Mineral deposits and metallogeny of Fennoscandia
Edited by Pasi Eilu
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METALLOGENIC AREAS IN FINLAND

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Forty-seven metallogenic areas have been identified in Finland. Of these, 10 areas are dominantly potential for ferrous metals (Fe, Ti, V, Cr), 11 for precious metals (Au, Pd, Pt), 11 for nickel, 8 for copper, zinc and/or lead, 4 for metals mostly used in advanced technologies ('high-tech metals' Be, Li, Nb, REE, Ta), and 3 for uranium. Many of the metallogenic areas are potential for more than just one major group of metals. The Finnish metallogenic areas include more than 30 different genetic types of metal deposits. By past production and present resources, the most significant deposit types include: mafic intrusion-hosted Ti-Fe-V (e.g., Mustavaara deposit at Koillismaa), mafic to ultramafic hosted Cr (Kemi), IOCG-style Fe±Cu,Au (Hannukainen deposit in the Pajala-Kolari area), magmatic Ni-Cu-PGE (Portimo, Koillismaa, Hitura and Kotalahti areas, and Kevitsa and Sakatti deposits), orogenic gold (Kittilä), and VMS (Vihanti-Pyhäsalmi). Highly significant are also the unique deposit types of Outokumpu Cu-Co and Talvivaara Ni-Zn-Cu-Co. Most of the known metal endowment of Finland was formed during the Palaeoproterozoic Era, during 2.45–1.92 Ga multi-stage rifting and the 1.9–1.8 Ga Svecofennian orogeny. Detected metal endowment in the Archaean is relatively low with minor komatiite-related Ni (Kuhmo) and orogenic gold deposits (Ilomantsi). Carbonatite-hosted Nb-REE at Sokli, dated to ca. 365 Ma, is the main post-Svecofennian metal deposit known from Finland.

Keywords (GeoRef Thesaurus, AGI): metallogenic provinces, mineral resources, metal ores, mines, production, Paleozoic, Proterozoic, Archean, Finland

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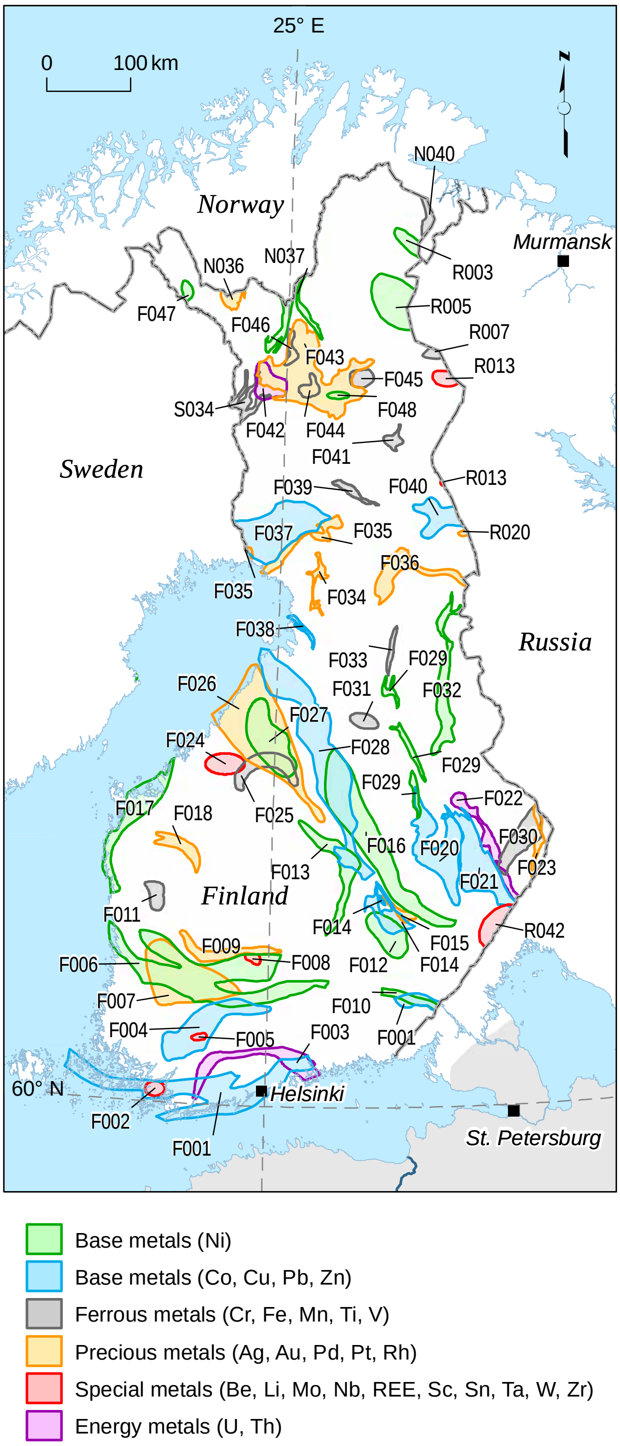

Figure 1. Index map of metallogenic areas in Finland. The names of the metallogenic areas are listed in Table 1. Note that areas coded to Norway (N), Sweden (S) and Russia (R) are described in sections for these countries.

Table 1. List of the metallogenic areas in Finland.

Code	Area name, main metals
F001	Orijärvi Zn, Cu, Ag, Pb
F002	Kemiö Ta, Be
F003	Palmottu U
F004	Häme Zn, Au, Ag
F005	Somero Li
F006	Vammala Ni, Co, Cu
F007	Pirkkala Au
F008	Eräjärvi Ta, Li, Be
F009	Tampere Au, Cu
F010	Telkkälä Ni, Co
F011	Peräkorpi Ti
F012	Puumala Ni, Co
F013	Ilmolahti Ni, Co, Cu
F014	Virtasalmi Cu
F015	Rantasalmi Au
F016	Kotalahti Ni, Co
F017	Oravainen Ni, Co
F018	Seinäjoki Au, Sb
F020	Outokumpu Co, Cu
F021	Hammaslahti Cu, Zn
F022	Koli U
F023	Ilomantsi Au
F024	Emmes Li
F025	Koivusaarenneva Ti, V
F026	Laivakangas Au, Cu
F027	Hitura Ni, Co
F028	Vihanti-Pyhäsalmi Zn, Cu
F029	Talvivaara Ni, Co, Zn
F030	Huhus Fe
F031	Otanmäki V, Fe, Ti
F032	Kuhmo Ni, Ag, Au
F033	Pääkkö Fe
F034	Oijärvi Au, Ag
F035	Portimo PGE, Cr, Ni
F036	Koillismaa PGE, V, Ni, Fe, Cu
F037	Peräpohja Cu, Co, Fe
F038	Haukipudas Zn, Cu
F039	Misi Fe, V
F040	Kuusamo-Kuolajärvi Co, Au
F041	Jauratsi Fe
F042	Kesänkitunturi U
F043	Kittilä Au, Cu
F044	Porkonen-Pahtavaara Fe, Mn
F045	Koitelainen Cr, V, PGE
F046	Pyhäjärvi V, Fe, Ti
F047	Ruossakero Ni, Co
F048	Sattasvaara Ni

The metallogenic areas id-coded to the neighbouring countries (Fig. 1) are listed and described in the respective country sections of this book.

F001 ORIJÄRVi Zn-Cu

Pasi Eilu & Mikko Tontti (GTK)

The Orijärvi area (F001; Fig. 1, Table 1) is within the southern half of the E-trending Uusimaa supracrustal belt and has a possible extension to the northeast across the Vyborg rapakivi batholith (Fig. 1). Area F001 (Fig. 2) is bounded to the north by the Häme volcanic belt, by the unmineralised northern half of the Uusimaa supracrustal belt, and in its eastern extension by the unmineralised supracrustal and intrusive rocks of the Saimaa-Lahdenpohja area. The southern boundary of the Orijärvi area is somewhere under the Gulf of Finland and, hence, not exactly known. Thus, the location of the boundary of area F001 drawn in the Fennoscandian metallogenic map is simply an educated guess based on information gathered from those areas of the Uusimaa belt that are dry land. In the west, the metallogenic area ends at the contact between the Uusimaa supracrustal belt and the Åland rapakivi massif. The rocks and mineral deposits of area F001 are largely similar to those in the Bergslagen region in central Sweden, and the Orijärvi area and the Uusimaa belt are commonly seen as an eastern extension of Bergslagen (Latvalahti 1979, Kähkönen 2005, Weihed et al. 2005). For example, by using the geological and metallogenic maps of Fennoscandia (e.g., Koistinen et al. 2001, Eilu et al. 2009) and geotectonic interpretations (e.g. Lahtinen et al. 2005), one may attempt to combine Bergslagen and Uusimaa supracrustal belts and the Bergslagen (S008, S009) and Orijärvi (F001) metallogenic areas.

The Uusimaa belt is formed by supracrustal and synvolcanic intrusive rocks at 1895–1875 Ma intruded by late-orogenic granitoids at about 1830–1810 Ma (Väisänen et al. 2002, Skyttä et al. 2005, Väisänen & Kirkland 2008). The 1895–1875 Ma igneous rocks show bimodal trends and dominantly calc-alkaline affinity, especially in the areas near VMS deposits. The region was affected by multiple stages of deformation and regional metamorphism during the Svecofennian orogeny, peaking at ca. 1880–1870 and 1830–1815 Ga (Kähkönen 2005, Skyttä et al. 2005, Väisänen &

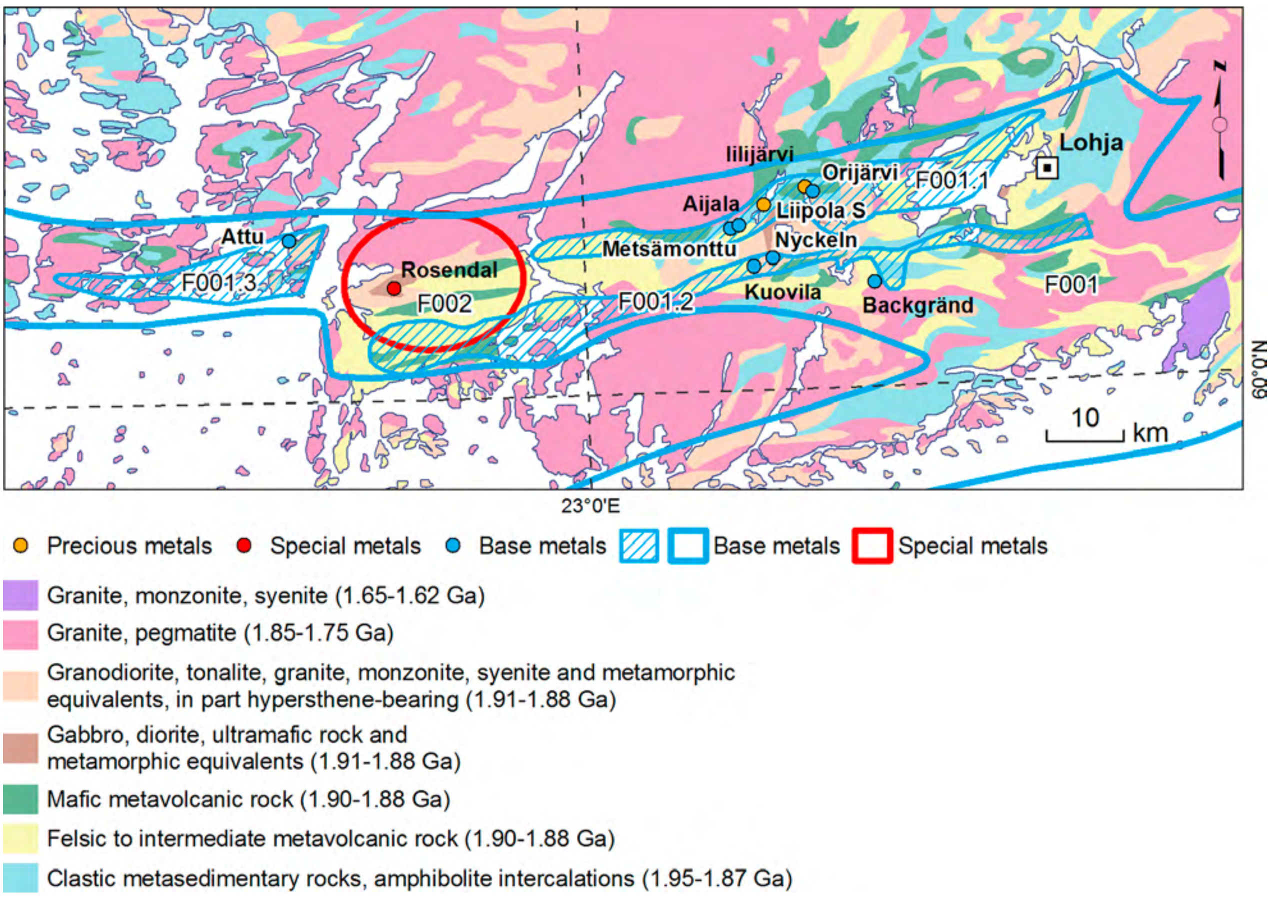

Figure 2. Geology of the central parts of the Orijärvi (F001) and Kemiö (F002) metallogenic areas, with the most significant base, precious and special metal occurrences of the region. Geology is from Koistinen et al. (2001).

Kirkland 2008). Most of the metallic mineralisation in the region (Fig. 2) is associated with the ca. 1895–1891 Ma rocks of the Aijala and Kuovila subareas (F001.1 and F001.2, respectively).

Four styles of metallic mineralisation has been detected within the Orijärvi area (Mikkola 1966, Latvalahti 1979, Mäkelä 1989, Saltikoff et al. 2006, Eilu 2007): 1) Zn-Cu±Pb,Au VMS (Aijala, Metsämonttu, Orijärvi), 2) possible epithermal Au±Cu (north-central F001), 3) banded iron formations (Jussarö, Nyhamn), and 4) skarn iron ores (minor occurrences along the entire Orijärvi area).

Aijala, **Metsämonttu** and **Orijärvi** (Table 2, Figs. 3 and 4) are the main mines of the Orijärvi area, and form the core of the Aijala subarea (F001.1). They all belong to the VMS type of mineralisation (Latvalahti 1979, Colley & Westra 1987, Mäkelä 1989): They are closely related to intensely altered felsic to mafic volcanic rocks and chemical sedimentary units (iron formation and chert). Alteration is characterised by the loss of Na and Ca and enrichment of K, Fe and Mg. The most typical altered rocks include cordierite-mica, cordierite-anthophyllite, and andalusite-cordierite-muscovite gneisses, and tremolite±diopside skarn reflecting metamorphosed equivalents of volcanic rocks altered in submarine VMS systems. The main ore minerals include in variable degrees chalcopyrite, sphalerite, galena, pyrite, pyrrhotite and fahlore. The base metal occurrences in the Kuovila and Attu subareas are largely similar to those in the Aijala subarea (Hangala 1987, Mäkelä 1989, Skyttä 2005).

The gold occurrences in the Orijärvi area and its surroundings, of which only **Iilijärvi** is listed below (Table 2), mostly show features fitting Au-rich VMS or epithermal mineralisation (Eilu 2007 and references therein). This suggests that they are premetamorphic and possibly closely related to the base metal deposits of the region. Some of the occurrences seem to be gold only, whereas others show enrichment in Au, Ag and base metals. The best investigated of the gold occurrences is Iilijärvi, one kilometre northwest from the Orijärvi mine (Fig. 3). The ore at Iilijärvi is chiefly hosted either by felsic metavolcanic rocks that have been altered and recrystallised into quartz rock or the main host is a metamorphosed chert (Colley & Westra 1987, Mäkelä 1989, Smith et al. 1992). In any case, andalusite-cordierite-muscovite gneiss derived from felsic volcanic rock and cordierite-anthophyllite gneiss derived from mafic volcanic rock surround and partially host the gold mineralisation. In addition to the style of alteration, its metal association and Au/Ag ratio, as well as the setting close to VMS deposits, strongly point towards a pre-metamorphic timing and gold-rich VMS or submarine epithermal style for mineralisation at Iilijärvi. Other gold occurrences are less easy to classify, but indications of an orogenic style of mineralisation remain rare, and may be due to remobilisation of ore minerals and the high degree of deformation and regional metamorphism.

Iron deposits in the Orijärvi area are probably all chemical sediments in primary origin. Many are still easily recognised as magnetite-quartz-Fe

Table 2. Base and precious metal deposits and occurrences in the Orijärvi area (F001). Only cases with a resource estimate available are shown.

Subarea **Occurrence**	**Tonnage (Mt)**	**Ag g/t**	**Au g/t**	**Cu %**	**Pb %**	**Zn %**	**When mined****	**Reference**
Aijala Zn-Pb-Cu±Au (F001.1)								
Iilijärvi	0.045	30	4	0.6	0.6	1.3	1788, 1884	Mäkelä (1989)
Metsämonttu	1.508*	25	1.43	0.28	0.74	3.34	1951–1974	Latvalahti (1979)
Aijala	0.835*	14	0.7	1.59		0.66	1670´s–1958	Latvalahti (1979)
Orijärvi	0.925*	40	0.4	1.3	1.03	3.32	1758–1954	Latvalahti (1979)
Kuovila Zn-Pb-Cu (F001.2)								
Backgränd	0.046	65		0.54	0.8	1.37		Mäkelä (1989)
Kuovila	0.01	6			0.4	1.4		Skyttä et al. (2005)
Liipola S	0.024	112				0.69		Mäkelä (1989)
Attu Zn-Pb-Cu (F001.3)								
Attu	4.32	43		0.16	1.05	1.76	1630, 1891	Hangala (1987)
Outside the subareas								
Salo-Issakka	1.8	14		0.33		1.65		Papunen (1990)

* Only the mined amount is reported.
** Mining has taken place in several time intervals.

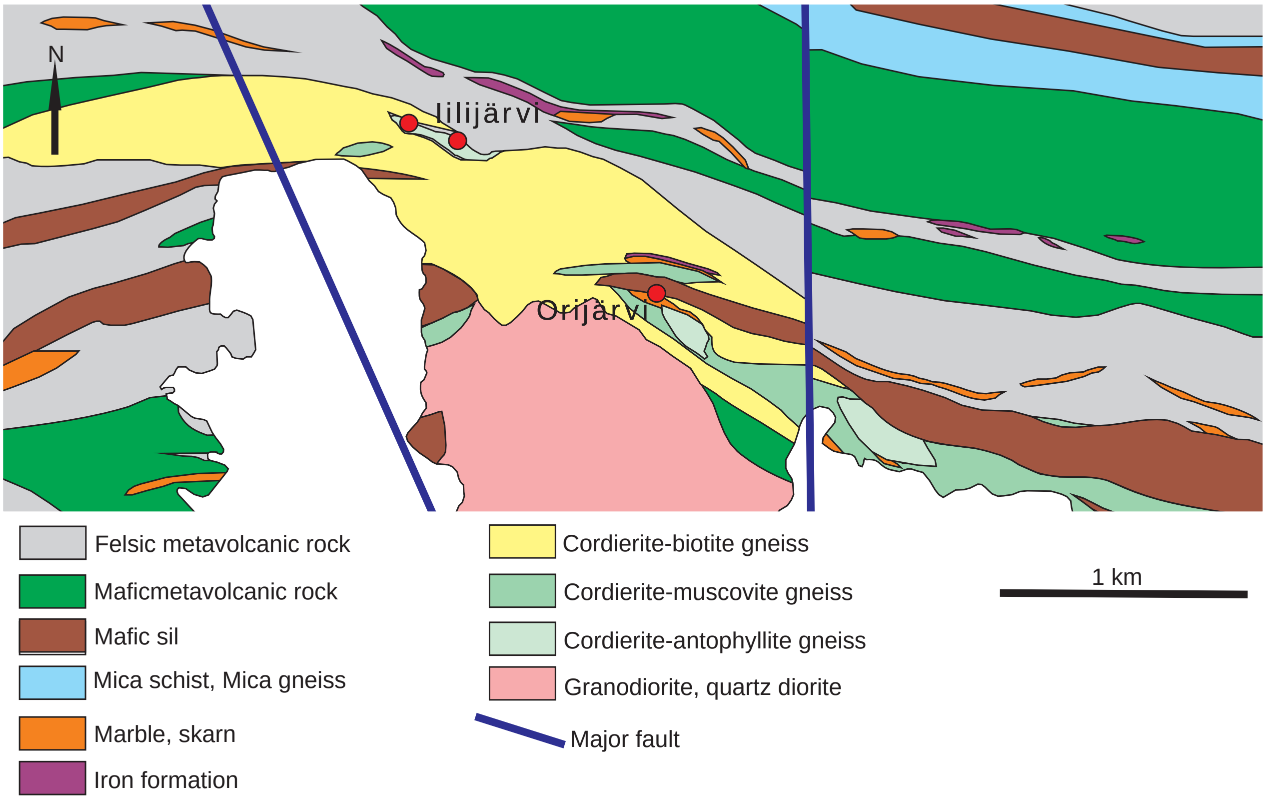

Figure 3. Surface geology of the Orijärvi-Iilijärvi region after Mäkelä (1989). The Orijärvi mine is at 60.229°N, 23.539°E.

Figure 4. Metsämonttu mine site during operation. Photo: Outokumpu Oy.

Table 3. Selected iron deposits and occurrences in the Orijärvi area (F001) and its surroundings in the Uusimaa belt.

Occurrence	Tonnage (Mt)	Fe %	Ti %	When mined**	Genetic type	Reference
Jussarö	28	28	0.09	1834–1967	BIF	Mikkola (1966), Puustinen (2003)
Nyhamn	10	20		1959	BIF	Saltikoff et al. (2006)
Sillböle	0.035*	30		1744–1866	Skarn	Saltikoff et al. (2006)
Ojamo	0.012*	45		1542–1838	Skarn	Saltikoff et al. (2006)

* Only the mined amount is reported.
** Mining has taken place in several time intervals, except at Nyhamn.

silicate banded iron formations, such as the magnetite ores at **Jussarö** and **Nyhamn**, and the numerous small iron occurrences within the Aijala and Kuovila subzones (e.g., Mäkelä 1989, Skyttä et al. 2005). A number of small iron occurrences, including those mined during the 16th to 19th centuries (Table 3), have traditionally been classified as skarns (Mäkelä 1989). They are, however, not skarns *sensu stricto* (i.e. formed in contact with and due to an intrusion), but multiply deformed iron formation units that suffered metamorphic skarnification and recrystallisation in contact with chemically reactive lithological units, such as marbles, or are recrystallised carbonate-facies iron formations (Mäkelä 1989).

F002 KEMIÖ Ta

Pasi Eilu (GTK)

The Kemiö metallogenic area (F002) is in the western part of the Uusimaa supracrustal belt (Fig. 2). The extent of area F002 is defined by the presence of a late-orogenic granitic, complex pegmatite swarm (Lindroos et al. 1996) with a significant potential for feldspar, quartz, tantalum and beryllium exploitation. Feldspar and quartz have been exploited from the Kemiö pegmatites

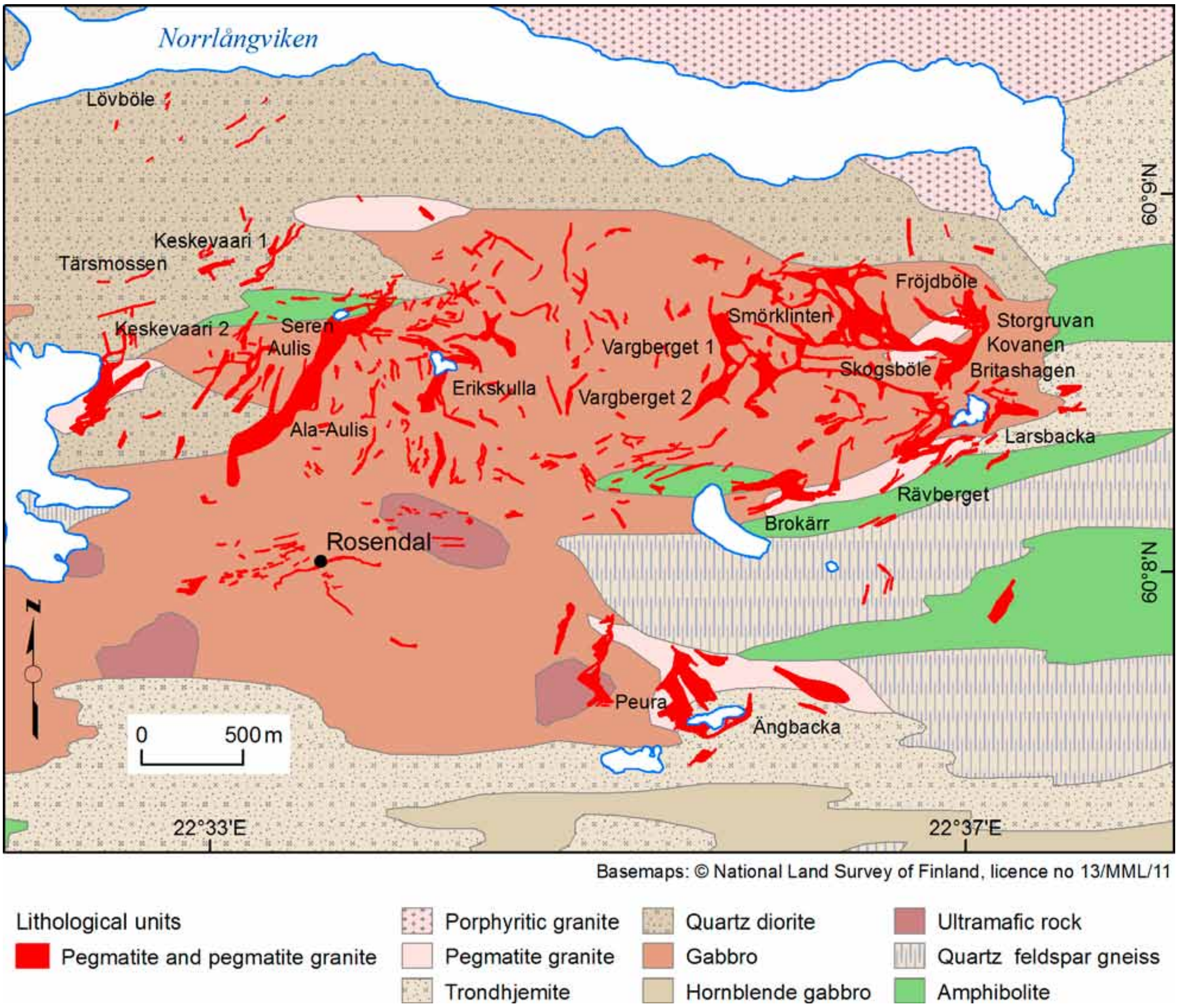

Figure 5. Geology of the central part of the Kemiö pegmatite region (metallogenic area F002), including the Rosendal Ta deposit, SW Finland. Pegmatites according to mapping by R. Alviola, in 1996–2002; geology based on the GTK digital bedrock database. Small white areas are lakes, the larger two are sea.

since the 17th century, with a total cumulative mining of about 5 Mt of pegmatite (Puustinen 2003). Minor volumes of beryl and columbite-tantalite have also been recovered (Puustinen 2003), but within the last 20 years the pegmatites have been explored as significant sources of tantalum metal.

The Rosendal deposit (Fig. 5) has an inferred resource of 1.3 Mt at 0.021 % Ta, 0.014 % Be and 0.08 % Sn (Alviola 1997). The deposit also contains recoverable albite, quartz and muscovite (Tertiary Minerals 2001). This resource estimate only covers the uppermost 50 m of one dyke. There are several similar, albeit apparently smaller, dykes at Rosendal, within an area 1 km long and 500 m wide. The mineral assemblage at Rosendal comprises microcline, albite, quartz, tapiolite, tantalite, chrysoberyl, beryl and cassiterite. The resource at Rosendal and known Ta-Nb mineral pegmatites in the region indicate that area F002 may have a significant, largely untested, Ta potential.

F003 PALMOTTU U

Esa Pohjolainen & Olli Äikäs (GTK)

The Palmottu area (F003) is a south-opening arc extending from the central to northern and eastern parts of the Uusimaa supracrustal belt. The high uranium contents of the bedrock and groundwater in the Uusimaa region are radiometrically and geochemically distinguishable. In particular, the uranium content of the late orogenic, 1.84–1.79 Ga, granites of southern Finland is relatively high. The main U-bearing minerals in the occurrences are uraninite, monazite, uranothorite, zircon, allanite and apatite (Räisänen 1989, Cuney et al. 2008).

Several uranium and thorium occurrences are known from the migmatised Uusimaa belt (Fig. 6); most of them are hosted by granitic and pegmatitic parts of the migmatites (Räisänen 1989). Many occurrences (e.g. Palmottu) have been discovered by means of aeroradiometric gamma anomalies in granitic areas (Seppänen 1985). All the known occurrences are small and their uranium grade is low (Table 4). Uranium occurrences of area F003 are mainly associated with late-orogenic granites (1.84–1.79 Ga) in migmatites. U-Pb analyses of uraninites and allanites from the eastern part of the area indicate uranium remobilisation and enrichment during the Ordovician, ca. 450 Ma ago (Vaasjoki et al. 2002). Monazite gives a concordant age of 1793 Ma at Palmottu; this date can be considered as the age of U mineralisation at the site (Vaasjoki 1996).

Most of the uranium occurrences in the western part of area F003 are related to the granitic dykes and lenses in migmatitic mica gneisses. The occurrences are located along the marginal zone of the late-orogenic Perniö granite and in paragneisses forming country rocks to the granite (garnet-bearing mica gneiss, quartz-feldspar gneiss and pyroxene-bearing charnockite). GTK discovered the **Palmottu** deposit at Nummi-Pusula (80 km NW of Helsinki) in 1979. Palmottu is an intrusive uranium deposit, rich in thorium (U/Th about 2:1). Two types of uraniferous dykes are present: 1) granite pegmatites and 2) sheared, quartz-rich granite with biotite accumulations (Räisänen 1989). Palmottu is on the southern limb near the crest of a large fold with a vertical, approximately E-W trending axial plane (Kuivamäki et al. 1991). The fractures now hosting the U-rich granitic dykes may have been opened during folding (Räisänen 1989), and the dykes were probably derived from the late-orogenic Perniö granite.

At Palmottu, uranium mainly occurs as disseminated uraninite typically associated with biotite accumulations in the granitic dykes of migmatitic mica gneisses. The main uranium and thorium minerals are uraninite and monazite. An alteration rim mainly consisting of coffinite ($USiO_4$) frequently surrounds uraninite grains. Conventional U-Pb dating of uraninite gave discordant ages (indicating the loss of lead) between 1678 and 1741 Ma (Ruskeeniemi et al. 1994). The only U^{6+} mineral identified is uranophane, occurring as a fracture fill (Kaija et al. 2000). Molybdenite occurs in small amounts. In total, 62 holes (9093 m) were drilled during 1981–1984 at Palmottu. The main ore body is discontinuous with a total length of 400 m and thickness from 1 to 15 m (Räisänen 1991). The mineralisation continues from the surface to a depth of at least 400 m.

In the eastern part of area F003, numerous uranium occurrences have been localised, mainly by ground and airborne radiometrics. Two uranium-rich boulders (glacial erratics) were found by Imatran Voima Oy (IVO) at **Alho**, northwest of Porvoo, in 1956 (boulder IVO-9: 36 % U_3O_8) and in 1957 (IVO-99: 12 % U_3O_8). The main minerals of boulder IVO-9 are uraninite, calcite, quartz, hematite and chlorite (Appelqvist & Kinnunen 1977). Uraninite is botryoidal, usually surrounded by carbonate. The bedrock source of the Alho boulders has not been discovered.

IVO had a field laboratory for milling and concentration tests at **Lakeakallio** (Fig. 6). From the Lakeakallio uranium occurrence, the company mined 557 tonnes of ore with a grade of 0.11 % U_3O_8 in 1958–1959. The host rock is granite that contains coarse-grained garnet and biotite nests. The country rocks are migmatitic mica gneiss and hornblende gneiss. The dominant ore minerals are uraninite, molybdenite and pyrite. Zircon and monazite are the radioactive accessories. Uraninite occurs at the grain margins of the gangue, and has a grain size of 0.2–0.4 mm. Remobilised uraninite has been found in microcracks around the primary uraninite. Milling and concentration tests at the IVO Lakeakallio field laboratory were also carried out on material from other occurrences known at the time from the eastern part of area F003.

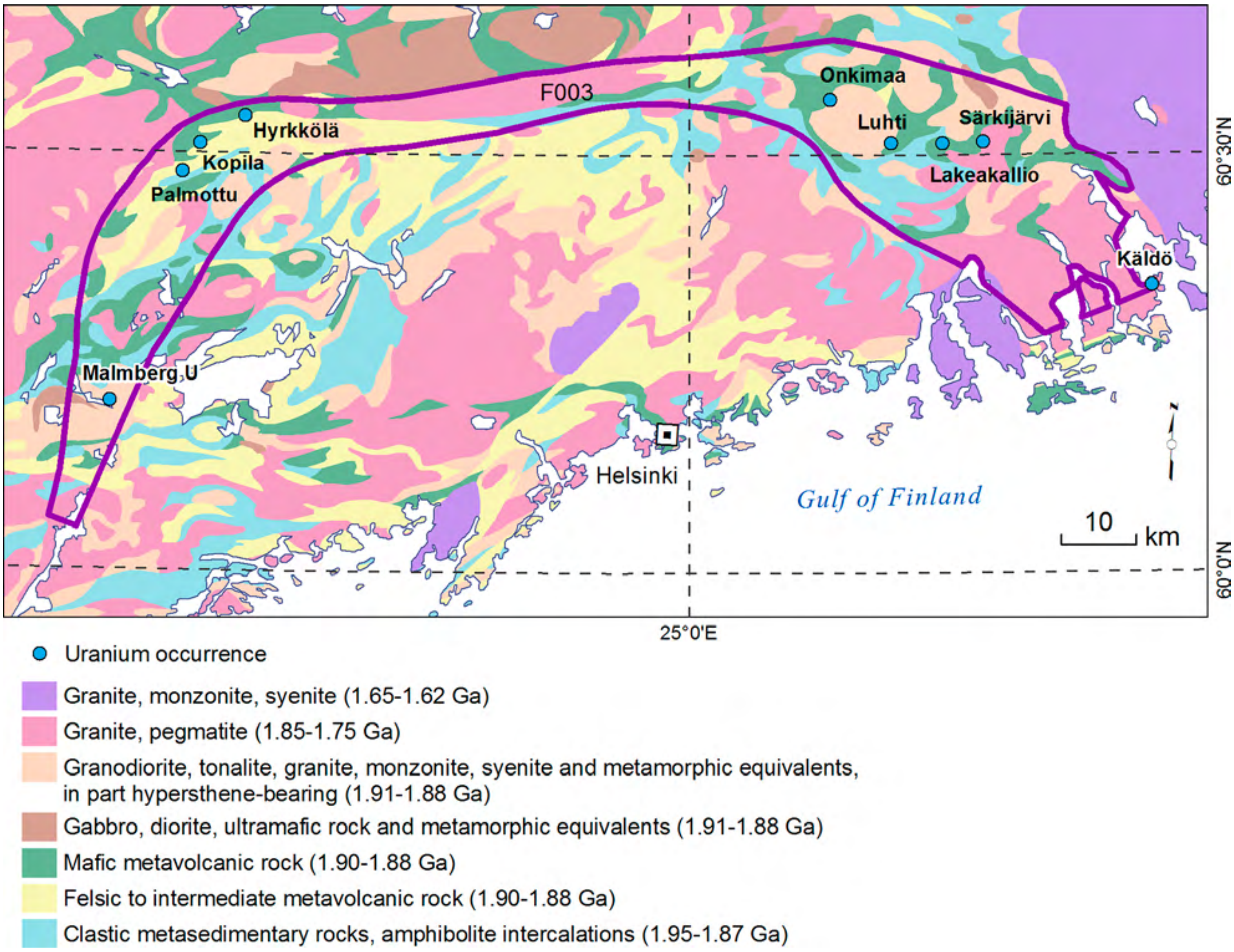

Figure 6. Geology of the Palmottu metallogenic area (F003) with selected uranium occurrences. Geology is based on Koistinen et al. (2001).

Table 4. Uranium occurrences with a resource estimate in the metallogenic area F003.

Occurrence	Ore tonnage (Mt)	U %	Main ore minerals	Reference
Lakeakallio	0.0006*	0.11	Uraninite, molybdenite	Appelqvist & Kinnunen (1977)
Onkimaa	2.7	0.01	Uraninite, zircon	Appelqvist (1974), Räisänen (1989)
Palmottu	1.018	0.11	Uraninite, monazite	Räisänen (1989), Kaija et al. (2003)

* Only the mined amount has been reported.

The **Onkimaa** uranium occurrence at Mäntsälä was discovered by GTK in 1972 (Appelqvist 1980). The mineralised rock is coarse-grained, almost a pegmatitic granite or granodiorite forming the neosome of migmatite. The radioactive minerals at Onkimaa are uraninite and zircon. Molybdenite is encountered in small amounts. Uraninite occurs as euhedral grains (0.15–0.25 mm in size) at grain boundaries and as inclusions in light-coloured gangue minerals.

F004 HÄME Au, Zn-Cu

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The Häme metallogenic area (F004) is within the WSW-trending Häme volcanic belt. The Häme area (Fig. 7) is bounded to the north by the Pirkanmaa migmatite belt (also called the Vammala migmatite zone), to the NW and W by barren areas of the Häme volcanic belt, and to the east and south by the Uusimaa supracrustal belt. The exact boundaries of area F004 can be questioned, however, as it is not very clear where the boundary between the Häme and Uusimaa supracrustal belts lie (Kähkönen 2005, Väisänen & Westerlund 2007), and the extent of gold and base metal potential along the Häme volcanic belt appears to gradually fade out to the west. Only the boundary to the north is distinct, where it coincides with the clear boundary (a major fault zone) between the Häme volcanic belt and the Pirkanmaa migmatite belt (Tiainen & Viita 1994, Vaasjoki et al. 2005).

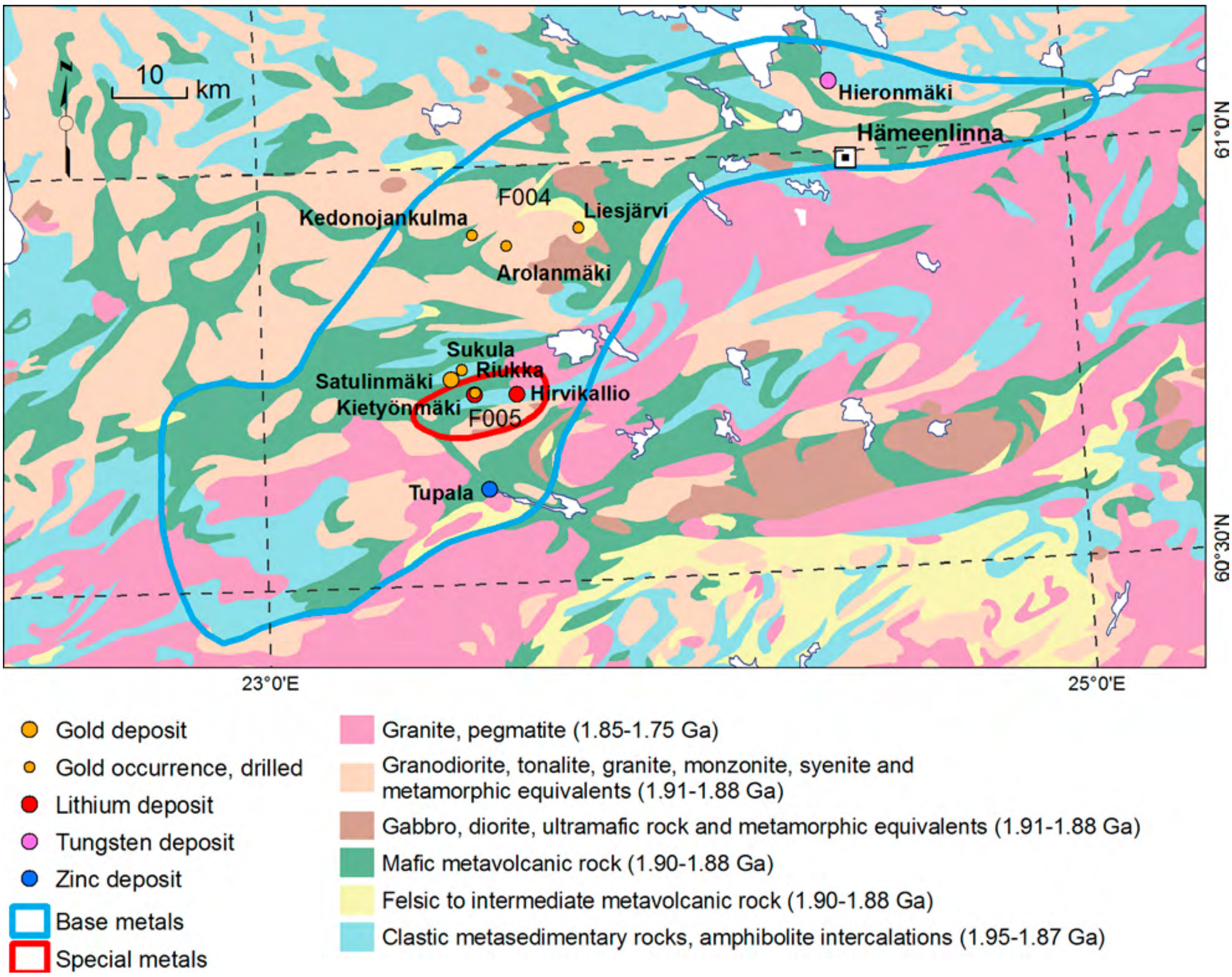

Figure 7. Geology of the Häme Au, Zn-Cu (F004) and Somero Li (F005) metallogenic areas and their immediate surroundings with the most significant metal occurrences and drilling-indicated gold occurrences. Geology is based on Koistinen et al. (2001).

Volcanic and sedimentary rocks, with intermediate volcanic rocks dominating, form the Häme volcanic belt. Age dating suggests that at least some of the supracrustal rocks were deposited at about 1880 Ga (Saalmann et al. 2009). The belt has been intruded by the ca. 1880 Ma I-type synvolcanic and synorogenic and the ca. 1830–1810 Ma S-type late-orogenic granitoids (Hakkarainen 1994, Tiainen & Viita 1994, Kähkönen 2005). According to Kähkönen (2005), the 1890–1880 Ma igneous rocks in Häme indicate an arc setting less evolved than within the Tampere schist belt or most of the Uusimaa supracrustal belt, and have a medium-K basaltic to rhyolitic composition. Like nearly all of southern Finland, the region has been affected by multiple stages of deformation and regional metamorphism during the Svecofennian orogeny, peaking at ca. 1880–1860 and 1830–1800 Ga (Kähkönen 2005, Saalmann et al. 2009).

Three or four styles of metallic mineralisation define the Häme metallogenic area (Mäkelä 1980, Mäkelä 1989, Papunen 1990, Peuraniemi 1992, Tiainen & Viita 1994, Eilu 2007, Kärkkäinen 2007, Saalmann et al. 2009, Tiainen et al. 2011): 1) Zn-Cu±Pb VMS (Tupala), 2) skarn(?) tungsten ores (Hieronmäki), 3) orogenic gold Au±Cu (Satulinmäki?), and 4) possibly epithermal or porphyry-related Cu±Au (Kedonojankulma).

Scattered VMS-style, Zn-Pb-Ag±Cu mineralisation occurs throughout the Häme area. The occurrences are intimately related to condierite±anthophyllite rocks and sericite schists, indicating metamorphosed equivalents of mafic to felsic volcanic rocks altered in submarine hydrothermal systems (Mäkelä 1980, Mäkelä 1989, Papunen 1990, Tiainen & Viita 1994). Only one occurrence, **Tupala**, has so far been determined to contain a tonnage large enough to warrant resource estimation (Table 5, Fig. 8). Tupala is a stratabound, partially remobilised, zinc-silver deposit hosted by intermediate and felsic volcanic rocks at a contact zone between intermediate and mafic volcanic rock sequences (Mäkelä 1989, Tiainen & Viita 1994).

The gold occurrences in area F004 may all

Table 5. Selected base and precious metal deposits and occurrences in the Häme Au, Zn-Cu area (F004).

Occurrence	Tonnage (Mt)	Ag g/t	Au g/t	Pb %	W %	Zn %	Genetic type	Reference
Tupala	0.76	39		0.71		3.86	VMS	Mäkelä (1989)
Satulinmäki	0.36		2.34				Epithermal or orogenic	Kärkkäinen et al. (2006), Koistinen (2006)
Hieronmäki	0.063				0.32		Skarn?	Peuraniemi (1992)

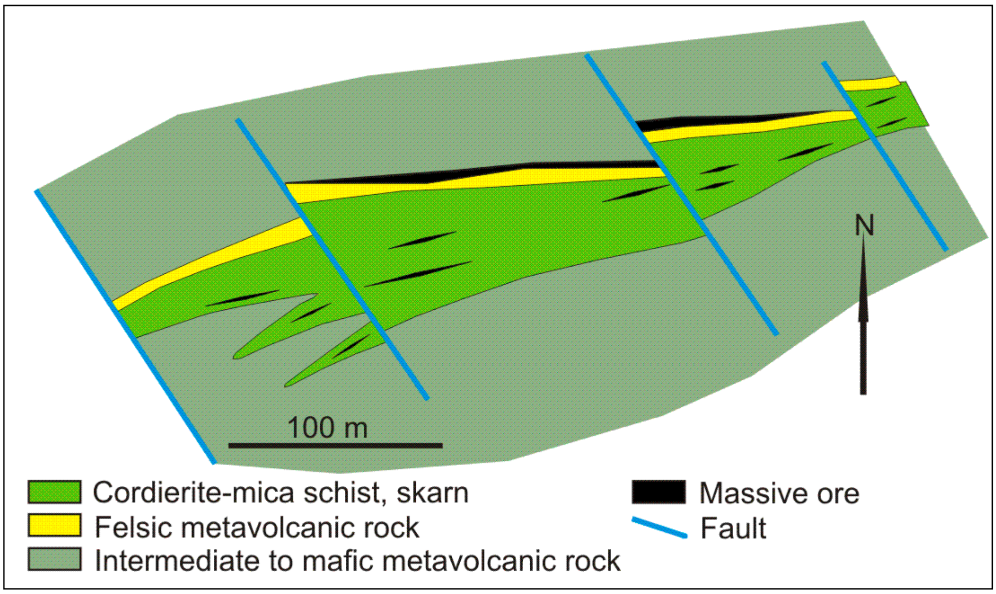

Figure 8. Surface geology at the Tupala Ag-Zn-Pb occurrence (after Mäkelä 1989).

represent the orogenic type or both orogenic and epithermal (or other syngenetic intrusion-related) types. Most of the exploration in the region has been carried out in the western parts of the Häme area (Kärkkäinen 2007), where the **Satulinmäki** deposit (Table 4) is the most extensively investigated of all gold targets. Recent structural geological studies at Satulinmäki (Kärkkäinen et al. 2006, Kärkkäinen 2007, Saalmann 2007, Saalmann et al. 2009) indicate that it is controlled by post-peak deformation structures and that mineralisation took place in possibly two stages of structural evolution of the area. Radiometric dating (hornblende Ar-Ar and zircon U-Pb) of auriferous quartz veins also suggests a late-orogenic timing (between 1.82 and 1.79 Ga; Saalmann et al. 2009). Satulinmäki, and similar occurrences within a few kilometres of it, are hosted by the locally most competent rock units, felsic dykes, and gold occurs closely associated with tourmaline- and arsenopyrite-rich quartz veins. A strong positive correlation occurs between Au, As, Bi, Sb and Te, and the most intensely altered host rock (Perälä 2003, Kärkkäinen et al. 2006, Kärkkäinen 2007). A similar style of mineralisation has also been detected in other localities near Satulinmäki (Saalmann 2007, Saalmann et al. 2009). Gold and gold-copper occurrences have additionally been detected elsewhere in area F004, and it has been suggested (Tiainen et al. 2011) that there are porphyry-type Cu-Au deposits in the area. Metamorphosed epithermal types of deposits are also possible.

The third obvious type of mineralisation in the Häme area is tungsten mineralisation, of which the **Hieronmäki** deposit is most extensively investigated (Table 5). Even at Hieronmäki, the available reporting is minor: the deposit may well be of skarn type (diopside, vesuvianite, garnet and calcite form the gangue), is enriched in As, Co, S, W and Zn, and is in a mafic to intermediate volcanic setting, but little more is known about it.

F005 SOMERO Li

Timo Ahtola (GTK)

The Somero rare metal pegmatite region (metallogenic area F005) is in the Häme volcanic belt between the towns of Tammela and Somero in SW Finland (Figs. 7 and 9). The Häme belt mainly consists of volcanic rocks intercalated with minor greywackes and metapelitic units. Syntectonic plutonic rocks of gabbroic, dioritic, granodioritic and tonalitic composition and late-tectonic K-granites and pegmatitic dykes (Saalmann et al. 2009) intrude the succession. The rocks were metamorphosed in amphibolite-facies conditions with the metamorphic grade increasing to the south leading to local migmatisation and partial melting. Late-tectonic potassic granites and pegmatitic dykes are the youngest magmatic rocks of the Häme volcanic belt (Saalmann 2007).

In the Somero area (approx. 400 km²), at least 56 rare metal pegmatites are known. Of these, at least nine contain lithium silicates and phosphates including cookeite, elbaite, heterosite-siclerite, lepidolite, lithiophilite, petalite, spodumene, triphylite and Li-Fe micas (Vesasalo 1959, Saikkonen 1981, Alviola 1989, 2004). According to Alviola (2003), these lithium pegmatites belong to the LCT (Li, Cs, Ta) family of Černý (1998). It is probable that there are still several unexposed lithium pegmatites in the region, to be discovered in the future.

The two largest lithium occurrences in the area are the Hirvikallio petalite pegmatite and the Kietyönmäki spodumene pegmatite (Table 6). Hirvikallio, the largest known petalite pegmatite dyke in Finland, is vertical, 170 m long, 5–25 m wide, and its average Li_2O content is 1.78 %. The lithium reserve total about 200 000 tonnes, estimated to the depth of 50 m. The pegmatite contains petalite accumulations 0.5–2 m in size in albitic aplite (Alviola 1989). The size of individual petalite crystals varies from 2 to 50 cm. The Kietyönmäki dyke swarm is composed of half a dozen Li pegmatite dykes and some pegmatite granites. In all but one of the pegmatites, petalite is completely altered to SQI (spodumene+quartz intergrowth). During 1987–1988, GTK drilled 17 holes in the Kietyönmäki dyke swarm. The largest dyke at Kietyönmäki is almost vertical, about 200 m long and 10 m wide (Alviola 1989).

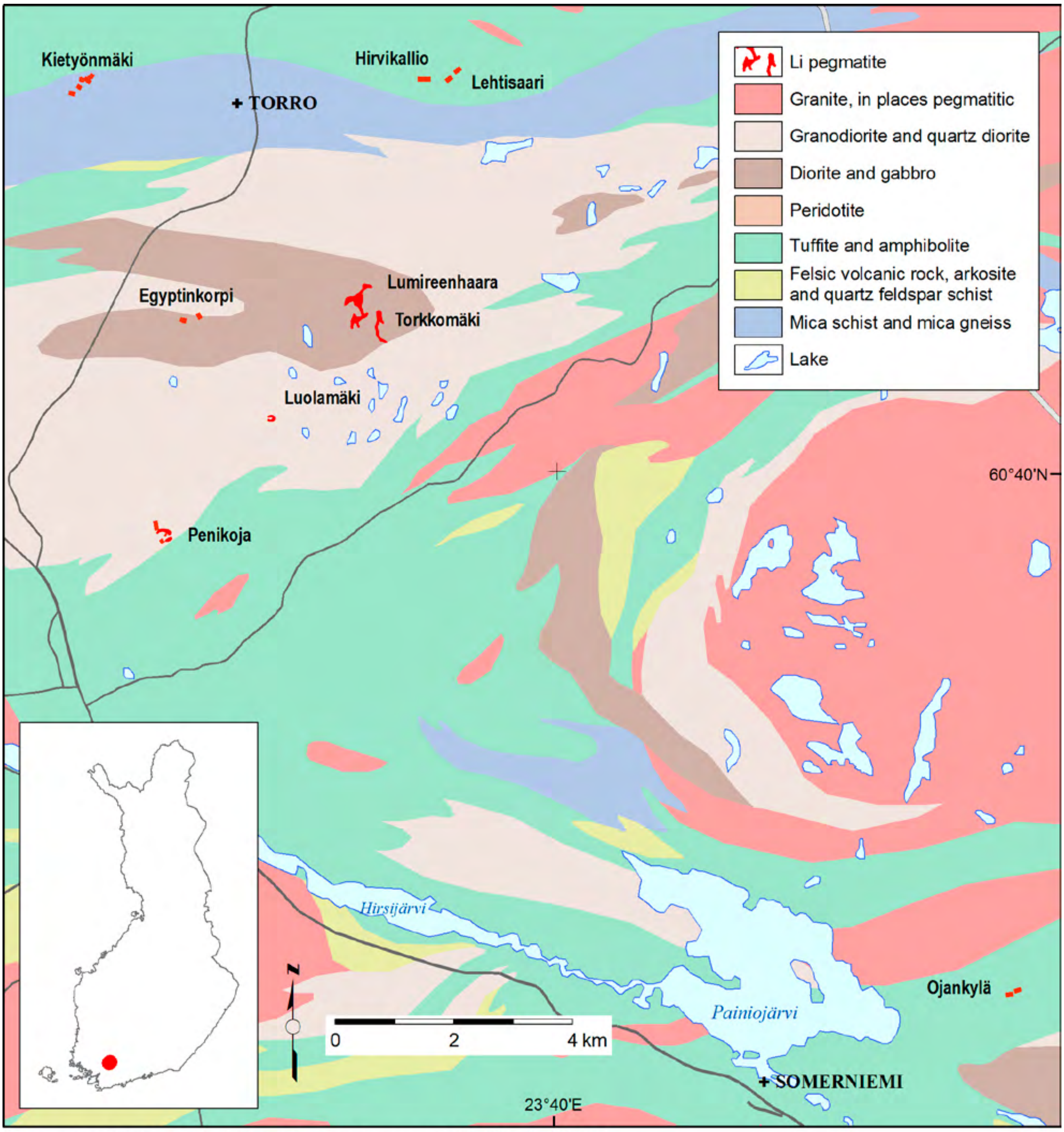

Figure 9. Rare metal pegmatites ('Li pegmatite' in the legend) in the central parts of the Somero area (F005), also called the Somero-Tammela rare metal province (map modified from Alviola et al. 2004).

Table 6. Rare metal occurrences with a resource estimate in the Somero Li area (F005).

Occurrence	Tonnage (Mt)	Li %	Sn %	Ta %	No. of dykes	References
Kietyönmäki	0.4	0.55	0.016	0.003	>5	Alviola (1989, 1993)
Hirvikallio	0.15	0.83			One	Vesasalo (1959), Saikkonen (1981)

F006 VAMMALA Ni

Markku Tiainen (GTK)

The arcuate, W- to NW-trending, Vammala Ni area (F006) is within the Pirkanmaa migmatite suite paragneisses (i.e., Pirkanmaa migmatite belt). Area F006 is bounded to the north by the Tampere schist belt and Central Finland Granitoid Complex, to the SW by the Satakunta Mesoproterozoic sandstone formation and to the south by Southern Finland supersuite. In the east, the area narrows and ends at the Vyborg rapakivi massif. Although not shown here, the Ni-potential area may in fact continue further to the northeast, towards the Kotalahti nickel area (F016). For more details of the geology of the Pirkanmaa migmatite belt, see the description of the Pirkkala metallogenic area (F007).

The narrow core areas of area F006 (Fig. 10), the Pori–Vammala and Kylmäkoski subareas (F006.1 and F006.2, respectively), have been delineated according to the spatial distribution of the known Ni deposits and occurrences and the favourable geology for intrusive-type Ni deposits (Papunen 1980, Häkli & Vormisto 1985, Gaál 1985, Mäkinen 1987, Liipo et al. 1997, Makkonen et al. 2010). The subareas include all nickel mines and known unexploited, economic and subeconomic, Ni deposits of area F006

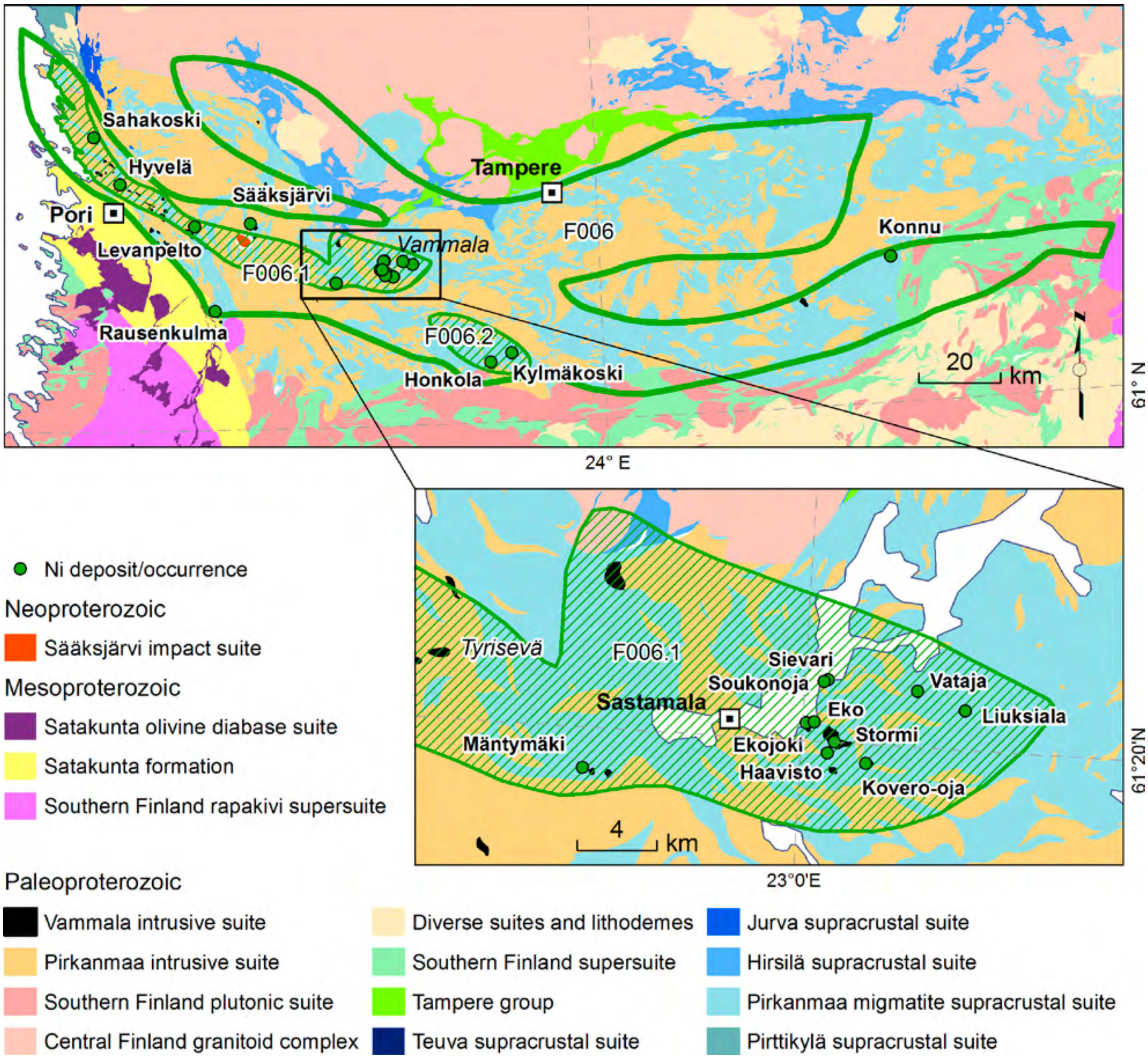

Figure 10. Geology of the Vammala Ni area (F006), with the Pori-Vammala and Kylmäkoski metallogenic subareas (F006.1 and F006.2, respectively), and the most significant nickel-copper occurrences of the region. Geology is from the GTK digital bedrock database.

(Table 7; Saltikoff et al. 2006). The gap between Pori–Vammala and Kylmäkoski subareas is due to granitoid-dominated geology and does not have significant indications of Ni deposits or ultramafic intrusions (Matisto 1973). The subareas are geologically essentially similar, although the number of ultramafic cumulate occurrences in the surroundings of Sastamala is much higher than in the Kylmäkoski subarea. The subareas are characterised by nickel-copper occurrences hosted by synorogenic differentiated ultramafic intrusions in a high-grade metamorphic, polydeformed, throndhjemitic schollen migmatite domain, in originally pelitic to psammitic sediments with sulphide interlayers. The mineralised intrusions are small, typically less than 0.5 km wide, olivine cumulates of arc-type tholeiitic basaltic magma. Dunitic and peridotitic basal layers of the intrusions typically host the sulphide occurrences (Fig. 11; Peltonen 1995, Lamberg 2005). In places, for example at Ekojoki, the core of the intrusion is mineralised (Lamberg 2005). The main ore minerals in the Vammala-type deposits are pyrrhotite, pentlandite and chalcopyrite. Sulphides occur as dissemination or matrix ore occupying the intercumulus of olivine cumulate (Fig. 12). Typical metal contents are 0.4–0.7 % Ni and 0.2–0.5 % Cu (Table 7). The PGE contents are low, except at Ekojoki, where PGE contents up to 1.6 ppm have been detected (Lamberg 2005). Three nickel deposits, **Kylmäkoski**, **Kovero-oja** and **Stormi**, were exploited in the Vammala Ni area during 1971–1994, yielding a combined total of 8.1 Mt of ore averaging 0.67 % Ni and 0.42 % Cu (Liipo et al. 1997). The majority of the ore, 7.4 Mt, was produced from the Stormi deposit.

The **Pori–Vammala subarea** (F006.1) includes two mined deposits, Stormi (Vammala) and Kovero-oja, four sub-economic deposits, namely Ekojoki, Mäntymäki, Hyvelä and Sahakoski, and a group of significant occurrences, including Sääksjärvi, Rausenkulma, Soukko, Liuksiala, Haavisto and Levanpelto (Fig. 10). In addition to the intrusions know to be mineralised, the subarea includes ultramafic intrusions that have the potential for nickel deposits. For example, the large serpentinised pyroxenite-peridotite Tyrisevä intrusion may, according to the mineral chemistry, be mineralised (Peltonen & Jokinen 2002).

The composition of the ultramafic intrusions changes along strike of the subarea from east to west. The intrusions near Stormi are mainly peridotitic and dunitic, whereas in the western part, near Pori, the intrusions seem to include more of the gabroidic and pyroxene-bearing phases and less of the dunitic phase. For example, the Hyvelä deposit is hosted by noritic pyroxene-cummingtonite gabbro and does not include substantial ultramafic phases (Stenberg & Häkli 1985), and the Sahakoski deposit is hosted by a lherzolite-norite intrusion (Mäkinen 1987).

By far the biggest deposit in area F006 is Stormi (Table 7). The ore is hosted by an ultramafic cumulate-textured intrusion at the bottom of the three-layered ultramafic Vammala complex, in the core of a regional F2–F3 antiform (Fig. 11; Häkli &Vormisto 1985, Peltonen 1995, Kilpeläinen 1998, Lamberg 2005). The three main units of the Vammala complex are: 1) a 70-m-thick upper serpentinite, 2) a 100-m-thick intermediate metapicrite

Table 7. Intrusion-hosted Ni-Cu deposits and occurrences with a resource estimate in the Vammala Ni Area (F006).

Subarea Occurrence	Tonnage (Mt)	Co %	Cu %	Ni %	When mined	Main host rock	Reference
Pori–Vammala Ni-Cu (F006.1)							
Ekojoki	1.19	0.02	0.42	0.51		Dunite	Dragon Mining (2007)
Hyvelä	0.807	0.03	0.26	0.52		Norite	Suomen Nikkeli (2006)
Kovero-oja	1.56	0.02	0.33	0.4	1975–1977	Peridotite	Grundström (1973)
Liuksiala	0.05		0.2	0.3		Peridotite	Grundström (1991a)
Mäntymäki	0.466	0.01	0.2	0.73		Lherzolite	Suomen Nikkeli (2006)
Rausenkulma	0.375	0.02	0.49	0.36		Peridotite	Grundström (1999)
Sääksjärvi	3.5	0.03	0.33	0.24		Peridotite	Heikkilä-Harinen (1977a)
Sahakoski	1.6	0.03	0.19	0.65		Peridotite	Belvedere Resources (2006)
Soukko	0.05		0.25	0.44		Peridotite	Grundström (1991b)
Stormi	9	0.04	0.41	0.6	1975–1994	Dunite	Liipo et al. (1997)
Kylmäkoski Ni-Cu (F006.2)							
Kylmäkoski	0.69*	0.01	0.48	0.5	1971–1974	Peridotite	Papunen (1980)

* Only the mined amount is reported.

layer (cortlandite) with metasedimentary intercalations, and 3) a 100-m-thick lower cumulate-textured layered ultramafic Stormi intrusion.

