25th International Applied Geochemistry Symposium
22 - 26 August 2011
Rovaniemi FINLAND

FIELD EXCURSION

Care of mine districts and the environment after closure of mines

25th IAGS2011

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Excursion guide, 18 - 20 August 2011

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Edited by Teemu Karlsson and Marja Liisa Räisänen

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Care of mine districts and the environment after closure of mines

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Abstract

The Finnish mining industry lives its upswing. At the same time with the gradually increasing mining activities in Finland, the need of post-treatment of closed mines and related environmental issues of operating ones are becoming more and more important. This field trip includes visits to old and active mining areas, and looks at their baseline studies, monitoring, after-care, environmental changes and geochemistry before and after the mining operations.

The reopened Luikonlahti mining area is an interesting example of the cyclic life of some mine sites. Besides the original Cu-ore waste, the tailings site contains a layer of more recent talc ore processing residue, which will be topped again when the concentrating plant processes ore from the nearby Kylylahti copper mine. An example of passive treatment for tailings effluents will be provided as well as an overview of the concentration process and the Kylylahti mine.

The copper plays a major role also in the Outokumpu area, which is well known for the closed copper mine, once the biggest in Europe. The old tailings site of Keretti has been covered and is now used as a golf course. Besides getting acquainted with the after treatment and history of the Outokumpu mine, also the GSF Mineral Processing Laboratory will be visited for their environmental research.

Additional examples of mine care will be provided in Sotkamo. The Talvivaara Ni-mine presents the newest generation of Finnish mines. The bioheap leaching technique used to extract metals from the ore, together with the planned uranium recovery, require a careful observing of the environmental issues and a modern environmental monitoring system. Another example of large scale mining activity integrated with environmental care is the Lahnaslampi talc mine, which is the biggest single talc producing unit in the world.

Further insight for the closed mines will be presented in Taivalkoski. Vanadium is not currently mined in Finland and one of the two closed vanadium mines is the Mustavaara mine. While the landscaping of the old mine is yet unfinished, there has been activity to reopen it.

To increase the different ways to enjoy the clean nature, the Geological Survey of Finland has been publishing geological hiking maps. The most recent publication concerns the Syöte area, which will be the topic of the last part of the excursion. Besides the normal useful information for hikers, a geological hiking map contains insight for the soil types, natural formations and geological sights.

Excursion program and route

Thursday, 18th August
Departure from Kuopio GTK at 9 am, the bus will go via the airport and the centre of the city if necessary.

Target 1. Luikonlahti old Co-mine, Altona Mining Ltd, Kaavi. Once closed and re-opened Luikonlahti mining district where we will get acquainted especially with the passive treatment system.

Target 2. Kylylahti Co-mine, Altona Mining Ltd, Polvijärvi. A recently opened copper mine.

Target 3. Mineral Processing Laboratory, Geological Survey of Finland, Outokumpu (Mintek). The GTK geolaboratory is a leading European facility hosting chemical, isotope, mineral research and mineral processing laboratories and a pilot plant.

Target 4. The Outokumpu mining district, Outokumpu. Getting acquainted with the after treatment and history of the Outokumpu Co-mine (the Keretti mine).

Dinner at Outokumpu Mining Museum, overnight at the Hotel Malmikumpu in Outokumpu.

Friday, 19th August
Target 5: Talvivaara Ni-mine, Talvivaara Mining Company Plc., Sotkamo. The modern Talvivaara mine presents the newest generation of Finnish mines. The environmental issues related to bioheap leaching and planned uranium recovery will be presented.

Target 6: Lahnaslampi talc-mine, Mondo Minerals, Sotkamo. The biggest single talc producing unit in the world.

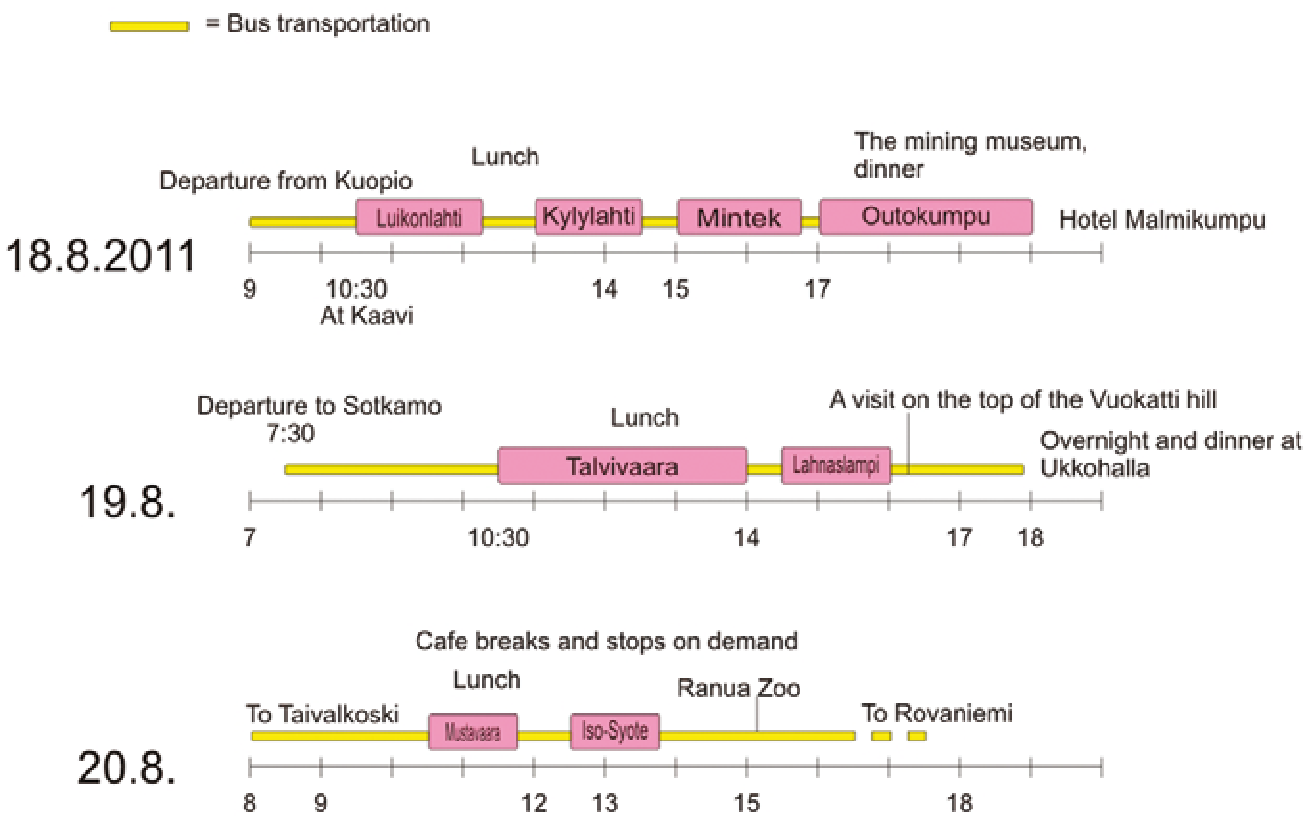
Overnight and dinner at Ukkohalla in Hyrynsalmi.

