987) was also of value in establishing the distribution of minerals and hydrothermal alteration typically associated with and accompanying gold mineralization.

Gold was also analysed from samples collected during previous scale investigations, which primarily represented weathered bedrock and chip samples (Lestinen 1979, 1980a, 1980b; Mäkinen & Lestinen 1990). The presence of scheelite was also assessed using UV light in selected suites of samples, for scheelite was known to be closely associated with gold mineralization in the Hattu schist belt. Field work was done in 1994, 1995 and 1996, involving

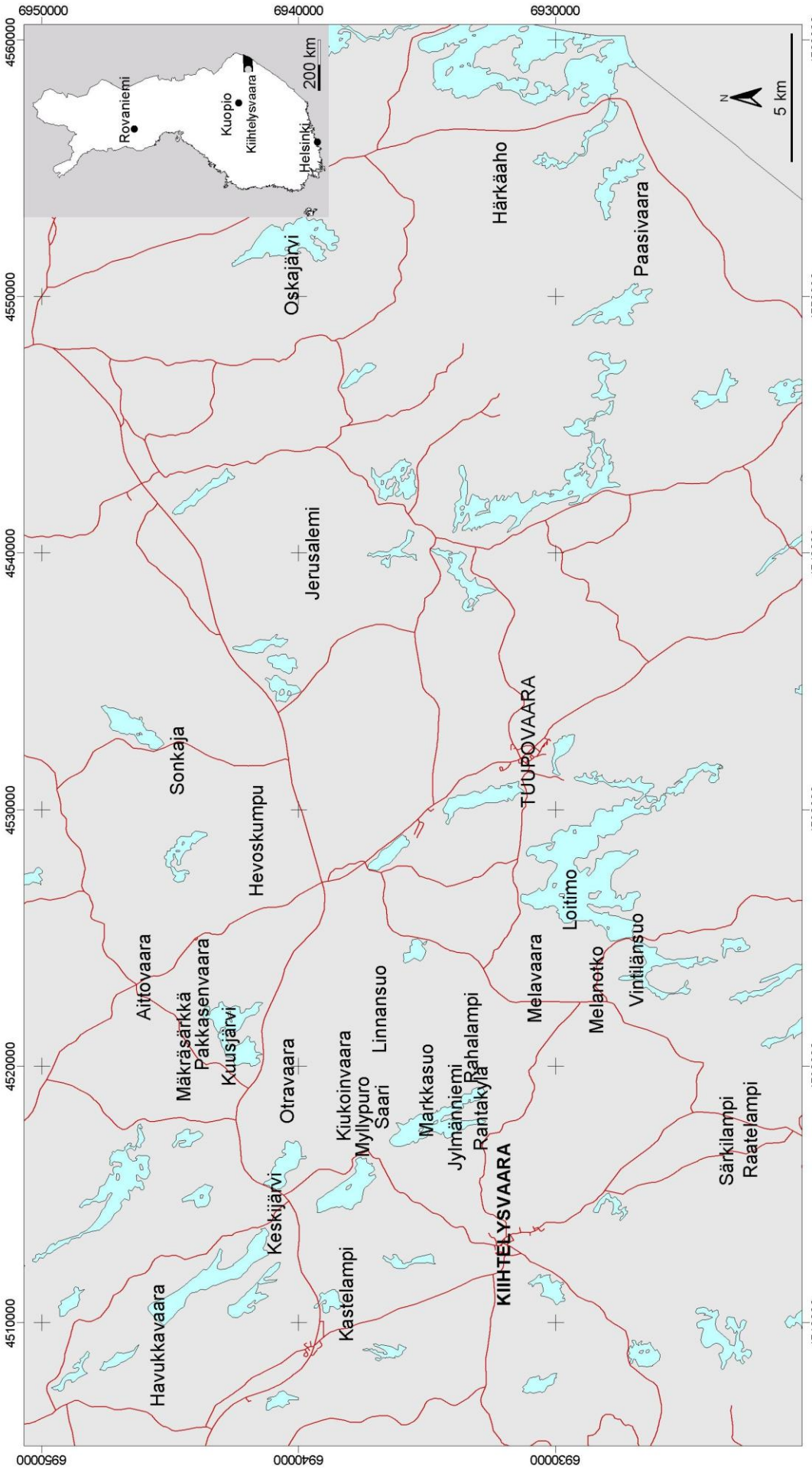


Fig. 3.4.1. Locations of exploration targets investigated in the FIN_KKJ 1: 100 000 mapsheets Kiihtelysvaara (4241) and Oskajärvi (4243).

Field

checking locations of interest, searching for new bedrock exposures and for analysis samples of mineralized bedrock and glacial boulders were collected. Percussion drill sampling of till and bedrock surface was also done during the winter months in 1995 and 1996. Some additional samples were chosen for the purpose of XRF geochemical studies and U-Pb isotopic dating.

3.4.2. Overview of the Archean bedrock geology of the Kiihtelysvaara – Kovero area

3.4.2.1. General background

The Archean bedrock of the Kiihtelysvaara – Kovero area and the southern part of the Hattu schist belt, on the FIN_KKJ 1: 100 000 mapsheets 4241 (Kiihtelysvaara) and 4243 (Oskajärvi), can be divided into either two or three principal rock groups (Frosterus & Wilkman 1920b, 1924b; Lavikainen 1975, 1986; Lundqvist et al. 1996; Nykänen 1971a, 1971b; Gaál et al. 1978; Luukkonen and Lukkarinen 1986; Tuukki et al. 1987) (Figure 3.4.2.1):

1. Archean granitoid gneisses older than the greenstone belts
2. Volcanic and sedimentary rocks of the Keskijärvi, Kuusjärvi and Sonkaja greenstone belts and the southern part of the Hattu schist belt
3. Granitoids and mafic dykes intruding the supracrustal belts

3.4.2.2. Potential older basement to greenstone belts

There are no obvious and diagnostic field criteria for distinguishing between possibly older basement and younger granitoids and migmatites, except where contacts are demonstrably intrusive. No examples of unconformable deposition on older granitoid gneisses have been found, nor is there isotopic evidence for distinctly older granitoid or gneissic domains in the Kiihtelysvaara area. Nykänen (1971b) considered a so-called amphibolite – leptite assemblage to be the oldest rocks in the region.

Rocks that have at times been assigned to a potentially older basement include cataclastic, commonly migmatitic banded gneisses, regarded as orthogneisses, with relict enclaves of still older material, and compositions varying from quartz diorite, granodiorite, tonalite and oligoclase granite (cf. Gaál et al., 1978). A number of narrow, highly tectonized, commonly cataclastic zones with sericitic schists, have been mapped along the boundary zones between granitoids and greenstones in the Suomussalmi, Kuhmo and Ilomantsi areas, and these have been interpreted as either brittle fault zones, or metamorphosed basement regolith at the base of the greenstone sequence (Gaál et al., 1978).

3.4.2.3. Volcanic and sedimentary rock units in the Keskijärvi, Kuusjärvi and Sonkaja greenstone belts

Greenstone belts occur as narrow synformal structures between granitoids, some of which have been interpreted as diapiric (cf. Gaál et al., 1978). They consist principally of metamorphosed mafic volcanics and lesser amounts of mica schists and felsic volcanics that are interpreted as representing stratigraphically younger units. The mafic volcanics comprise banded amphibolites, hornblende schists and chlorite schists, with primary eruptive features, such as pillow lavas, preserved in many places. Komatiitic basalts and serpentinites are also present, and spinifex textures have also occasionally been found (Tuukki et al., 1987). Mafic volcaniclastic lithologies predominate in the Keskijärvi belt and gabbroic amphibolites in the Kuusjärvi belt, contrasting with the mica schists and tholeiitic basalts in the Sonkaja belt (Nykänen, 1971b; Tuukki et al., 1987).

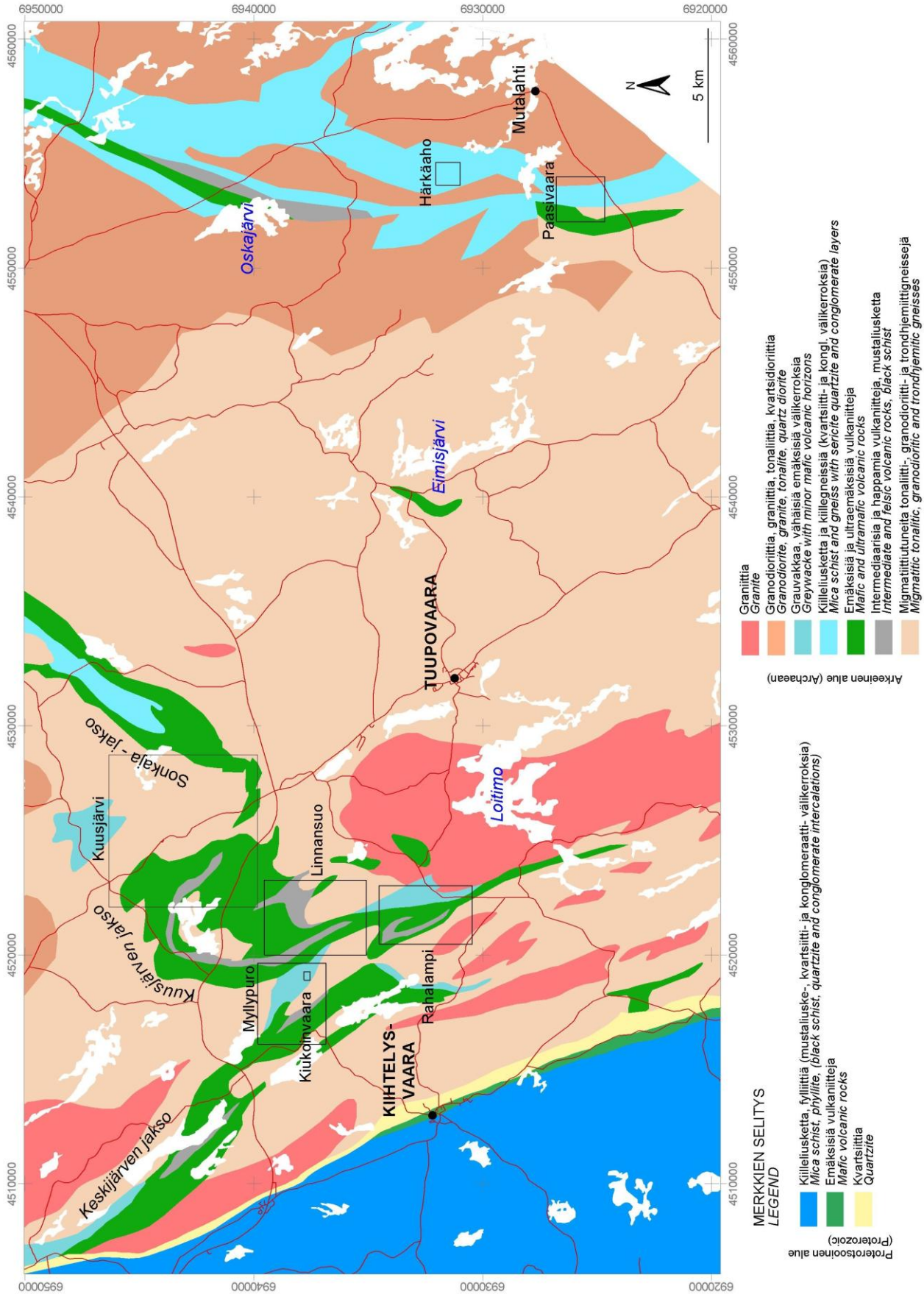


Fig. 3.4.2.1. Bedrock geology of the FIN_KKJ 1: 100 000 scale Kiihtelysvaara (4241) and Oskajärvi (4243) mapsheet areas (Lavikainen 1975; Lundqvist et al. 1996; Nykänen 1971a). The rectangular areas indicate detailed maps shown in other figures..

Tholeiitic basalts and felsic volcanics (rhyolites and dacites) are present and widespread in each of the belts, whereas serpentinites occur as elongate lenticular bodies. Komatiitic basalts form narrow continuous units in both the Kuusjärvi and Keskijärvi belts. A thin silicate-facies iron formation is present within the tholeiitic sequence, while a considerably thicker oxide-facies iron formation occurs within the mica schists of the Keskijärvi belt.

According to the interpretation by Nykänen (1971b) and Väyrynen (1933), the stratigraphical sequence consists of, from oldest to youngest:

1. amphibolites, banded hornblende schists, chloritic schists, serpentinites and quartz-magnetite iron formations;
2. quartzo-feldspathic metasedimentary schists, mica schists, graphitic pelitic schists, hydrothermally altered quartz rocks and sericite schists, with massive pyritic ore
3. metagabbro and metadiorite
4. quartz dioritic and granodioritic gneisses
5. oligoclase granites
6. monzogranites

In contrast, Tuukki et al. (1987) define the following stratigraphic sequence within the Kuusjärvi belt, excluding granitoids and again from oldest to youngest:

1. pillowed tholeiitic lavas;
2. pillowed komatiitic basaltic lavas;
3. sulfidic – graphitic schists and felsic volcanics;
4. Fe-tholeiites and iron formations;
5. serpentinites, felsic volcanics and gabbros;
6. mica schists and felsic volcanics

Tuukki et al. (1987) interpret the tholeiitic volcaniclastics and pillow lavas as the oldest exposed units in the Keskijärvi belt, followed by serpentinites, felsic to intermediate volcanics, conglomerates, iron formations and uppermost, mica schists. The Sonkaja belt resembles the Kuusjärvi belt except that mafic volcanics and mica schists occur in roughly equal proportions.

3.4.2.4. Rock units intruding the supracrustal belts

A wide variety of granitoids surround and intrude the greenstone belts, ranging from extensive plutonic bodies to porphyritic dyke swarms (Nykänen 1971b; Pekkarinen 1979; Tuukki et al., 1987). The use of strain state is highly misleading in assigning relative ages to intrusive rocks and moreover, most contacts are highly strained, being in many places cataclastic or mylonitic.

Intrusive rocks form discrete small quartz diorite plutons, variably strained gneissose porphyritic granodiorites and quartz monzodiorites, with tonalites being especially common. The earliest isotopic age determinations from the Kiihtelysvaara – Kovero region indicated ages between 2 800 – 2 600 Ma (Kouvo and Tilton 1966). During the present study, a sample was collected from a granodiorite cutting the andalusite-bearing peltic metasediments at Kiukoinvaara (A1520, FIN_KKJ4 coordinates 6937.80N, 4519.00E, on 1: 20 000 mapsheet 4241 05). Zircon separated from this sample formed a homogenous prismatic, brownish population interpreted as magmatic in origin, typically bipyramidal and only slightly rounded prism faces, with aspect ratios of 2 – 5. A pooled analytical result defined a chord with an upper intercept of 2 726 ± 14 Ma and lower intercept of 412 ± 41 Ma, although exclusion of the four most discordant fractions yields an upper intercept of 2 722 ± 4 Ma (Irmeli Mänttäri, personal communication, 1999). The metasediments record at least one deformation event that is not present in the granodiorite, predating the foliation shared by both rock types. This is most apparent from relict inclusion trails in the (subsequently retrogressed) andalusite porphyroblasts; moreover, if the foliation parallel to

the lithological layering in the metasediments is older than that preserved in the porphyroblasts, then there are possibly two deformation events that took place during prograde metamorphism, prior to emplacement of the granodiorite. It is therefore possible that the metasedimentary sequence is older than currently thought. Both the metasediments and granodiorite are truncated by a massive mafic dyke, which has chilled margins, as is typical of Paleoproterozoic dykes in the Archean terrains of eastern Finland.

Weakly deformed feldspar porphyritic dacitic to andesitic dykes, usually no more than several tens of meters in thickness, are common, and intrude mica schists as well as felsic volcanics. The youngest group of granites are usually only slightly folitated and mylonitic, as for example the Loitimo or Kutsu biotite microcline monzogranite, which has yielded a surprisingly young U-Pb zircon age of 2 553 ± 22 Ma (GTK sample A91, Kouvo and Tilton, 1966).

Paleoproterozoic mafic dykes, trending between WNW – ESE and NW – SE are relatively abundant, and are commonly strongly magnetic. They are generally massive, with ophitic texture comprising hornblende and plagioclase and only show the effects of Proterozoic deformation and recrystallization at dyke margins (Sorjonen-Ward, 1993a). The dykes cut all Archean rock types discordantly, including some prominent brittle-ductile mylonite zones at Saari, near Heinävaara, which also trend NW –SE and dip at 60º - 70º towards the NE.

3.4.2.5 Mineral occurrences and mineralization indications

Occurrences of stratiform massive pyrite within the greenstone belts have long been known and mined, with the largest deposit being at Otravaara, from which 22 000 tonnes of ore were mined between 1918 and 1923 (Aurola 1954). The pyritic ore at Otravaara occurs within a brecciated horizon with quartz and sericite. Similar stratiform mineralization is found over a distance of 7 km within this stratigraphic interval, which consists of amphibolites and stratified felsic volcanics with graphitic pelites (Saksela 1923; Aurola 1954; Nykänen 1971b) and fine-grained tuffaceous volcaniclastic horizons, including lapilli tuffs (Männikkö et al. 1987; Tuukki et al. 1987). Hydrothermally altered rocks, with sericite – quartz – chlorite – epidote – carbonate assemblages occur within a stratabound zone several meters thick. Similar alteration and pyritic mineralization has been found widely throughout the greenstone belts (Männikkö et al. 1987; Tuukki et al. 1987), at Hevoskumpu, (Aurola & Vähätalo 1939), Pakkasenvaara (Aurola 1955) and at Rahalampi (Lestinen 1979). Pyrhhotite is relatively abundant at the margins of the pyritic zones, as well as sporadic chalcopyrite, sphalerite and galena.

Relatively anomalous zinc (maximum value = 1 500 ppm) and copper (maximum value = 930 ppm) values in till in the Linnansuo area are attributed to sphalerite and chalcopyrite weathered from graphitic sulfide-bearing schists (Mäkinen and Lestinen 1990). Felsic volcanic boulders found to the east of Otravaara also contain spahalerite (maximum value = 3 590 ppm Zn) and fuchsitic bands, which are indicative of their having been derived from Otravaara-type mineralization (Damstén 1989). Low grade mineralization (maximum values of Zn = 0.8 %, Pb = 1030 ppm, Cu = 990 ppm) were assayed from RAB drilling of mica schists and graphitic schists at Myllypuro (Mäkinen and Lestinen 1990), while granitic rocks at Rantakylä (Kiihtelysvaara) also contained a weak disseminations of galena and sphalerite. Mäkinen and Lestinen (1990) also described similar galena – sphalerite mineralization in amphibolites and mica gneisses at Vintilänsuo.

Albitic metadolerite dykes commonly contain anomalous copper (Cu = 500 – 1 000 ppm), with disseminated chalcopyrite (Pekkarinen 1977; Lestinen 1980b; Salminen 1980, Mäkinen and Lestinen 1990) and occasionally bornite and covelline (Lavikainen 1986). The Pogosta Granodiorite pluton, which lies between the southern part of the Hattu schist belt and the Sonkaja

belt (Sorjonen-Ward 1993a) contains quartz vein networks with molybdenite, at Jerusalemi (Roos, 1981), and molybdenite has also been found sporadically in other places (Nykänen 1971b; Lestinen 1980b).

The banded iron formations in the Kiihtelysvaara – Kovero greenstone belts are rather thin and iron oxide contents are relatively low (Lehto and Niiniskorpi, 1977). Chalcopyrite has been found within the iron formations at Havukkavaara (Nykänen 1971b) and within amphibolite enclaves in monzogranite at Kastelampi (Salminen 1980).

Exploration activity was undertaken in the Särkilampi – Raatelampi are south of Kiihtelysvaara between 1972 – 1975 (Pekkarinen, 1977). A skarn-like unit about a meter in thickness was found in the contact zone between a lenticular banded iron formation and amphibolites, containing chalcopyrite, pyrite, pyrrhotite and molybdenite. The same horizon also assayed up to 10 – 15 ppm gold in some samples, although abundances were in general much lower. This area lies adjacent to the Paleoproterozoic unconformity and a conglomeratic breccia above the unconformity, immediately to the west of this mineralization yielded a gold nugget 4 mm in length. Therefore, 5 holes were drilled through this unit but gold values were generally low, with a maximum grade of 0.1 ppm Au (Pekkarinen, 1977).

Several large boulders of mafic volcanic rock containing bands of magnetite with anomalous gold were found about two kilometers to the southeast of the Särkilampi – Raatelampi occurrence (Damstén, 1986). A total of 3 holes were drilled (combined length of 409.26 m) which intersected the magnetite layer; metal contents were however low, with maximum values of Au = 0.6 ppm, Cu = 0.24 %, Zn = 0.37 % and Mo = 500 ppm (Damstén, 1986).

3.4.2.6. Tectonics and structural evolution

Nykänen (1971b) distinguished two deformation events or trends, with orientations NW – SE (310º - 330º) and SW – NE (010º - 060º) and considered that the latter trend was the earlier of the two, at least in the Kuusjärvi belt. The Keskijärvi belt trends essentially NW – SE, with predominantly steeply SE-plunging fold axes and lineations, while the Sonkaja belt trends NE – SW and has gently to moderately N-plunging lineations. In general, foliations and lithic layering in all greenstone belts are steep, between 60º and 85º.

Bowes (1976) recognized a total of six Archean deformation events, of which the first two would have pre-dated those described by Nykänen (1971b), essentially representing layer parallel foliations and metamorphic mineral growth. The younger structures identified by Bowes (1976) represent only minor folding and faulting events that cause local complications but are not of regional significance.

Männikkö (1988) defined six Archean events in the Keskijärvi and Kuusjärvi belts and an additional Paleoproterozoic faulting event:

1. D1: intrafolial isoclinal folding and foliation, generally overprinted and obscured by younger structures;
2. D2: intense axial planar foliations accompanying isoclinal folding and metamorphic differentiation banding, which represents the main deformation event;
3. D3: rotation of earlier structures into present steeper orientations;
4. D4: pervasive axial planar foliations associated with asymmetric folding and mineral lineations; D4 foliations overprint D2 foliations;
5. D5: open to tight folding with relatively weak axial planar foliation
6. D6: crenulations and minor faulting, and folds with variably plunge
7. D7: Paleoproterozoic NW-SE trending fault zones.

The Kiihtelysvaara – Kovero area was presumably buried to considerable depth beneath Paleoproterozoic cover sequences and nappe complexes during the Svecofennian orogeny, because K-Ar isotopic systems in biotite, and in some places hornblende, have been disturbed and reset to ages between 1 850 – 1 800 Ma (Kontinen et al., 1992); this implies temperature conditions of > 350ºC, possibly near the greenschist – amphibolite transition (cf. Sorjonen-Ward, 1993a).

3.4.3. Surficial deposits in the Kiihtelysvaara – Kovero area

Surficial deposits in the Kiihtelysvaara – Kovero region consist predominantly of basal till and have been described by Frosterus ja Wilkman (1917, 1920a), Repo (1957), Salminen (1980), Kurimo (1982), Rainio (1983, 1985) ja Salminen ja Hartikainen (1985). According to Salminen (1980), deposits are generally 3 – 5 m thick, although may more than to 10 m thick in deep valleys; conversely, bedrock exposures are abundant in topographically elevated areas.

During the final deglaciation event, the Kiihtelysvaara area lay in the area of convergence between two major glacial lobes. The extensive Mäkräsärkä ice-marginal formation, which correlates with the Salpausselkä II formation further to the southwest, was deposited in front of the NNW ice lobe that terminated just north of Kuusjärvi. Within the area between Tuupovaara and Aittojärvi and Linnansuo, glaciofluvial sand deposits are widespread, while along the Iiksenjoki valley, extensive and relatively thick fluviatile sands and silts were deposited. Weathered bedrock is generally buried beneath till, as in the Linnansuo area, but post-glacial weathering phenomena are also sporadically observed, particularly where graphitic and sulfidic schists are exposed at the surface (Salminen, 1980).