The lower layered ultramafic Stormi intrusion consists of a 2–20-m-thick pyroxenitic and peridotitic marginal series and an almost 100-m-thick dunitic layered series (Lamberg 2005). The layered series consists of olivine, olivine-chromite, olivine-sulphide and olivine-sulphide-chromite cumulates, also including orbicular peridotite at the bottom of the intrusion. The nickel-copper ore is mainly hosted by the dunitic subzones of the layered series, but also in places by the marginal peridotites and pyroxenites (Fig. 11). Offset-type mineralisation has been encountered as massive sulphide veins in the mica gneiss country rocks of the ultramafic intrusion. The main ore minerals, as coexisting phases in the ore, are monoclinic pyrrhotite, pentlandite and chalcopyrite. Hexagonal pyrrhotite occurs as inclusions in the monoclinic pyrrhotite. The nickel content of olivine ($Fo_{75–85}$) varies from 500 to 3000 ppm (Mäkinen & Makkonen 2004), which indicates the deposition of a nickel-bearing sulphide phase from the magma.

The Kylmäkoski subarea (F006.2) includes one mined deposit, Kylmäkoski, the small drilled occurrence of Honkola, and a few indications of nickel mineralisation, both mineralised erratics and outcrops including large ultramafic fragments or sills. The Kylmäkoski deposit is hosted by a peridotitic-dunitic intrusion 260 x 100 m wide and 80 m thick. The deposit consists of pentlandite-pyrrhotite-chalcopyrite dissemination as an intercumulus phase in olivine and olivine-pyroxene cumulates (Papunen 1985). In addition to Ni, Cu and Co, elevated PGE contents have been observed at Kylmäkoski as arsenides (Gervilla et al. 1998)

Several mafic-ultramafic intrusions have been explored outside the Pori-Vammala and Kylmäkoski subareas, but no economic deposits have been found so far. For example, the small Konnu nickel occurrence at Padasjoki, in the easternmost part of area F006, is hosted by a pyroxenite-perodotite sill, indicating the continuation of the Vammala metallogenic area to the east (Kärkkäinen et al. 2003, Tiainen et al. 2007).

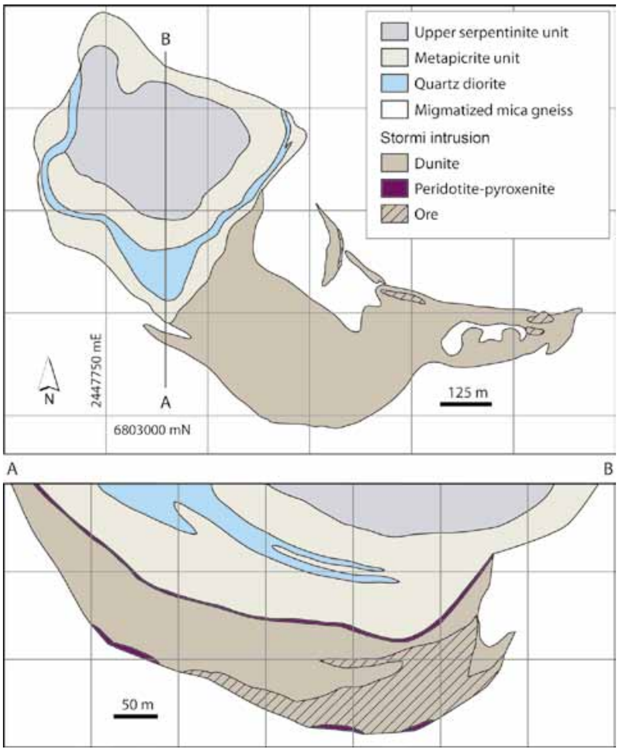

Figure 11. The Vammala ultramafic complex, modified after Häkli and Vormisto (1985) and Lamberg (2005). Surface plan (upper) and cross section (lower) along the line A–B. Grid according to Finnish national KKJ coordinates.

Figure 12. Pyrrhotite-pentladite ore in peridotite at Stormi. Scanned image by Hannu Makkonen, GTK.

F007 PIRKKALA Au

Pasi Eilu & Niilo Kärkkäinen (GTK)

The Pirkkala Au area (F007) is defined by the extent of orogenic gold mineralisation within the Pirkanmaa migmatite belt in SW Finland (Fig. 1). To the north, metallogenic area F007 is clearly bounded by the distinct boundary between the Pirkanmaa migmatite belt and Tampere schist belt, and to the south by the less-distinct boundary between the Pirkanmaa migmatites and the Häme volcanic belt, respectively. To the east and west its boundaries are vague: perhaps the metallogenic area should be open along strike at both ends.

The turbidite-dominated Pirkanmaa migmatite belt is a Svecofennian subduction zone complex pushed towards the present north, below the Tampere schist belt (Kähkönen 2005). In addition to turbiditic mica schist and gneisses, the belt contains minor volumes of black schists, mafic lavas (max age 1.92 Ga), arenites, conglomerates and chert. The area was intruded by synorogenic, ca. 1.89 Ga, mafic-ultramafic, and extensive, ca. 1.88 Ga, tonalites, and metamorphosed under high-T amphibolite facies conditions peaking at about 1.88 Ga (Kilpeläinen 1998, Peltonen 1995 and 2005, Nironen 2005, Saalmann et al. 2010). The region suffered another major stage of deformation and metamorphism during 1.83–1.80 Ga (Kähkönen 2005, Saalmann et al. 2010).

The Pirkkala metallogenic area is characterised by orogenic gold mineralisation; other types of gold mineralisation have not so far been identified in the region (Eilu 2007, Kärkkäinen 2007). Area 007 partially overlaps the Vammala Ni area (F006), and the mineralisation in both took place due to Svecofennian orogenic processes. However, there is only partial regional overlap, no local spatial overlap between the mineralisation types, they are possibly separated by 30–80 Ma in age, and the exact mineralisation processes are very different; hence, two distinct metallogenic areas have been defined within the Pirkanmaa migmatite belt.

Eilu (2007) lists 13 drilling-indicated gold occurrences (at least 1 m @ ≥1 g/t Au) from the Pirkkala area. The present number of known occurrences is close to 20 and seems to increase every year as exploration extends into new areas (Kärkkäinen 2007, Eilu 2012a). Despite the regionally extensive exploration, enough drilling to define a resource estimate has only been carried out at two localities (Table 8). Mica gneiss or synorogenic intermediate intrusive rocks host most of the occurrences in the area. All are gold-only occurrences with a distinct structural control by local shear zones and the hosts typically being the locally most competent lithological units (e.g., Saalmann et al. 2010). The dominant sulphides are pyrite, pyrrhotite, arsenopyrite and löllingite, and the gold occurs both in quartz veins and in the immediate wallrocks of these veins.

The largest known deposit in area F007 is **Jokisivu**, where the current *in situ* resource estimate is 12 t of gold at an average grade of 6.5 g/t Au (Dragon Mining 2010). The two main ore bodies at Jokisivu comprise several auriferous quartz vein arrays surrounded by altered host rock (Figs. 13 and 14). The deposit is controlled by a conjugate set of brittle-ductile shear zones between two major NW-trending shear zones in upper-amphibolite facies rocks (Luukkonen 1994). Most of the gold (90 %) occurs as free native grains chiefly in quartz veins and vein selvages, is locally related to arsenopyrite, and commonly occurs with the minor tellurides (Luukkonen 1994, M. Kilpelä, pers. comm. 13 May 2006). Visible gold commonly occurs in quartz veins. According to age dating and structural interpretation by Saalmann et al. (2010), the hosting diorite at Jokisivu has an age of ca. 1.88 Ga, whereas the mineralisation took place during ca. 1.80 Ga regional-scale granite magmatism and shear zone development. The dominant alteration mineral assemblage diopside-garnet-hornblende-labradorite (Grönholm 2006) suggests mineralisation under mid-amphibolite facies PT conditions.

Table 8. Orogenic gold deposits with a resource estimate in the Pirkkala Au area (F007).

Occurrence	Tonnage (Mt)	Au g/t	Main ore minerals	Host rocks	Reference
Jokisivu	1.831[1]	6.5	Pyrrhotite, arsenopyrite, löllingite	Diorite, mafic volcanic rock	Grönholm (2006), Dragon Mining (2010)
Kaapelinkulma	0.161	6.2	Pyrrhotite, arsenopyrite, löllingite	Quartz diorite, tonalite	Rosenberg (1997), Dragon Mining (2009)

1) Mining started at Jokisivu in 2009.

Figure 13. Jokisivu open pit in September 2009. Photo: Pasi Eilu, GTK.

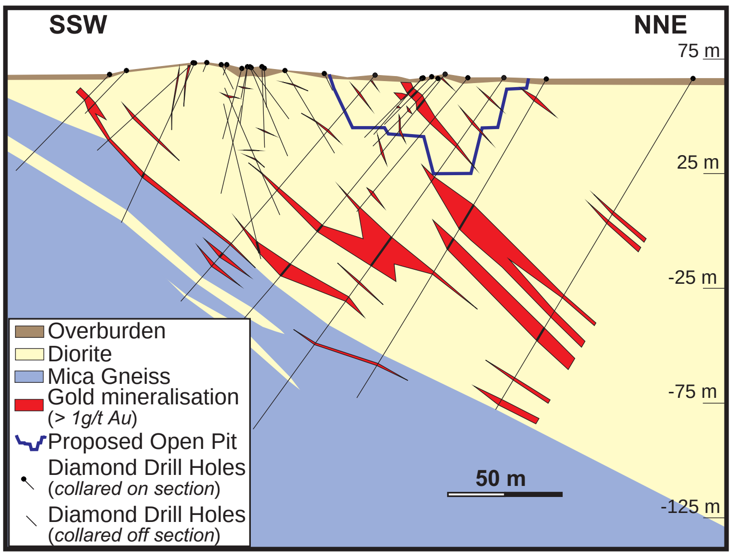

Figure 14. Section across the Kujankallio lodes of the Jokisivu gold deposit. Image: courtesy of Polar Mining, 2009.

F008 ERÄJÄRVI Ta-Li-Be

Pasi Eilu (GTK)

The Eräjärvi metallogenic area (F008) is in the NE margin of the Pirkanmaa migmatite belt, immediately to the south of the Tampere schist belt (Fig 15). Area F008 is defined by the presence of late-orogenic (ca. 1.80 Ga) LCT type of complex pegmatites best known for their numerous Li and Be minerals and Fe-Mn phosphates (e.g., Volborth 1960, Lahti 1981, 1987). More than 70 complex and numerous simple pegmatite dykes are known from the area. The pegmatites are enriched in B, Be, Li, Nb, Sn and Ta (Lahti 1981, Alviola 2004). About 30 pegmatite dykes have been exploited, on a small scale, for quartz, feldspar, muscovite, beryl, amblygonite, and columbite-tantalite, from about 1910 to 1966 (Puustinen 2003). So far, no significant Ta resource has been detected, but area F008 remains potential for rare metals, including Be, Li, Nb and Ta.

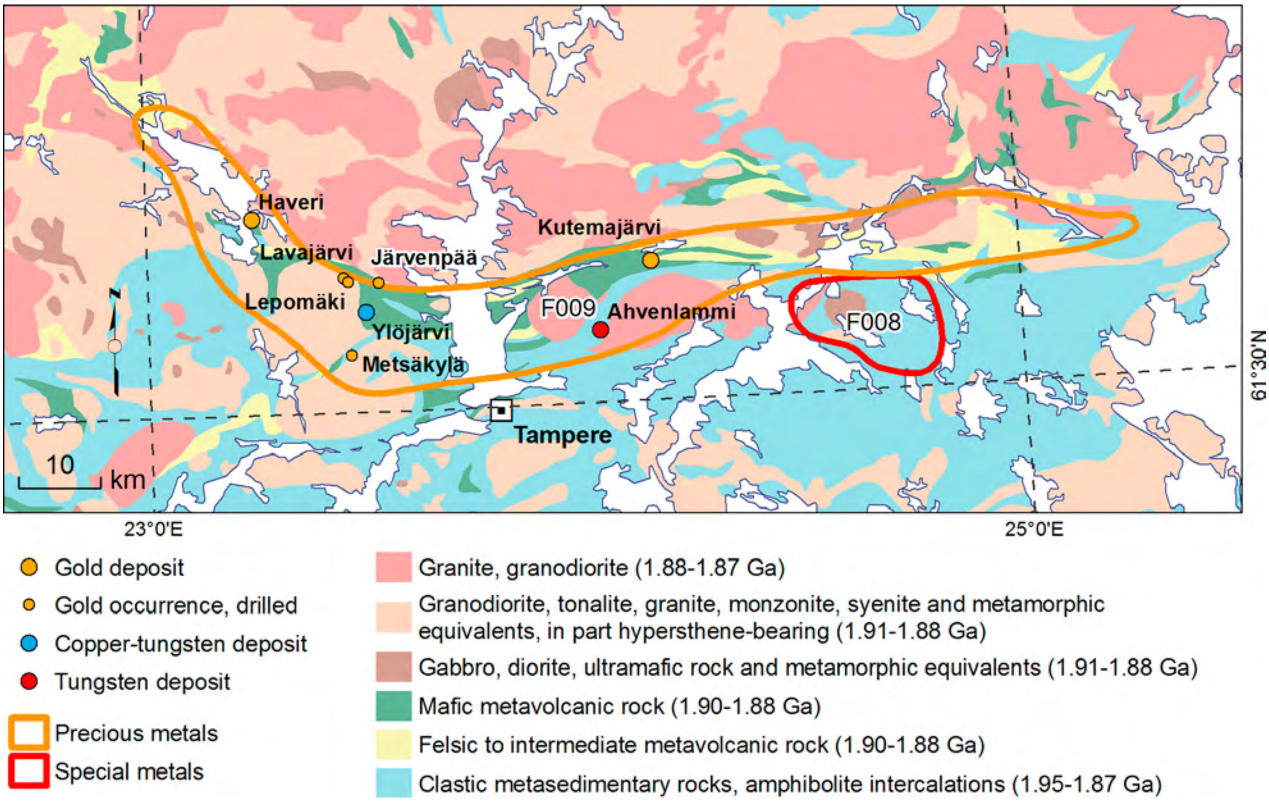

Figure 15. Geology of the Eräjärvi (F008) and Tampere (F009) metallogenic areas and their surroundings, with the most significant metallic deposits and drilling-indicated gold occurrences. Geology from Koistinen et al. (2001).

F009 TAMPERE Au, Cu

Pasi Eilu (GTK)

The Tampere area (F009) comprises the E-trending Tampere schist belt and its possible extension to the east and northeast. Metallogenic area F009 is bounded to the north by the Central Finland Granitoid Complex and to the south by the Pirkanmaa (migmatite) belt (Fig. 15). The Tampere schist belt is formed by supracrustal rocks formed during ca. 1905–1889 Ma and deformed and metamorphosed by 1.88 Ga, indicating a very rapid evolution for the area (Kähkönen 2005). The oldest unit seem to be the ca. 1905 Ma, primitive, EMORB basaltic volcanic rocks at Haveri. However, most of the supracrustals have an arc-like affinity and comprise medium- to high-K intermediate to felsic volcanic and volcaniclastic rocks and turbidites (Kähkönen 2005). The belt has been intruded by hypabyssal (synvolcanic?) porphyries and synkinematic (1.89–1.87 Ga) granitoid batholiths (Nironen 2005).

At least six types of metallic mineralisation have been detected within the Tampere area (Himmi et al. 1979, Mäkelä 1980, Luukkonen 1994, Poutiainen & Grönholm 1996, Talikka & Mänttäri 2005, Eilu 2007, 2012a, 2012b): 1) gold-copper VMS (Haveri), 2) metamorphosed epithermal gold (Kutemajärvi), 3) porphyry- or granitoid-related breccia pipe copper-tungsten (Ylöjärvi, Ahvenlammi?), 4) orogenic gold (western Tampere belt), 5) granitoid-related gold (along Hämeenkyrö batholith margin, western Tampere belt), and 6) zinc VMS (central and western Tampere belt). The latter three styles of mineralisation have only been detected as tiny showings and are not further considered here. Porphyry Cu±Au deposits may occur near high-sulphidation epithermal gold deposits (Hedenquist et al. 1996) and granitoid-related breccia-hosted copper deposits (e.g., Paull et al. 1990). However, no distinct porphyry deposits have so far been detected from the Tampere area.

Haveri (Fig. 17) was the first mine in Finland where gold was among the main commodities (Table 9). The deposit is in the westernmost part of area F009 (Fig. 15), hosted by mafic lava and hyaloclastite, and is stratiform on a large (>100 m) scale (Fig. 16). The host rocks belong to the oldest unit of the Tampere schist belt. The main ore minerals at Haveri are pyrrhotite, chalcopyrite, and magnetite. Gold occurs both closely associated with chalcopyrite and in silicified zones with low copper grades, but is restricted throughout to the domain of sulphide mineralisation. The following genetic types have been suggested for the deposit: VMS, IOCG, and VMS copper overprinted by orogenic gold mineralisation (Mäkelä 1980, Karvinen 2003, Strauss 2004). However, most of the evidence supports the hypothesis of a metamorphosed and deformed gold-rich VMS-style stringer-zone mineralisation, possibly originally resembling the Hellyer deposit in Tasmania (Schardt et al. 2001) as summarised by Eilu et al. (2004) and Eilu (2011b). The present setting of the deposit seems to be in a fold closure (Nironen 1994), suggesting at least some degree of remobilisation of the sulphides from their primary sitings and, hence, obscuring its genetic type.

The **Ylöjärvi** Cu-W(-Ag-As-Au) deposit (Clark 1965, Himmi et al. 1979) is in the western part of the Tampere schist belt (Fig. 15). The ore is in two subvertical, discordant, tourmaline breccia pipes 150 m apart in intermediate tuffite and plagioclase porphyry (Fig. 18). In the area, there also are smaller, unexploited breccia bodies (pipes?) of a similar style. The matrix of the breccia is composed of tourmaline with smaller, variable volumes of ore and other gangue minerals. The major ore minerals at Ylöjärvi are arsenopyrite, chalcopyrite and scheelite. The deposit is about 200–400 m from the Hämeenkyrö synorogenic granodiorite batholith, and research in the area suggests that the mineralising fluids were derived from the batholith, and that the deposit is genetically close to porphyry copper mineralisation (e.g., Himmi et al. 1979).

The **Ahvenlammi** tungsten deposit is in the easternmost part of the Tampere metallogenic area, in supracrustal rocks probably belonging to the Tampere schist belt. Scheelite occurs at Ahvenlammi in quartz and scheelite-only veins, and as dissemination and fracture-fill in greywacke (Luukkonen 1994). The occurrence could be related to the local granites and, hence, go broadly into the same genetic category as the Ylöjärvi deposit.

Kutemajärvi (Orivesi) is the third mine in the Tampere area. It is within a >30 km long, E-trending, variably sericitised zone close to the northern boundary of the Tampere schist belt, with the Järvenpää gold prospect, from which no resource has been reported (Eilu 2007, Eilu 2012a). These occurrences best fit into the category of (metamorphosed) high-sulphidation epithermal gold deposits (Hedenquist et al. 1996), as 1) they are characterised by intense sericitisation, which at Kutema surrounds the ore bodies hosted by metasomatic quartz rock, 2) the proximal alteration zone is surrounded by pyrophyllite-andalusite-quartz rock (Fig. 19), 3) the silicified and sericitised rocks are characterised by intense depletion of nearly all major and trace elements, but enriched in Ag, Au, As, Bi, F, S, Si and Te, 4) the proximal alteration assemblages contain minor amounts of F- and P-rich minerals (e.g. apatite, fluorite, topaz and lazulite), and 5) there are no indications of K or CO_2 enrichment (Luukkonen 1994, Poutiainen & Grönholm, 1996, Talikka & Mänttäri 2005). The geological setting characterised by potentially subaerial, intermediate to felsic volcanism (Kähkönen 2005) is also favourable for an epithermal mineralising system. Epithermal systems commonly do not survive orogeny, as they are easily eroded. However, similar alteration sequences and metal associations have been described, for example, at the Hope Brook (Newfoundland, Canada) and Brewer (Carolina slate belt, USA), where the rocks have been metamorphosed under upper-greenschist or lower-amphibolite facies conditions (Dube et al. 1998, Ayuso et al. 2005). At Kutemajärvi, a possible source for the mineralising fluids is the hypabyssal porphyry immediately to the north of the deposit (Fig. 19), in contact with the alteration halo around the gold deposit (Talikka & Mänttäri 2005).

Table 9. Deposits and occurrences in the Tampere area (F009) included in the FODD database.

Occurrence (Alternative name)	Tonnage (Mt)	Ag g/t	Au g/t	Cu %	W %	When mined	Genetic type	Reference
Haveri	26.26*		1	0.5		1842–1865, 1942–1962	VMS	Mäkelä (1980), Lappland Goldminers (2008)
Ylöjärvi (Paroinen)	4.013**	13.9	0.04	0.75	0.11	1943–1966	Porphyry?	Clark (1965), Himmi et al. (1979)
Kutemajärvi (Orivesi)	2.78		8.9			1990, 1994–2003, 2007–	Epithermal	Poutiainen & Grönholm (1996)
Ahvenlammi	1.12				0.16		Skarn?	Luukkonen (2004)

* Mined 1.56 Mt @ 2.82 ppm Au, 0.37 % Cu (Mäkelä 1980).
** Only the mined amount is anywhere reported.

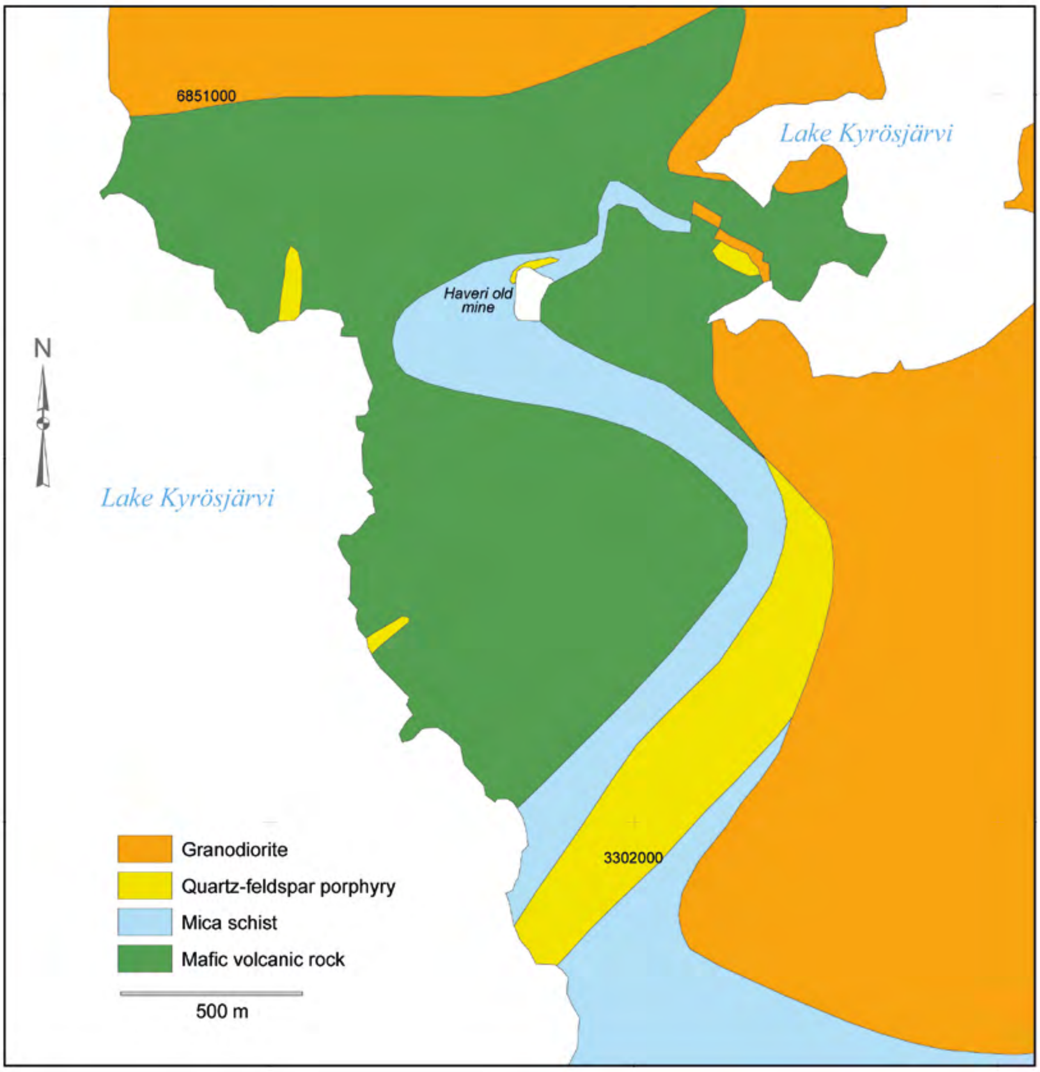

Figure 16. Haveri area, according to Strauss (2004). Possibly, most of what is marked as mica schist in this map is in fact spilitised mafic volcanic rock, especially within the area <500 m from the old mine. Coordinates according to the Finnish National YKJ grid. The Haveri old pit is at 61.713°N, 23.244°E.

Figure 17. The old open pit at Haveri, with the headframe in the background, in November 2004. View to the north; photo: Pasi Eilu, GTK.

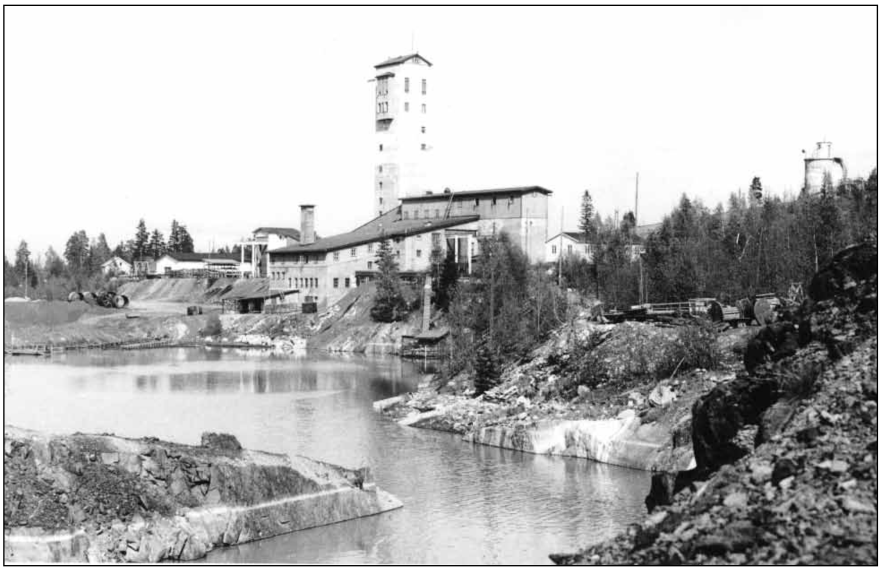

Figure 18. Ylöjärvi mine during operation in 1960s. The mine is at 61.609°N, 23.500°E. Photo: courtesy of Outokumpu Oy.

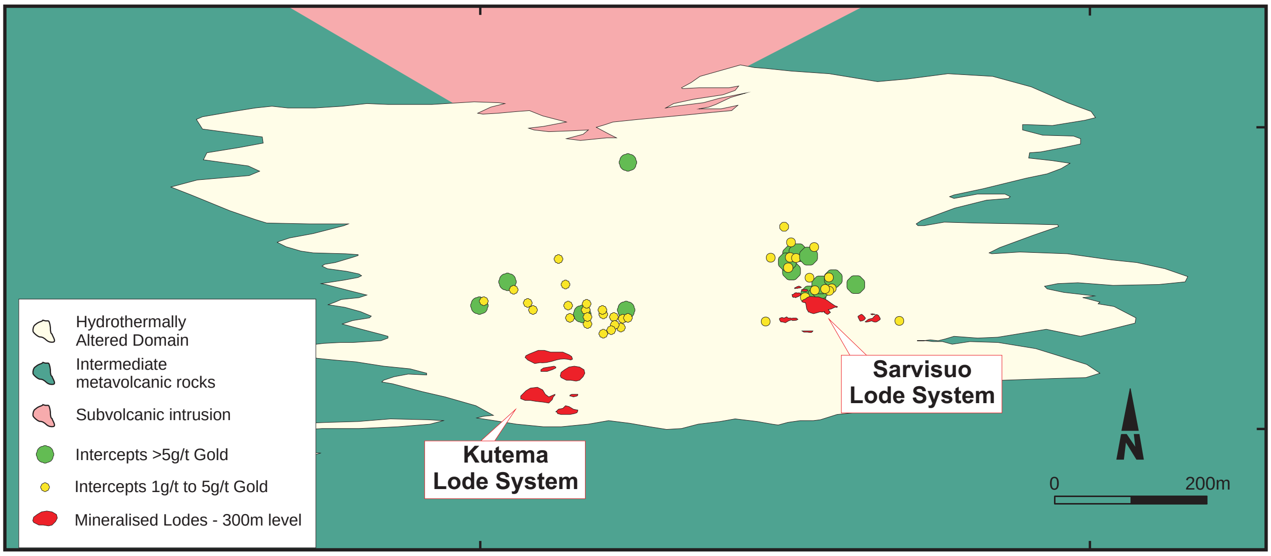

Figure 19. Surface geology of Orivesi gold mine and its immediate surroundings. The Kutema Lode System is at 61.653°N, 24.157°E. Image: Polar Mining, 2009.

F010 TELKKÄLÄ Ni-Cu

Hannu Makkonen (Belvedere Mining Oy)

The WNW-trending, Telkkälä Ni-Cu area (F010) is within the southern part of the Saimaa-Lahdenpohja metaturbidite-synorogenic intrusive area. Area F010 (Fig. 20) is defined by the presence of nickeliferous, ca. 1.89–1.88 Ga, synorogenic mafic-ultramafic intrusions. It is bounded to the north by Svecofennian metaturbidites and synorogenic granitoids and to the south by the Mesoproterozoic Vyborg rapakivi massif. Among the synorogenic gabbros, hornblende varieties predominate, but norites are also present (Häkli 1985). Area F010 is related to a distinct positive gravimetric anomaly; the known nickel deposits are in the southern part of this anomaly. The domain covering the so far discovered nickel deposits (Table 10) and their immediate surroundings defines an area of high potential of discoveries, which we here call the Telkkä Ni subarea (F010.1).

The most important deposit so far discovered in the area F010 is **Telkkälä** (Fig. 21). It is hosted by a differentiated mafic-ultramafic intrusion composed of a cummingtonite gabbro-norite-perknite outer part and of a peridotitic core. The intrusion is located within veined migmatitic and schollen-migmatitic garnet-cordierite-mica gneisses. The horizontal dimensions of the Telkkälä intrusion are 50 x 150 metres and the depth is about 50 metres. In addition to this, there is a 200-m-long peridotite at the depth of 110–225 m, hosting the deep ore. The Telkkälä intrusion was intruded before or during the main stage of regional deformation and metamorphism, D_2, of the area.

The Telkkälä deposit consists of three ore bodies: 1) surface ore, including massive ore in peridotite and perknite, as well as network and disseminated ore in cummingtonite gabbro, 2) offset ore made by a major massive sulphide vein, and 3) deep ore, consisting of massive, network and disseminated ore in peridotite and norite and massive ore in the contact zone of norite and peridotite. The main ore minerals are pyrrhotite,

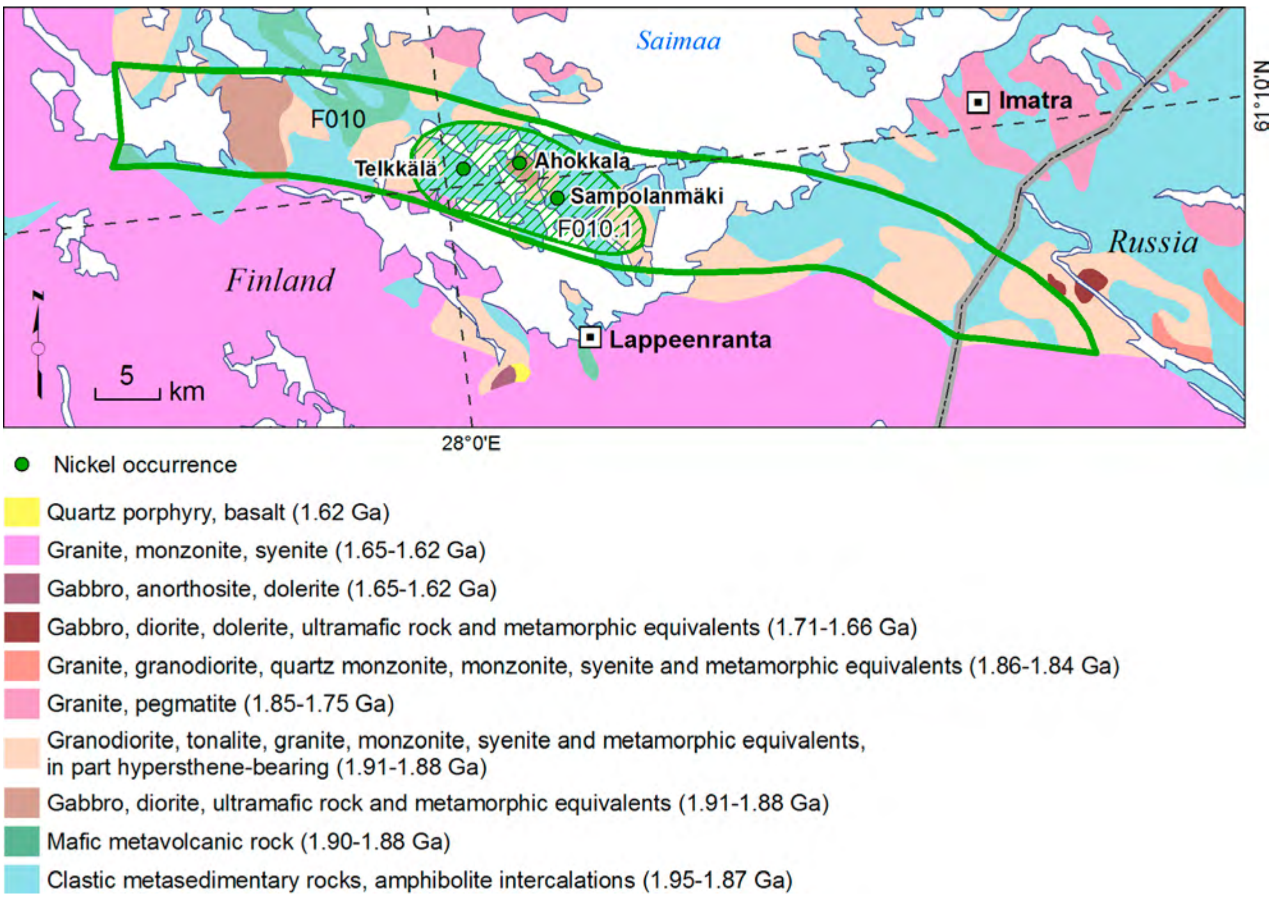

Figure 20. Geology of the Telkkälä Ni-Cu metallogenic area (F010), with the Telkkä metallogenic subarea (F010.1), and the most significant nickel-copper occurrences of the area (Table 10). Geology is from Koistinen et al. (2001).

pentlandite and chalcopyrite. According to Häkli et al. (1975), the massive and breccia ores were formed in the cooling stage of the intrusion, when the increased hydraulic pressure brecciated the rocks and sulphide liquid invaded the open spaces. Copper-rich sulphide liquid, which segregated from the bulk of the sulphide liquid, produced chalcopyrite stringers of the second generation. An alternative explanation for the massive ores is that sulphides were remobilised during the D_2–D_3 deformation stages and emplaced into D_3 shear structures, forming the massive sulphide ore. The Telkkälä deposit was mined in two phases, first the surface ore in 1969–1970 (211 331 tonnes at 1.06 % Ni and 0.29 % Cu), and then the deep ore in 1988–1992 (394 065 t at 1.41 % Ni and 0.35 % Cu) (Isomäki 1992, 1994).

Table 10. Mafic-ultramafic intrusion-hosted Ni-Cu deposits and occurrences in the Telkkälä Ni-Cu area (F010). All deposits with a resource estimate are within subarea F010.1.

Occurrence	Tonnage (Mt)	Co %	Cu %	Ni %	When mined	Main host rock	Reference
Telkkälä	0.605*	0.05	0.33	1.29	1969–1970, 1988–1992	Peridotite, gabbro	Isomäki (1992)
Ahokkala	0.02		0.2	1.25		Norite	Kärkkäinen et al. (2003)
Sampolanmäki	0.03		0.2	0.4		Gabbro	Kärkkäinen et al. (2003)

* Only the mined amount is reported

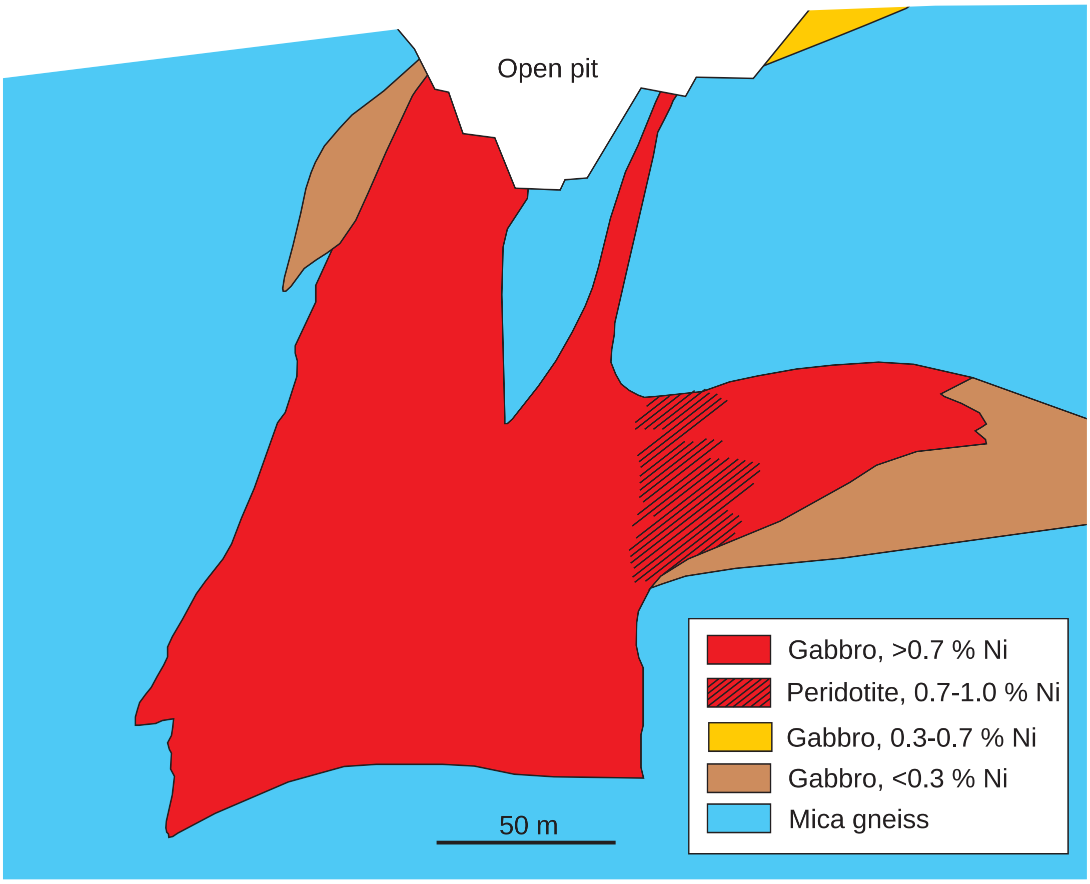

Figure 21. Geology of the Telkkälä nickel mine, at 61.1794°N, 28.0275°E. Modified from Eeronheimo and Pietilä (1988).

F011 PERÄKORPI Ti

Niilo Kärkkäinen (GTK)

The Peräkorpi Ti area (F011) comprises a cluster of Ti, P and Fe-rich gabbro intrusions within the westernmost corner of the Central Finland Granitoid Complex (Fig. 22). The Central Finland Granitoid Complex belongs to primitive arc complex of Central Finland and is composed of collision-related intrusions (1.89–1.87 Ga) and granitic intrusions (1.88 Ga) post-dating the main stage of crustal thickening (Korsman et al. 1997). The Peräkorpi Ti area is composed of several P-Ti-Fe-rich mafic intrusions at the contact zone between the postorogenic Lauhavuori granite in the west and the synorogenic granodiorite-dominant area in the east (Fig. 22). Peltonen (2005) classified the Peräkorpi Ti-Fe-P gabbros into Group III in his three-part division of the Svecofennian mafic-ultramafic intrusions. Their geochemical characteristics are similar to anorogenic gabbros, and they form a bimodal magmatic suite with potassium-rich granites. Perämaa and Lauhavuori granite intrusions are probably related to same geotectonic event, a mature postorogenic type of magmatism (Peltonen 2005).

There are three major intrusions: Perämaa (Peräkorpi) at Honkajoki, and Kauhajärvi and Lumikangas at Kauhajoki (Fig. 22, Table 11). Apatite-rich Ti-Fe occurrences also occur in geophysical anomalies at Kirveskylä near Kauhajärvi and at Hyyppä near Lumikangas (Huuskonen & Kärkkäinen 1994). At Ratuskylä, there is an analogous anomaly under thick overburden. The length of these intrusions varies between 2 and 10 km and the width between 1 and 3 km. All of these intrusions are quite similar in hosting low-grade apatite-ilmenite-ilmenomagnetite deposits with an average of about 20 wt% of the three ore minerals combined. Ilmenite is mainly igneous and occurs as separate grains, although much of ilmenite also occurs as lamellas in magnetite (ilmenomagnetite). The normative ratio of ilmenite to magnetite averages 1.5. Perämaa and Kauhajärvi show distinct differentiation from peridotite to anorthosite, whereas Lumikangas is composed of rather homogeneous layered gabbro and monzogabro.

The **Kauhajärvi** intrusion (Fig. 23) has a thin,

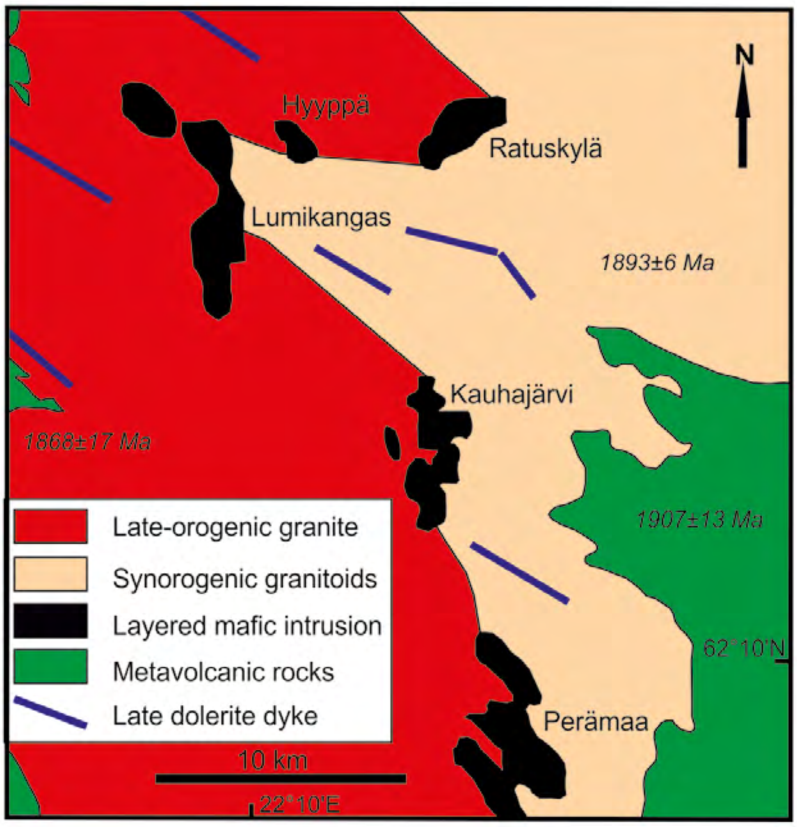

Figure 22. Geology of the central parts of the Peräkorpi metallogenic area (F011) and the most significant titanium occurrences of the area (based on Kärkkäinen & Appelqvist 1999). Numbers in italics indicate igneous ages in Ma for the rocks that are labelled.

poorly-layered, gently-dipping, basal zone (50 m thick) of gabbro. It is crystallised from a rather primitive magma under relatively low f_{O2} conditions. The voluminous, modally well-layered main zone (>400 m) is composed of peridotite, olivine gabbro, gabbronorite, gabbro and anorthosite, and represents more evolved parental magma that crystallised under relatively high f_{O2} conditions (Kärkkäinen & Appelqvist 1999). The Fe-Ti oxides and apatite are concentrated in several layers that are up to tens of metres thick and contain 4–8 % TiO_2, 19–40 % Fe_2O_3 and 1–3.6 % P_2O_5. Ilmenite, apatite and Ti magnetite (ilmenomagnetite) have crystallised coevally with mafic silicates (olivine, pyroxenes) from an early intrusive stage, and are common throughout the intrusion. The Ti/Fe ratio, TiO_2/Fe_2O_3 = 0.16–0.20, does not vary across the stratigraphy of the intrusion. The small variation in the Fe/Mg ratio and the high abundance of apatite (2–8 %) throughout the main zone, without a clear stratigraphic variation, indicate that iron and phosphorus were enriched together with titanium in the parental magma. A high P in magma allowed the crystallisation of ilmenite under relatively oxidising conditions.

The drilled part of the 5 km long **Lumikangas** magnetic and gravity anomaly, 15 km northwest of the Kauhajärvi gabbro, comprises gently-dipping (30° to the E) layered mafic intrusion characterised by uniformly high P_2O_5 and TiO_2, a rather high K_2O, and low Cr contents, a high normative alkali feldspar content, and coeval crystallisation of apatite, Fe-Ti oxides and mafic silicates (Sarapää et al. 2006a). Its composition varies from dark oxide gabbro (>10 % ilmenite and magnetite) to apatite-rich leucogabbro and monzogabbro in the upper part of the intrusion. The oxide-rich part is 1200 m long, 300 m wide and 200 m thick, and contains 19 % of ore minerals: 8.7 wt% ilmenite (up to 21 wt%), 5.4 % apatite (up to 17 wt%) and 4.8 wt% magnetite (up to 17 wt%).

Table 11. Ilmenite-magnetite-apatite occurrences with a resource estimate from the Peräkorpi area (F011). All are hosted by a layered intrusion.

Occurrence	Tonnage (Mt)	Ti %	Main host rock	References
Perämaa	200*	3.2	Peridotite	Pakarinen (1984)
Kauhajärvi	9.6	6.6	Peridotite	Kärkkäinen (1999), Kärkkäinen & Appelqvist (1999)
Lumikangas	230*	2.8	Monzogabbro	Sarapää et al. (2006a, 2006b)

* Due to the low density of drilling, only a rough estimate is available.

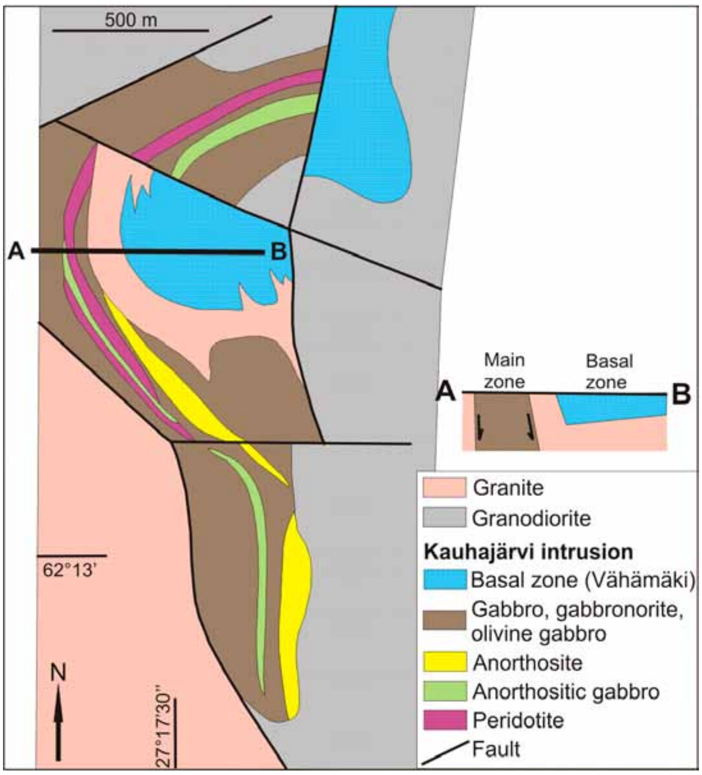

Figure 23. Geology of the Kauhajärvi gabbro (based on Kärkkäinen & Appelqvist 1999).

F012 PUUMALA Ni-Cu

Hannu Makkonen (Belvedere Mining Oy)

The NW-trending Puumala Ni-Cu area (F012) is entirely within the Saimaa-Lahdenpohja metaturbidite-synorogenic intrusive area (Fig. 24). It comprises a set of mineralised tholeiitic mafic-ultramafic intrusions surrounded by metaturbidites and synorogenic granitoids. The metallogenic area includes two small subareas with high potential for discoveries: Niinimäki Ni (F012.1) and Kekonen Ni (F012.2). They differ distinctly in their country rocks. The Niinimäki subarea is located within a granulite facies garnet-cordierite-(sillimanite) gneiss area, representing the 1830 Ma thermal metamorphism with K granites (e.g., Korsman et al. 1988). This younger metamorphic event largely destroyed the fingerprints of the earlier ca. 1.89 Ga metamorphic event. The Kekonen subarea, by contrast, is characterised by country rocks typical for the Kotalahti Ni area, that is, variously migmatised metaturbidites and synorogenic, mainly tonalitic granitoids. Despite the currently different environment, the mafic-ultramafic intrusions and related deposits in both subareas were originally similar (Makkonen 1996).

The Niinimäki subarea (F012.1) includes nickel deposits and occurrences of the Luonteri-Heiskalanmäki belt and the **Niinimäki** deposit to east (Fig. 24). The eastern boundary of the area, and thus of the Puumala Ni-Cu area, may extended some tens of kilometres to the east-southeast from Niinimäki, where there are a few small Ni-Cu occurrences (e.g. **Kitula** and several deposits at Partalansaari). The latter are, however, outside any designated metallogenic area in the map by Eilu et al. (2009).

The N-trending Luonteri-Heiskalanmäki belt is 2 km wide and 15 km long. The dip of the metasedimentary units and embedded sill-like intrusions is steep. The stratigraphic footwall of the intrusions, where the Ni-Cu deposits are located, is towards the east (Makkonen 1996). The largest intrusions are over 2 km long but narrow. The most important deposits include, from south to north, **Pihlajasalo**, **Rietsalo** and **Heiskalanmäki** (Table 12). In addition, several showings have been found and, on the basis of glacial erratic boulder data, at least a few are still to be found. The PGE contents of the ore are anomalously high at Rietsalo (up to 1 m @ 1.2 g/t Pt) and Heiskalanmäki (0.19 g/t Pt, 0.29 g/t Pd) compared to a typical Svecofennian Ni-Cu deposit (Makkonen 1996a).

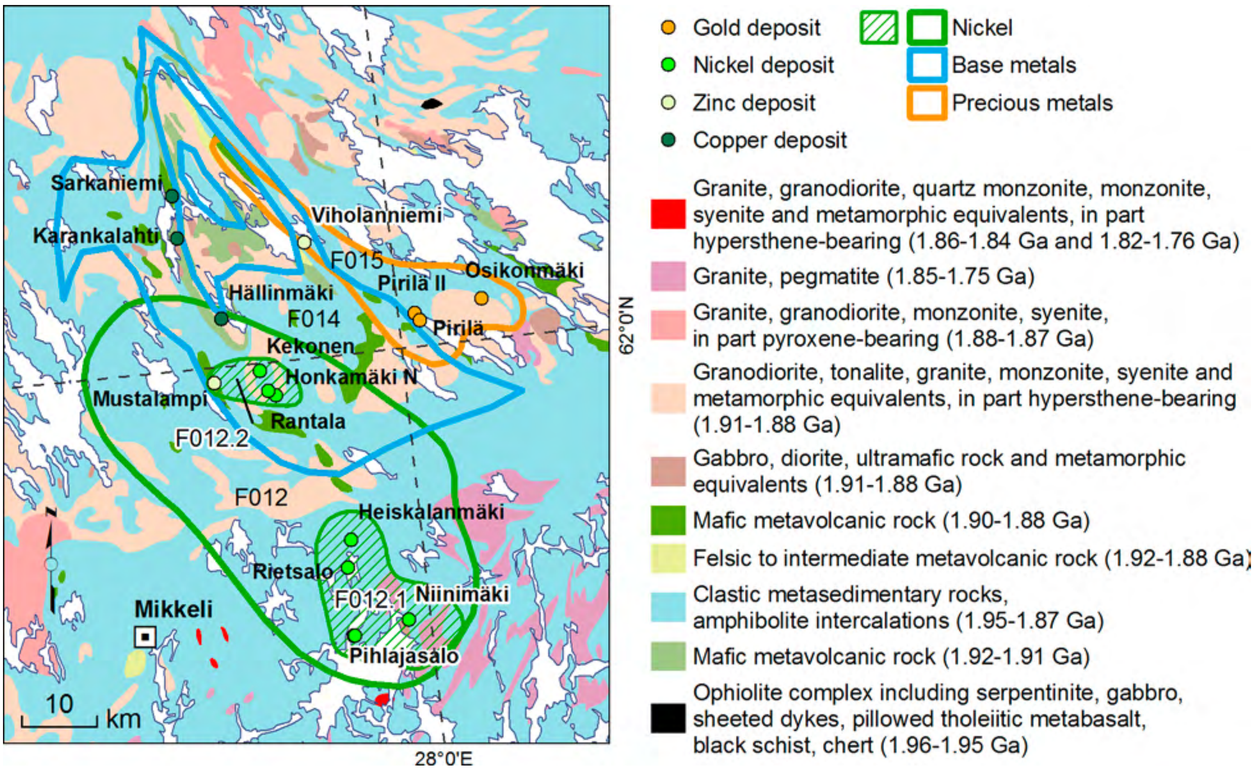

Figure 24. Geology of the Puumala Ni (F012), Virtasalmi Cu (F014) and Rantasalmi Au (F015) metallogenic areas with the most significant nickel, copper and gold occurrences of the area. Geology is from Koistinen et al. (2001).

Around the **Niinimäki** intrusion itself, the dip of the metasedimentary units is shallow or subhorizontal. Consequently, the mafic-ultramafic intrusions are not as elongated as in the Luonteri-Heiskalanmäki belt. The following description for the Niinimäki intrusion and deposit is slightly modified from Makkonen et al. (2008). The horizontal section of the Niinimäki intrusion at the 100 m level is 1 x 2 km and the total thickness is 300 m (Fig. 25). At the surface, the intrusion only occupies an area of 1 km^2, the intrusion being partly overlain by mica gneiss. The layering and schistosity in the surrounding gneisses conforms with the intrusion contacts.

The Niinimäki intrusion mainly consists of gabbro. Because of the high metamorphic grade, there are no primary magmatic minerals left, the main mineral phases being metamorphic orthopyroxene and plagioclase, or in places hornblende and biotite. In mineralised zones near peridotite, the gabbro is altered and the main minerals are plagioclase, chlorite, serpentine and biotite. Peridotite occurs as 50–150 m thick layers with sharp contacts within the gabbro near the stratigraphic footwall of the intrusion. In contrast to the gabbro, olivine and orthopyroxene are the predominant primary magmatic minerals in the peridotite. The ultramafic rock can thus be classified as a harzburgite. Olivine is partly serpentinised and clinoamphibole occurs as an alteration product after orthopyroxene. Minor pyroxenite, composed of orthopyroxene and clinoamphibole, is associated with the peridotite. Small amounts of tonalite also occur within the intrusion, possibly representing the latest differentiates (Makkonen 1997). Country rock contamination is shown, for example, by a high LREE content, high Zr/MgO ratio, and low ε_{Nd} (1.9 Ga) value of 1.0 ± 0.4. *In situ* nickel depletion is found in olivine, and nickel depletion is also shown by the whole rock Ni–MgO ratio (Makkonen 1996). Nickel orebodies occur at the western margin of the intrusion, hosted by both gabbro and peridotite (Table 12). Disseminated sulphides (pyrrhotite, pentlandite, chalcopyrite) occur in the harzburgite and disseminated, net-textured and massive sulphides in the altered gabbro. Near the surface, the gabbro-hosted ore is altered to pyrite-violarite ore (Makkonen & Forss 1994, 1995)

The Kekonen subarea (F012.2) includes three Ni-Cu deposits (Table 12) and a few occurrences without a resource estimate. In addition, there are a few unexplored, relatively large intrusions that could host nickel deposits. Schollen migmatites, typical country rocks for the Svecofennian Ni-bearing intrusions, exist near the **Kekonen** deposit. The petrology of the Saarijärvi intrusion, just south of Kekonen, has been studied by Pietikäinen (1986) and Makkonen (1996). It is an example of a Ni-potential intrusion with Ni depletion and contamination features (enriched LREE, ε_{Nd} (1.9 Ga) 0.4 ± 0.3). Drilling intersects of 0.7 % Ni have been reported in the Saarijärvi intrusion, but no distinct ore body has so far been identified. The Kekonen deposit includes portions where PGE and Au contents are anomalously high (0.45 m @ 0.15 g/t Pd, 0.21 g/t Au; Makkonen 1996a, Makkonen 1996).

Table 12. Mafic-ultramafic intrusion-hosted Ni-Cu occurrences with a resource estimate in the Puumala Ni-Cu area (F012).

Subarea **Occurrence**	**Tonnage (Mt)**	**Co %**	**Cu %**	**Ni %**	**Main host rock**	**Reference**
Niinimäki Ni (F012.1)						
Niinimäki peridotite	2.4	0.016	0.13	0.36	Harzburgite	Makkonen & Forss (1995)
Niinimäki gabbro	0.223	0.043	0.27	0.87	Metagabbro	Makkonen & Forss (1994, 1995)
Rietsalo	0.056	0.015	0.53	0.53	Gabbro	Makkonen (1996a)
Heiskalanmäki	0.055	0.015	0.25	0.55	Gabbro	Makkonen (1995)
Pihlajasalo 1	0.01	0.023	0.24	1.14	Perknite	Makkonen & Mursu (2004)
Pihlajasalo 2	0.01	0.012	0.22	0.55	Gabbro	Makkonen (1996b)
Kekonen Ni (F012.2)						
Kekonen	0.056	0.02	0.21	0.54	Olivine gabbronorite	Makkonen (1985, 1996)
Honkamäki	0.01	0.02	0.2	0.35	Hornblendite	Makkonen (1992a)
Rantala	0.02		0.34	0.53	Picrite	Makkonen (1996a)

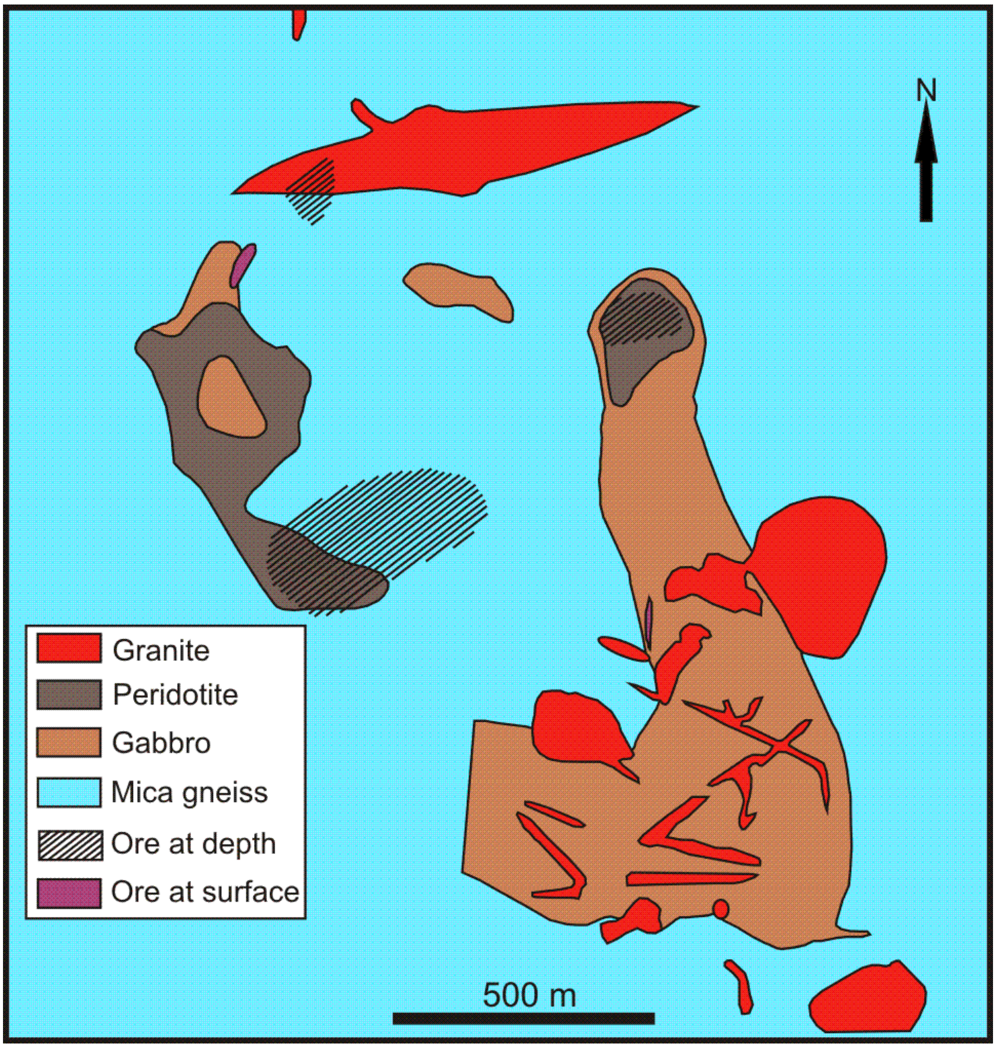

Figure 25. Geology of the Niinimäki nickel deposit, located at 61.6766°N, 27.945°E. Modified from Makkonen & Forss (1995) and Grundström (1998), mapped by J. Vilen (GTK) in 1997.

F013 ILMOLAHTI Ni-Cu

Hannu Makkonen (Belvedere RMining Oy)

The NW-trending Ilmolahti Ni-Cu area (F013) is a west-opening arcuate belt near the eastern margin of the Central Finland Granitoid Complex (Fig. 1). It contains scattered nickeliferous mafic-ultramafic intrusions surrounded by metaturbidites and synorogenic granitoids. Most of the deposits are of low nickel grade. Deposits in the middle of area F013, such as **Törmälä** (Kontoniemi & Forss 1999) and **Mäkisalo**, are in the Rautalampi granulite domain. Within area F013, only the Törmälä deposit is close to being economic based on its nickel grade and ore amount (Table 13).

The Rautalampi granulite domain, about 40 km west of the Archaean craton, belongs to the contact area between the Central Finland Granitoid Complex and the Savo schist belt. The central part of the Törmälä region forms a structural dome, with gneissic tonalites (1.93–1.91 Ga) in the centre, together with the mafic-ultramafic rocks (Lahtinen 1994, Pääjärvi 2000). The tonalites are the oldest rocks in the area, which means that the mafic-ultramafic intrusions occur stratigraphically at the lowest level in the area. In addition to the Törmälä and Majasaari intrusions, several relatively large, unexplored intrusions occur within or near the structural dome.

The Törmälä gabbro-peridotite intrusion has a surface extent of around 50 x 150 m. The thickness of the body is up to 40 m and it dips gently to the NW. The contacts with the surrounding tonalite gneisses are tectonised. The main rock types are olivine gabbronorite and plagioclase-bearing lherzolite, whereas coarse-grained gabbronorite and pyroxenite are found along the intrusion margins. The central part of the intrusive body is slightly more mafic (higher whole-rock Mg-number and higher Fo) than the margins. Sulphides (pyrrhotite, pentlandite, chalcopyrite) occur in varying amounts as coarse-grained disseminations and breccias throughout the intrusion body. The highest sulphide concentrations are found near the footwall contact. (Makkonen et al. 2008)

Country rock contamination features typical for Svecofennian nickeliferous intrusions are not obvious at Törmälä. This is probably because in most of the Svecofennian nickel-rich intrusions the country rock is mica gneiss, whereas at Törmälä it is tonalitic gneiss. The ε_{Nd} (1.88 Ga) value in the Törmälä peridotite is 1.2–1.4 ± 0.4, whereas much lower values are common in other analysed intrusions within the Svecofennian domain (Makkonen & Huhma 2007). Nickel depletion is distinct in both olivine and whole rock at Törmälä (Makkonen et al. 2008).

Table 13. Mafic-ultramafic intrusion-hosted Ni-Cu deposits and occurrences in the Ilmolahti Ni-Cu area (F013).