Saturday, 20th August
Target 7: Mustavaara V-mine, Taivalkoski. One of the two closed vanadium mines in Finland. The landscaping of the old mine is yet not done, there has been activity to reopen the mine.

Target 8: Iso-Syöte and the Syöte national park. An introduction to the GTK's geological outdoor maps and the Iso-Syöte, the most southern fell of Finland.

Arrival to Rovaniemi at evening, the people will be taken to their hotels.

Outline of the excursion:



Weather and clothing:
Weather in August can vary considerably - the temperature range is in between 10 to 25ºC, being typically around 15-20ºC in daytime. It is recommended that one should have a weatherproof jacket in case of rain.

Although the field targets are generally easily accessed, one could have hiking type boots. Hard hats and safety classes are provided by the companies if necessary.

SAFETY INSTRUCTIONS:

The instructions of your guides and hosts MUST be followed at all times. Be aware of loose boulders in the waste rock piles and open cut walls. Be aware of heavy machinery, safety equipment provided by the companies must be worn all the time.

Mobile numbers of your guides:

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Introduction

Teemu Karlsson
Geological Survey of Finland

The Finnish mining industry has a long history spanning to the first iron mines in the 16th century. During the years, about 1000 mines have been in operation (Puustinen 2003). Today the Finnish mining industry lives its upswing. The tonnages of excavated mineral material have rocketed from 29.8 Mt in 2005 to 71.5 Mt in 2010. Last year (2010) there were about 50 mines operating in Finland, of which 10 were mining metallic ores.

Mining activities tend to have an effect on the surrounding environment. At the same time with the gradually increasing mining activities in Finland, the need of post-treatment of closed mines and related environmental issues of operating ones are becoming more and more important. The mining companies are obligated to use the best available techniques and environmental practices to prevent negative impact on the environment.

The mining life-cycle is usually divided into three main stages, namely exploration, production and rehabilitation, of which the production-phase has typically the most significant effect on the environment. The rehabilitation-phase after mining activities is intended to ensure safety and to minimize potential negative environmental impacts of the closed mine. The changes a mine causes in the surrounding environment are site-specific and depend on the nature of the ore, mining and processing methods and the size, geometry and location of the deposit. (Heikkinen et al. 2008)

This field trip includes visits to old and active mining areas in eastern Finland, and looks at their baseline studies, monitoring, after-care, environmental changes and geochemistry before and after the mining operations. The excursion targets are presented in Figure 1.

The first day is devoted to the copper-related mining activity in the Outokumpu type formations; the already once closed and re-opened Luikonlahti mining district, the recently opened Kylylahti mine, and the old rehabilitated Outokumpu mine. Besides getting acquainted with the after treatment and history of the Outokumpu mine, also the GTK Mineral Processing Laboratory in Outokumpu will be visited for their environmental research.

The second day includes two large scale mines: the Talvivaara Ni-mine and the Lahnaslampi talc-mine, both situated in Sotkamo in the province of Kainuu, some 150 km north from the first day targets. The Talvivaara Ni-mine presents the newest generation of Finnish mines. The bioheap leaching technique used to extract metals from the ore, together with the planned uranium recovery, require a careful observing of the environmental issues and a modern environmental monitoring system. The Talvivaara is the biggest excavator of the Finnish mines with a total tonnage of 30 Mt in 2010 (Materia 2011). Another example of a large scale mining activity integrated with environmental care is the Lahnaslampi talc mine, which is the biggest single talc producing unit in the world.

The last day includes a visit to the closed vanadium mine of Mustavaara, situated in Taivalkoski municipality. Vanadium is not currently mined in Finland and one of the two closed vanadium mines is the Mustavaara mine. While the landscaping of the old mine is yet unfinished, there has been activity to reopen it.

The last day will also offer an introduction to the GTK's geological outdoor maps, the Syöte national park and the most southern fell, an arctic hill, of Finland, Iso-Syöte.

An overview of the geological settings of Finland

Finland occupies the central part of the Precambrian Fennoscandian Shield, which is one of the oldest parts of the Eurasian continent. Finland is located on the main part of the transitional zone between dominantly Archaean and dominantly Palaeoproterozoic rocks (Fig. 2). The time span of the rich variety of geological conditions which led to formation of the bedrock of Finland ranges from c. 3000 Ma (the oldest granitoids in the north) to 1600 Ma (large rapakivi bodies in the south). The Finnish bedrock contains many different types of ore provinces, industrial mineral occurrences and useful rock materials, for example the Palaeoproterozoic rifting and subsidence of the Karelian craton margin -related formations of finer-grained graphic schists which host the extensive low grade Talvivaara nickel deposit, and the also Palaeoproterozoic ophiolite-related Cu-Co-Zn deposits of the Outokumpu region. (Korsman et al. 1997)