Glacial striations in bedrock in the area covered by the Kiihtelysvaara and Oskajärvi (FIN_KKJ 1: 100 000 mapsheets 4241 and 4243 generally display two trends: an older trend from the NNW (330º) and a younger WNW (280º - 300º) trend relating to the last deglaciation (Repo, 1957; Salminen and Hartikainen, 1985). Boulders near the surface have typically been transported between 1 – 3 km, whereas fine material (< 0.06 mm) in basal till is interpreted as having travelled only some hundreds of meters from its source (Salminen and Hartikainen, 1985).

3.4.4. Sampling and measurement methods and procedures

3.4.4.1. Sampling and analysis of surficial materials

Till and other surficial materials were sampled by percussion drilling during three separate stages:

1. Regional stage (1974 – 1975), with sampling from upper levels of till (mean depth = 1.54 m) along profiles, and sample density of 7.8 km/ km^2
2. Local scale sampling (1996) from basal till on a regular grid (16 samples/km^2), with retrieval of weathered bedrock and bedrock chips where possible,
3. Detailed sampling (1977 -1980, 1984, 1994 – 1996) from basal till and/or weathered bedrock (mean depth = 5.6 m), mostly along linear profiles with sampling density between 100 – 400 samples/km^2.

Sampling was done with portable drilling equipment (Cobra, Wacker and Partner) with flow-through drilling rods (Kauranne 1975; Gustavsson et al. 1979; Salminen 1980). During the regional scale surveys samples (100 – 300 g) were collected at 100 m intervals along profiles spaced 1.0 – 1.5 km apart and oriented orthogonal to glacial flow directions.

3.4.4.1.1. Regional scale till sampling surveys

Samples collected during the 1974 – 1976 regional surveys were analyzed in a semi-quantitative manner using emission quantometry (tape-in tape-out method). Samples obtained from the greenstone belts and surrounding areas on the Kiihtelysvaara (FIN_KKJ 4241) mapsheet (2 102 samples from till, 17 from bedrock, and 9 from weathered bedrock) were analyzed for gold and tellurium in 1993 – 1994 using the GFAAS technique (Niskavaara and Kontas, 1988; Kontas, 1993). Sample distributions according to individual 1: 20 000 scale mapsheets are:

4241 03: 205	4241 04: 44	4241 05: 320
4241 06: 314	4241 07: 100	4241 08: 315
4241 09: 426	4241 12: 378	

A total of 703 samples collected during regional stage sampling over the southern continuation of the Hattu schist belt, on the Oskajärvi (FIN_KKJ 4243) mapsheet, were analyzed for gold and tellurium; of these 679 were till samples and 24 from bedrock. Distributions according to 1: 20 000 mapsheets were as follows:

4243 04: 289	4243 05: 237	4243 06: 177.

3.4.4.1.2. Local scale sampling stage

A total of 284 samples were analyzed using ICP-AES after aqua regia leaching for Ag, Al, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Sr, Ti, V ja Zn. Gold and tellurium (analyzed with GTK process 521U) and arsenic (process 516A) were determined with GFAAS. Till samples were analyzed from < 0.06 mm sieved separates, while weathered and fresh bedrock samples were crushed in a carbon steel mill.

3.4.4.1.3. Detailed sampling surveys

Detailed surveys in the Kiihtelysvaara area (FIN_KKJ 1: 20 000 mapsheets 4241 05, -07, -08) focussed specifically on Linnansuo, Melanotko, Myllypuro, Rahalampi, Rantakylä, Kissanloso and Vintilänsuo (Figure 3.4.1); samples collected between 1978 – 1984 were analyzed for Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn using atomic absorption spectrophotometry (Lestinen 1980a, b, Mäkinen & Lestinen 1990). The 0.06 – 0.5 mm size fractions from these samples were also inspected under UV light for the presence of scheelite during 1994 – 1995. The abundance of scheelite and high Co and Cu concentrations were criteria used in selecting samples for gold and tellurium analysis (GFAAS, 521U), of which 484 were eventually chosen.

An additional detailed sampling survey was made by percussion drilling at 10 m intervals along selected profiles during 1994 – 1996 with a percussion drill, the aim being to obtain samples from basalmost till and underlying bedrock. A total of 540 samples were obtained from Linnansuo, Myllypuro, Kiukoinvaara and Melavaara on the Kiihtelysvaara 1: 100 000 mapsheet area and 490 samples from the Paasivaara and Härkäaho areas on the Oskajärvi mapsheet. As well as Au and Te, these samples were analyzed with ICP-AES for the same suite of elements as in the district scale sampling surveys, namely Ag, Al, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Sr, Ti, V and Zn. Bedrock chips, and clasts from weathered till were examined to determine rock type and for the presence of hydrothermal alteration or ore minerals.

3.4.4.2. Outcrop and boulder samples

A total of 259 samples from outcrops and boulders were analyzed between 1994 and 1996. Most samples were obtained using a hammer, apart from six sites, where a portable drill was used. Samples were analyzed for Au and Te with GFAAS and other elements with AAS and ICP-AES. Platinum was analyzed using GFAAS from 3 samples and 13 samples were analyzed with XRF.

3.4.4.3. Geophysical surveys

Low-altitude airborne geophysical surveys flown by GTK cover the entire Kiihtelysvaara and Oskajärvi 1: 100 00 mapsheet areas (refer to Section 2.2.1) but no ground geophysical surveys were made in the area during the current project. Previous surveys in the region included 12 line km in the contact zone between Archean and Paleoproterozoic rock units (Pekkarinen, 1977; Damstén, 1986). Slingram measurements were made in the 1970's some two kilometers south of Särkilampi, and further surveys were made further east in the same area during the 1980's. Systematic gravity surveys were also done during the 1980's over a 1 km^2 area south of Särkilampi. Down-hole misé-a-la-masse and magnetometry measurements were made in the three holes drilled 2 km southeast of Särkilampi.

3.4.5. Results of investigations

3.4.5.1. Regional till geochemical sampling

Figure 3.4.5.1a shows gold concentrations in till, based on regional scale sampling, in the Kiihtelysvaara (FIN_KKJ 4241) area and in the southern part of the Hattu schist belt, within area covered by the Oskajärvi (FIN_KKJ 4243) mapsheet. Table 3.4.5.1 shows corresponding statistical data from the same samples. Gold abundances tend to be somewhat higher in the Kiihtelysvaara area than in the Oskajärvi mapsheet area, with a total of 8 samples having Au > 100 ppb. The most conspicuous and continuous gold anomalies occur in the southern part of the Kuusjärvi belt and to the northwest of Havukkavaara in the Keskijärvi belt. On the basis of this sampling, the Sonkaja belt does not appear to be anomalous with respect to gold. However, the southern part of the Hattu schist belt shows sporadic anomalies, especially at the southernmost end, for example at Paasivaara.

Tellurium abundances in till are about three times higher in the Kiihtelysvaara area than in the area sampled on the Oskajärvi mapsheet. This is attributable to the presence of a distinctive and widespread graphitic sulfide-bearing pelitic unit in the Kuusjärvi belt, which contains telluride minerals as well as iron sulfides (Figure 3.4.5.1b). However, tellurium is also clearly anomalous in the southern part of the Kuusjärvi belt, coincident with elevated gold concentrations.

3.4.5.2 Results of sampling in local scale surveys

Local scale surveys, based on a 250 m x 250 m sampling grid, were only undertaken on the area to the east of the Kuusjärvi belt, in an attempt to more precisely delineate the distribution of gold anomalous areas indicated in the more regional sampling. In practice, sampling was partly impeded by the thick, well-sorted sediments along the Jänisjoki river valley.

284 samples were analyzed for Au and Te (of which 275 represent till, 4 were from weathered bedrock, 1 was from sand and 4 were from gravel). The highest concentrations obtained were Au = 264 ppb and Te = 5 700 ppb, which were considered too low to warrant further investigations (Figure 3.4.5.2).

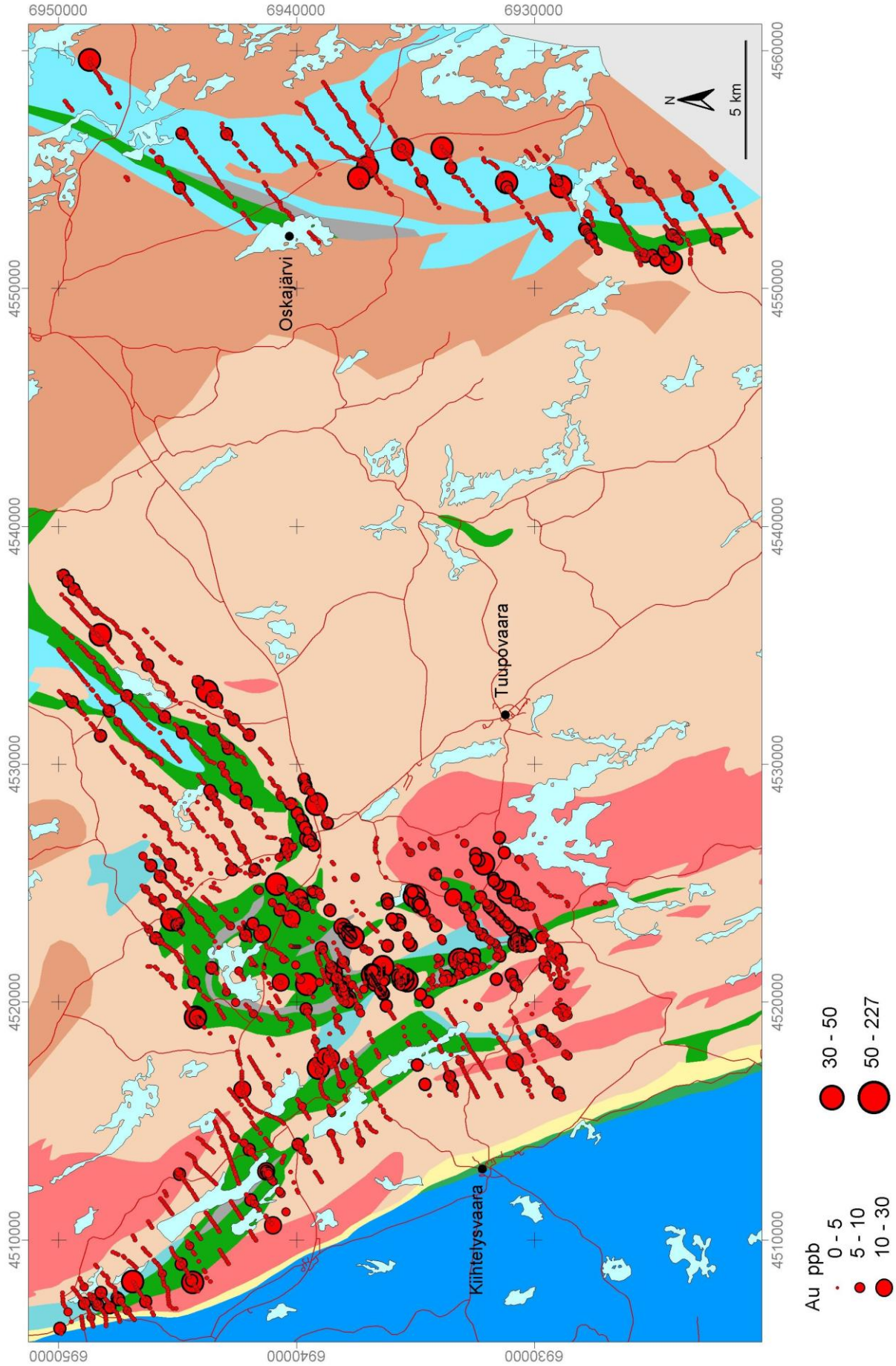


Fig. 3.4.5.1a. Gold contents in till based on regional scale geochemical soil sampling in the FIN_KKJ 1: 100 000 scale Kiihtelysvaara and Oskajärvi map sheet areas. Explanations as in Figure 3.4.2.1.

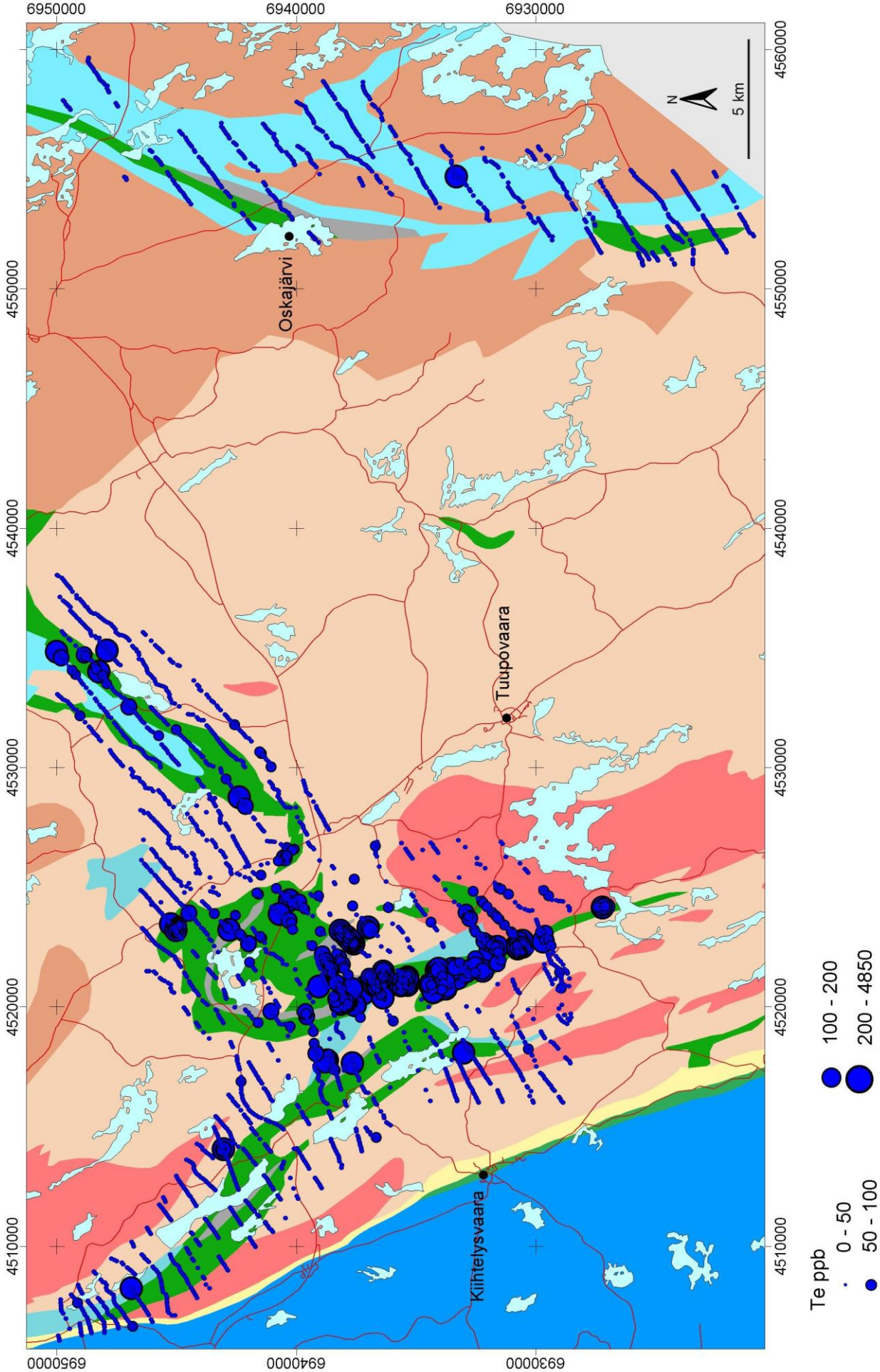


Fig. 3.4.5.1b. Tellurium contents in till based on regional scale geochemical soil sampling in the FIN_KKJ 1: 100 000 scale Kiihtelysvaara and Oskajärvi map sheet areas. Explanations as in Figure 3.4.2.1.

Table 3.4.5.1. Statistical parameters of the areal geochemical sampling stage on Kiihtelysvaara and Oskajärvi map sheet areas.

	Kiihtelysvaara		**Oskajärvi**	
Element	Gold (Au)	Tellurium (Te)	Gold (Au)	Tellurium (Te)
Number of samples	2128	2128	703	703
Average	3.6 ppb	24 ppb	3.1 ppb	7.3 ppb
Median	2.0 ppb	15 ppb	< 1 ppb	< 5 ppb
Σ 95 %-point	16 ppb	61 ppb	8 ppb	19 ppb
Σ 99 %-point	45 ppb	172 ppb	54 ppb	35 ppb
Maximum content	227 ppb	2720 ppb	147 ppb	351 ppb
Number of anomalous samples	6 points > 100 ppb	3 points > 1 ppm	2 points > 100 ppb	0 points > 1 ppm
Average sampling depth	1.5 m		1.9 m	

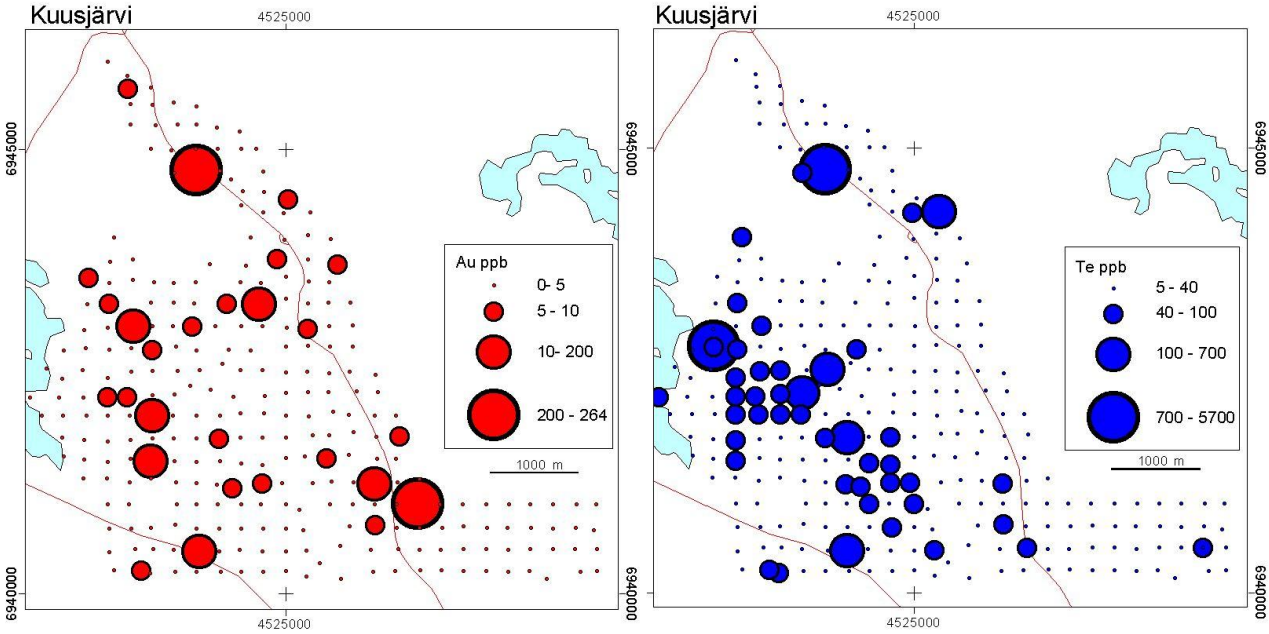


Fig. 3.4.5.2. Distribution of gold and tellurium in till based on local scale geochemical soil sampling in the surroundings of Kuusjärvi, Kiihtelysvaara.

3.4.5.3. Results of detailed till geochemical surveys

A total of 1 514 samples were collected and analyzed, of which 484 samples were obtained during earlier surveys (between 1978 – 1984), while the remaining 1 030 were collected during 1994 – 1996 (Table 3.4.5.3).

3.4.5.3.1 Myllypuro (Kiihtelysvaara)

A total of 356 samples were analyzed from the Myllypuro area (Table 3.4.5.3). The highest gold values were obtained to the west and northwest of Kiukoinvaara, in an area dominated by metasediments in which former andalusite porphyroblasts have been pseudomorphed by sericite.

The metasediments show two distinct foliations and have also been affected by intense NW-SE trending mylonitic deformation (Figure 3.4.5.3.1).

Table 3.4.5.3. Amounts of till and rock/weathered bedrock samples collected at different targets on the schist belts of Kiihtelysvaara and on the southern part of the Hattu schist belt.

Target	***Years samples collected***	***Till***	***Rock/weathered bedrock***	***Total***
Myllypuro	1978-1980, 1984	327	17	344
	1995	-	12	12
Kiukoinvaara	1995	9	34	43
Linnansuo	1979-1980	66	15	81
	1994-1995	12	333	345
Rahalampi	1979	4	43	47
Melavaara	1995	-	98	98
Vintilänsuo	1979-1980	4	6	10
Rantakylä	1979	-	2	2
Aittovaara	1995	1	41	42
Paasivaara, Ilomantsi	1996	192	158	350
Härkäaho, Ilomantsi	1995	-	140	140
Total		**615**	**899**	**1514**

At Saari, the metasediments are intruded by a coarse-grained monzogranite, similar to the Loitimo and Kutsu granites. Some 1.5 km to the northwest, highly strained tonalites resemble intermediate banded volcanic rocks. A virtually undeformed mafic dyke cuts discordantly across all of these highly strained granitoids; an area of barren milk quartz rock immediately to the west of this (shown in yellow in Figure 3.4.5.3.1) did not show any anomalous gold concentrations. The Myllypuro area also contains abundant feldspar-porphyry dykes and microcline granite dykes of variable thickness, pegmatitic dykes tens of meters thick, and finer-grained felsic dykes that are typically less than a meter in width. The intense bedrock fracture pattern, reflected in local topography, defines a rhomboidal pattern generated by intersecting NW-SE trending faults and mafic dykes and N-S trending fault zones.

3.4.5.3.2 Kiukoinvaara (Kiihtelysvaara)

A mineralized rock sample from Kiukoinvaara assaying 0.5 ppm Au was submitted to GTK in late 1994 (Marjatta Lievonen, sample number 94/4969, FIN_KKJ4 coordinates 6937.740N, 4519.018E). The sample had been collected from a 5-30 cm thick quartz vein within a microcline granite dyke cutting metasediments. Four additional samples were collected from the same outcrop, yielding gold concentrations of < 10, 5 240, 830 and 1 720 ppb respectively. The same samples also contained elevated Te (maximum value = 9 360 ppb), Zn (maximum value = 5 350 ppm), Pb (maximum value = 5 290 ppm), Ag (maximum value = 56.8 ppm) and As (maximum value 9.06 % As). Despite the relatively high gold contents, and the steep orientation of the quartz vein, the site was not considered to be of sufficient potential to warrant drilling.

A glacial boulder found at Kiukoinvaara (sample 99/AAH/95, FIN_KKJ4 coordinates = 6937.660N, 4519.090E) consisted of metasediments transected by a quartz vein some 20 cm thick which contained arsenopyrite and elevated Au (170 ppb) and W (215 ppm). Some 30 m to the north of this location another boulder, of vein quartz, was found, which assayed 17 ppm Ag, 2 550 ppm Pb and 3 590 ppb Te. Pegmatitic veins in the Kiukoinvaara area commonly contain arsenopyrite (for example, sample 112/AAH/95, FIN_KKJ4 coordinates 6937.100N, 4519.940E, contained 1.45 % As), and occasionally Au (up to 215 ppb) and Te (up to 879 ppb Te). Numerous other quartz vein boulders in the immediate vicinity nevertheless contained low concentrations.