Occurrence	Tonnage (Mt)	Co %	Cu %	Ni %	Main host rock	Reference
Ilmolahti	0.21	0.04	0.28	0.37	Peridotite	Papunen & Vorma (1985)
Mäkisalo	0.104	0.03	0.28	0.43	Gabbro	Kontoniemi & Forss (2001)
Ohensalo	0.137		0.29	0.24	Gabbro	Heikkilä-Harinen (1977b)
Törmälä	0.116	0.03	0.33	0.6	Gabbro	Heino (1999), Kontoniemi & Forss (1999)

F014 VIRTASALMI Cu

Kaj Västi (GTK)

The Virtasalmi Cu area (F014) is located in the northwestern corner of the Saimaa Schist area. It is bordered in the west by the Central Finland Granitoid Complex and in the east by the Savo Schist Belt. It overlaps the Puumala Ni area (F012) in the south and the Rantasalmi Au area in the east (F015) (Fig. 24).

Area F014 comprises NW-trending supracrustal (1.92–1.90 Ga) and synorogenic plutonic (1.90–1.88 Ga) rocks affected by polyphase deformation and upper-amphibolite to granulite facies metamorphism. Supracrustal rocks are mafic to intermediate metavolcanic and metasedimentary rocks. Metavolcanic rocks are mainly amphibolites, diopside amphibolites and iron-rich skarn rocks, which contain andradite, diopside-hedenbergite, epidote, magnetite and locally scapolite. In places, there are marble intercalations in the amphibolites. Metasedimentary rocks in the region include mica gneiss and mica schist (Lawrie 1987, 1992, Pekkarinen 2002).

The relatively small metallogenic area F014 is characterised by the Virtasalmi-type (Hällinmäki-type) amphibolite and iron-rich garnet skarn hosted Cu deposits, which typically contain only traces of other base metals. The mineralised skarns probably are metamorphosed equivalents of altered and metamorphosed mafic volcanic rocks and ore formed in sea floor-related hydrothermal systems, and the ores could therefore be classified into the VMS (*sensu lato*) category of mineralisation (Lawrie 1987, 1992).

All Cu occurrences in the area comprise disseminated, brecciated and locally massive sulphide mineralisation (Fig. 26). The brecciated ore type occurs as mesh-like structures or lenses and is related to skarn rocks. Disseminated ore mainly occurs in diopside amphibolites (Hyvärinen 1969, Lawrie 1987, Pekkarinen 2002). Chalcopyrite is practically the only Cu-bearing sulphide, although in places there also is cubanite. Pyrrhotite, pyrite and magnetite also occur as major ore minerals. Only the **Hällinmäki** (Virtasalmi) deposit has been exploited (Fig. 27). Other Cu occurrences listed in Table 14 are prospects where resources and Cu contents vary between 0.003–0.37 Mt and 1.0–2.85 %, respectively.

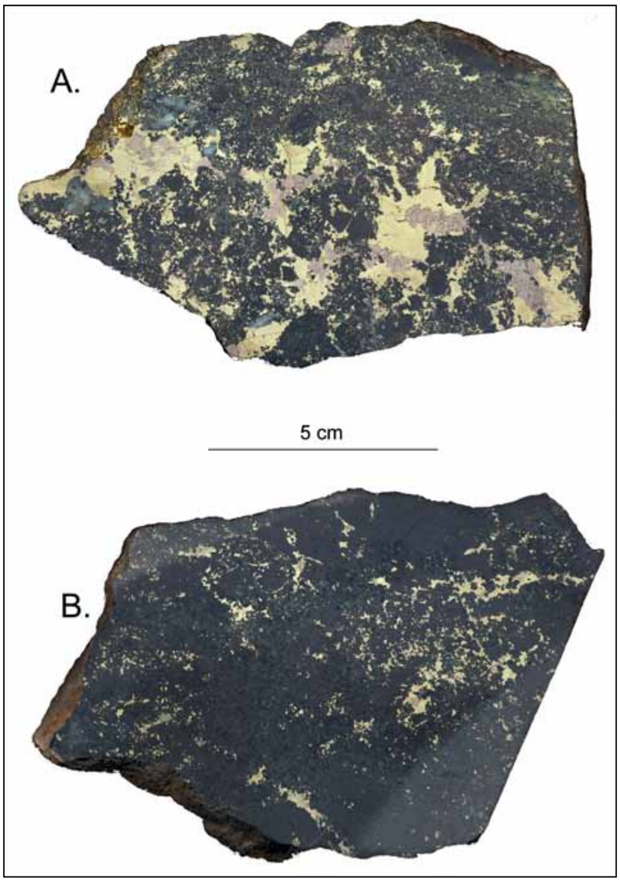

Figure 26. A) Chalcopyrite (yellow), and pyrrhotite (brown) in andradite skarn. B) Disseminated chalcopyrite with minor pyrrhotite in diopside amphibolite. Both images at the same scale. Scanned image by Kaj Västi, GTK.

The now exhausted volcanogenic-exhalative Hällinmäki deposit comprised five ore bodies (Fig. 28), was about 500 m long and 2–30 m wide, and extended to the depth of 350 m (Hyvärinen 1969, Pulkkinen 1985, Lawrie 1987). The polydeformed stratabound deposit with the subjacent stockwork zone is located on the eastern limb of a large, northerly plunging F2 antiform. This structure is refolded around the hinge of a major, upright F3, open to tight fold, the axial plane of which trends NW–SE through the area (Lawrie 1987). The interlayering of mafic metavolcanic rocks with marbles and clastic metasedimentary rocks and enrichment in incompatible elements suggest an intracratonic rift geotectonic setting for the Cu deposit. The deposit also shows lateral zoning with a marked increase in magnetite to the SE, where silicate facies iron formation occurs at the same level as the Cu mineralisation. Extensive hydrothermal alteration was coeval with exhalative mineralisation (Lawrie 1987).

On the fringes of area F014 there are a few zinc occurrences dissimilar to the Virtasalmi-type Cu. The former are hosted by felsic to intermediate volcanic rocks, quartz-carbonate rock and mica gneiss and contain about 0.3–2.9 % zinc and only minor amounts of copper. In addition, the Viholanniemi deposit also contains some lead (0.64 %), silver and gold (Table 14).

Figure 27. Hällinmäki (Virtasalmi) open pit on 27 September 2007, at 62.0576°N, 27.552°E. Photo: Kaj Västi, GTK.

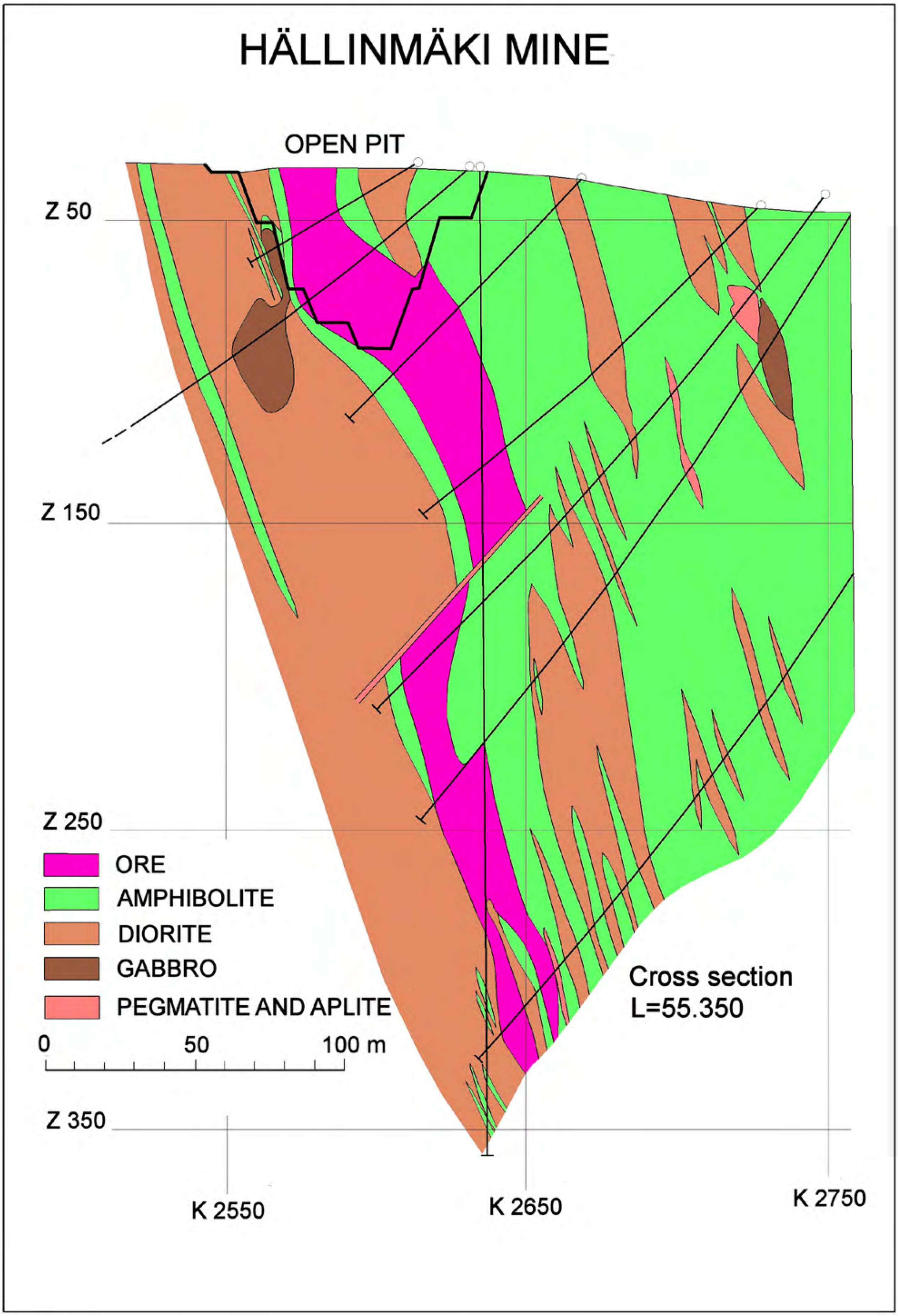

Figure 28. Section across the ore body A of the Hällinmäki mine. View to the NW. Modified from Vaajoensuu et al. (1978).

Table 14. Copper and zinc occurrences in metallogenic area F014.

Occurrence (Alternative name)	Tonnage Mt	Cu %	Zn %	Ag g/t	Au g/t	Main host rock	Reference
Virtasalmi-type Cu occurrences							
Hällinmäki (Virtasalmi)	4.2*	0.73			0.1	Garnet skarn, Amphibolite	Hyvärinen (1969), Pulkkinen (1985), Lawrie (1987)
Karankalahti	0.37	1.02				Garnet-diopside-epidote skarn, Amphibolite	Grundström et al. (1986)
Sarkaniemi	0.029–0.086	2.85				Garnet-epidote skarn, Amphibolite	Grundström (1979)
Karhuniemi	0.013–0.018	0.5–0.6				Garnet skarn, Amphibolite	Grundström (1976)
Lari	0.003–0.005	1.28				Garnet skarn	Hyvärinen (1969), Grundström (1977a)
Sahinjoki	0.003	1.0				Amphibolite, Diopside-epidote skarn	Grundström (1977b)
Zinc occurrences							
Viholanniemi S	0.19	0.19	2.31	26	0.7	Quartz-carbonate rock	Makkonen (1991a, 1991b)
Viholanniemi N	0.058	0.12	1.97	105	1.1	Quartz-carbonate rock	Makkonen (1991a, 1991b)
Mustalampi S	0.0105		5.6			Felsic to intermediate volcanic rock	Makkonen (1989)
Mustalampi N	0.0255		1.75			Felsic to intermediate volcanic rock	Makkonen (1989)

* Mined in 1966–1983; only the mined amount and grade has been reported.

F015 RANTASALMI Au

Pasi Eilu and Olavi Kontoniemi (GTK)

The Rantasalmi Au area (F015) is a NW-trending domain along the Kolkonjärvi Shear Zone (KSZ), a boundary between the Savo and the Saimaa Schist areas. The KSZ is one of the major transcurrent, possibly transcrustal faults of the 50–100 km wide, NW-trending Raahe-Ladoga suture zone between the Karelian and Svecofennian terranes in Finland (Korsman 1988). In the SW, area F015 overlaps with the Virtasalmi Cu area (F014) and in the NE it is close to and follows the strike of the SW boundary of the Kotalahti Ni area (F016) (Fig. 24).

Three occurrences with a resource estimate are known from the area F015 (Table 15): the main deposit, **Osikonmäki**, is clearly of the orogenic type (Kontoniemi 1998a, 1998b), whereas the **Pirilä** deposits may be orogenic or of the metamorphosed syngenetic type. The Osikonmäki deposit (Fig. 29) comprises several complex ore bodies (e.g. Osikko E and W) in a synkinematic tonalite (intrusion dated to 1887 ± 5 Ma; Vaasjoki & Kontoniemi 1991). The ore bodies comprise

Table 15. Gold deposits in the Rantasalmi metallogenic area (F015).

Occurrence	Tonnage (Mt)	Ag g/t	Au g/t	Cu %	Pb %	Host rocks	Reference
Osikko E	2.0 1.8 3.0		3.0 3.2 1.65			Tonalite	Kontoniemi & Ekdahl (1990), Parkkinen (1992), Belvedere Resources (2011)
Osikko W	0.09		4.9			Tonalite	Kontoniemi (1992)
Pirilä	0.3	32	6.5	0.18	0.76	Intermediate volcanic rock	Makkonen & Ekdahl (1988), Parkkinen (2003)
Pirilä II	0.03		2.7			Intermediate volcanic rock	Makkonen (1987), Makkonen & Ekdahl (1988)

both auriferous quartz veins and mineralised host rock and form, at least, a 3-km-long mineralised domain in the E-trending, south-dipping Osikonmäki shear zone (Kontoniemi 1998a, 1998b). The mineralisation is related to peak deformation, but appears to have been metamorphosed under upper-amphibolite facies conditions. Native gold chiefly occurs with Bi-Se-Te minerals at Osikonmäki, as inclusions and at grain boundaries within and between arsenopyrite, löllingite, quartz and plagioclase (Kontoniemi et al. 1991).

The Pirilä occurrence is a single-lode gold deposit also enriched in silver and base metals. It comprises auriferous arsenopyrite-quartz veins and intensely altered host rock in a major fold hinge in intermediate metavolcanic rock (Makkonen 1987, Makkonen & Ekdahl 1988). Gold and electrum inclusions are primarily near the contact between arsenopyrite and löllingite at Pirilä, but submicroscopic gold also occurs in löllingite (Makkonen & Ekdahl 1988).

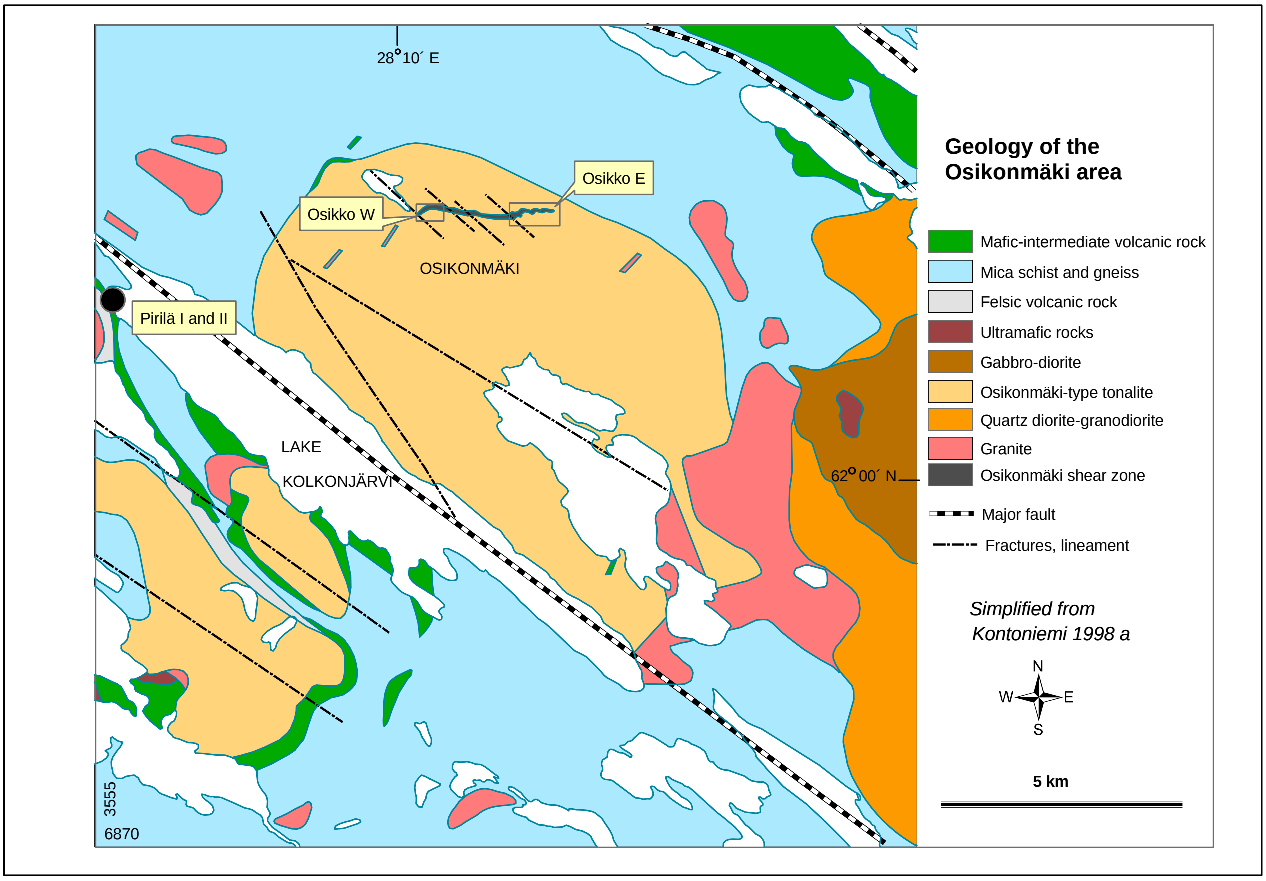

Figure 29. Geological map of the Osikonmäki–Pirilä region within metallogenic area F015 (simplified from Kontoniemi 1998a).

F016 KOTALAHTI Ni

Hannu Makkonen (Belvedere Mining Oy)

The NW-trending Kotalahti Ni area (F016) is entirely within the Savo supracrustal belt (Fig. 30). It is bounded to the northeast by the Archaean craton margin and to the southwest by the Central Finland Granitoid Complex. The exact boundaries of area F016 can be questioned, however, because the nickel-potential intrusions appear to simply gradually fade out to the southwest. The boundary to the northeast is more distinct, as the intrusion of Svecofennian nickel-rich magma took place in the craton margin zone, and did not significantly extend into the Archaean domain.

The Savo supracrustal belt is mainly formed by migmatised mica gneisses of greywacke and mudrock origin. Felsic and mafic volcanic rocks, as well as graphite schists and gneisses, are locally

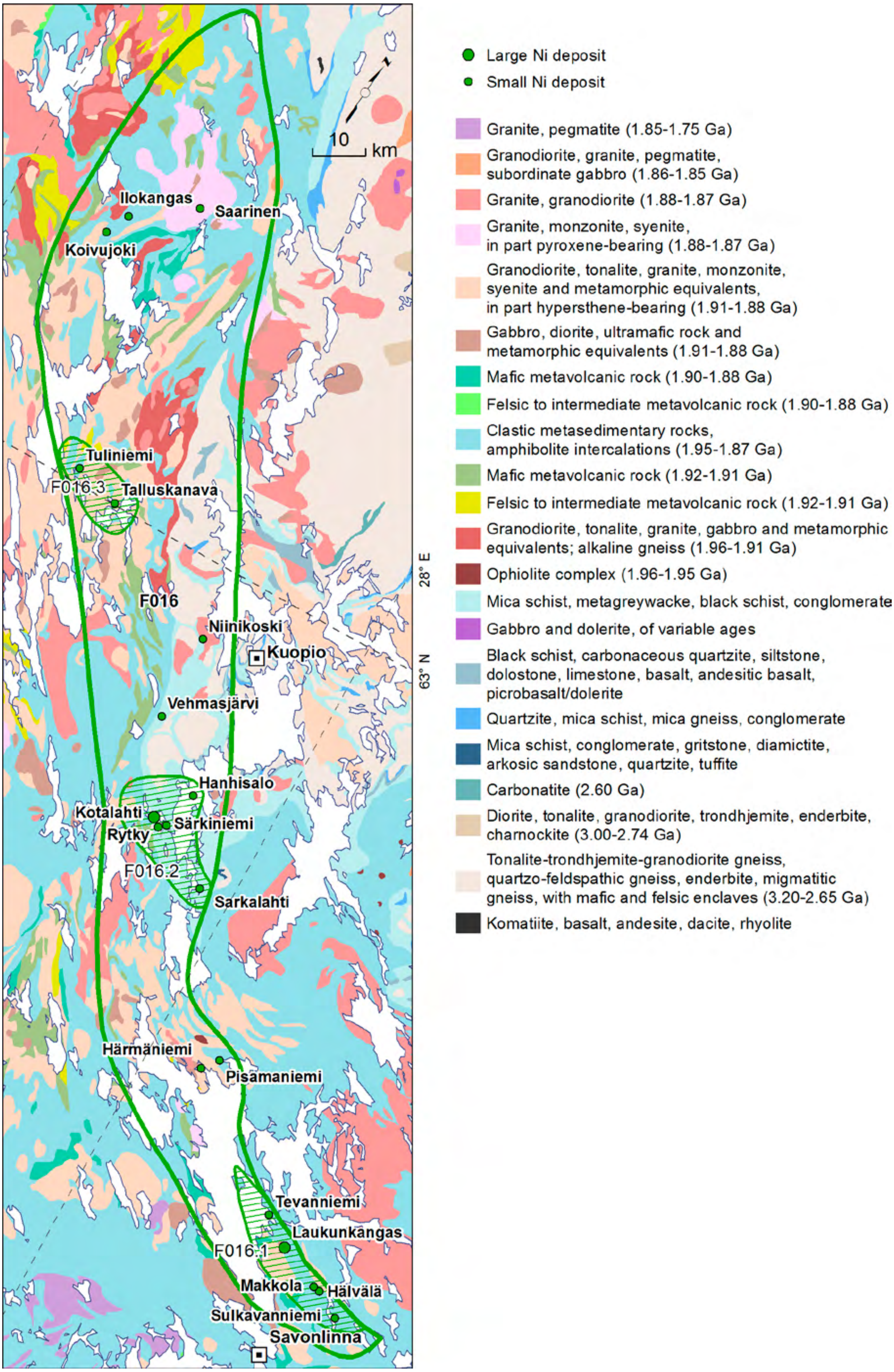

Figure 30. Geology of the Kotalahti Ni area (F016) with the Laukunkangas (F016.1), Kotala (F016.2) and Tallus (F016.3) metallogenic subareas, and the most significant nickel-copper occurrences of the region. Geology is based on the GTK digital bedrock database.

abundant (Kähkönen 2005). Volcanic rocks form major belts, but also occur as narrow discontinuous belts or limited occurrences within both metasedimentary and intrusive complexes. The volcanic rocks belong to ca. 1.92 Ga bimodal and to 1.88 Ga mafic-intermediate age groups (Kousa & Lundquist 2000). The former, forming the primitive arc complex of central Finland, are economically important due to massive sulphide deposits (metallogenic area F028). The 1.88 Ga nickel-rich mafic-ultramafic intrusions mostly occur within the mica gneiss, but also within and at the contact zone of the Archaean gneiss, as in the Kotalahti area (Fig. 31).

The following description of the metamorphism and deformation of the Savo belt is mainly from Kähkönen (2005). The eastern parts of the Savo belt, in particular, are characterised by fault-bounded blocks with variable metamorphic and structural histories. The metamorphic grade varies from medium-T amphibolite facies (550–600 °C) to granulite facies (800–880 °C) at pressures of 5 ± 1 kbar. The metamorphic evolution culminated close to a main phase of granitoid magmatism at ca. 1885 Ma. Deformation was polyphase and in many places produced complex interference patterns. The two earliest folding phases produced isoclinal to tight recumbent folds with east-to-northeast vergence; a regionally pervasive foliation or gneissose banding also developed during these phases. A third folding phase turned the flat-lying structures subvertical and resulted in approximately N-oriented elongate antiforms and synforms, which cover the structure of the Savo belt. Open curving of the axial planes of these folds is largely due to a fourth phase of deformation. North-striking dextral shear zones are related to the third phase, whereas a system of NE-striking sinistral and S-striking dextral zones characterises the fourth deformation phase.

Most of the mafic-ultramafic Ni-potential intrusions in area F016 are rather small, with roughly 10 km as the maximum dimension at the present erosion level. Typically, the maximum horizontal dimension is less than 2 km. The intrusions are composed of a differentiation series from ultramafic to gabbroic (locally to dioritic and quartz dioritic) rocks. Intrusions composed solely of ultramafic rocks exist but are rare. Intrusions are mainly in areas of higher metamorphic grade than the surrounding region, and thus in a relatively deep crustal section. These potential areas are commonly within local gravimetric highs because of the abundance of the mafic-ultramafic rocks themselves and because of the relatively dense minerals of the country rocks.

The intrusion of Ni-rich magma took place in early D_2 (e.g. Mäkinen & Makkonen 2004, Peltonen 2005), and thus into flat-lying rock units. This is important to note from the exploration point of view. In most of the studied intrusions within the Kotalahti belt, it has been possible to recognise the stratigraphic footwall of the intrusion as the most promising locality for nickel ore in an intrusion (e.g. Forss et al. 1999, Makkonen et al. 2003). According to Makkonen (2005), the magma intruded within a high-temperature shear zone between a large magma reservoir and a D_2 imbrication zone. Peltonen (2005) emphasised the importance of transtensional shear systems developed at the continental margin, which locally facilitated the ascent of melts along subvertical shear zones. Within shear zones, magmas are expected to rise faster and undergo less fractionation during emplacement, thus retaining a high nickel potential. The parental magma for the intrusions was EMORB-type tholeiitic basalt with an MgO content of 10–15 % (Makkonen & Huhma 2007, Barnes et al. 2009).

Most of the intrusions show evidence of wall rock or country rock contamination indicated, for example, by elevated LREE and low to negative ε_{Nd} in peridotites and a distinct nickel depletion (Mäkinen & Makkonen 2004, Lamberg 2005, Makkonen & Huhma 2007, Makkonen et al. 2008). These features have successfully been used in exploration within metallogenic area F016. In some intrusions however, it is obvious that the early-formed sulphides with nickel have been left at lower crustal levels than the present intrusion body, which makes the lithogeochemical exploration for Ni deposits complicated.

Typical nickel ore in the area F016 is composed of pyrrhotite, pentlandite and chalcopyrite. The ore is disseminated, network-textured or massive. The nickel content in massive ores can be 5–10 %. The Ni/Cu ratio is usually 1.5–3.5 and the Ni content in the sulphide fraction varies from 1–10 %, being mostly 3–8%. This large range reflects the variable amount of external sulphur assimilated by the mafic magma. PGE contents are typically low and show a distinct negative Pt anomaly in the mantle/chondrite normalised PGE pattern. Offset ores have been the economic backbone for many deposits in the Kotalahti area. These are ore bodies that occur outside the main host intrusion, usually enclosed by the country rocks. Typical offset ore mainly comprises massive and network sulphides, and has a high nickel content. Opinions on the origin of the offset ore bodies range from synmagmatic deposition to tectonic remobilisation of the sulphides.

Some of the most important ore indications for nickel exploration in the Kotalahti Ni area (F016) include the following:

- The intrusions can usually be found on local gravimetric highs, also below the gneisses.
- A positive magnetic anomaly usually exists, formed by monoclinic pyrrhotite or peridotitic host rock.
- All economic deposits include *peridotitic* differentiates as host rocks.
- The nickel ore locates in the stratigraphic footwall of the intrusion.
- The existence of offset ore seems to be a rule.

Kotalahti and **Laukunkangas** deposits are economically the most important in area F016 (Table 16). Both are hosted by a differentiated intrusion, but at Kotalahti the deformation history and probably also the emplacement history is more complex (cf. Papunen 2003). The Kotalahti deposit is of high importance for the Finnish nickel industry because its discovery in 1954 and opening of the mine in 1959 led to the establishment of a nickel smelter at Harjavalta in the 1960s.

The Kotala subarea (F016.2) is in the craton margin, partly within the Archaean area (Fig. 31). Kotalahti and Rytky intrusions are within the Kotalahti Dome, which is composed of Archaean gneiss surrounded by a Palaeoproterozoic craton-margin supracrustal sequence. The Kotalahti intrusion is a subvertical sheet with a length of approximately 1.3 km and a maximum width of 200 m. The southernmost intrusive body extends downwards to a depth of more than 1000 m (Papunen 2003). The wall rocks of the intrusion mainly consist of Archaean gneisses (Fig. 31). The U-Pb zircon age obtained for a gabbro in the Kotalahti intrusion is 1883 ± 6 Ma (Gaál 1980).

The rock types at **Kotalahti** range from olivine and olivine-enstatite cumulates to orthopyroxenites, poikilitic gabbros, ophitic gabbronorites and diorites (Papunen 2003). Among the peridotitic rocks, coarse-grained lherzolite is in the stratigraphic footwall and is overlain by medium-grained lherzolite (Mäkinen & Makkonen 2004). The ore bodies from north to south include Mertakoski, Välimalmio, Vehka and Huuhtijärvi. A separate massive offset, called the Jussi ore body, is present as a subvertical slab in the black-schist and calc-silicate wall rock some 150 m east of the Vehka ore body. The Jussi ore body extends to a depth of more than 1000 metres. Disseminated sulphides are common in ultramafic rocks and poikilitic gabbros, whereas ophitic gabbros and diorites are almost barren. Breccia-type sulphides occur as irregular masses, commonly along the contacts in the thinner central part of the intrusion (Papunen 2003). The Kotalahti deposit is similar in geology, host rocks and ore composition to the neighbouring Rytky deposit.

In the recent study by Seppä (2009), the peridotitic host rock of the Kotalahti deposit was found to be layered. Layering is seen in the gradual change of, for example, the Mg number, MgO and whole rock Ni/Co values towards the intrusion contact. In addition, in the Jussi ore body, layered peridotite was found as the host rock. These facts suggest that at Kotalahti the intrusion also originally formed a subhorizontal body, which was later folded into a subvertical setting. Inevitably, this gives new ideas for further exploration at Kotalahti.

The average composition for different ore types at Kotalahti is given in Table 17. According to Papunen and Vorma (1985), the Kotalahti ore averages 0.70 % Ni, 0.27 % Cu, 0.03 % Co and 4.00 % S. The main sulphide minerals are pyrrhotite, pentlandite and chalcopyrite; in the Jussi ore body, pyrite also is significant. In the disseminated ores, pyrrhotite is troilite and hexagonal pyrrhotite in composition, whereas in the breccia ores (vein network ores) and in the Jussi ore body in particular, the monoclinic variant predominates. Gersdorffite, mackinawite and argentian pentlandite are the common accessory sulphides. The Jussi ore body also contains portions rich in millerite and bornite (Papunen & Koskinen 1985). The PGE content of the Kotalahti ore is insignificant. There is a distinct negative Pt anomaly in the PGE pattern (Papunen 1989, Makkonen & Halkoaho 2007). The $\delta^{34}S$ in ores hosted by the ultramafic rocks is +1.4 to +2.6 ‰ and in the Jussi orebody +1.4 to +2.8 ‰ (Papunen & Mäkelä 1980).

The Laukunkangas subarea (F016.1) in the southeastern end of the Kotalahti Ni area forms a distinct concentration of nickel-copper deposits in a linear belt, which is characterised by an intense positive gravimetric anomaly. It has been suggested that the nickeliferous intrusions here follow the primary craton margin at the time of the emplacement of the mafic magma similarly, for example, to the Thompson Belt in Canada (e.g., Makkonen 2008). The **Laukunkangas** and **Hälvälä** deposits of subarea F016.1 have been mined (Table 16). On the basis of glacial erratic boulder data, the Laukunkangas subarea still has good potential for new deposits. The Tallus subarea (F016.3) includes two minor, low-grade deposits, **Talluskanava** and **Tuliniemi**. Based on the boulder data, however, more deposits could be found from subarea F016.3.

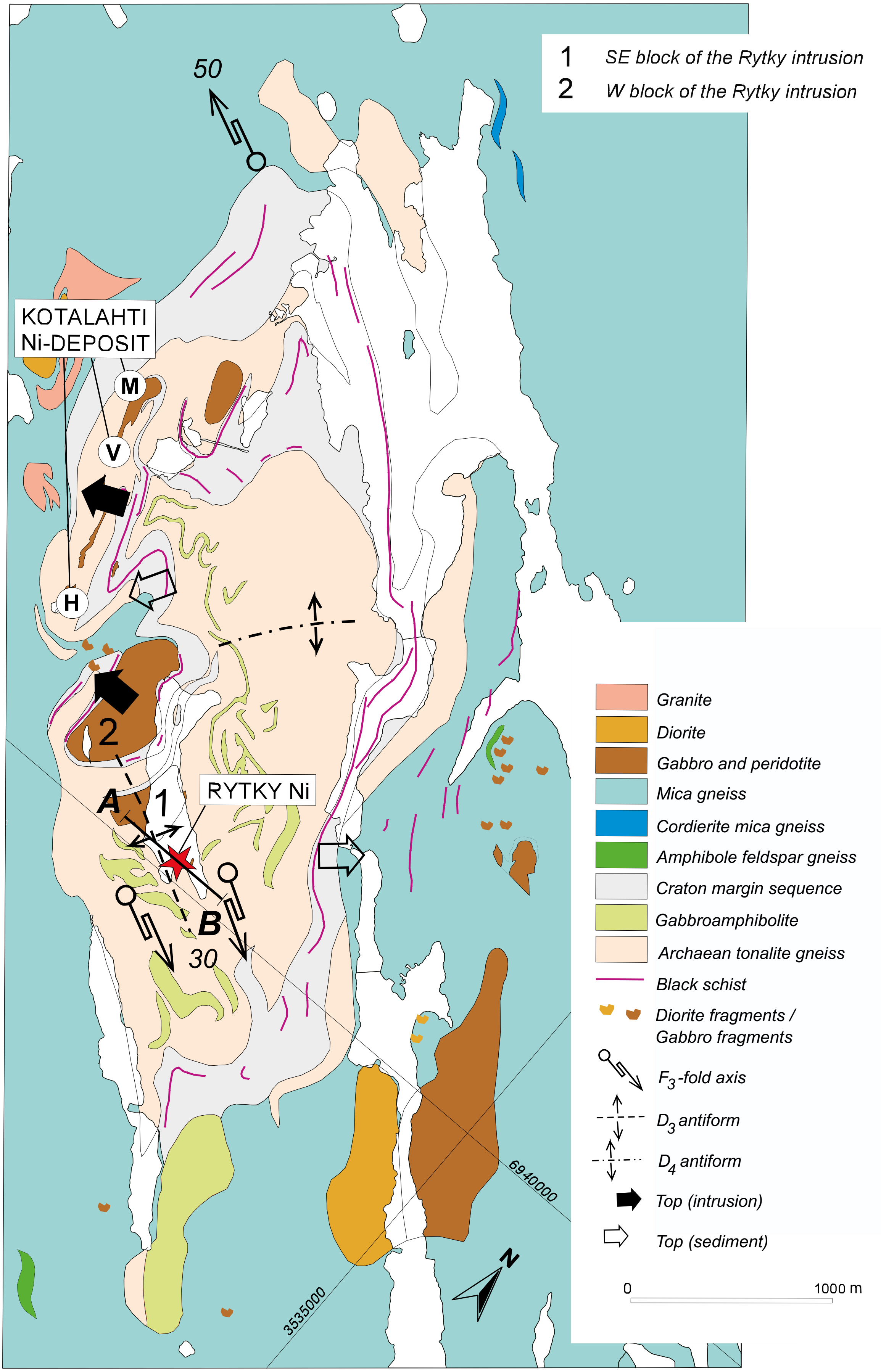

Figure 31. Kotalahti Dome geology. M = Mertakoski ore body, V = Vehka orebody, H = Huuhtijärvi ore body (Mäkinen & Makkonen 2004).

Table 16. Magmatic intrusion-hosted Ni-Cu deposits and occurrences with a resource estimate in the Kotalahti metallogenic area (F016).

Subarea **Occurrence**	**Tonnage (Mt)**	**Co %**	**Cu %**	**Ni %**	**When mined**	**Main host rock**	**Reference**
Laukunkangas Ni (F016.1)							
Sulkavanniemi	0.194		0.09	0.32		Norite	Puustjärvi (1987)
Hälvälä	0.448	0.075	0.36	1.5	1988–1992	Mica gneiss	Eeronheimo (1985a)
Makkola	0.526	0.034	0.18	0.52		Pyroxenite	Eeronheimo (1985b)
Laukunkangas	7.9	0.03	0.20	0.72	1984–1994	Harzburgite	Grundström (1985), Juhava et al. (1989), Puustinen et al. (1995)
Tevanniemi	0.182	0.03	0.15	0.63		Olivine gabbronorite	Eeronheimo (1988)
Kotala Ni (F016.2)							
Sarkalahti	0.19	0.03	0.33	1.02		Peridotite	Papunen & Vorma (1985), Belvedere (2006)
Rytky	1.54	0.03	0.29	0.71		Lherzolite	Suomen Nikkeli (2007)
Särkiniemi	0.292	0.06	0.53	0.91	2007–2008	Peridotite	Kontoniemi & Forss (1997)
Kotalahti*	12.36	0.03	0.26	0.66	1959–1987	Peridotite, Pyroxenite	Puustinen et al. (1995)
Hanhisalo	0.143	0.02	0.2	0.61		Gabbro	Kontoniemi & Forss (1998)
Niinikoski	0.083	0.045	0.13	0.43		Gabbro	Makkonen (2002)
Vehmasjärvi	0.036	0.06	0.69	0.94		Peridotite	Makkonen & Forss (1999)
Koivujoki	0.025		0.3	0.94		Peridotite	Ekdahl (1993)
Tallus Ni (F016.3)							
Talluskanava	0.15	0.02	0.19	0.33		Peridotite	Nurmi (1976), Papunen & Vorma (1985)
Tuliniemi	0.09		0.15	0.34		Norite	Ekdahl (1993)

* Only the mined amount and grades have been reported.

Table 17. Chemical composition of different ore types at Kotalahti calculated to 100 % sulphides (in weight %); from Papunen and Koskinen (1985).

Ore type	**Ni %**	**Cu %**	**Co %**
Disseminated ore in peridotite	9.81	2.90	0.41
Disseminated ore in pyroxenite	9.19	2.79	0.45
Disseminated ore in perknite	8.41	2.86	0.40
Disseminated sulphides in diorite and quartz diorite	1.37	1.54	0.38
Breccia ore, Mertakoski ore body	6.53	2.75	
Breccia ore, Välimalmi ore body	6.14	2.05	
Breccia ore, Vehka ore body	6.38	1.74	
Breccia ore, Huuhtijärvi ore body	6.65	2.10	
Breccia ore, Jussi ore body	11.23	6.47	

F017 ORAVAINEN Ni

Markku Tiainen (GTK)

The N-trending Oravainen Ni area (F017) is an east-opening arcuate belt along the eastern shore of the Gulf of Bothnia in western Finland (Fig. 1). It is defined by the presence of scattered nickeliferous mafic-ultramafic intrusions surrounded by metaturbidites of the Western Finland supersuite and strongly deformed migmatites of the Vaasa Complex. Two different types of nickel deposits have been found in area F017: a typical Svecofennian synorogenic intrusion-hosted type represented by the Oravainen deposit, and a possibly younger, diabase-hosted type at Petolahti (Table 18).

The **Oravainen** Ni deposit (Fig. 32) is hosted by a pipe-formed ultramafic intrusion within the strongly deformed, migmatitic Oravainen paragneisses of the Vaasa Complex (Isohanni 1985a, Mäkitie 2000, Sipilä et. al. 2008, GTK internal bedrock database). Two roundish pipe-formed nickel bearing ultramafic intrusions, interpreted by Isohanni (1985a) as feeding channels for the ultramafic magma, have been observed in the Oravainen area. The ultramafic intrusion hosting the nickel deposit has been referred to as 'Ni ultramafite' and the other, weakly mineralised intrusion as 'B ultramafite'.

The Ni ultramafite is a 90 x 30 m oval at the surface, sub-vertical, plunging at 70° to the east and extending to a depth of at least 250 m (Isohanni 1985a). Its composition varies concentrically from a dunitic core to peridotite and pyroxenite at the margins. The main rock type of the intrusion is peridotite. The best sulphide mineralisation is in the dunitic core, and the metal grades decrease towards the margins. The roundish, 60 x 40 m wide, B ultramafite is about 50 m SW of the

Table 18. Mafic-ultramafic intrusion-hosted Ni deposits and occurrences in the Oravainen metallogenic area.

Occurrence	Tonnage (Mt)	Co %	Cu %	Ni %	Pd g/t	Pt g/t	When mined	Reference
Petolahti	0.2358	0.02	0.38	0.47	0.6	0.1	1972–1973	Himmi (1975), Sipilä et al. (1985)
Oravainen	1.3	0.03	0.16	0.95				Isohanni (1985a)

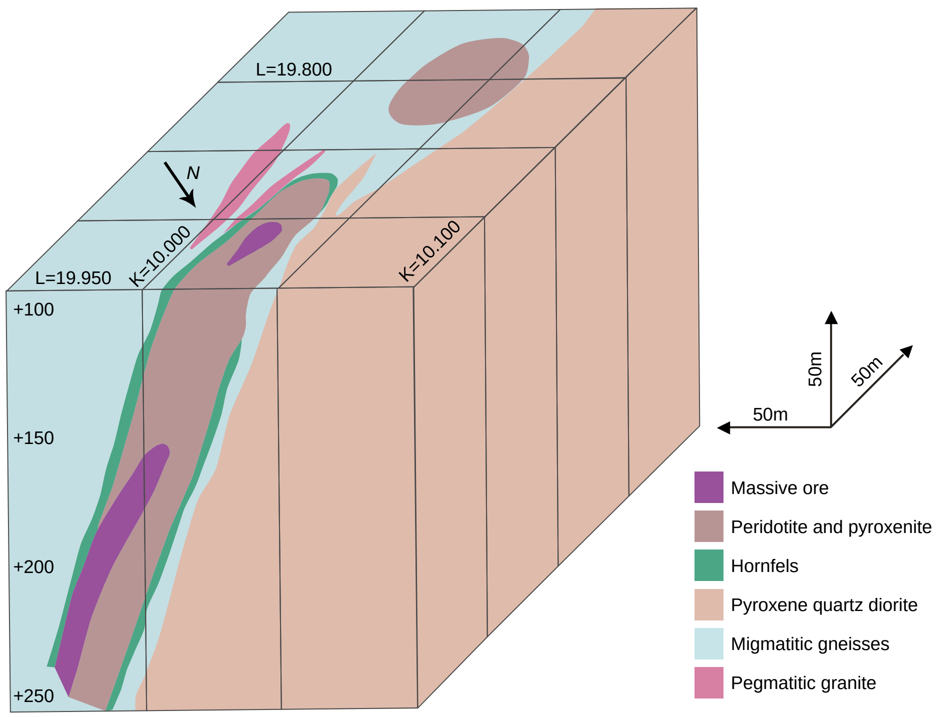

Figure 32. Geology of the Oravainen intrusion and nickel deposit, located at 63.320°N, 22.311°E (Isohanni 1985a). Grid is in 50 m intervals.

Ni ultramafite. The former is mainly composed of peridotite and is less distinctly differentiated. There is only weak sulphide dissemination in the B ultramafite, in the margins of the intrusion.

Dunite at Oravainen contains rare enstatite and augite relicts, whereas olivine is completely serpentinised. The grain size of the olivine pseudomorphs is 0.1–2 mm; augite and enstatite grains are larger and they show a poikilitic texture in relation to olivine. Peridotite is the main rock type of both intrusions and is composed of small euhedral olivine grains, medium- to coarse-grained, subhedral, poikilitic enstatite, and anhedral augite. Some phlogopite and amphibole has also been interpreted to be primary. Serpentine, amphiboles, phlogopite, chlorite, talc and carbonate occur as alteration products. Around the sulphide-rich parts, the euhedral olivine and poikilitic enstatite occur locally as silicate nodules up to 10 mm in diameter in the sulphide matrix. Pyroxenites have been encountered at the NE end of the Ni ultramafite intrusion and commonly form a narrow seam in the transitional zone between hornfels and peridotite. In the pyroxenite, enstatite occurs as euhedral prismatic grains up to 6 mm in size, augite is anhedral and phlogopite occurs as large, ragged, commonly poikilitic grains. The Fo content of the olivine varies from 70.2 % to 84.6 %. The highest Fo contents have been encountered in B ultramafite and in the SW part of Ni ultramafite. The extensive variation in the Ni content of olivine is typical for a mineralised intrusion.

In both intrusions at Oravainen, the sulphides occur as fine- to medium-grained dissemination and small blebs, typically as matrix ore containing olivine pseudomorphs as embedded euhedral grains (Isohanni 1985a). In the Ni ultramafite, the sulphides locally form a network texture (Fig. 33), and in the dunitic even almost differentiate massive ore. Main sulphide minerals are pyrrhotite, pentlandite and chalcopyrite. Cubanite, mackinawite and violarite are also encountered in the central part of Ni ultramafite. Magnetite occurs both in the sulphide mineralisation and as an alteration product of olivine. In the sulphide phase, magnetite occasionally appears as intergrowths with pyrite. Chromite has been encountered as euhedral mineral grains and as intergrowths with pyrrhotite. Arsenides (gersdorffite, niccolite, maucherite) have been encountered as fine-grained dissemination and as fillings in microcracks. Pyrrhotite occurs as large grains, including the monoclinic type and a combination of hexagonal pyrrhotite and troilite. Pentlandite mainly occurs as 3–4 mm grains, and a minor amount as small grains and as exsolution lamellae in pyrrhotite. Chalcopyrite mainly occurs as large grains together with other sulphides. The Ni value of the sulphide phase is 4.0–14.76 % Ni, and the Ni/Cu ratio is 3.5–6.6. On average, the nickel value of the sulphide phase is 5.55 % Ni and the Ni/Cu ratio is 5.8.

The **Petolahti** Ni-Cu deposit is hosted by a diabase dyke 600–700 m long and 7–70 m wide enveloped by biotite paragneisses of the Pirttikylä suite of the Western Finland supersuite (Sipilä et.

Figure 33. Pyrrhotite-pentlandite ore in peridotite at Oravainen. Sample from an erratic boulder. Scanned image, GTK.

Figure 34. Disseminated pyrrhotite-pentlandite ore at Petolahti. Scanned image, GTK.

al. 1985). Sipilä et al. (1985) interpreted the Petolahti diabase as belonging to the subjotnian Häme diabase group, whereas Lehtonen et al. (2005) regarded it as one of the Svecofennian orogenic mafic-ultramafic intrusions of 1.89–1.88 Ga in age.

The main ore types at Petolahti include disseminated sulphides and sulphide veins in olivine diabase and sulphide dissemination in wall rock (Figs. 34 and 35). The sulphide dissemination in olivine diabase occurs as interstitial blebs of 0.2–4 mm in diameter between the silicates. The main sulphides are pyrrhotite, chalcopyrite and pentlandite. Pyrite has only been encountered in the wall rocks. Ilmenomagnetite and ilmenite occur as a uniform dissemination in the diabase, whereas magnetite occurs as secondary mineral with the sulphides. Pyrrhotite is almost always enveloped by pentlandite and chalcopyrite. The sulphides segregated at the same time with the differentiation of the magma, which resulted in the formation of olivine diabase, pyroxene diabase and finally quartz diabase. The sulphide veins in the olivine diabase crystallised from the residual sulphide melt. The exsolution textures of pyrrhotite, chalcopyrite and pentlandite indicate that the sulphides crystallised as a solid solution at a high temperature and a fairly low water pressure, and that they were exsolved when the temperature dropped (Sipilä et al. 1985).

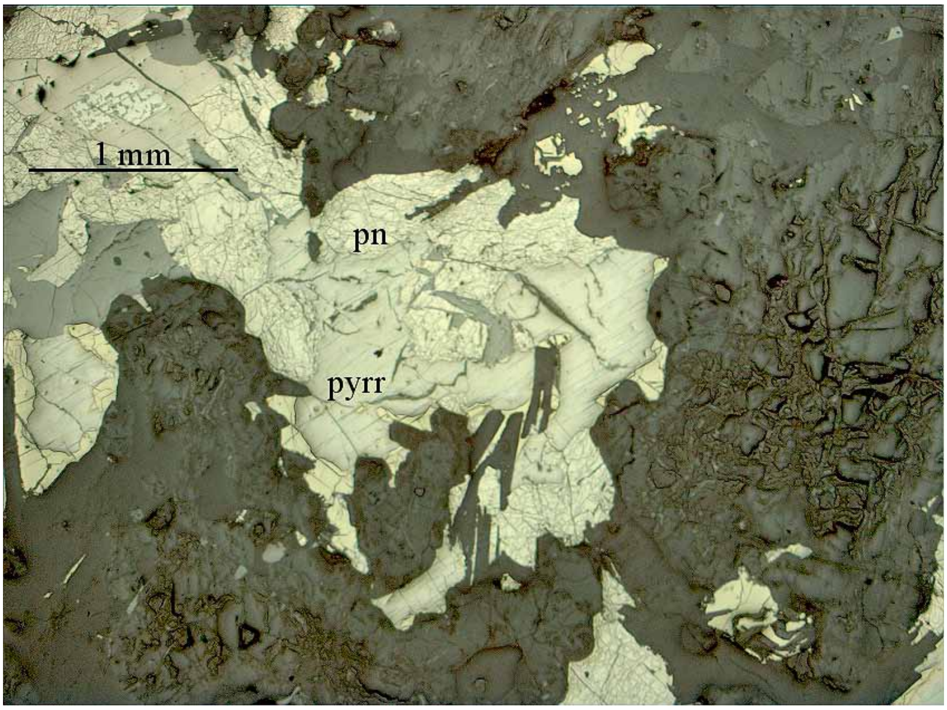

Figure 35. Pyrrhotite-pentlandite ore (pyrr, pn, respectively) in olivine diabase at Petolahti. Photo: Hannu Makkonen, GTK.

F018 SEINÄJOKI Au-Sb

Pasi Eilu and Niilo Kärkkäinen (GTK)

The Seinäjoki Au-Sb area (F018) is defined by the extent of orogenic gold±antimony mineralisation within the southern part of the Pohjanmaa supracrustal belt (Fig. 36). To the east and west its boundaries are vague: the metallogenic area should perhaps be open along strike at both ends.

The Pohjanmaa supracrustal belt comprises 1.91–1.88 Ga turbiditic greywackes and volcanic rocks of various compositions (Kähkönen 2005, Lehtonen et al. 2005). The belt is composed of two different volcanic associations (Mäkitie & Lahti 1991). A scattered zone of calc-alkaline intermediate volcanic and subvolcanic rocks occurs on the southern border of the Pohjanmaa Belt close to the Central Finland Granitoid Complex. Separated by a greywacke basin close to the Vaasa Granite, there is a volcanic belt composed of tholeiitic volcanic rocks associated with black shales, marbles and cherts. The regional metamorphic grade is at mid- and upper-amphibolite facies in the region, and is characterised by high pressure (garnet, sillimanite present) in the northern part and by low pressure (andalusite, cordierite present) in the southern part of the belt (Mäkitie 2000). Regional metamorphism peaked at 1.89–1.88 Ga when the region also was intruded by synkinematic granitoids (Mäkitie et al. 1999, Nironen 2005).

Area F018 is characterised by orogenic gold and gold-antimony mineralisation in bedrock (Eilu 2007) and by numerous Au and Sb anomaly fields in till (Lestinen et al. 1991). About ten Au and Au-Sb occurrences are known from the area (Pääkkönen 1966, Eilu & Pankka 2009), but only for three (Table 19) has enough work been done for a preliminary resource estimate. **Kalliosalo** is the best-known Au-Sb deposit in Finland. It comprises auriferous quartz vein arrays in a plagioclase porphyry. The deposit is controlled by a discordant shear zone and is close to a regional NW-trending shear zone. Part of the gold is in aurostibite, and native antimony is the main Sb carrier. A significant part of the native gold occurs as inclusions in löllingite-arsenopyrite (Appelqvist 1993). **Timanttimaa** is a typical orogenic gold-only occurrence close to a NE-trending shear zone. It comprises an auriferous quartz vein network in felsic plagioclase porphyry and tonalite with predominantly free gold in quartz veins (Kärkkäinen 1993).

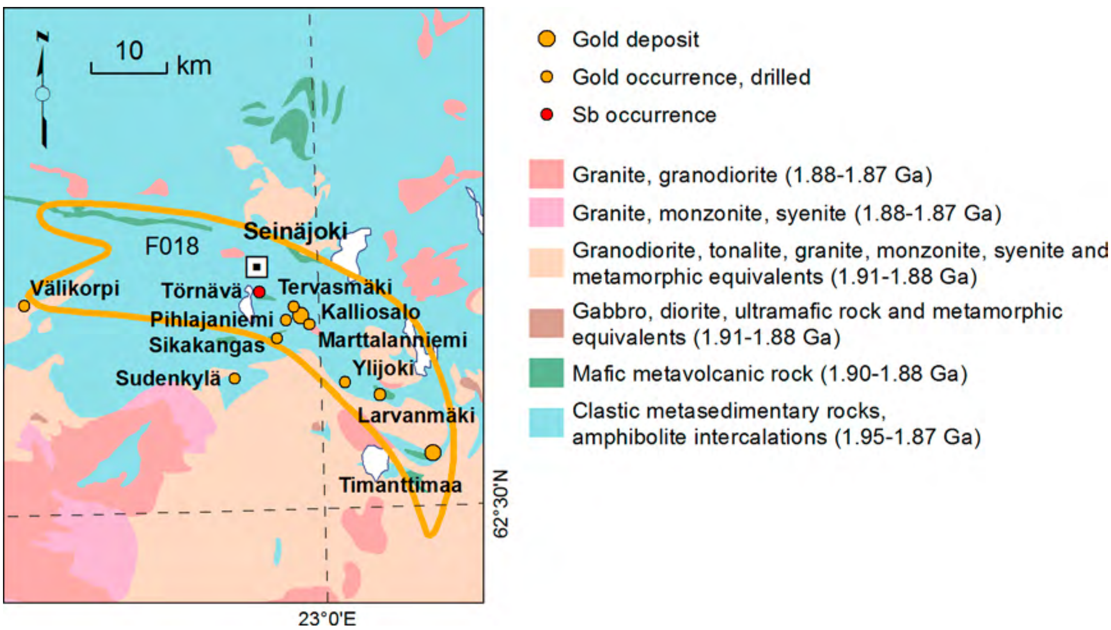

Figure 36. Seinäjoki Au-Sb (F018) metallogenic area, and the most significant gold±antimony occurrences of the region. Geology is from Koistinen et al. (2001).

Table 19. Gold±antimony deposits in the Seinäjoki metallogenic area (F018).

Occurrence	Tonnage (Mt)	Au g/t	Sb %	Main ore minerals	Host rocks	Reference
Sikakangas	0.171	1.32		Arsenopyrite, pyrrhotite	Plagioclase porphyry	Isomaa et al. (2010)
Timanttimaa	1.0	1		Pyrrhotite, arsenopyrite	Felsic volcanic rock	Kärkkäinen (1993)
Kalliosalo	0.3 1.04	1	0.85 0.41	Arsenopyrite, antimony, löllingite, stibnite, aurostibite, pyrrhotite	Plagioclase porphyry	Saltikoff (1980), Tyni (1983), Appelqvist (1993)
Törnävä E Törnävä W	0.2 0.3	<1	1.37 0.57	Pyrrhotite, antimony, gudmundite, stibnite	Mica gneiss, Mica schist	Pääkkönen (1966)

F020 OUTOKUMPU Cu-Co, Ni

Asko Kontinen (GTK)

The Outokumpu area (F020) is within the Palaeoproterozoic North Karelia Schist Belt (Fig. 37). The Outokumpu area is defined by the boundaries of the Outokumpu Allochthon (also known as the 'Outokumpu Nappe Complex' or 'Outokumpu Nappe'), which contains serpentinite bodies with the diagnostic host-rock assemblage of the polymetallic and polygenetic, Outokumpu-type copper-cobalt-zinc and Kokka-type nickel mineralisation. The boundaries of the Outokumpu Allochton as they are shown in Figure 37 are generalised after delineations presented in Koistinen (1981), Park & Bowes (1983), Gaal & Parkkinen (1993) and Kontinen et al. (2006).

The Outokumpu Allochthon is >85% composed of schistose, medium- to high- grade metaturbiditic wackes and pelites, which are typically sand-dominated, medium to thinly bedded and lack psephitic interbeds or channellisation. No metavolcanic rocks as intercalations or synsedimentary magmatic intrusions are found in the primarily turbidite sequence, which is apparently kilometres thick. Relatively deep-water deposition of the turbidites has been proposed, probably at continental slope-rise fans in a passive margin type environment (Kontinen & Sorjonen-Ward 1991, Peltonen et al. 2008, Lahtinen et al. 2009). The wacke schist contains layers of black schists (black turbidite muds), especially in the presumably lowermost parts of the allochton (Loukola-Ruskeeniemi 1999, Kontinen et al. 2006). Apart from abundant graphite (5–10%), these carbonaceous schists also commonly contain plentiful iron sulphides (5–20 wt%), and are strongly enriched in Ni, Cu and Zn relative to the upper crust. Redox-sensitive metals such as Sb, Se, Mo, V and U also occur at elevated concentrations. The cobalt content is systematically relatively low, 33 ppm on average. The Mo, V, U plus high S enrichment in the black shale intervals imply at least periodically anoxic-sulphidic depositional conditions, but also a generally oxygenated atmosphere at the time of the Outokumpu deposition ca. 1.95–1.91 Ga ago.

Wacke sediments in the Outokumpu Allochthon were deposited subsequent to 1920 ± 20 Ma, which is the age of their youngest dated detrital zircon grains (Lahtinen et al. 2009). The black schist interleaved lower units of the Outokumpu Allochthon host numerous fault-bound (exotic) bodies of serpentinite (after mantle peridotites) with variable component of 1.96 Ga gabbroic, basaltic and plagiogranitic rocks. These bodies are interpreted as fragments of 1.95 Ga mafic-ultramafic oceanic floor/crust that became tectonically incorporated among the turbidite sediments during the early obduction of the Outokumpu Allochthon at ca. 1.90 Ga (Peltonen et al. 2008). Serpentinites in the ophiolite fragments show at their margins the omnipresent listwaenite to birbirite alteration. Where ideally developed, the alteration zonation is as follows, from proximal to distal parts: 1–5 m of carbonate rock, 1–10 m of carbonate-silica rock, and 1–50 m of silica rock (birbirite). These zones are metamorphosed and recrystallised to carbonate-tremolite±olivine, tremolite±diopside and quartz rock, respectively. Thick alteration zones are typically flanked by thick zones of sulphide-rich black schist.

Some of the Outokumpu area serpentinite bodies host in their carbonate-silica alteration envelopes massive-semimassive Cu-Co-Zn (Figs. 38 and 39) and disseminated Ni sulphides of the Outokumpu and Kokka type, respectively. Of these

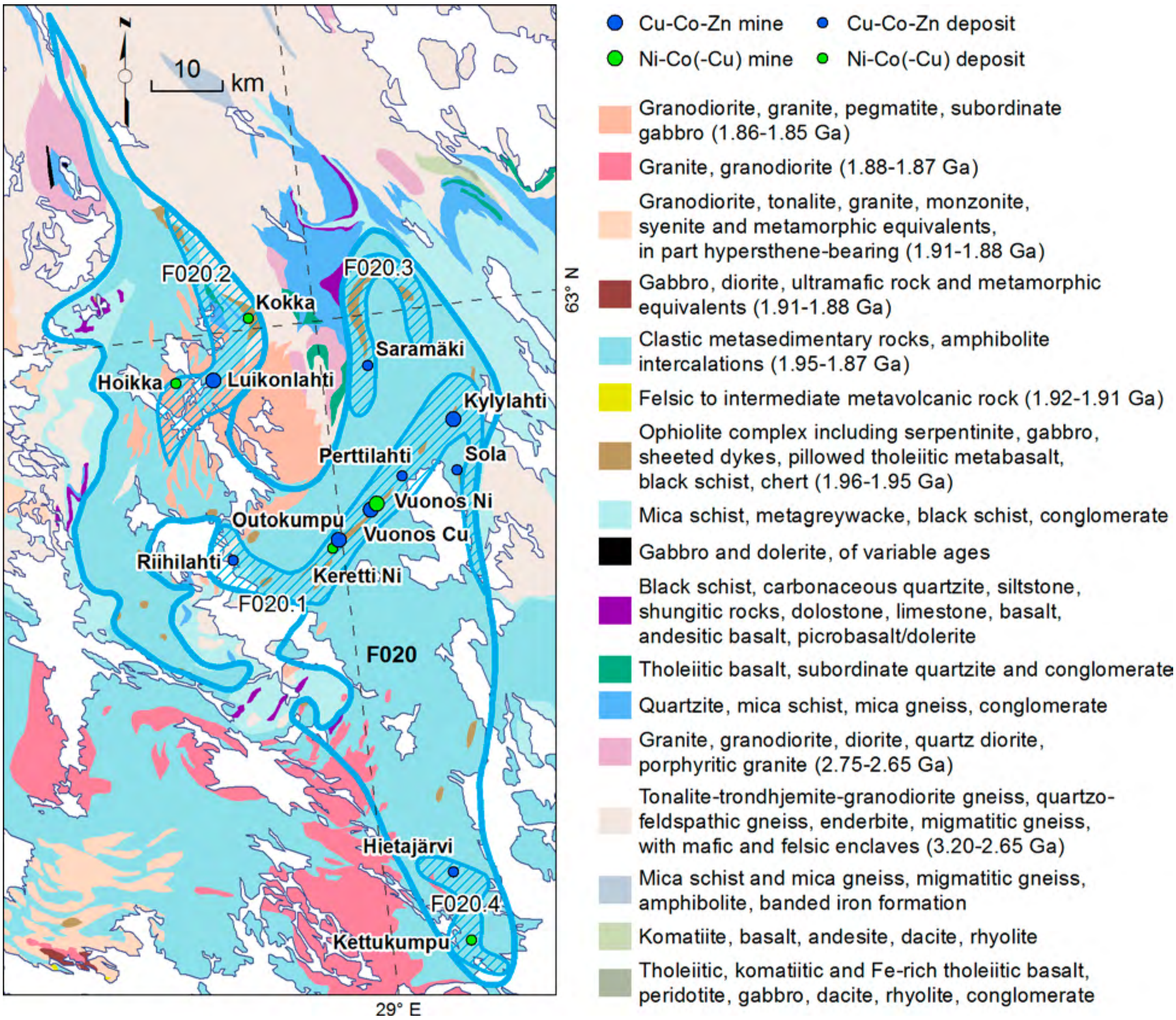

Figure 37. Geology of the Outokumpu Cu-Co, Ni (F020) metallogenic area and the metallogenic subareas, and the most significant base metal occurrences of area F020. Geology based on Koistinen et al. (2001).

two mineralisation types, the economically far more significant Outokumpu Co-Cu (Table 20) is in all cases found with a parallel zone of Ni-dominated mineralisation in the hosting skarn-quartz rocks. In contrast, the Kokka Ni also widely occurs in environments without any Cu-Co mineralisation. Weak Ni mineralisation is, in fact, a ubiquitous feature of the Outokumpu alteration assemblage, which systematically contains 1500–3000 ppm Ni in pyrrhotite and pentlandite. The concept of Kokka-type Ni mineralisation refers to rambled zones of more elevated Ni contents and Ni sulphides within the alteration zones, commonly in locations of intense shearing and in proximity to highly sulphidic black schists (Huhma 1975).

The metallogenic subareas of F020 are defined by distinct deposit clusters (Fig. 37). Between the subareas, there are no other differences between the deposits besides the deposit size and metamorphic grade (Kontinen et al. 2006, Peltonen et al. 2008). In the Keretti subarea (F020.1), the metamorphic grade is lowest in the NE at **Kylylahti** (lower-amphibolite facies) and highest in the SW at **Riihilahti** (upper-amphibolite facies). At Kylylahti (Fig. 39), the sulphide bodies are predominantly pyritic and show elevated contents of such more ‘volatile’ elements as As, Sb and Hg, whereas at Riihilahti, ore bodies are thoroughly pyrrhotitic with much lower Sb, As and Hg. The metamorphic control (cf., Vaasjoki et al. 1974) also shows up in that at Kylylahti a large part of Co is in pyrite, whereas at Riihilahti nearly all cobalt is in pentlandite. The large **Outokumpu** deposit is partly pyritic and relatively rich in As and Au, whereas the thinner, smaller Vuonos and **Perttilahti** deposits (Table 20) are thoroughly pyrrhotitic and low in As and Au. The Luikonlahti and Hietajärvi subareas are in mid- to upper-amphibolite facies environments, and their deposits are thus totally recrystallised to metamorphic granoblastic texture, and are thoroughly pyrrhotitic and very low in As and Au. The effects of metamorphism on the Kokka type Ni occurrences are restricted mainly to a grain size increase and increased remobilisation of the sulphides into blotches and veinlets.