The surficial deposits in Finland are relatively young, formed mainly during the last glaciation or thereafter as a result of various geological processes, like the phased retreating of the glacier, and the uplift of land which is still going on today. These deposits have considerable economic importance as a source of raw materials (e.g. gravel, peat), a substratum for renewable natural resources (agriculture, forestry) and a reservoir of groundwater. Therefore they should be treated with care and used rationally and appropriately. The glacial deposits in the excursion zone, as well as in the whole Finland,

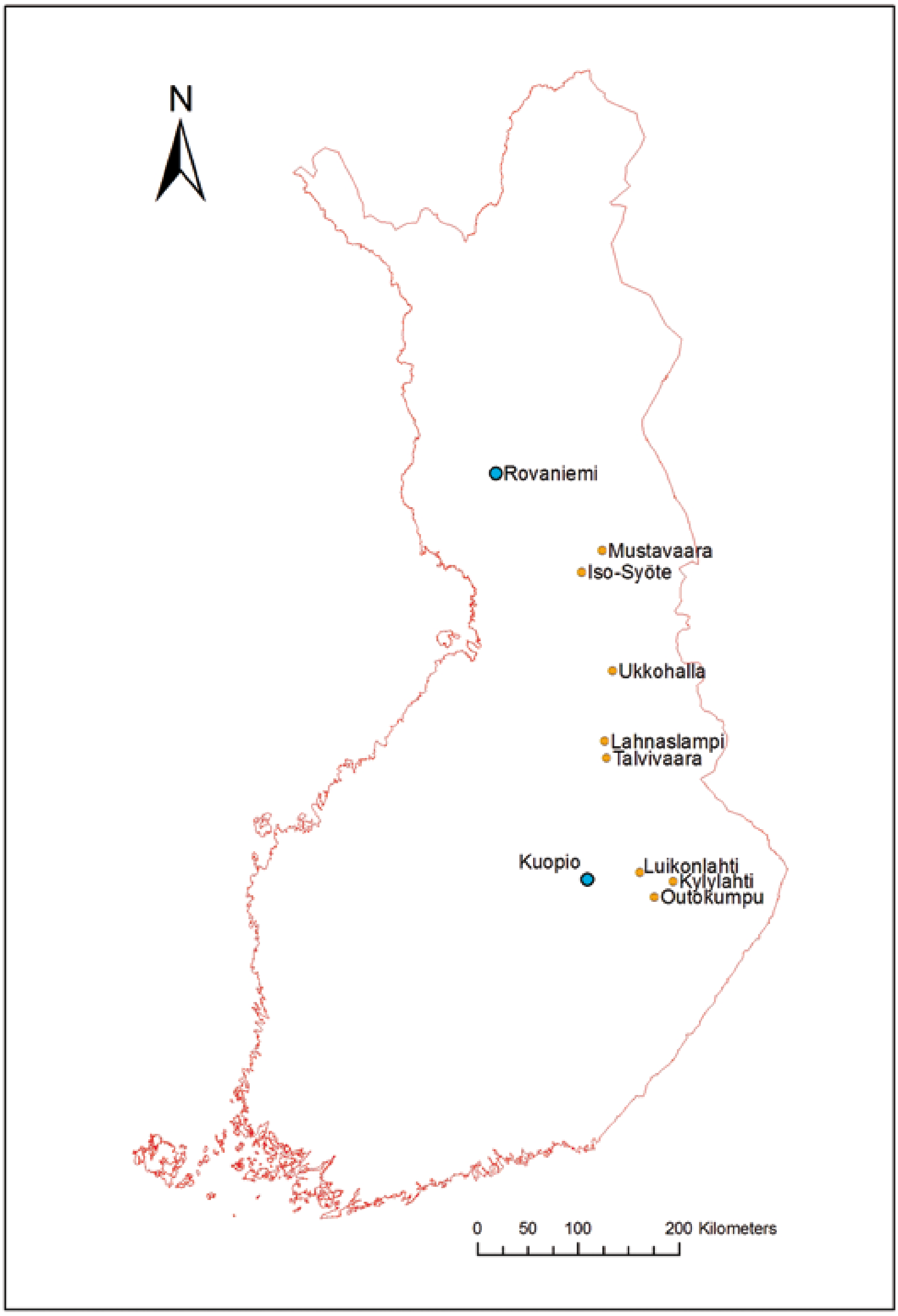


Fig. 1. Figure 1: The excursion targets. Basemap: © National Land Survey of Finland, licence no 13/MML/11, Logica Suomi Oy.

consist mainly of till, of which most is sandy. Other important surficial deposits are end moraines, glaciofluvial formations (e.g. eskers), peat deposits and shore formations. (Eronen et al. 1990) The mean rainfall in eastern Finland varies from 600 to 700 mm / year with a distinctive seasonal variation in precipitation, with the driest season in spring(March-April) and the heaviest rains in late spring and summer (May-July). From December to April the land is covered by snow and the temperatures remain generally below zero. (Räisänen 2009)