In order to more precisely locate the source of the anomalous boulders described above and to extrapolate prospective trends, 34 samples were obtained along two profiles by percussion

drilling at 2-3 meter sampling intervals (Figure 3.4.5.3.2), sampling both basal till and material from the bedrock interface. One sample of metagraywacke contained 160 ppb Au (FIN_KKJ4 coordinates 6937.680N, 4519.094E) and was associated with an arsenic halo (166 – 508 ppm As) that extended several meters either side of the sampling site. These results were not considered sufficiently interesting to justify follow-up by drilling.

If there had been anomalous gold mineralization in the Kiukoinvaara area during latest Archean time, it is conceivable that numerous veins and brittle deformation events have caused both structural disruption and local enrichment, though not sufficient for generating economically interesting gold mineralization.

3.4.5.3.3 Linnansuo (Kiihtelysvaara)

Gold concentrations were determined from 81 samples collected by percussion drill in 1979 – 1980 from the Linnansuo area (Table 3.4.5.3). An additional 345 samples were taken during this project, in 1994 – 1995 but as with the earlier samples, gold contents were low, the highest value obtained being 145 ppb Au (Figure 3.4.5.3.3). Several analyses along the sampling profiles showed somewhat elevated gold in proximity to the greenstone belt contacts, suggesting that there may be some local enrichment. However, no further investigations were made.

3.4.5.3.4. Rahalampi, Melavaara, Rantakylä and Vintilänsuo (Kiihtelysvaara)

A combined total of 59 analyses were made on percussion drilling samples obtained from till at Rahalampi (Figure 3.4.5.3.4), Rantakylä and Vintilänsuo during 1978 – 1980 (Table 3.4.5.3.1). An additional 98 samples were obtained from Melavaara (Figure 3.4.5.3.4) during the current project, with the intention of providing an interpretation of the gold anomalies identified during regional stage sampling. However, because the highest value obtained was only 35 ppb Au, no further investigations were made.

3.4.5.3.5. Aittovaara (Eno)

Regional till geochemical sampling in the Aittovaara area, near the southwestern end of the Sonkaja belt, revealed some anomalous gold concentrations. The 42 percussion drilling samples taken from the area did not, however, yield any significant indications of mineralization, the maximum gold contents being only 11 ppb Au.

3.4.5.3.6. Paasivaara and Härkäaho (Ilomantsi)

Percussion drill sampling of till and the bedrock interface (490 samples) was undertaken at Paasivaara and Härkäaho in the southern extension of the Hattu schist belt. Gold abundances proved to be generally low (Figure 3.4.5.3.6), as did assays of sulfide-bearing boulders and bedrock exposures found in the area. Despite this, the area is still considered prospective, partly because of the presence of gold anomalies in regional scale till geochemical data, but also because of the documented presence of gold mineralization further south, in Russia, at Jalonvaara, as well as in the northern part of the Hattu schist belt.

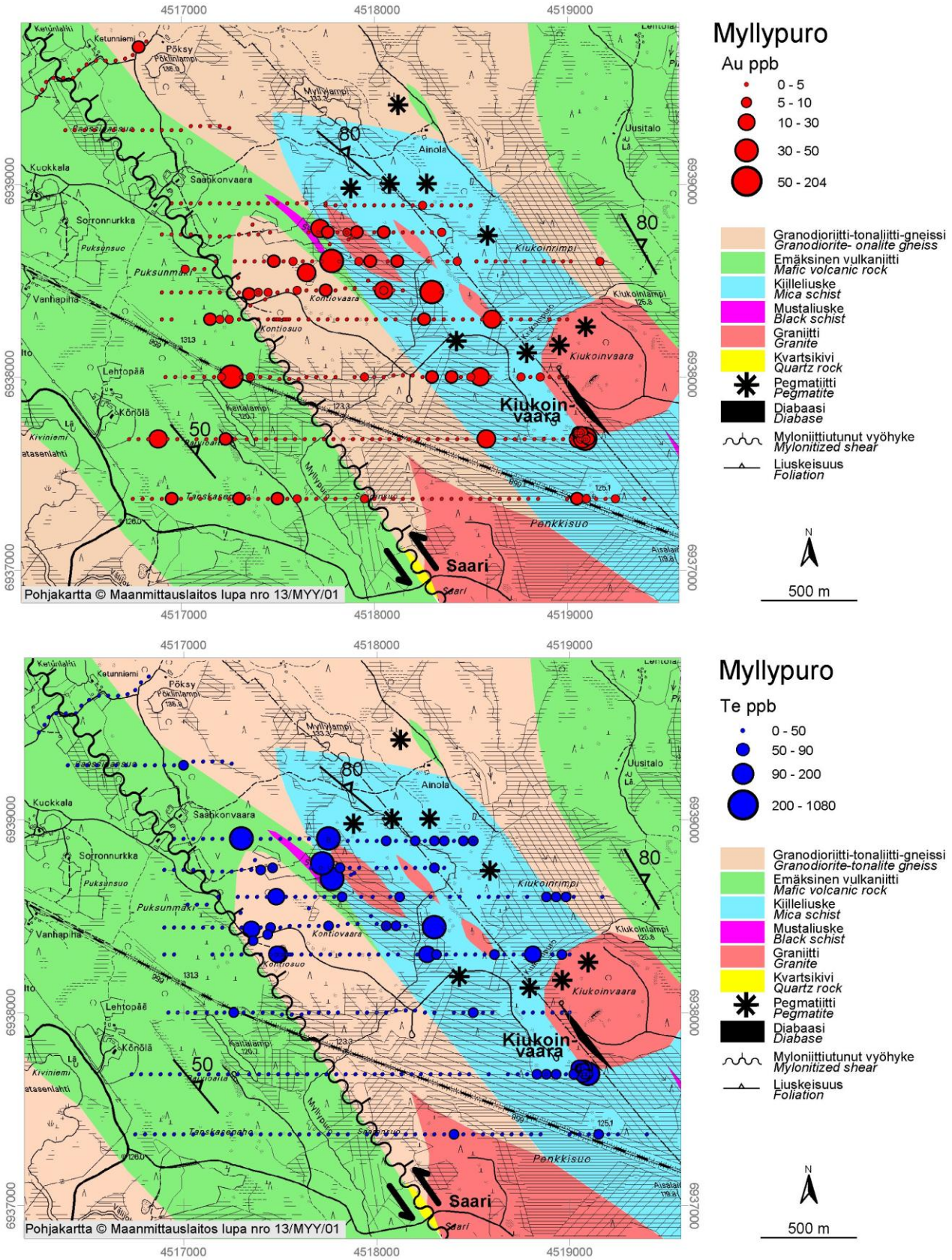


Fig. 3.4.5.3.1. Bedrock geology (Nykänen 1971a and GTK mapping during 1995 - 1996) and gold and tellurium contents in weathered bedrock and basal till at Myllypuro, Kiihtelysvaara.

3.4.5.4. Outcrop and glacial boulder observations

3.4.5.4.1 Previous investigations

Bedrock observations made during the University of Oulu North Karelian Mineral Exploration Project were reviewed during the present project for evidence of alteration or other indications of gold mineralization. Particular attention was given to observations of tourmaline, arsenopyrite and descriptions of hydrothermal alteration in outcrop. Numerous outcrops were revisited on the basis of such indications and samples were taken for analysis where necessary.

During sampling undertaken for the systematic GTK bedrock geochemical mapping program (KALLIOGEOKEMIA), care was taken to avoid outcrops affected by hydrothermal alteration, or with abundant veins undertaken by GTK. Therefore, it is not surprising that the geochemical analyses from the Kiihtelysvaara and Oskajärvi mapsheet areas did not provide any indications of anomalous gold.

Members of the public have been active in sending samples from the Kiihtelysvaara area to GTK for idenitification and analysis. Submitted material includes a boulder of hornblende schist that assayed 2 600 ppm Pb and 3 700 ppm Cu (FIN_KKJ4 coordinates 6938.800N, 4517.080E). Another pyritic boulder contained 2 000 ppm cobalt and several other boulders containing scheelite and arsenopyrite have also been found.

3.4.5.4.2. Outcrop and glacial boulder observations from the 1994 field season

During the 1994 field season, 13 outcrop samples and boulders were analyzed for gold; a sample collected from the Kastelampi copper showing (90/00251) contained 80 ppb Au, while two of the four samples taken from the Rahalampi pyrite occurrence (25/AAH/94 and 26/AAH/94) contained 40 ppb and 80 ppb Au respectively. A quartz-tourmaline outcrop at Aittovaara also showed modest gold enrichment, with 30 ppb Au (1/AAH/94, FIN_KKJ4 coordinates 6945.240N, 4523.400E).

3.4.5.4.3. Outcrop and boulder observations from the 1995 field season

During the 1995 field season, 138 samples, of which 53 were from bedrock exposures and 85 from boulders, were collected and analyzed for Au and Te (GTK analytical procedure 521U). Atomic absorption spectrophotometry (AAS) was used to analyze Ag, Cu, Fe, Ni, Pb and Zn from 29 samples, with W also being analyzed by spectrometry and As by GFAAS. A further 109 samples were analyzed (some semiquantitatively) with ICP mass spectrometry for Ag, As, Ca, Cd, Co, Cu, Fe, Mg, Mn, Mo, Ni, Pb, S, Sb and Zn. Sample distribution according to FIN_KKJ 1:20 000 scale mapsheets was as follows: 4241 03 = 17 samples, 4241 05 = 88 samples, 4241 06 = 8 samples, 4241 08 = 9 samples, 4243 04 = 13 samples and 4243 05 = 3 samples. In total, 266 outcrop and boulder observations were made during 1995.

Small amounts of silver (maximum value of 8.2 ppm) were found in boulders of pyrrhotite-bearing felsic volcanic rock (FIN_KKJ4 coordinates = 6938.420N, 4517.610E), as well as anomalous Pb (maximum value = 2 850 ppm) and Zn (maximum value = 5 200 ppm). It would be relatively straightforward to determine the source of these boulders.

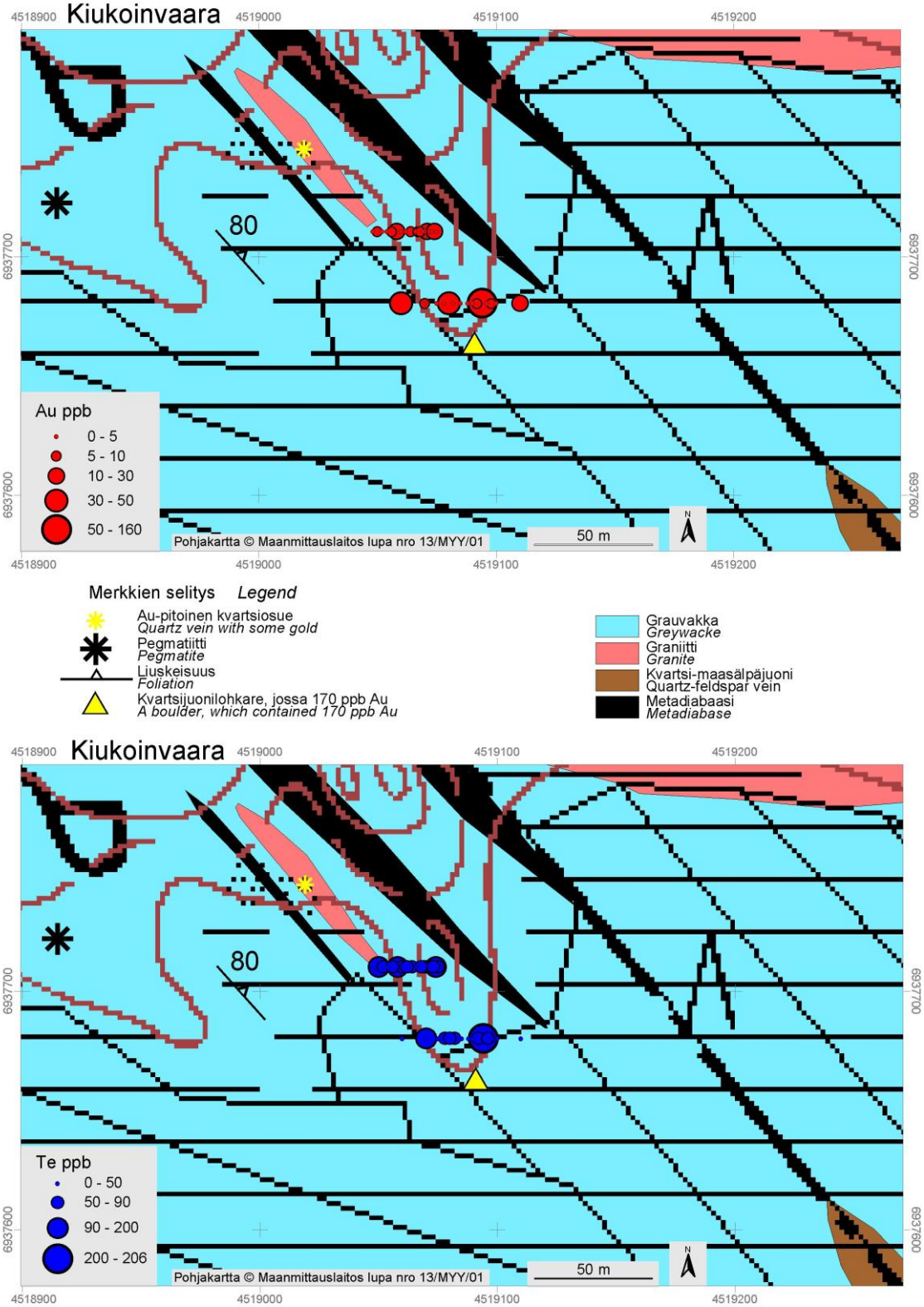
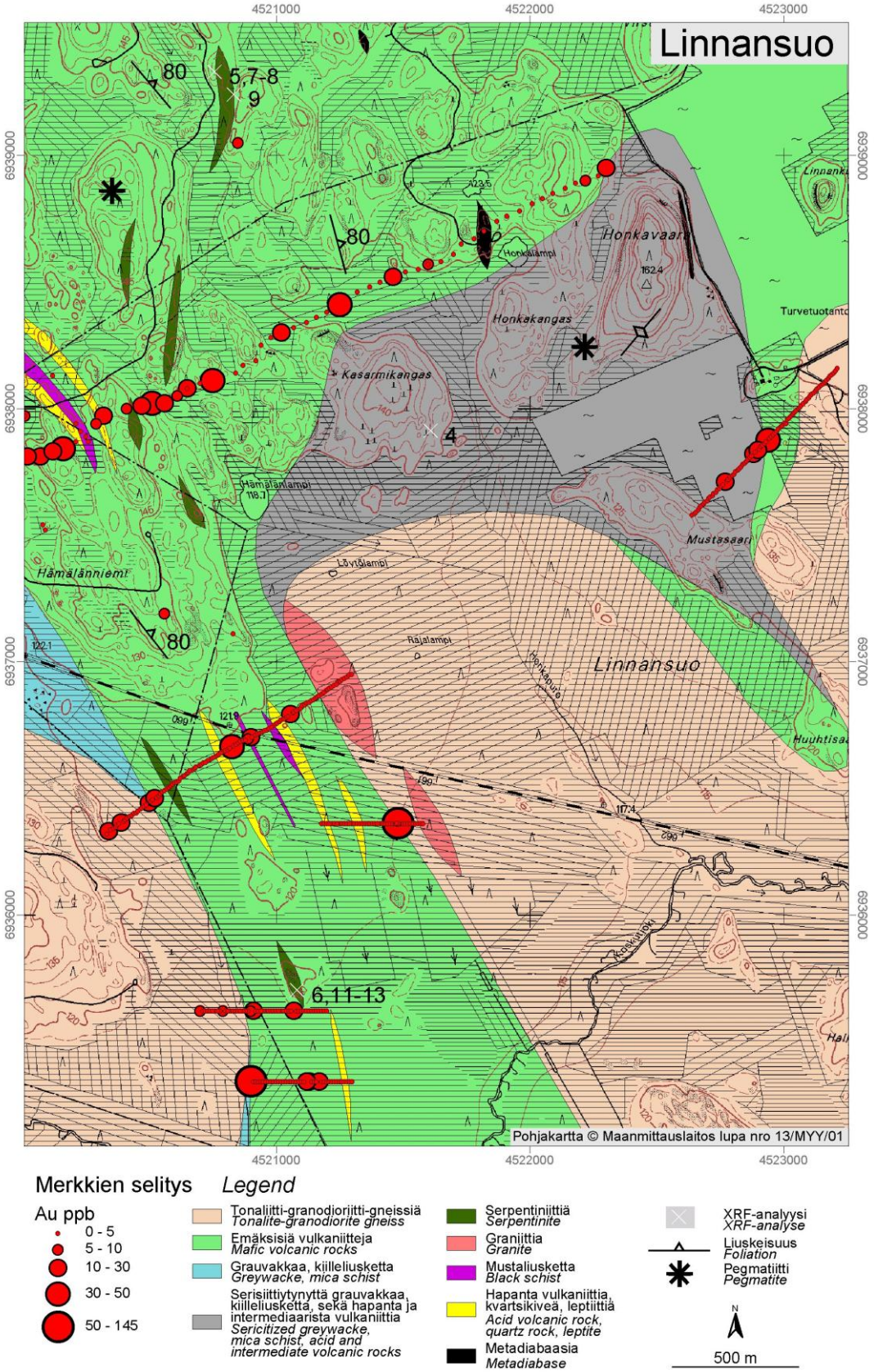


Fig. 3.4.5.3.2. Location of the Kiukoinvaara target in the Kiihtelysvaara area, showing gold and tellurium contents in samples collected from the rock surface by a percussion drill. The bedrock map is based on Nykänen (1971a) and GTK observations made in 1995 - 1996.

Fig.



3.4.5.3.3. Gold contents at the till – bedrock interface based on target scale geochemical sampling at Linnansuo, Kiihtelysvaara. Bedrock geology is based on Nykänen (1971a) and Lundqvist et al. (1996) and on GTK bedrock observations made in 1995 - 1996. The numbers refer to those used in Table 3.4.5.4.5.

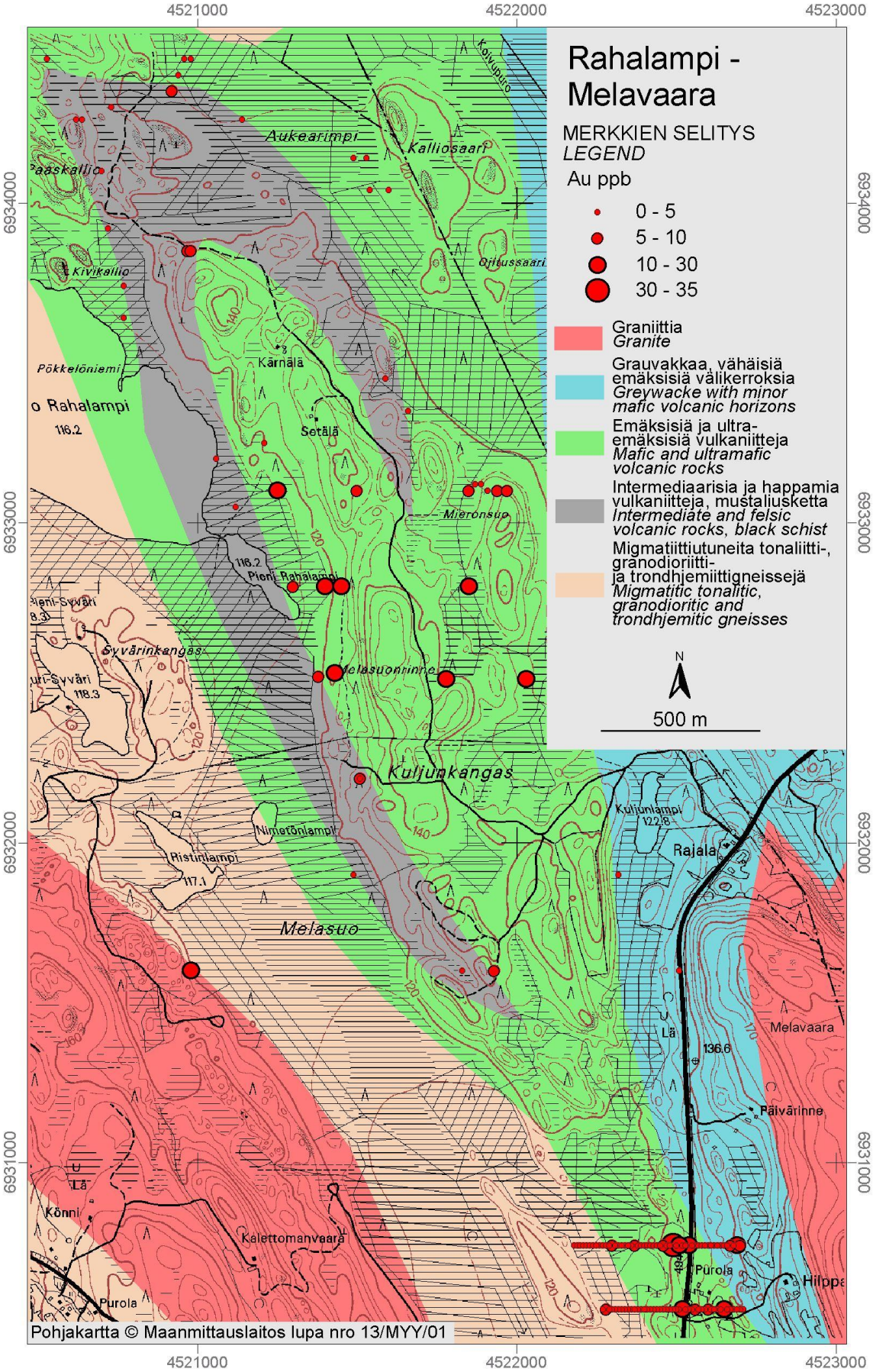
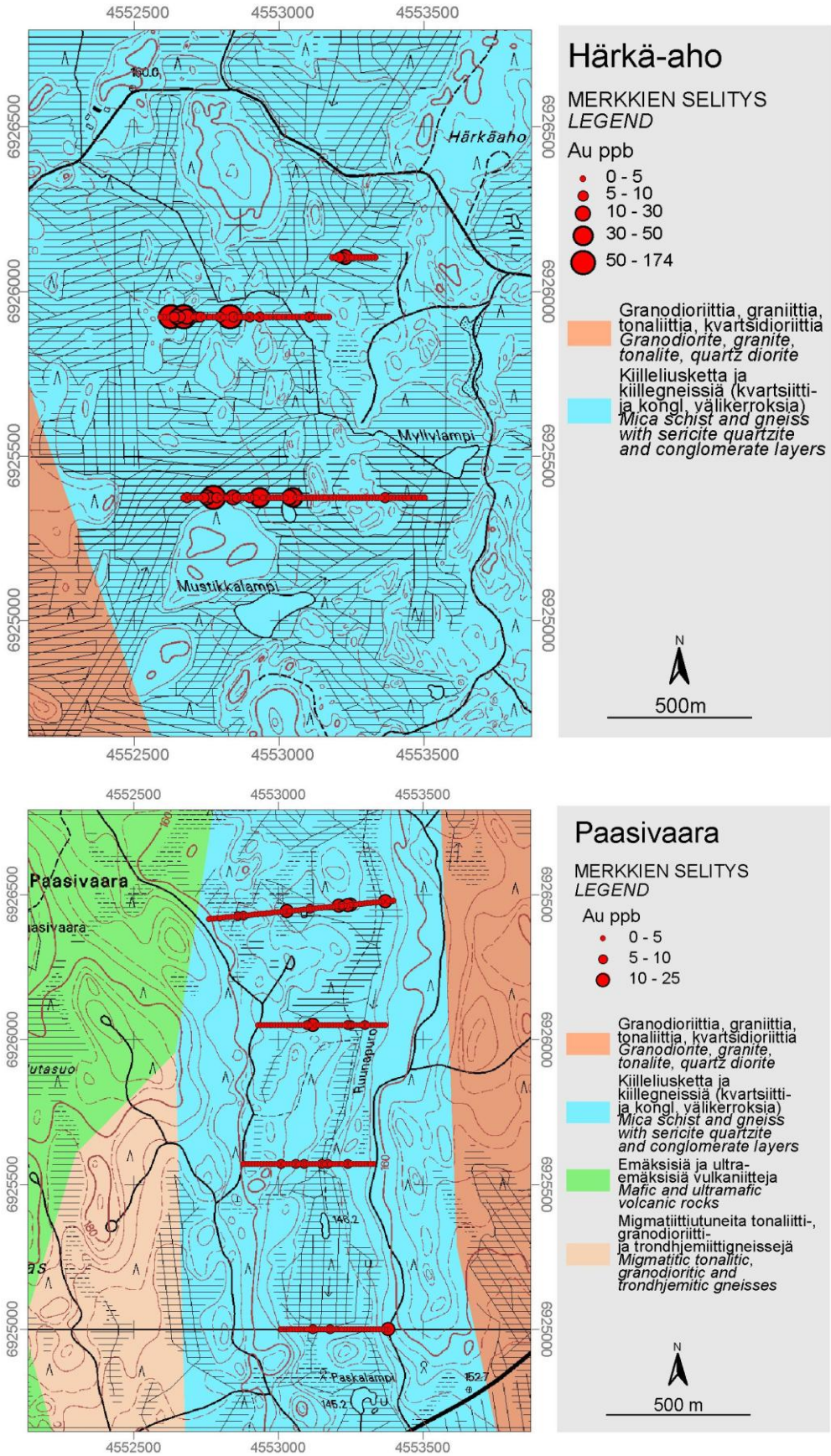


Fig. 3.4.5.3.4. Gold contents in till and weathered bedrock in the Rahalampi-Melavaara area, Kiihtelysvaara. Bedrock geology is based on the map of Lundqvist et al. (1996).