The Outokumpu Co-Cu type is interpreted polygenetic with a primary inhalative-exhalative Cu-Co-Zn mineralisation event(s) ca. 1.95 Ga, in a hot spring environment in spreading zones or leaky transforms in a predominantly ultramafic ocean floor (Peltonen et al. 2008). The Ni mineralisation in the carbonate-silica alteration assemblage occurred during the ca. 1.90 Ga obduction of the ophiolite fragments, inside the host turbidite sediments, when low T (<200°C) carbonaceous and sulphidic fluids altered the outer margins of the ultramafic bodies to sulphide-bearing carbonate to quartz rocks. Nickel originally in ferromagnesian mantle minerals, such as olivine, was during this process relocated into sulphides. The exceptionally high Ni content in the Co-Cu type ores (Table 20) is interpreted to reflect early syntectonic interaction of the Cu-Co protosulphides with the Ni sulphides, by simple 'mechanical' mixing of the two sulphide end members or by fluid-assisted diffusion or the transport of Ni from the Ni occurrences into the Cu-Co bodies. Later syntectonic solid-state remobilisation and concentration of the Cu-Co-Zn-Ni sulphides into fault-controlled positions completed the geometric style of the Outokumpu type deposits as thin (1–15 m) and narrow (50–450 m) but long (1– >5 km) sheets. In such serpentinite bodies or ophiolite fragments that obducted without any Cu-Co protosulphides, only rambled local Ni enrichments of the Kokka type were generated in structurally favourable positions.

From the exploration standpoint, besides the probability of Outokumpu type Cu-Co deposits only occuring in a fraction of the observed serpentinite bodies (those obducted with Cu-Co protosulphides), one should also note that, on the basis of Pb isotope compositions, the commonly accompanying black shales did not significantly contribute to the genesis and metal budgets of the ore bodies (Peltonen et al. 2008). Experience from past exploration confirms this inference, as the black schists and their characters, such as metal tenors and ratios, have nowhere been observed to be useful vectors to the Cu-Co ores. However, the genesis of the Outokumpu alteration assemblage and Kokka-type Ni occurrences involved the influx of S and some rare metals, such as As, Sb and Pb, from the black shales.

Table 20. Metallic mineral deposits with a resource estimate in the Outokumpu Cu-Co, Ni Area (F020).

Subarea, **Occurrence**	**Tonnage (Mt)**	**Mined (Mt)**	**Ag g/t**	**Au g/t**	**Co %**	**Cu %**	**Ni %**	**Zn %**	**Reference[1]**
Keretti (F020.1)									
Keretti Ni	1.76			0.15	0.11	0.39	0.46	0.2	Parkkinen & Reino (1985)
Outokumpu	28.5[2]	28.5	8.9	0.8	0.24	3.8	0.12	1.07	Huhma & Huhma (1970)
Vuonos Cu	5.89[2]	5.89	11	0.1	0.15	2.45	0.13	1.6	Huhma & Huhma (1970)
Vuonos Ni	5.5[2]	5.5	0.3		0.03	0.04	0.2		Parkkinen & Reino (1985)
Sola	0.1				0.1	2	0.15	1	Huhma & Huhma (1970)
Perttilahti	1.324				0.15	2.15	0.14	1.89	Huhma & Huhma (1970)
Riihilahti	0.7		6	0.3	0.09	0.72	0.03	0.09	Parkkinen (1997)
Kylylahti	8.4			0.68	0.29	1.25	0.20	0.54	Universal Resources (2010)
Luikonlahti (F020.2)									
Luikonlahti	7.7[2]	7.7			0.12	1.2	0.09	0.65	Eskelinen et al. (1983)
Kokka	2.47					0.01	0.35		Parkkinen (1997)
Hoikka	0.2				0.04	0.5	0.15		Parkkinen (1997)
Saramäki (F020.3)									
Saramäki	3.4				0.09	0.71	0.05	0.63	Parkkinen (1997)
Hietajärvi (F020.4)									
Kettukumpu	0.4				0.07	0.44	0.18	0.1	Parkkinen (1997)
Hietajärvi	0.34		0.7		0.15	0.71	0.18	1.21	Huhma & Huhma (1970)

1 References in addition to Kontinen et al. (2006) and Peltonen et al. (2008).
2 Only the mined amount has been reported.

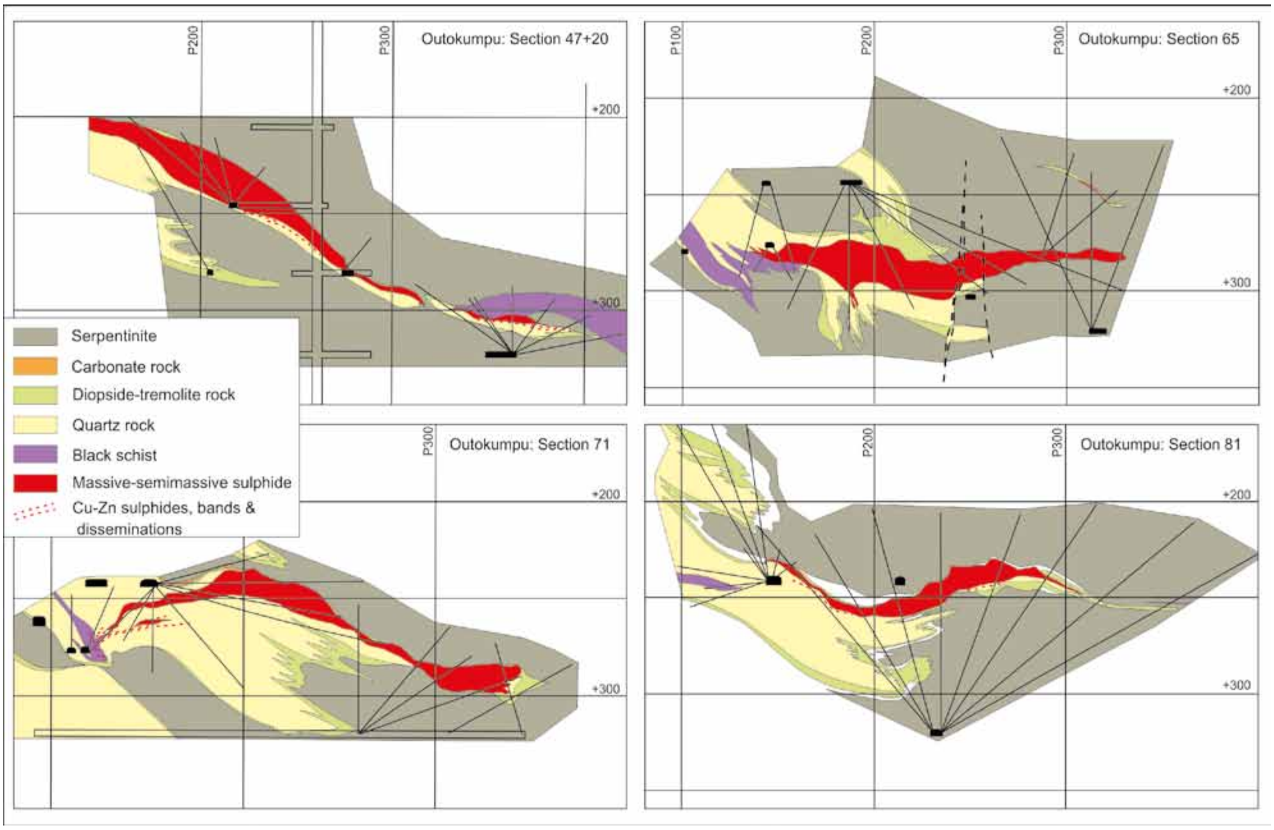

Figure 38. Sections across the SW part of the Outokumpu Cu-Co-Zn deposit, located at 62.7245°N, 28.992°E. Numbers on the right (+100, +200, +300) indicate reference levels in metres, small black polygons indicate underground drives and the black diagonal lines are drill hole traces. View to the NE. Modified from Kontinen et al. (2006).

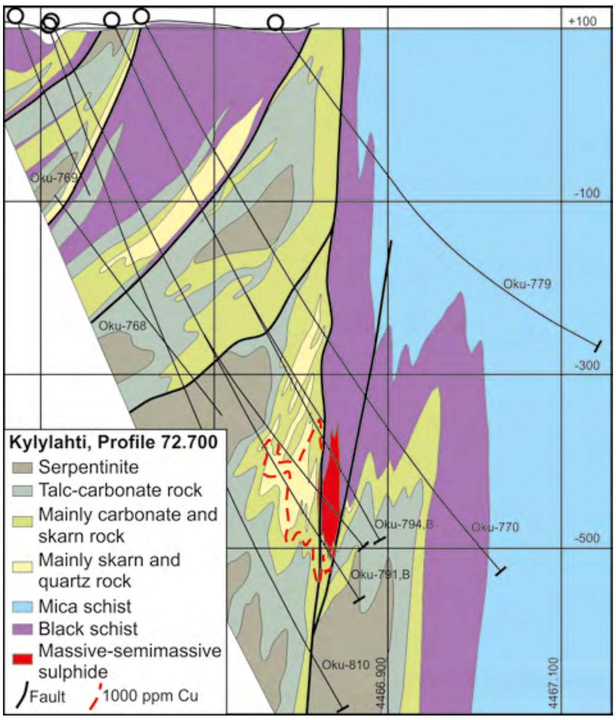

Figure 39. Geological section across the deeper parts of the Kylylahti Cu-Co deposit (62.8558°N, 29.3453°E) and its wallrocks. Numbers on the right (+100, -100, etc.) indicate reference levels in metres. Codes of the type 'Oku-810' are drill hole numbers. Modified from Kontinen et al. (2006).

F021 HAMMASLAHTI Cu-Zn

Kaj Västi (GTK)

The extent of the Hammaslahti metallogenic area (F021) is defined by the estimated extent of the apparently diagnostic rock sequence for the Hammaslahti-style copper-zinc mineralisation (Figs. 1 and 40). The diagnostic sequence includes both mafic volcanic and turbiditic sedimentary units of the Höytiäinen Belt (Vaasjoki et al. 2005). The extent of metallogenic area F021 is defined by the

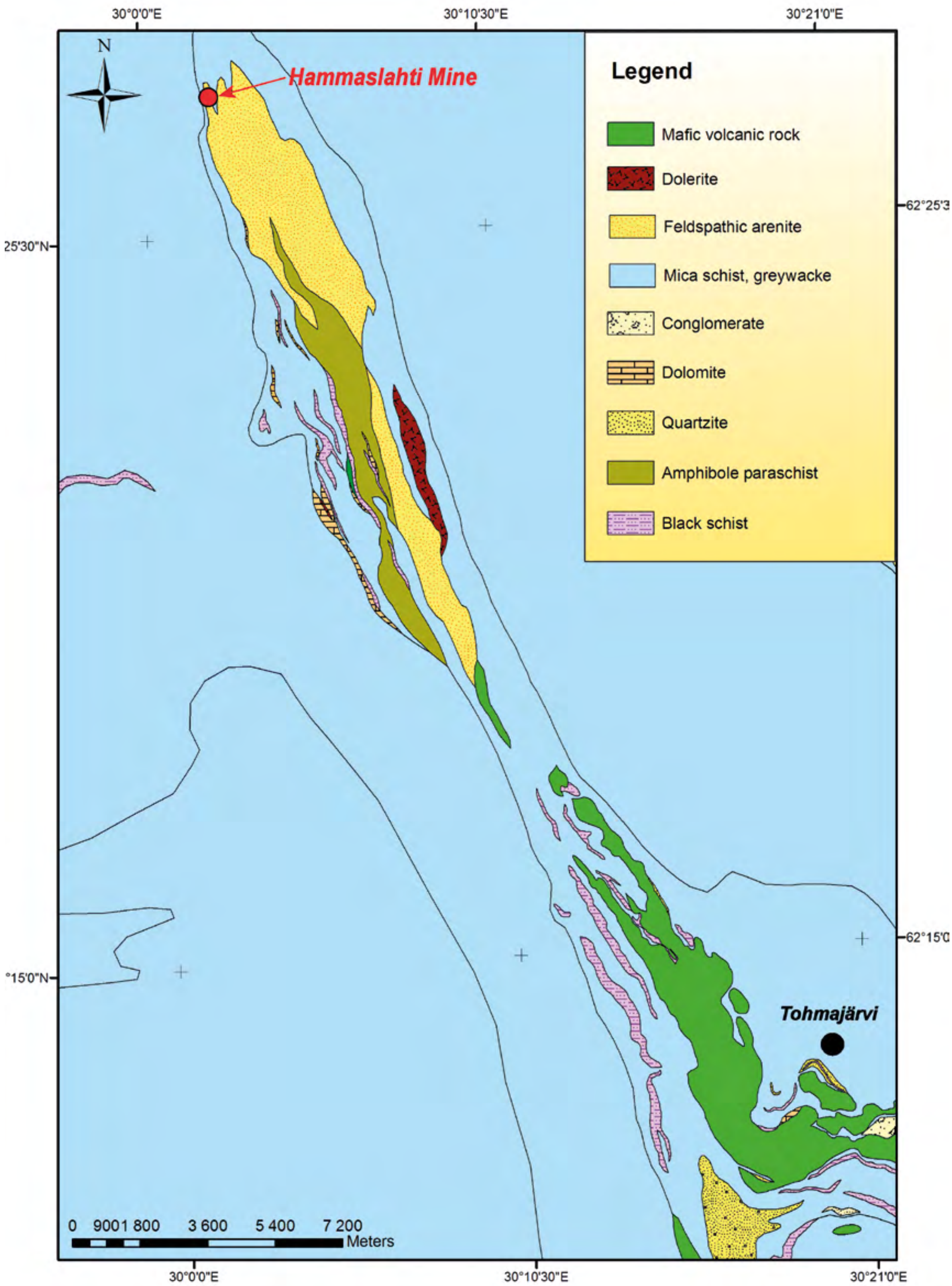

Figure 40. Geology of the central parts of the Hammaslahti metallogenic area (F021). Geological map is based on the GTK digital bedrock database.

extent of the diagnostic lithological sequence, as seen in the outcrop and estimated from low-altitude aerogeophysical surveys by GTK (Eilu et al. 2009, Damsten 2010a, b).

Bedrock of metallogenic area F021 mainly comprises coarse- to fine-grained metasedimentary rocks. Tholeiitic metabasalts, which are interpreted to have erupted in a rifted basin, form a large igneous complex in the Tohmajärvi region some 20 km SE of the Hammaslahti mine (Nykänen 1971, Ward 1987). The Hammaslahti Cu deposit itself is located on the northwestern margin of a 2-km-wide and 8-km-long NNW-trending arkosite formation which, after a short break, can be traced for about 10 km to the SSE (Fig. 40). Partly within and on the western margin of the arkosite formation, there is a 12-km-long conglomerate formation. These coarse-grained metasedimentary rocks are, in turn, enclosed by a relatively thin mica schist-phyllite shell and a thicker greywacke formation. Black schist, skarn rock, dolomitic marble and amphibolite intercalations are common both in conglomerate and mica schist-phyllite units. About 12 km east of the Hammaslahti mine, area F021 is bounded by the Archaean basement complex.

The **Hammaslahti** Cu-Zn deposit consists of three ore bodies (S, N and Z) hosted by hydrothermally altered quartz greywacke and arkosite. In places, the deposit is closely related to black schist and tremolite skarn (Karppanen 1986, Hämäläinen 1987, Loukola-Ruskeeniemi et al. 1992, Rantala, 2011). According to Kousa et al. (2008), the deposit probably represents a subseafloor hydrothermal system distal to contemporaneous mafic magmatism. The irregular and elongated ore bodies occur in an *en echelon* pattern in a N-trending zone, dipping steeply to the W with a plunge of 25–30° to the south. Alteration in and around the ore is characterised by depletion of Ca, Na, K, Sr and Rb and enrichment of S, Fe, Cu, Zn and Au (Loukola-Ruskeeniemi et al. 1991). The S and N ore bodies mainly consist of remobilised breccia ore, a stringer-like impregnation network and banded breccia, with local high-grade chalcopyrite concentrations. Pyrrhotite and chalcopyrite are the major sulphides in the S and N ore bodies. The Z ore body, lying further to the north, differs from the other lodes in that sphalerite, in addition to chalcopyrite and pyrite, is one of the major ore minerals. Galena, cubanite, mackinawite and arsenopyrite are minor sulphides in the ore (Karppanen 1986, Hämäläinen 1987). The pre-mining assessment of the ore resources indicated 4 Mt at 1.0 % Cu (Hyvärinen 1970) or, according to Koistinen (1971), >5 Mt @ about 1 % Cu. However, when mining operations ended in 1986, a total of 7 Mt of ore containing 1.16 % Cu had been produced (Loukola-Ruskeeniemi et al. 1992). In addition, the Z orebody yielded 0.28 Mt @ 1.55 % Zn, 0.52 % Cu, 0.59 ppm Au and 5.2 ppm Ag (Hämäläinen 1987). Of all the three ore bodies, the southernmost (S) was of the highest value, accounting for 70 % of the total ore reserves.

F022 KOLI U

Olli Äikäs (GTK)

The Koli U area (F022) is a narrow, NW-trending belt following the boundary between the Palaeoproterozoic Höytiäinen Belt and the Archaean Eastern Finland Complex (Fig. 41). Area F022 comprises basal quartzites and conglomerates in the lowermost part of the Höytiäinen Belt, above and at the unconformity against the largely Neoarchaean TTG-rocks of the basement (Äikäs & Sarikkola 1987, Vaasjoki et al. 2005). Area F022 extends for 140 km from Värtsilä in the SE (at the Finnish-Russian border) to Juuka in the NW.

Archaean granitoids near the Proterozoic unconformity are characterised by monzogranites and stromatic migmatites with potassic granite leucosomes; the youngest granitoids are 2.63 Ga in age (Sorjonen-Ward & Luukkonen 2005). A large part of these granitoids show enhanced radioactivity in airborne geophysical data. In the sedimentary sequence above the unconformity, the NW part (Koli belt) is mainly composed of arenites known as the Herajärvi Group (Kohonen & Marmo 1992), whereas the SE part (Kiihtelysvaara-Värtsilä belt) contains a highly variable suite of sedimentary and mafic volcanic units, including dolomitic marble and black schist (Pekkarinen 1979, Pekkarinen & Lukkarinen 1991). The counterpart of the Herajärvi Group is absent or markedly thinner in the SE; on the other hand, marble and black schist are absent in the NW. The mafic Koli sill complex, which intrudes both the Archaean basement and part of the overlying Herajärvi Group, was emplaced at about 2220

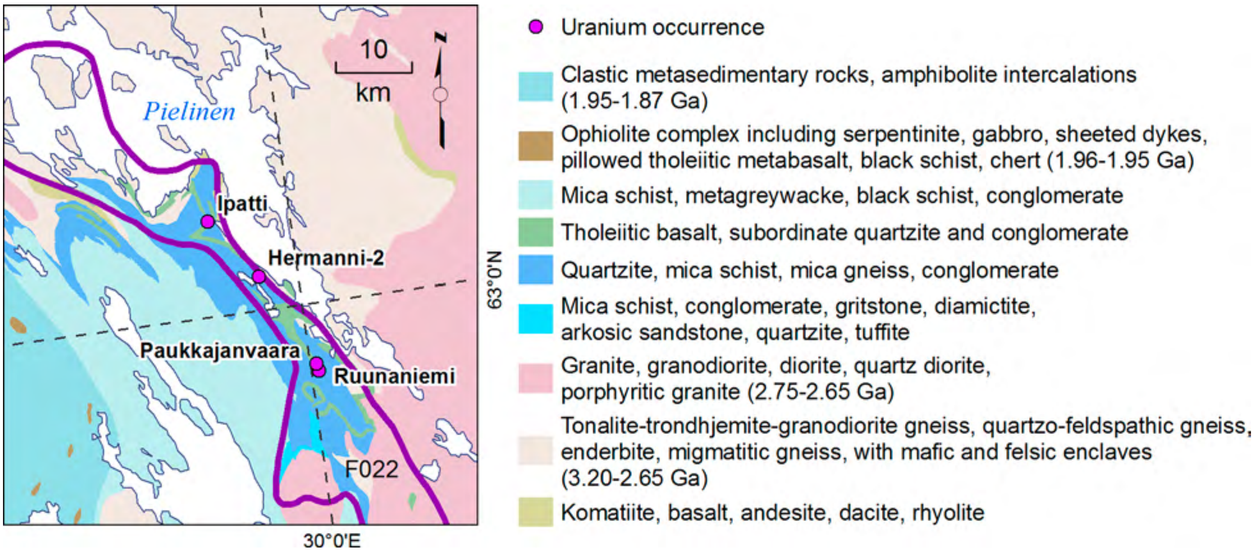

Figure 41. Central parts of the Koli metallogenic area (F022). Geology simplified from the GTK digital bedrock map database.

Ma. Tholeiitic dyke swarms of age groups 2.1 Ga and 1.98 Ga (Vuollo & Huhma 2005) cut the Archaean basement and the overlying basal units of the Höytiäinen belt. With the epicontinental sedimentary rocks deposited at the craton margin, the Koli U area represents an orogenic foreland setting with respect to Svecofennian NE-vergent thrusting.

In its NW part, area F022 contains minor deposits and occurrences of uranium in the Herajärvi Group metasedimentary rocks, commonly showing a close spatial association between uranium and mafic dykes (Piirainen 1968, Äikäs & Sarikkola 1987, Pekkarinen et al. 2006). In the SE part, occurrences of thorium and uranium in quartz-pebble conglomerates are known both in the basal and upper parts of the sedimentary pile. In addition, showings of uranium ± molybdenum have been drilled in the Archaean basement adjacent to the Proterozoic unconformity (Pekkarinen 1979). Structural and thermochronological constraints indicate that the Koli U area has experienced lower-amphibolite facies PT conditions, and remained at elevated temperatures until at least 1.82 Ga. Therefore, late-orogenic retrograde hydrothermal processes are a plausible mechanism for mobilisation of uranium (Sorjonen-Ward & Äikäs 2008).

The styles of uranium mineralisation within area F022 range from primary stratiform conglomerate and sandstone occurrences to epigenetic veins and breccia infills in and along mafic dykes in the Proterozoic host rocks (Äikäs & Sarikkola 1987). The main uranium minerals in these occurrences are pitchblende and uranophane. In the Archaean basement, uranium occurs as uraninite in metasomatic pegmatoid pockets, possibly related to Palaeoproterozoic events of mineralisation (Pekkarinen 1979). Pilot-scale mining and milling was carried out at **Paukkajanvaara** from 1958 to 1961, with 0.04 Mt ore at 0.14 % U treated in 1960−1961.

F023 ILOMANTSI Au, Mo

Peter Sorjonen-Ward (GTK), Margarita Korsakova (SC Mineral)

The Ilomantsi metallogenic area (F023) comprises the N-trending eastern part of the Ilomantsi greenstone belt and the immediately surrounding country rocks (Fig. 42). The Finnish part of the area is also known as the Hattu schist belt (e.g., Sorjonen-Ward 1993).

The eastern part of the Ilomantsi greenstone belt is similar to those Neoarchaean greenstone belts in Canada, Australia, Brazil, India and southern Africa in which peak metamorphic conditions were in the lower-amphibolite facies (e.g., Eckstrand et al. 1996, Goldfarb et al. 2001). The

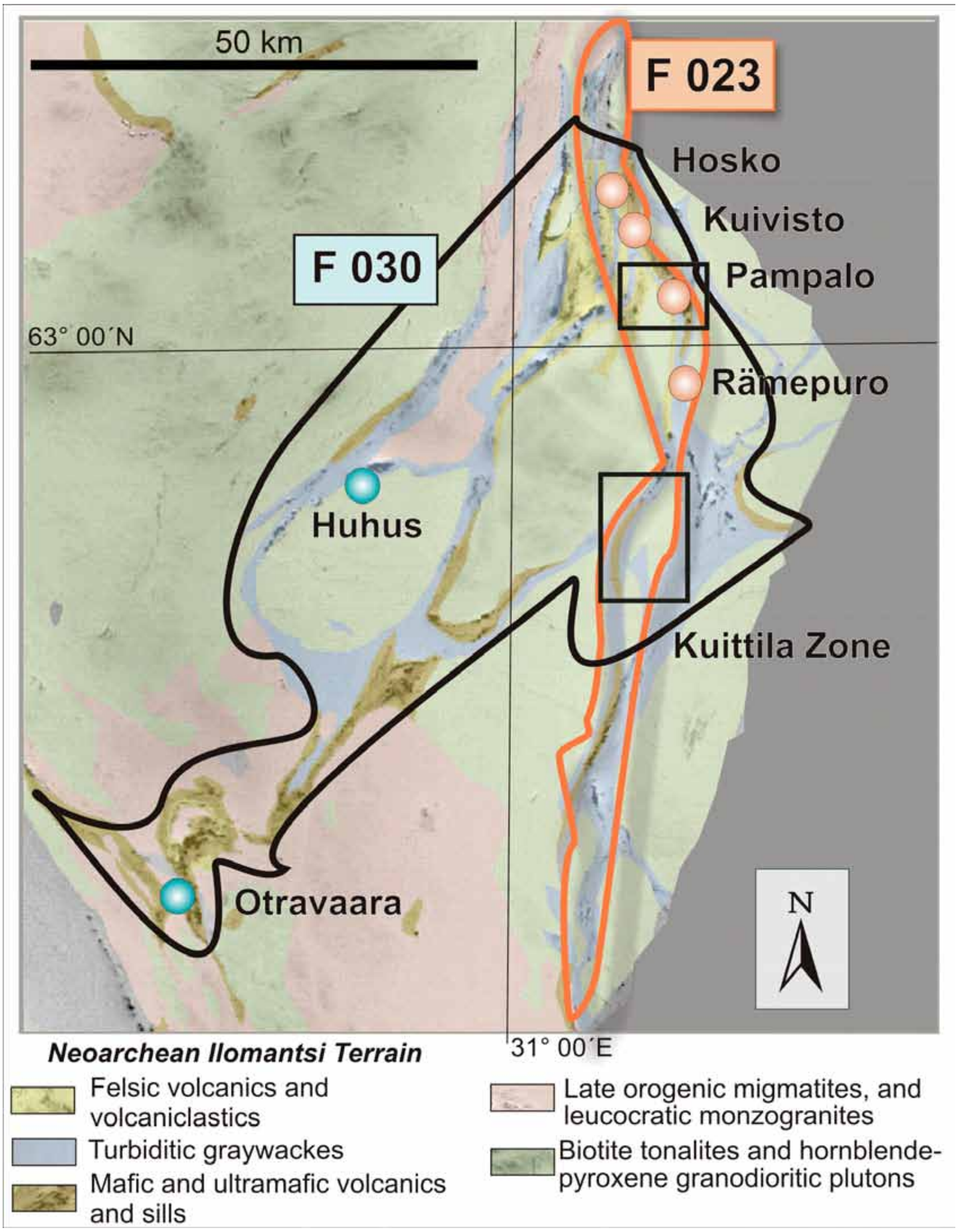

Figure 42. Simplified geological map of the Neoarchaean Ilomantsi greenstone belt and surroundings, indicating principal Au and Fe occurrences in metallogenic areas F023 (Ilomantsi, Finnish part only) and F030 (Huhus), respectively. The black rectangle enclosing Pampalo indicates the location of Figure 44a, and the larger black rectangle indicates the location of a more detailed map of the Kuittila Zone (Fig. 45). Geology based on the GTK bedrock database. Aeromagnetic map based on GTK survey data in the background. Proterozoic rocks in the lower left corner in light grey, Russian territory on right in dark grey.

Ilomantsi greenstones are dominated by felsic to intermediate epi- and volcaniclastic rocks with intercalations of tholeiitic and komatiitic volcanic rocks, BIF, and felsic to intermediate porphyries (Sorjonen-Ward 1993, Sorjonen-Ward & Luukkonen 2005, Feoktistov et al. 2007). Isotopic constraints indicate that the supracrustal sequence was deposited during a brief time around 2.76–2.75 Ga and was intruded by felsic to intermediate granitoids and porphyries with ages from 2746 to 2725 Ma (Vaasjoki et al. 1993, Sorjonen-Ward & Luukkonen 2005). The greenstone sequence thus represents one of the youngest Archaean supracrustal units in the Fennoscandian Shield, and was deformed and metamorphosed simultaneously with and shortly after depositions, at 2.74−2.63 Ga, thus coinciding with the global Neoarchaean orogenic event.

The most important metallic commodity in the Ilomantsi area is orogenic gold, but there are also indications of Mo-W mineralisation in the granitoids intruding the greenstone belt (Nurmi et al. 1993, Luukkonen et al. 2002, Raw Mineral Base of the Republic of Karelia 2005, Eilu 2007). Gold mineralisation and accompanying hydrothermal alteration in the Hattu schist belt coincides with well-defined narrow high-strain zones, delineating the generally N-S trending Hattu Au subarea (F023.1) (Fig. 42). Magnetite-quartz and sulphide-quartz banded iron formations are also present within the eastern part of the Ilomantsi greenstone belt. However, the most significant BIF occurrences are within the western branch of the greenstone belt, defined here as a separate metallogenic area (Huhus Fe, F030) and discussed in a separate section below.

Gold mineralisation at Ilomantsi is rather typical of the orogenic category as defined by Groves (1993) and Goldfarb et al. (2001). Each of the occurrences is characterised by a strong structural control and gold is, at present, the sole commodity of economic interest. Typical metal-enrichment associations at both district and prospect scales include Au-As-Sb-Te-W±B, with Au/Ag >1; quartz veining is abundant, although sulphides, which comprise 1–3 vol%, are more common as dissemination dispersed through altered rocks. Gold commonly occurs in a native form, with the dominant sulphide ore minerals being pyrite, pyrrhotite and arsenopyrite, the latter being more typical of the turbidite-hosted Hosko (or Valkeasuo) occurrence in the northernmost part of area F023. Alteration is in many places subtle, although pervasive, and typically includes carbonate, potassic alteration (sericite and biotite) chlorite and tourmaline (Nurmi et al. 1993, Rasilainen 1996, Poutiainen & Partamies 2003). The occurrences are predominantly within N–S and NW-trending ductile shear zones, and mineralisation has been found in nearly all rock types present within the greenstone belt: intermediate volcaniclastic to clastic rocks, komatiitic to basaltic volcanic rocks, granitoids, and quartz-feldspar porphyries (Nurmi et al. 1993, Eilu 2007). Mesoscopic and microstructural evidence indicates that the gold mineralisation was mostly likely concurrent with alternating ductile and brittle rock behaviour under peak-metamorphic conditions (Sorjonen-Ward 1993); this deformation event is correlated with the regional-scale syn-D3 to D4 phase recognised throughout eastern Finland, between 2.72−2.69 Ga (Sorjonen-Ward & Luukkonen 2005).

In total, 16 gold occurrences with ore-grade intersections have so far been indicated by drilling in the Finnish part of the Ilomantsi area (Eilu 2007), and several further occurrences have been drilled in the Russian part of the area. However, resource estimates have only been reported for seven occurrences (Table 21). Test mining was undertaken at Pampalo in two stages during 1996−1999, when 1784 kg of gold was produced from 0.1258 Mt of ore (Figs. 43 and 44), and full-scale production started at the mine in early 2011 (Endomines 2011). Gold exploration within area F023 has only been systematically undertaken in the central parts of the area covered by subarea F023.1. Therefore, the potential for further discoveries within the region as rather high.

Molybdenum mineralisation in area F023 is most prominent in its southernmost part, with 10.93 Mt (at 0.03 % Mo) at Jalonvaara. The Jalonvaara deposit is confined to endo- and exocontacts of a small porphyry granite massif. Indications of Mo ± W mineralisation have also been detected in other parts of the Ilomantsi metallogenic area, for example at Kuittila (Fig. 45), in the central part of subarea F023.1. The style of molybdenum mineralisation varies from quartz vein networks and molybdenite dissemination in granitoids to pyrite-molybdenite dissemination in sericite schist associated with granite (Kojonen et al. 1993, Nurmi et al. 1993, Raw Mineral Base of the Republic of Karelia 2005). Textural relationships at Kuittila indicate that laminated quartz-tourmaline-albite veins containing molybdenite and scheelite form geometrically regular networks that are locally disrupted by ductile shear zones with sericitic alteration and quartz-carbonate-pyrite veins, containing gold (Sorjonen-Ward 1993). It is therefore concluded that the Mo±W mineralisation was a late-stage magmatic event, subsequently overprinted by syntectonic gold mineralisation. Isotopic dating of zircon from the Kuittila Tonalite (Vaasjoki et al. 1993) and molybdenite from veins (Stein et al. 1998) are consistent with, but do not unequivocally demonstrate these age relationships. Moreover, the auriferous shear zones at Kuittila contain scheelite, whereas the distribution of scheelite in the Pampalo deposit has proven to be a practical qualitative vector for gold mineralisation (Esa Sandberg, pers. comm. 2006).

Table 21. Orogenic gold occurrences with a reported resource within the Ilomantsi metallogenic area (F023).

Occurrence	Tonnage (Mt)	Au g/t	Main ore minerals	Main host rock	Reference
Kuittila	0.275	2.58	Pyrite, pyrrhotite	Tonalite	Damsten (1990)
Kuivisto	0.1	4	Pyrrhotite, pyrite	Intermediate volcaniclastic schist	Heino et al. (1995), Parkkinen (2003)
Muurinsuo	0.997	1.8	Pyrrhotite, pyrite	Felsic to intermedi-ate sediments	Rasilainen (1996), Endomines (2009)
Pampalo	1.6488	4.3	Pyrite	Intermediate vol-caniclastic schist	Nurmi et al. (1993), Rasilainen (1996), Endomines (2010b)
Rämepuro	0.223	4.2	Pyrrhotite, pyrite	Tonalitic por-phyry dyke	Ojala et al. (1990), Nurmi et al. (1993), Endomines (2009)
Soanvaara	0.5	3	Pyrite, chalcopyrite	Chlorite-mica schist	Raw Mineral Base of the Republic of Karelia (2005)
Valkeasuo	1.077	2.8	Pyrrhotite, arsenopyrite	Felsic to intermediate volcaniclastic schists	Heino et al. (1995), Endomines (2009)

Figure 43. The Pampalo mine site in summer 2010. Photo: Seppo Huttunen, courtesy of Endomines Ab.

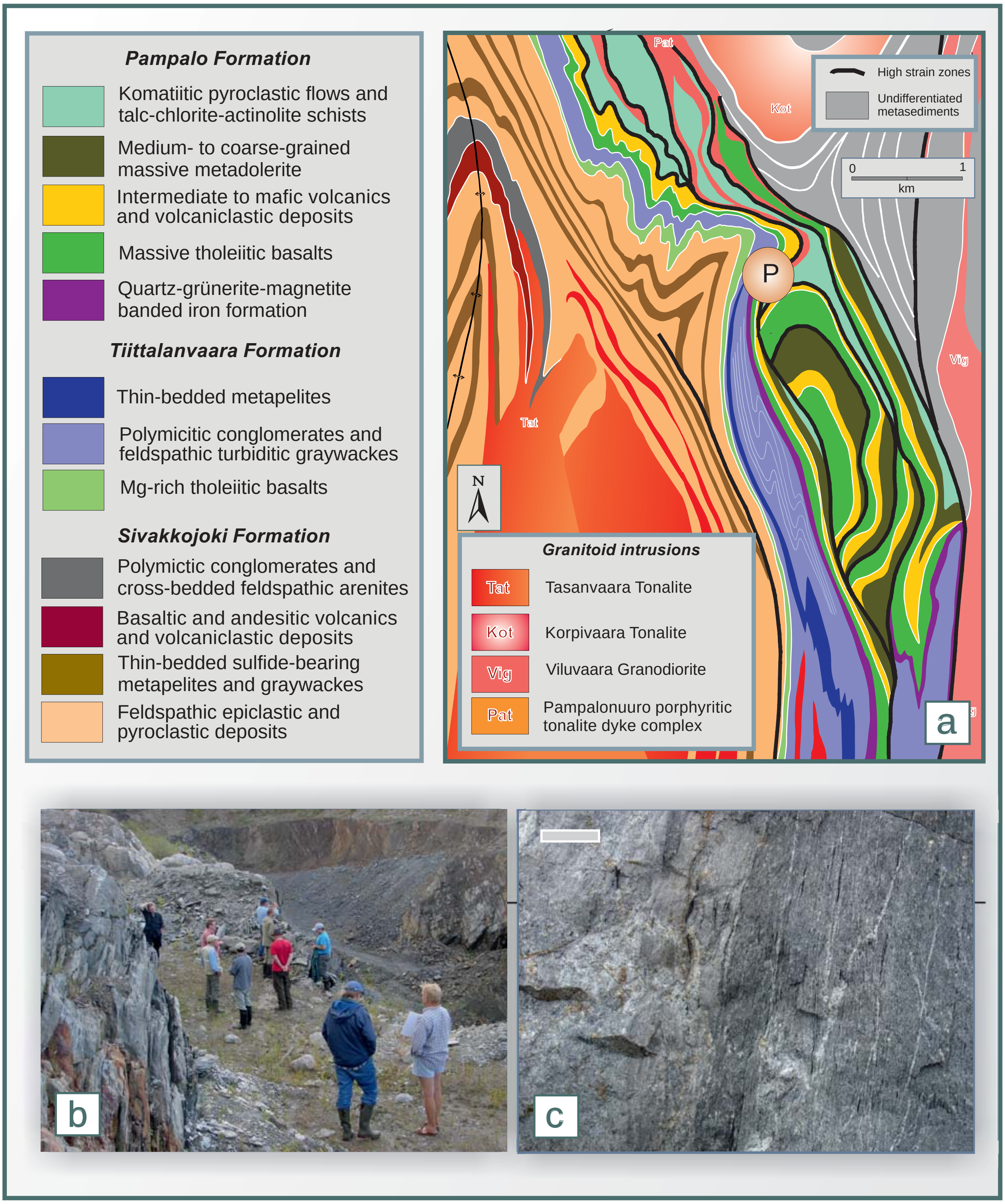

Figure 44. (a) Stratigraphic setting of the Pampalo Zone in the northern part of the Hattu schist belt (see location in Fig. 42); location of the Pampalo gold deposit indicated by the symbol P. (b) View towards the southwest into the Pampalo open pit. The entrance to the decline into to the underground mine is at the right margin, to the right of project geologist Esa Sandberg (wearing shorts and sandals). Outcrops in the foreground at left are talc-chlorite schists of the hanging wall, immediately east of the main lodes. The far wall beyond the decline shows a steep westerly dip in a mafic volcanic and banded iron formation defining the footwall to the deposit (WGS84 coordinates 62° 59´8"N 31° 15´ 58"E). (c) Typical example of ore-grade material, in which sulphides and gold are disseminated through strongly foliated and veined rock of intermediate composition, inferred to have been derived from a volcaniclastic protolith. Scale bar is approximately 5 cm. Photos: Peter Sorjonen-Ward, GTK.

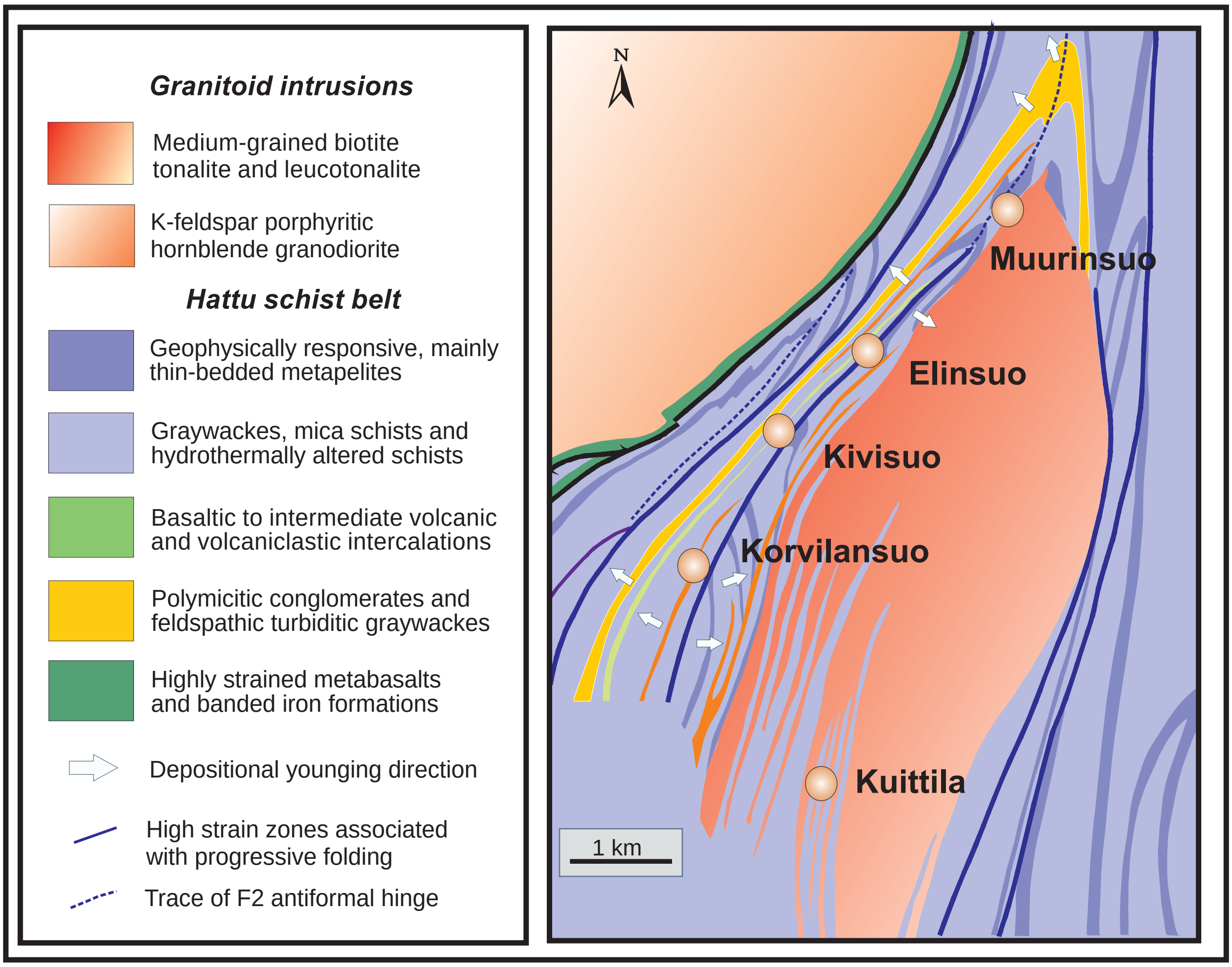

Figure 45. Geological map of the Kuittila Zone, showing the asymmetric distribution of gold occurrences along and within the western margin of the Kuittila Tonalite. Dots mark drilling-indicated gold occurrences, two of which (Kuittila and Muurinsuo) have been drilled sufficiently to permit provisional resource estimation. The location of the Kuittila occurrence is 62.773°N, 31.199°E.

F024 EMMES Li

Timo Ahtola (GTK)

The Emmes (Kaustinen or Kruunupyy–Ullava) 500 km² Li area (F024) is a part of the Pohjanmaa schist belt (Fig. 46). Alviola et al. (2001) suggested that lithium pegmatites in area F024 belong to the albite-spodumene subgroup of the LCT (Li, Cs, Ta) pegmatite family of Černy and Ercit (2005). These Palaeoproterozoic 1.79 Ga (U-Pb columbite age) albite-spodumene pegmatites crosscut the Svecofennian 1.95–1.88 Ga supracrustal rocks composed of greywackes and mica schists with intercalations of sulphide-bearing black schist and volcanic metasedimentary rock (Alviola et al. 2001). The regional metamorphic grade varies from lower- to upper-amphibolite facies. The LCT pegmatites in the area are younger than the 1.89–1.88 Ga peak of regional metamorphism (Mäkitie et al. 2001).

The average mineral composition of the spodumene pegmatites in the Emmes area is 32 % quartz, 30 % albite, 20 % spodumene, 13 % microcline and 5 % mica, with accessory volumes of columbite, triphylite, beryl, tourmaline, apatite and garnet (Ahtola et al. 2010a, 2010b). The dykes are 200–400 m long, some are very narrow, but others up to 10–25 m wide (Fig. 47). The area is mostly covered by glacial till and postglacial sediments, and none of the dykes discovered so far were originally exposed. Spodumene occurs as long and quite thin laths. Its colour varies from colourless or grey to green and brownish red. The average Li_2O content of the pegmatites is around 1 %. The best known and the biggest lithium deposit is Länttä, presently held by Keliber Oy (Table 22). Exploration since the 1960s in the region indicates that, in addition to those so far discovered, the area probably contains dozens of spodumene pegmatite dykes. Hence, the spodumene pegmatites of area F024 potentially form the largest lithium resource in the EU area.

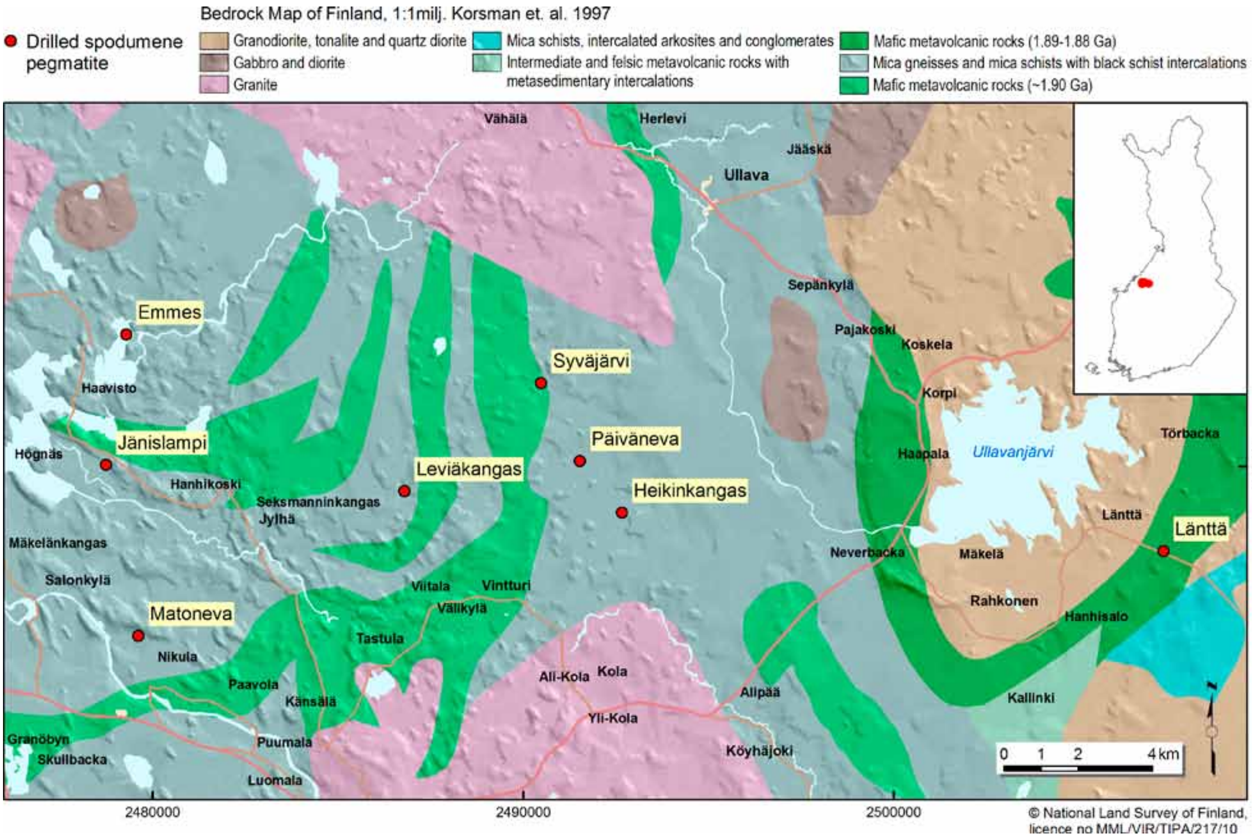

Figure 46. Bedrock of the central parts of the Emmes Li area and drilled spodumene pegmatites in the area. Geology according to Korsman et al. (1997), main roads in red, lakes and rivers in pale blue, digital elevation model in the background. Coordinates according to the Finnish national KKJ grid. The Emmes deposit is at 63.671°N, 23.580°E.

Table 22. Rare metal occurrences with a resource estimate in the Emmes Li area (F024).

Occurrence	Tonnage (Mt)	Be %	Li %	Ta %	No. of dykes	Reference
Emmes	1.1		0.54			Säynäjärvi (1972)
Länttä	2.95		0.43	0.0065	One	Grøndahl (2009)
Leviäkangas	2.1	0.0067	0.33	0.0059	One	Ahtola et al. (2010a)
Syväjärvi	2.6	0.0053	0.46	0.0021	Several	Ahtola et al. (2010b)

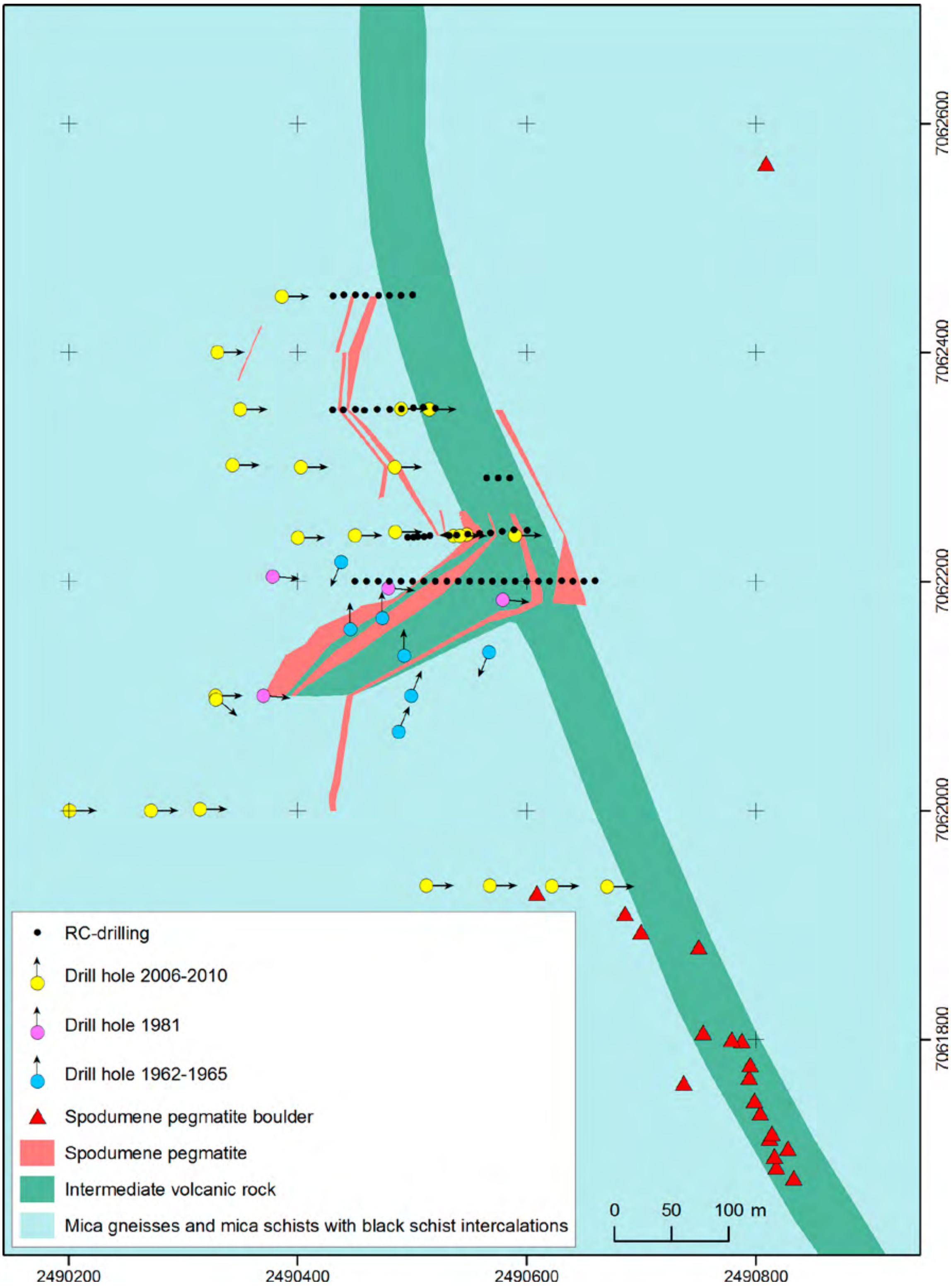

Figure 47. Geology the Syväjärvi spodumene pegmatite area (Ahtola et al. 2010b). Coordinates according to Finnish national KKJ grid. The Syväjärvi deposit is at 63.396°N, 23.484°E.

F025 KOIVUSAARENNEVA Ti

Niilo Kärkkäinen (GTK)

The Koivusaarenneva Ti area (F025) comprises a chain of ilmenite-rich gabbro intrusions on the northwestern part of the Central Finland Granitoid Complex (CFGC), close to the Pohjanmaa supracrustal belt (Fig. 48). Mafic intrusions have been found here in regional geophysical surveys, indicated by gravity and magnetic highs in an area with only a few outcrops.

The mafic intrusions of area F025 were emplaced at 1881 Ma into tonalitic bedrock, and belong to a larger gabbro province interpreted to have been formed in tensional zones in the vicinity or margin of convergent plate boundaries in the Kälviä-Halsua region, western Finland (Kärkkäinen & Bornhorst 2003). The most common rock types in these intrusions are medium-grained gabbro, gabbronorite and pyroxenite, all characterised by Fe-Ti oxides. The rocks have been recrystallised under regional metamorphism at mid-amphibolite facies PT conditions. This has resulted in almost all pyroxene being uralitised and the plagioclase mainly being oligoclase. Common features of these intrusions include their small size and layered structure, mainly gabbroic composition, pyroxenite as the most mafic rock type, the occurrence of igneous ilmenite and magnetite, the absence or a low content of apatite, low MgO in ilmenite and high V in magnetite (Kärkkäinen & Bornhorst 2003). Five ilmenite deposits (Table 23) in area F025 are presently (2011) being explored by Kalvinit Oy (a subsidiary of Endomines Oy), and a mining concession has been applied for.

The main ilmenite deposit of area F025 is hosted by the **Koivusaarenneva** gabbro, which is a 3-km-long, 0.5–1-km-thick, sill-like intrusion. Koistinen (1996) estimated it to contain 44 Mt of mineralised rock with 15 % ilmenite and 6 % vanadiniferous magnetite (0.6 % V in magnetite). Koivusaarenneva gabbro can be divided into three zones, lower, middle and upper (Fig. 49), and the characteristic minerals in these zones are ilmenomagnetite, ilmenite and apatite, respectively (Kärkkäinen & Bornhorst 2003). The main rock type in all zones is a metamorphosed gabbro or gabbronorite. The lower zone contains minor ilmenite-rich layers with abundant ilmenomagnetite. The TiO_2/Fe_2O_{3TOT} ratio is constant at 0.2 for all rock types in the lower zone. The middle zone contains a 1.5-km-long, 50–60 m thick, Ti-mineralised layer that grades at 8–48 % ilmenite and 2–25 % magnetite (Fig. 50). The average ratio of ilmenite to magnetite is 4:1. The TiO_2/Fe_2O_{3TOT} ra-

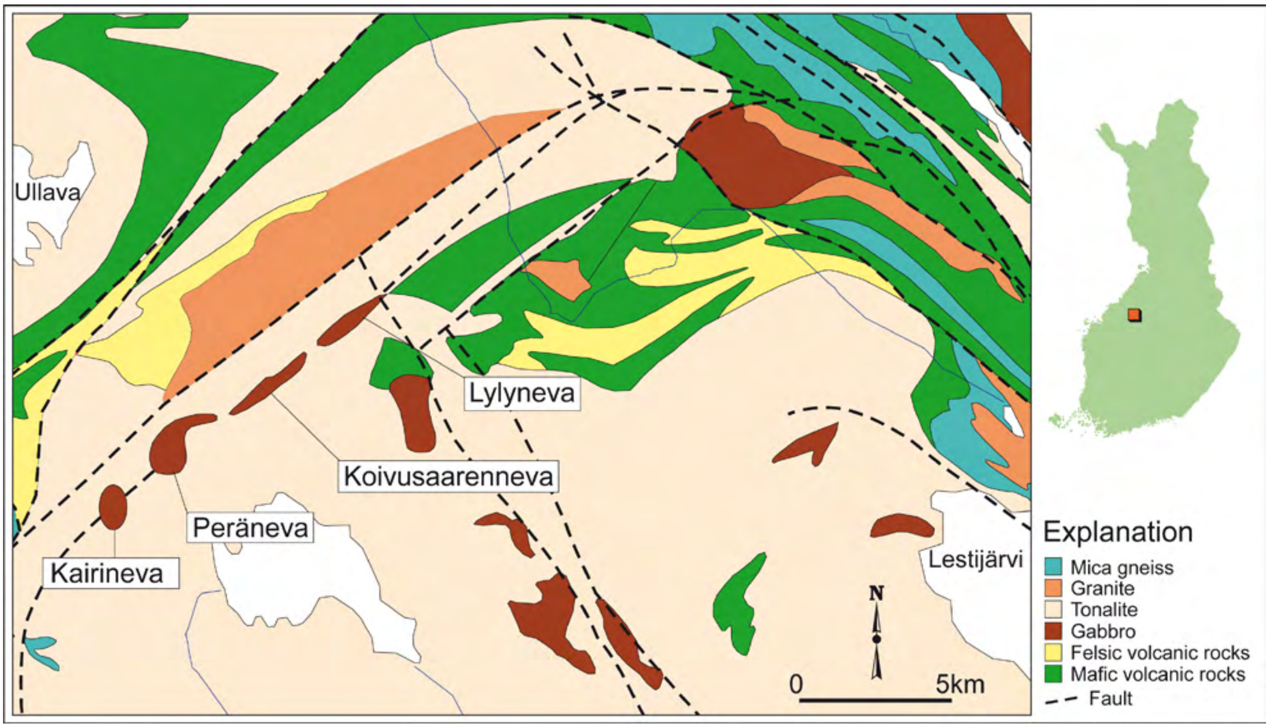

Figure 48. Geology of central parts of the Koivusaarenneva metallogenic area (F025); named are the most significant known titanium occurrences of the region (Kärkkäinen & Bornhorst 2003). The Koivusaarenneva intrusion is at 63.586°N, 24.239°E.

tio of the middle zone is 0.23–0.50. Ilmenite is the dominant Fe-Ti oxide in the upper zone, which consists of P-rich gabbro and leucogabbro.

The mineralogy of the Fe-Ti oxides varies according to the stratigraphic position, but is constant along the strike within each stratigraphic unit at Koivusaarenneva. Magmatic ilmenite (Fig. 51) dominates in the middle and the upper zones, and is also common in the lower zone where part of the ilmenite occurs as exsolution lamellae in titanomagnetite (Kärkkäinen & Bornhorst 2003). The grain size of the ilmenite and magnetite is 0.1–1.2 mm. Metamorphic processes have only slightly affected the ore mineralogy, most importantly by causing recrystallisation of titanomagnetite (ulvospinel) to ilmenomagnetite. Ilmenite is low in MgO (<0.5 %) and Cr (<100 ppm), whereas the V content of magnetite is high (0.6 %); locally, the Cr content in magnetite is also relatively high (Table 24).

The chemical composition and cryptic layering of the three zones at Koivusaarenneva suggest crystallisation from successive pulses of Ti-rich tholeiitic magma. The parent magmas for the lower and middle zones are similar. The lower zone is interpreted to have been generated by relatively closed-system fractional crystallisation, and based on the common ilmenomagnetite, under relatively high oxygen fugacity (Kärkkäinen & Bornhorst 2003). The upper zone has also been generated by relatively closed-system fractional crystallisation, but the parental magma was far more evolved, although primarily similar to magma of the two lower zones.

The genesis of the Fe-Ti oxide-rich layers in the middle zone can be explained by deposition from several magma pulses in an open system, because of the small volume of the rock in the middle zone (Kärkkäinen & Bornhorst 2000). The middle zone may represent a channel for magma flow

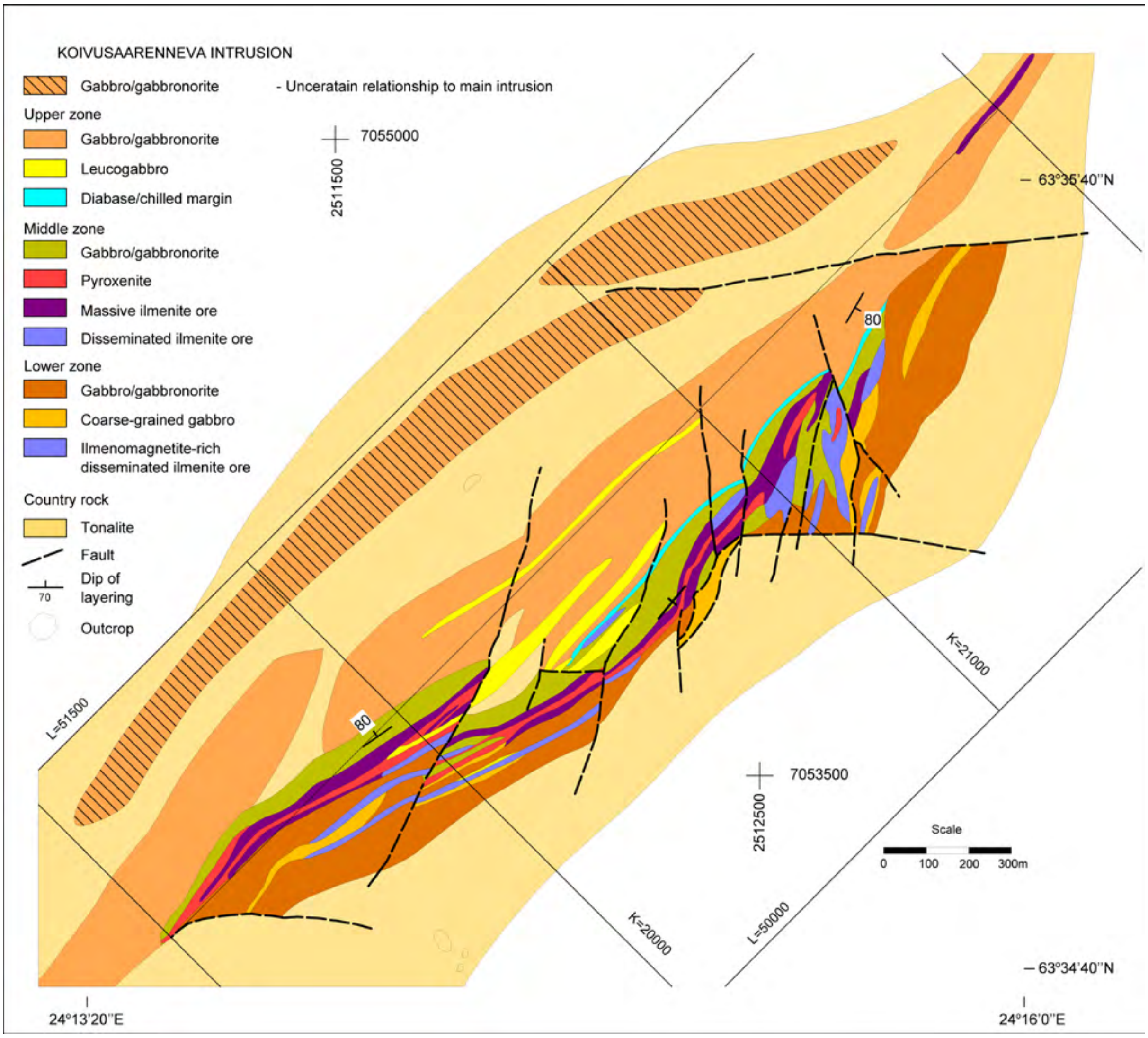

Figure 49. Surface geology of the Koivusaarenneva gabbro (Kärkkäinen & Bornhorst 2003).