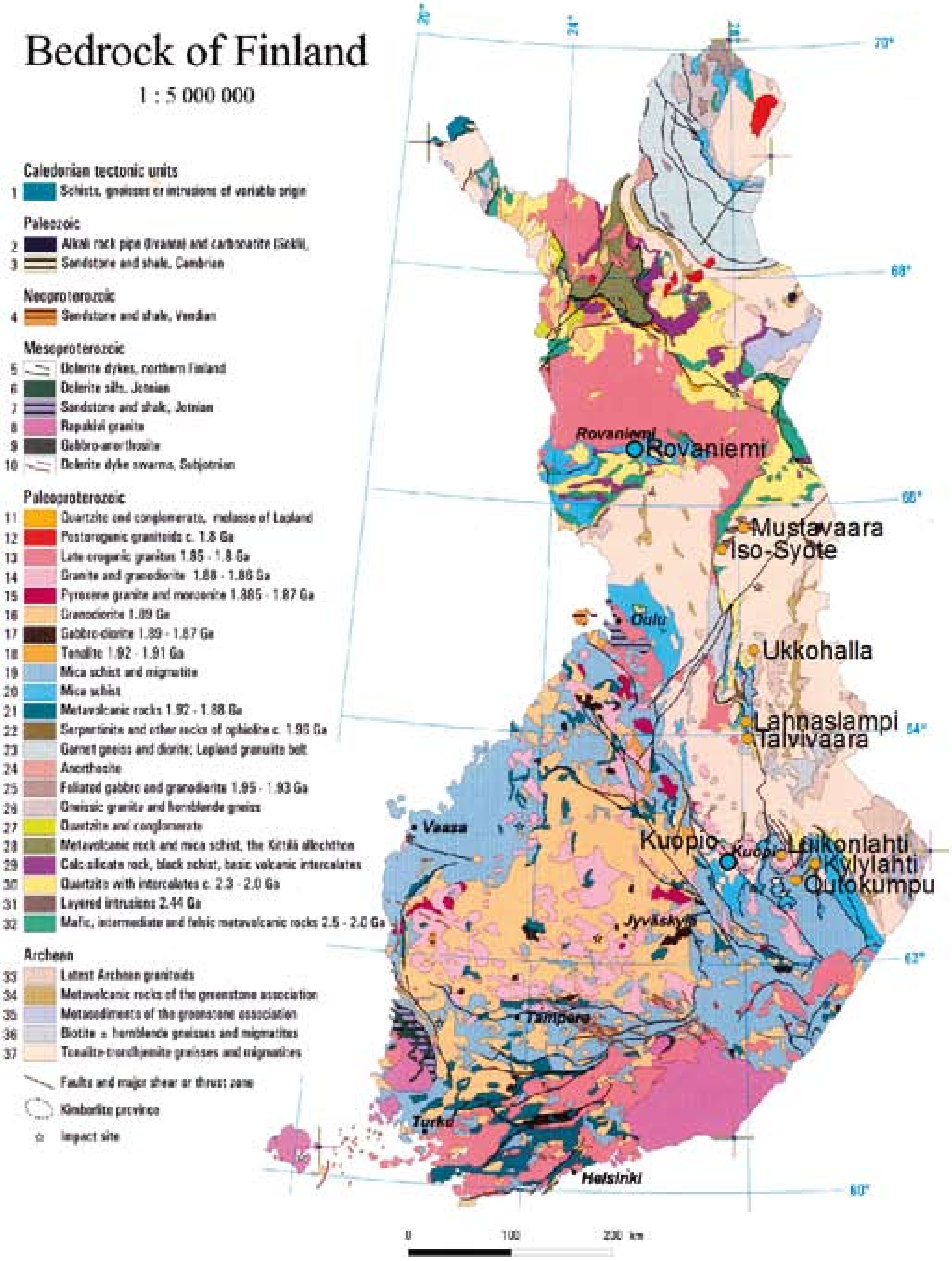


Fig. 2: Bedrock of Finland. Geological Survey of Finland 1999.

1. Luikonlahti

Teemu Karlsson
Geological Survey of Finland

Marja Liisa Räisänen
Centre for Economic Development, Transport and the Environment

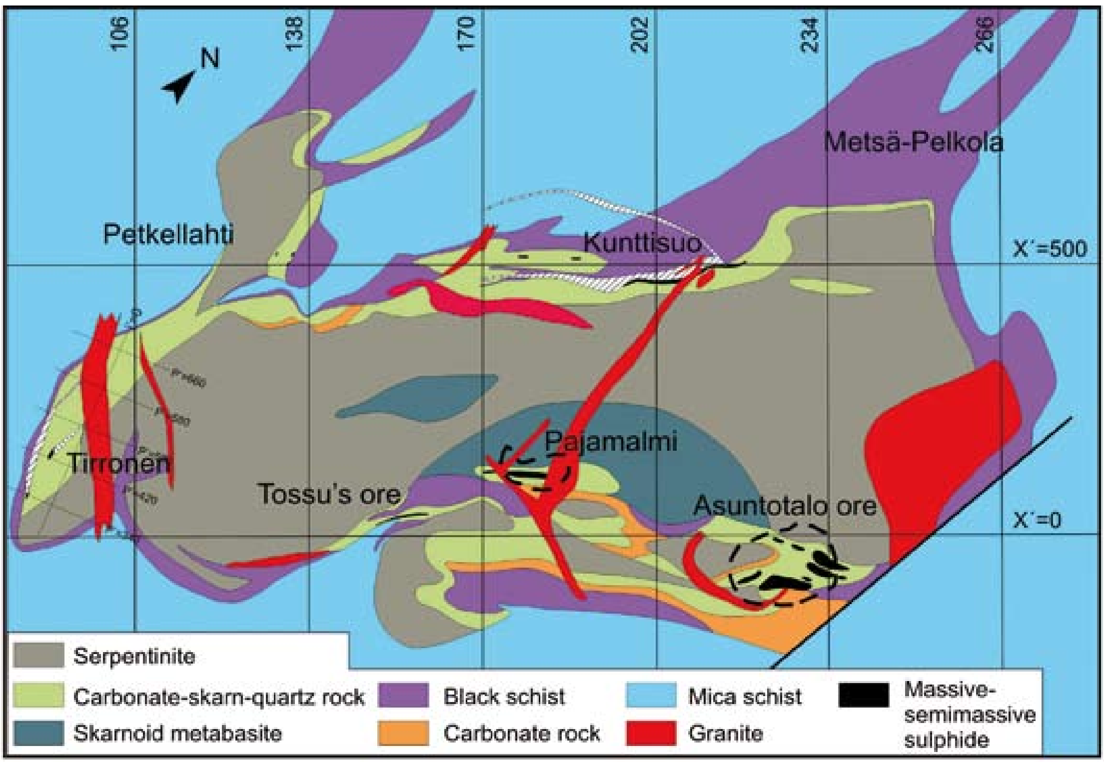
Target guides: Marja Liisa Räisänen (Centre for Economic Development, Transport and the Environment), Mikko Keränen (Altona Mining Ltd)