3.4.5.3.6. Gold contents in till and weathered bedrock at Paasivaara, Ilomantsi. Bedrock geology is based on the map of Lundqvist et al. (1996).

At Paasivaara (FIN_KKJ4 coordinates = 6925.535N, 4552.784E), within the southern part of the Hattu schist belt, a meter wide zone of rusty quartz rock occurred between mafic and felsic volcanic units, assaying Pb = 1.78 % , Zn = 1.51% and Ag = 23.8 ppm, but only 30 ppb Au. Further north, at Multikangas (locality 16/AAH/95, FIN_KKJ4 coordinates = 6932.040N, 4553.260E), cataclastic deformation zones in biotite tonalite contained 8 760 ppm Zn, 1 750 ppm Pb and was also weakly anomalous in gold (Au = 30 ppb).

Samples were collected from outcrops across the pyritic ore zone at Otravaara, at 3 meter intervals and were analyzed in groups of three with GFAAS and ICP. Gold contents remained below 10 ppb in all 8 analyses.

3.4.5.4.4. Outcrop and glacial boulder observations from the 1996 field season

A total of 111 bedrock and glacial boulder observations were made during the 199 field season. Gold and tellurium were analyzed from 108 samples, of which 66 represented bedrock chips, or samples obtained with a portable drill, and 42 were from glacial boulders; 21 of the boulder samples represented material from both the Kiihtelysvaara and Oskajärvi 1: 100 00 mapsheets areas submitted to GTK by members of the public. Some 35 samples were also analyzed using ICP.

An amphibolite with biotite alteration some distance to the north of Raatevaara (FIN_KKj4 coordinates 6923.60N, 4517.60E) contained moderate amounts of pyrite and some chalcopyrite and was also analyzed for gold, with two samples assaying 472 ppb and 486 ppb respectively. This area may warrant further evaluation, as indications of anomalous gold concentrations have been found over a distance of a few kilometers (Pekkarinen, 1977, Damstén, 1986).

Extensive areas of quartz veining were found at Havukkavaara (about 100m x 500 m, FIN_KKJ4 coordinates 6946.6N, 4508.2E), Saari (about 20 m x 30 m, coordinates 6936.95N, 4518.26E) and at Keskijärvi (about 1 m x 15 m, coordinates 6941.16N, 4514.83E). These vein netwoks are associated with relatively late brittle – ductile deformation zones that can be traced in a NW – SE direction for > 20 km. At Saari (FIN_KKJ4 coordinates 6396.97N, 4518.28E), the monzogranitic protolith is so strongly mylonitic that in places it resembles a finely banded felsic volcanic rock. None of the samples collected and analyzed from these quartz rocks contained gold at concentrations greater than regional background levels. Neither was anomalous gold found in samples taken from banded iron formations.

3.4.5.4.5. Whole-rock XRF analyses

A total of 13 XRF analyses were made from the Kiihtelysvaara area. Two of these analyses were from the narrow (0.5 – 1.0 m thick) felsic dykes intruding the metasediments at Kiukoinvaara (Table 3.4.5.4.5). One sample showed weakly anomalous Pb, Zn and As.

The mafic rocks that were analyzed, such as the pillow lavas northwest of Linnansuo, are Fe-tholeiitic in composition. One of the komatiitic samples analyzed (sample 10) had relatively high nickel, but low sulfur, which is indicative of nickel sequestration by silicate phase minerals. The same sample also apparently had rather high arsenic, but since sulfur contents are low, this may be an analytical error.

Table 3.4.5.4.5. Bedrock XRF analyses from the Kiihtelysvaara area (analyses not normalized).

		1	2	3	4	5	6	7	8	9	10	11	12	13
		FV	FV	ANDMS	ANDMS	Fe THOL	Fe THOL	MAF	BIF	BASKOM	KOM	KOM	TLS	CLS
SiO_2	%	66.8	69.0	70.0	64.1	51.0	49.2	47.1	53.7	46.0	42.3	39.6	60.5	36.8
Al_2O_3	%	17.6	16.6	12.7	17.0	13.7	13.8	14.8	5.2	9.1	2.5	3.6	0.9	12.0
Fe_2O_3	%	1.81	2.60	6.21	5.52	12.60	11.50	14.90	23.10	12.60	8.25	10.30	3.55	12.10
Na_2O	%	7.08	5.29	2.42	2.26	3.18	2.93	3.21	0.45	0.82	0.00!	0.00!	0.00!	0.00!
K_2O	%	1.67	0.89	0.94	2.21	0.15	0.50	0.22	0.09	0.17	0.003!	0.01	0.02	0.01
MgO	%	0.99	1.11	2.84	2.27	6.58	8.46	5.54	4.72	15.10	31.40	33.90	30.00	28.40
CaO	%	1.47	2.70	1.70	2.67	8.50	8.95	9.65	5.90	9.55	3.01	1.69	0.95	1.77
TiO_2	%	0.27	0.45	0.64	0.66	1.39	0.46	1.51	0.44	0.35	0.09	0.13	0.10	0.35
P_2O_5	%	0.15	0.13	0.09	0.06	0.11	0.03	0.13	0.11	0.03	0.007!	0.013!	0.04	0.03
MnO	ppm	310	360	820	1010	1690	2010	2340	2060	2310	1400	1500	590	1520
V	ppm	33	53	124	169	344	227	357	118	187	67	71	14!	163
Cr	ppm	39	41	231	198	142	158	149	69	1906	1456	2752	235	1428
Ni	ppm	22	16!	99	180	75	61	91	24	405	2388	1465	921	471
Cu	ppm	0!	0!	7	98	21	13!	13!	220	25	0!	50	0!	61
Zn	ppm	218	43	94	164	81	62	122	147	110	132	93	54	96
Sc	ppm	0!	0!	5!	13!	40	45	44	9!	39	8!	9!	0!	39
Ga	ppm	28	28	24	27	24	16!	19!	15!	14!	9!	9!	7!	16!
As	ppm	90	0!	1!	21!	6!	1!	4!	8!	11!	2180	10!	3!	8!
Rb	ppm	56	40	27	58	5!	17	2!	0!	14	0!	4!	0!	2!
Sr	ppm	328	425	175	195	109	227	170	8!	47	16	6!	6!	1!
Y	ppm	4!	7!	17	10!	26	13	31	17	6!	4!	4!	4!	2!
Zr	ppm	125	129	136	120	89	22	111	31	19	6!	6!	8!	26
Nb	ppm	4!	5!	5!	4!	5!	1!	6!	2!	0!	2!	2!	3!	2!
Mo	ppm	0!	0!	0!	0!	0!	0!	0!	0!	0!	0!	0!	0!	0!
Sn	ppm	0!	0!	0!	3!	2!	0!	5!	4!	4!	0!	0!	0!	5!
Sb	ppm	0!	0!	0!	0!	0!	0!	0!	0!	0!	7!	0!	0!	0!
Ba	ppm	604	304	283	669	49	106	51	29	53	14!	25	17!	35
La	ppm	13!	6!	11!	21!	7!	3!	12!	5!	11!	4!	2!	6!	0!
Ce	ppm	40	27!	27!	42	35	16!	30	16!	20!	10!	12!	12!	12!
Pb	ppm	269	69	24!	30!	15!	19!	12!	9!	18!	15!	18!	12!	10!
Bi	ppm	2!	0!	0!	0!	0!	3!	0!	4!	1!	4!	4!	3!	1!
Th	ppm	0!	4!	3!	9!	0!	0!	0!	0!	2!	0!	0!	0!	2!
U	ppm	0!	0!	0!	0!	0!	2!	0!	0!	0!	0!	0!	0!	0!
Cl	ppm	100	60!	60!	80	100	120	210	190	100	80	60!	30!	30!
S	%	0.04	0.00!	0.47	0.57	0.02	0.007!	0.01	1.75	0.009!	0.03	0.14	0.008!	0.02
C	%	0.03	0.09	<0.01	0.49	<0.01	0.01	<0.01	0.39	<0.01	0.88	0.31	0.05	<0.01

! = content is below detection limit, < = content is below the number shown

1. Felsic vein, x=6937.74, y=4519.00, Kiihtelysvaara, Kiukoinvaara
2. Felsic vein, x=6938.69, y=4518.48, Kiihtelysvaara, Kiukoinrimpi
3. Andalusite mica schist, x=6937.74, y=4519.00, Kiihtelysvaara, Kiukoinvaara
4. Andalusite mica schist, x=6937.92, y=4521.61, Tuupovaara, Kasarmikangas
5. Fe tholeiite, x=6939.33, y=4520.74, Kiihtelysvaara, Linnansuo-NW
6. Fe tholeiite, x=6935.73, y=4521.53, Tuupovaara, Koskutjoki
7. Mafic pillow lava, x=6939.33, y=4520.74, Kiihtelysvaara, Linnansuo-NW
8. Banded iron formation, x=6939.33, y=4520.74, Kiihtelysvaara, Linnansuo-NW
9. Basaltic komatiite, x=6939.23, y=4520.82, Kiihtelysvaara, Linnansuo-NW
10. Komatiite, x=6934.38, y=4517.97, Kiihtelysvaara, Jylmänniemi
11. Komatiite, x=6935.73, y=4521.53, Tuupovaara, Koskutjoki
12. Talc schist, x=6935.73, y=4521.53, Tuupovaara, Koskutjoki
13. Chlorite schist, x=6935.73, y=4521.53, Tuupovaara, Koskutjoki.

3.4.6 Data capture and storage

Data relating to surficial geological investigations have been recorded in Excel spreadsheet format, from which they can be readily extracted to other programs for further processing and interpretation. Geochemical data from outcrops and glacial boulders have also been tabulated in Excel format, and other outcrop data have been transferred from field data sheets to the database used in GTK. Gravity measurements are available from GTK as ASCII xyz files. Primary data from Slingram and magnetic surveys and the results of down-hole geophysical measurements are also archived and available on mapsheets at GTK.

3.4.7 Significant project results and conclusions

Investigations into the gold prospectivity of the greenstone belts of the Kiihtelysvaara area and the southern part of the Hattu schist belt between 1994 – 1996 began with an assessment of till geochemical data obtained during regional scale surveys in 1973 – 1974, and further analysis of Au and Te. Significant gold anomalies were found in till samples from both regions, which led to more detailed surveys in 1994 – 1996, aimed at more accurately defining bedrock sources of the anomalies. Weak gold enrichment in bedrock was sporadically found, but no indications of significant gold mineralization. The only area investigated that may warrant further evaluation is at Linnansuo, where contacts between greenstones and granitoids showed some evidence of gold enrichment.

Numerous bedrock outcrops were checked during 1994 – 1996, in order to evaluate previous evidence for gold enrichment, as well as searching for new indications. However, gold abundances in samples taken from outcrops proved to be very low, irrespective of whether host rocks were silicified quartz rocks, banded iron formations, Otravaara-type pyritic schists or other rock samples containing ore minerals. Kiukoinvaara was the only area where quartz veins, in a monzogranite cutting metasediments containing retrogressed andalusite, were found to contain not only anomalous gold, but also base metals.

The Kiukoinvaara gold occurrence is representative of the diversity and relatively limited degree of mineralization in the Kiihtelysvaara area. The area was subjected to a complex geological and structural history during Archean time, under ductile and brittle conditions. The latest Archean monzogranitic intrusions and pegmatites, as well as felsic dykes, porphyries and Paleoproterozoic mafic dykes, may have caused structural disruption of what might have previously been more coherent mineralization. In general, it seems that the greenstone belts in the Kiihtelysvaara area are unlikely to be prospective for gold.

The southern part of the Hattu schist belt was given less priority during the present project, partly due to the relatively poor exposure. Moreover, the thickness of glacial deposits made percussion drill sampling less effective than in areas of shallow overburden. There are at present no known reasons why the southern part of the Hattu schist belt would be inherently less prospective than the northern part, especially given the presence of gold mineralization still further south, across the Russian border. One notable difference between this area and the Kuusjärvi belt is the lack of abundant felsic dykes.

3.5. KUHMO – NURMES – LIEKSA REGION

3.5.1. Areas investigated

The main focus of research in the Kuhmo - Nurmes - Lieksa – region was systematic bedrock mapping of the Nurmes (FIN_KKJ 1: 100 00 mapsheet 4321) area, with a total of 4 100 outcrop observations. Field work was completed in 1999 and together with several hundred observations from surrounding area, data were transferred to the GTK bedrock geology databases during the year 2000, with the map and explanatory notes having been published in 2003 and 2005 respectively.

Exploration-related investigations were of a provisional nature, including glacial boulder tracing and limited till sampling in the Ruunaa area (Lieksa), after a boulder containing disseminated magnetite, chalcopyrite and pentlandite had been submitted to GTK by local prospector Onni Silvennoinen. Due to lack of resources and other priorities, no further follow-up investigations were undertaken in the area.

During 1997, the provenance of some boulders found along new forestry road networks were investigated, for they were identical in composition to the host rocks at the Tainiovaara nickel deposit, near Lieksa, yet glacial transport directions precluded Tainiovaara from being their source. However, it was soon established that aggregate spread on the forestry road was obtained from a gravel pit near Tainiovaara, and hence that the mineralized samples were indeed likely to have originated from the Tainiovaara deposit.

Gold investigations were also undertaken, particularly around the Sepponen occurrence, which is located at the municipal boundary between Lieksa and Kuhmo. Mineralization at Sepponen shares many features in common with the gold occurrences and mineralized boulders in the southern part of the Kuhmo greenstone belt, and is described in more detail in the following Section 3.5.1.1.

3.5.1.1. Gold mineralization at Sepponen

The Sepponen gold occurrence is situated outside the margins of the Kuhmo greenstone belt, some 32 km ESE of the town of Kuhmo on FIN_KKJ mapsheet 4324 08 (FIN_KKJ4 grid coordinates 7083.900N, 4488.850E). The first indications of mineralization in the area came from a sample submitted to GTK by a member of the public in 1992.

The Sepponen area is poorly exposed, but bedrock is characterized by Archean migmatites and granitoids intruding medium- to high grade amphibolites, mica gneisses and cordierite-anthophyllite rocks (Figures 3.5.1.1, 3hE and 3hF). The latter rock type is interpreted as tectonized and intensely hydrothermally altered relict mafic rocks correlative with the greenstone belt volcanics. Similar highly metamorphosed rocks are found some tens of kilometers to the southeast, across the Russian border, in the Tuulijärvi area, for which isotopic ages of 3 370 Ma – 3 130 Ma have been obtained (Kozhevnikov et al., 1987).

Systematic Slingram, magnetic and IP surveys were done over an area of about 0.5 km^2 at Sepponen. The gold anomaly is associated with a shear zone discernible as a weak Slingram quadrature component anomaly, and which is also marked by sporadically magnetic anomalies. IP chargeability at the same site is also rather weak.

Gold at Sepponen is paragenetically associated with arsenopyrite and a D_4 shear zone which deforms intensely altered amphibolites; quartz veins containing arsenopyrite are also present.

Channeled samples sawn from bedrock revealed elevated gold concentrations up to several ppm Au over an interval several centimeters in width. Similar minor occurrences have also been found elsewhere in the Kuhmo – Nurmes - Lieksa area but have not been investigated in detail.

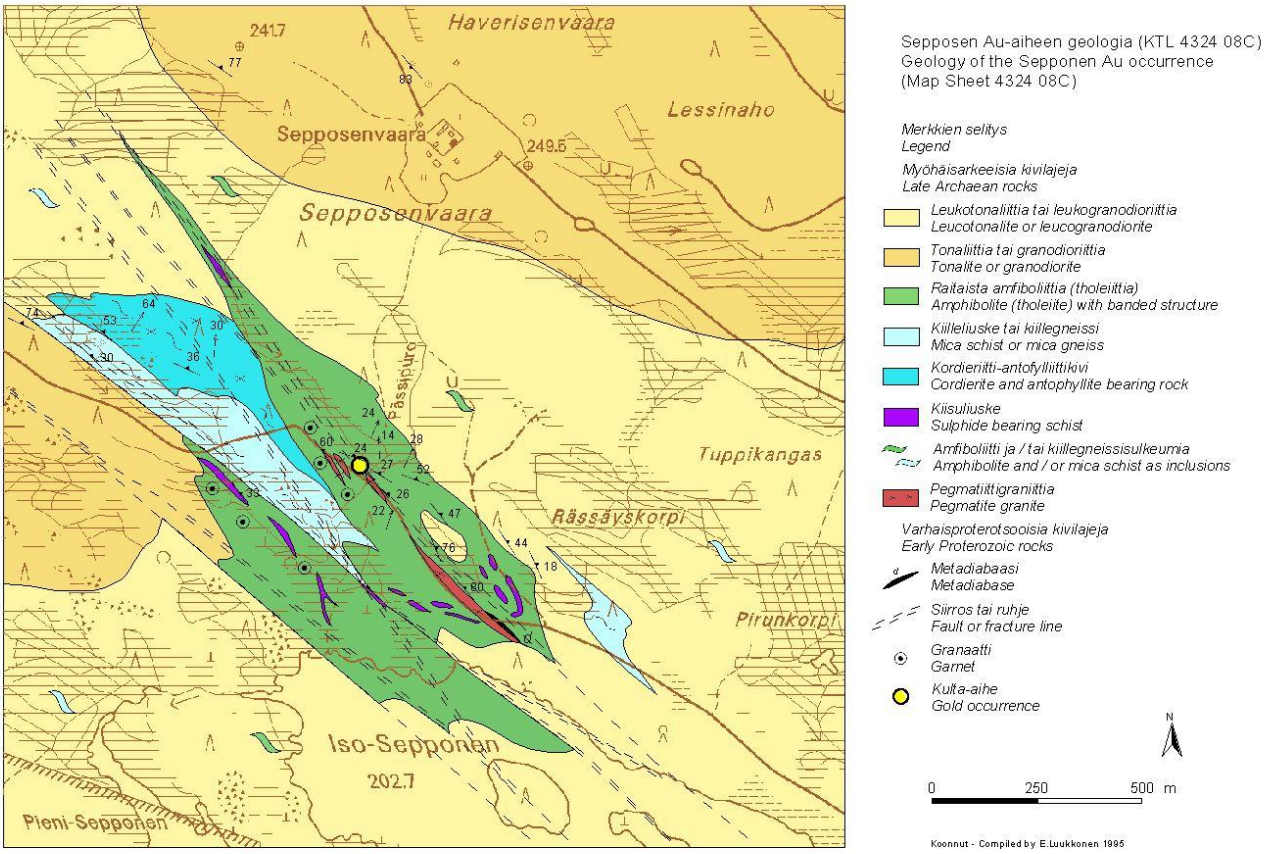


Fig. 3.5.1.1. Bedrock geology of the Sepponen gold prospect, Kuhmo.

3.5.2. Significant results

The most important research related to the project in the Kuhmo – Nurmes – Lieksa area was the completion of the Nurmes 1: 100 000 geological mapsheet and bedrock observations from adjacent areas.

Nickel and gold mineralization was identified in several places, but all occurrences were small in size and at low concentrations. Exploration should be directed preferentially at more extensive greenstone belts, at least until they have been thoroughly investigated, before investing time and effort into exploration within the adjacent higher grade granitoid and gneiss terrain. Detailed mapping and study of the Kuhmo – Nurmes – Lieksa region is nevertheless essential to obtaining a comprehensive understanding of Archean crustal evolution in Finland.

4. SUMMARY

This research program , investigating the Archean terrains of eastern Finland and their mineral potential, represented a new approach to research within GTK, in that prior to 1992, research had been organized within rather strictly defined specialist areas, such as geophysics, geochemistry or ore geology. Instead, this current project included acquisition, interpretation and synthesis of various types of data, leading to more effective collaboration within and between research groups. Inevitably, because the project goals were rather ambitious and the methodology new, not all objectives were fulfilled as originally planned.

At the same time, employee pay structure within GTK shifted towards providing bonus incentives, together with a requirement for greater accountability of project outcomes, on the basis of which further allocation of resources was determined. This was particularly necessary when defining priorities and targets for allocation of staff and resources for drilling and geochemical and geophysical surveys. A further significant development during the course of the research programs was the transition in reporting and archiving of data, from paper documentation to electronic databases.

Project management was mainly coordinated by researchers with practical experience working in the terrains of interest. Individual projects within the overall research program began with collation of existing geological data and revision of key areas, relevant to understanding Archean crustal evolution and mineralization potential. After this stage, it was possible to define areas for more detailed study and sampling, including geochemical and ground geophysical surveys, eventually leading to selection for drilling targets. From 1994 onwards, financial resources and capacity for drilling capacity increased significantly, as funding was reallocated from projects in northern Finland. However, progressive budget restrictions meant a general reallocation of priorities, with greater focus on the Suomussalmi greenstone belt, where some targets had already been reported and offered for public tender through the then Ministry of Trade and Industry. Some of the more important outcomes of the research program are described briefly below.

Perhaps the most significant outcome of the research program was the detailed mapping and documentation of the Suomussalmi greenstone belt, at either 1: 10 000 or 1: 20 000 scale, so that the overall level of data density and geological understanding is now comparable with that of the Kuhmo greenstone belt. A total of 2 119 outcrop observations were made and reported from the greenstone belt and its immediate surroundings, which when added to previous information, makes a total of 2 472 data entries for the Suomusalmi region. In the Kuhmo greenstone belt and surroundings, 662 observations were made during the present project, which results in a total of 9 619 bedrock observations in the GTK databases. A combined total of 12 091 bedrock observations were documented during the entire research program.