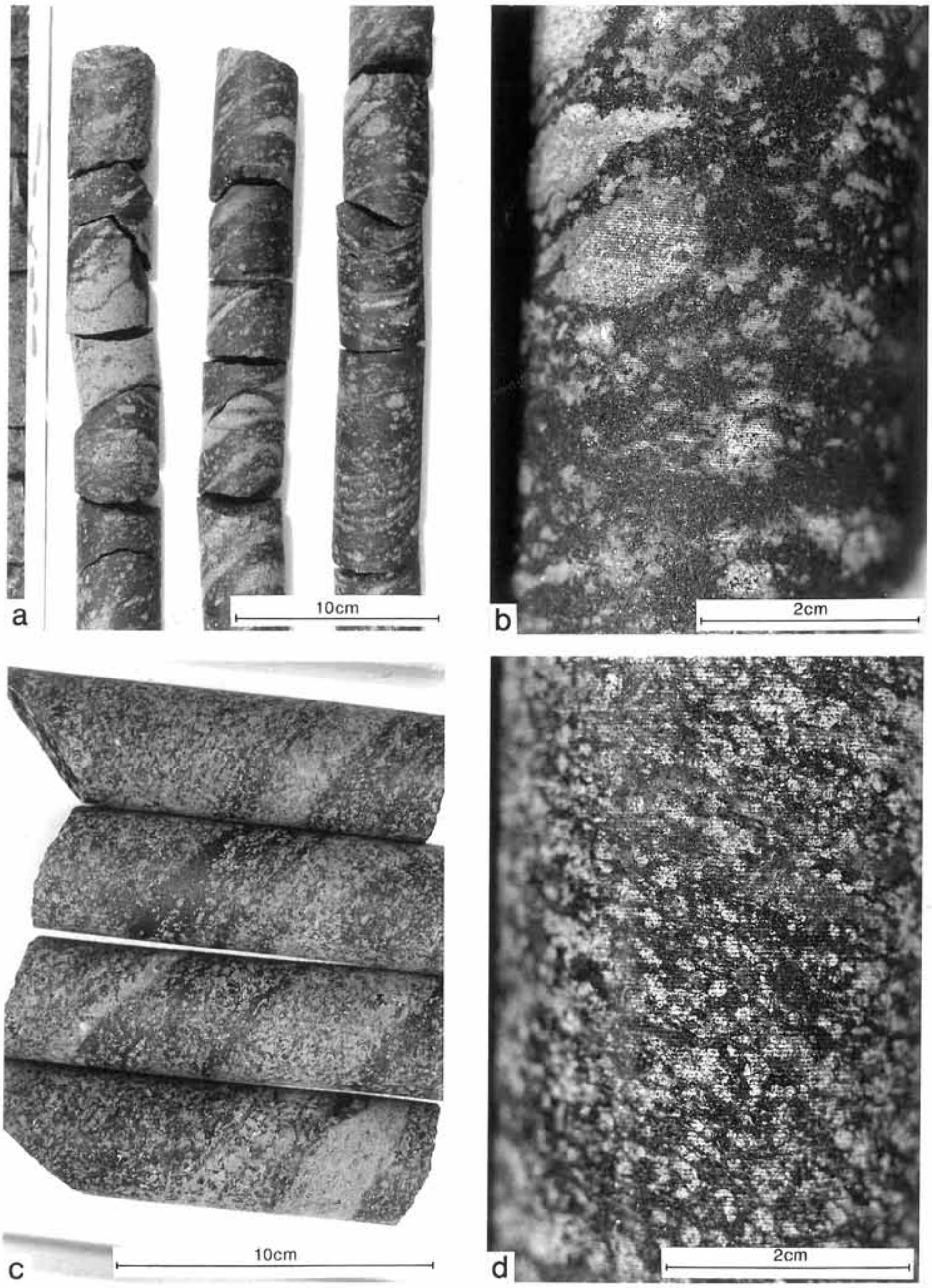

Figure 50. Ilmenite ore in drill core; middle zone of the Koivusaarenneva intrusion. Photo: Niilo Kärkkäinen, GTK.

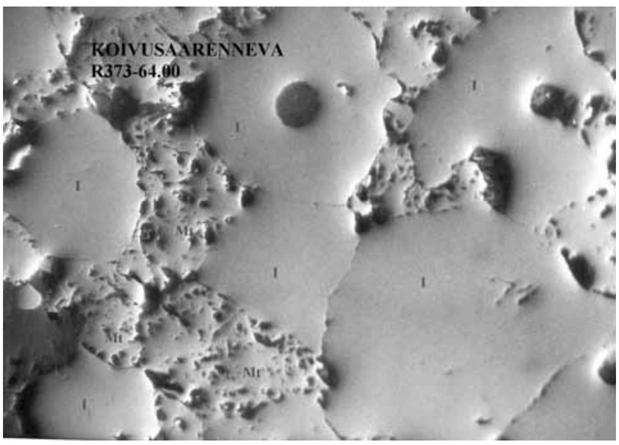

Figure 51. Photomicrograph of the Koivusaarenneva ore. Grain size of ilmenite is 0.5–3 mm. Field of view 10 mm. Image: Niilo Kärkkäinen, GTK.

where the large mass of oxides was trapped and accumulated in favourable localities within the channelways from multiple magma pulses. Ti-rich melt droplets or suspended oxides were removed from a Ti-saturated magma and sank to the floor of a shallow magma chamber to form the mineral deposit composed of a Fe-Ti oxide-rich matrix between a silicate framework. The Ti- and Fe-depleted magma then flowed out of the poorly crystallised intrusion and was replaced by a new pulse of Ti-saturated parent magma (Kärkkäinen & Bornhorst 2003).

The **Kaireneva** and **Peräneva** gabbro bodies were found in a regional gravity survey (6–7 points/km^2) and drilling (Sarapää et al. 2003). The hosts to ilmenite ore at Kaireneva are poorly layered, homogenous gabbro and gabbronorite (Sarapää et al. 2003). Peräneva is a complex intrusion system between Koivusaarenneva and Kaireneva (Sarapää & Kärkkäinen 2001). **Lylyneva** is characterised by apatite-rich ilmenite-magnetite ore lenses (Sarapää & Kärkkäinen 2003).

Economically, the most favourable intrusions for ilmenite are those among several interconnected intrusions, as is the case within the Koivusaarenneva Ti area. The magma-flow genesis (Kärkkäinen & Bornhorst 2003) for Ti mineralisation in area F025 is supported by the fact that the Koivusaarenneva gabbro is a member in a chain of small intrusions, three of which, Lylyneva, Peräneva, and Kaireneva, also host ilmenite deposits. Hence, there is potential for further discoveries in the area. Such discoveries essentially require gravity surveys with at least seven survey points per km^2.

Table 23. Ilmenite-magnetite occurrences with a resource estimate in the Koivusaarenneva metallogenic area (F025). All are hosted by a layered mafic intrusion.

Occurrence	**Tonnage (Mt)**	**TiO_2 %**	**Main host rock**	**Reference**
Koivusaarenneva				
indicated	32	7.8	Gabbronorite,	Endomines (2010a)
inferred	30	6.7	Pyroxenite	
Kaireneva (Kairineva)				
indicated	6.4	10.0	Gabbronorite	Endomines (2010a)
inferred	0.1	7.3		
Peräneva				
inferred	2.9	9.3	Gabbronorite	Endomines (2010a)
Lylyneva				
inferred	1.7	15.5	Gabbronorite	Endomines (2010a)
Riutta				
Inferred	0.8	8.9	Gabbronorite	Endomines (2010a)

Table 24. Electron microprobe analyses of ilmenite and magnetite from the Koivusaarenneva gabbro (Kärkkäinen & Bornhorst 2003). Sample codes indicate the drill hole (R373) and downhole depth in metres.

Mineral Zone Sample	**Ilmenite Middle Zone R373, 142.59**	**Ilmenite Middle Zone R373, 163.90**	**Magnetite Middle Zone R373, 183.18**
FeO_{TOT}	47.67	47.34	88.92
TiO_2	48.30	49.64	0.05
MnO	1.35	0.62	0.00
MgO	0.17	1.02	0.00
Cr_2O_3	0.02	0.01	3.04
V_2O_3	0.22	0.29	3.15
SiO2	0.04	0.02	0.04
Al_2O_3	0.05	0.05	0.19
CaO	0.02	0.00	0.00
NiO	0.01	0.02	0.05
ZnO	0.03	0.01	0.05
Total	97.88	99.02	97.43

F026 LAIVAKANGAS Au

Kaj Västi, Jarmo Nikander, Olavi Kontoniemi, Pasi Eilu (GTK)

The Laivakangas Au area (F026) is located in the NW part of the NW-trending Raahe–Ladoga suture zone between the Karelian and Svecofennian terranes in Finland (Korsman 1988). Area F026 is considered to extend for about 200 km along the Raahe–Ladoga suture (Figs. 1 and 52). It is located immediately to the SW of the Vihanti-Pyhäsalmi Zn area (F028). In its central part, it overlaps the Hitura Ni area (F027) and Koivusaarenneva Ti-V area (F025).

At least two major styles of mineralisation can be defined from area F026: orogenic gold, and porphyry Cu-Au and porphyry Mo (Table 25). Most of the known 30 drilling-indicated Au occurrences (Eilu & Pankka 2009) appear to belong to the orogenic gold category. A few occurrences have most of their features more akin to the porphyry style, at least those three listed in that category in Table 25.

Only one to ten holes have been drilled into most of the known gold occurrences in area F026. A few of the occurrences, especially those listed in Table 25, have been shown to be more promising and been drilled more thoroughly. A full feasibility study for the Laivakangas (Laiva) deposit was completed in 2010, and gold production started in 2011 (Nordic Mines 2010). Other occurrences mentioned below are or have been under extensive exploration during the past few years. Gold deposits in the region are typically hosted by quartz diorite, tonalite, ophitic (hypabyssal) gabbro or intermediate to mafic metavolcanic rock. In places, mica gneiss, mica schist and felsic schist also host the mineralisation (Table 25).

The **Laivakangas** deposit is hosted by silicified shear zones and quartz veins within quartz diorite and intermediate to mafic metavolcanic rock (Luukas et al. 2004, Nordic Mines 2009). The deposit is cut by post-mineralisation granite. Gold mostly occurs as native and in minor amounts in maldonite as inclusions in arsenopyrite, löllingite and gangue. The generally east–west-striking mineralised vein swarms dip steeply to the south. The horizontal dimensions of the deposit are 1.3 by 1.2 km; the deposit is open at the depth of 300 m. According to the feasibility study, the measured and indicated mineral reserve amounts to 11.7 Mt at 1.86 ppm Au. In addition, there is a measured and indicated resource of 4.9 Mt at 1.83 ppm Au (Nordic Mines 2010).

The **Kopsa** deposit has historically been interpreted as a porphyry gold-copper mineralisation, possibly overprinted by later brittle style epigenetic auriferous quartz vein mineralisation (Eilu & Pankka 2009). Ore minerals occur within the Kopsa intrusion (quartz diorite – granodiorite) as compact sulphide veins and stringers in connection with quartz veins. Commonly, the ore minerals are near the contact of veins and within fractures cutting the quartz veins. The main ore minerals are pyrrhotite, arsenopyrite and chalcopyrite and occasionally löllingite. Gold (electrum) and related Bi and Bi-Te minerals occur in both the arsenic and silicate phases as inclusions (in löllingite, arsenopyrite, quartz) and along sulphide and silicate grain boundaries (Eilu & Pankka 2009, Kontoniemi 2009).

The **Hirsikangas** deposit is in a contact area of the Himanka volcanic rocks and pelitic schists, hosted by a 'felsic schist' that probably comprises strongly sheared and altered porphyry and greywacke. Regional prograde metamorphism at Hirsikangas took place under amphibolite facies conditions, and the most characteristic metamorphic minerals in the metasedimentary rocks include biotite, andalusite and fibrolitic sillimanite (Kontoniemi & Mursu 2006). To the NW of Hirsikangas, dextral folding is possibly associated with a strike-slip shear system. Ductile-brittle shears are focused within vertical *en echelon* lenses of felsic schist, and the orientation of the lenses follows the strike of the ductile shears and perhaps also the axial plane of shear folding. Principal ore minerals are pyrrhotite, arsenopyrite and löllingite with accessory ilmenite, sphalerite, chalcopyrite, scheelite and native gold. Gold and related minerals typically occur at grain boundaries of and fractures in silicate grains, rarely also associated with sulphide minerals (Kontoniemi & Mursu 2006).

Subarea F026.1 has been defined around the known deposits of **Ängeslampi**, **Ängesneva** and **Vesiperä** (Fig. 52). In addition to these three with resource data, nine gold occurrences have so far been found by drilling in the rather small area of F026.1 (Eilu & Pankka 2009 and references therein). All occurrences of the subarea have been classified into the orogenic gold category. They seem to mostly be hosted by the locally most competent rock type, a hypabyssal gabbro, and all occurring close to or within subsidiary shear zones of one of the major NW-trending shear zones of the Raahe–Ladoga suture. Native gold occurs associated with arsenopyrite, löllingite and gangue

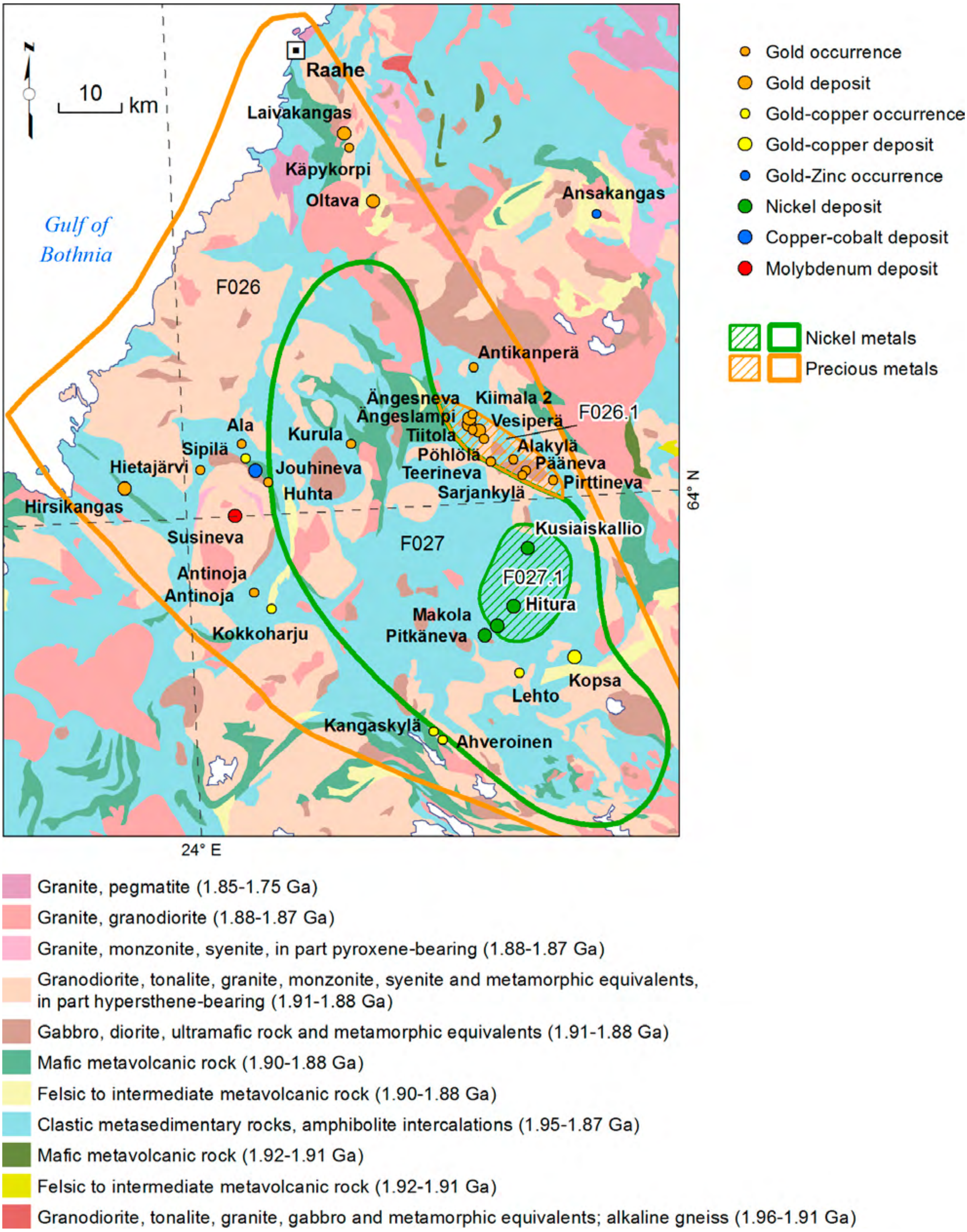

Figure 52. Hitura Ni (F027) and Laivakangas Au (F026) metallogenic areas with the most significant metal deposits of the region. Geology is from Koistinen et al. (2001).

in quartz veins and biotitised host rocks. More discoveries, and increases in the known resources, are expected from this area 20 km long and 2–5 km wide with ongoing exploration.

Table 25. Selected metal deposits in the Laivakangas Au area (F026).

Occurrence (Alternative name)	Tonnage (Mt)	Au g/t	Co %	Cu %	Mo %	Main host rock	Reference
Orogenic gold							
Ängeslampi	0.27	3.1		0.14		Hypabyssal gabbro*	Sipilä (1988)
Ängesneva	3.85	1.19				Hypabyssal gabbro*	Västi (1991a), Belvedere Resources (2010a)
Hirsikangas	5.675	1.25				Felsic schist	Kontoniemi & Mursu (2006), Belvedere Resources (2009)
Laivakangas (Laiva)	20.73	1.88				Quartz diorite, Mafic volc. rock	Nordic Mines (2010)
Oltava**	0.000718	30				Quartz diorite, Mica gneiss	Nikander (1999)
Vesiperä	0.3	2.5				Hypabyssal gabbro*	Västi (1991b)
Porphyry Cu-Au, porphyry Mo							
Jouhineva	0.45	0.88	0.18	0.81		Meta-andesite	Isohanni (1984, 1985b)
Kopsa	25	0.57		0.18		Tonalite	Gaál & Isohanni (1979)
Susineva	0.3				0.04	Granodiorite	Gaál & Isohanni (1979)

* The rock type has also commonly been called 'plagioclase porphyry'
** Resource data available for only one lode

F027 HITURA Ni

Hannu Makkonen (Belvedere Mining Oy)

The Hitura metallogenic area (F027) is close to the NW end of the Raahe–Ladoga suture in western Finland. Its extent is defined by nickel indications around the known deposits near the boundary between the Savo and Pohjanmaa supracrustal belts (Fig. 52). The Hitura area is completely inside the Laivakangas Au area (F027) and partially overlaps the Koivusaarenneva Ti area (F025). However, there is no local spatial overlap between the mineralisation types, and the exact mineralising processes are different. Hence, three distinct metallogenic areas have been defined within the region (Fig. 52).

The main rock types in the area F027 are mica gneiss and mica schist, the latter mainly occurring in the western part of the area. The metasedimentary rocks are of lower metamorphic grade in the western part and have been interpreted as stratigraphically younger. The metamorphic grade in the eastern part is at upper-amphibolite facies, which peaked at D_2 and produced various types of migmatites, including schollen migmatite typical of the Svecofennian nickel areas. Schollen migmatites are most common within the Hitura-Makola subarea (F027.1). Another similar region is at Reisjärvi, in the southern part of area F027. These regions, probably representing the deepest crustal sections and including numerous nickel-bearing glacial erratics, are the most potential areas for new discoveries within the F027 (Kousa et al. 2000, Makkonen 2005).

There are five nickel deposits (Table 26), more than five drilling-indicated occurrences and a large number of other indications, mainly glacial erratics, of nickel mineralisation in area F027, listed in the GTK mineral deposit and ore indication databases. These all belong to the mafic-ultramafic intrusion-hosted subtype of the magmatic nickel deposit category, and are of Svecofennian synorogenic age, ca. 1.88 Ga. The parent magma for these deposits was tholeiitic basalt with an MgO content of 10–15 %. Area F027 is similar to the Vammala Ni area (F006) in that the intrusions are mainly peridotitic and commonly serpentinised. In contrast, in the Kotalahti Ni area (F016), the intrusions are mainly of differentiated gabbro-peridotite type. This fact gives challenges for exploration in the Hitura and Vammala areas, because of the important *negative* gravimetric anomalies and complicated magnetic anomalies (remanent magnetism) due to the serpentinites potentially hosting nickel deposits (Peltonen 2005).

The **Hitura** ultramafic complex consists of three separate, closely-spaced serpentinite massifs surrounded by migmatised mica gneiss (Figs. 53 and 54). In addition to migmatised gneisses, a belt of sulphide- and graphite-bearing schists and mylonitic rocks not far from the Hitura body characterises the immediate environment. The horizontal extent of the ultramafic complex is 0.3 km by 1.3 km. The deepest drilling intersections are at the level of about 800 m. Geophysical surveys indicate that the intrusion continues to at least 1000 m below the surface. The core of the complex is serpentinite, and marginal zones are amphibole-rich ultramafic rocks. Pegmatitic dykes, with an age of 1877 ± 2 Ma, are not uncommon (Isohanni et al. 1985).

The contacts of the Hitura complex against gneissic wall rocks are commonly tectonic. The contact zone is characterised by dislocated mafic blocks, erratic wall-rock inclusions and, locally, by massive sulphide lumps in a soft talc-rich matrix, indicating late-tectonic movements and faults. The gneiss near the contact ("contact gneiss") is typically homogenised and contains small garnet crystals and large pale dots of feldspars and quartz. Pyrrhotite dissemination is common in the gneisses near the serpentinite body. Some small serpentinite tongues in mica gneisses, partly nickel mineralised, are found in the western side of the Hitura massive. Shear zones with narrow mica gneiss tongues separate the three ultramafic massifs (Meriläinen et al. 2008).

Several nickel ore bodies occur in the contact zones and in the core of the North Hitura serpentinite massif. From west to east, the ore bodies in the contacts are Länsimalmi, Pohjoiskaari, Koilliskaari and Itämalmi. In the centre of the North Hitura, there is the Keskitappi (Central Core) ore body. In the massif between the core and the contacts, there is low-grade nickel mineralisation. Possible mineral resources of the Middle and South Hitura massifs are not exactly known (Meriläinen et al. 2008). The main ore minerals at Hitura are pyrrhotite and pentlandite but, in places, vallerite, mackinawite, chalcopyrite and cubanite are abundant. Pentlandite is the main nickel-bearing mineral, but mackinawite containing up to 6% Ni is locally also important. Copper is mainly in vallerite, but locally Cu is also hosted by chalcopyrite and cubanite. Many accessory minerals have been identified at the site, such as pyrite, violarite, maucherite, niccoline, gersdorffite and millerite. Pyrite only occurs in joints with carbonates. Platinum minerals, such as sperrylite, michenerite, irarsite, iridarsenite and hollingworthite, have also been detected (Meriläinen et al. 2008).

Table 26. Magmatic intrusion-hosted Ni-Cu deposits and occurrences in the Hitura Ni area (F027). Only deposits for which there is a public resource estimate are included. For the fifth, Räihäneva, resource information has not been published.

Occurrence	Tonnage (Mt)	Co %	Cu %	Ni %	When mined	Main host rock	Reference
Hitura	19.36[1, 2]	0.02	0.18	0.52	1970–	Dunite	Kuisma (1985), Belvedere Resources (2010b)
Makola	1.08	0.05	0.44	0.74	1941–1954	Dunite	Geol. Surv. Finland Ore Deposit Database
Pitkäneva	1.7	0.02	0.06	0.22		Peridotite	Papunen & Vorma (1985)
Kusiaiskallio	0.798		0.14	0.22		Gabbro-Peridotite	Papunen & Vorma (1985)

1 Mined until the end of 2011: 16 Mt; NI 43-101 compliant reserves are 1.32 Mt @ 0.67 % Ni, 0.24 % Cu, resources (measured + indicated) 2.422 Mt @ 0.66 % Ni, 0.22 % Cu, inferred resource 0.615 Mt @ 0.67 % Ni, 0.29 % Cu (Belvedere Resources 2010b).

2 The ore also contains roughly 0.1 ppm Pt and 0.1 ppm Pd (Kojonen et al. 2003).

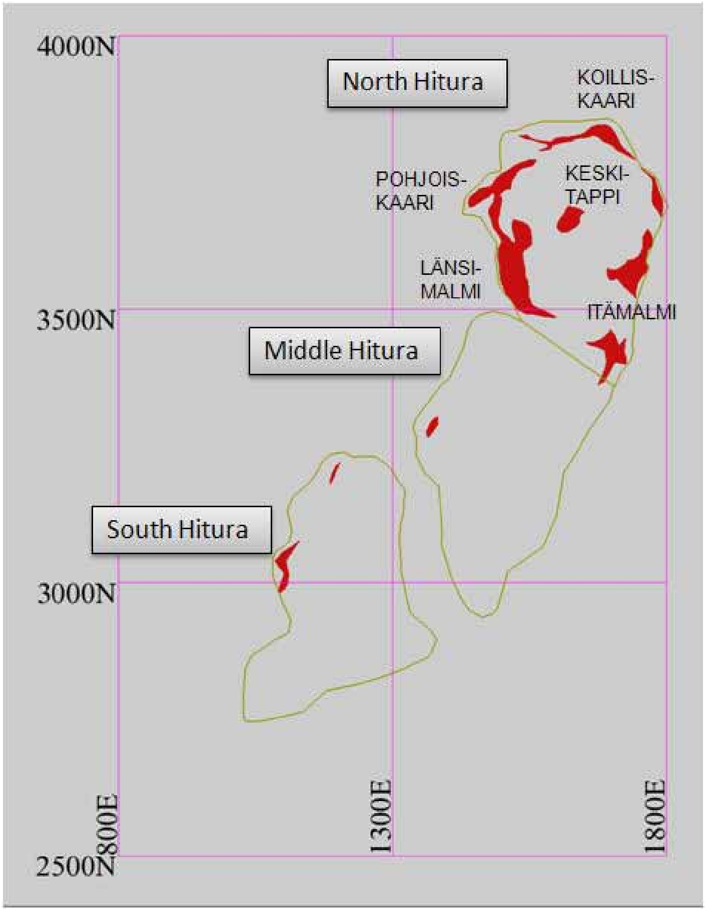

Figure 53. Geology of the Hitura nickel deposit (200 m level). Ore in red, intrusion borders in green. Surpac figure by H. Makkonen.

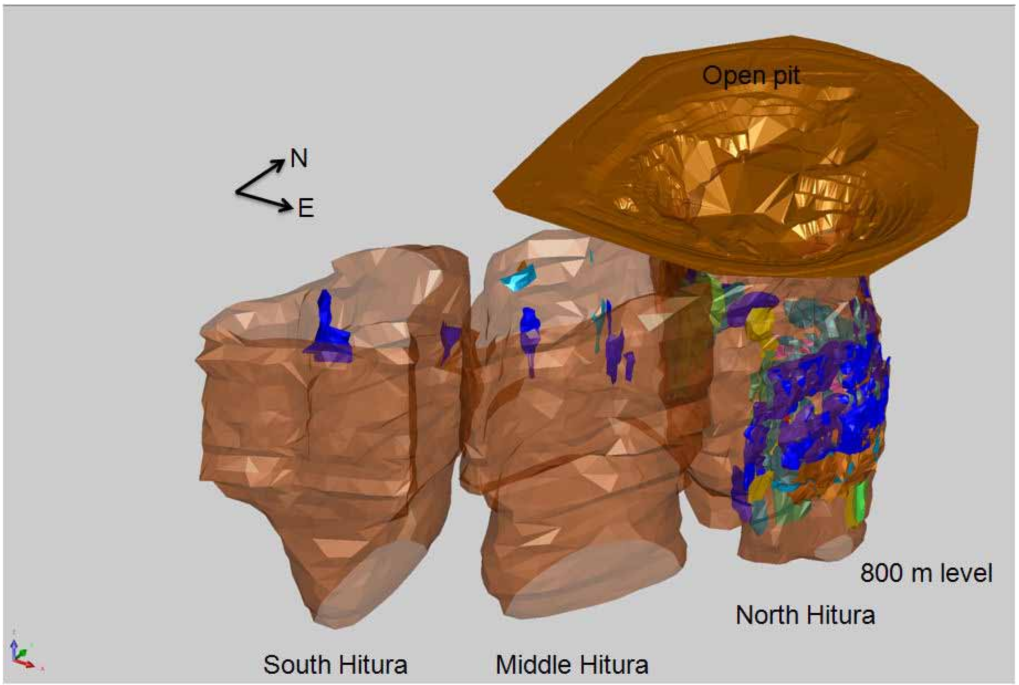

Figure 54. Hitura deposit looking from the SE. Open pit (at its maximum depth of 170 m in 1990) and intrusion bodies in brown, underground ore body solids in blue, yellow, green and brown. The North Hitura body is known to continue to at least 800 m from the surface, but the depth of the South and Middle Hitura bodies is unknown. Surpac figure by H. Makkonen.

F028 VIHANTI–PYHÄSALMI Zn-Cu

Kaj Västi (GTK)

The Vihanti–Pyhäsalmi area (F028) is located on the NE edge of the Svecofennian domain (Figs. 1 and 55), in the NW part of the Raahe–Ladoga suture, previously commonly called the Main Sulphide Ore Belt of Finland (Kahma 1973). The Raahe–Ladoga suture has been described as a collisional boundary zone between Proterozoic and Archaean domains (Lahtinen 1994). The Vihanti–Pyhäsalmi area comprises the central part of the northwestern Savo schist belt (Vaasjoki et al. 2005) and is 10–40 km wide and about 300 km long. In the SE part, it partly overlaps the Kotalahti Ni area (F016). The Laivakangas Au area (F026) and the Hitura Ni area (F027) are immediately to the SW of the Vihanti–Pyhäsalmi area (Fig. 1).

Most of the massive sulphide deposits in the area F028 are hosted by metavolcanic rocks, locally also by metasedimentary rocks, in a Palaeoproterozoic island arc environment, close to the Archaean Karelian craton. In the Pyhäsalmi region (subarea F028.3), volcanic activity started in an extensional continental margin with felsic volcanism and continued in a rifted marine environment with mafic volcanism. Large-scale hydrothermal alteration and mineralisation occurred close to the centres of mafic volcanism. Without a longer hiatus, volcanic activity continued with more calc-alkaline volcanism (Kousa et al. 1997). In the northwestern end of the area, in subarea F028.1, volcanogenic rocks are predominantly intermediate and mafic in composition. An essential part of this rock assemblage is composed of what is called the Lampinsaari-type rock association comprising felsic metavolcanic rocks, skarns and graphite tuffs (Luukas et al. 2004). According to Rauhamäki et al. (1980), volcanic activity within subarea F028.1 took place in two stages. The earlier cycle started under marine conditions and comprised felsic volcanic rocks and chemically precipitated carbonate rocks, and is characterised by the formation of Lampinsaari-type ore bodies. The deposition of volcanic and carbonate rocks continued concurrently with ore formation, culminating in the stages of zinc ore deposition. After mineralisation, more felsic volcanic rocks were erupted during the later cycle. Graphite tuff between the zinc ore and the later volcanic cycle refers to reducing conditions (op. cit.).

The Vihanti–Pyhäsalmi metallogenic area includes a great number of Zn-Cu deposits and prospects. It is particularly known from the two world-class VMS-type Zn deposits at **Pyhäsalmi** and **Vihanti** (Figs. 56 and 57), but there also are a few smaller mines and a number of unexploited deposits and occurrences. Currently, only the Pyhäsalmi mine is active. Within the vicinity, there are three smaller mined VMS-type deposits: **Mullikkoräme**, **Ruostesuo** and **Kangasjärvi** (Table 27).

In the northwestern part of area F028, only the Vihanti (Lampinsaari) deposit has been exploited (Fig. 57). The deposit consists of five types of mineralisation: zinc, copper, pyrite, lead-silver-gold and uranium-phosphorous ore. According to Autere et al. (1991), the U-P type is the oldest, whereas the Pb-Ag and Zn ores are the youngest. The Zn ores, hosted by dolomite and skarn rock, were by far the most important ore types for the economy of the mine, containing over 75 % of the total ore resource. The U-P mineralisation with over 1 Mt of low grade ore has never been exploited. In addition to the Vihanti deposit, there are a couple of smaller unexploited deposits (Table 27) in subarea F028.1. Although intense exploration has been carried out in the Vihanti district, only minor showings have so far been detected.

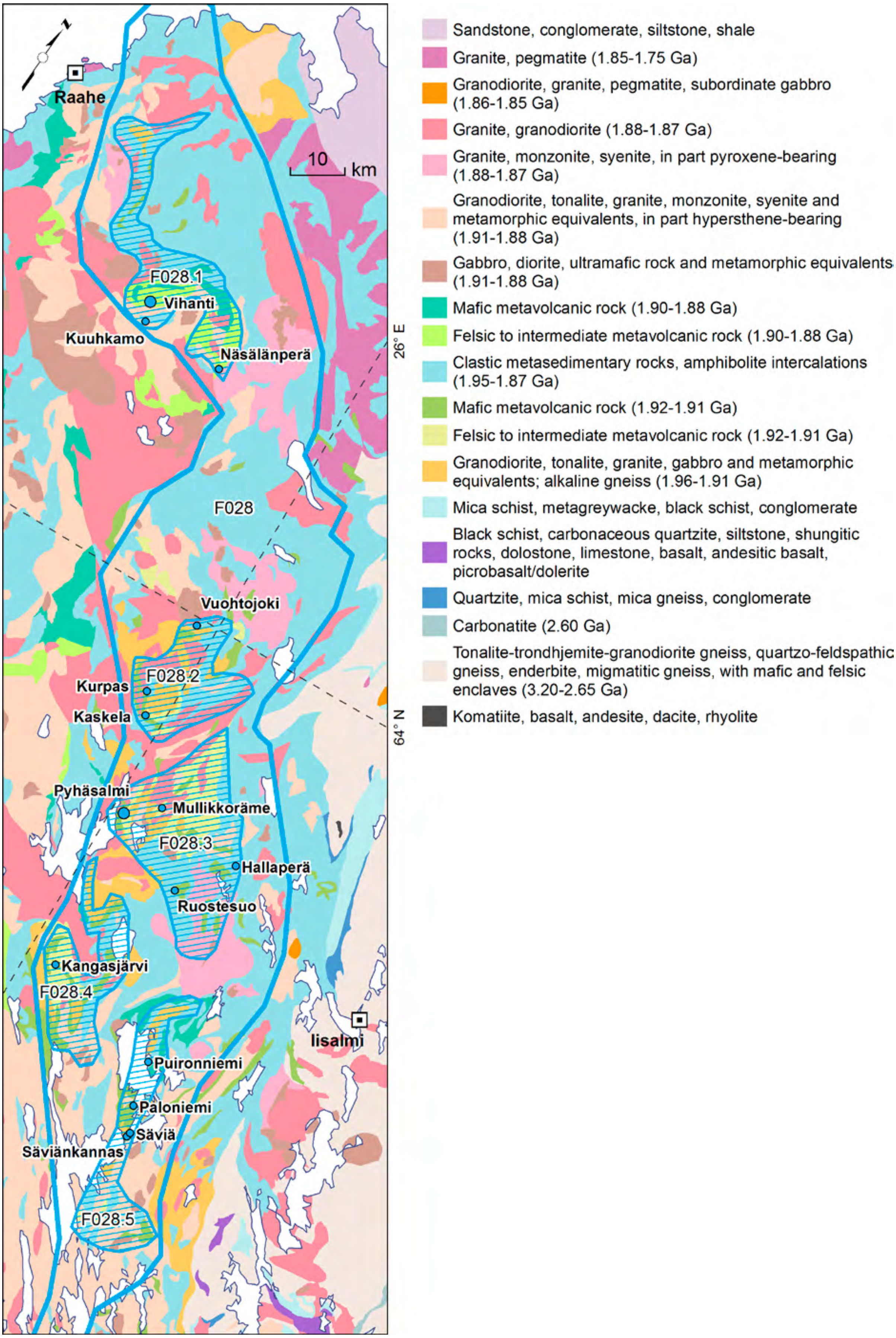

Figure 55. Geology of the Vihanti–Pyhäsalmi metallogenic area (F028), with the most significant base metal occurrences. Geology simplified from the GTK digital bedrock map database.

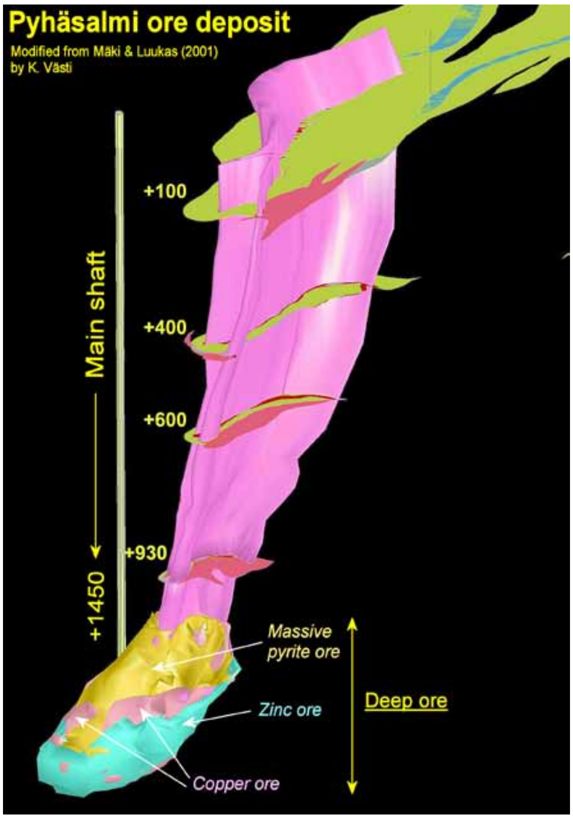

Figure 56. A 3D model of the Pyhäsalmi Zn-Cu deposit viewed from the southeast. The deep ore was discovered on 19 December 1996 (Luukkonen et al. 2000).

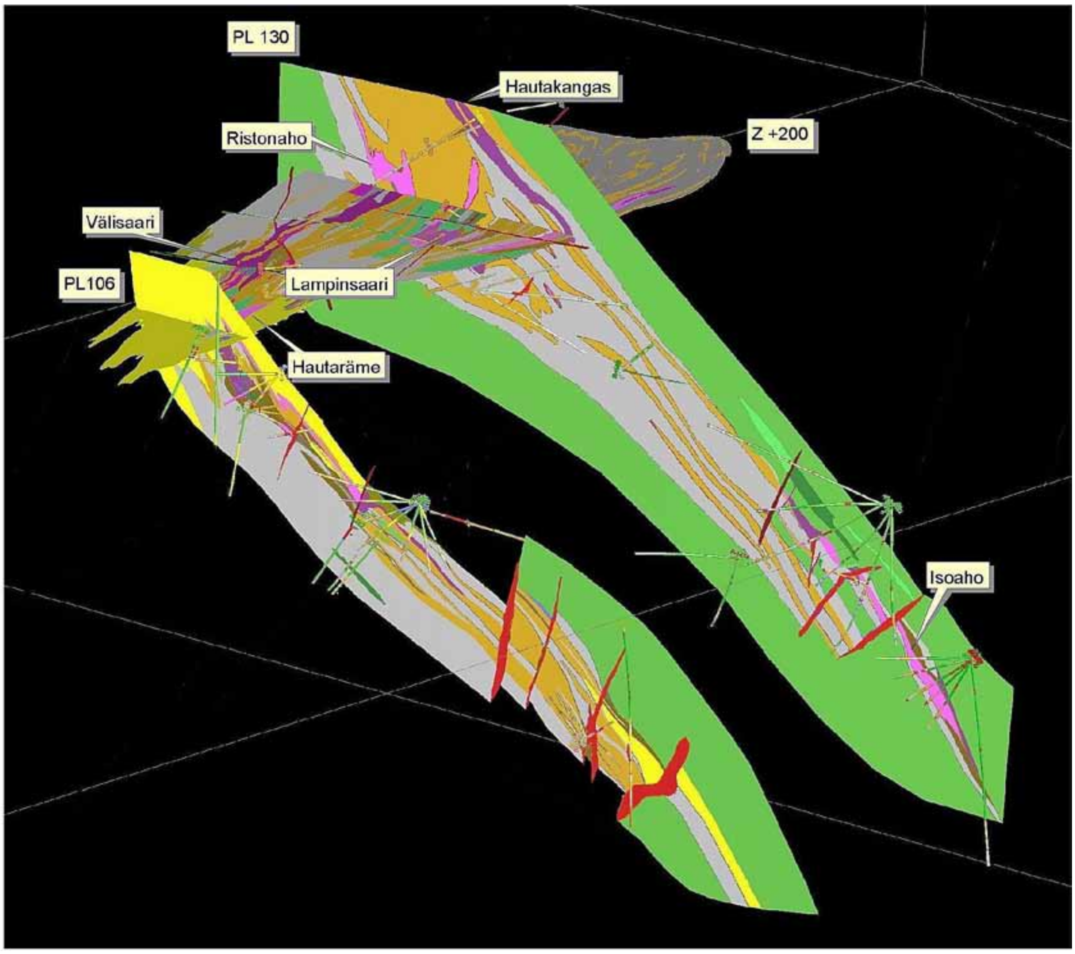

Figure 57. Geological cross sections of the Vihanti mine, looking from the southwest (Kousa & Luukas 2004). Intermediate volcanic rock (possibly tuffite) is indicated in green, skarn-banded felsic volcanic rock in grey, skarn and dolomite in orange, cordierite-sillimanite gneiss in yellow, younger dikes in red, pyrite ore in dark purple and zinc ore in pale purple.

Table 027. Selected Zn-Cu deposits in the Vihanti–Pyhäsalmi area (F028). Note that all host rocks are metamorphosed.

Occurrence	Tonnage Mt	Mining	Zn %	Cu %	Pb %	Ag g/t	Au g/t	Main host rocks	Reference
Vihanti, mined	28.1	1954–1992	5.12	0.48	0.36	25	0.49	Dolomitic marble, Skarn	Kousa et al. (1997)
Vihanti, resource	9.164		0.36	0.34				Dolomitic marble, Skarn	Outokumpu (1992)
Pyhäsalmi, mined*	45.6	1962–	2.5	0.9		14	0.4	Rhyolitic tuff and lava	T. Mäki (pers. comm. 2010)
Pyhäsalmi, resource**	19.8		2.2	0.5		14	0.3	Rhyolitic tuff and lava	Inmet Mining (2010)
Mullikkoräme, mined	1.148	1990–2000	6.1	0.3	0.7	45	1.0	Fels. volc. rock, Dolomitic marble	Luukas et al. (2005)
Mullikkoräme, resource***	2.815		7.4	0.3	0.7	59	0.7	Fels. volc. rock, Dolomitic marble	Puustjärvi (1992)
Ruostesuo, mined	0.24	1988–1990	2.63	0.3		8	0.3	Rhyolite, Basalt	Reino et al. (1992)
Ruostesuo, resource***	2.769		1.72	0.38		9.9	0.38	Rhyolite, Basalt	Kousa et al. (1997)
Kangasjärvi, mined	0.086	1986	5.12	0.06		5.0	0.3	Rhyolite	Roberts et al. (2004)
Kangasjärvi, resource***	0.3		5.4	0.06	0.02	5	0.3	Rhyolite	Puustjärvi (1992)
Säviä Cu ore bodies	4.0			1.1		5–15	0.2	Felsic pyroclastic rock	Laitakari (1968), Kousa et al. (1997)
Säviä Zn ore bodies	1.0		2.0	0.23		7.5		Felsic pyroclastic rock	Laitakari (1968), Kousa et al. (1997)
Hallaperä	3.1		0.98	0.47		12	0.3	Mica gneiss, Tonalite	Helovuori (1980)
Vuohtojoki	0.7		2.6	0.3		8	0.2	Felsic tuffite, Cordierite gneiss	Puustjärvi (1992), Marttila (2001)
Kaskela	0.124		3.9	0.4	0.1	12		Felsic tuffite	Puustjärvi (1994)
Kurpas	0.4		0.55	0.63				Mafic volcanic rock	Puustjärvi (1992)
Kuuhkamo	0.25		4.0					Diopside skarn, Cordierite gneiss	Pekkarinen (1990)
Näsälänperä	0.1		2.0	0.05		15		Felsic volcanic rock	Mäkelä (1980)

* Mined 1962–2009
** Ore reserves and resources estimated as at end of 2009
*** Remaining global resource

F029 TALVIVAARA Ni-Zn-Cu

Asko Kontinen (GTK)

Most of the Talvivaara area (F029) is within the N-S trending, Palaeoproterozoic, Kainuu supracrustal belt (Laajoki 1991, 2005). Its extent is defined by the areal distribution of the known Talvivaara-type polymetallic deposits and occurrences and their host rock assemblages, outlining two clusters in the central and southern part of the Kainuu belt, and one in the northernmost part of the North Karelia schist belt in the south (Fig. 58).

The main components of the Proterozoic strata in the Kainuu belt are: (1) Sumi-Sariola and Jatuli stage, 2.5–2.1 Ga, cratonic and epicratonic, dominantly quartz-arenite sequences, (2) Lower Kaleva stage, 2.1–1.95 Ga, riftogenous wacke-pelite sequences, and (3) Upper Kaleva stage, 1.95–1.90 Ga, deep-water turbidite wackes and pelites (Kontinen 1986b, 1987, Laajoki 2005). Of these sequences, the two older ones are autochthonous, whereas the third is at least partly located in allochthonous units carrying fault-bound, exotic ophiolithic fragments of 1.95 Ga oceanic crust (Peltonen et al. 2008 and references therein). The Kainuu belt was deformed and metamorphosed in multiple medium- to low-pressure, low- to medium-temperature events during the 1.91–1.78 Ga Svecofennian orogenesis.

The Talvivaara-type deposits occur in association with sulphide- and metal-rich carbonaceous (now graphitic) sediments. Carbonaceous sediments first appear in the Karelian record as thin layers in the topmost 2.1 Ga dolomitic and tuffaceous strata of the Jatuli sequence. They become abundant in the upper parts of the Lower Kaleva sequence, which are characterised by quartz-rich wackes and pelites, locally with phosphorite-banded silicate-magnetite iron formation intercalations. Layers of carbon- and sulphide-rich sediments are also common in the deeper-water turbidites of the Upper Kaleva stage. Graphitic-sulphidic metasedimentary units in both of the Kaleva sequences are, on average, strongly enriched relative to average upper crust in redox-sensitive metals, such as As, Fe, Mo, Sb, Se, V and U, and also in the base metals Cu, Zn and Ni (Loukola-Ruskeeniemi 1999). The pattern of metal enrichment is similar to that in many Phanerozoic metal-enriched black shales, especially in those deposited in large oxic-anoxic stratified restricted-marine basins or ocean-wide during so-called oceanic anoxic events. These basins were characterised by a high settling flux of organic matter and bio-trapped and particle-adsorbed metals, and their enhanced retention in slowly accumulating anoxic-sulphidic bottom sediments (e.g. Algeo & Maynard 2004, Tribovillard et al. 2006). The source of metals was ultimately in the global ocean water that during the anoxic events may, however, have been enriched in metals relative to the modern standard, ultimately probably related to coevally intensified submarine plume-related volcanic activity (Condie et al. 2001, Kerr 2005).

Compared to the average Kalevian black schist, black schists in the Talvivaara-type deposits have similar concentrations of the more redox-sensitive elements, such as V (650 ppm), Mo (60 ppm), Se and U (15 ppm), but several times more Ni (6.3 x 350 ppm), Co (5.7 x 35 ppm), Cu (4.3 x 300 ppm) and Zn (3.3 x 1500 ppm) (Loukola-Ruskeeniemi 1999, Kontinen et al. 2006, Talvivaara Mining Company 2010). The manganese concentration is also elevated (7.5 x 400 ppm). Although a hydrothermal hot spring source of the excess base metals has been proposed (Ervamaa & Heino 1980, Loukola-Ruskeeniemi 1991, Loukola-Ruskeeniemi & Heino 1996), the high degree of enrichment, especially in the hydrothermally relatively immobile Ni, is a problem that is not yet satisfactorily explained. Some clues can be seen in the following characteristics of the Talvivaara occurrences:

The mineralised units of area F029 seem to be stratabound and stratigraphically controlled, occurring in particularly highly graphitic (5–15 wt% graphite-bound C) and sulphidic (5–30 % S mainly in pyrrhotite and pyrite) mud-dominated units, in several cases immediately above and locally interbedded in phosphorite-chert-black shale sequences intercalated with silicate- and oxide-facies iron formations. There are no volcanic intercalations or igneous intrusions in the mineralised units or underlying metasediments. There is little evidence of such aspects as obvious leach zones in the footwall sedimentary units or distinct metal zonation in the mineralised units themselves. In the largest of the known deposits, Talvivaara, the mineralised unit is roughly 12 km along its exposed length and is surprisingly uniform in its metal content and ratios. All the known mineralised units show a similar enrichment in C, Fe, S and redox-sensitive metals to the background 'barren' black shales. Mineralised muds also show Co/Ni, Cu/Ni or Zn/Ni ratios broadly similar to the accompanying 'barren' black schists, or black shales of area F029 in general, with no tendency in these rations towards high values, in contrast to the typical sea-floor hydrothermal Cu+Zn±Pb (e.g. Goodfellow et al. 1999) or sediment-hosted Cu±Zn±Pb±Co±Ni deposits (e.g. Jowett et al. 1986, Cailteaux et al. 2005 and cited references). Other chemical indicators of hydrothermal metal contribution, such as significant positive Eu anomalies in chondrite and shale-normalised REE patterns (e.g. Douville et al. 1999, Bodeï et al. 2008), are also lacking in the Talvivaara ore (Kontinen, unpublished data).

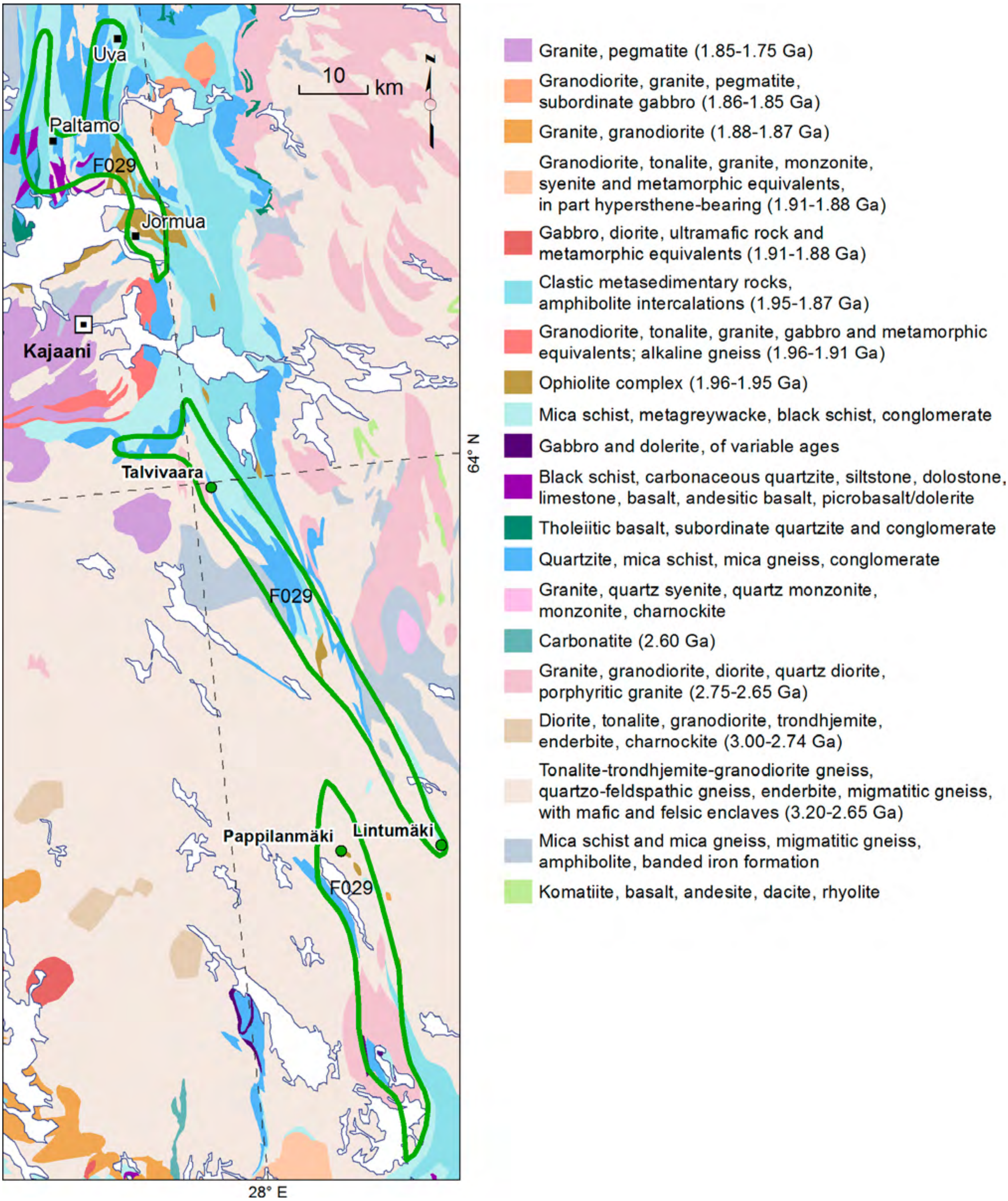

Figure 58. Geology of the Talvivaara metallogenic area (F029), and the base metal occurrences with a resource estimate in the area. Geology is from the GTK digital bedrock database.

When combined, the above features point to synsedimentary metal enrichment, most likely by the very same mechanisms that produced the metal enrichment in the associated 'barren' graphitic metasedimentary units, but under a water column that for one reason or another was apparently temporally and distinctly enriched in Ni, Co, Cu and Zn. The elevated Mn and Fe provide support for effective cycling of Mn and Fe hydroxides-oxihydroxides over basinal redoxclines also probably contributing to the high base metal levels. High Fe±Mn and S, as at Talvivaara, probably require (far-field as no near-field are present) hydrothermal sources of Fe, Mn and S. On the other hand, the uniformly high Ni/Cu (1.9 ± 0.6) and Ni/Zn (0.5 ± 0.1) ratios (based on data in Heino 1986) provide evidence for the origin of the base metals in a well-mixed and very large, probably oceanic seawater-type reservoir (presently Ni/Cu = 2.5 and Ni/Zn = 0.7; Li 2000). Although a synsedimentary origin, probably as inferred above, seems the most likely genetic scenario, large-scale diagenetic-early metamorphic enrichment in the base metals cannot yet be excluded as an alternative, although less likely model.

Talvivaara-type deposits have often been genetically and stratigraphically correlated with the ultramafic-associated Outokumpu-type Co-Cu-Zn-Ag±Au semimassive-massive sulphide deposits (e.g. Mäkelä 1981, Loukola-Ruskeeniemi 1999). However, several observations counter such a relationship. For example, the lead isotope composition of whole rocks and galena from Talvivaara and Outokumpu are highly different, suggesting different metal sources (Peltonen et al. 2008). Moreover, the maturity and sources of the contained epiclastic materials seem quite different; the Talvivaara formation comprises highly weathered quartz-rich materials from Archaean and/or recycled Archaean sources, whereas Outokumpu greywackes and interbedded black shales seem to derive from a predominantly Proterozoic (1.98–1.92 Ga) source (Kontinen et al. 2006, Lahtinen et al. 2009).

The giant **Talvivaara** deposit is located in the central part of area F029 (Figs. 58 and 59). The deposit has an exposed strike length of about 12 km. It comprises one or two originally <50 m thick layers of strongly metal-enriched, massive to laminated, graphite- and sulphide-rich muds intercalated with layers centimetres to metres thick of thinly bedded to laminar pyritic muds and carbonate rocks that are now metamorphosed and recrystallised to coarse-grained carbonate-diopside-tremolite calc-silicate rocks (Ervamaa & Heino 1980, Loukola-Ruskeeniemi & Heino 1996). Upright compressional folding and related reverse faulting in a late stage of the tectonic deformation significantly contributed to the volumes of minable ores by tectonically thickening and piling up the mineralised rock (Figs. 59 and 60). The present sulphide mineral assemblage of the ore is pyrrhotite-pyrite-sphalerite-chalcopyrite-pentlandite±alabandite. Nickel, which holds 80 % of the total metal value of the deposit, is located in pyrrhotite (21 %) and its pentlandite exsolutions (71 %) (Riekkola-Vanhanen 2010). Although only a negligible host to Ni, (metamorphic) pyrite contains the main part of the total Co in the deposit.

Based on drill core observations, at its footwall contacts the Talvivaara formation abruptly grades with the appearance of quartz wacke interbeds into a unit of quartz wackes originally at least hundreds of metres thick with subordinate interlayers of graphitic-sulphidic phyllite, metacarbonate rocks and mass-low conglomerate. The hanging-wall contact of the ore involves a rapid shift to black shale-intercalated, graphite-rich feldspathic wackes (the Kuikkalampi formation), possibly representing a shift to the Upper Kaleva deposition. In its middle part, the Talvivaara deposit is overlain by a small klippe (Viteikko; Figs. 59 and 60) of the allochthonous Upper Kaleva turbidites with thin lenses of talc-carbonate altered ophiolithic mantle peridotites spread all along its basal contact.

Distinct features of the other Talvivaara-type occurrences include the metal-rich graphitic and sulphidic schists in the Jormua region lying almost directly on an Archaean gneissic basement, separated from the latter only by a thin (<100 m) layer of conglomerate and quartz wacke (Rastas 1969, Ervamaa 1974). In the Paltamo region (Fig. 58), the mineralised sediments occur intercalated with mass-waste psephite layers rich in dolomite and mafic volcanic rock boulders from the immediately underlying uppermost Jatulian strata (Heino 1982, Kärki 1988). In the Uva region, quartz wacke-intercalated metal-rich black shales are immediately above wackes and muds with thin layers of chert-banded silicate-magnetite iron formation (Kontinen 1986a, 1986b). In the Rautavaara region, at **Pappilanmäki**, mineralised black metasedimentary rocks sit on mylonitised basement gneisses and alternate with layers of chert-banded silicate iron formation that are centimetres to metres in thickness (Sipilä 1984, Lauri Pekkarinen, pers. comm. 2010).

The currently mined giant Talvivaara deposit (Fig. 61) in the central part of area F029 is presently the only economically exploitable Talvivaara-type deposit. However, many of the

Ni-Cu-Co-Zn occurrences detected in area F029 have a potential for at least a few tens of millions of tonnes of Talvivaara-grade ore (Heino 1982, Sipilä 1984, Vanne 1984, Äikäs 1996). At present, only three of these occurrences have been studied to the extent that there is a publicised resource estimate for them (Table F028).

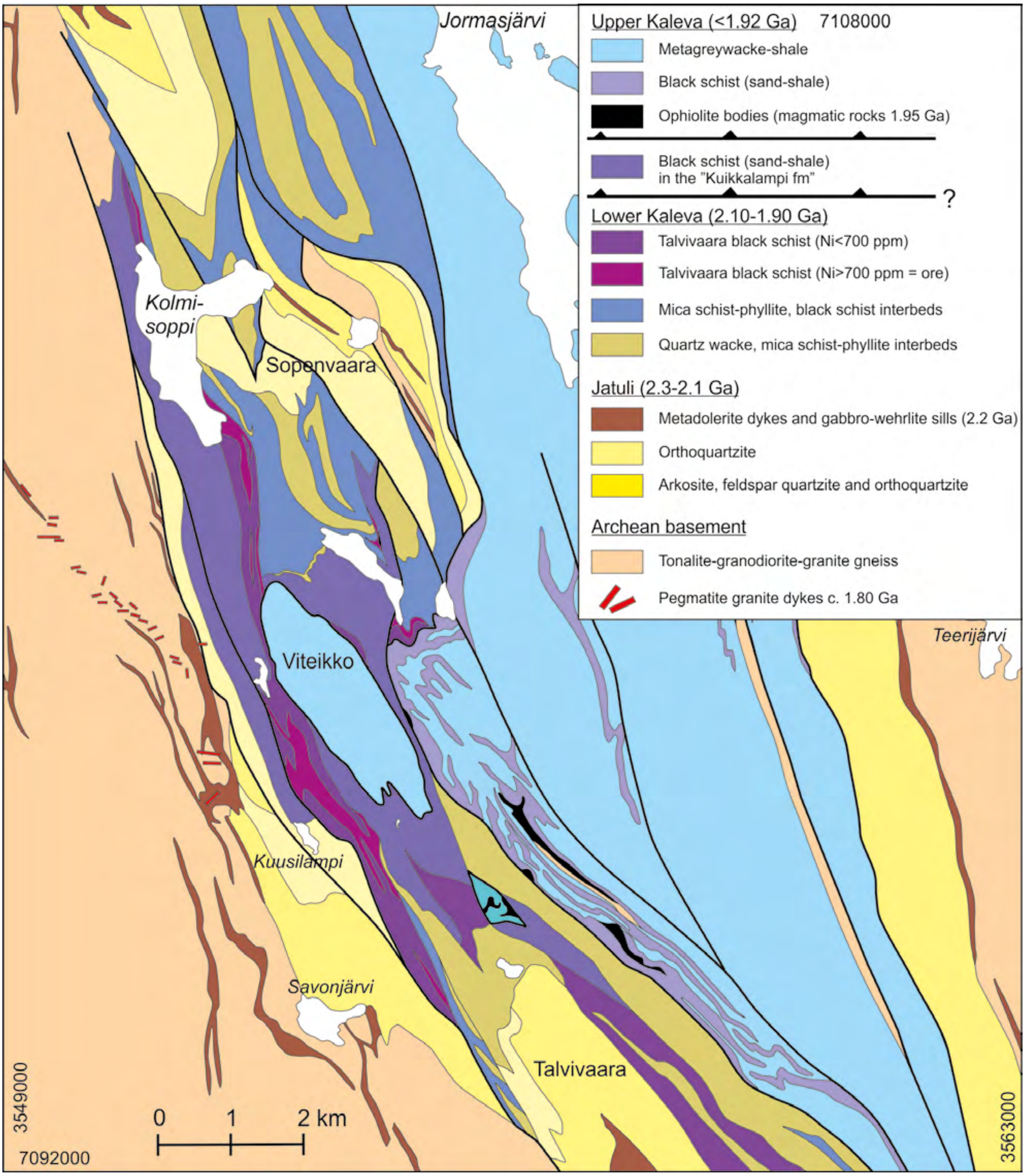

Figure 59. Surface geology at the Talvivaara deposit (defined by Ni >700 ppm) and its surroundings. Mapping and interpretation by Asko Kontinen, GTK. North up, grid: Finnish national YKJ.

Table 28. Metallic mineral deposits with a resource estimate in the Talvivaara Ni area (F029). All deposits are hosted by graphitic metaturbidites.

Occurrence	Tonnage (Mt)	Mined	Ag g/t	Co %	Cu %	Ni %	Mn %	Zn %	Reference[1,2]
Lintumäki	4				0.09	0.18		0.4	Geol. Surv. Finland Ore Deposit Database
Pappilan-mäki (R1)	34.26			0.01	0.10	0.19		0.39	Western Areas (2011)
Talvivaara	1577	2007–	2	0.02	0.13	0.22	0.3	0.49	Talvivaara Mining Company (2010)

1 References in addition to Kontinen et al. (2006) and Peltonen et al. (2008).
2 Data on Ag and Mn concentrations at Talvivaara from Heino (1986)

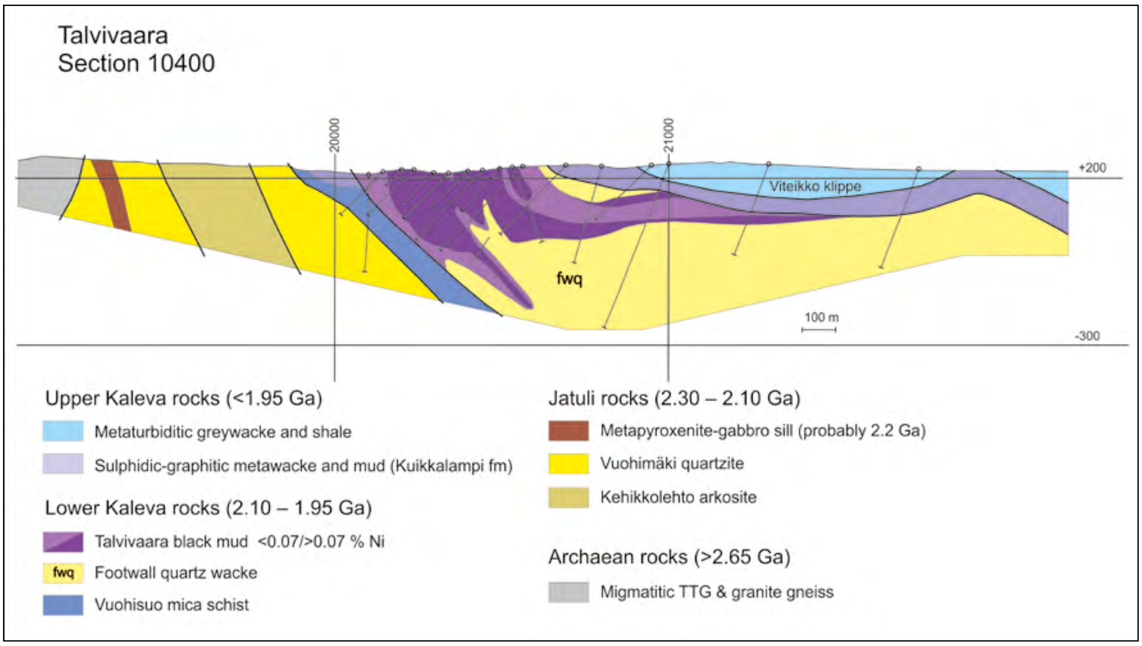

Figure 60. Section across the Talvivaara deposit at the Kuusilampi ore body. Mapping and interpretation by Asko Kontinen, GTK. View to the NNW.

Figure 61. Talvivaara mine site in 2010; view to the SE. The extent of the excavated area is 0.7 x 2.5 km. Photo courtesy Talvivaara Mining Co.