The Luikonlahti mining area is located in the Kaavi municipality in eastern Finland. The Luikonlahti area was first claimed in 1910, but the first indication of a possibly economic copper mineralization was found in 1929 by the Geological Commission of Finland. Next year a small massive Cu-deposit called the Pajamalmi ore was found. The main ore body, called the Asuntotalo ore, was not found until 1944. Extensive research and test mining were carried out after the World War II, but insufficient tonnages and remote location caused all exploration activity to be suspended for the next ten years. When the exploration started again, this time with better techniques, it was found that the ore body continued at depth, while two additional smaller ore bodies were also discovered. The dimensions of the main ore were maximum width 80 m, depth 480 m and length 700 m. The dip of the ore body was almost vertical, allowing the use of low cost mining meth ods. (Loukola-Ruskeeniemi and Sorjonen-Ward 1997, Eskelinen et al. 1983). The geological map of the Luikonlahti area is presented in Fig. 3 as well as the locations of the ores. The Luikonlahti area is part of the same tectonostratigraphic sequence and shares many of the distinctive characteristics of the Outokumpu-type massive sulphide deposits (Loukola-Ruskeeniemi and Sorjonen-Ward 1997).

After mine development, construction of railroads, power lines, roads and other infra-structure, the mining operations started as open pit mining at Asuntotalo ore in 1968 and moved to underground in 1971. The smaller Kunttisuo and Pajamalmi ores were mined in 1980 – 1983. The mining activities at the Luikonlahti mine were ended in 1983. (Eskelinen et al. 1983).

The Luikonlahti Cu-Co-Zn deposit consists of three ore bodies of which the Asuntotalo is the greatest. From these three ore bodies a total of 7.7 Mt ore was mined containing on average 1.1 % Cu, 0.1 % Co, 0.6 % Zn and 18 % S (Eskelinen et al. 1983). The metal production at Luikonlahti ceased in 1983, but talc production that started in 1979 continued up to 2006. Besides the talc, a nickel concentrate was produced from the talc ore when feasible (Räisänen 2009). The Luikonlahti processing plant was purchased by the Altona Mining in 2010 to process ore from the Kylylahti mine (Vesanto 2010).

Fig. 3: Geological map of the Luikonlahti area (from Kontinen et al. 2006).



The Luikonlahti tailings impoundment is situated in the drained Lake Petkellampi (Fig. 4), and covers ca. 27 ha in formerly glaciated terrain with silt and till. The base of the impoundment contains approximately 6 Mt of sulfide tailings which are overlain by 2.5 Mt of magnesite-rich tailings from the talc production (Räisänen and Juntunen 2004). The talc tailings will be covered again and the tailings impoundment expanded when the Luikonlahti concentration plant starts to process ore from the recently opened Kylylahti copper mine in 2012. The waste rock piles are located north of the tailings impoundment as shown in Fig. 4. The oldest sulfide tailings contain mainly quartz and iron sulphides and variable amounts of talc, chlorite, calcite, diopside, graphite, sphalerite, chalcopyrite and pentlandite. The pH varies from 3.5 – 4.5 (oxidized tailings) to 6.5 – 8.7 (water saturated, unoxidized tailings). The magnesite-rich tailings, originated from the talc production, contain mainly magnesite, talc, chlorite, micas and minor amount of iron, nickel and arsenic sulphides. The pH varies from 6.5 to 7.5, which reflects the low content of acid generating minerals and high content of buffering carbonate minerals. The total element concentrations of these two different tailings types are presented in the Table 1. (Räisänen and Juntunen 2004).