Systematic ground geophysical surveys were undertaken over a combined area of > 300 km^2 in the Suomussalmi, Kuhmo and Ilomantsi greenstone belts. Additional profiles were measured across selected targets and down-hole geophysical measurements were made in a number of drill holes. Ground geophysical surveys were important in defining and tracing potentially mineralized zones and in drilling target selection, while airborne geophysical data were particularly useful in mapping geological units and major structures, especially in poorly exposed terrain.

The primary purpose of till geochemical surveys and data interpretation were in identifying anomalous concentrations in till (and weathered bedrock) and attempting to define their extent and ultimate sources. Previous experience from geochemical surveys in the Hattu schist belt, which represents the eastern part of the Ilomantsi greenstone belt, indicated the effectiveness of systematic sampling along regularly spaced profiles for identifying potentially mineralized zones.

Once such prospective areas are defined, more detailed geochemical surveys can be made, in combination with ground geophysics and reconnaissance POKA drilling profiles.

Another direct outcome of the geochemical mapping program is the availability of an extensive and validated geochemical database covering the greenstone belts of eastern Finland, which can also be used in environmental monitoring and research applications.

A number of major deformation zones that were evidently critical in localization of gold mineralization were found during bedrock and till geochemical mapping of the Suomussalmi greenstone belt; the Moukkori, Pahkosuo, Kuikkapuro and Syrjälä gold occurrences all lie within or close to such zones, characterized by structurally controlled hydrothermal alteration and brittle-ductile vein networks. Similarly, a prominent deformation zone that almost bisects the Kuhmo greenstone belt from north to south is closely associated with gold mineralization at Tammasuo, Palovaara, Timola, Iso Aittojärvi, Pieni Aittojärvi, Jousijärvi, Mujesuo and Louhiniemi. The Lokkiluoto gold showing in lake Ontojärvi, previously investigated by Kajaani Oy, was also examined in further detail. Therefore, there is abundant evidence for widespread structurally controlled transport of gold-bearing hydrothermal fluids in both the Suomussalmi and Kuhmo greenstone belts and further exploration is clearly justified.

The main priority in relation to potential komatiite-hosted nickel mineralization was in the Saarikylä area within the Suomussalmi greenstone belt. As a result, a better understanding was gained concerning the distribution and internal structure of komatiitic cumulate sequences. A significant outcome of investigations in the Saarikylä area was discovery of the Kauniinlampi and Vaara disseminated nickel sulfide occurrences, both of which occur komatiitic cumulates and both of which show additional enrichment in platinum-group elements. However, massive sulfide deposits have not yet been found. Nickel exploration in the Kuhmo greenstone belt was restricted to the areas around Teerisuo, Sika-aho, Naurispuro and Kellojärvi. With the exception of the Sika-aho occurrence, there was little incentive for further evaluation, although the Kuhmo greenstone belt as a whole is still considered highly prospective for komatiite-hosted nickel mineralization.

5. ACKNOWLEDGMENTS

The success of the project depended on the dedication and skills of many people, both in the bedrock mapping and mineral resources group, as well as other GTK technical staff in the laboratory and in the field. We are especially grateful to Hannu Huhma and Irmeli Mänttäri and to the memory of the late Matti Vaasjoki for isotopic dating of samples and for their assistance in writing and checking the relevant sections in the report. Numerous discussions with Professor Heikki Papunen (University of Turku) and Robin Hill (CSIRO Exploration and Mining, Perth, Australia), particularly with respect to komatiitic volcanism and mineralization, were very instructive in developing the research program. Peter Sorjonen-Ward and the late Seppo Lavikainen also provided useful background information on the Hattu schist belt and Ilomantsi region in general. We are also grateful to Peter Sorjonen-Ward for translating this manuscript to English.

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We extend our sincere thanks to all of these people, and to others who have nor been named but who have provided invaluable help in various ways.

6. REFERENCES

Aravanis, T. 1995. Down hole IP surveys at Honeymoon Well, CRAE Report No 20945 (CRA Exploration Pty Ltd). 27 p.

Aurola, E. 1954. The mines and quarries of Finland. Geotekn. Julk. 55, 1 - 123.

Aurola, E. 1955. Über die Geschiebevertrachtung in Nordkarelien. Acta Geographica 14, 32 – 52; also Geotekn. Julk. 56.

Aurola, E. & Vähätalo, V. 1939. The pyrite deposit of Hevoskumpu in Tuupovaara. Bull. Comm. Géol. Finlande 125, 87 - 95.

Barnes, S.J., Coats, C.J.A. & Naldrett, A.J. 1982. Petrogenesis of a Proterozoic Nickel Sulfide-Komatiite Association: the Katiniq Sill, Ungava, Quebec. Econ. Geol. 77, 413 - 429.

Barnes, S.J., Boyd, R., Korneliussen, A., Nilsson, L-P., Often, M., Pedersen, R.B. & Robins, B. 1988. The use of mantle normalization and metal ratios in discriminating between the effects of partial melting, crystal fractionation and sulphide segregation on platinum-group elements, gold, nickel and copper: examples from Norway. In: Prichard, H.M., Potts, P.J., Bowles, J.Fw. & Cripp, S.J. (eds) Geoplatinum. Elsevier, London, 113 - 143.

Blais, S. 1989. Les ceintures de roches vertes archèennes de Finlande Orientale: Gèologie, pètrologie, gèochimie et èvolution gèodynamique. Mèmoires et Documents du Centle Armoricain d´Ètude Structurale des Socles, Rennes, 22. Universitè de Rennes, 256 p.

Björklund, A. & Gustavsson, N. 1987. Visualization of geochemical data on maps: New options. Journal of Geochemical Exploration 29, 89 - 103.

Bornhorst, Th.J. & Rasilainen, K. 1993. Mass transfer during hydrothermal alteration associated with Au mineralization within the late Archean Hattu schist belt, Ilomantsi, eastern Finland. In: Nurmi, P.A. & Sorjonen-Ward, P. (eds) 1993. Geological development, gold mineralization and exploration methods in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 273 - 289.

Bornhorst, Th.J., Rasilainen, K. & Nurmi, P.A. 1993. Geochemical character of lithologic units in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. In: Nurmi, P.A. & Sorjonen-Ward, P. (eds) 1993. Geological development, gold mineralization and exploration methods in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 133 - 145.

Bowes, D.R. 1976. Archean crustal history in the Baltic Shield. In: Windley B.E. (ed.) 1976. The Early History of the Earth. Wiley, New York, 481 - 488.

Butt, C.R.M. & Nickel, E.H. 1981. Mineralogy and geochemistry of the weathering of the disseminated nickel sulfide deposit at Mt. Keith, Western Australia. Econ. Geol. 76, 1736 - 1751.

Chernet, T. 1994. Ore mineralogy of the Moukkori Gold prospect. Geological Survey of Finland, unpublished report M19/4513/94/1/42. 16 p.

Damstén, M. 1986. Tutkimusselostus Kiihtelysvaaran kunnassa valtausalueella Viesimo 1, kaiv. rek. n:o 3489/1 suoritetuista malmitutkimuksista. Geological Survey of Finland, unpublished report M06/4241/83/1/10. 5 p., 7 app. (in Finnish)

Damstén, M. 1989. Enon Kuusjärvellä Otravaaran rikkikiisumalmin E- ja NE-puolisilla alueilla tehdyt moreenigeokemialliset tutkimukset 1984 - 1985. Geological Survey of Finland, unpublished report M19/4241/89/1/10. 2 p. (in Finnish)

Damstén, M. 1990. Tutkimustyöselostus Ilomantsin kunnassa valtausalueilla Kuittila 1 - 3, kaiv.rek.n:ot 3808 ja 3956 suoritetuista tutkimuksista. Geological Survey of Finland, unpublished report M06/4244/90/1/10. 8 p., 5 app. (in Finnish)

Damstén, M., Hartikainen, A., Koistinen, E. & Nurmi, P.A. 1994a. Tutkimustyöselostus Ilomantsin kunnassa valtausalueilla Muurinsuo (kaivosrekisterinro 4273/1), Korvilansuo 1 (4165/1), Kelokorpi 1 (4165/2), Palosuo (5027/1), Muurinsuo 2 (5359/1), Muurinsuo 3 (5359/2) sekä valtausvarausalueilla Elinsuo (156/93), Kiimasuo (156/93) ja Viinivaara (25/94) suoritetuista kultamalmitutkimuksista vuosina 1984 - 1993. Geological Survey of Finland, unpublished report M06/4244/94/1/10. 15 p., 3 app. (in Finnish)

Damstén, M., Nurmi, P.A., Sorjonen-Ward, P. & Hartikainen, A. 1994b. Tutkimustyöselostus Ilomantsin kunnassa valtausalueilla Pampalo 1 (kaivosrekisterinro 4847/1), Pampalo 2 (kaivosrekisterinro 5055/1) ja Pampalo 3 (kaivosrekisterinro 5090/1) suoritetuista kultamalmitutkimuksista vuosina 1990 - 1993). Geological Survey of Finland, unpublished report CM06/4333/94/1/10. 37 p., 1 app. (in Finnish)

Diez, G. & Engel, W. 1989. A review of the Ala-Luoma Ag-Zn deposit in the Suomussalmi Greenstone Belt, eastern Finland, related to an Archean rift model. In: Fifth meeting of the European Union of Geosciences, Strasbourg, 20 - 23 March 1989. Terra abstracts 1 (1), 126 - 127.

Elo, S. 1997. Interpretation of the Gravity Anomaly Map of Finland. Geophysica 33 (1), 51 - 80.

Engel, W. & Diez, G-J. 1989. A modified stratigraphy and tectono-magmatic model for the Suomussalmi Greenstone Belt, eastern Finland, based on the re-mapping of the Ala-Luoma area. Bulletin of the Geological Society of Finland 61 (2), 143 - 160.

Frosterus, B. 1920. Suomen geologinen yleiskartta1:400 000, maalajikartta, lehti D3, Joensuu. Geological Map of Finland 1:400 000, the map of Quaternary deposits, sheet D3, Joensuu. Geological Survey of Finland.

Frosterus, B. & Wilkman, W.W. 1917. Suomen geologinen yleiskartta 1: 400 000, maalajikartan selitys, lehti D3, Joensuu. Geological Map of Finland 1:400 000, explanation to the map of Quaternary deposits, sheet D3, Joensuu. Geological Survey of Finland. 153 p. (in Finnish)

Frosterus, B. & Wilkman, W.W. 1920. Suomen geologinen yleiskartta 1: 400 000, vuorilajikartan selitys, lehti D3, Joensuu. Geological Map of Finland 1:400 000, explanation to the map of Pre-Quaternary rocks, sheet D3, Joensuu. Geological Survey of Finland. 189 p. (in Finnish)

Frosterus, B. & Wilkman, W.W. 1924. Suomen geologinen yleiskartta1:400 000, vuorilajikartta, lehti D3, Joensuu. Geological Map of Finland 1:400 000, the map of Pre-Quaternary rocks, sheet D3, Joensuu. Geological Survey of Finland.

Gaál, G. & Gorbatschev, R. 1987. An Outline of the Precambrian Evolution of the Baltic Shield. Precambrian Research 35, 15 - 52.

Gaál, G., Mikkola, A. & Söderholm, B. 1978. Evolution of the Archean crust in Finland. Precambrian Research 6, 199 - 216.

Galley, A.G. 2001. Mineralization in Archaean volcanic belt. In: K.F. Cassidy, J.M. Dunphy and M.J. Van Kranendonk (eds) 4th International Archaean Symposium 24 - 28 September, Perth, Western Australia. Extended Abstracts. AGSO - Geoscience Australia Record 2001/37, 11 - 13.

Groves, D.I., Barrett, F.M. & Brotherton, R.H. 1983. Exploration significance of chrome-spinels in mineralized ultramafic rocks and nickel-copper ores. Geol. Soc. S. Afr., Spec. Publ. 7, 21 - 30.

Groves, D.I. & Keays, R.R. 1979. Mobilization of ore-forming elements during alteration of dunites, Mt Keith - Betheno, Western Australia. Can. Mineral. 17, 373 - 389.

Cruau, G., Tourpin, S., Fourcade, S. & Blais, S. 1992. Loss of isotopic (Nd, O) and chemical (REE) memory during metamorphism of komatiites: new evidence from eastern Finland. Miner. Petrol. 112, 66-82.

Gustavsson, N., Noras, P., & Tanskanen, H. 1979. Seloste geokemiallisen kartoituksen tutkimusmenetelmistä. Summary: Report on geochemical mapping methods. Geol. Surv. Finland, Rep. Invest. No 30, 20 p.

Halkoaho, T., Koistinen, E., Luukkonen, E., Niskanen, M., Pietikäinen, K. & Tenhola, M. 2000. The Vaara - Kauniinlampi Komatiitic Nickel Prospects in Suomussalmi, Eastern Finland (register numbers of claims 5376/1, 5376/2, 5789/1, 5789/2, 6171/1, 6271/1, 6273/1, 6676/1, 6770/1 and 6938/1). Geological Survey of Finland, unpublished report CM06/4513-4514/2000/1. 37 p., 1 app.

Halkoaho, T., Liimatainen, J., Papunen, H. & Välimaa, J. 1996. Komatiittiprojektin loppuraportti 1a, University of Turku, 99 p. (in Finnish)

Halkoaho, T., Liimatainen, J., Papunen, H. & Välimaa, J. 1997. Cr-rich basalts in komatiitic volcanic association of the Archaean Kuhmo greenstone belt, Finland: Evidence for reducing conditions during magma generation. In: Papunen H. (ed.) Mineral Deposits: Research and Exploration Where do They Meet? Balkema, Rotterdam, 431 - 434.

Halkoaho, T., Liimatainen, J., Papunen, H. & Välimaa, J. 2000. Exceptionally Cr-rich basalts in the komatiitic volcanic association of the Archaean Kuhmo greenstone belt, eastern Finland. Miner. Petrol. 70, 105 - 120.

Halkoaho, T., Luukkonen, E., Niskanen, M. & Pietikäinen, K. 1999. Mobilized Ni-mineralization of the Kauniinlampi komatiite cumulate complex in the Archaean Suomussalmi greenstone belt, Finland. In: Precambrian rift formation, magmatism, metallogeny: correlation of geological complexes in Fennoscandia: proceedings of the international conference, Petrozavodsk 1999. Petrozavodsk: Karelian Research Centre, RAS, 174 - 175.

Halkoaho, T., Niskanen, M. & Tenhola, M. 2001a. Tutkimustyöselostus Suomussalmen kunnassa valtausalueella Kuohunsuo 1 (kaivosrekisterinumero 5470/1) suoritetuista kulta- ja

nikkelimalmitutkimuksista vuosina 1995 - 1997. Geological Survey of Finland, unpublished report M06/4511/2001/1/10. 10 p. (in Finnish)

Halkoaho, T., Niskanen, M. & Tenhola, M. 2001b. Tutkimustyöselostus Kuhmon kaupungissa valtausalueilla Naurispuro 1 ja 2 (kaivosrekisterinumerot 6503/1 ja 6503/2) suoritetuista kulta- ja nikkelimalmitutkimuksista vuosina 1997 - 1999. Geological Survey of Finland, unpublished report M06/4412/2001/4/10. 10 p. (in Finnish)

Hanski, E. 1984. Geology of the gabbro-wehrlite association in the eastern part of the Baltic Shield. Arkeeisten alueiden malmiprojekti, report 20. University of Oulu. 78 p.

Hanski, E. 1986. The Gabbro-Wehrlite Association in the Eastern Part of the Baltic Shield. In: Friedrich, G.H., Genkin, A.D., Naldrett, A.J., Ridge, J.D., Sillitoe, R.H., and Vokes, F.M. (eds) Geology and Metallogeny of Copper Deposits. Proceedings of the Copper Symposium 27th International Geological Congress Moscow, 1984. Special Publication No. 4 of the Society for Geology Applied to Mineral Deposits. Springer-Verlag, Berlin Heidelberg, 151 - 170.

Harris, J.F. 1981. Sampling and analytical requirements for effective use of geochemistry in exploration for gold. In: Levinson, A.A. (ed.) 1981. Precious metals in the Northern Cordillera. Proc.Symp.13. - 15.4.1981 Vancouver, British Columbia, Canada, 53 - 67.

Hartikainen, A. 1987. Geochemical prospecting for gold in Ilomantsi, Finland. In: Gold '87: program and abstracts, Turku, Finland, May 12 - 13, 1987. Turun yliopiston geologian ja mineralogian osaston julkaisuja, University of Turku. Opintomoniste 19, 25.

Hartikainen, A. 1993. Moreenigeokemian käytöstä kullanetsinnässä, esimerkkinä Ilomantsin tutkimukset. In: Haapala, I., Hyvärinen, L. & Salonsaari, P. (eds) 1993. Malminetsinnän menetelmät. Helsinki: Yliopistopaino, 106 - 122. (in Finnish)

Hartikainen, A. 2001. Tutkimustyöselostus Kuhmon kaupungin Härmänkylässä sijaitsevan valtauksen Timola 1 (kaivosrekisterinumero 5451/1) alueella tehdyistä kultatutkimuksista. Geological Survey of Finland, unpublished report M06/4412/2001/1/10. 10 p., 1 app. (in Finnish)

Hartikainen, A. & Damstén, M. 1991. Application of till geochemistry to gold exploration, Ilomantsi, Finland. Journal of Geochemical Exploration 39 (3), 323 - 342.

Hartikainen, A., Kontas, E. & Salminen, R. 1983. Kultasormuksen aiheuttama kontaminaatio. Geologi 35 (8), 132. (in Finnish)

Hartikainen, A. & Niskanen, M. 2001. Maaperägeokemialliset kultatutkimukset Hatun liuskejaksolla Ilomantsissa vv. 1983 - 1995. Geological Survey of Finland, unpublished report S/41/4244/1/2001, 24 p., 40 app. (in Finnish)

Hartikainen, A. & Nurmi, P.A. 1993. Till geochemistry in gold exploration in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. In: Nurmi, P.A. & Sorjonen-Ward, P. (eds) Geological development, gold mineralization and exploration methods in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 323 - 352.

Heino, T. 1995. Raportti valtausalueilla Palo 1 - 3, kaivosrekisterinumerot 4351/1, 4351/2 ja 4351/3 vuosina 1988 - 1993 suoritetuista tutkimuksista. Geological Survey of Finland, unpublished report M06/4412/95/1/10. 8 p. (in Finnish)

Heino, T. 1998. Hyrynsalmi, Puistola 1 (kaivosrekisteri N:o 5657/1) ja Paatola 1 (kaivosrekisteri N:o 5619/1) nikkeliesiintymän mineraalivarantoarvio. Geological Survey of Finland, unpublished report M19/4421/98/1/10. 33 p. (in Finnish)

Heino, T. 2000. Mineral Resource Assessment of the Kuikkapuro 1 (mine.reg. N:o 6748/1), Kuikkapuro 2 (N:o 6841/1), Kuikkapuro 3 (N:o 6880/1), Kuikkapuro 4 (N:o 6880/2) and Kuikkapuro 5 (N:o 6912/1) gold mineralization, Geological Survey of Finland, report CM19/4511/2000/1 (associated with report CM06/4511/2000/1).

Heino, T. 2001. Mineral Resource Assessment of the Pahkosuo gold mineralization, claims Pahkosuo (mine reg. N:o 5621/1), Pahkosuo 2 (N:o 6272/1), Pahkosuo 3 (N:o 6272/2) and Pahkosuo 4 (N:o 6410/1). Geological Survey of Finland, unpublished report M19/4513/2001/1. 3 p., 19 app.

Heino, T., Hartikainen, A., Koistinen, E. & Niskanen, M. 1995a. Tutkimustyöselostus Ilomantsin kunnassa valtausalueilla Sivakko 1 (5188/1), Korpilampi 1 - 2 (5402/1-2), Korpi 1 - 4 (5356/1-4), Kuivisto 1 (5210/1), Kuivisto 2 - 3 (5356/5-6), Pihlajavaara 1 - 2 (5511/2-3) ja Valkeasuo 1 - 2 (4853/1, 5511/1) suoritetuista kultamalmitutkimuksista vuosina 1992 - 1995 sekä neljältä vireillä olevalta valtaukselta (Sivakko 2 - 3 ja Valkeasuo 3 - 4). Geological Survey of Finland, unpublished report M06/4333/95/1/10.

Heino, T., Hartikainen, A. & Koistinen, E. 1995b. Ilomantsin Pampalon vyöhykkeen kulta-aiheiden syväkairaustulokset ja moreenigeokemialliset kartat (Hatun liuskejakso). Geological Survey of Finland, associated with report M06/4333/95/1/10.

Heino, T. & Kilpelä, M. 1995. Tutkimustyöselostus valtausalueella Lokki 1, kaivosrekisterinumero 4969/1 suoritetuista tutkimuksista. Geological Survey of Finland, unpublished report M06/4413/1995/1/10. 5 p. (in Finnish)

Heino, T. & Koistinen, E. 1997. Suomussalmi, Housuvaara 1 ja Pahkalampi 1. Kultaesiintymien mineraalivarantoarvio. Geological Survey of Finland, unpublished report M19/4513/97/1/10. 82 p. (in Finnish)

Hintikka, V., Laukkanen, J. & Leppinen, J. 1999. Preliminary concentration tests of Archaean komatiite hosted nickel sulphide ore in Vaara, Suomussalmi, eastern Finland. Research Report No.KET 4026/99. VTT, Chemical Techonlogy, Mineral Processing. 13 p., 10 app.

Huhta, P. 1989. Heavy minerals of till in gold prospecting in the Hattu schist belt, Ilomantsi, eastern Finland. In: Autio, S. (ed.) Geological Survey of Finland, Current Research 1988. Geological Survey of Finland, Special Paper 10, 59 - 60.

Huhta, P. 1993. The use of heavy mineral concentrates from till in gold exploration in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. In: Nurmi, P.A. & Sorjonen-Ward, P. (eds) Geological development, gold mineralization and exploration methods in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 363 - 372.

Hyppönen, V. 1973. Suomen geologinen kartta 1:100 000, kallioperäkartta. Lehti 4412, Hiisijärvi. Geological Map of Finland 1:100 000, Pre-Quaternary rocks, sheet 4412, Hiisijärvi. Geological Survey of Finland.

Hyppönen, V. 1976. Suomen geologinen kartta 1:100 000, kallioperäkartta. Lehti 4411, Ontojoki. Geological Map of Finland 1:100 000, Pre-Quaternary rocks, sheet 4411, Ontojoki. Geological Survey of Finland.

Hyppönen, V. 1978. Suomen geologinen kartta 1:100 000, kallioperäkartta. Lehti 4413, Kuhmo. Geological Map of Finland 1:100 000, Pre-Quaternary rocks, sheet 4413, Kuhmo. Geological Survey of Finland.

Hyppönen, V. 1983. Ontojoen, Hiisijärven ja Kuhmon kartta-alueiden kallioperä, Suomen geologinen kartta 1:100 000, kallioperäkartan selitys. Lehdet 4411, 4412 ja 4413. Summary: Pre-Quaternary rocks of the Ontojoki, Hiisijärvi, and Kuhmo map-sheet areas. Geological Map of Finland 1:100 000, explanation to the maps of Pre-Quaternary rocks, sheets 4411, 4412 and 4413. Geological Survey of Finland. 60 p.

Irvine, T.N. 1982. Terminology for layered intrusions. Journal of Petrology 23, 127 - 162.

Jahn, B-M., Auvray, B., Blais, S., Capdevila, R., Cornichet, J., Vidal, F. & Hameurt, J. 1980. Trace element geochemistry and petrogenesis of Finnish greenstone belts. Journal of Petrology 21, 201 - 244.