F030 HUHUS Fe

Peter Sorjonen-Ward (GTK)

The Huhus Fe area (F030) comprises the central and western parts of the Ilomantsi greenstone belt (Fig. 42). The Ilomantsi greenstone belt is dominated by felsic to intermediate epi- and volcaniclastic rocks with associated felsic to intermediate volcanic and subvolcanic units, and intercalations of tholeiitic and komatiitic volcanic rocks, and banded iron formation (BIF) (Sorjonen-Ward 1993, Sorjonen-Ward & Luukkonen 2005). The generally distinct geophysical signatures of the latter rock types indicate that they are widely distributed, and facilitate lithostratigraphic interpretation in poorly exposed terrain (Fig. 62). The supracrustal rocks appear to have been deposited and erupted over a relatively brief period around 2.76−2.75 Ga, and were intruded by granitoids with ages from 2746 to 2725 Ma (Sorjonen-Ward & Luukkonen 2005). The greenstones were metamorphosed and deformed during ca. 2.72–2.65 Ga, that is, during the global Neoarchaean orogenic event. Peak-metamorphic conditions within area F030 are predominantly at amphibolite facies, with characteristic mineral assemblages in BIFs including garnet and grünerite or ferroactinolite. The region experienced a greenschist facies metamorphic overprint during the Palaeoproterozoic Svecofennian orogeny, with dynamic recrystallisation of mineral fabrics, but only minor tectonic reworking. However, structurally focussed retrograde fluid-rock interaction has in many places modified the magnetic signature of the Archaean rocks (Sorjonen-Ward 1993).

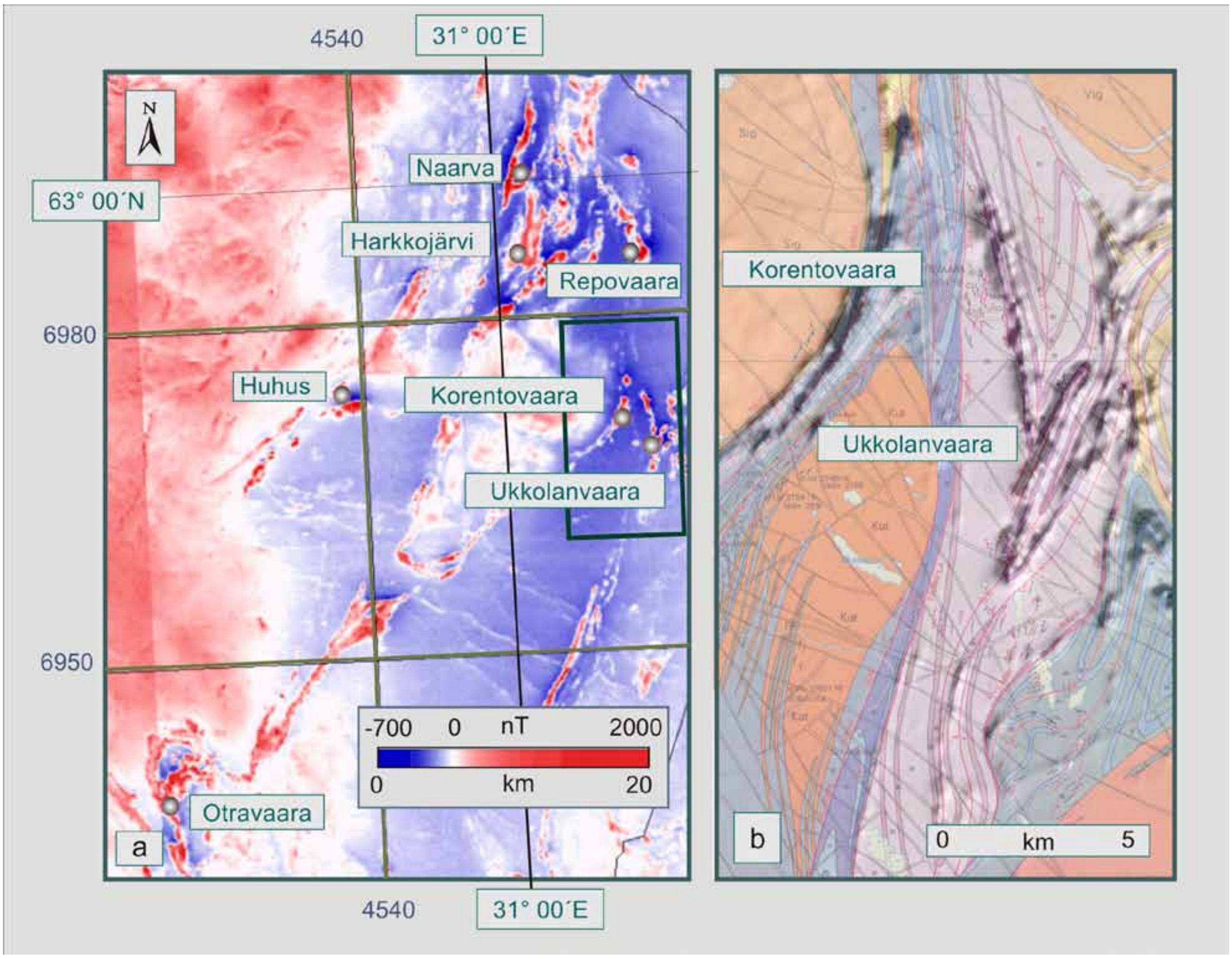

Figure 62. (a) Total magnetic intensity image of the area F030 and surroundings (red shades indicating anomaly maxima), including the Ilomantsi greenstone belt, indicating a correlation between anomalies and stratigraphically confined BIF occurrences (grey dots; Table 29). The grid corresponds to the Finnish national KKJ grid. (b) Southern part of the Hattu schist belt, showing magnetic anomalies due to the Korentovaara and Ukkolanvaara BIFs, intercalated within the turbiditic sediments of the Korvilansuo (blue hues) and Ukkolanvaara (purple hues) Formations, respectively. Orange hues indicate granitoids. Aeromagnetic maps based on GTK survey data.

The BIFs of the Ilomantsi greenstone belt were the subject of reconnaissance resource assessment by Rautaruukki Oy in the 1970s to 1980s (Lehto & Niiniskorpi 1977, Hugg & Heiskanen 1983). The BIFs typically comprise alternating units of magnetite-, sulphide- and silicate-dominated BIF associated with diverse rock types, including mica schists of epi- to volcaniclastic origin, and felsic and mafic volcanic rocks (Lehto & Niiniskorpi 1977, Hugg & Heiskanen 1983, Laajoki 1985). Many of the smaller Fe occurrences are stratigraphically associated with felsic and mafic volcanic horizons that show evidence of exhalative or subseafloor hydrothermal alteration; these may show lateral, along-strike variations in intensity, ranging from garnet-epidote-grünerite-arsenopyrite assemblages to weakly altered sediments containing actinolite and disseminated sulphide (Sorjonen-Ward 1993). Lehto and Niiniskorpi (1977) also discriminated between grünerite-dominated oxide facies, containing abundant garnet and Fe-hornblende, and Fe-hornblende-dominated assemblages, with biotite and chlorite, occurring more typically in metagraywackes. In these two facies, much of the iron is bound in sulphides or silicates rather than in more readily exploitable oxides. However, both of these facies types appear to be transitional to more classical BIF in which silica-rich layers alternate with magnetite-rich bands (Fig. 63).

Chemical analyses and mineralogical documentation are available for numerous Fe occurrences in area F030, and many have also been been delineated with ground geophysical surveys. However, only a few occurrences have been drilled, with mineral resource estimates being, at least in part, based on the dimensions and magnitude of geophysical anomalies (Table 29).

Within the Hattu schist belt, which forms the eastern branch of the Ilomantsi greenstone belt (Fig. 62), the stratigraphic context of iron formations is better constrained than in the Huhus area itself (Sorjonen-Ward 1993). There appears to be a distinct BIF unit at the transition from an upwards-fining coarse clastic sequence containing polymictic conglomerates of felsic provenance (Tiittalanvaara Formation) and the mafic and ultramafic eruptive units of the overlying Pampalo Formation. This iron formation unit is also present in the hanging wall of the Pampalo Au deposit (Sorjonen-Ward 1993), where local sulphidation has occurred in association with synorogenic hydrothermal alteration. Niiniskorpi (1975) and Lehto and Niiniskorpi (1977) defined the BIFs in this area as the **Repovaara** occurrence, for which a resource estimate of 2.2 Mt has been quoted (Hugg & Heiskanen 1983). In the southern part of the Hattu schist belt, the **Korentovaara** and **Ukkolanvaara** occurrences (Table 29) are intercalated within turbiditic metagraywackes, with lesser amounts of mafic material (Laajoki & Lavikainen 1977), which were interpreted by Sorjonen-Ward (1993) as more distal with respect to principal volcanic centres.

The **Huhus** deposits, from which area F030 takes its name, are blanketed by extensive glaciofluvial deposits, so that their extent and character has only been delineated by geophysical surveys, with limited till geochemistry and bedrock drilling (Kurki 1980). The BIFs are within a poorly understood sequence that includes mafic amphibolites, banded metasediments and felsic units that are most likely of volcanic or subvolcanic intrusive origin: the latter rocks are associated with Zn-Pb mineralisation that has been drilled in several places (Kurki 1980). A preliminary resource estimate, to depths of 100 m and 500 m (Table 29), has been provided for two separate ore lenses (Sipilä 1964, Hugg & Heiskanen 1983).

Magnetic anomalies associated with BIFs have also been mapped elsewhere in the western part of area F030, but their stratigraphic context and extent is not well-constrained. The **Naarva** BIF occurrences have been mapped along the eastern and western margin of the Naarva Granodiorite, over a total distance of 2.8–3.0 km, with a thickness of up to 200 m. Ore grade intersections in two narrow lenses form the basis for a resource estimate of 0.6 Mt. At **Harkkojärvi**, drilling has indicated the presence of BIF units overlying a metasedimentary sequence that also includes felsic porphyries.

In the southwestern part of area F030, a few small deposits of pyritic ore have been discovered, which were exploited for sulphur (total production 0.022 Mt with maximum concentrations of 47.8 % Fe and 36.6 % S) at the beginning of the 20^{th} century (e.g., Saksela 1951, Männikkö et al. 1987). These occurrences are hosted by felsic volcanic rocks within the Otravaara Formation and are likely to record subseafloor volcanic-related hydrothermal processes, although remobilisation during subsequent deformation is also likely. The paucity of metals other than Fe, apart from local Zn anomalies, nevertheless led Männikkö et al. (1987) to interpret the deposits as chemogenic sulphide-facies iron formations. However, the sporadic presence of other ore minerals, including pyrrhotite, marcasite, pentlandite and chalcopyrite at both Otravaara and Harkkojärvi, suggests a possible affinity between the two, and is consistent with hydrothermal alteration processes.

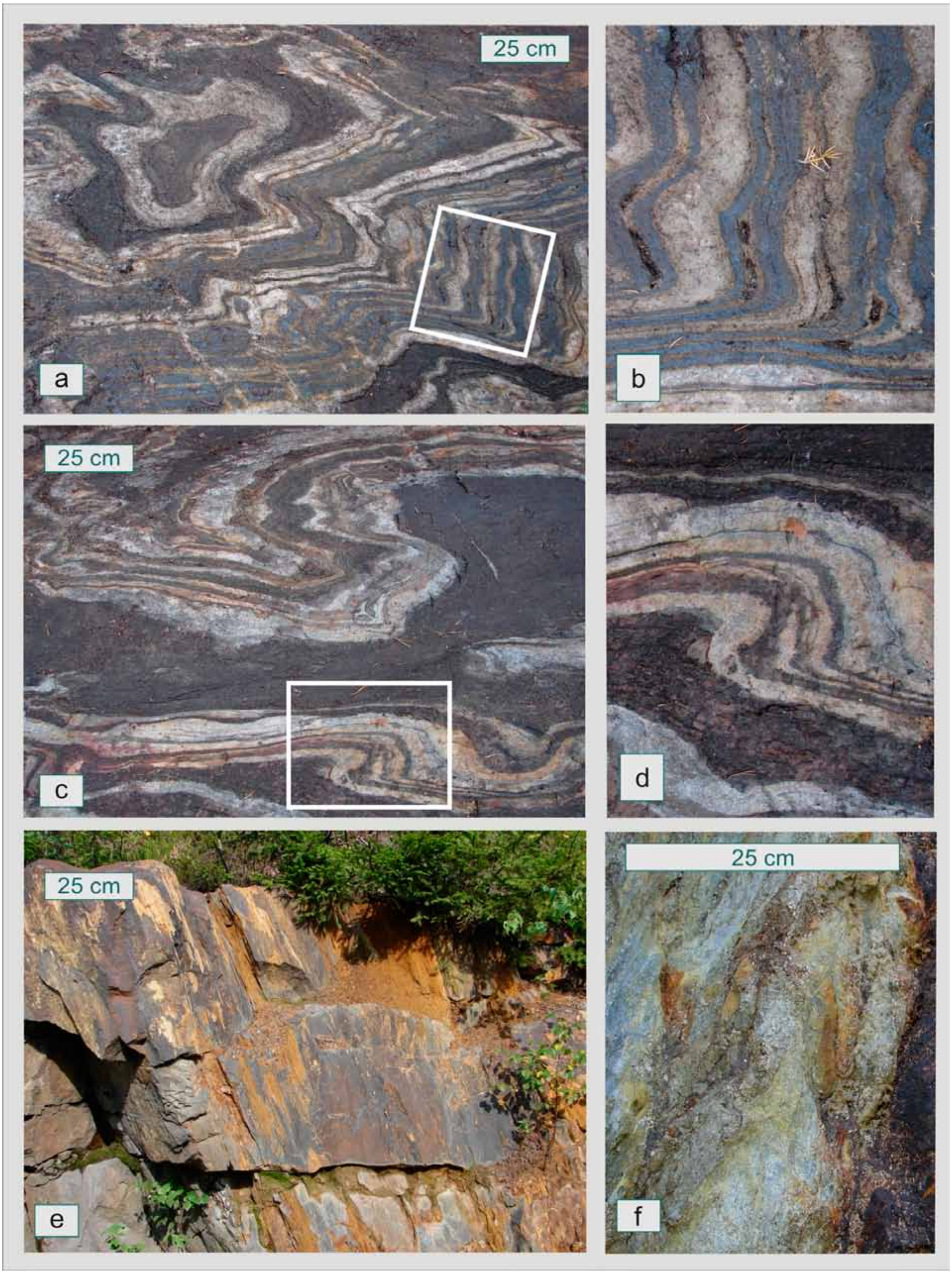

Figure 63. Examples of BIFs from the Ukkolanvaara occurrence (which is better exposed than other locations); (a) rhythmic alternation of silica-rich and magnetite bands, intercalated with more pelitic fine-grained layers, defining a spectacular refold interference pattern; (b) detail of silica-rich and magnetite bands; refolded fold illustrating distinct alternation between rhythmic BIF couplets and intercalated fine-grained pelitic and mafic sediments; (d) detail from (c) showing silicic and magnetite bands alternating with a mafic layer containing coarse porphyroblastic garnet (location at 62º49.905'N, 31º16.898'E). Figures (e) and (f) from the Otravaara sulphide-facies iron formation, showing hydrothermally altered felsic volcanic rocks and a detailed view with disseminated pyrite in strongly foliated sericitic schists (location at 62º34.6464'N, 30º23.0173'E). Photos: Peter Sorjonen-Ward, GTK.

Table 29. Iron occurrences with a reported resource within the Huhus area (F030).

Occurrence	Tonnage (Mt)	Fe %	Main ore minerals	References
Huhus (100 m)[1]	7.2	25.9	Magnetite	Sipilä (1964), Hugg & Heiskanen (1983)
Huhus (500 m)[1]	36.4	25.9	Magnetite	Sipilä (1964), Hugg & Heiskanen (1983)
Harkkojärvi	1.3	n.a.	Magnetite	Hugg & Heiskanen (1983)
Naarva	0.6	22.5	Magnetite	Hugg & Heiskanen (1983)
Repovaara	2.2	22.5	Magnetite	Hugg & Heiskanen (1983)
Korentovaara	1.1	<23	Magnetite	Hugg & Heiskanen (1983)
Ukkolanvaara	1.1	n.a.	Magnetite	Hugg & Heiskanen (1983)
Otravaara	0.022	<47	Pyrite	Saksela (1951), Männikkö et al. (1987)

1 Resource estimated to the depths of 100 m and 500 m below surface.

F031 OTANMÄKI V-Ti-Fe

Tapio Kuivasaari, Akseli Torppa, Olli Äikäs, Pasi Eilu (GTK)

The Otanmäki V-Ti-Fe area (F031) is defined by several vanadium-rich magnetite-ilmenite deposits in a Palaeoproterozoic belt of orthoamphibolite-gabbro-anorthosite intrusives and alkaline granitoids along the boundary between the Archaean Pudasjärvi and Iisalmi blocks, immediately to the west of the Palaeoproterozoic Kainuu schist belt (Figs. 1 and 64). In addition to ferrous metals, area F031 is a potential source for REE, Zr and Nb in gneissic alkaline granitoids. The belt of intrusive alkaline granitoids extends a few tens of kilometres to the east of area F031. Hence, there remains a possibility that the metallogenic area is also significantly larger, extending to the east of what is now drawn on the Fennoscandian metallogenic map.

The ferrous-metal deposits in the Otanmäki area are magmatic magnetite-ilmenite ores in deformed and metamorphosed gabbros of ca. 2060 Ma in age (Talvitie & Paarma 1980). Due to recrystallisation, ilmenite and magnetite occur as discrete, separate grains (Pääkkönen 1956), which was a significant advantage in processing the ore when the Otanmäki and Vuorokas deposits were mined. In total, about 31 Mt of ore was mined from these two deposits (Puustinen 2003). This means that there still remains at least 16 Mt of reserves and an additional 3 Mt of resources at Otanmäki and Vuorokas (Illi et al. 1985) for future exploitation (Table 30).

Both Otanmäki and Vuorokas are composed of a number of ore lenses in a domain about 2 km long (Fig. 65). The lenses are subvertical, 2–200 m long and 3–50 m thick. The main minerals are magnetite and ilmenite, in a ratio of about 2:1. The V content in magnetite is 0.62 %. Pyrite comprises 1–2 % of the ore (Pääkkönen 1956, Illi et al. 1985). The gangue minerals are chlorite, hornblende and plagioclase. The processing plant at Otanmäki produced magnetite, ilmenite and pyrite concentrates and vanadium pentoxide (from the vanadium plant). For the economy of the mine, V_2O_5 was the main product for most of the mine life (Stigzelius et al. 1970, Illi et al. 1985). During the lifespan of the mine and the plant, a total of 7.6 Mt iron concentrate, 3.8 Mt ilmenite concentrate, 0.2 Mt pyrite concentrate and 55 545 tons of V_2O_5 were produced (Illi et al. 1985).

Another style of metallic mineralisation within area F031 is defined by rare metal and REE occurrences mainly associated with alkaline gneisses. In Table 30, this style of mineralisation is represented by the Katajakangas deposit, hosted by alkali-metasomatised gneisses in Archaean granitic protoliths (Hugg 1985, Puumalainen 1986). Other rare metal-REE occurrences have also been detected in area F031, but a resource estimate has only been reported for Katajakangas. The known occurrences are elongated bodies characterised by sericitic alteration, a spatial relationship with pegmatites, and an ore mineral assemblage including fergusonite (Nb, Y, HREE), allanite (LREE), columbite-tantalite (Nb), magnetite, zircon and traces of sulphides (Hugg 1985, Äikäs 1990).

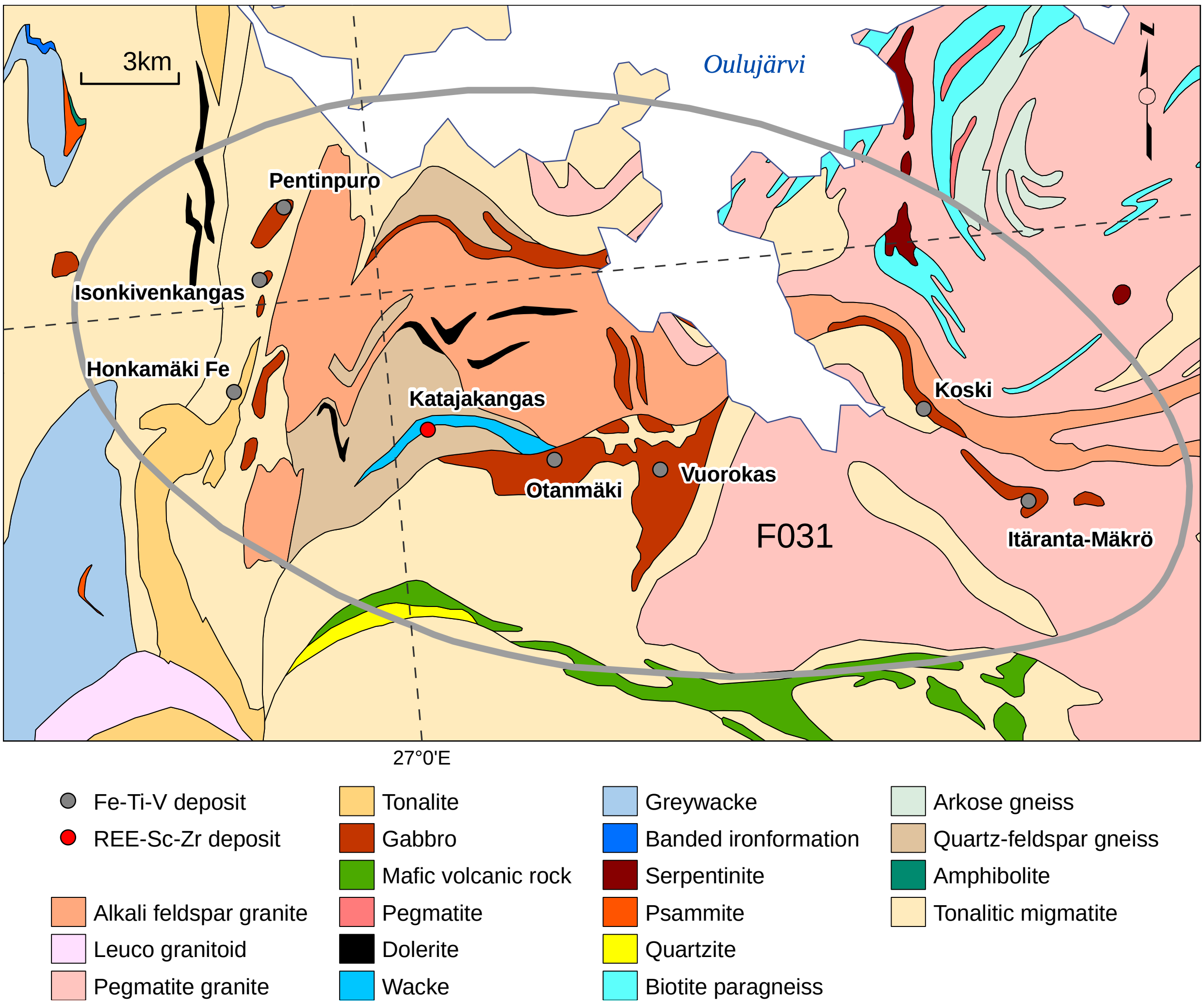

Figure 64. Otanmäki metallogenic area (F031) and its most significant metal deposits. Geology based on the GTK digital bedrock database.

Table 30. Metallic mineral deposits with a resource estimate in the Otanmäki V-Ti-Fe area (F031). Tonnage gives the total size, mined and all remaining resources and reserves.

Occurrence	Tonnage (Mt)	Mined	Fe %	Ti %	V %	Nb %	REE %	Zr %	Reference
Honkamäki Fe	17		30						Hugg & Heiskanen (1983)
Isonkiven-kangas	0.1		19.68		0.17				Hugg & Heiskanen (1983)
Itäranta-Mäkrö	0.15		30.29	6.78	0.25				Kinnunen (1979a)
Katajakangas	0.46					0.53	2.4	0.84	Hugg (1985)
Koski	1.09		29	7.02	0.24				Kinnunen (1979b)
Otanmäki	42	1949–1985	33.92	7.57	0.26				Pääkkönen (1956), Illi et al. (1985)
Pentinpuro	3		34.8	7	0.22				Hugg & Heiskanen (1983)
Vuorokas	8	1965–1985	32.5	5.5	0.26				Hugg & Heiskanen (1983)

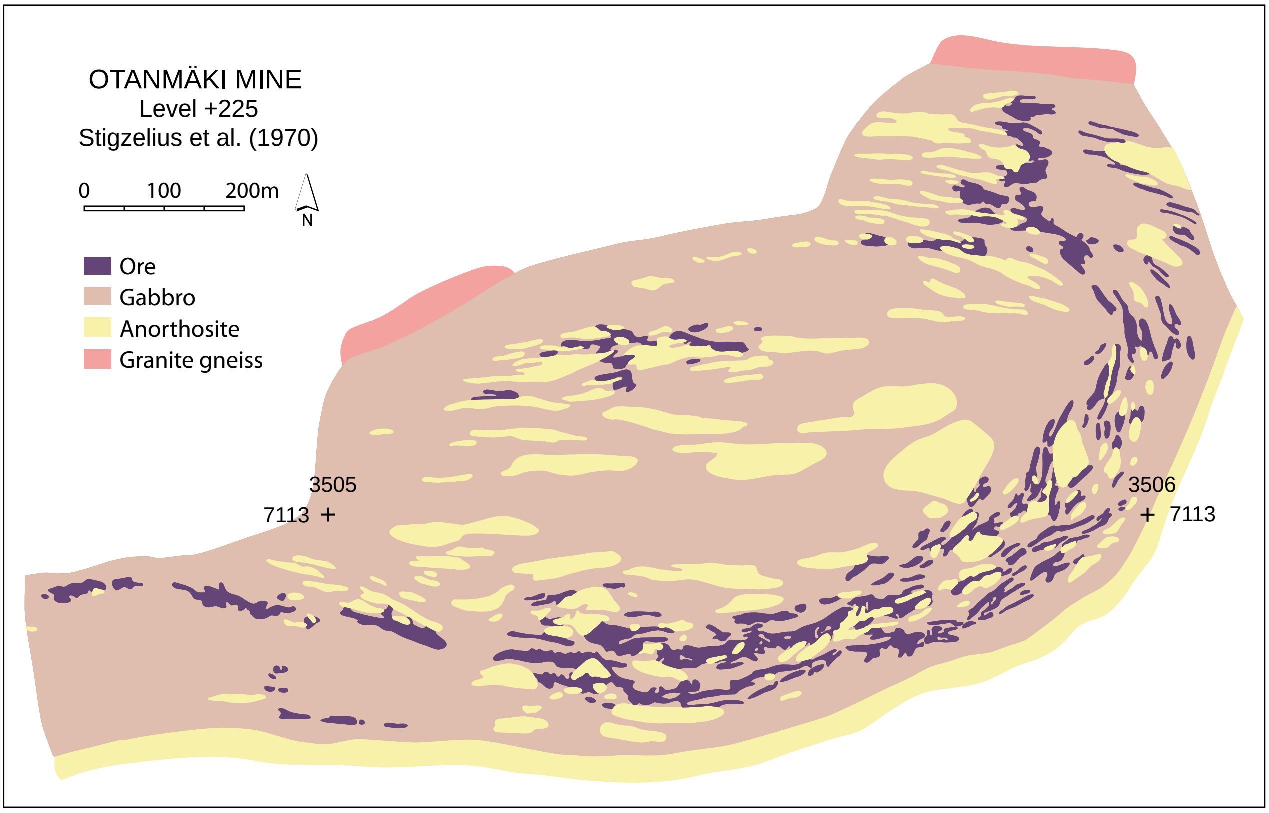

Figure 65. Geology at the Otanmäki Fe-Ti-V deposit and its immediate surroundings at the 255 m level of the mine (original by Ole Lindholm in 1965, in Lindholm & Anttonen 1980). National YKJ coordinates shown on the map. The deposit is at 64.117°N, 27.100°E.

F032 KUHMO Ni, Ag, Au

Tapio Halkoaho & Pasi Eilu (GTK)

The Kuhmo metallogenic area (F032) comprises, from south to north, the Archaean Tipasjärvi, Kuhmo and Suomussalmi greenstone belts and the immediate country rocks of these belts (Fig. 66).

The greenstone belts of the Kuhmo area are similar to Neoarchaean greenstone belts in Canada, Australia, Brazil, India and southern Africa, which are known for their numerous and large gold and komatiite-related nickel deposits (e.g. Eckstrand et al. 1996, Goldfarb et al. 2001). The greenstone belt array defining area F032 is north-trending, typically less than 10 km wide, and characterised by tholeiitic and komatiitic volcanic rocks, together with related intrusive and subvolcanic cumulates, and minor felsic volcanic and volcaniclastic units possibly formed in a rift setting (Luukkonen 1992). The margins of the greenstone belts comprise 3000–2800 Ma metavolcanic rocks, and the central parts are chiefly formed by 2800–2750 Ma tholeiitic and komatiitic metavolcanic rocks. Metasedimentary rocks only dominate in the south. The latter are chiefly greywacke-like, volcanogenic, and possibly 2740–2700 Ma in age (Luukkonen 1992, Sorjonen-Ward & Luukkonen 2005). The country rocks of the greenstones are Neoarchaean granitoids that are mostly 2760–2690 Ma in age.

The three main styles of metallic mineralisation in the Kuhmo area are 1) komatiite-related Ni(-Cu-PGE), 2) orogenic gold and 3) VMS or epithermal Ag-Zn-Pb (Papunen et al. 1989, Pietikäinen et al. 2000, Halkoaho et al. 2000, Luukkonen et al. 2002). The domains potential for these deposit types largely overlap; they only locally deviate at scales of up to a few kilometres. Hence, only subareas for the highest potential for these deposit types have been drawn (Eilu et al. 2009). Magnetite-quartz and sulphide-quartz banded iron formation also are present within the

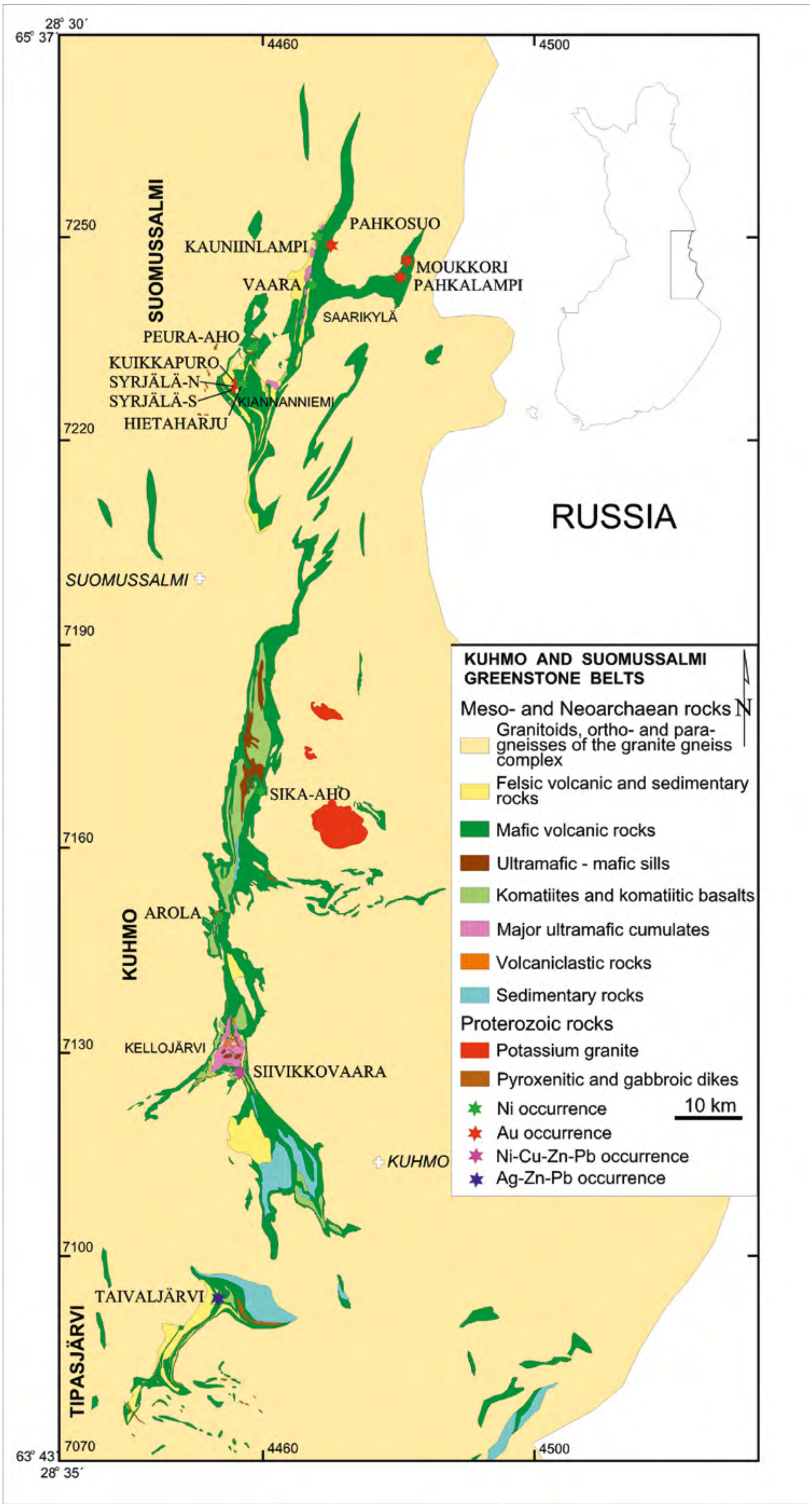

Figure 66. Geology of the Tipasjärvi, Kuhmo and Suomussalmi greenstone belts and metallic deposits with a resource estimate. The metallogenic area F032 essentially covers the area of these three greenstone belts. Geology is based on Korsman et al. (1997). North up.

Table 31. Nickel deposits with a resource estimate in the Kuhmo metallogenic area (F032).

Subarea, Occurrence	Tonnage (Mt)	Ni %	Cu %	Co %	Pd g/t	Pt g/t	Main host rock	Reference
Kuhmo F032.3								
Arola	1.5	0.46	0.01				Altered mafic lava*	Vulcan Resources (2007)
Sika-aho	0.175	0.66					Chlorite-quartz-sericite-carbonate schist	Heino (1998)
Siivikkovaara	0.1	0.3	0.33	0.015			Plagioclase-bearing amphibole rock	Makkonen & Halkoaho (2007)
Suomussalmi F032.5								
Hietaharju	1.083	0.8	0.4	0.05	1.17	0.49	Basaltic komatiite	Vulcan Resources (2009)
Peura-aho	0.495	0.6	0.27	0.04	0.58	0.27	Basaltic komatiite	Vulcan Resources (2009)
Vaara	8.241	0.32	0.02	0.01	0.14	0.07	Komatiite	Vulcan Resources (2009)
Kauniinlampi	0.5	0.45					Komatiite	Halkoaho et al. (2000)

* Quartz-carbonate-chlorite schist

greenstone belts, but these deposits are so small (1–20 m wide) that no resource estimate is available for them (Hugg & Heiskanen 1983).

Nickel deposits of area F032 can be divided into three genetic groups (Makkonen & Halkoaho 2007): 1) 'normal' magmatic komatiite-komatiitic basalt nickel deposits (Vaara, Peura-aho and Hietaharju), 2) nickel deposits that have been created by secondary, younger tectonometamorphic processes and where nickel is not in its primary magmatic position (Kauniinlampi, Sika-aho and Arola) and 3) polymetallic hydrothermal-like deposits, similar to those presently forming in black smoker environments on the sea floor (Siivikkovaara, Table 31).

The disseminated type of nickel mineralisation in the **Vaara** komatiite cumulate lens (Figs. 66 and 67) is hosted by olivine ortho- to mesocumulate in the Suomussalmi belt. In this occurrence, all chalcophile elements follow each other, unlike in the mobilised type. The sulphide dissemination of Vaara has a very high Ni/S ratio. The sulphides are considered to have formed as the result of crustal sulphide contamination of komatiitic magma. Major ore minerals include millerite, pyrite, violarite, Ni-rich pentlandite and chalcopyrite, whereas minor ore minerals include magnetite, chromite, galena, sperrylite, merenskyite and hollingworthite. Serpentinisation and host rock alteration has upgraded the quality of disseminated sulphides through the oxidation of iron of primary sulphides. Compared to the Australian komatiitic nickel deposits, the PGE tenors are abnormally high (Halkoaho et al. 2000; Table 31).

The **Sika-aho** disseminated nickel deposit is located in the Kuhmo greenstone belt. Sika-aho is of the mobilised ore type, but its nickel source is probably komatiitic. Its host rock is intensely foliated and anomalously SiO_2-rich chlorite-quartz-sericite-carbonate schist, which is situated between altered komatiitic cumulates and chlorite schist, which are surrounded by a series of volcanosedimentary rocks (Heino 1998, Luukkonen et al. 1998 and 2002). Major ore minerals are pentlandite and pyrrhotite. Pentlandite occurs as individual grains, intergrown with pyrrhotite, and inclusions and exsolutions in pyrrhotite. Minor ore minerals are Ni-Fe arsenides (Heino 1998). The Sika-aho deposit is 80 m long, 1–9 m wide and at least 150 m deep (max. 200 m). The 0.175 Mt resource (Table 31) is based on a 0.35 % Ni cut-off and contains 2.42 % S (Heino 1998, Luukkonen et al. 1998 and 2002).

Gold mineralisation within F032 is of the orogenic type as defined by Groves (1993). Typical characteristics of the occurrences include the following: the structure is the single most important control for mineralisation, gold is the sole potential commodity, the metal association (elements most commonly enriched) is Au-As-Sb-Te-W, Au/Ag >1, quartz veining is abundant, sulphide contents are at 1–3 vol%, the dominant ore minerals are pyrrhotite, arsenopyrite and pyrite, gold occurs in the native form, and carbonatisation and potassic alteration (sericitisation and biotitisation) haloes surround mineralisation (Heino 2000, Pietikäinen et al. 2000, Parkkinen 2001). The occurrences are closely related to N-, NW- and NE-trending fault and shear zones, and are hosted by practically all supracrustal rock types detected in the greenstone belts: komatiitic to basaltic volcanic rocks, quartz-feldspar porphyries and intermediate volcaniclastic to clastic rocks (Eilu 2007). The timing of gold mineralisation in the area is suggested to be syn-D3 to D4 of the local deformation stages, that is, during 2.70–2.65 Ga (Luukkonen 2001, J. Ojala, pers. comm. 2002). The metallogenic subareas Kuhmo Au (F032.2) and Tormua Au (F032.4) include nearly all known gold occurrences in the Kuhmo area (Fig. 66). The subareas follow the N to NNW trends of the main shear zones of the Kuhmo and Suomussalmi greenstone belts.

In total, 22 gold occurrences with ore-grade material have so far been indicated by drilling in the Kuhmo area (Eilu 2007). Of these, there is a reported resource for only six cases. None of the deposits have been exploited. This partly reflects the small volume of exploration effort, but may also suggest that the occurrences are relatively small, although some do have high gold grades and could thus be suitable for small-scale mining (Table 32, Fig. 68).

A few Ag-Zn-Pb occurrences have been discovered in the Kuhmo area. Of these, there is a resource estimate only for the test-mined **Taivaljärvi** 4.617 Mt at 113 g/t Ag, 0.02 ppm Au, 0.36 % Pb, and 0.72 % Zn (Sotkamo Silver 2011). Taivaljärvi is hosted by felsic and intermediate volcanic rocks, associated with intense Na depletion and the formation of K mica, biotite, garnet, tremolite, cordierite and ankerite in various parts of the alteration halo. The mineralisation is clearly syngenetic, either of VMS or epithermal type (Papunen et al. 1989). Taivaljärvi and other indications of similar styles of mineralisation define the Taivaljärvi Ag-Zn metallogenic subarea (F032.1) in the southern part of the Kuhmo area (Fig. 66). A similar style of mineralisation has also been detected along the N-S strike of the Kuhmo area, within both the Kuhmo and Suomussalmi greenstone belts (Kopperoinen & Tuokko 1988). However, Taivaljärvi still is the only one shown to contain any significant ore tonnage.

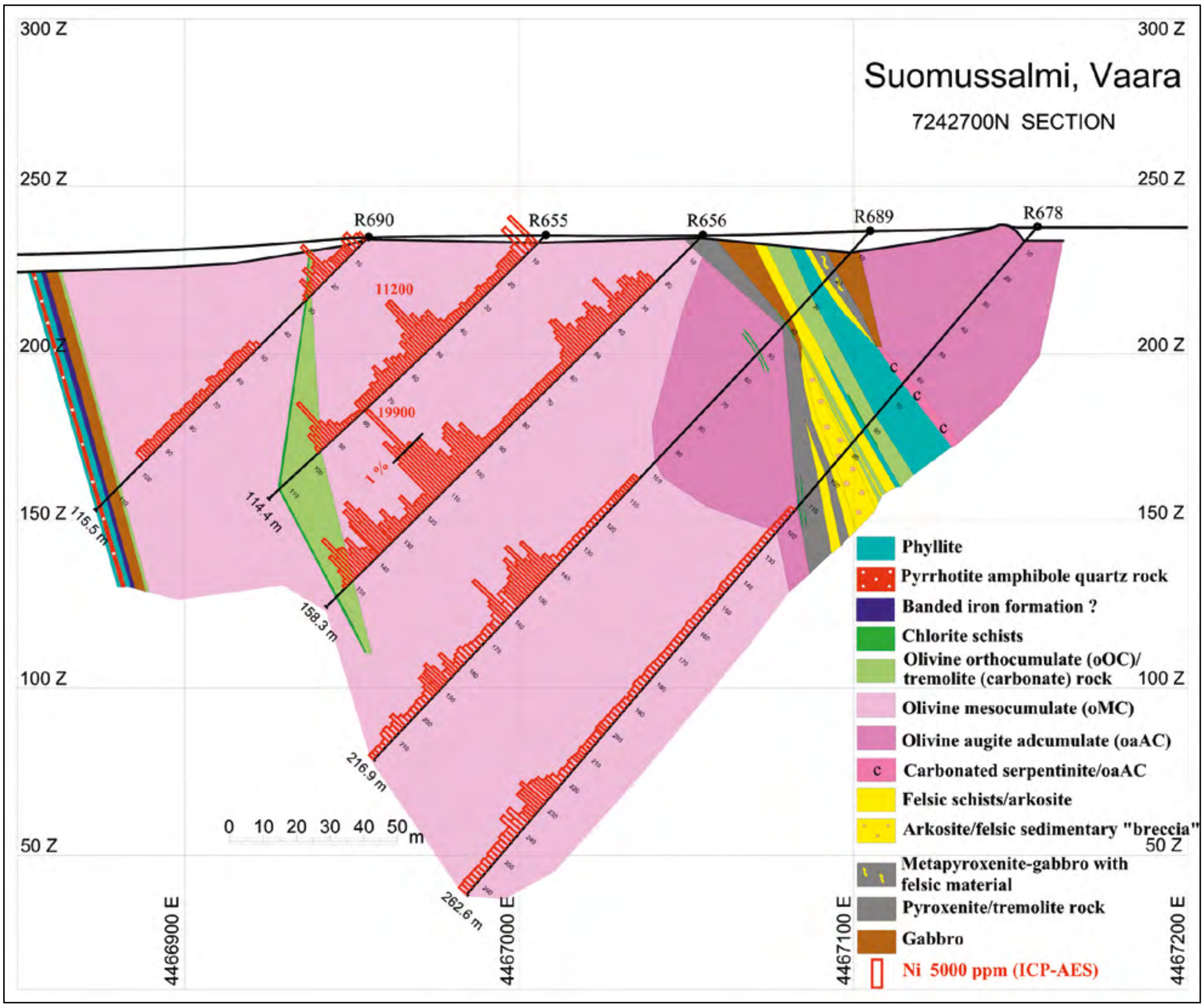

Figure 67. The southernmost drill-hole profile across the Vaara nickel occurrence with Ni content variation; view to the north (Halkoaho et al. 2000). The deposit is at 65.2794°, 29.2906°E.

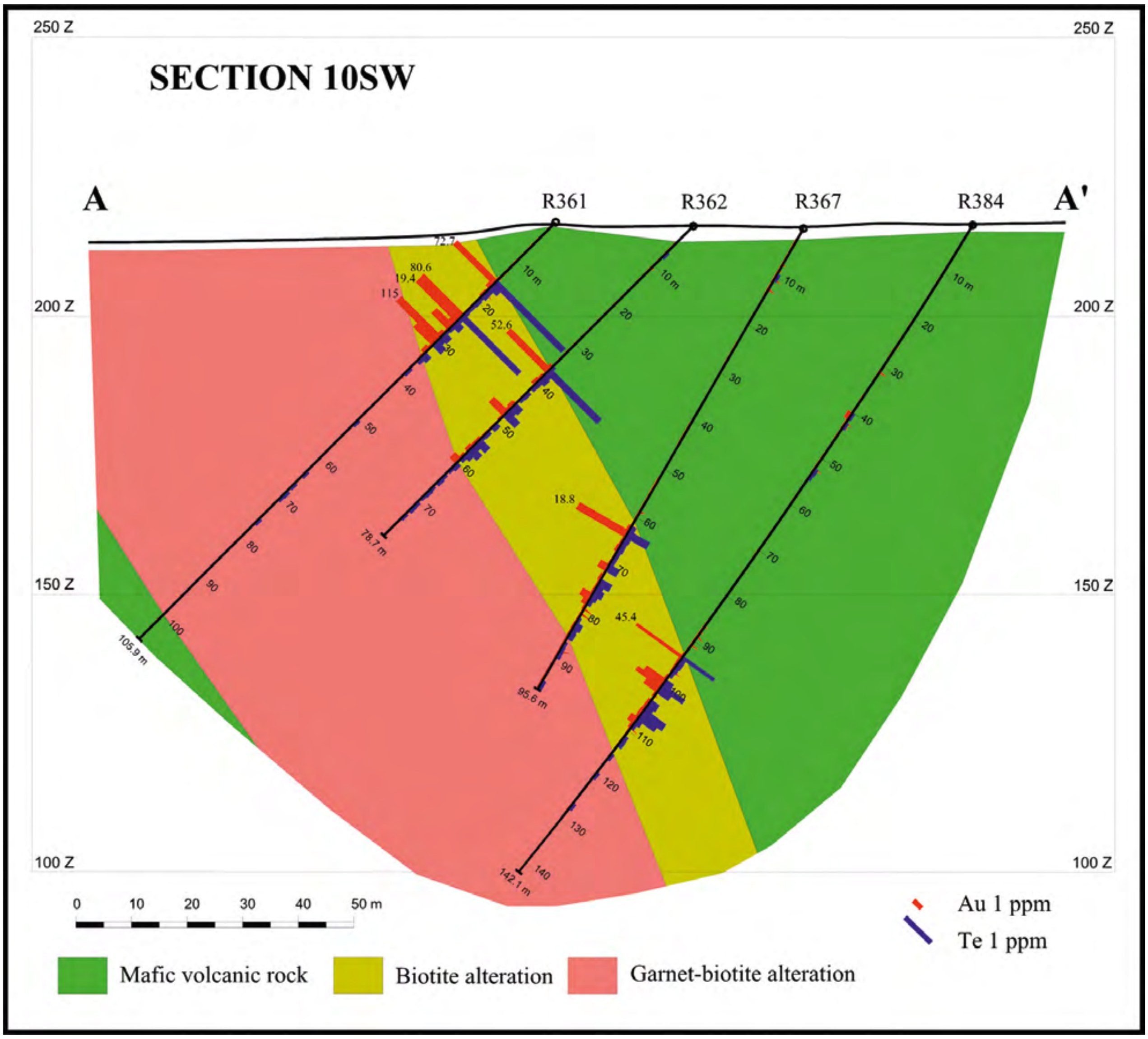

Figure 68. A drilled section across the Kuikkapuro gold occurrence, at 65.15171°N, 29.0553°E. View to NW. From Pietikäinen et al. (2000).

Table 32. Gold occurrences with a reported resource within the Kuhmo metallogenic area; all are within the Tormua subarea (F032.4).

Occurrence	Tonnage (Mt)	Au g/t	Main host rock	Reference
Kuikkapuro	0.054	14.6	Mafic volcanic rock	Heino (2000)
Moukkori	0.024	10.6	Mafic volcanic rock	Parkkinen (2001)
Pahkalampi	0.25	3.5	Mafic volcanic rock	Nordic Mines (2007)
Pahkosuo	0.098	1.55	Mafic volcanic rock	Heino (2001)
Syrjälä-N	0.057	1.55	Intermediate agglomerate	Pietikäinen et al. (2000)
Syrjälä-S	0.090	1.15	Intermediate agglomerate, quartz sericite rock	Pietikäinen et al. (2000)

F033 PÄÄKKÖ Fe

Mikko Tontti (GTK)

The Pääkkö Fe area (F033) is within the western part of the Kainuu schist belt (Fig. 69). The extent of N-trending metallogenic area F031 is defined by the presence of banded iron formation in the Central Puolanka Group of the N-trending Kainuu belt. The age of the Central Puolanka Group is uncertain: either the rocks are Neoarchaean or Palaeoproterozoic. The age of the Pääkkö Fe deposits is uncertain (Sakko & Laajoki 1975, Huhma et al. 2000).

The **Pääkkö** area includes several superior-type iron formations around Väyrylänkylä at Puolanka (Table 33), in the northern part of the Kainuu schist belt (Saltikoff et al. 2006). The deposits are within a roughly 10-km-long sedimentary sequence that consists of tuffites, dolomitic marbles, black shales, phyllites, metadiabases, quartzites and iron formations. In places, the rocks are so intensely weathered that kaolinite occurrences characterise the area (Laajoki 1975a, 1975b).

The dominant iron formation type is grunerite-rich quartz-magnetite(-hematite-goethite-) banded, representing a mix of oxide- and silicate-facies types. In addition, quartz-siderite-banded carbonate-facies type and iron-rich black schists and phyllites of the sulphide-facies category have been encountered in the region (Niiniskorpi 1975, Ervamaa & Laajoki 1977, Laajoki & Saikkonen 1977, Lehto & Niiniskorpi 1977, Gehör 1994a). The iron formations are relatively rich in REE and their REE distribution patterns show depletion of Ce. This is due to regularly occurring apatite, which is interpreted to be of marine origin (Laajoki 1975b). The **Tuomivaara** deposit, beyond any distinct metallogenic area, 50 km SSE along strike from Pääkkö, has very similar features to the Fe deposits of area F033 (Makkonen 1975, Gehör 1994b).

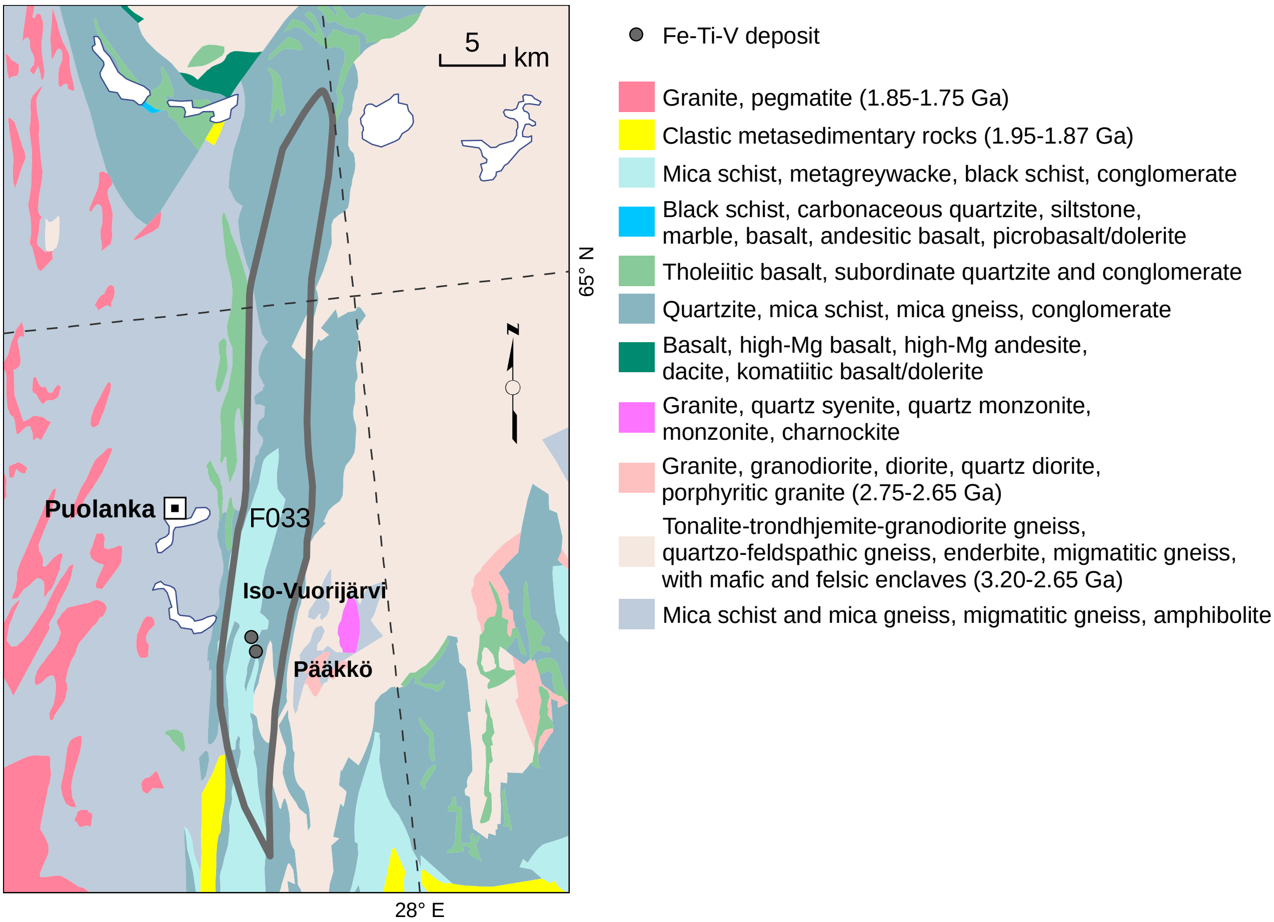

Figure 69. Geology of the Pääkkö Fe area (F033) and its immediate surroundings, with locations of the main iron occurrences. Geology based on the GTK digital bedrock database.

Table 33. Iron occurrences with a reported resource within the Pääkkö area (F033). For comparison, data on the Tuomivaara deposit are also included. All occurrences listed are of banded iron formation type.

Occurrence	Tonnage (Mt)[1]	Fe %	Mn %	P %	Ti %	V %	Main ore minerals	Reference
Iso-Vuorijärvi	5.9	26	0.05	1.04	0.04	0.02	Magnetite, siderite	Ervamaa (1977), Hugg & Heiskanen (1983)
Pääkkö	16.4	26	0.06	1.11	0.06	0.03	Magnetite, siderite	Ervamaa (1977), Hugg & Heiskanen (1983)
Tuomivaara	39	27		0.2–2.0			Magnetite, siderite	Makkonen (1975), Gehör & Havola (1988)

1) The resource is calculated only to the depth of 100 m below the surface.

F034 OIJÄRVI Au

Heikki Juopperi, Jukka Konnunaho & Pasi Eilu (GTK)

The Oijärvi area (F034) covers most of the Archaean, north-trending Oijärvi–Yli-Ii greenstone belt (Figs. 1 and 70). In geological maps, the Oijärvi and Yli-Ii greenstones appear as separate entities in the north and south, respectively, but recent aeromagnetic surveys by GTK suggest a continuum of greenstones between the two parts.

The greenstones of metallogenic area F034 are within the western part of the Meso- to Neoarchaean Pudasjärvi complex in western Finland (Sorjonen-Ward & Luukkonen 2005, Vaasjoki et al. 2005). Little is known about the geology of these poorly exposed regions: they appear as typical small Archaean greenstone sequence within an extensive TTG terrain, a setting that can be encountered in any craton. The belts are formed by komatiitic to tholeiitic volcanic rocks and fine-grained clastic sedimentary rocks (Tolppi 1999, Juopperi et al. 2001, Sorjonen-Ward & Luukkonen 2005, Rossi & Konnunaho 2006, Sarapää et al. 2008). Most of the greenstones are strongly altered and sheared. The sequences are intruded by small synorogenic granitoids and felsic porphyry dykes, and cross cut by Palaeoproterozoic dolerites. The regional metamorphic grade in the Oijärvi belt is mid- to upper-greenschist facies, whereas amphibolite-facies conditions seem to prevail in the southern extension of area F034 (Tolppi 1999, Juopperi et al. 2001).

Two styles of metallic mineralisation have been detected in the Oijärvi Au area: 1) orogenic gold, and 2) possibly epithermal Au-Ag-Zn-Pb (Juopperi & Karvinen 1999, Tolppi 1999, Rossi 2000, Juopperi et al. 2001, Rossi & Konnunaho 2006, Sarapää et al. 2008). The domains potential for these deposit types probably overlap; hence, only one metallogenic area has been defined for the greenstone belt. Work by Rossi and Konnunaho (2006) demonstrated that the Yli-Ii greenstones host similar gold-potential shear zones to the Oijärvi greenstones.

Orogenic gold occurrences within area F034 are controlled by the main along-strike shear zones of the greenstone belt. The occurrences are hosted by mafic and ultramafic volcanic rocks and felsic dykes, are within a carbonation and sericitisation envelope, contain 1–3 vol% pyrite and free native gold, and are enriched in Au, Ba, Bi, CO_2, K, Li, Rb, S and Te, and show grades up to 10 g/t Au per metre of drill core (Tolppi 1999, Juopperi et al. 2001). The **Kylmäkangas** occurrence (Fig. 71), in the central part of the Oijärvi greenstone belt, deviates from this pattern: the potential commodity association is Au-Ag-Cu-Pb-Zn, the Au/Ag ratio is 0.1−0.2, the occurrence is hosted by intensely silicified, dacitic to rhyolitic quartz-feldspar porphyry, and the very fine-grained native gold in quartz is associated with electrum and hessite (Rossi 2000, Juopperi et al. 2001). Local quartz veins at Kylmäkangas are barren. The style of alteration, siting of gold, Au/Ag ratio, and metal association together suggest that Kylmäkangas is a high-sulphidation epithermal occurrence metamorphosed under upper-greenschist facies conditions. The published mineral resource at Kylmäkangas is 1.924 Mt at 4.07 ppm Au (Agnico-Eagle 2010).

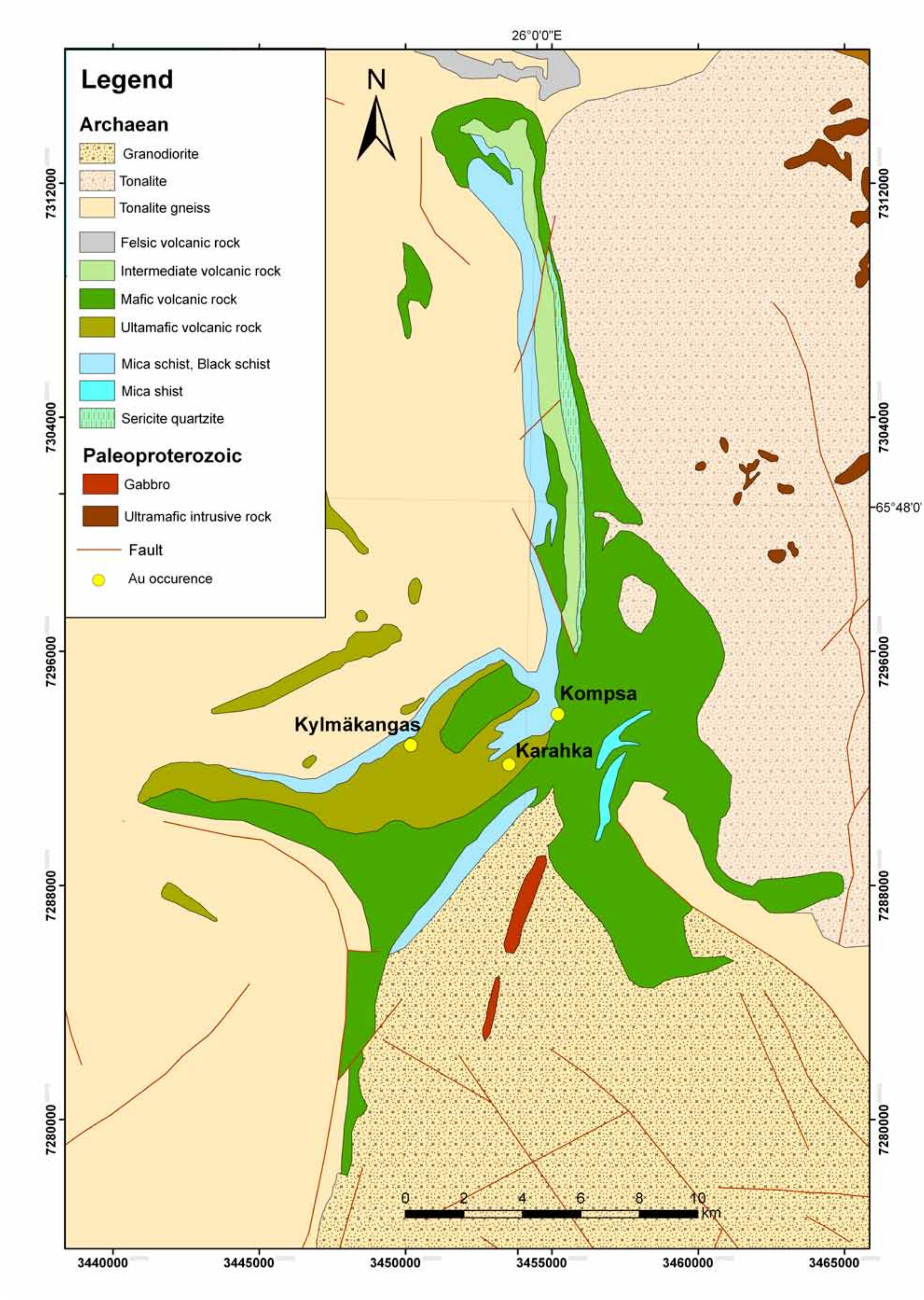

Figure 70. Geology of the northern part of the Oijärvi greenstone belt and locations of drilling-indicated gold occurrences in the area. Geology from GTK digital map database, gold occurrences from Eilu & Pankka (2009).

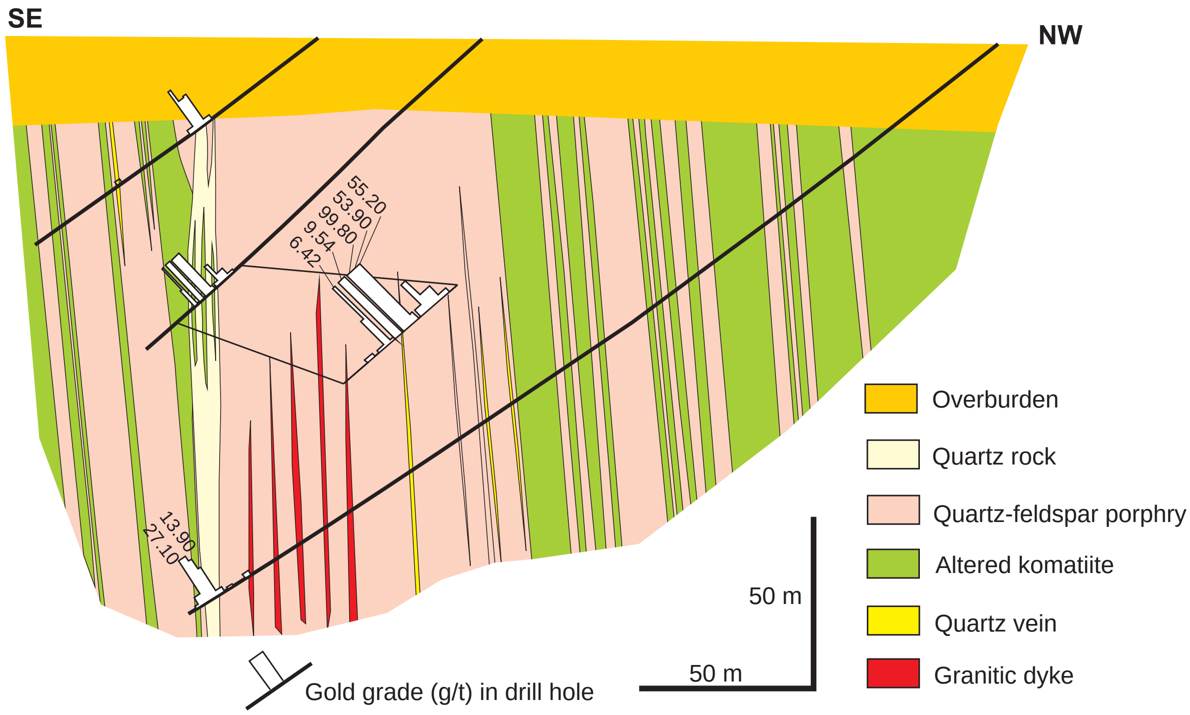

Figure 71. A drilled section across the Kylmäkangas gold occurrence, at 65.7264°N, 25.911°E. From Juopperi et al. (2001). Gold grades are given in g/t.