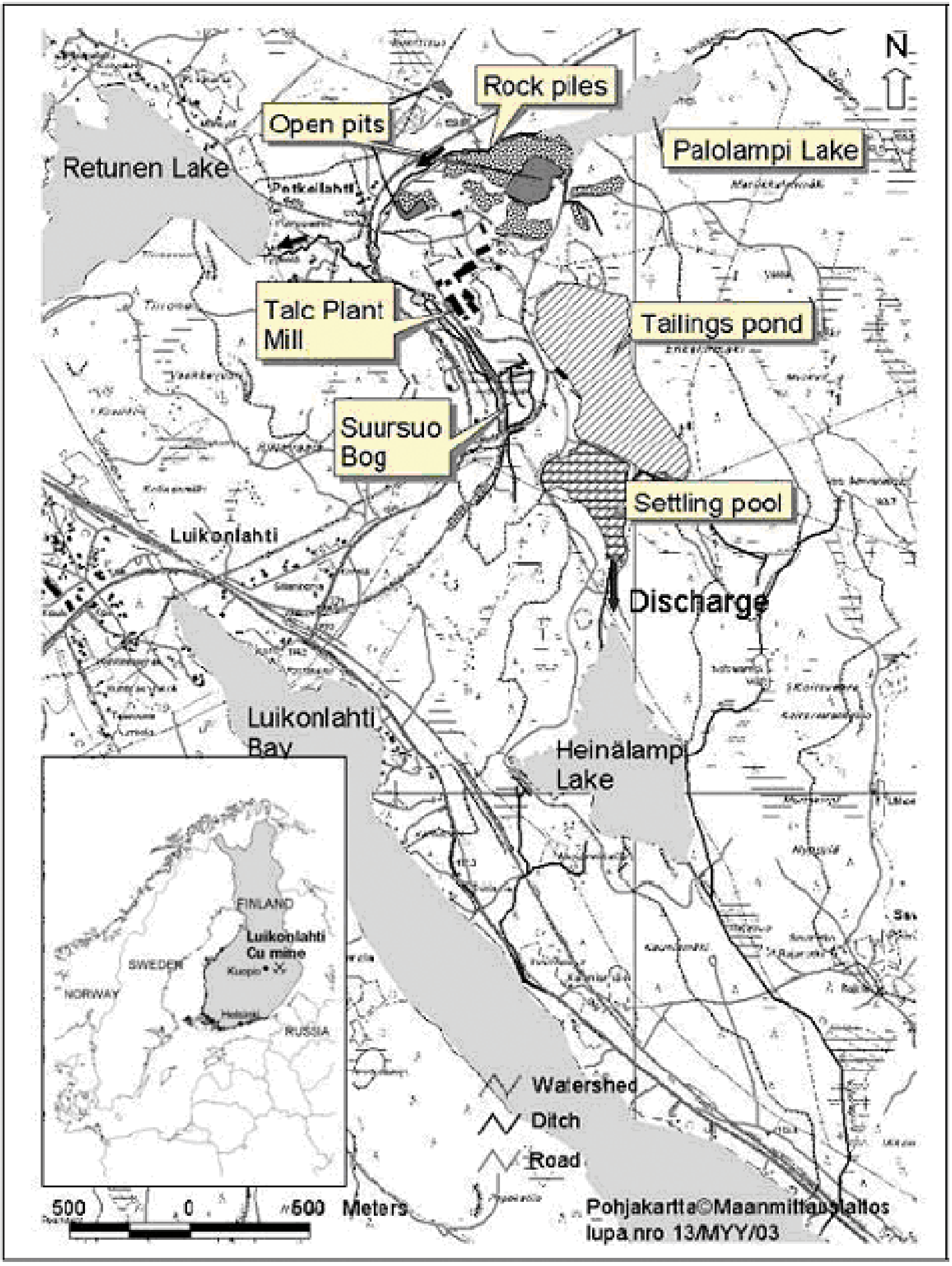


Fig. 4: Location of the Luikonlahti copper mine and the mine site. Basemap: © National Land Survey of Finland, licence no 13/MML/11, Logica Suomi Oy. (Räisänen 2005).

Table 1: Total element concentrations of magnesite and pyritic tailings in the Luikonlahti tailings impoundment. Key: "<" concentration under the detection limit, "-" no measurement. (Räsänen and Juntunen 2004).

		Magnesite tailings (upper layer)	Pyritic tailings, unoxidized	Pyritic tailings, oxidized
Fe	g/kg	52	109	145
S	g/kg	10	70	97
As	mg/kg	83	<20	<20 (max 35)
Cd	mg/kg	0.8	4.0	4.4
Co	mg/kg	57	369	497
Cr	mg/kg	196	82	36
Cu	mg/kg	37	836	1228
Mn	mg/kg	954	481	345
Ni	mg/kg	960	392	610
Zn	mg/kg	117	3211	3764
C	g/kg	87	-	-
Si	g/kg	98	318	-
Al	g/kg	4.9	16	-
Mg	g/kg	224	45	-
Ca	g/kg	20	50	-
Na	g/kg	<0.5	4.7	-
K	g/kg	0.1	4.7	-
Ti	g/kg	0.5	0.8	-

The decommissioning of the facility included the thickening of the magnesite-rich tailings and flooding to retard the sulfide oxidation (Räisänen and Juntunen, 2004). The purification of the leachate from the impoundment was based on a peat-limestone-based wetland-type passive system (see Fig. 5). The covering of the acid generating tailings with alkaline (magnesite-rich) tailings had the greatest impact on leachate purification in the short-term, compared with the passive treatment system. The net acidic seepage from the oxidized sulfide tailings changed to net alkaline and consequently, concentrations of metals variably reduced from 70% to 99%, depending on the seepage point (Heikkinen et al. 2009, Räisänen 2009). Moreover, the seepage changed from oxidative to reductive (negative pe) thus maintaining Fe dissolution. This results in the quick oxidation of Fe and precipitation of Fe oxyhydroxides in the constructed pond. In 2010, findings showed that the dense vegetation spread close to ponds' outlets effectively promotes sedimentation of precipitates and also retention of metals. However, sulfate reduction and precipitation of Fe and trace metal sulfide have not reached equilibrium in three years' period of passive treatment leading to lower retention rate of sulfate than Fe.