Johanson, B. & Kojonen, K. 1989. Ore mineralogy of gold occurrences in the Hattu schist belt, Ilomantsi, eastern Finland. In: Autio, S. (ed.) Geological Survey of Finland, Current Research 1988. Geological Survey of Finland, Special Paper 10, 49 - 52.

Johanson, B., Törnroos, R. & Kojonen, K. 1991. Thallian silver telluride from the Korvilansuo gold prospect in the Archaean Hattu schist belt, Ilomantsi, eastern Finland. In: Autio, S. (ed.) Geological Survey of Finland, Current Research 1989-1990. Geological Survey of Finland, Special Paper 12, 91 - 96.

Juvonen, R. 1999. Analysis of Gold and Platinum group elements in geological samples. Academic Dissertation. Geological Survey of Finland, Espoo, 83 p.

Kauranne, L.K. 1975. Regional geochemical mapping in Finland. In: Jones, M.J. (ed.) Prospecting in Areas of glaciated Terrain, Inst. Min. Metall, London, 71-81.

Keays, R.R. 1982. Palladium and iridium in komatiites and associated rocks: application to petrogenetic problems. In: Arndt, N.T. & Nisbet, E.G. (eds) Komatiites. George Allen & Unwin, London, 435 - 457.

Kesola, R. 1998. Enon kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Eno map-sheet area. Geological Map of Finland 1:100 000, Explanation to the Maps of Pre- Quaternary Rocks, Sheets 4242. Geological Survey of Finland. 40 p.

Käpyaho, A. 2007. Archaean crustal evolution in eastern Finland: New geochronological and geochemical constraints from the Kuhmo terrain and the Nurmes belt. Geological Survey of Finland, Special Publications 63 (Ph.D thesis). 20[97] p. + 1 app.

Koistinen, E. & Halkoaho, T. 2000. Mineral Resource Assessment of the Vaara Nickel Occurrence. Geological Survey of Finland, unpublished report CM19/4513/2000/1. 10 p., 3 app.

Kojonen, K.K. 1981. Geology, geochemistry and mineralogy of two Archean nickel-copper deposits in Suomussalmi, eastern Finland. Geological Survey of Finland, Bulletin 315. 58 p.

Kojonen, K., Johanson, B., O'Brien, H.E. & Pakkanen, L. 1993. Mineralogy of gold occurrences in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. In: Nurmi, P.A. & Sorjonen-Ward, P. (eds) Geological development, gold mineralization and exploration methods in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 233 - 271.

Kojonen, K., Johanson, B. & Pakkanen, L. 1994. Three new telluride minerals from Archean gold deposits in the Hattu schist belt, Ilomantsi, eastern Finland. In: International Mineralogical Association 16th general meeting, 4 - 9 September 1994, Pisa, Italy. Abstracts. Pisa: Societé Italiana di Mineralogia e Petrologia, 209-210.

Kojonen, K., Johanson, B. & Pakkanen, L. 1995. Telluride mineralogy of Archean gold deposits in Ilomantsi greenstone belt, eastern Finland. In: Eötvös Workshops in Science: advanced studies in ore mineralogy 95, July 9 - 14, 1995, Budapest, Hungary. Programme and abstracts. Budapest: Eötvös Loránd University, 20.

Kojonen, K., Pakkanen, L. & Johansson, B. 1996. Kullan esiintyminen Suomussalmen Pahkalammen kultamalmiaiheessa. Geological Survey of Finland, unpublished report M42.4/4513/-96/1. 13 p. (in Finnish)

Kontas, E. 1981. Rapid determination of gold by flameless atomic absorption spectrometry in the ppb and ppm ranges without organic solvent extraction. Atomic Spectroscopy 2 (2), 59 - 61.

Kontas, E. 1991. Gold contamination of the fine fraction of till during sampling and sample preparation. In: Björklund, A. (ed.) Gold geochemistry in Finland. Journal of Geochemical Exploration 39 (3), 289 - 294.

Kontas, E. 1993a. Determination of gold and palladium by aqua regia digestion, stannous chloride-mercury coprecipitation and flameless atomic absorption. In: Kontas, E. (ed.) Analytical methods for determining gold in geological samples. Geological Survey of Finland, Report of investigation 114, 29 - 32.

Kontas, E. 1993b. Analytical methods for determining gold in geological samples. In: Kontas, E. (ed.) Analytical methods for determining gold in geological samples. Geological Survey of Finland, Report of investigation 114, 5 - 11.

Kontas, E., Niskavaara, H. & Virtasalo, J. 1987. Flameless Atomic Absorption Determination of Gold and Palladium in Geological Reference Samples. Geostandards Newsletter 10 (2), 169 - 171.

Kontinen, A. 1990. The Nurmes paragneiss belt – a major metasedimentary unit within the late Archaean terrain of eastern Finland. Abstracts in second symposium on the Baltic Shield, with workshop on correlation with Laurentia. Lund, Sweden, June 5 - 7, ILP/IGCP-275, 55.

Kontinen, A. 1991. Evidence for significant paragneiss component within the late Archaean Nurmes gneiss complex, eastern Finland. In: Autio, S. (ed.) Geological Survey of Finland, Current Research 1989 – 1990. Geological Survey of Finland, Special Paper 12, 17 - 19.

Kontinen, A. & Paavola, J. 2006. A preliminary model of the crustal structure of the eastern Finland Archaean Complex between Vartius and Vieremä, based on constrains from surface geology and FIRE 1 seismic survey. In: Kukkonen, I.T. & Lahtinen, R. (eds) Finnish Reflection Experiment FIRE 2001-2005. Geological Survey of Finland, Special Paper 43, 223 - 240.

Kontinen, A., Paavola, J. & Lukkarinen, H. 1992. K-Ar ages of hornblende and biotite from Late Archaean rocks of eastern Finland – interpretation and discussion of tectonic implications. Geological Survey of Finland, Bull. 365. 31 p, 1 app.

Kopperoinen, T. 1987. Kuhmon liuskejakson Ag-esiintymien geokemiallisista tutkimuksista. Geologi 39, 69 - 73. (in Finnish)

Kopperoinen, T. & Tuokko, I. 1988. The Ala-Luoma and Taivaljärvi Zn-Pb-Ag-Au deposits, eastern Finland. In: Marttila, M. (ed.) Archaean geology of the Fennoscandian Shield: proceedings of a Finnish-Soviet symposium in Finland on July 28 - August 7, 1986. Geological Survey of Finland. Special Paper 4, 131 - 144 .

Korhonen, J. 1993. FINMAG, vers 2.0. The Aeromagnetic Map of Finland 1:2 000 000. Geological Survey of Finland, Otaniemi.

Korsman, K., Koistinen, T., Kohonen, J., Wennerström, M., Ekdahl, E., Honkamo, M., Idman, H. & Pekkala, Y. (eds) 1997. Bedrock map of Finland 1:1 000 000. Geological Survey of Finland, Espoo.

Kotslovskaya, E. & Yliniemi, J. 1999. Deep Structure of the Earth's Crust Along the SVEKA Profile and its Extention to the North-East. Geophysica 35, 111 - 123.

Kouvo, O. & Tilton, G.R. 1966. Mineral ages from the Finnish Precambrian. J.Geol. 74, 421 - 442.

Kozhevnikov, V.N., Chukhonin, A.P. & Shulesko, I.K. 1987. Asynchronous high-temperature metamorphism of oldest rocks in Western Karelia. Transactions (Doklady) of the USSR Academy of Sciences, Earth Science Sections 292, 1441 - 1445.

Kranck, E.H. 1945. The molybdenum deposit at Mätäsvaara in Carelia (E-Finland). Geol.Fören. I Stockholm, Förh. 67, 325 - 350.

Kurimo, H. 1982. Ice-lobe formation and function during the deglaciation in Finland and adjacent Soviet Karelia. Boreas 11, 59 - 78.

Kurimo, M. & Airo, M-L. 2001. Lentogeofysiikan käyttö kohteellisissa tutkimuksissa. Sovelletun Geofysiikan XIII Neuvottelupäivät, Silja Serenade, 2. - 4.10.2001. Extended abstracts. Vuorimiesyhdistys. Sarja B 78, 11.

Kurki, J. 1980. Suomussalmen Aittojärven Mo-esiintymä. Geologi 32, 94. (in Finnish)

Kurki, J. 1989. Granitoids and Mo -mineralization in Aittojärvi. In: Gaál, G. (ed.) Archean granitoids and associated Mo, W and Au mineralization in eastern Finland. Geological Survey of Finland, Guide 25, 16 - 18.

Laitakari, A. 1937. Suomen malmit, hyödylliset mineraalit, kivet ja maalajit. Geotekn. Julk. 42, 160 p. (in Finnish)

Laiti, I. 1983. Suomen geologinen kartta 1:100 000, kallioperäkartta. Lehti 4242, Eno. Geological Map of Finland 1:100 000, Pre-Quaternary rocks, sheet 4242, Eno. Geological Survey of Finland.

Lavikainen, S. 1973. Suomen geologinen kartta 1:100 000, kallioperäkartta. Lehti 4244, Illomantsi. Geological Map of Finland 1:100 000, Pre-Quaternary rocks, sheet 4244, Ilomantsi. Geological Survey of Finland.

Lavikainen, S. 1975. Suomen geologinen kartta 1:100 000, kallioperäkartta. Lehti 4243, Oskajärvi. Geological Map of Finland 1:100 000, Pre-Quaternary rocks, sheet 4243, Oskajärvi. Geological Survey of Finland.

Lavikainen, S. 1986. Oskajärven kartta-alueen kallioperä, Suomen geologinen kartta 1:100 000, kallioperäkartan selitys, lehti 4243. Summary: Pre-Quaternary rocks of the Oskajärvi map-sheet area. Geological Map of Finland 1:100 000, explanation to the map of Pre-Quaternary rocks, sheet 4243. Geological Survey of Finland, Espoo. 42 p.

Lavikainen, S. 1989. The granitoid rocks of the Ilomantsi region. In: Gaál, G. (ed.) 1989. Symposium Precambrian granitoids. Petrogenesis, geochemistry and metallogeny, August 14 - 17, 1989, Helsinki, Finland. Excursion C-3: Archean granitoids and associated Mo, W and Au mineralization in eastern Finland. Geological Survey of Finland, Guide 25, 69 - 72.

Lehtinen, M. 1983. Kuhmon Arolan alueen geologiasta ja nikkeliesiintymästä. Unpublished MSc Thesis, University of Turku. 126 p. (in Finnish)

Lehto, T. & Niiniskorpi, V. 1977. Pohjois- ja Itä-Suomen rautamuodostumat. Summary: The iron-formations of northern and eastern Finland. Geological Survey of Finland, Research report – tutkimusraportti 22. 49 p. (in Finnish)

Leinonen, S. 1992. Suomussalmen, Haaposen ja Kivikankaan vuolukivien geologia ja soveltuvuus hyötykäyttöön. Geologian ja mineralogian syventävien opintojen tutkielma 77260S. Unpublished MSc Thesis, University of Oulu. 111 p. (in Finnish)

Lestinen, P. 1979. Rahalammen kohteen geokemialliset tutkimukset. Väli-Suomen kohdetutkimusryhmän raportti 5/1979. Geological Survey of Finland, unpublished report S41/4241/5/1979. 25 p., 26 app. (3 geol. maps). (in Finnish)

Lestinen, P. 1980a. Väli-Suomen kohdetutkimusryhmä, raportti 1/1980 Vintilänsuo-Penkkisuo. Geological Survey of Finland, unpublished report S/41/4241 05/1/1980. 13 p., 28 app. and appendix report (17 p.). (in Finnish)

Lestinen, P. 1980b. Väli-Suomen kohdetutkimusryhmä, raportti 3/1980, Kissanloso. 9 p., 6 l. Geological Survey of Finland, unpublished report S/41/4241 08/1/1980. 9 p., 6 app. (in Finnish)

Liipo, J. 1999. Mineralogical studies from the early Proterozoic and Archean ultramafic rocks from eastern Finland, emphasis on chromite as a petrogenetic indicator. Res Terrae. Ser. A 15, 100 p.

Liipo, J., Vuollo, J., Nykänen, V. & Piirainen, T. 1994. Chromite compositions as evidence for an Archaean ophiolite in the Kuhmo greenstone belt in Finland. Bull. Geol. Soc. Fin. 66, 3 - 18.

Liipo, J.P., Vuollo, J.I., Nykänen, V.M. & Piirainen, T.A. 1995. Zoned Zn-rich chromite from the Näätäniemi serpentine massif, Kuhmo greenstone belt, Finland. Can. Miner. 33, 537 - 545.

Lodders, K. 1996. An experimental and theoretical study of rare-earth-element partitioning between sulfides (FeS, CaS) and silicate and applications to enstatite achondrites. Meteoritics & Planetary Science 31, 749 - 766.

Lohva, J., Kurimo, M., Niskanen, M. 1996. The accuracy of aerogeophysical measurements – ground geophysical data as a reference. EAGE 58th Conference, Amsterdam, 3. - 7.6.1996. Extended Abstracts , Volume 1, 180.

Lundqvist, T., Bøe, R., Kousa, J., Lukkarinen, H., Lutro, O., Roberts, D., Solli, A., Stephens, M. & Weihed, P. 1996. Bedrock map of Central Fennoscandia, scale 1: 1 000 000. Espoo, Trondheim, Uppsala. Geological Survey of Finland, Geological Survey of Norway, Geological Survey of Sweden.

Luukkonen, E.J. 1985. Structural and U-Pb isotopic study of late Archaean migmatitic gneisses of the Presvecokarelides, Lylyvaara, eastern Finland. Trans. R. Soc. Edinburgh: Earth Sci. 76, 401 -410.

Luukkonen, E.J. 1986. Suomen geologinen kartta 1:100 000, kallioperäkartta. Lehti 4421, Moisiovaara. Geological Map of Finland 1:100 000, Pre-Quaternary rocks, sheet 4421, Moisiovaara. Geological Survey of Finland.

Luukkonen, E.J. 1987. Suomen geologinen kartta 1:100 000, kallioperäkartta. Lehti 4423 + 4441, Ala-vuokki. Geological Map of Finland 1:100 000, Pre-Quaternary rocks, sheet 4423 + 4441, Ala-Vuokki. Geological Survey of Finland.

Luukkonen, E.J. 1988a. Moisiovaaran ja Ala-Vuokin kartta-alueiden kallioperä, Suomen geologinen kartta 1:100 000, kallioperäkartan selitys, lehdet 4421, 4423 + 4441. Summary: Pre-Quaternary rocks of the Moisiovaara and Ala-Vuokki map-sheet areas. Geological Map of Finland 1:100 000, explanation to the map of Pre-Quaternary rocks, sheets 4421, 4423 + 4441. Geological Survey of Finland, Espoo. 90 p.

Luukkonen, E.J. 1988b. The structure and stratigraphy of the northern part of the late Archaean Kuhmo greenstone belt, eastern Finland. In: Marttila, E. (ed.) 1988. Archaean geology of the Fennoscandian Shield. Geological Survey of Finland, Special Paper 4, 71 - 96.

Luukkonen, E.J. 1992. Late Archaean and early Proterozoic structural evolution in the Kuhmo - Suomussalmi terrain, eastern Finland. Turun Yliopiston julkaisuja. Annales Universitatis Turkuensis. Sarja-Ser. A. II. Biologica-Geographica-Geologica 78, 1 - 37.

Luukkonen, E.J. 1993. Suomen geologinen kartta 1:100 000, kallioperäkartta. Lehti 4414 + 4432, Lentiira. Geological Map of Finland 1:100 000, Pre-Quaternary rocks, sheet 4414 + 4432, Lentiira. Geological Survey of Finland.

Luukkonen, E. 1997. Tutkimustyöselostus Suomussalmen kunnassa valtausalueella Härkövaara 1 suoritetuista nikkelimalmitutkimuksista vuosina 1994 - 1996. Geological Survey of Finland, unpublished report M06/4513/97/1/12. 14 p., 1 app. (in Finnish)

Luukkonen, E.J. 2001. Lentiiran kartta-alueen kallioperä kallioperä, Suomen geologinen kartta 1:100 000, kallioperäkartan selitys, lehdet 4414 + 4432. Summary: Pre-Quaternary rocks of the Lentiira map-sheet area. Geological Map of Finland 1:100 000, explanation to the map of Pre-Quaternary rocks, sheet 4414 + 4432. Geological Survey of Finland, Espoo. 51 p.

Luukkonen, E. & Halkoaho, T. 1998. Rytyksen komatiittinen kumulaattikompleksi. In: Luukkonen, E. J. (ed.) 1998. Syysekskursio: Suomussalmen, Kuhmon ja Kostamuksen arkeeiset vihreäkivivyöhykkeet ja niihin liittyvä malminmuodostus: excursio quide 22. - 24.09.1998. Vuorimiesyhdistys. Sarja B 66, 16 - 19. (in Finnish)

Luukkonen, E., Heino, T., Tenhola, M., Niskanen, M. & Hartikainen, A. 1997. Tutkimustyöselostus Suomussalmen kunnassa valtausalueilla Saarilampi 1 (Kaivosrekisteri No 5351/1), Housuvaara 1-2 (Kaivosrekisteri No 4876/1-2), Mullikko 1 (Kaivosrekisteri No 5029/1), Pahka 1 (Kaivosrekisteri No 5029/2) ja Pahkalampi 1 (Kaivosrekisteri No 5232/1) suoritetuista kultamalmitutkimuksista vuosina 1990 - 1997. Geological Survey of Finland, unpublished report M06/4513/97/1/10.

Luukkonen, E., Heino, T., Niskanen, M. & Tenhola, M. 1998. Tutkimustyöselostus Hyrynsalmen kunnassa valtausalueilla Kaivolampi 1 - 2 (Kaivosrekisteri No 6143/3 ja 6143/2), Puistola 1 - 2 (Kaivosrekisteri No 5657/1 ja 6143/1), Paatola 1 - 2 (Kaivosrekisteri No 5619/1 ja 5619/2), Kiviharju 1 - 2 (Kaivosrekisteri No 5986/3 ja 5986/4), Siltajoki 1 (Kaivosrekisteri No 5986/2), Jokiperänaho 1 - 2 (Kaivosrekisteri No 5656/1 ja 6119/1), Rinneaho 1 (Kaivosrekisteri No 5657/3) ja Hietaniemi 1 - 2 (Kaivosrekisteri No 5657/2 ja 5986/1) suoritetuista kulta- ja nikkelimalmitutkimuksista vuosina 1993 - 1997. Geological Survey of Finland, unpublished report M06/4421/98/1/10. 20 p. (in Finnish)

Luukkonen, E.J. & Lukkarinen, H. 1986. Explanation to the stratigraphic map of Middle Finland. Geological Survey of Finland, Rep. of Invest. 74.

Luukkonen, E.J. & Sorjonen-Ward, P. 1997. Arkeeinen kallioperä -ikkuna 3 miljardin vuoden taakse. In: Lehtinen, M., Nurmi, P. & Rämö T.(eds) 1997. 3 000 vuosimiljoonaa. Suomen Kallioperä. Geological Society of Finland, 105 - 163. (in Finnish)

Markey, R., Stein, H., Morgan, J., Hannah, J. & Sundblad K. 1999. Comparison of alkaline fusion versus carius tube digestion for Re-Os dating of molybdenite; lessons from the Aittojarvi, Finland standard. Geological Society of America, 1999 annual meeting. Abstracts with Programs – Geological Society of America 31, 7.

Marston, R.J., Groves, D.J., Hudson, D.R. & Ross, J.R. 1981. Nickel sulfide deposits in Western Australia: A Review. Econ. Geol. 76, 1330 - 1363.

Martin, H. 1989. Archaean chronology in the eastern part of the Baltic Shield: a synthesis. Precambrian Research 43, 63 - 77.

Martin, H., Auvray, B., Blais, S., Capdevila, R., Hameurt, J., Jahn, B.M., Piquet, D., Quérré, G. & Vidal, Ph. 1984. Origin and geodynamic evolution of the Archaean crust of eastern Finland. Bull. Geol. Soc. Fin. 56, 135 - 160.

Matisto, A. 1954. Suomen geologinen yleiskartta 1:400 000, kivilajikartta, lehti D5, Suomussalmi. Geological Map of Finland 1:400 000, the map of Pre-Quaternary rocks, sheet D5, Suomussalmi. Geological Survey of Finland.

Matisto, A. 1958. Suomen geologinen yleiskartta 1:400 000, kivilajikartan selitys, lehti D5, Suomussalmi. Geological Map of Finland 1:400 000, explanation to the map of Pre-Quaternary rocks, sheet D5, Suomussalmi. Geological Survey of Finland. 115 p. 1 map. (in Finnish)

Mäkinen, J. & Lestinen, P. 1990. Sinkki-lyijy-kupari-hopea- ja uraaniaiheiden moreenigeokemiallinen etsintä Kiihtelysvaaran itäpuoleisella pohjagneissialueella. Kohteet: Linnansuo, Melanotko, Markkasuo, Myllypuro, Rantakylä. Geological Survey of Finland, unpublished report S/41/4241/1/1990. 22 p., 63 app. (in Finnish)

Männikkö, K.H. 1988. Myöhäisarkeeisen Koveron liuskejakson länsiosan deformaatio ja metamorfoosi. Pohjois-Karjalan malmiprojekti, report 15. University of Oulu. 108 p., 6 app. (in Finnish)

Männikkö, K.H., Määttä, T.T., Ojala, V.J. & Tuukki, P.A. 1987. Otravaaran rikkikiisumalmin ja sen ympäristön geologia. Pohjois-Karjalan malmiprojekti, report 4. University of Oulu. 78 p., 11 app. (in Finnish)

Männikkö, K.H. & Tuukki, P.A. 1989. Sonkaja-jakson (Koveron liuskejakson itäosan) geologia. Pohjois-Karjalan malmiprojekti, report 20. University of Oulu. 52 p., 4 app. (in Finnish)

Nakamura, N. 1974. Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. Geochim Cosmochim Acta 38, 757 - 775.

Nenonen, J. & Huhta, P. 1993. Quaternary glacial history of the Hattu schist belt and adjacent parts of the Ilomantsi district, eastern Finland. In: Nurmi, P. A. & Sorjonen-Ward, P. (eds) Geological development, gold mineralization and exploration methods in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 185 - 191.

Nichol, I., Lavin, O.P., McClenaghan, M.B. & Stanley, C.R. 1992. The Optimization of Geochemical Exploration for Gold using Glacial Till. Exploration Mining Geology 1 (4), 305 - 326.

Nieminen, J. 1998. Kuhmon Kellojärven polymiktinen vulkaaninen konglomeraatti. Unpublished MSc Thesis, University of Turku. 106 p. (in Finnish)

Niiniskorpi, V. 1975. Itä-Suomen rautamuodostumat. Selostus Lapin rautamalmien horisonttisidonnaisuusprojektin tutkimuksista Itä-Suomessa. Pohjois-Suomen malmigeologinen toimikunta. Geological Survey of Finland, unpublished report PSMT/P10/76/3. 222 p. (in Finnish)

Nikkarinen, M. 1991. Size, form and composition of gold grains in glacial drift in Ilomantsi, eastern Finland. In: Björklund A. (ed.) Gold geochemistry in Finland. J.Geochem.Explor. 39, 295-302.

Niskavaara, H. 1990. Reductive coprecipitation as a separation method for the determination of gold, palladium, platinum, rhodium, silver, selenium and tellurium in geological samples by graphite furnace atomic absorption spectrometry. Analytica Chimica Acta 231, 273 - 282.

Niskavaara, H. 1995. A comprehensive schema of analysis for soils, sediments, humus and plant samples using Inductively coupled plasma atomic emission spectrometry (ICP-AES. In: Autio, S. (ed.) Geological Survey of Finland, Current Research 1993 - 1994. Geological Survey of Finland, Special Paper 20, 167 - 175.