F035 PORTIMO Cr, PGE-Ni

Tapio Halkoaho & Markku Iljina (GTK)

The Portimo metallogenic area (F035) is defined by the Tornio, Kemi, Penikat and Portimo layered intrusions and their immediate country rocks in SW Lapland (Fig. 72). The mineralised layered intrusions are mafic to ultramafic in composition and have an age of ca. 2.44 Ga (Perttunen & Vaasjoki 2001). They straddle along the boundary between the Archaean Pudasjärvi complex and the Palaeoproterozoic Peräpohja schist belt, in a siting analogous to all layered intrusions of similar age within the Fennoscandian shield (Alapieti et al. 1990, Iljina & Hanski 2005). The intrusions and their metal deposits are described below in geographic order, from west to east.

The *Tornio intrusion* is the westernmost layered intrusion of the Portimo area and extends across the Finnish-Swedish border, about 25 km NW from Kemi. The 6-km-long and 0.4–0.5-km-wide intrusion dips at 65–75° to the NE. It contains several thin chromitite layers, where the Cr_2O_3 content varies between 26 and 32 %, FeO_{tot} between 22 and 28 % and Cr/Fe between 0.9 and 1.2 (Söderholm & Inkinen 1982).

The *Kemi intrusion* contains the sole mine presently active within the Finnish layered intrusions, the **Kemi** chromium mine (Table 34; Fig. 73; Alapieti et al. 1989a, Alapieti & Huhtelin 2005, Huhtelin 2008). The deposit was found by GTK in 1959, and mining started by Outokumpu in 1966 as an open-pit operation. Underground mining started at Kemi in 2005. The chromitite layer parallels the basal contact zone of the Kemi intrusion and is known over the whole length of the intrusive complex. In the central part of the intrusion, the basal chromitite layer widens into a thick chromitite accumulation. The chromite-rich unit has an average dip of 70° to the NW. The thickness of the main chromitite unit is from a few metres to over 160 metres and averages at 40 m. The lower contact of the chromitite unit lies stratigraphically 50–100 m above the basal contact of the complex. The top of the main chromitite unit is layered in structure, the hanging-wall contact of the ore being sharp, whereas the lower part is brecciated and characterised by gradually diminishing chromite dissemination towards the bottom of the intrusion, accompanied by irregular ore lumps. The average Cr/Fe ratio in the ore is 1.6. According to a recent seismic reflection survey in the area, the intrusion extends to a depth of 2–3 km, possibly to 4 km, and the chromitite unit may extend down to 2–2.5 km or more (Outokumpu 2010). This would mean much larger resources than what is presented in Table 34.

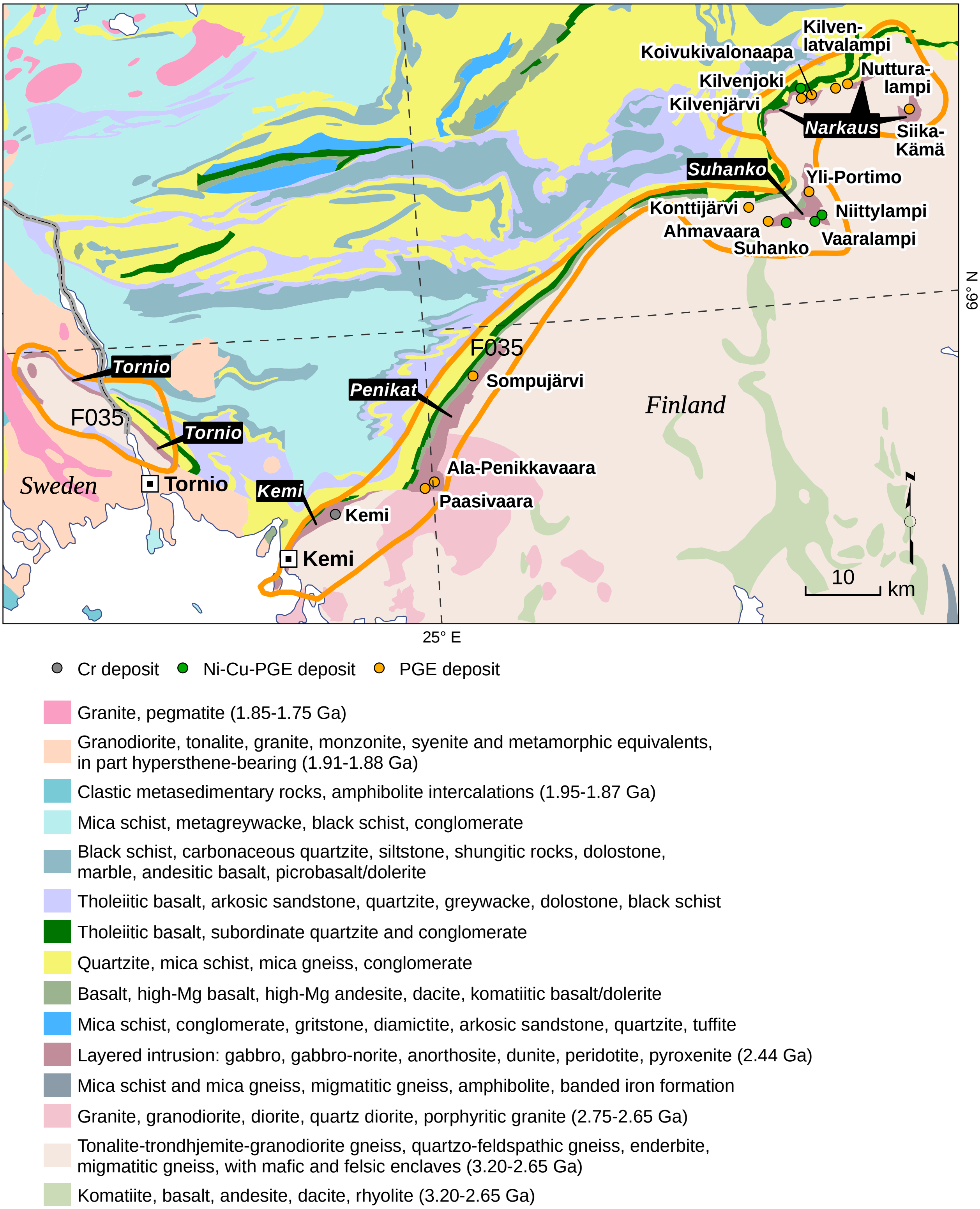

Figure 72. Geology of the Portimo metallogenic area (F035), main layered intrusions (white font in black background), and locations of the main PGE±Ni-Cu and Cr occurrences in the region. Note that the Tornio intrusion extends across the Finnish–Swedish border. Geology is from the GTK digital bedrock database and from Koistinen et al. (2001).

Figure 73. The Kemi mine in 2008. Kemi is the only Cr producer within the EU. Photo: courtesy of Outokumpu Oy.

The *Penikat intrusion* is about 25 km NE from Kemi. It dips to the NW with an angle of about 40–70° (Alapieti & Lahtinen 1986, 1989, 2002, Alapieti et al. 1990, Huhtelin et al. 1990, Halkoaho 1993, Halkoaho et al. 2005). Three well-explored reef-type PGE occurrences are known within the intrusion: 1) *Sompujärvi (SJ) Reef* at the contact between megacyclic units III (boninitic-like, Cr-rich magma type) and IV (tholeiitic like, Cr-poorer magma type), 2) *Ala-Penikka (AP) Reef* at the lower part of megacyclic unit IV, and 3) *Paasivaara (PV) Reef* at the contact between megacyclic units IV and V (Table 34). In the sulphide-bearing AP and PV reefs, the dominant sulphide assemblage is pyrrhotite-chalcopyrite-pentlandite. In the SJ reef, base metal-free chromite and silicate variants are dominant. The silicate mineralogy of the reefs is dependent on the host rock type. Base metal-bearing reefs generally contain 0.8–2 vol% sulphides and their typical metal contents range at approximately 0.06–0.24 % Ni and 0.11–0.36 % Cu. The base metal-free chromite reefs normally contain less than 0.05 % S and Cu, and about 0.08 % Ni, including the silicate-bound Ni (Alapieti & Lahtinen 2002). The silicate reefs have very low S and Cu contents, at < 0.02 % and <0.015 %, respectively, all Ni is in silicates, and the Cr content is normally low, below 0.05 % (Halkoaho 1993).

The SJ Reef is roughly 1 m thick and has a total precious metal grade (3PGE+Au) of 1–10 ppm. In certain places, for example in Kirakkajuppura, at northernmost end of the intrusion, the total precious metal grade is several hundreds of ppm. The AP reef is typically 0.2–0.4 m thick with grades at about 5 ppm 3PGE+Au. In the pothole parts of the AP reef, the best drill intercept so far detected is 20 m at 0.3–12 ppm 3PGE+Au. The average thickness of the PV reef is about 1 m and the 3PGE+Au grade <10 ppm (Alapieti & Lahtinen 1986, Halkoaho et al. 1990a, 1990b, 2005, Huhtelin et al. 1990, Alapieti and Lahtinen 2002). The lower part (megacyclic units I–III) of the Penikat intrusion also contains several thin chromitite layers (Alapieti & Lahtinen 1986 and 1989, Alapieti et al. 1990, Halkoaho 1993).

The Portimo Complex consists of the *Suhanko* and *Narkaus intrusions*. It hosts a variety of PGE mineralisation including (Alapieti et al. 1989b, Huhtelin et al. 1989, Lahtinen et al. 1989, Iljina 1994, 2005):

- PGE-rich Cu-Ni-Fe sulphide dissemination in the marginal series of the Suhanko and Konttijärvi intrusions.
- Predominantly massive pyrrhotite deposits located close to the basal contact of the Suhanko intrusion.

- Rytikangas Reef in the layered series of the Suhanko intrusion.
- Siika-Kämä Reef in the Narkaus layered series.
- Offset Cu-PGE mineralisation below the Narkaus intrusion.

The offset metal enrichment and the first two styles of mineralisation represent a contact-type mineralisation in the immediate vicinity of the basal contact of the intrusions, whereas the reef types form stratiform enrichments well inside the layered sequences.

Disseminated PGE-rich base-metal sulphide zones, normally 10–30 m thick, occur throughout the marginal series of the Konttijärvi and Suhanko intrusions (Fig. 74; Table 34). Their distribution is apparently erratic and they generally extend from the lower peridotitic layer of the marginal series downwards for some 30 m into the basement. The Pt+Pd contents vary from only weakly anomalous values to 2 ppm for most of the marginal series of the Suhanko intrusion, but are up to >10 ppm in several sites in the **Konttijärvi** and **Ahmavaara** deposits. Sulphides have also accumulated to form massive concentrations in the Suhanko intrusion. Similar to the disseminated sulphides, the massive sulphides have much higher PGE, Ni and Cu concentrations at Ahmavaara compared to the other massive sulphide deposits hosted by the Suhanko Intrusion.

The offset mineralisation is sporadically distributed in the basement gneisses and granites below the Narkaus intrusion. The largest and the best-known are below the Kilvenjärvi block. These form a cluster of ore bodies (all offset occurrences listed in Table 34). The offset mineralisation represents the richest PGE deposit type within the region, with Pt+Pd contents up to 100 ppm. An offset occurrence is predominantly a Pd deposit, as it has a much higher Pd/Pt ratio than any other PGE deposit of area F035, and is extremely low in Os, Ir, Ru, and Rh. Furthermore, it is extremely irregular in form, containing disseminated sulphide-PGM 'clouds', massive sulphide veins or bodies, and breccias in which sulphide veins brecciate the country-rock granitoids. The proportions of base-metal sulphides and PGM are highly variable, but the massive sulphide bodies are generally richer in PGE. In general terms, the more sulphide-rich occurrences are closer to the basal contact of the intrusion and those poorer in sulphides are encountered in a wider zone below the intrusion

The **Siika-Kämä Reef** (Table 34) of the *Narkaus intrusion* is most commonly located at the base of MCU III, but in places it may lie somewhat below that or in the middle of the olivine cumulate layer of MCU III. Chlorite-amphibole schist similar to that in the Sompujärvi Reef in the Penikat Intrusion commonly hosts the Siika-Kämä Reef. In some parts of the reef, the PGE mineralisation is accompanied by chromite seams or chromite dissemination. The thickness of the reef varies from less than one metre to several metres, and many drill holes penetrate a number of mineralised layers separated by PGE-poor layers up to several metres thick. Mineralisation at Siika-Kämä is among the most sulphide-deficient within the Portimo Complex, in some places containing no visible sulphides at all, and rarely exceeding a whole-rock sulphur content of 1 wt%.

Table 34. PGE±Ni-Cu and Cr deposits with a resource estimate in the Portimo metallogenic area (F035).

Occurrence	Tonnage (Mt)	Cr %	Au g/t	Pd g/t	Pt g/t	Cu %	Ni %	Deposit subtype	References
Kemi	160.1[1]	19							Outokumpu Oy, Annual Reports for 2004–2010
Sompujärvi	6.7[2]		0.1	3.08	5.36			Reef	Reino et al. (1993)
Ahmavaara	187		0.1	0.82	0.17	0.17	0.09	Contact	Puritch et al. (2007)
Konttijärvi	75.3		0.07	0.95	0.27	0.1	0.05	Contact	Puritch et al. (2007)
Niittylampi	1.04			0.68	0.27	0.49	0.67	Contact	Lahtinen (1986)
Suhanko	1.0		0.04	0.9	0.2	0.31	0.27	Contact	Lahtinen (1986)
Vaaralampi	32		0.06	0.55	0.2	0.2	0.31	Contact	Reino et al. (1978), Holland (2011)
Siika-Kämä	43.1		0.08	2.7	0.72	0.11	0.08	Reef	Gold Fields (2003)
Kilvenjärvi	0.7		0.8	7.27	1.12	2.74		Offset	Outokumpu (1987)
Kilven-latvalampi	3.2			1.4	0.5	0.5		Offset	Saltikoff et al. (2000)
Kilvenjoki	0.175		0.84	2.5	0.06	6.11	0.28	Offset	Outokumpu (1987)

1 Includes 37.1 Mt of ore mined by the end of 2010.
2 Later drilling shows much more extent for and perhaps about 35 Mt of mineralised rock with similar grades as for the 6.7 Mt.

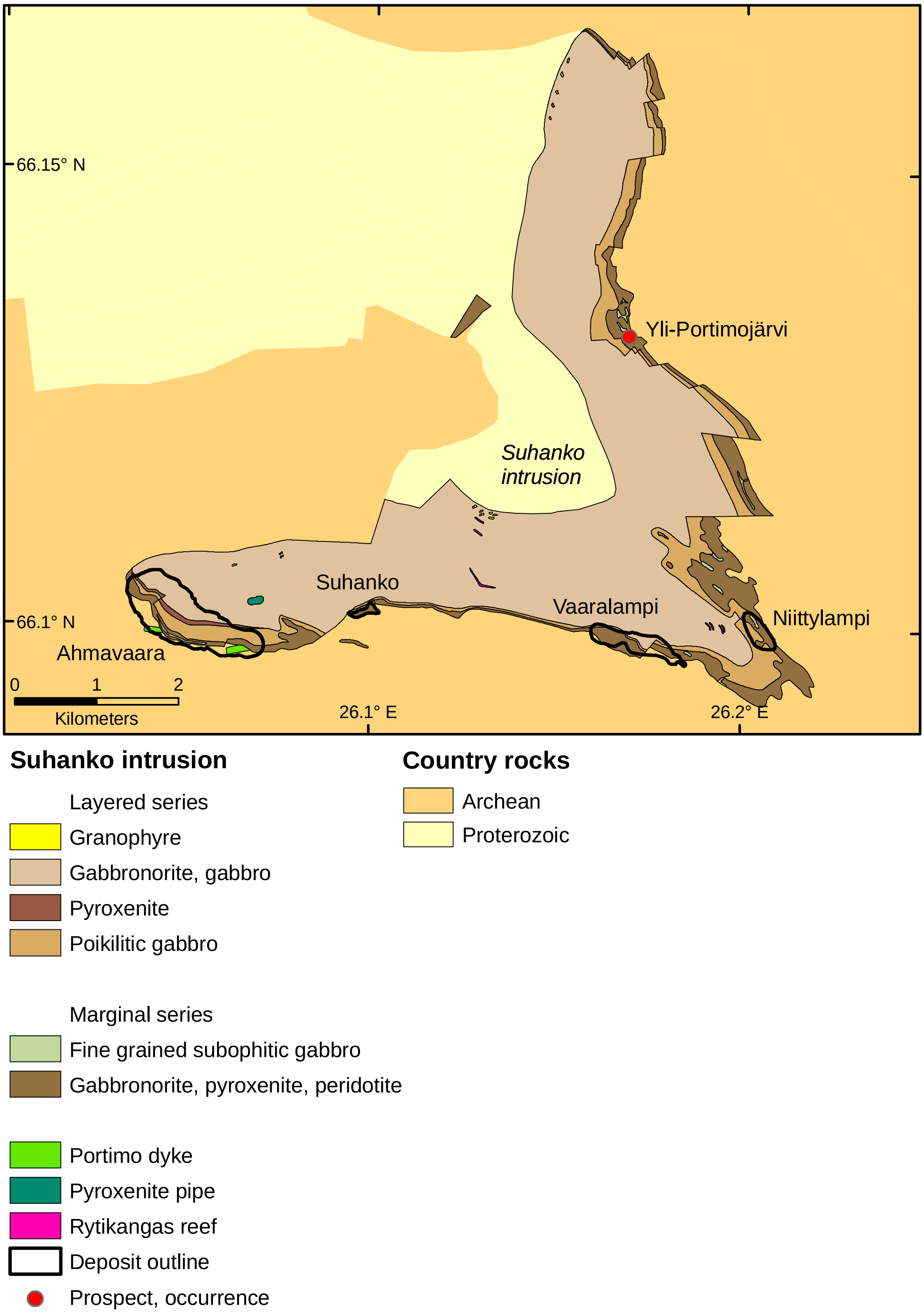

Figure 74. Geology of the Suhanko intrusion, with contact-type PGE deposits within the intrusion, after Rasilainen et al. (2010).

F036 KOILLISMAA PGE-Ni-Cu, Vi-Fe-Ti

Tuomo Karinen (GTK)

The Koillismaa metallogenic area (F036) is defined by the layered intrusions of the Koillismaa–Näränkävaara Complex and their immediate country rocks, in eastern Finland, about 150 km northeast of the city of Oulu (Fig. 75). The intrusive complex comprises the Koillismaa Intrusion, the Näränkävaara Intrusion, and a strong positive gravity anomaly (regarded as a major dyke at depth) that connects the western and eastern parts of the complex. The westernmost part of the complex (the Koillismaa Intrusion) consists of separate bodies that represent blocks of a single, sheet-like layered intrusion. These blocks straddle the boundary between the Archaean Eastern Finland complex and the Palaeoproterozoic Kuusamo schist belt, whilst the Näränkävaara Intrusion is surrounded by rocks of the Archaean basement complex. (Alapieti 1982, Alapieti & Lahtinen 2002, Iljina & Hanski 2005, Karinen 2010). The layered intrusions of the Koillismaa-Näränkävaara Complex are mafic to ultramafic in composition and have an age of ca. 2.44 Ga (Alapieti 1982).

The Koillismaa–Näränkävaara Complex hosts two principal types of metallic mineralisation. Both types are located in the Koillismaa Intrusion, but since the Näränkävaara Intrusion is of the same 2.44 Ga age, the metallogenic zone is also extended to the eastern part of the complex. The mineralisation types are:

- PGE-rich Cu-Ni-sulphide occurrences in the layered and marginal series of the Koillismaa Intrusion (Alapieti 1982, Alapieti & Lahtinen 2002, Iljina & Hanski 2005, Karinen 2010). Due

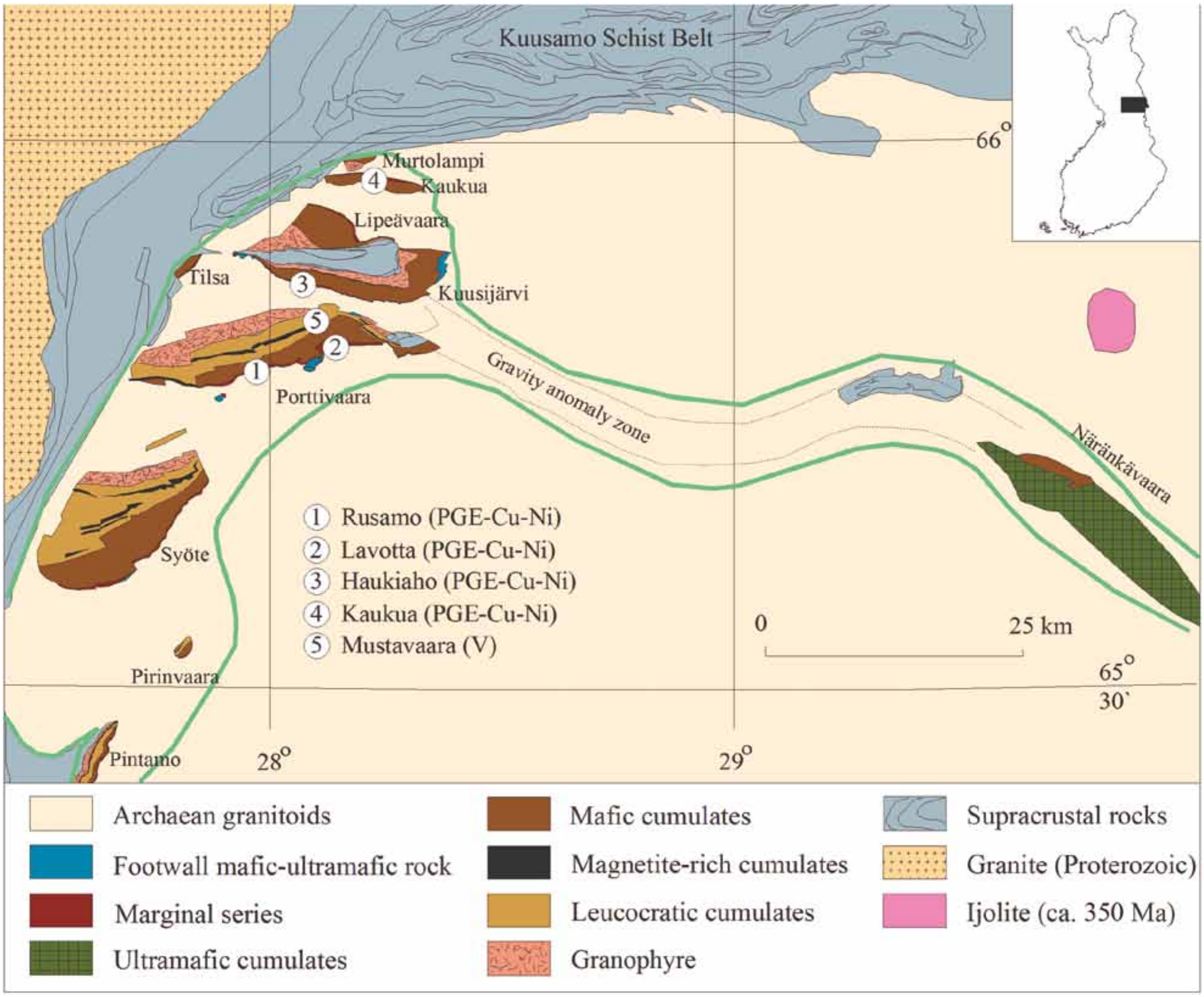

Figure 75. Geological map of the Koillismaa metallogenic area (F036), the boundaries of which are marked here by a green line. The intrusive blocks of the 2.44 Ga layered intrusions and the main metallic mineral deposits of the area are named. The 'Gravity anomaly zone' is explained in the text. The map is based on Karinen (2010).

to their location in the intrusion stratigraphy, the occurrences of the layered series represent reef-type and the occurrences of the marginal series represent contact-type PGE mineralisation.

- An orthomagmatic V-Ti-Fe-rich layer in magnetite gabbro subzone of the layered series of the Koillismaa Intrusion (Juopperi 1977, Alapieti 1982, Iljina & Hanski 2005, Karinen 2010). This type of mineralisation is represented by the Mustavaara vanadium mine (Juopperi 1977, Alapieti 1982), which so far is the only deposit that has been mined (1976–1985) within area F036.

There is one known reef-type occurrence in the Koillismaa Intrusion. It is sub-economic and is located in the middle part of the intrusion stratigraphy, in the contact of two subzones of the layered series. The mineralisation is usually less than 30 m in stratigraphic thickness and is sporadically distributed in location and in the amount of sulphides. Another feature of the mineralisation is the occurrence of metre-sized noncumulus-textured gabbronoritic bodies adjacent to the sulphide-bearing rocks. The principal sulphide minerals are pyrrhotite, chalcopyrite and pentlandite, which occur disseminated together with relatively low-temperature minerals in cm-sized pockets of clusters. The PGE grade correlates positively with the amount of these clusters. The mineralisation, referred to as the Rometölväs Reef (RT Reef), has been found from the Pirinvaara, Syöte, Porttivaara and Kuusijärvi blocks (Piispanen & Tarkian 1984, Karinen 2010).

The marginal series of the Koillismaa Intrusion is up to 200 m thick and displays a distinct basal reversal where the cumulates grade upwards in the stratigraphy from gabbroic to ultramafic rocks. The chalcophile metals-enriched domain is usually concentrated in the middle part of the marginal series, in the place where the rock grades from mafic to ultramafic. The mineralised part is typically 15–40 m thick and has gradational upper and lower contacts. Sulphides comprise 1–5 vol% of the rock and mostly occur as fine dissemination in the interstices of silicate grains. The principal sulphide minerals are pyrrhotite, chalcopyrite, pentlandite and, in places, pyrite. (Alapieti 1982, Karinen 2010)

The Koillismaa Intrusion has generally been regarded as target with greater potential for contact-type than the reef-type PGE-Cu-Ni mineralisation. In Table 35, all the PGE occurrences are of contact type. Of these, the Kaukua occurrence is worth mentioning, since there the PGE grades appear to be higher in comparison to other known contact-type occurrences of area F036 (Nortec Ventures 2009a, 2009b, Nortec Minerals 2010, 2011).

The **Mustavaara** vanadium deposit is in the magnetite gabbro layer of the upper part of the layered series of the Koillismaa Intrusion (magnetite-rich cumulates in Fig. 75). The layer is uniform and can be traced in almost every block of the intrusion. In the Mustavaara mine, the magnetite gabbro layer is about 240 m thick, strikes nearly east–west and generally dips at about 40º to the north (Juopperi 1977, Alapieti 1982, Karinen 2010). The grades of Fe, Ti and V in the magnetite gabbro show a positive correlation with the amount of the ilmenomagnetite, which is an oxide phase that originally crystallised as titaniferous magnetite, but which later during the subsolidus phase reacted to form composite grains of fine ilmenite lamellae and V-bearing magnetite host. In the Mustavaara mine, the amount of oxide was used to divide the magnetite gabbro into four distinct layers, of which the three lower ones made up the ore. The lowest ore layer was about 5 m thick and contained 25–35 vol% oxide minerals and 0.38 % V (0.68 % V_2O_5), whereas the middle layer, 15–50 m in thickness, was poorest in oxides at about 15 vol% with 0.22% V (0.39 % V_2O_5). The upper layer of ore varied from 10 to 40 m in thickness and contained 0.26 % V (0.46 % V_2O_5). During mining, one significant challenge to over-

Table 35. Deposit list of the Koillismaa Intrusion. Examples of PGE-Ni-Cu and V deposits with a resource estimate in the Koillismaa area (F036).

Occurrence	Tonnage (Mt)	Au g/t	Pd g/t	Pt g/t	Cu %	Ni %	Ti %	V %	References
Haukiaho	27.0	0.22	0.55	0.21	0.36	0.24			Iljina et al. (2005)
Kaukua	12.112	0.08	0.71	0.25	0.15	0.10			Nortec Minerals (2011)
Lavotta	3	0.2	0.26	0.18	0.26	0.21			Lahtinen (1983), Iljina (2004)
Rusamo	1.5	0.15	0.38	0.27	0.39	0.24			Lahtinen (1983), Iljina (2004)
Mustavaara	43.5[1]						5	0.2	Puustinen (2003), Adriana Resources (2006)

1 Includes 13.5 Mt of ore mined during 1976–1985.

come was the optimisation of the production line to gain the maximum V-grade with the minimum amount of ilmenite lamellae in the magnetic concentrate. The mine started in 1976 and operated until 1985. An open pit 1800 m in length resulted, varying in width from 130 to 290 m and in depth from 50 to 135 m (Juopperi 1977). The mine produced 13.446 Mt of ore at 0.2 % V (0.36 % V_2O_5). The tonnage given in Table 35 only covers the uppermost 100 m of ore; drilling indicates that the deposit probably extends beyond 200 m depth.

F037 PERÄPOHJA Cu-Co

Markus Kyläkoski & Pasi Eilu (GTK), Jan-Anders Perdahl (SGU)

The Peräpohja area (F037) covers the main parts of Peräpohja Schist Belt (PSB) (age ca. 2.4–1.9 Ga; Perttunen & Vaasjoki 2001) in Finland and parts of the similar-aged supracrustal rocks in Sweden, immediately to the north of the Portimo metallogenic area (F035, Fig. 72). These schist belts, metamorphosed chiefly under upper-greenschist to lower-amphibolite facies conditions, comprise well-preserved volcano-sedimentary sequences deposited in intracontinental to open marine environments. Their evolution generally follows that of the other Karelian schist belts of the Fennoscandian shield (Hanski & Huhma 2005, Lahtinen et al. 2005).

Only a few mineral deposits have been detected from area F037. These include the mafic volcanic- and dolomite-hosted Vähäjoki deposit of possibly iron oxide-copper-gold (IOCG) class (Eilu et al. 2007), a few quartz-carbonate vein-hosted and dolerite-associated Cu-Au occurrences possibly of the orogenic gold class (Eilu 2007), and enigmatic bonanza-grade Au-U occurrences in the central northern part of the area (Rompas, Rumavuoma and others; Hudson et al. 2011). Of these, only one in Finland and two in Sweden have been test mined (Table 36).

Although intermittent exploration has been conducted since its discovery in 1943, the **Vähäjoki** deposit has so far proven uneconomic. Vähäjoki comprises a set of magnetite ore bodies aligned in a N-trending zone (Fig. 76). In total, 14 magnetite ore bodies have been assessed at Vähäjoki; these have a combined resource of 10.5 Mt of iron ore with a variable copper, cobalt and gold content. The best gold lodes are 0.1 Mt, 0.23 Mt and 1.0 Mt in size and contain 0.5 g/t Au, 0.03–0.5 % Co and 0.05–1 % Cu. In addition, there are at least 15 magnetite bodies that are not included in the resource estimate (Korvuo 1982).

Besides the deposits listed above, the PSB contains a number of small Cu occurrences and showings through most of the stratigraphic column. Host rocks range from siliciclastic and carbonaceous sediments to mafic volcanic rocks and dolerite sills (Mikkola 1949, Isomaa & Sandgren 2006, Kyläkoski 2009). The dominant Cu sulphide is chalcocite. Bornite and chalcopyrite are typically associated, and local occurrences of metallic copper are also known. Anomalous Co and Au contents commonly accompany Cu, an association that is also depicted in regional and local till geochemistry (e.g., Koivisto 1984, Rossi 1992). Some or all of these occurrences may belong to the 'clastic sediment-hosted stratiform Cu' deposit class or their close associates (Kyläkoski 2007, 2009). In addition, molybdenum occurrences and indications are known from the northern part of the PSB (e.g., Yletyinen 1967).

In Sweden, burghers from Tornio discovered two copper deposits in 1640, Bruksberget and

Table 36. Deposits and occurrences in the Finnish part of the area F037 included in the FODD database. No grade and tonnage data are available for the historic mines in Sweden.

Occurrence	Tonnage (Mt)	Au g/t	Co g/t	Cu %	Fe %	When mined	Genetic type	Reference
Kivimaa	0.023*	5.3		1.87		1969	Orogenic?	Aulanko (1968), Rouhunkoski & Isokangas (1974)
Vähäjoki	10.5**	0.2	0.03	0.17	39.4		IOCG?	Korvuo (1982), Liipo & Laajoki (1991)

* Mined 18 000 tonnes.
** Includes perhaps a half of the all magnetite ore bodies detected at Vähäjoki.

Stora Pahtavaara (Taipale) from the present area F037. The deposits were test mined shortly after, and there has been small-scale mining during different periods since then, last attempt ending in 1844 (Awebro et al. 1986). The mineralisation comprises chalcopyrite and bornite dissemination in quartz-carbonate veins within amphibolite (Lindbergson & Kautsky 1961) situated in fuchsite-bearing Karelian quartzites.

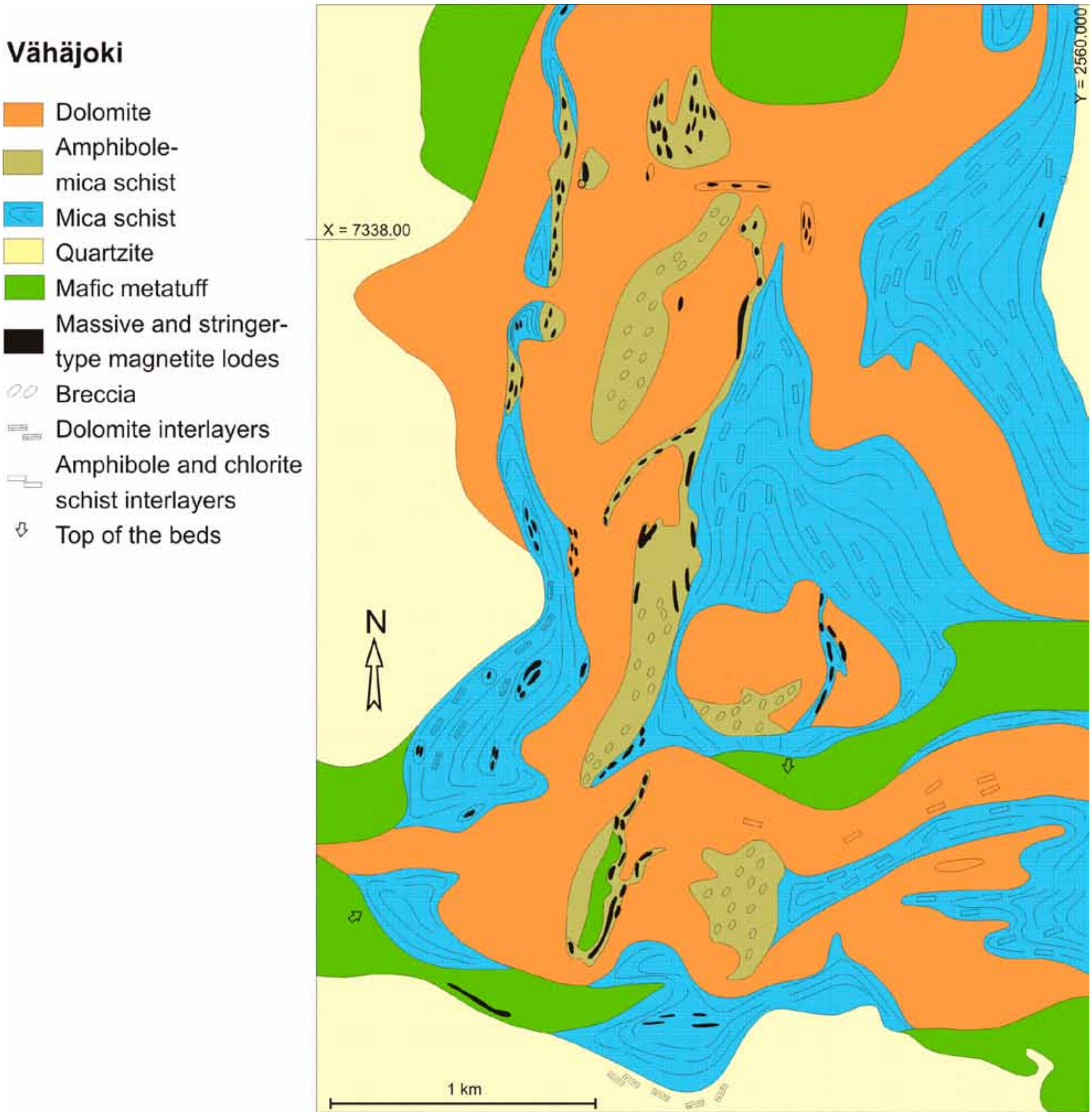

Figure 76. Geology at Vähäjoki, after Liipo and Laajoki (1991). The Au-Co-Cu mineralisation is apparently irregularly hosted by the magnetite lodes. Map coordinates are according to Finnish National Grid, Zone 2, metric values; the most intensely explored ore bodies at 7336000, 2558000 which is equivalent to 66.111°N, 25.279°E.

F038 HAUKIPUDAS Zn

Esko Korkiakoski & Pertti Heikura (GTK)

The Haukipudas Zn area (F038) is within the southwestern part of the Northern Ostrobothnia volcano-sedimentary belt (NOB) in western Finland. The NW-trending area F038 is defined by the interpreted extent of the most zinc deposit-potential part of the lowermost units of the NOB (Fig. 77).

The Palaeoproterozoic NOB covers an area of approximately 2500 km^2. The stratigraphy presented below is from the GTK digital bedrock database and parallel to Korkiakoski (2002). To the north it is bordered by Archaean basement gneisses, whereas the western and southwestern margins are delineated by younger (1830 Ma) Svecofennian granites and unmetamorphosed Muhos and Hailuoto Formations (600–1200 Ma). The NOB predominantly consists of coarse- to fine-grained turbiditic metasedimentary units (greywackes, mica schists and phyllites) and intercalated sulphidic black schists. They represent folded and, at least partly, overthrusted Lower-Kaleva (2060–1950 Ma) sequences grading from fine-grained deepwater accumulations (phyllite-black schist-mafic volcanic rock-chert association) to more coarse-grained greywackes with some conglomerate lenses representing proximal turbidite basin deposits. The turbiditic rocks are underlain by partly skarn-altered dolomite, black schist and MORB-type mafic volcanic sequences. Interestingly, some of the volcanic rocks belonging to the

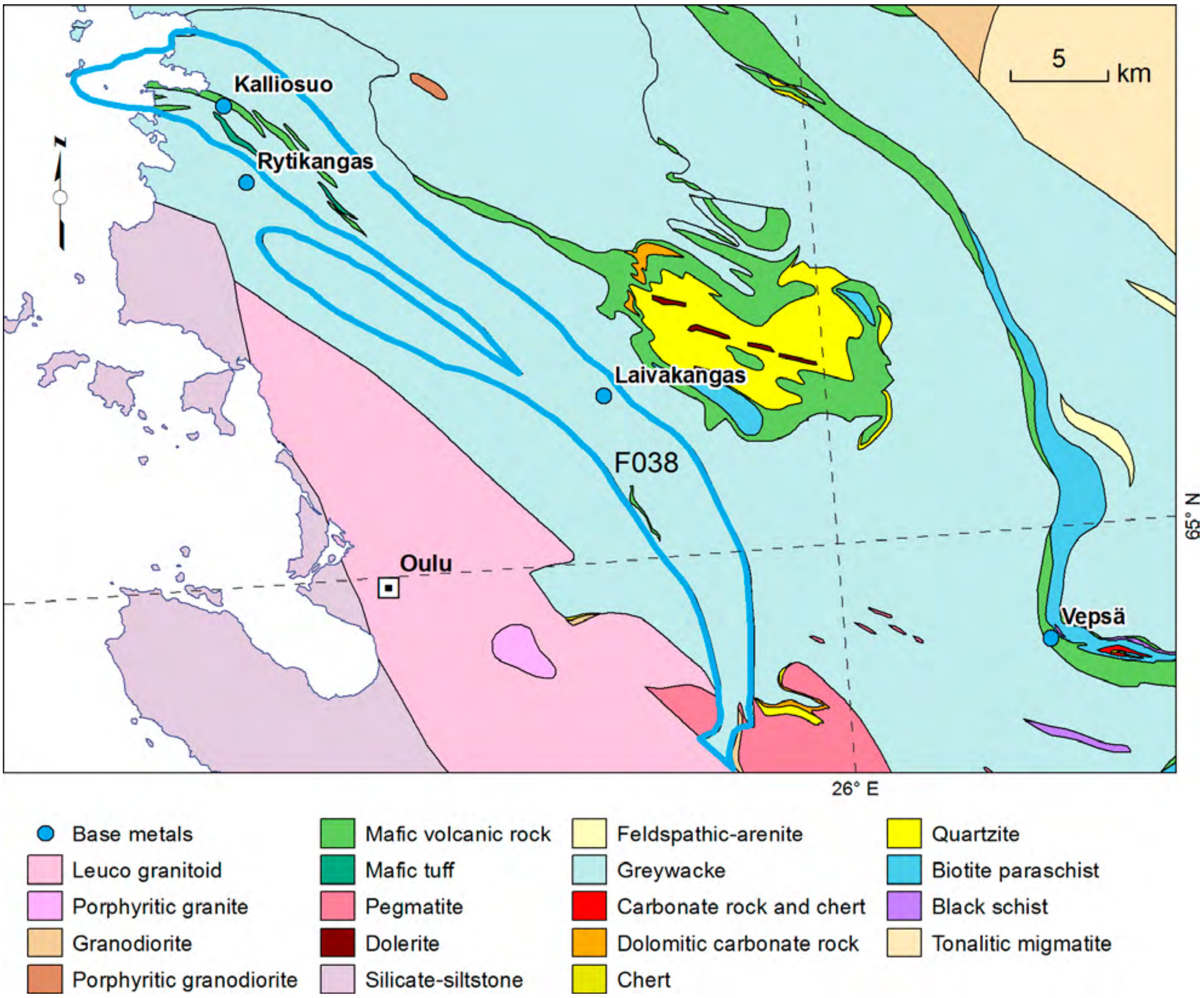

Figure 77. Geology of the Haukipudas Zn area (F038) and its immediate surroundings, with locations of zinc occurrences so far detected in the metallogenic area and the entire Northern Ostrobothnia volcano-sedimentary belt. Geology based on the GTK digital bedrock database.

Haukipudas Formation, in the lower part of the NOB, are komatiitic in composition. The oldest metasedimentary units occurring in the southern part of metallogenic area F038 consist of Jatulian (2300–2100 Ma) conglomerates and arkosites accumulated on the Archaean basement complex. The quartzites of the Koiteli Formation surrounded by turbiditic sediments are thought to be Jatulian in age.

The accumulated geological, geochemical and geophysical data clearly indicate that the NOB, especially its SW part, which is here defined as the Haukipudas metallogenic area (F038), is potential for sediment-hosted (SEDEX) zinc-copper and lead-silver sulphide deposits (Korkiakoski 2002). The rocks belonging to phyllite-black schist-mafic volcanic rock-chert association are locally hydrothermally altered and form economically the most interesting exploration targets for SEDEX-type deposits. This is indicated by a number of known ore-grade boulders and a few drill intercepts from the area (Vanhanen 1995). In addition, anomalous Pb-Ag values have been detected from the shallow-marine black schist-dolomite association from area F038 (Ahtonen 1996). So far, no economic deposits have been located within the NOB. This may partly be related to the fact that abundant sulphidic black schists of the area produce strong geochemical and geophysical anomalies, making it difficult to distinguish the possible ore-related anomalies from those caused by barren schists.

F039 MISI Fe

Tero Niiranen (GTK)

The NW-trending Misi Fe area (F039) covers the northeastern part of the Peräpohja schist belt in southern Lapland (Fig. 1). The boundaries of area F039 are essentially defined by low-altitude aeromagnetic data, as there are very few outcrops beyond the central parts of the area F039. To the north and east, the area is bounded by the Central Lapland granitoid complex, and to the southwest and northeast by clastic sedimentary, dominantly arkositic, sequences of the Peräpohja belt (Fig. 78).

The bedrock of the Misi metallogenic area consists of a 2.3–2.1 Ga supracrustal sequence of quartzites, dolomitic marbles, mafic metavolcanic rocks and mica schists that are locally overlain by ≤1.98 Ga quartz-feldspar schists and bimodal metatuffs (Hanski 2002, Niiranen et al. 2003, Hanski et al. 2005). The 2.20–2.12 Ga gabbros and 1.80–1.77 Ga granitoids comprise the intrusives of the area (Hanski et al. 2001a, Niiranen et al. 2005). Area F039 was subjected to multiphase deformation and up to amphibolite facies metamorphism during the Svecofennian orogenic events in 1.90–1.77 Ga.

Several small magnetite occurrences are known in area F039 (Table 37). Nuutilainen (1969) lists 13 drilling-defined magnetite occurrences in the belt. The magnetite occurrences are lenticular- to irregular-shaped replacement bodies and veins hosted by tremolite- and serpentine-dominated skarns. All of the known occurrences are within highly albitised varieties of 2.20–2.12 Ga gabbros or located at the contacts of the albitised gabbros and the 2.3–2.1 Ga quartzite-dolomitic marble sequence (Niiranen et al. 2003). The chemical composition of the magnetite occurrences indicates that they are Ti, P, and S poor and enriched in V (Nuutilainen 1969).

Niiranen et al. (2005) proposed a metasomatic origin for the Misi magnetite deposits. In their model, the iron was precipitated from deep circulating high-salinity brines that also caused the widespread albitisation and iron depletion of the mafic country rocks. U-Pb age dating of the albitised wall rocks of the Raajärvi deposit indicates that the albitisation took place at 2.06–2.01 Ga (Niiranen et al. 2005). This suggests that the mineralisation slightly post-dates the intrusion of the gabbros in the region. Figure 79 shows the geology of the Raajärvi deposit as an example of the magnetite deposits in the Misi belt.

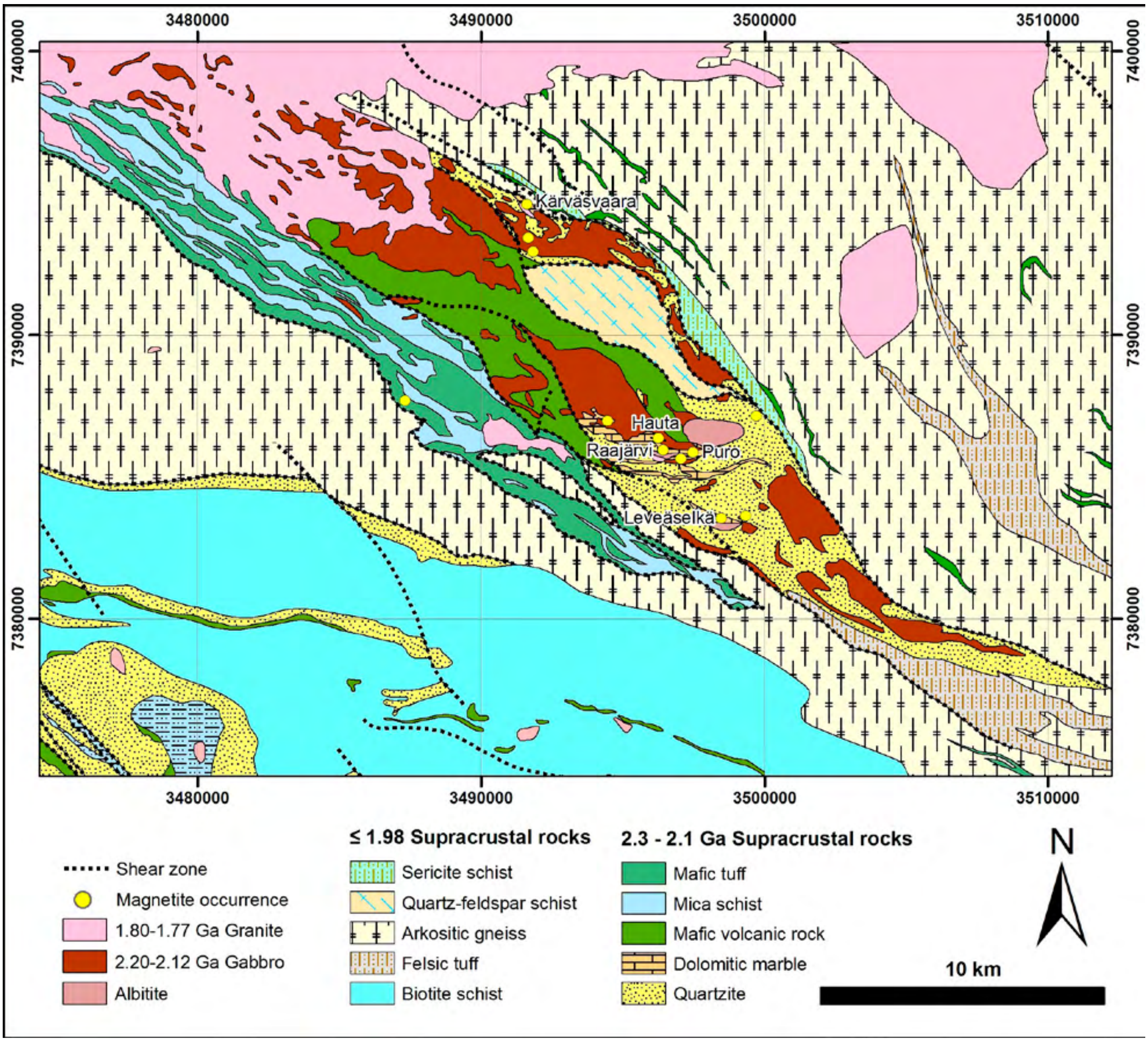

Figure 78. Geology of the Misi metallogenic area (F039) and surroundings, with metallic deposits that have a resource estimate. Metallogenic area F039 essentially covers the NW-trending gabbro-rich supracrustal belt in the centre of the map. Geology is from the GTK digital bedrock database.

Table 37. Iron deposits with a resource estimate in the Misi area (F039).

Occurrence	Tonnage (Mt)	Mined (Mt)	Fe %	When mined	Main host rock	Reference (in addition to Nuutilainen 1969)
Leveäselkä	1.3	1.1	47	1972–1974	Serpentine skarn	Hugg & Heiskanen (1983)
Puro	1	0.06	53.9	1966–1967	Tremolite skarn	Hugg & Heiskanen (1983)
Raajärvi	6.55	5.12	46	1961–1975	Tremolite skarn	Puustinen (2003)
Kärväsvaara	1.35	0.93	52.1	1958–1967	Tremolite skarn	Puustinen (2003)
Hauta	0.24		34.8		Tremolite skarn	Hugg & Heiskanen (1983)

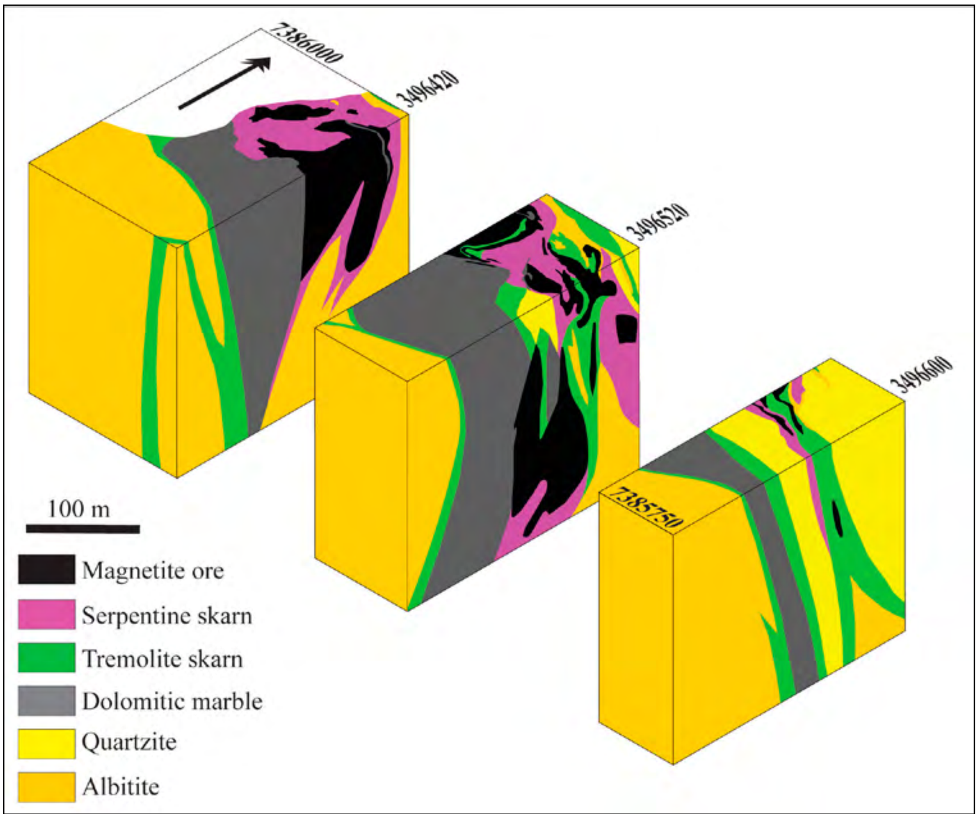

Figure 79. Sectioned 3D geology of the Raajärvi deposit, located at 66.5646°N, 26.9157°E. Modified after Niiranen et al. (2003) and unpublished Rautaruukki data. Coordinate system: Finnish national KKJ3. The arrow points to the north.

F040 KUUSAMO-KUOLAJÄRVI Co-Au

Pasi Eilu (GTK), Margarita Korsakova (SC Mineral), Olli Äikäs (GTK)

The Kuusamo-Kuolajärvi metallogenic area (F040) covers the central and eastern parts of the Kuusamo-Paanajärvi and Salla-Kuolajärvi Palaeoproterozoic schist (greenstone) belts, across the Finnish-Russian border (Figs. 1 and 80). In the north, area F040 is bounded by the Salla greenstones, in the east by Archaean granite-greenstone terrain, in the southeast by the ca 2.45 Ga Olanga layered intrusions, and in the south and west by higher-metamorphic grade supracrustals of the Kuusamo schist belt. The latter two boundaries are defined by a gradual decrease in indications of Au-Co and U mineralisation, whereas the other boundaries of F040 are rather sharp.

The Kuusamo-Paanajärvi and Salla-Kuolajärvi belts (KKB) form the southeastern part of the Lapland greenstones, which extend for >500 km across the northern Fennoscandian shield. The KKB was formed, at least in its central parts, in an intracratonic failed rift setting related to the breakup of the Archaean Karelian craton (Hanski & Huhma 2005). The rocks of the belt comprise clastic sedimentary and volcaniclastic rocks with abundant indications of evaporates, and three or four stages of mafic volcanism and associated mafic sills and dikes, all deposited or intruded between ca. 2.44 and 1.90 Ga (Dain & Ivanov 1978, Pankka 1992, Räsänen & Vaasjoki 2001, Vanhanen 2001, Afanas'eva 2003, Feoktistov et al. 2007). The rocks were probably subjected to the same orogenic stages as the Central Lapland greenstone belt, during the Palaeoproterozoic (see the description of metallogenic area F043). During the compressive epochs (1.91–1.88, 1.85–1.79 Ga), the degree of regional metamorphism varied from upper-greenschist to upper-amphibolite facies within the KKB (Silvennoinen 1991). The highest metamorphic grade was attained in the west and northwest, near the contact with the Central Lapland Granite Complex. From there, the metamorphic grade at the present surface decreases towards the central parts of the belt, which also hosts all gold occurrences. From the central parts, the metamorphic grade again increases to-

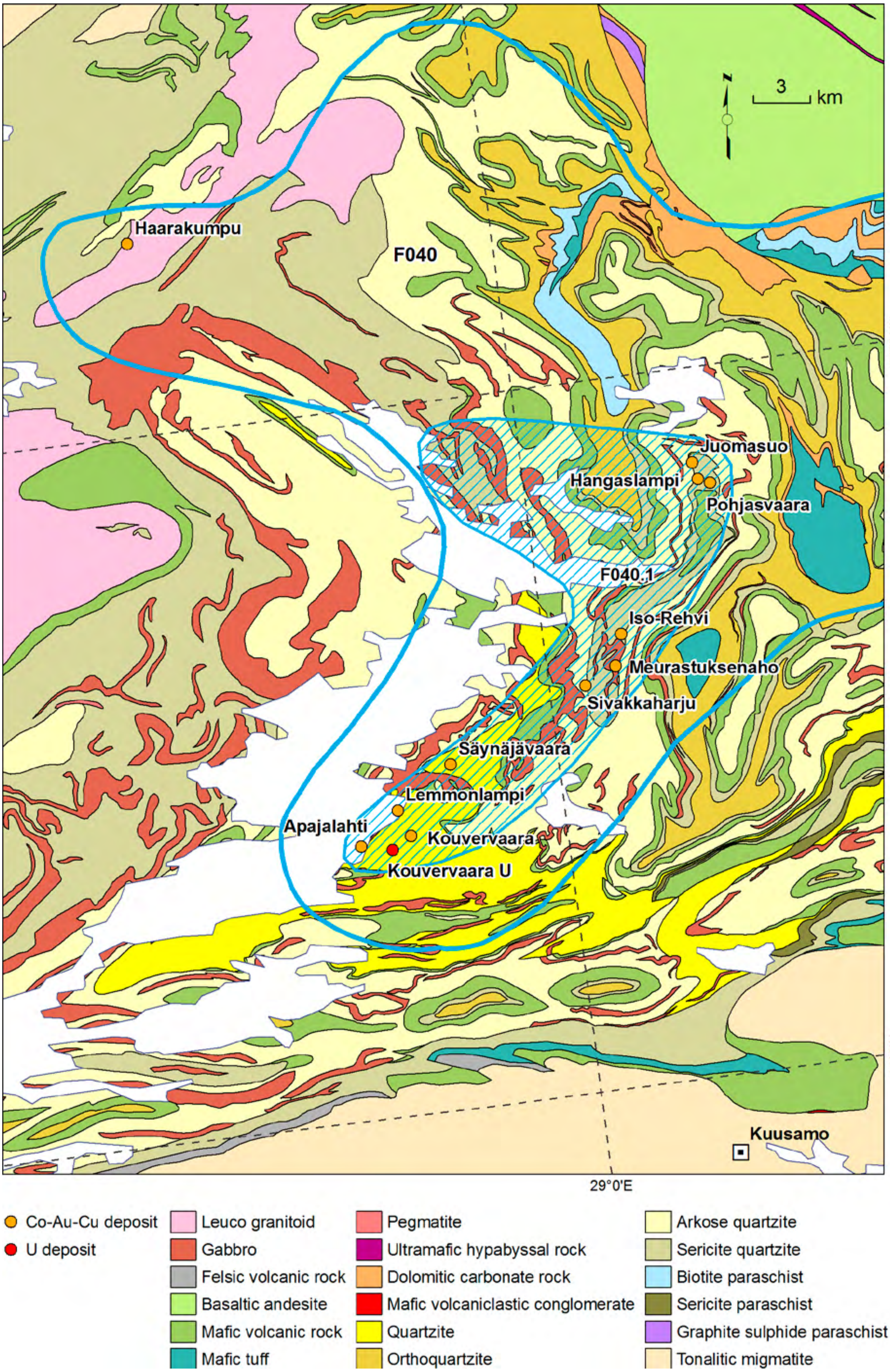

Figure 80. Geology of the western part of the Kuusamo-Kuolajärvi metallogenic area (F040), including the Kuusamo subarea (F040.1), and metallic deposits with a resource estimate in the region. Geology is based on the GTK digital bedrock database.

wards the eastern flank of the belt.

The main styles of metallic mineralisation in metallogenic area F040 are epigenetic Au-Co-Cu±U and stratabound clastic-hosted U (Pankka 1992, Pankka & Vanhanen 1992, Vanhanen 2001). Models of orogenic gold with atypical metal association, iron oxide-copper-gold (IOCG), epithermal and syngenetic style have all been suggested for the Au-Co-Cu±U occurrences within area F040 (Dain & Ivanov 1978, Bezrukov 1989, Pankka 1992, Pankka & Vanhanen 1992, Vanhanen 2001, D.I. Groves, pers. comm. 2006, Eilu & Pankka 2009). The timing and parts of alteration seem to fit with the orogenic style of mineralisation. Alteration, metal association and the mineralising fluid(s) fit best with the IOCG hypothesis. Mineralising fluid(s), metal association, rift−shelf tectonic setting, indications of very early deformation, and host rock associations are consistent with the syngenetic (pre-metamorphic) hypothesis. Structural control and gold fineness fit with all of the genetic styles proposed.

The region covered by subarea F040.1 is most intensely explored and investigated within the Kuusamo-Kuolajärvi area. In addition to those listed in Table 38, there are many more Au-, Au-Co-Cu- and U-mineralised occurrences within the entire F040, many of these explored to some extent, both in Finland and Russia, but there is no tonnage information on them. The general sequence of alteration related to Au-Co-Cu±U deposits within the F040.1 is reported as follows (Pankka 1992, Pankka & Vanhanen 1992, Vanhanen 2001): Albitisation is the most extensive alteration type and is, apparently, premetamorphic. Albitisation is followed by a sequence of syn- to late-metamorphic(?) alteration stages. The first of them is the Mg-Fe metasomatism, which is closely related to gold mineralisation and indicated by the formation of chlorite, tremolite-actinolite, magnetite, chloritoid, talc and Fe sulphides. The next stage is K±S metasomatism, indicated by biotite and sericite ± pyrite and additional(?) gold mineralisation and ductile deformation. This is followed by a stage of carbonation, silicification, further gold mineralisation (or remobilisation) and brittle deformation. These uncertainties in the timing of alteration and mineralisation are one of the major reasons why the genetic type of metallic mineralisation is largely uncertain within area F040.

The largest known deposit within area F040 is **Juomasuo** in the central Kuusamo schist belt, within subarea F040.1 (Fig. 81). Test mining of 17.6 t of ore took place in 1992. Exploration resumed at site in 2010, and the deposit now has an *in situ* resource of 8060 kg gold and 1964 t cobalt (Dragon Mining 2011a; Table 38). The deposit is enriched in Au, Cu, Mo, Ni, REE and U. It is hosted by albitised, biotitised and sulphidised mafic volcanic rock and sericite quartzite. Juomasuo comprises one major and a number of smaller lodes controlled by a NW-trending fault crossing an axial culmination in a NE-trending anticline. Native gold is chiefly associated with Bi and Te minerals as inclusions in pyrite, cobaltite and uraninite, between silicates, and in tiny Au-Bi-Te rich veinlets oriented parallel to foliation and enveloped by silicates. (Pankka 1992, Vanhanen 2001)

The **Maiskoe** gold-only deposit is in the northern part of F040, in Russia. The deposit is hosted by Jatulian andesitic basalt and gabbro-pyroxenite sills and dykes intruded into the basalt (Fig. 82). According to gravimetric data, the deposit is in the exocontact of a concealed granitoid massif and close to two parallel thrust zones. The occurrence is hosted by two quartz veins in sheared and altered rock. The mineralised veins are traced along the strike for 2.5–3.8 km and to a depth for 60–80 m. Veins have a lens-shaped form with pinches and swells. Major ore minerals are sulphides, which form banded and locally nested impregnation (0.5–1.0 % on average). In decreasing order, the ore minerals are: chalcopyrite, pyrrhotite, cobaltite, cubanite, mackinawite, galena, sphalerite, nickel tellurides, lead and gold. Native gold is associated with a telluride-galena assemblage. The gold content in the veins shows an extreme variation from traces to 580 g/t Au. In mineralised localities south of Maiskoe, the gold content varies from 0.1–0.5 g/t Au to 90 g/t Au. The Maiskoe deposit was mined in 1995–1997 and 51 kg of gold was produced. (Dain & Ivanov 1978, Bezrukov 1989, Afanas'eva 2003)

Stratabound clastic-hosted uranium deposits have been detected in subarea F040.1 and elsewhere in the Finnish part of area F040. However, there is a resource estimate only for **Kouvervaara U** (Table 38), and even this estimate appears to be based on scarce data. The Kouvervaara sandstone-type uranium occurrence is subvertical, more than 3 km long, but only a few centimetres to some metres thick, and it is cut by several faults (Vanhanen 1989a). The uranium grade varies from 0.05 % to 0.217 % and averages 0.0385 % per metre of drill core, and the average thickness is 4 m (Vanhanen 1989a, Wallis 2006). Due to a small number of drill hole intercepts, the tonnage given in Table 38 is only provisional. The occurrence is possibly of the roll-front type; it is associated with albitisation and the contact between sericite schist and arkose quartzite (Pankka & Vanhanen 1992).

Table 38. Gold-cobalt and uranium deposits and occurrences in the Kuusamo-Kuolajärvi Au-Co, U area (F040) having a reported resource estimate.