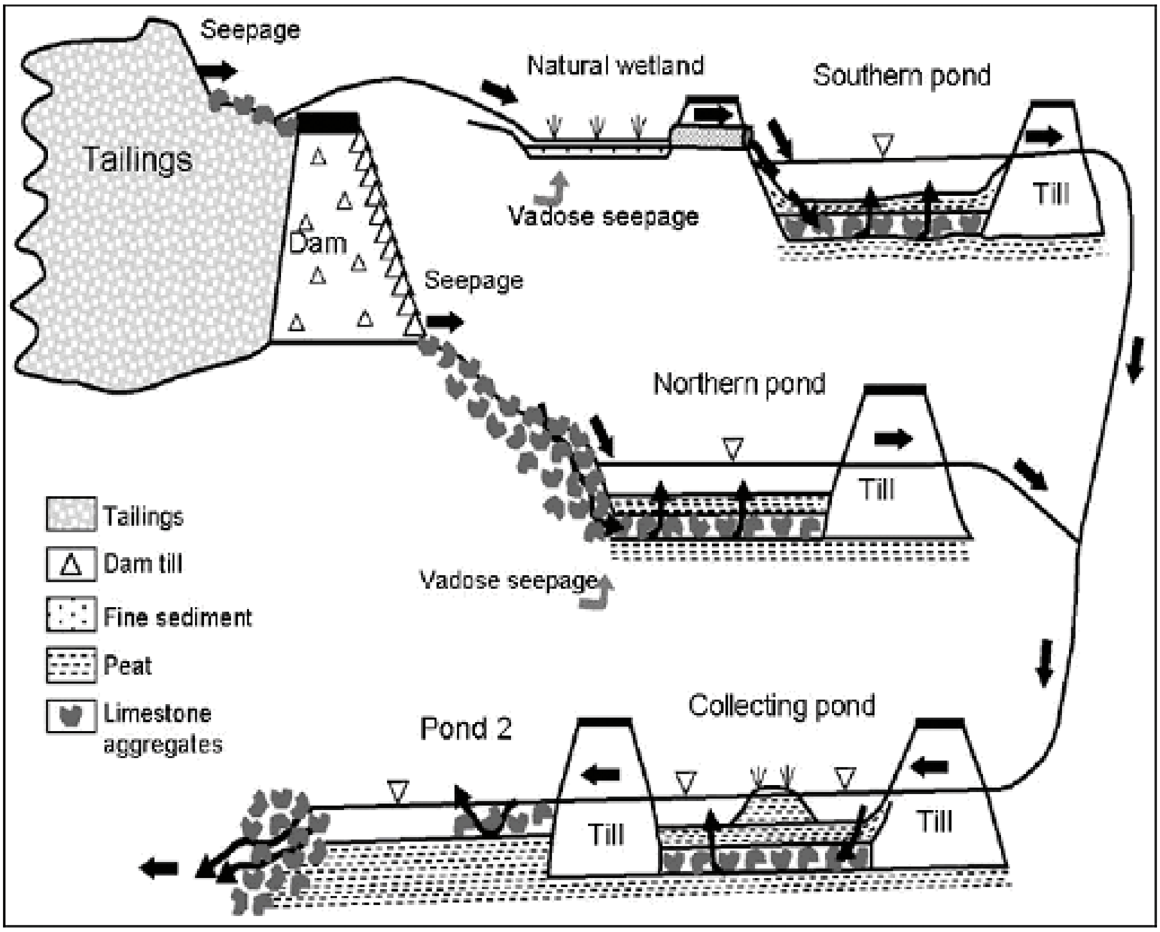


Fig. 5. The seepage sites and the Suursuo passive treatment system at the Luikonlahti area (Räisänen 2009).

2. Kylylahti

Teemu Karlsson
Geological Survey of Finland

Target guide: Seppo Tuovinen (Altona Mining Ltd)

The Kylylahti deposit, located in Polvijärvi municipality, was discovered by the Outokumpu Oy in 1984. During the first active exploration phase in 1983–1986 the deep ore body was intersected by drilling, but the investigations came to a conclusion in 1986 when Outokumpu Oy decided to discontinue cobalt production and processing. During the second active exploration phase between 1994–1995, the surface extension of the deeper ore body was identified, as well as further extensions to the disseminated sulphide envelope, resulting in an increase in the estimated reserves (Loukola-Ruskeeniemi and Sorjonen-Ward 1997). The mining operations have been delayed until now. The recent owner, Altona Mining Ltd, has started building the underground mine site infrastructure in 2010 and the mine should be in full operation in 2012 (Vesanto 2010).

The ore is hosted within a package of serpentinite, talc-carbonate, tremolite skarn and quartz rocks. The tremolite skarn-quartz rock-sulphide assemblage was born by metasomatic alteration of ultramafic rocks and is a part of the Palaeoproterozoic Jormua-Outokumpu thrust belt (Peltonen et al. 2008). At the contact of these rocks and sulphidic black schists formed the Kylylahti mineralisation (Vulcan Resources 2009). The mineralizations are confined within SSW-NNE trending, almost vertical eastern limb of the massif (Fig. 6).

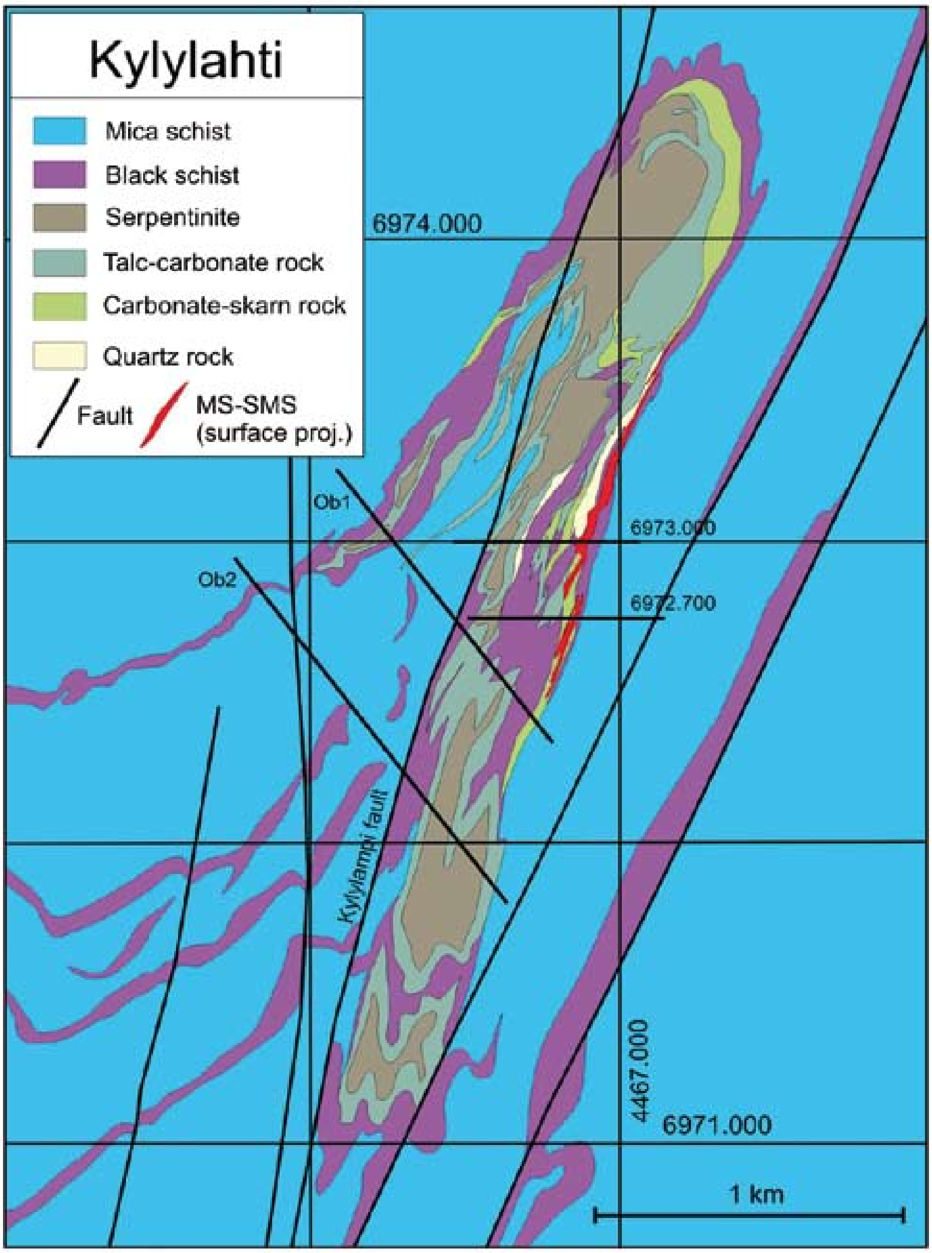


Fig. 6. The geological map of the Kylylahti massif (Kontinen et al. 2006).