Niskavaara, H. & Kontas, E. 1988. Determination of Au, Pd, Pt, Rh, Ag, Te and Se with graphite furnace-AAS in geological samples after separation and preconcentration by reductive co-precipitation. In: First Rio Symposium on Furnace Atomic Absorption Spectrometry, September 18 - 23, 1988, Rio de Janeiro, Brazil: program and abstracts, 1 p.

Nurmi, P.A. 1993. Ilomantsin kultaesiintymät. In: Nurmi P.A. (ed.) 1993. Itä-Suomen kultaesiintymät: excursio quide 28. - 29.9.1993. Vuorimiesyhdistys B 54, 11 - 21. (in Finnish)

Nurmi, P.A., Hartikainen, A., Damstén, M. & Rasilainen, K. 1989. Sampling strategies and pathfinder elements in till and rock geochemical gold exploration, Hattu schist belt, Ilomantsi, eastern Finland. In: Autio, S. (ed.) Geological Survey of Finland, Current Research 1988. Geological Survey of Finland, Special Paper 10, 53 - 57.

Nurmi, P.A., Sorjonen-Ward, P. & Damstén, M. 1993. Geological setting, characteristics and exploration history of mesothermal gold occurences in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. In: Nurmi, P.A. & Sorjonen-Ward, P. (eds) Geological development, gold mineralization and exploration methods in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 193 - 231.

Nurmi, P.A. & Sorjonen-Ward, P. (eds) 1993. Geological development, gold mineralization and exploration methods in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17. 386 p. + 1 app. map.

Nykänen, O. 1967. Suomen geologinen kartta 1:100 000, kallioperäkartta. Lehti 4232 + 4234, Tohmajärvi. Geological Map of Finland 1:100 000, Pre-Quaternary rocks, sheet 4232 + 4234, Tohmajärvi. Geological Survey of Finland.

Nykänen, O. 1968. Tohmajärven kartta-alueen kallioperä, Suomen geologinen kartta 1:100 000, kallioperäkartan selitys, lehti 4232 + 4234. Summary: Pre-Quaternary rocks of the Tphmajärvi map-sheet area.Geological Map of Finland, 1:100 000, explanation to the map of Pre-Quaternary rocks, sheet 4232 + 4234. Geological Survey of Finland, Espoo.

Nykänen, O. 1971a. Suomen geologinen kartta 1:100 000, kallioperäkartta. Lehti 4241, Kiihtelysvaara. Geological Map of Finland 1:100 000, Pre-Quaternary rocks, sheet 4241, Kiihtelysvaara. Geological Survey of Finland.

Nykänen, O. 1971b. Kiihtelysvaaran kartta-alueen kallioperä, Suomen geologinen kartta 1:100 000, kallioperäkartan selitys, lehti 4241. Summary: Pre-Quaternary rocks of the Kiihtelysvaara map-sheet area.Geological Map of Finland, 1:100 000, explanation to the map of Pre-Quaternary rocks, sheet 4241. Geological Survey of Finland, Espoo. 68 p.

O'Brien, H.E., Nurmi, P.A. & Karhu, J.A. 1993. Oxygen, hydrogen and strontium isotopic compositions of gold mineralization in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. In: Nurmi, P.A. & Sorjonen-Ward, P. (eds) Geological development, gold mineralization and exploration methods in the late Archean Hattu schist belt, Ilomantsi, eastern Finland, Geological Survey of Finland. Special Paper 17, 291 - 306.

Ojala, V.J. 1988. Ilomantsin Hattuvaaran Rämepuron Au-mineralisaation geologia. Pohjois-Karjalan malmiprojekti, report 19, University of Oulu, 78 p. + 10 app. tables. (in Finnish)

Ojala, V.J., Pekkarinen, L.J., Piirainen, T. & Tuukki, P.A. 1990. The Archean gold mineralization in Rämepuro, Ilomantsi greenstone belt, eastern Finland. Gold ´89 in Europe, Toulouse, France. Terra Nova 2:3, 240 - 244.

Ojala, V.J., Piirainen, T., Pitkäjärvi, J.T., Tuukki, P.A. & Uusikartano, A.J. 1988. Tutkimukset Hatun liuskejaksolla kesällä 1987. Pohjois-Karjalan malmiprojekti, report 13, University of Oulu, 34 p. + 17 app. (in Finnish)

Paakkola, J., Piirainen, T., Koivumaa, S., Lanne, E., Saarnisto, M. & Taipale, K. 1981. Kuhmon ja Kittilän malmiprojektin loppuraportti. Kuhmon ja Kittilän malmiprojekti, report 49, University of Oulu, 93 p. (in Finnish)

Pajunen, M. 1990. Syväkairausraportti K52/4412/90/R1, Kuhmo, Jousijärvi. Geological Survey of Finland, unpublished report. 5 p. (in Finnish)

Pajunen, M. & Poutiainen, M. 1999. Palaeoproterozoic prograde metasomatic-metamorphic overprint zones in Archaean tonalitic gneisses, eastern Finland. Bulletin of the Geological Society of Finland 71, 73 - 132.

Pakkanen, L. & Luukkonen, E. 1995. Native nickel and copper in the Kauniinvaara ultramafic body of the late Archaean Suomussalmi greenstone belt, eastern Finland. In: Autio, S. (ed.) Geological Survey of Finland, Current Research 1993 - 1994. Geological Survey of Finland, Special Paper 20, 23 - 29.

Papunen, H. 1989. Platinum-group elements in metamorphosed Ni-Cu deposits in Finland. In: Prendergast, M.D. & Jones, M.J. (eds) 1989. Magmatic sulphides - the Zimbabwe volume. London: The Institution of Mining and Metallurgy, 165 - 176.

Papunen, H., Halkoaho, T., Liimatainen, J. & Luukkonen, E. 2001. Metallogeny of the Archaean Tipasjärvi - Kuhmo - Suomussalmi greenstone belt, Finland. In: Cassidy, K.F., Dunphy, J.M. & Van Kranedonk, M.J. (eds) 2001. 4th International Archaean Symposium, 24 - 28 September 2001, Perth, Western Australia: extended abstracts. AGSO - Geoscience Australia, Record 2001/37, 456 - 458.

Papunen, H., Kopperoinen, T. & Tuokko, I. 1989. The Taivaljärvi Ag-Zn deposit in the Archaean greenstone belt, eastern Finland. Economic Geology 84, 1262 - 1276.

Pekkala, Y. & Niemelä, M. 1997. Vuolukivi - elämää tulikiven lämmössä. Summary: Soapstone - life in the heat of firestone. Vuoriteollisuus 55 (1), 27-32.

Pekkarinen, L. 1977. Selostus Kiihtelysvaaran Särkilammen ympäristössä suoritetuista malmitutkimuksista vuosina 1972 - 1975. Geological Survey of Finland, unpublished report M19/4241/77/1/10. 8 p., 6 app. (1 geol. map.). (in Finnish)

Pekkarinen, L.J. 1979. The Karelian formations and their depositional basement in the Kiihtelysvaara - Värtsilä area, East Finland. Geological Survey of Finland Bull. 301, 141 p. 1 app.

Pekkarinen, L. 1989. The Hattuvaara Au occurence, Ilomantsi. In: Gaál, G. (ed.) Symposium Precambrian granitoids. Petrogenesis, geochemistry and metallogeny, August 14 - 17, 1989, Helsinki, Finland. Excursion C-3: Archean granitoids and associated Mo, W and Au mineralization in eastern Finland. Geological Survey of Finland, Guide 25, 60 - 68.

Perttula, J-P. 1983. Granaatin koostumuksen määritys taitekertoimen ja alkeiskopin koon avulla. Laudatur-työselostus. University of Turku. 4 p. (in Finnsih)

Pietikäinen, K., Hartikainen, A., Niskanen, M. & Tenhola, M. 2000. The gold prospects: Kuikka, Syrjälä N, Syrjälä S and Tupakkiloma in Kiannaniemi, Suomussalmi, eastern Finland (register numbers of claims 6318/1, 6318/2, 6318/3, 6748/1, 6841/1, 6880/1, 6880/2, 6912/1 and claim reservation 77/2000. Geological Survey of Finland, unpublished report CM06/4511/2000/1. 25 s, 2 app.

Pietikäinen, K. & Niskanen, M. 2001a. Tutkimustyöselostus Suomussalmen kunnan Saarikylässä sijaitsevasta valtauksesta Paskolampi 1 (Kaiv. RN:o 5267/1). Geological Survey of Finland, unpublished report M06/4513/2001/3/10. 7 p., 5 app. (in Finnish)

Pietikäinen, K. & Niskanen, M. 2001b. Tutkimustyöselostus Suomussalmen kunnan Saarikylässä sijaitsevasta valtauksesta Ala-Luoma 1 (Kaiv. RN:o 5267/2). Geological Survey of Finland, unpublished report M06/4513/2001/4/10. 6 p., 3 app. (in Finnish)

Pietikäinen, K. & Niskanen, M. 2001c. Tutkimustyöselostus Suomussalmen kunnan Saarikylässä sijaitsevista valtauksista Seipelä 1 (Kaiv. RN:o 6550/1) ja Siikaselänne 1 (Kaiv. RN:o 5620/1) sekä niitä ympäröivästä valtausvarausalueesta (69/1977). Geological Survey of Finland, unpublished report M06/4513/2001/2. 9 p., 7 app. (in Finnish)

Piirainen, T. (toim.) 1985. Arkeeisten alueiden malmiprojektin loppuraportti. Arkeeisten alueiden malmiprojekti, report 48. University of Oulu. 183 p. (in Finnish)

Piirainen, T. & Vuollo, J. (eds) 1991. Arkeeinen ja proterotsooinen geologinen evoluutio ja malminmuodostus: Pohjois-Karjalan malmiprojektin loppuraportti. University of Oulu, Pohjois-Karjalan malmiprojekti, report 31, 145 p. (in Finnish)

Piquet, D. 1982. Mécanismes de recrystallisation métamorphiques dans les ultrabasites: exemple des roches vertes archéennes de Finlande orientale (Ceintures de Suomussalmi - Kuhmo) Thèse 3ème cycle, Universitè de Rennes, 246 p.

Pitkäjärvi, J.T. 1988. Koveron liuskejaksoa leikkaavien granitoidien petrogenesis. Pohjois-Karjalan malmiprojekti, report 14. University of Oulu. 42 p., 6 app. (in Finnish)

Poutiainen, M. & Luukkonen E.J. 1994. The geology and fluid inclusion studies of some epigenetic gold deposits in the Archaean Kuhmo and Suomussalmi greenstone belts, eastern Finland. Fift Biennal Pan-American Conference on Research on Fluid Inclusions. Abstracts, 77 - 78.

Rainio, H. 1983. The Tuupovaara end moraine in North Karelia, eastern Finland: an ice-marginal formation of the same age as the Salpausselkä ridges. Bulletin of the Geological Society of Finland 55, 67 - 76.

Rainio, H. 1985. Pohjois-Karjalan Salpausselkien aikaiset reunamuodostumajaksot tarvitsevat nimet. Geologi 37 (3), 48 - 50. (in Finnish)

Rainio, H. 1990. Koitere end moraine, Hattujärvi ice-marginal formation, Ilomantsi. In: Mäkinen K. (ed.) Mid-Norden Project: Subproject Quaternary Geology. Guide for the excursion to central Finland, 3. - 7.9.1990. Rovaniemi: Geological Survey of Finland, 48 - 49.

Rasilainen, K. 1996. Geochemical alteration of gold occurences in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland Bull. 388, 80 p., 5 app.

Rasilainen, K. 1997. Geochemistry of hydrothermal alteration at the late Archean Pampalo gold deposit, eastern Finland. In: Papunen, H. (ed.) Mineral deposits: research and exploration - where do they meet? Proceedings of the Fourth Biennial SGA Meeting, Turku, Finland, 11 - 13 August 1997. Balkema, Rotterdam, 297 - 300.

Rautiainen, I., Hagel-Brunnström, M-L., Heiskanen, L. & Kallio, E. 1996. Production oriented method for the determination of rare earth and other trace elements in rocks by ICP-MS, Fresenius J Anal Chem 355, 393 - 396.

Rautio, J. 2000. Arkeeinen Huutoniemen serpentiniitti Suomussalmella. Unpublished MSc Thesis, University of Turku. 87 p. (in Finnish)

Repo, R. 1957. Untersuchnungen Über die Bewegungen des Inlandeises in Nordkarelien. Bull. Comm. géol. Finlande 179, 178 p.

Roos, S. 1981. Ilomantsin Jerusalemin molybdeniesiintymästä. Unpublished MSc Thesis, University of Turku. 93 p., 4 app. (in Finnish)

Ross, J.R. & Keays, R.R. 1979. Precious metals in volcanic-type nickel sulfide deposits in Western Australia. Part I. Relationship with tha composition of the ores and their host rocks. Can. Mineral. 17: 417 - 435.

Rämö, O.T. & Luukkonen, E.J. 2001. 2.4 Ga A -type granites of the Kainuu Region, eastern Finland: Characterization and Tectonic Significance. J. Conf. Abs. 6, 771.

Saarnisto, M., Peltoniemi, H., Uusikartano, K., Tuokko, I. & Koivumaa, S. 1980. Kuhmon ja Kittilän malmiprojektit, report 39. University of Oulu. 127 p. (in Finnish)

Saarnisto, M. & Peltoniemi, H. 1984. Glacial stratigraphy and compositional properties of till in Kainuu, eastern Finland. Fennia 162:2, 163 - 199.

Saarnisto, M. & Taipale, K. 1984. Influence of the Kuhmo Greenstone Belt (Eastern Finland) upon the Lithology and Geochemistry of Till. In: Königsson, L-K. (ed.) Ten Years of Nordic Till Research. Striae 20, 39 - 44. Uppsala.

Saksela, M. 1923. Über die Petrologie des Otravaara-gebietes in östlichen Finnland. Bull. Comm. géol. Finlande 65.

Salminen, R. 1980. On the geochemistry of copper in the Quaternary deposits in the Kiihtelysvaara area, North Karelia, Finland. Geological Survey of Finland. Bull. 309, 48 p.

Salminen, R. (ed.) 1995a. Alueellinen geokemiallinen kartoitus Suomessa 1982 - 1994. Summary: Regional geochemical mapping in Finland in 1982 - 1994. Geological Survey of Finland, Research report – tutkimusraportti 130, 47 p., 24 app. maps. (in Finnish).

Salminen, R. 1995b. Gold in geological samples. Geological Survey of Finland, Report of investigation 114, 29 - 32.

Salminen, R. & Hartikainen, A. 1985. Glacial transport of till and its influence on interpretation of geochemical results in North Karelia, Finland. Geological Survey of Finland, Bull. 335, 48 p.

Salminen, R. & Hartikainen, A. 1986. Tracing of gold, molybdenum and tungsten mineralization by use of a step by step geochemical till study in Ilomantsi, eastern Finland. In: Prospecting in areas of glaciated terrain: papers presented at the seventh international symposium organized by The Institution of Mining and Metallurgy and The Geological Survey of Finland, Kuopio, 1 - 2 September, 1986. London: The Institution of Mining and Metallurgy, 201 - 209.

Sandström, H., Hagel-Brunnström, M.-L. & Kiirikki, E. 1989. The use of automated X-ray fluoresence spectrometry in determination of major elements in rock samples. In: Autio, S. (ed.) Geological Survey of Finland, Current Research 1988. Geological Survey of Finland, Special Paper 10, 123 - 127.

Saxén, M. 1923. Über die Petrologie des Otravaaragebieties im östlichen Finnland. Bulletin de la Commission géologique de Finland, 65, 63 p.

Sokolov, V.A. & Heiskanen, K.J. 1985. Evolution of Precambrian volcanogenic-sedimentary lithogenesis in the south-eastern part of the Baltic Shield. In: Laajoki, K. & Paakkola, J. (eds) Proterozoic exogenic processes and related metallogeny. Geological Survey of Finland Bull. 331, 91 - 106.

Sorjonen-Ward, P. 1993a. An overview of structural evolution and lithic units within and intruding the late Archean Hattu schist belt, Ilomantsi, eastern Finland. In: Nurmi, P.A. & Sorjonen-Ward, P. (eds) Geological development, gold mineralization and exploration methods in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 9 - 102.

Sorjonen-Ward, P. 1993b. 1:50 000 Geological map of the Hattu schist belt, Ilomantsi district, eastern Finland. In: Nurmi, P.A. & Sorjonen-Ward, P (eds) Geological development, gold mineralization and exploration methods in the late Archean Hattu schist belt, Ilomantsi, Eastern Finland. Geological Survey of Finland, Special Paper 17, appendix.

Sorjonen-Ward, P. 1997. An overview of the geological setting and nature of gold mineralisation in the late Archean Hattu schist belt, eastern Finland. In: Loukola-Ruskeeniemi, K. & Sorjonen-Ward, P. (eds) Research and exploration - where do they meet? 4th Biennial SGA Meeting, August 11 - 13, 1997, Turku, Finland. Excursion guidebook A4: ore deposits in eastern Finland. Geological Survey of Finland, Guide 42, 49 - 55.

Sorjonen-Ward, P. & Claoué-Long, 1993. Preliminary note on the ion probe results for zircons from the Silvevaara granodiorite, Ilomantsi, eastern Finland. In: Autio S. (ed.) 1993. Geological Survey of Finland, Current Research 1991 - 1992. Geological Survey of Finland, Special Paper 18, 25 - 29.

Stein, H.J., Markey, R.J., Morgan, J.W., Sundblad, K. & Kouvo, O. 1995. Precise dating with the Re-Os method: molybdenite from tonalites in the Fennoscandian Shield track Archean metamorphism or cooling history. In: Geological Society of America 1995 Annual Meeting, New Orleans, Lousiana, November 6 - 9, 1995. Geological Society of America. Abstracts with Programs 27 (6), A-281.

Streckeisen, A. 1976. To each plutonic rock its proper name. Earth-Science Reviews 12: 1 - 33.

Sun, S.-S. 1980. Lead isotopic study of young volcanic rocks from mid-ocean ridges, ocean islands and island arcs. Phil Trans R Soc Lond A297, 409 - 446.

Sun, S.-S. 1982. Chemical composition and origin of the earth's primitive mantle. Geochim. Cosmochim. Acta 16, 179 - 192.

Taipale, K. 1983a. Itä-Suomen arkeeisista granitoideista ja niihin liittyvistä molybdeeniesiintymistä. Arkeeisten alueiden malmiprojekti, report 14. University of Oulu. 26 p. (in Finnish)

Taipale, K. 1983b. The geology and geochemistry of the Archaean Kuhmo greenstone-granite terrain in the Tipasjärvi area, eastern Finland. Acta Univ. Ouluensis A 151, Geol. 5, 98 p.

Taipale, K. & Tuokko, I. 1981. Kuhmon arkeeisen vihreäkivivyöhykkeen geologiasta ja malmimineralisaatioista. Kuhmon ja Kittilän malmiprojektit, report 47. University of Oulu. 65 p. (in Finnish)

Tenhola, M. & Hartikainen, A. 1997. Geokemialliset maaperätutkimukset Kuhmon ja Suomussalmen arkeeisella vihreäkivivyöhykkeellä: kullanetsintään liittyviä ongelmia. Neljännet Geokemian Päivät. Sarja B, No 64, 1997 (extended abstracts, ed.. Pekka Lestinen). Vuorimies yhdistys - Bergsmannaforeningen r.y. 21 - 24. (in Finnish)

Tenhola, M. & Luukkonen, E. 1994. Regional and detailed till geochemistry in gold exploration in Late Archaean Kuhmo and Suomussalmi Greenstone Belt, eastern Finland. In: IV Joint International Symposium on Exploration Geochemistry, a Tribute to Academican L.V. Tauson, Irkutsk, September 7 - 10, 1994. Lisna Publishers, Russia, Abstracts, Volume 1, 176.

Tenhola, M. & Nenonen, K. 1993. Till geochemistry and Quaternary geology in the Housuvaara area: a part of the Kuhmo - Suomussalmi Archaean gold province. In: Jokinen, S. (ed.) Guide for the Mid-Norden Quaternary and Environmental Excursion to Finland 6 - 10.9.1993, Mid-Norden Project, Subproject Quaternary Geology. Kuopio: Geological Survey of Finland, 16 - 19.

Tenhola, M. & Niskanen, M. 2001a. Tutkimustyöselostus Kuhmon kaupungissa valtausalueella Louhiniemi 1 (kaivosrekisteri No 6822/1) suoritetuista kultamalmitutkimuksista vuosina 1998 - 1999. Geological Survey of Finland, unpublished report M06/4412/2001/2/10. 7 p. (in Finnish)

Tenhola, M. & Niskanen, M. 2001b. Tutkimustyöselostus Kuhmon kaupungissa valtausalueilla Aitto 1 (Kaivosrekisteri No 5032/1), Mujesuo 1 (Kaivosrekisteri No 5412/1), Jousijärvi 1 (Kaivosrekisteri No 5333/1) sekä Härmänkangas 1 (Kaivosrekisteri No 6108/1) suoritetuista kulta- ja sinkkimalmitutkimuksista vuosina 1992 - 1999. Geological Survey of Finland, unpublished report M06/4412/2001/3/10. 8 p., 1 app. (in Finnish)

Tenhola, M., Pietikäinen, K., Hartikainen, A. & Niskanen, M. 2001. The Pahkosuo Gold Prospects in Suomussalmi, Eastern Finland in 1991 - 1998 (register numbers of claims; Pahkosuo 1, 5621/1; Pahkosuo 2, 6272/1; Pahkosuo 3, 6272/2; Pahkosuo 4, 6410/1). Geological Survey of Finland, unpublished report M06/4513/2001/1. 17 p., 3 app.

Tulenheimo, T. 1999. Kuhmon Kellojärven kerroksellinen ultramafinen muodostuma. Unpublished MSc Thesis, University of Turku. 199 p. (in Finnish)

Tuukki, P.A. 1991a. Arkeeinen Koveron liuskejakso ja sen mafisten ja ultramafisten kivien geokemia ja petrogenesis. Pohjois-Karjalan malmiprojekti, report 28. University of Oulu. 129 p., 2 app. (in Finnish)

Tuukki, P.A. 1991b. Pohjois-Karjalan arkeeiset liuskevyöhykkeet. In: Piirainen, T. & Vuollo, J. (eds) Arkeeinen ja proterotsooinen geologinen evoluutio ja malminmuodostus. Pohjois-Karjalan malmiprojektin loppuraportti, Pohjois-Karjalan malmiprojekti, report 31. University of Oulu, 13 – 62. (in Finnish)

Tuukki, P.A., Männikkö, K.H., Ojala, V.J. & Pitkäjärvi, J.T. 1987. Koveron liuskejakson geologia. Pohjois-Karjalan malmiprojekti, report 9. University of Oulu. 123 p., 2 app. (in Finnish)

Tuukki, P.A. & Uusikartano, A.J. 1988. Tektonis-magmaattisten diagrammien käyttö Koveron liuskejakson mafisten vulkaniittien tektonisen synty-ympäristön määrittämisessä. Pohjois-Karjalan malmiprojekti, report 10. University of Oulu. 36 p., 4 app. (in Finnish)

Vaasjoki, M. 1989. Leads from late Archaean and early Proterozoic mineralizations in the Fennoscandian shield: constraints on early crust-forming proceeses. Geological Survey of Finland, Special Paper 10. 31 - 32.

Vaasjoki, M., Sorjonen-Ward, P. & Lavikainen, S. 1993. U-Pb age determinations and sulfide Pb-Pb characteristics from the late Archean Hattu schist belt, Ilomantsi, eastern Finland. In: Nurmi, P. A. & Sorjonen-Ward, P. (eds) Geological development, gold mineralization and exploration methods in the late Archean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 103 - 131.