Subarea, Occurrence	Tonnage (Mt)	Au g/t	Co %	Cu %	U %	Main host rocks	Reference
Kuusamo subarea (F040.1)							
Kouvervaara U	0.3*				0.04	Sericite quartzite	Vanhanen (1989a), Pankka & Vanhanen (1992), Wallis (2006)
Apajalahti	0.1	10				Sericite quartzite	Pankka (1992), Vanhanen (2001)
Iso-Rehvi	0.04	4	0.05	0.10		Phyllite	Vanhanen (1991, 2001)
Juomasuo	1.42	5.7	0.15	0.03		Mafic volcanic rock	Vanhanen (2001), Dragon Mining (2011a)
Kouvervaara	1.58	0.4	0.2	0.2		Sericite quartzite	Tarvainen (1985), Pankka (1992), Vanhanen (2001)
Hangaslampi	0.278	6.2	0.1	0.1	0.03	Sandy siltstone	Vanhanen (2001), Dragon Mining (2011a)
Säynäjävaara	0.4	1	0.06	0.02		Sericite schist	Vanhanen (2001), Pankka et al. (1991), Pankka (1992)
Pohjasvaara	0.095	4.9	0.1	0.3		Sericite schist	Vanhanen (2001), Dragon Mining (2011a)
Sivakkaharju	0.047	7.5	0.03	0.12	0.03	Sericite schist	Vanhanen (2001), Dragon Mining (2004)
Lemmonlampi	0.09	0.35	0.3	0.4		Dolerite	Pankka et al. (1991), Vanhanen (2001)
Meurastuksenaho	0.366	3.6	0.25	0.28		Sericite quartzite	Vanhanen (1989b, 2001), Dragon Mining (2011a)
Outside subarea F040.1							
Maiskoe	0.1	7.6				Volcanic rock	Bezrukov (1989)
Haarakumpu	4.68		0.17	0.34		Supracrustal rocks	Vartiainen (1984)

* Grade and tonnage based on limited data only.

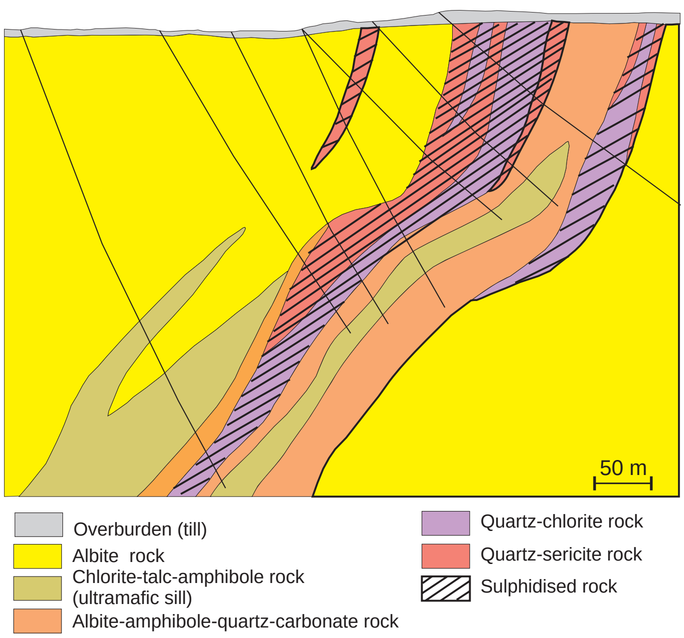

Figure 81. Section across the Juomasuo cobalt-gold deposit, after Pankka (1992). View to the NW. The deposit is at 66.2888°N, 29.1995°E.

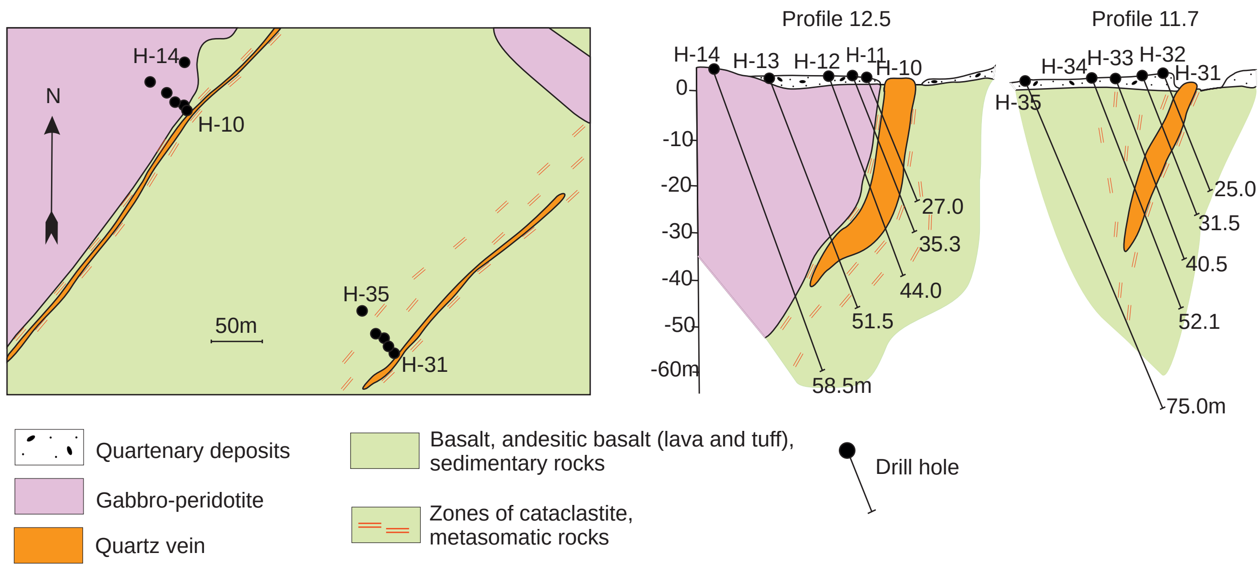

Figure 82. Geological map and sections across the Maiskoe gold deposit. Modified from the publication Raw Mineral Base of the Republic of Karelia (2005). The deposit is at 66.633°N, 29.717°E.

F041 JAURATSI Fe

Jorma Räsänen (GTK)

The Jauratsi Fe area (F041) is in the eastern part of Central Lapland greenstone belt (CLGB), where it comprises the area of the Siulionpalo Formation and its extensions to the north and southeast (Figs. 1 and 83). The Jauratsi area is bounded by a tectonic contact to the northeast, to the volcanic rocks of the >2.43 Ga Salla Group and to the 2.44 Ga Akanvaara layered intrusion (Mutanen 1997). Elsewhere, area F041 is bounded by the volcanic and sedimentary rocks of the Sodankylä Group, which are cut by a mafic dyke yielding a zircon age of 2070 ± 5 Ma (Räsänen & Huhma 2001).

The Siulionpalo Formation (Fig. 83), which in CLGB lithostratigraphy is the lowest unit of the 2.15–2.05 Ga Savukoski Group, lies immediately above the mafic volcanic rocks of the Sodankylä Group. It is overlain by the ca. 2.05–2.0(?) Ga Sattasvaara-type komatiites (Räsänen et al. 1995), locally called the Kummitsoiva Formation and the Kummitsoiva komatiite complex (Saverikko 1983). The lithology is comparable to the Matarakoski and Sattasvaara Formations, respectively, at Sodankylä in central CLGB. The Siulionpalo Formation essentially comprises oxide- to sulphide-facies iron formation. It consists of black, sulphide-rich schist and banded iron formation units associated with minor, mainly tuffitic, felsic volcanic rocks.

The main deposits of area F041 are composed of banded haematite-magnetite deposits, which are associated with iron sulphide-rich schists, have a lateritic goethite-rich cover, and were first described by Rieck et al. (1967). The **Jauratsi** iron deposit (Fig. 83, Table 39) locally contains relatively high Cu and Zn concentrations, up to 0.09 % and 0.4 %, respectively (Kerkkonen 1982). Potential mineral resources at the Jauratsi deposit have been estimated at more than 20 million tonnes (Korkalo 2006). The **Reposelkä** deposit is in a sulphide-facies iron formation (Table 39). To the south of Jauratsi is the **Vesilaskujänkä** VMS-style Cu-Co occurrence, associated with highly albitised felsic tuffites and sulphidic black schist.

Table 39. Metallic mineral deposits with a resource estimate in the Jauratsi Fe area (F041).

Occurrence	Tonnage (Mt)	Co %	Cu %	Fe %	Ni %	S %	Zn %	References (in addition to Kerkkonen 1982)
Jauratsi	16.5		0.03	27	0.05	17.8	0.06	Hugg & Heiskanen (1983)
Reposelkä	26			15		15		Roos (1982)
Vesilaskujänkä	1.8	0.01	0.35	12	0.02	8.1		Saltikoff et al. (2000)

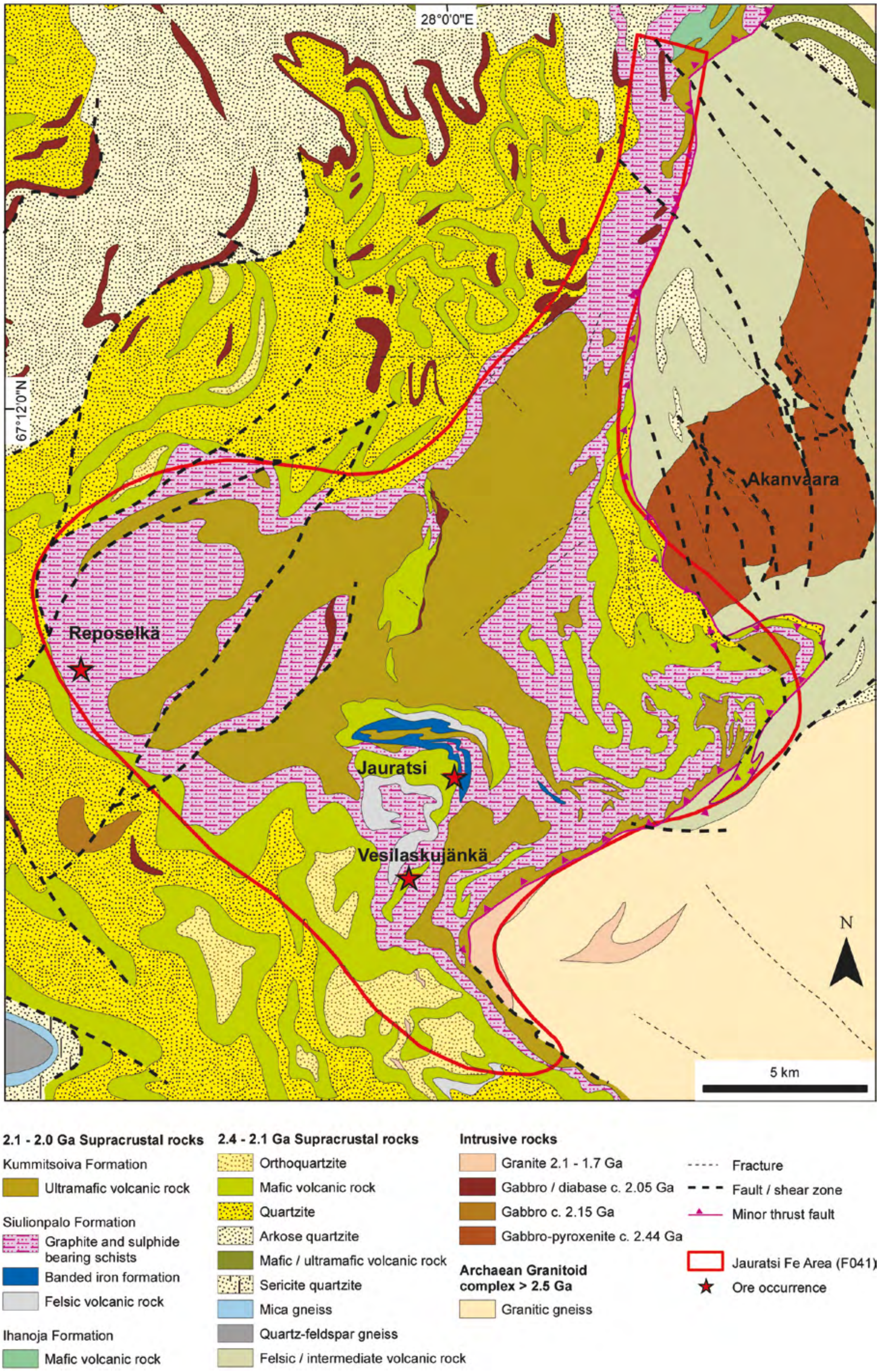

Figure 83. The Siulionpalo Formation and geology of the Jauratsi Fe area (F041) and its surroundings. Geology simplified from the GTK digital bedrock map database.

F042 KESÄNKITUNTURI U

Esa Pohjolainen (GTK)

The Kesänkitunturi U area (F042) is in the SW part of the Central Lapland greenstone belt (CLGB) (Figs. 1 and 84). The metallogenic area covers rocks of the Savukoski and Kumpu groups of the CLGB. Uranium deposit classes detected in the area include the sandstone and vein types. Four occurrences are known, and a mineral resource has been defined for two of them, Kesänkitunturi and Pahtavuoma.

The **Kesänkitunturi** metamorphosed sandstone deposit is hosted by sericite quartzite of the Ylläs formation, which rests disconformably on top of older schists and is discordantly overlain by younger clastics of the ca. 1.80–1.88 Ga Kumpu group (Lehtonen et al. 1998, GTK digital bedrock map database). *In situ* resources of Kesänkitunturi are 950 t U, with an average grade of 0.065 % U for 1.4 Mt of ore. Uranium occurs as uraninite in cement between quartz blastoclasts in the quartzite. The rock contains torbernite as a secondary uranium mineral; chalcopyrite and pyrite are also encountered. The deposit is completely within the Pallas-Yllästunturi National Park.

The **Pahtavuoma** vein-type deposit consists of three ore bodies in fine-grained metasedimentary rocks of the Matarakoski formation in the 2.15–2.05 Ga Savukoski group of the CLGB. The lodes are thin, subvertical sets of veins and lenses, with thicknesses varying from a few centimetres to several metres. The lengths and depths of the lodes are 100 m. Each lode is composed of more than one parallel vein, where uranium occurs in rich pods or nests. *In situ* resources in the two best bodies are 500 t U, with an average grade 0.39 % U. The main U-bearing mineral is uraninite, which forms intergrowth structures with pyrrhotite and molybdenite (Korkalo 2006). In addition to U, the 0.14 Mt occurrence is enriched in Ag (avg. 24 g/t), Co (0.01 %), Cu (0.24 %) and Pb (0.09 %). The uraniferous veins at Pahtavuoma are connected to shear zones or fractures younger than the main deformational event of the CLGB.

Uraninite-bearing veins also are present at **Laavivuoma**, 1.5 km west of Pahtavuoma. Uraninite occurs as roundish or angular grains in veins with brown amphibole, quartz and molybdenite. The uraninite grains are partly fractured due to subsequent deformation, grain fractures are filled by quartz. Uraninite also occurs as bands, in the cement of microbreccia, and as inclusions with magnetite and ilmenite inside brown amphibole. Colloform pitchblende occurs in veins and clusters with silicates and fine-grained molybdenite (Pääkkönen 1988).

The **Aakenusvaara** occurrence is located 10 km east of the Pahtavuoma deposit. Pebbles of uraniferous biotite schist were identified in outcrops of radioactive conglomerate about 5 km to the SE from the Aakenusvaara occurrence. A subsequent search for the provenance of this type of mineralized rock led to the discovery of the Aakenusvaara occurrence. It is located in the Pittarova formation metasediments and metavolcanic rocks of the Savukoski group of the CLGB, 2 km SE of the Saattopora gold mine. Uraninite occurs as roundish grains with a variable degree of alteration, as dissemination and as chains of grains in biotite schist layers. Pitchblende fills microcracks, which cut all preceding mineral phases in the biotite schist (Pääkkönen 1989).

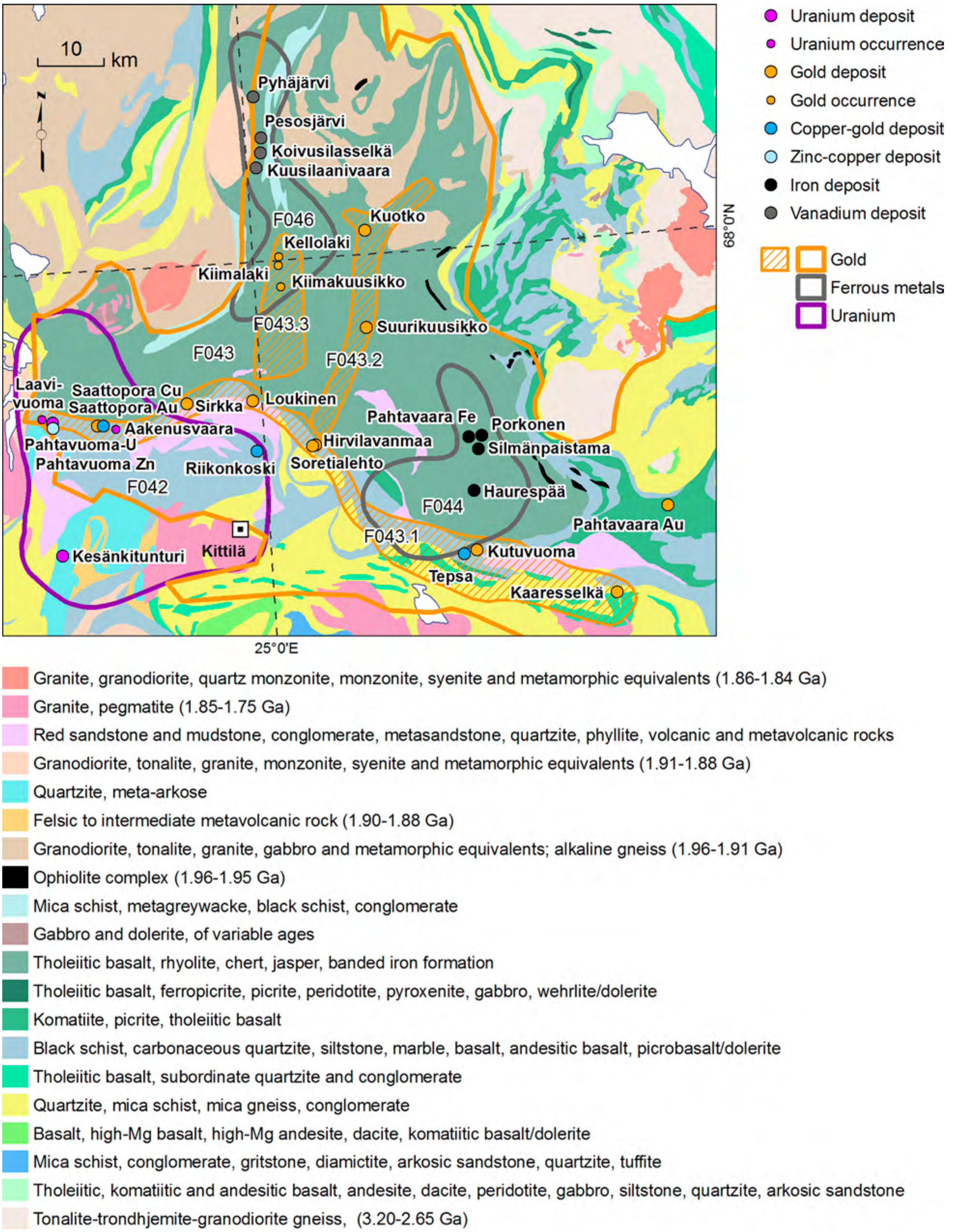

Figure 84. Geology of Central Lapland, metallogenic areas F042, F043, F044 and F046, and metallic deposits with a resource estimate. Geology is from the GTK digital bedrock map database.

F043 KITTILÄ Au, Cu

Pasi Eilu, Tero Niiranen, Helena Hulkki, Vesa Nykänen (GTK)

The Kittilä metallogenic area (F043) covers most of the Central Lapland greenstone belt (CLGB). It extends from the Pajala Shear Zone in the west to Sodankylä in the southeast, north of Koitelainen intrusion in the northeast, and to the Central Lapland Granitoid Complex in the south (Fig. 84). The boundaries of area F043, other than that to the west, are not exact, as indications of gold mineralisation just appear to gradually fade out.

The Central Lapland greenstone belt (CLGB) is the largest mafic volcanic-dominated province preserved in Fennoscandia. It extends from the Norwegian border in the northwest to the Salla greenstones near the Russian border in the southeast. The belt was initially formed in an intracratonic rift setting related to the breakup of the Archaean Karelian craton (Hanski & Huhma 2005). The sequence starts with bimodal komatiitic and felsic volcanic rocks, dated at ca. 2.45 Ga, which overlie unconformably the Archaean basement and represent the onset of rifting (Peltonen et al. 1988, Lehtonen et al. 1998, Manninen et al. 2001). This was followed by 300–400 Ma of deposition of quartzite, turbidite, carbonate rock, iron formation, graphitic schist and basalt, intermittently intruded by mafic dykes and sills dated at ca. 2.2 Ga, 2.10 Ga, and 2.05 Ga (Huhma 1986, Lehtonen et al. 1998, Vaasjoki 2001). Rifting culminated in extensive mafic and ultramafic volcanism and the formation of oceanic crust at about 1.97 Ga. Fragments of oceanic crust were subsequently emplaced back onto the Karelian craton, as indicated within the CLBG by the Nuttio ophiolites (Hanski & Huhma 2005). The emplacement of the ophiolites was followed by the main compressional deformation associated with the Svecofennian synorogenic plutonism, between 1.92–1.86 Ga (Vaasjoki 2001, Lahtinen et al. 2005). Deformational evolution of the CLGB during 1.92–1.77 Ga apparently took place as follows (Ward et al. 1989, Sorjonen-Ward et al. 1992, Mänttäri 1995, Lahtinen et al. 2005, Patison 2007): D_1 and D_2 during 1.92–1.88 Ga, D_3 either during 1.92–1.88 Ga or 1.84–1.79, and the latest, completely brittle D_4 in ca. 1.77 Ga or slightly post-1.77 Ga. Note, however, that the timing for the deformation stages is chiefly indirect, with very few robust radiometric dates setting definite values for any of the stages; in particular, the timing of D_3 is poorly constrained (Lahtinen et al. 2005, Patison 2007). Saalmann and Niiranen (2010) list five deformation stages for the Hanhimaa and western Sirkka Shear Zone areas, with D_1–D_4 being mostly ductile and D_5 brittle. Somewhat similar geotectonic evolution to that for the CLGB can be envisioned for both the Kuusamo and Peräpohja belts for the entire Proterozoic (e.g., Lahtinen et al. 2005).

The main styles of metallic mineralisation in the area F043 are orogenic gold and seafloor-style (syngenetic) zinc-copper deposits (Inkinen 1979, Korkiakoski 1992, Korvuo 1997, Eilu et al. 2007). The orogenic gold type (Table 40) can be further divided into gold-only and gold-copper subtypes. In addition, the gold palaeoplacers of the <1.88 Ga Kumpu Group molasse sequence overlying the greenstone sequences (Härkönen 1984) can be regarded as belonging to area F043, and their gold is probably derived from the orogenic and/or syngenetic occurrences in the region.

Gold mineralisation within area F043 is of the orogenic type as defined by Groves (1993), and the entire CLGB is in many aspects, except for age, similar to Neoarchaean greenstone belts elsewhere in the world rich in orogenic gold mineralisation. Typical characteristics of the occurrences include the following: the structure is the single most important control for mineralisation, Au/Ag >1, quartz veining is abundant, the sulphide contents are at 1–3 vol%, the dominant ore minerals are pyrite, arsenopyrite and pyrrhotite, gold mostly occurs in the native form, carbonatisation, sericitisation and biotitisation haloes surround mineralisation, and most occurrences are in lower- to mid-greenschist facies rocks (Härkönen et al. 1999, Eilu et al. 2007, Patison 2007, Patison et al. 2007). In addition to structure, another significant factor in locally controlling gold mineralisation is the tuffite and phyllite units pervasively albitised (± carbonated) in the early stages of the regional evolution. During the later orogenic stages, these were the locally most competent units, which thus provided the best sites for local dilation, veining and mineralisation (e.g. Grönholm 1999, Saalmann & Niiranen 2010).

Many of the occurrences of area F043 are of the gold-only style, but about a half of the occurrences also contain Co, Cu and/or Ni as a potential commodity (Table 40). This has been explained by the latter belonging to the subcategory of 'anomalous metal association' as defined by Goldfarb et al. (2001) for similar deposits at, for example, Sabie–Pilgrim's Rest in South Africa, and Tennant Creek, Pine Creek and Telfer in Australia. The gold-only orogenic mineralisation derives

Table 40. Gold±copper deposits and occurrences in the Kittilä metallogenic area (F043) having a reported resource estimate.

Subarea, Occurrence	Tonnage (Mt)	Mined (Mt)	Au g/t	Co %	Cu %	Ni %	Genetic type	Reference
Sirkka Au-Cu (F043.1)								
Hirvilavanmaa	0.11		2.9				Orogenic	Härkönen & Keinänen (1989)
Kaaresselkä	0.3		5		nr		Orogenic	Pulkkinen (1999)
Kutuvuoma	0.068	tm	6.7				Orogenic	Anttonen (1995), Korkalo (2006)
Loukinen[1]	0.114		0.5		nr	0.45	Orogenic	Holma & Keinänen (2007)
Riikonkoski[2]	9.45		nr		0.45		Orogenic[2]	Yletyinen & Nenonen (1972)
Saattopora Au[3]	2.163	2.163	2.9		0.25		Orogenic	Korvuo (1997), Eilu et al. (2007)
Saattopora Cu	11.6		0.25	0.01	0.62	0.1	Orogenic[2]	Lehtinen (1987), Korkalo (2006)
Sirkka	0.25	tm	0.8	0.1	0.38	0.32	Orogenic[2]	Vesanto (1978)
Soretialehto	0.013		3.5				Orogenic	Keinänen & Holma (2001)
Suurikuusikko Au (F043.2)								
Suurikuusikko (Kittilä Mine)	58.64	2.2[4]	3.74				Orogenic	Härkönen et al. (1999), Patison et al. (2007) , Agnico-Eagle (2011)
Kuotko	1.116		3.4				Orogenic	Härkönen & Keinänen (1989), Agnico-Eagle (2011)
Beyond the subareas								
Pahtavaara Au	4.3	3.5	2.7				Orogenic or syn-genetic	Korkiakoski (1992), Lappland Goldminers (2010)

nr Not reported in the resource estimate, but analysed drill intercepts indicate that the deposit contains, at least in parts, several g/t gold (if Cu reported) or 0.1–2 % copper (if Au reported).
tm Small-scale test mining only.
1 Four or five ore bodies known, some probably with higher gold and lower base metal grades, but only one with a reported resource estimate.
2 Either a syngenetic Cu deposit overprinted by orogenic gold mineralisation or an orogenic deposit with an anomalous metal association.
3 Only the mined tonnage has been reported; there are probably resources at depth, but their volume is unknown.
4 Mining in 2008–2010 (Mining Registry official statistics and Agnico-Eagle annual reports)

from low-salinity orogenic fluids devoid of base metals, whereas the orogenic Au-Cu±Co±Ni±Ag mineralisation derives from moderate- to high-salinity orogenic fluids formed in an intracratonic setting of evaporate-bearing, volcanosedimentary sequences locally rich in base metals subjected to orogenic processes (Groves 1993, Goldfarb et al. 2001). Obviously, both low- and moderate-salinity fluids have been active within the CLGB, which indeed has all the above-mentioned features for moderately saline, base metal-enriched fluids to be formed (e.g., Hanski & Huhma 2005).

Despite multiple efforts (Mänttäri 1995, Sorjonen-Ward et al. 1992, 2003, Rastas et al. 2001), the dating of gold mineralisation in northern Finland is not well constrained. Most or all of orogenic gold mineralisation apparently took place during a continent-continent collision epoch of the evolution of the Fennoscandian shield, at 1.85–1.79 Ga. However, some orogenic mineralisation may be related to the earlier compressional stage, the microcontinent accretion, at 1.92–1.88 Ga, as is implied by the preliminary Re-Os data from Suurikuusikko. Saalmann and Niiranen (2010) suggest that a significant part of gold mineralisation postdates the 1.79–1.77 Ga Nattanen-type granites.

Three subareas with a high potential of discovery of gold deposits have been defined for F043: Sirkka, Suurikuusikko and Hanhimaa (F043.1, F043.2, F043.3, respectively; Figure 84). The worm-shaped Sirkka Subarea covers the west- to northwest-trending Sirkka Shear Zone and its subsidiary faults: there are more than 30 drilling-indicated occurrences, of which one (**Saattopora**; Fig. 85) has been mined, and two (**Kutuvuoma**, **Sirkka**) test mined. A few are gold-only occurrences, but most cases include Cu and some also Co and Ni as potential commodities. Quartz-carbonate±albite veining is extensive, the dominant hosts are komatiite, intermediate tuffite and phyllite, and pre-gold albitisation is common in tuffite and phyllite (Korvuo 1997, Pulkkinen 1999, Hulkki & Keinänen 2007, Eilu & Pankka 2009). Occurrences within the Sirkka Subarea

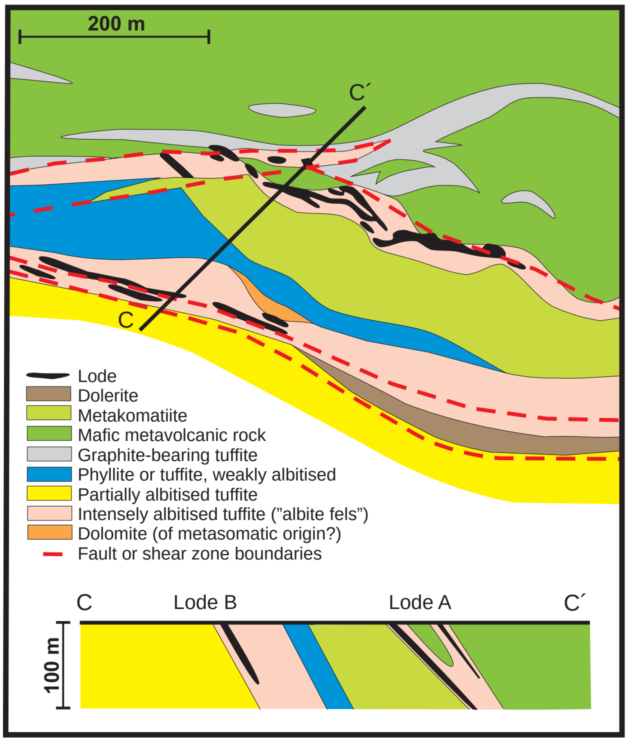

Figure 85. Geological map and a section across the Saattopora deposit. Note the presence of all lodes within the most intensely albitised tuffite, that is, within the locally most competent rock unit. Modified from Korvuo (1997).

are, in most aspects, similar to the Pahtohavare and Bidjovagge copper-gold deposits in Sweden (S037) and Norway (N036), respectively (Ettner et al. 1994, Lindblom et al. 1996).

The Suurikuusikko subarea (F043.2) comprises the north- to northeast-trending Kiistala Shear Zone and its immediate surroundings (Fig. 84). It includes the **Suurikuusikko** (Kittilä mine) and **Kuotko** gold deposits. They are structurally controlled gold-only occurrences in greenstones, and characterised by carbonate-biotite-graphite-chlorite alteration. At Suurikuusikko (Fig. 86), nearly all of the gold is refractory, bound in arsenopyrite and pyrite, whereas free native gold dominates at Kuotko (Härkönen & Keinänen 1989, Härkönen et al. 1999, Patison et al. 2007). Exploration data summarised by Eilu and Pankka (2009) show that subarea F043.2 must be regarded as having a great potential for further discoveries, as practically all drilling within the shear zone system, both along strike and to the depth of >1 km, has intercepted high gold grades.

The Hanhimaa subarea (F043.3; Fig. 84) contains the most recent gold discoveries in northern Finland. The subarea F043.3 is N- to NE-trending, containing the 20-km-long Hanhimaa Shear Zone (HSZ) with its subsidiary faults and surrounding bedrock. Interestingly, the shear and fault system is parallel to the Kiistala Shear Zone. The gold potential in the Hanhimaa subarea was

Figure 86. Aerial view of the Suurikuusikko (Kittilä) mine site in September 2010. The ore zone is visible as a dark grey band in the middle of the main open pit. The small Rouravaara open pit is at upper left. View to the NE. Photo: courtesy of Agnico-Eagle Mines Ltd.

identified in 2002. Since then, three gold prospects (Kiimalaki, Kellolaki and Kiimakuusikko) have been located within the 100−200 metre wide domain of strongly sheared and hydrothermally multiply altered greenstones and felsic dykes within the HSZ proper and in subsidiary faults to it (Dragon Mining 2009, 2011b, Saalmann & Niiranen 2010). The metal association in the drill intercepts varies from gold-only through Au-Ag to Au-Ag-Pb-Zn-Sb-Cu, suggesting orogenic gold mineralisation with both normal and anomalous metal association plus a possibility of syngenetic (VMS-style?) base-metal mineralisation overprinted by orogenic gold system(s) (Dragon Mining 2009 and 2011b). Nearly all exploration, and all drilling, has so far been performed for a small part of subarea F043.3. This suggests that much more is still to be discovered within the subarea.

The **Pahtavaara** gold deposit (Fig. 87) in the southeastern part of area F043 is somewhat an enigma. It has many of the alteration characteristics of amphibolite-facies orogenic gold deposits and an obvious structural control, but has an anomalous barite-gold association and a very high fineness (>99.5 % Au) of gold (Kojonen & Johanson 1988, Korkiakoski 1992). The geometry of high-grade quartz-barite lenses and amphibole rock bodies relative to biotite-rich alteration zones is also anomalous. Pahtavaara may well be a metamorphosed seafloor alteration system with ore lenses as either carbonate- and barite-bearing cherts or quartz-carbonate-barite veins. The gold may have been introduced later, but its grain size, textural position (nearly all is free, native, and occurs with silicates, not sulphides) and high fineness point to a pre-peak metamorphic timing, which is highly anomalous for orogenic gold.

There are a number of VMS-style (or other syngenetic type) base-metal occurrences in the southern part of the Kittilä area. Most of them are obviously small, have seen only minor drilling, and have no resource estimate. The main exception is the **Pahtavuoma** copper-zinc deposit, near the SW corner of area F043, containing 21.4 Mt at 0.3 % Cu, 0.67 % Zn, 0.03 % Co and 10 g/t Ag (Inkinen 1979, Korvuo 1997). The deposit is open at the depth of 300–400 m. Pahtavuoma comprises six zinc-rich and four copper-rich ore bodies. In two periods during 1974−1993, 0.3 Mt of copper ore was test mined at Pahtavuoma at grades of 1.07% Cu and 26 ppm Ag (Puustinen 1995). As suggested in Table 40, a number of low-grade syngenetic(?) base-metal occurrences may have been overprinted by orogenic gold mineralisation within area F043. This is one of the possible reasons, in addition to the moderate-salinity orogenic fluids and extensive supracrustal sequences with highly variable rock types and multiple deformation, why there are so many polymetallic occurrences in northern Finland where the processes of mineralisation and genetic types of the ores are difficult to determine.

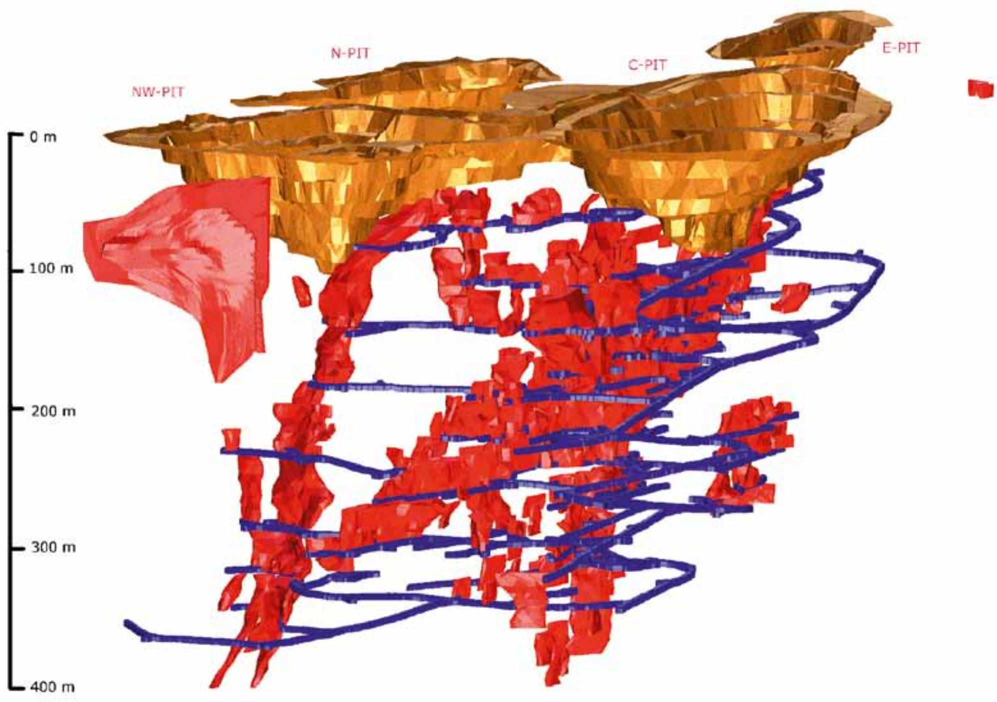

Figure 87. Open pits (brown), underground drives (blue) and ore bodies as of December 2010 in the Pahtavaara gold mine. View to the NE. Image: courtesy of Lappland Goldminers AB.

F044 PORKONEN-PAHTAVAARA Fe-Mn

Helena Hulkki & Tuomo Karinen (GTK)

The Porkonen-Pahtavaara area (F044) is in the Palaeoproterozoic Central Lapland greenstone belt (CLGB), entirely inside the Kittilä metallogenic area (F043) (Fig. 84). Extent of metallogenic area F044 is defined by the presence of chemical sediments of the Porkonen Formation of the Kittilä Group of the CLGB (Lehtonen et al. 1998). These chemical sediments predominantly comprise alternating layers of chert, iron-rich minerals and graphite, and they are commonly mixed on a fine scale with volcaniclastic material (Paakkola & Gehör 1988). Besides the chemical sediments, the Porkonen Formation comprises graphitic tuffaceous schists and mafic lavas. The geological evolution of the region is briefly described in the description of metallogenic area F043.

Oxide-, carbonate- silicate- and sulphide-facies iron formation occur area F044. Typically, the oxide facies is in the lower, carbonate facies in the mid- and sulphide facies in the upper part of the sequence. Abundant manganese characterises the carbonate-facies iron formation, as is the case in the **Silmänpaistama** deposit (Table 41). The sequence also contains phosphorite bands a few millimetres thick (Paakkola 1971, Gehör 1994). All deposits are deformed and metamorphosed under lower- to mid-greenschist facies conditions, and are fine-grained. Hence, and due to being rather small, they have never been exploited, except their jasper been used as a decorative stone to a small extent (Kinnunen 1982), even though they have intermittently been explored for more than 150 years (Saltikoff et al. 2006).

Table 41. Iron occurrences with a reported resource within the Porkonen-Pahtavaara metallogenic area (F044). The data are from Paakkola (1971), Hugg & Heiskanen (1983) and Gehör (1994).

Occurrence	Tonnage (Mt)1	Fe %	Mn %	Main ore minerals
Haurespää	15.3	33		Magnetite, goethite, haematite, siderite
Pahtavaara Fe	14	30		Magnetite, goethite, haematite
Porkonen	9	30		Magnetite, goethite, haematite
Silmänpaistama	7	21.4	5.9	Siderite, manganosiderite, magnetite, goethite, haematite

F045 KOITELAINEN Cr, V, PGE

Markku Iljina, Tuomo Karinen, Pasi Eilu (GTK)

The Koitelainen area (F045) covers the Koitelainen intrusion in Central Lapland (Figs. 1 and 88). Koitelainen is the largest of the ca. 2.45 Ga mafic to ultramafic layered intrusions that occur near the Archaean-Proterozoic boundary in the northern parts of the Fennoscandian shield. The intrusion is subhorizontal, 26 x 29 km in horizontal extent and roughly 3 km in thickness (Mutanen 1997). The emplacement of the 2.45 Ga intrusions is part of a large plume-related rifting event (Mu-

Table 42. Metallic mineral deposits and occurrences in the Koitelainen metallogenic area (F045) having a reported resource estimate.

Occurrence	Tonnage (Mt)	Cr %	PGE g/t[2]	Pd g/t	Pt g/t	V %	Main host rock	Reference
Koitelainen LC	2[1]	15.7		0.9	0.48	nd	Chromitite	Mutanen (1989, 1997)
Koitelainen UC	70	14.4	1.1			0.4	Chromitite	Mutanen (1989, 1997)
Koitelainen V	15					0.2	Gabbro	Mutanen (1989, 1997)

1 The deposit is probably much larger, as three to six LC layers seem to extend for at least 20 km along strike (Mutanen 1997); however, due to minor drilling, the total tonnage cannot be reliably estimated.
2 'PGE g/t' indicates the combined Pd and Pt content.
nd The chromite is reported to be V-rich, but the V content of the occurrence is not reported (Mutanen 1997).

tanen & Huhma 2001, Alapieti 2005). This event belongs to a global episode of igneous activity at the beginning of the Proterozoic that produced several layered intrusions and mafic dyke swarms on other cratons, and was, at least in Fennoscandia, related to the initial breakup of an Archaean craton (Alapieti & Lahtinen 2002, Hanski et al. 2001b, Iljina & Hanski 2005).

Mineralisation at Koitelainen is stratiform. There are two major, sulphide-free, PGE-enriched chromite reefs (**Koitelainen UC** and **Koitelainen LC,** Table 42) possibly extending across the entire intrusion, and a V-rich gabbro (**Koitelainen V**). Both of the chromite reefs are enriched in vanadium. Although the intrusion hosts a V-rich magnetite gabbro, the UC reef still is the most significant V mineralisation within the intrusion. The main V mineral in the UC and LC reefs is chromite and in the gabbro magnetite. The Koitelainen V deposit is a magnetite gabbro 40 m thick, located in the middle part of the upper third of the intrusion. The UC reef has a varying thickness of 0.8–2.2 m and, at surface, it extends along strike for 60 km. The LC reef layers occur within 60 m of the stratigraphy of the intrusion, and are known for about 20 km along strike. (Mutanen 1989, 1997)

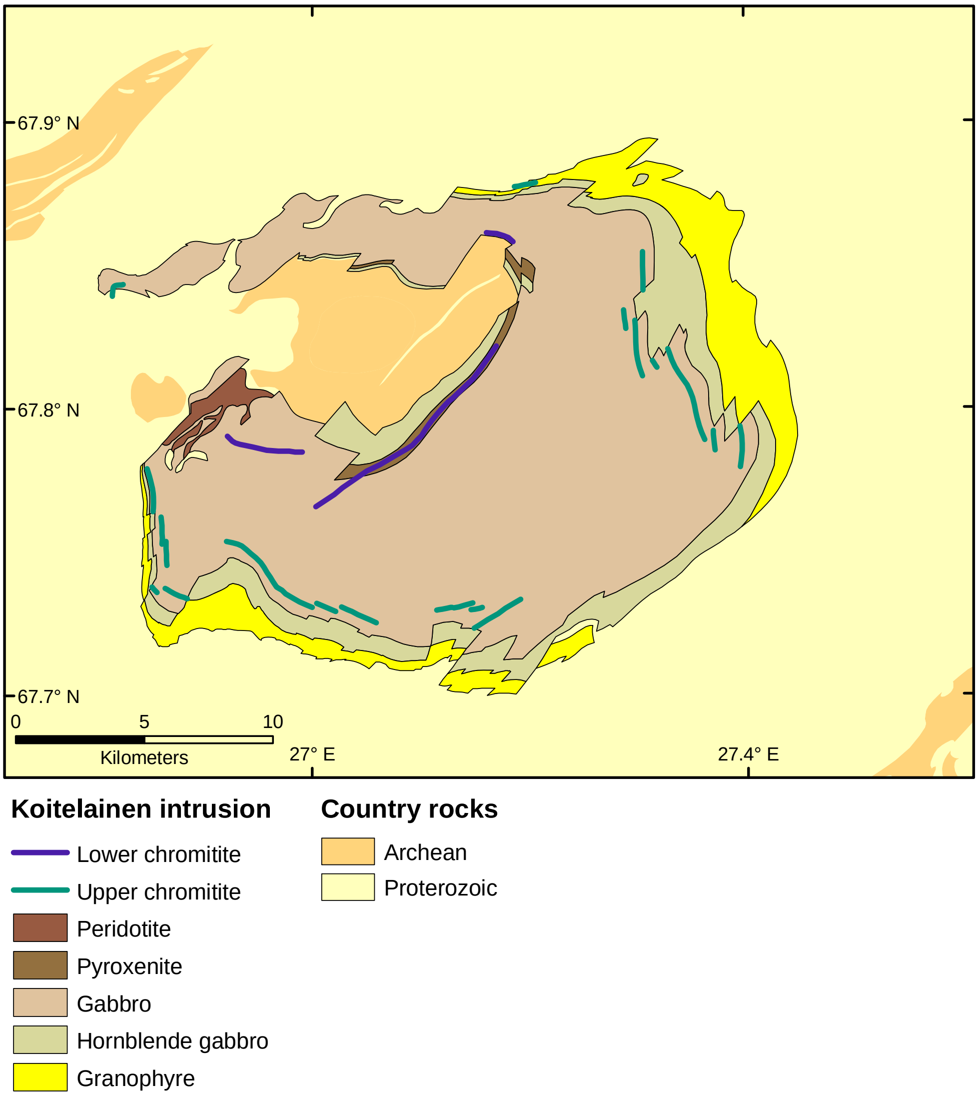

Figure 88. Geology of the Koitelainen intrusion and its immediate surroundings, after Rasilainen et al. (2010). 'Lower chromitite' and 'Upper chromitite' indicate the surface exposures of the Koitelainen LC and Koitelainen UC deposits, respectively.

F046 PYHÄJÄRVI V-Ti-Fe

Tuomo Karinen & Pasi Eilu (GTK)

The Pyhäjärvi area (F046) is located in the northern part of the Palaeoproterozoic Central Lapland greenstone belt (CLGB), almost entirely inside the Kittilä metallogenic area (F043) (Fig. 84). The extent of metallogenic area F046 is defined by the presence of V ± Ti-Fe occurrences in highly altered and deformed, medium-grained mafic rocks running along the N- to NE-trending contact of the supracrustal rocks and monzonitic intrusion (Makkonen et al. 1968, Lehto & Niiniskorpi 1977, Hugg & Heiskanen 1983). The supracrustal rocks belong to the 2.1–2.0 Ga Kittilä Group in the lithostratigraphic division of the CLGB. There is no age determination for the monzonitic intrusion, but it is assumed to belong to the 1.89–1.86 Ga Haparanda suite (Lehtonen et al. 1998).

Very little information is available on the F046 deposits (Table 43), as only minor exploration has been carried out in the area. The vanadium ore occurs as semimassive-massive oxide veins and dissemination in amphibolite. Immediately to the west of the amphibolites, there are gabbroic rocks, but there is no knowledge of how the ore is related to these gabbros; for instance, there is not enough data to show whether the ore could possibly represent residual liquid of the gabbros. Furthermore, there is no idea how the hosting amphibolite and the gabbros are related to the monzonitic intrusion. Individual vanadium ore veins are a few centimetres to 2.5 m wide. Ore bodies are 50–400 m long, 5–15 m wide and eastward gently dipping, open at depths of 100–300 m. The main ore minerals in all vanadium (± Ti-Fe) occurrences are ilmenite and magnetite, which occur disseminated and as subparallel veins in the host rock (Makkonen et al. 1968, Hugg & Heiskanen 1983). The main gangue in the ore veins is chlorite. The grades in the Pyhäjärvi occurrence (two samples from the old drill cores) have recently been checked by GTK with the following results: 0.61–0.70 % V (1.09–1.25 % V_2O_5), 10.6–11.0 % TiO_2 and 62.5–68.7 wt% Fe_2O_3 and 0.015–0.018 % Co, with no REE or precious metals detected. The grades are similar to those originally reported from these drill cores.

Table 43. The V-Ti-Fe occurrences with a reported resource within the Pyhäjärvi metallogenic area (F046).

Occurrence	Tonnage (Mt)1	Fe %	Ti %	V %	References
Kuusilaanivaara	0.25			0.4	Makkonen et al. (1968), Hugg & Heiskanen (1983)
Koivusilasselkä	0.85	25–30		0.31	Lehto & Niiniskorpi (1977), Hugg & Heiskanen (1983)
Pesosjärvi	0.70			0.22	Makkonen et al. (1968), Lehto & Niiniskorpi (1977), Hugg & Heiskanen (1983)
Pyhäjärvi	2.70*	25	3	0.4	Makkonen et al. (1968), Lehto & Niiniskorpi (1977), Hugg & Heiskanen (1983)

* Makkonen et al. (1968) suggested that the total amount of ore to the depth of 400 m could be about 6.0 Mt.

F047 RUOSSAKERO Ni

Tuomo Karinen, Jukka Konnunaho (GTK), Jan-Anders Perdahl (SGU)

The Ruossakero metallogenic area (F047) is in the northwesternmost Finland and in the adjacent part of Sweden. It is defined by the extent of the Archaean, komatiite-bearing greenstones, and the presence of layered intrusions potentially containing PGE deposits near the Archaean–Proterozoic boundary (Figs. 1 and 89).

In Finland, the metallogenic area includes two Ni-enriched domains, Ruossakero and Sarvisoaivi, where the mineral occurrences are associated to ultramafic bodies in the Archaean, komatiite-dominated greenstones. The Ruossakero domain is a zone of ultramafic komatiitic (serpentinite, dunite and minor pyroxenite) bodies 4-km-long and 1-km-wide. At Sarvisoaivi, a few km to the west of Ruossakero, the main hosting body is 700 m x 700 m wide and 200–300 m thick. Geophysical studies and bedrock mapping indicate another ultramafic body (SE-trending, about 1 km long, 3.5–35 m thick) within the Sarvisoaivi domain (Isomaa 1982).

The Ruossakero nickel deposit has a surface extension of 340 m x 100 m and a thickness of 100 m. Isomaa (1988) estimated that the deposit hosts 5.44 Mt @ 0.53 % Ni (cut off at 0.4 wt%). The preliminary feasibility study in 1996 suggested an open-pittable 1.6 Mt @ 0.61 % Ni (0.5 % Ni cut off) (Lahtinen 1996). At 0.3 % Ni cut off, the deposit could be 35.6 Mt with 0.42 % or 0.33 % Ni, depending on calculation method used (Lahtinen 1996). Pyrite and millerite are the principal ore minerals in the deposit. They occur as dissemination together with minor chalcopyrite in three distinct subzones that vary in thickness from 4 to 42 metres (average thickness 24 m).

To the south, several mafic-ultramafic bodies have been found within the poorly explored Archaean province north of Kiruna in Sweden, but no mineral resource estimates have been made for them. A few of these are within the domain of metallogenic area F047. One of the largest intrusions is Kurkovare, being at least 6 km long and up to 940 m wide. The intrusion is mainly medium-grained consisting of anthophyllite, tremolite, chlorite, talc, olivine and serpentine. The northernmost part is altered to soapstone. The magnesium content varies between 30 and 40 % MgO, nickel between 0.10 and 0.38 % Ni (mainly silica bonded), and chromium between 0.4 and 2.4 % with an average of 0.78 % Cr (Lilljequist 1980). Geophysical surveys suggest the presence of additional mafic-ultramafic intrusions in the neighbourhood, within the Swedish part of area F047.

The relationship between the intrusions and the known komatiitic volcanic rocks is unclear for most cases within the Ruossakero metallogenic area. However, the presence of the 2.44 Ga Kaamajoki-Tshokkoaivi layered intrusion in the Finnish part (Heikura et al. 2004) indicates that not all Ni-Co-(PGE) potential of the area F047 is confined to Archaean komatiites.

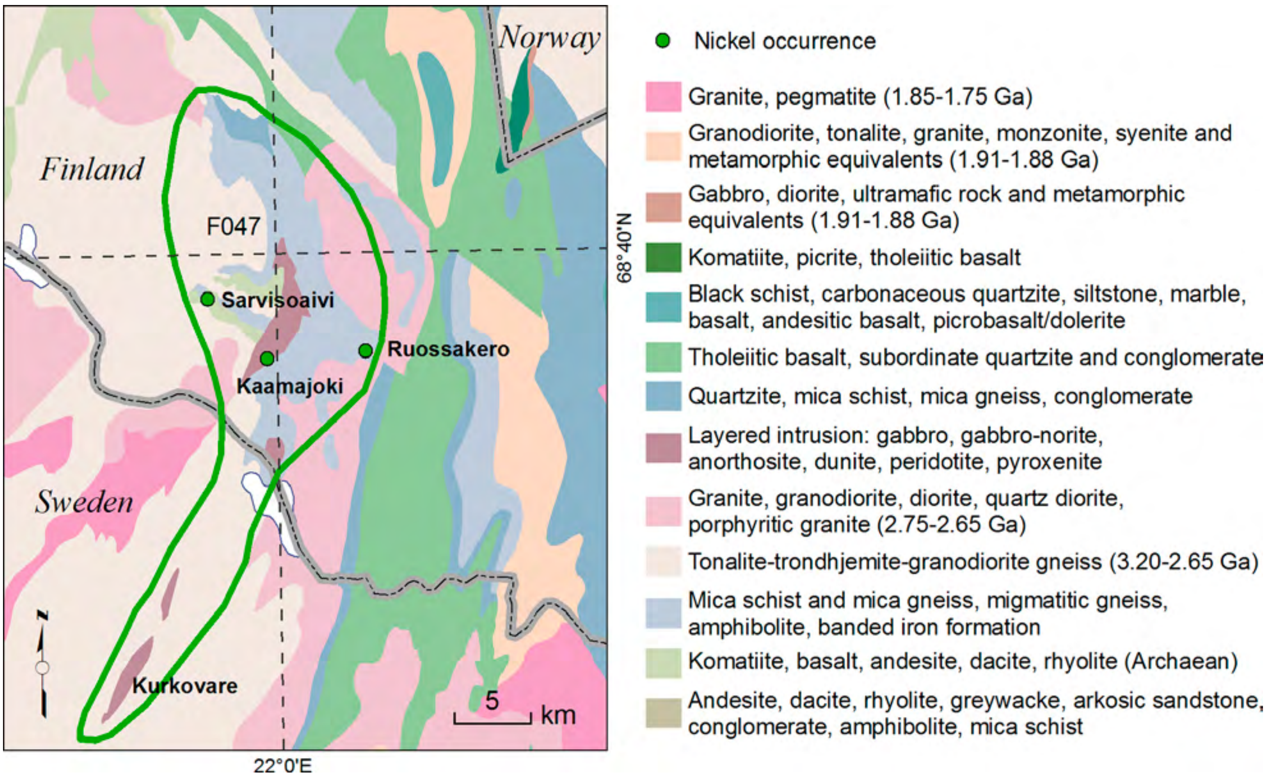

Figure 89. Geological map of the Ruossakero metallogenic area (F047). Geology based on Koistinen et al. (2001).

F048 SATTASVAARA Ni

Jorma Räsänen (GTK)

The Sattasvaara metallogenic area (F048) is in the central part of Central Lapland greenstone belt (CLGB), where it covers the essential parts of the Sattasvaara Formation (Figs. 1 and 90). The Sattasvaara Formation is composed of komatiites and picrites constituting the upper part of the Savukoski Group, whereas the lower part is dominated by graphite- and sulphide-bearing schists of the Matarakoski Formation, which includes the first manifestation of extensive black schists in the Palaeoproterozoic lithostratigraphy of the Central Lapland greenstone belt (Räsänen et al. 1995). According to mineral assemblages (amphibole+cholorite±biotite), the rocks of area F048 are metamorphosed under greenschist-facies conditions and, though their primary mineralogy is changed, primary volcanic textures and structures are well preserved.

The general outline of the CLGB is given by Hanski and Huhma (2005) and in the description of the Kittilä area (F043). The Sattasvaara Formation comprises ultramafic and mafic komatiites and minor basalts, which lie on the sulphide-rich black schists of the approximately 2.15–2.05 Ga Matarakoski Formation (e.g. Saverikko 1985, Korkiakoski 1992, Lehtonen et al. 1998, Räsänen 1996, 2005). In the Sattasvaara metallogenic area, komatiites occur in an E-trending synclinal structure nearly 10 km wide and 40 km long. A large proportion of the volcanic rocks are pillow lavas and fragmental rocks, but massive lava flows and sill-like ultramafic to mafic cumulates are also present. So far, there are no reliable radiometric age data for the volcanic rocks of the Sattasvaara Formation, but one of its branches continues far into northern Norway, where Krill et al. (1985) have reported a Sm-Nd age of 2085 ± 85 Ma from the komatiites. The Kevitsa mafic-ultramafic intrusion is enclosed by sulphide-bearing black schists of the Matarakoski Formation immediately to the east of area F048 (Fig. 90), and yields an age of about 2050 Ma (Sm-Nd 2052 ± 25 Ma and U-Pb 2057 ± 5 Ma; Huhma et al. 1996, Mutanen 1997).

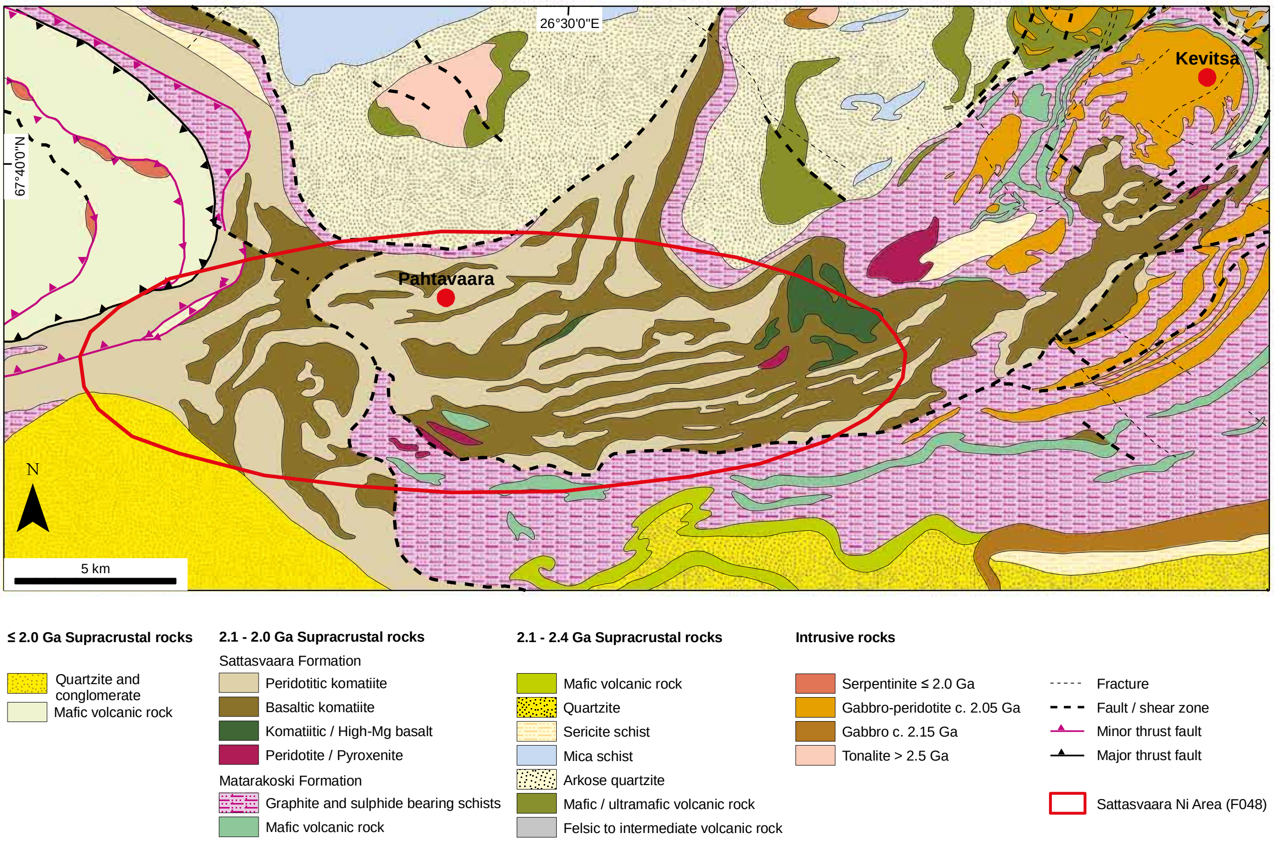

Figure 90. Sattasvaara metallogenic area (F048) in the Central Lapland greenstone belt. Geology simplified from the GTK digital bedrock map database. For reference, the locations of the Pahtavaara gold mine (Fig. 84) and the intrusion-hosted Kevitsa Ni-Cu-PGE mine are also shown.

The presence of abundant komatiites with underlying sulphidic schists in area F048 suggests a significant potential for komatiite-hosted Ni (±Cu±PGE) mineralisation. On GTK's geochemical maps (Salminen 1995), the komatiite area shows a distinct Ni anomaly which on low-altitude airborne geophysical maps appears as a high magnetic anomaly surrounded by a high electromagnetic anomaly which, for one, is induced by schists. The schists providing an important stratigraphic key horizon compose the Matarakoski Formation, which is a complex volcano-sedimentary sequence including sulphide-rich black schists, quartzites and greywacke-like schists with felsic to intermediate volcanic rocks. It also contains mafic volcanic rocks. These are intruded by sill-like ultramafic to mafic cumulates and overlain by komatiites of the Sattasvaara Formation, which form a comagmatic suite ranging from peridotitic komatiites to more evolved basaltic komatiites and komatiitic/high-Mg basalts (7–37 % MgO, 0.2–1.3 % TiO_2), also including Ti-rich volcanic rocks classified as picrites (12–18 % MgO, 1.5–2.0 % TiO_2), and named as a komatiite-picrite association by Hanski et al. (2001c). This rock association is highly potential for Ni mineralisation. It broadly resembles the roughly coeval Proterozoic rocks of the Cape Smith Belt in Canada, where several komatiite-hosted Ni (±Cu±PGE) deposits have been found in the Raglan Formation (e.g., Arndt 1982, St-Onge & Lucas 1994, Lesher 1999, Jowitt et al. 2010). Moreover, sulphidic sedimentary and felsic to intermediate volcanic rocks constitute substrates to the Proterozoic Ni deposits at Pechenga in north-west Russia (e.g., Abzalov & Both 1997, Barnes et al. 2001, Foster 2003), and to the Archaean komatiite-hosted nickel sulphide deposits in Western Australia (e.g. Groves et al. 1986, Frost & Groves 1989, Cowden & Roberts 1990, Lesher & Arndt 1995, Fiorentini et al. 2006).

No nickel sulphide deposit with a resource has so far been reported from the Sattasvaara area. However, there is a large disseminated Ni-Cu-PGE deposit in the **Kevitsa** mafic-ultramafic intrusion, which lies in the same lithology as the volcanic rocks of the Sattasvaara Formation (Fig. 90), although not considered as comagmatic with the Sattasvaara komatiites. The mineral resource at Kevitsa is 275 Mt @ 0.3 % Ni, 0.41 % Cu, 0.015 % Co, 0.15 g/t Pd, 0.2 g/t Pt and 0.11 g/t Au (First Quantum Minerals 2011). In addition, there is the recent ultramafic-hosted Ni-Cu discovery at **Sakatti**, to the SE of area F048 (Coppard 2011).

SIGNIFICANT DEPOSITS NOT INCLUDED IN ANY METALLOGENIC AREA

Pasi Eilu (GTK)

There are two significant mineral deposits in Finland that could not be connected to any metallogenic areas described above. These are briefly described in this section.

The **Korsnäs** Pb-REE deposit in westernmost Finland is geographically inside the Oravainen Ni Area (F017). Korsnäs is a unique deposit hosted by a large, N-trending, calcite-diopside-barite-fluorite-allanite vein (or a carbonatite dyke) that cuts the local Svecofennian mica gneisses (Isokangas 1978). It was mined between 1959 and 1972 and yielded some 0.87 Mt of ore averaging 3.6 % Pb. Allanite and a few other REE minerals (Papunen & Lindsjö 1972) also made the deposit prospective for REE. During the pilot production of an REE concentrate, the ore proved to contain 0.83 % RE_2O_3. In the immediate vicinity of the Korsnäs mine there is also a group of unexploited, 1–20-m-wide carbonate veins or dykes that may contain significant REE grades (Rehtijärvi & Kinnunen 1979).

The **Akanvaara** Cr-V-Ti-PGE deposit has an analogous geological setting and internal structure to that of Koitelainen (F045). It is hosted by a mafic layered intrusion, with a surface area of about 50 km^2 (Fig. 83). Structurally, it is a block-faulted monocline with a general dip towards the southeast. The immediate floor consists of felsic volcanic rocks, and the lowermost exposed roof rocks are felsic volcanic rocks. The intrusion hosts Cr, V, Ti, PGE and Au occurrences. At least 23 chromitite layers and numerous chromitite bands of uncertain continuity have been located. The thickness of the chromitite layers and sub-layers ranges from a few centimetres up to 3 metres, and they define three potentially large deposits (Mutanen 1998). Chromitites with proven metallurgical properties and substantial amounts of vanadium also contain a range of complex platinum-group mineral associations (Mutanen 1997, 1998, 2005, Alapieti & Lahtinen 2002). U-Pb analyses of zircons from the Akanvaara gabbroic rocks give an age of 2436 Ma, whereas the granophyre cap has an age of 2420 Ma (Mutanen & Huhma 2001). The Os and Nd isotopic systematics of the intrusion point to the existence of coeval, crustally contaminated komatiitic volcanism (Hanski et al. 2001b).

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