Vaasjoki, M., Taipale, K. & Tuokko, I. 1999. Radiometric ages and other isotopic data bearing on the evolution of Archaean crust and ores in the Kuhmo - Suomussalmi area, eastern Finland. Bulletin of the Geological Society of Finland 71, 155 - 176.

Vaasjoki, M., Ward, P. & Lavikainen, S. 1989. U-Pb zircon ages from the late Hattu schist belt. Current Research 1988, Geol. Surv. Finland Spec. Paper 10, 33 - 36.

Vauhkonen, R. & Leinonen, S. 1998. Kivikankaan ja Haaposen vuolukivimuodostuma. In: Luukkonen, E. J. (ed.) 1998. Syysekskursio: Suomussalmen, Kuhmon ja Kostamuksen arkeeiset vihreäkivivyöhykkeet ja niihin liittyvä malminmuodostus: excursion quide 22. - 24.09.1998. Vuorimiesyhdistys. Sarja B 66, 19 - 20. (in Finnish)

Vuollo, J. 1994. Palaeoproterozoic basic igneous events in Eastern Fennoscandian shield between 2.45 and 1.97 Ga. Studied by means of mafic dyke ewarms and ophiolites in Finland. Acta Univ. Oul. A 250, 47 + 67 p.

Väyrynen, H. 1933. Über die Stratigraphie der Karelischen Formationen. Bull. Comm. géol. Finlande 101, ss. 54 - 78.

Wager, L.R. & Brown, G.M. 1968. Layered Igneous Rocks. Oliver & Boyd, Edinburg and London, 588 p.

Wager, L.R., Brown, G.M. & Wadsworth, W.J. 1960. Types of igneous cumulates. Journal of Petrology 1, 73 - 85.

Wilkman, W.W. 1921. Suomen geologinen yleiskartta 1: 400 000, vuorilajikartan selitys, lehti D4, Nurmes. Geological Map of Finland 1:400 000, explanation to the map of Pre-Quaternary rocks, sheet D4, Nurmes. Geological Survey of Finland. 126 p. (in Finnish)

Wilkman, W.W. 1924. Suomen geologinen yleiskartta1:400 000, vuorilajikartta, lehti D4, Nurmes. Geological Map of Finland 1:400 000, the map of Pre-Quaternary rocks, sheet D4, Nurmes. Geological Survey of Finland.

Zeidler, W. 1949. Om gruvdriften i Mätäsvaara åren 1940 - 1947. Vuoriteollisuus - Bergshanteringen 1, 20 - 33. (in Swedish)

Yliniemi, J. 1986. Preliminary structure of the Earth´s crust on the Kostamus - Oulu and Kostamus - Viitasaari profiles. Paper presented at the 20th General Assemply of the European Seismol. Commission, August 21 - 30, Kiel; Abstracts: Terra Cognita, 6, (6), S3.9, 345.

Yliniemi, J., Jokinen, J. & Luukkonen, E. 1996. Deep Structure of the Earth Crust Along the GGT/SVEKA Transect Extension to North-East. In: Global Geoscience Transect/SVEKA. Proceedings of the Kuopio seminar, Finland 25 - 26.11.1993. Geological Survey of Finland, Research report – tutkimusraportti 136, 56 p.

Appendix 1. Geochemical sampling targets in the Suomussalmi greenstone belt, sample numbers, and significant elements, with their respective maximum concentrations. Codes for the different sampling materials: T=till, WBR=weathered bedrock, WT=till containing weathered bedrock material, BR=bedrock, Others= silt, sand.

Target and the sampling year	Map sheet	Total number of samples	Samling material and number of samples					Elements and their maximum concentrations
			T	WBR	WT	BR	Others	
Isosuo, Suomussalmi, 1993	4513 09	68	52	15	1			Au (3 420 ppb), Te (1 190 ppb), Mo (11.5 ppm).
Iso Housuvaara-Saarilampi, Suomussalmi, 1992- 1993	4513 08, 09	667	745	532	58	2		Au (11 100 ppb), As (1 800 ppm), Zn (18 300 ppm), Te (9 490 ppb), Pb (2 380 ppm), Cu (3 660 ppm), Ni (2 280 ppm), S (2.5 %), Ag (7.3 ppm), Fe (18.6 %).
Moukkori belt (Moukkori-Kaiskonkangas), Suomussalmi, 1991-1993	4513 06, 09	1 182	555	495	121	11		Au (1 960 ppb), As (2 970 ppm), Te (109 000 ppb), Cu (1 110 ppm), Ni (1 240 ppm), Mo (50 ppm), S (2.8 %), Zn (1 800 ppm), Fe (19.0 %).
Lahna-aho, Suomussalmi, 1995	4513, 06	255	122	123	49	1		Au (970 ppb), Te (3 000 ppb), Zn (110 ppm).
Pahkalampi, Lauttalampi, Suomussalmi, 1991-1995	4513 06,	1 477	866	532	79			Au (15 100 ppb), Te (45 100 ppb), Pb (2 450 ppm), Cu (1 320 ppm), Co (172 ppm), Mo (55.4 ppm), As (794 ppm), Fe (13.1 %).
Isopuinen, Suomussalmi, 1997	4513 03	153	16	99	38			Au (360 ppb), As (228 ppm), Cu (518 ppm), Co (71 ppm), Zn (295 ppm).
Teerilampi, Suomussalmi, 1994, 1997	4514 04	456	81	30	345			Au (2 440 ppb), Te (774 ppb), As (3 410 ppm), Cu (679 ppm), S (0.6 %), Mo (55.6 ppm).
Tulilampi, Suomussalmi, 1998	4514 04	931	226	585	120			Au (1 670 ppb), Te (9 940 ppb), As (1 580 ppm), Cu (1 970), Mo (70 ppm), Pb (780 ppm), Ag (13.3 ppm), Zn (2 210 ppm) S (2.3 %).
Pahkosuo, Suomussalmi	4513 03	783	269	455	59			Au (5 100 ppb), Te (33 300 ppb), As (1 790 ppm), Ag (19.5 ppm), Mo (397 ppm), Pb (278 ppm), Cu (1 170 ppm), Ni (2 400 ppm), S (2.5 %), Fe (14.2 %).
Paisesuo/ Kiviaho Suomussalmi, 1997	4513 03	548	56	385	106		1	Au (3 330 ppb), Te (18 100 ppb), As (550ppm), Cr (1 960 ppm), Co (204 ppm).
Paskolampi, Suomussalmi, 1994	4513 03	473	173	300				Ni (3 610 ppm), Cr (4 000 ppm), Au (3 310 ppb), As (1 750 ppm), Co (451 ppm), Mo (18.1 ppm), Fe (19.9 %).

Appendix 1 continues

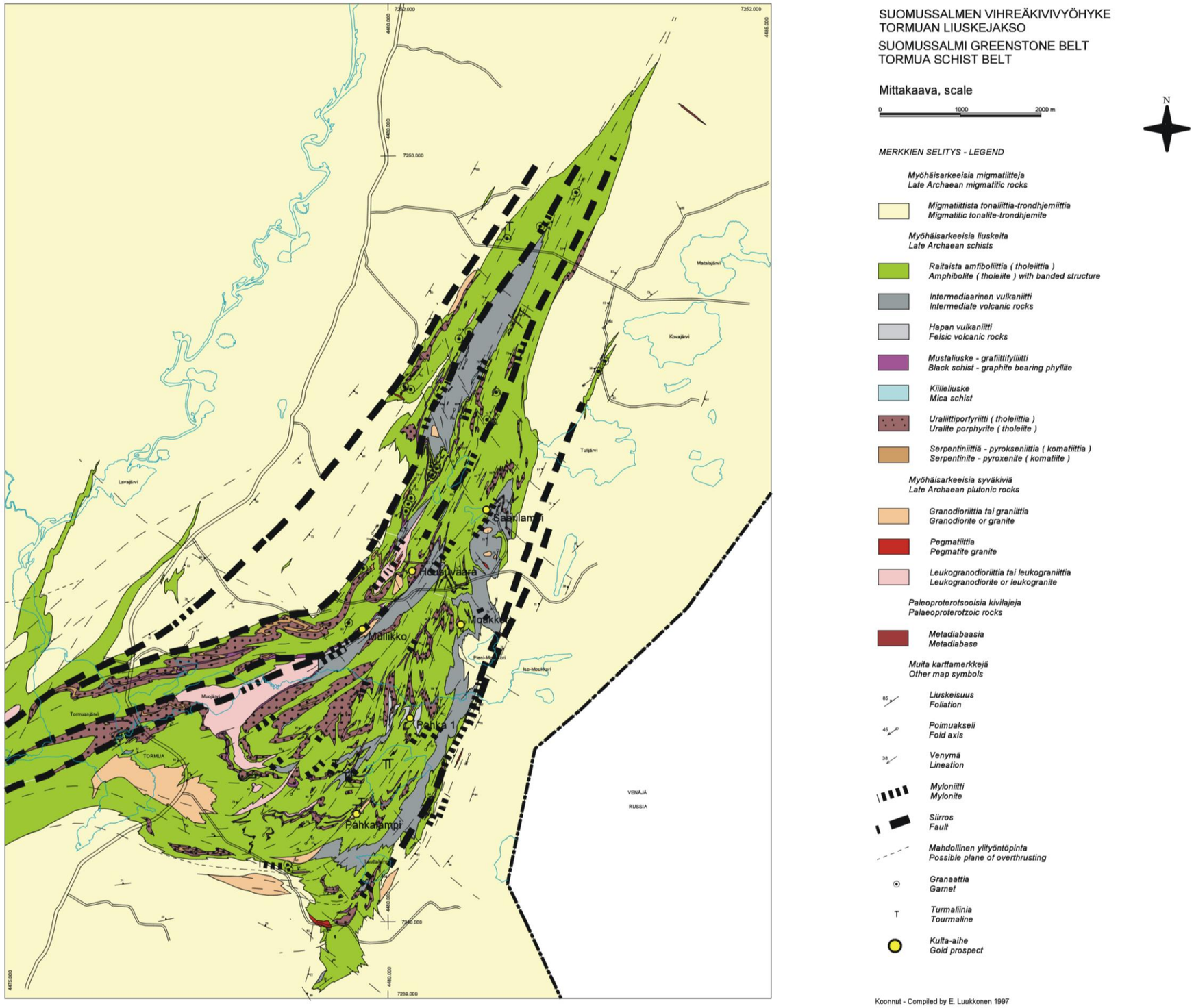
Seipelä, Suomussalmi, 1994-1996	4513 03, 06	887	194	644	44		5	Au (64 600 ppb), Te (56 100) ppb, As (36 200 ppm), S (37 700 ppm), Cu (2 330 ppm), Ni (1 490 ppm), Fe (17.7 %).
Syrjälä, Tupakkiloma, Suomussalmi, 1996, 1997	4511 10	302	11	288	3			Au (5 130 ppb), As (1 560 ppm), Te (6 130 ppb), Cr (2 630 ppm), Ni (1 630 ppm), S (5 680) ppm, Fe (10.2 %).
Nuottiaho, Suomussalmi, 1997	4511 10	214	5	205	4			Au (86 ppb), Ni (2 340 ppm), Co (128 ppm), Pb (323 ppm).
Kuikkapuro, Suomussalmi, 1999	4511 10	123	64	44		15		Au (1 530 ppb), Te (1 980 ppb), As (9 250 ppm).

Appendix 2. Geochemical sampling targets in the Kuhmo greenstone belt, sample numbers, and significant elements, with their respective maximum concentrations. Codes for the different sampling materials: T=till, WBR=weathered bedrock, WT=till containing weathered bedrock material, BR=bedrock, Others= silt, sand

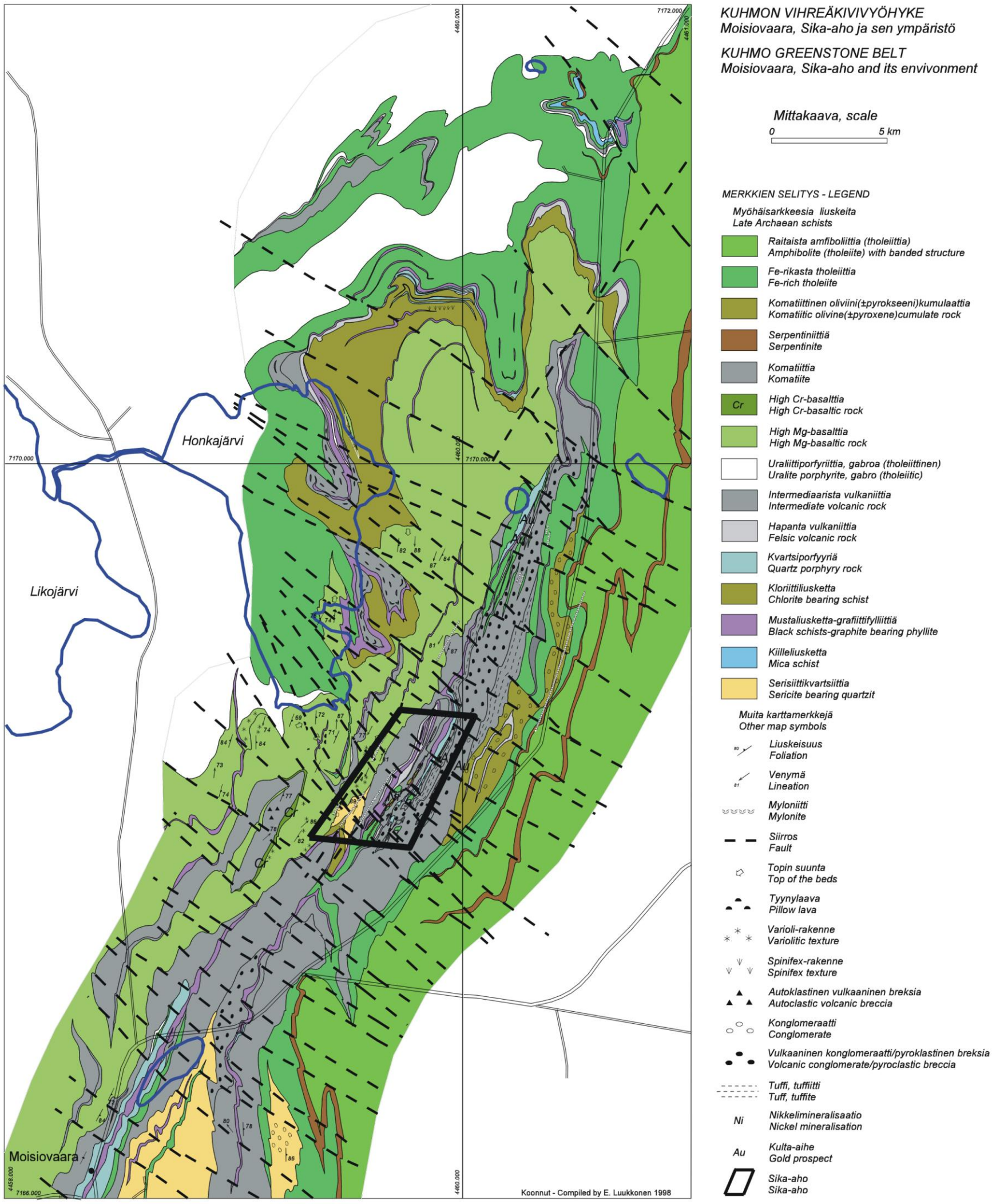
Target and the sampling year	Map sheet	Total number of samples	Samling material and number of samples					Elements and their maximum concentrations
			T	WBR	WT	BR	Others	
Viitavaara/ Lokkisuo, Suomussalmi, 1997	4423 02	538	411	478	70	1	8	Au (615 ppb), Te (1 980 ppb), As (1 080 ppm), Ni (1 630 ppm), Fe (19.6 %), S (20.6 %).
Sika-aho/ Tammasuo, Hyrynsalmi, 1993-1995	4421 10,11 4423 01, 02	1087	331	727	24	4	1	Au (8 800 ppb), Ni (5 120 ppm), Cr (3 110 ppm), As (1 270 ppm), S (14 900 ppm), Fe (18.7 %).
Sauna-aho, Hyrynsalmi, 1993	4423 01	84	52	23	9			Cu (177 ppm), local stage Cu (13 897) ppm, Fe (9.6 %).
Sopasenaho, Hyrynsalmi, 1988-1993	4412 12	384	184	187	13			Au (3 810 ppb), Ni (2 300 ppm),Te (2 160 ppb), Cu (1 160 ppm), Co (232 pm), Fe (14.9 %).
Valtasenaho, 1993, Hyrynsalmi	4412 12	38	99	19	10			Au (927 ppb, local stage), Cu (213 ppm), Zn (600 ppm), Fe (3.2 %).
Matalansuo, Hyrynsalmi, 1993	4412 12	166	56	89	21			Au (344 ppb), As (509 ppm), Cu (1 450 ppm), Ni (2 430 ppm), Fe (10.4 %), S (15 000 ppm).
Kelosuo-Taussuo Hyrynsalmi, 1990	4412 12	131	90	34	6		1	Au (940 ppb), Ni (881 ppm), Zn (1 912 ppm), Fe (7.1 %).
Palovaara, Hyrynsalmi, 1987-1992	4412 11, 12	889	485	372	32			Au (647 ppb), Cu (2 939 ppm), Pb (3 340 ppm), Ag (15.6 ppm), Zn (6 990 ppm), Ni (2 110 ppm), Fe (13.9 %).
Naurispuro, Kuhmo, 1996	4412 11	344	122	210	12			Ni (1 580 ppm), Au (956 ppb), Zn (1 390 ppm), Pb (445 ppm), As (837 ppm), Te (1 250 ppb), Cr (2 760 ppm).
Juurikkajoki, Kuhmo, 1991	4412 11	190	81	97	9	3		Ni (1 830 ppm), Co (1 320 ppm), Au (199 ppb), Zn (2 820 ppm), Fe (23.4 %).
Iso Aittojärvi, Kuhmo, 1990	4412 11	233	112	83	36		2	As (10 800 ppm), Cu (4 580 ppm), Ni (1 220 ppm), Pb (519 ppm), Au (174 ppb), Fe (10.5 %).
Jousijärvi, Kuhmo, 1991 ja 1994	4412 11	254	172	48	16	10	1	Au (1 020 ppb), As (6 180 ppm), Ni (1 010 ppm), Fe (23.8 %).
Mujesuo, Kuhmo, 1993 ja 1994	4412 11	381	204	119	57	1	2	Au (51.7 ppb), As (494 ppm), Ni (2 050 ppm), Cu (408 ppm).
Kangaslampi, Kuhmo, 1991	4412 11	43	22	12	8			Zn (650 ppm), Cu (971 ppm), Au (414 ppb), Fe (9.3 %) , S (3.0 %).

Appendix 2 continues

Pieni Kangaslampi, Kuhmo, 1989, 1991	4412 11	28	15	10		3		Au (148 ppb), Zn (353 ppm), Fe (7.6 %).
Louhiniemi, Kuhmo, 1998	4412 10	453	212	212	29	6		Au (203 ppb), As (1 680 ppm), Ni (2 280 ppm), Cr (2 630 ppm), Zn (812ppm), Fe (8.8 %).
Pyyliönniemi, Kuhmo, 1996	4412 10	103	27	56	18		2	Au (20 ppb), local stage Au (927 ppb). Ni (4 750 ppm), Cr (4 650 ppm), Co (208 ppm), Fe (19.1 %).

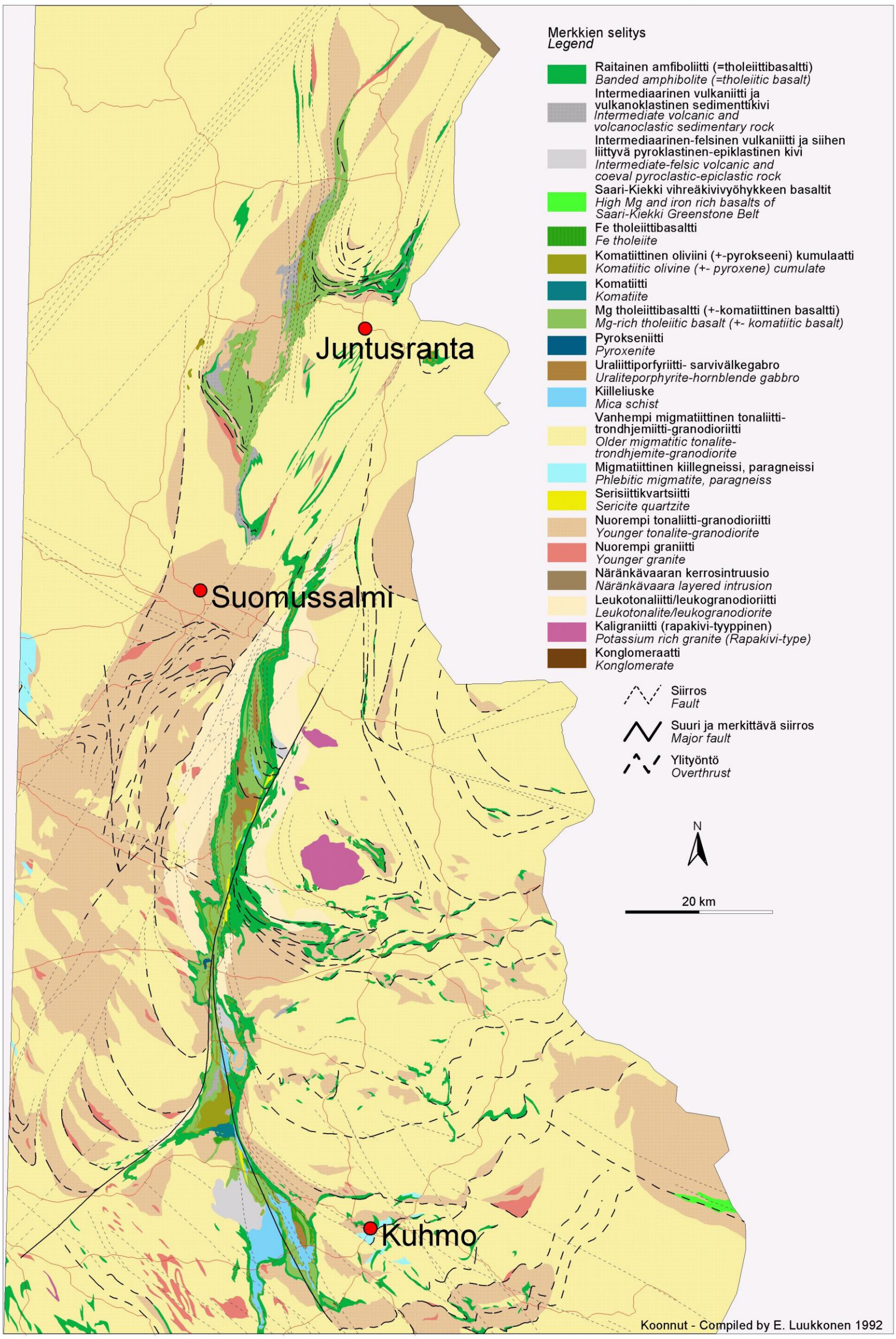


Appendix 3. Bedrock geology of the Tormua Schist Belt.



Appendix 4. Bedrock geological map of the Moisiovaara area, Kuhmo greenstone belt.

Kuhmon ja Suomussalmen vihreäkivivyöhyke ja sen lähiympäristö
Kuhmo and Suomussalmi Greenstone Belts and the surrounding bedrock



Appendix 5. Bedrock geological map of the Kuhmo and Suomussalmi greenstone belts and surrounding terrain.