Two types of mineralisations are presented in Kylylahti: 1. semimassive-massive sulphide lenses at the contact of the carbonate-skarn-quartz rocks and the black schists, and 2. skarn-hosted disseminations, including minor sulphide veinlets, blotches and semimassive sulphide lenses that parallel the strike of the semimassive lenses (Peltonen et al. 2008).

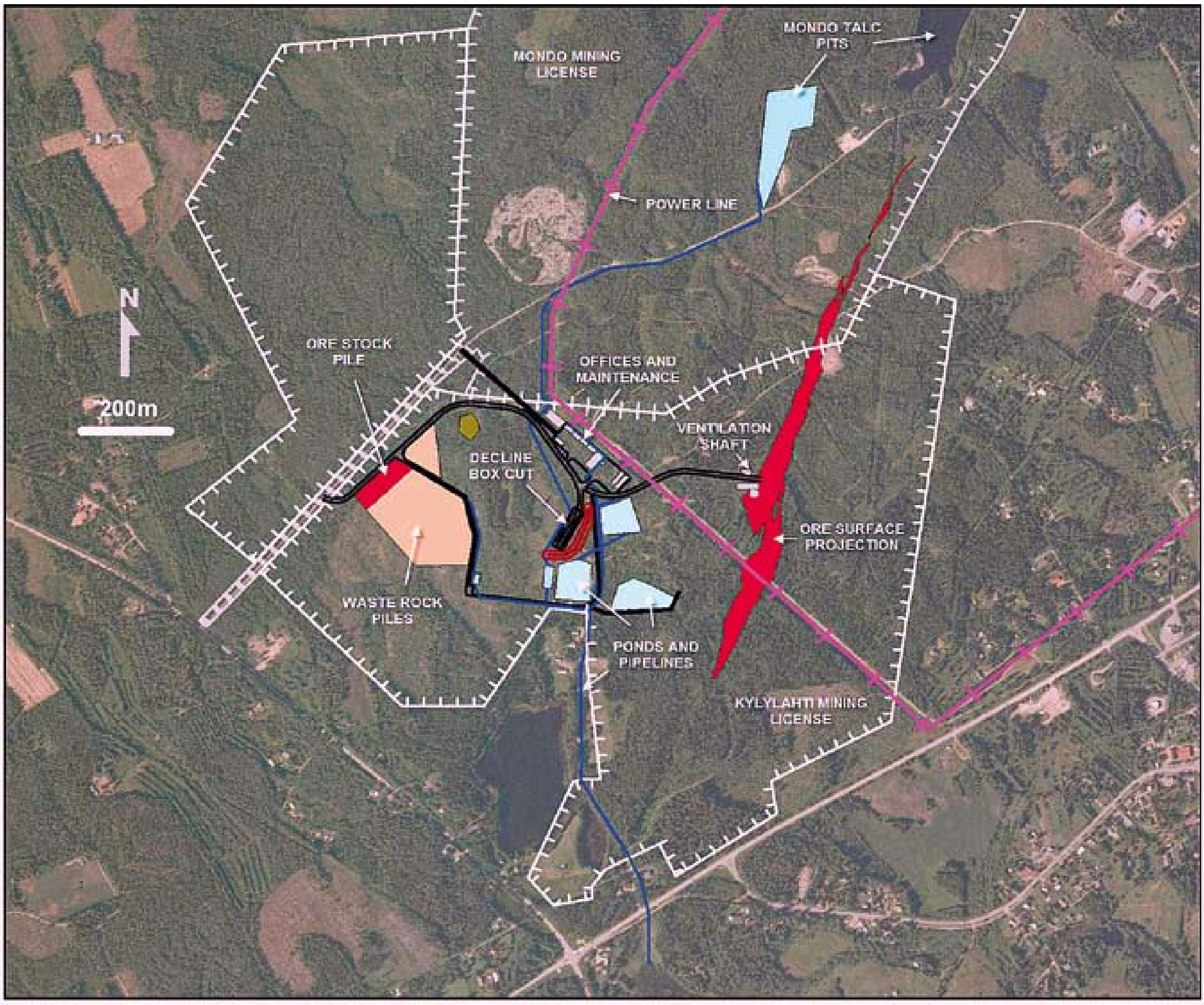
According to Pekkarinen et al. (1998), the mineralisation 1 contains approximately 1.95 Mt ore with 2.63 wt.% Cu, 0.39 wt.% Co, 0.13 wt.% Ni, 0.76 wt.% Zn, 0.9 g/t Au and 20.6 wt.% S, mostly being confined in the "deep ore" lens. The "disseminated" sulphide mineralisations (2) contain 1.43 Mt low-grade resource at 0.61 wt.% Cu, 0.18 wt.% Co, 0.33 wt.% Ni, 0.39 wt.% Zn, 0.9 g/t Au and 8.9 wt.% S.

The terrain consists mainly of 1-10 m thick sandy till which forms small hummocks and is partly covered by peat. The mine district is divided by a minor N-S gravel formation (esker). The background values of Fe, S and heavy metals like Cu, Cr, Ni and Zn are naturally higher than average. The nearest surface water is the Kylylampi lake located ca. 500 m SSE from the mine. The mine is not located on a classified ground water aquifer. The nearest important aquifer called Räiskykorpi is located 800 m from the NE corner of the Kylylahti mine. (Vulcan Resources 2006).

The ore will be sent to the Luikonlahti processing plant, so there will be no tailings impoundments at the Kylylahti mine site, which is presented in Figure 7. The waste rocks produced during operations consist mainly of mica schists and serpentinites. The estimated total amount of waste rock produced during the operations is 350 000 t and most of it will be used as backfill in the mine or in earth construction at the mine site. The rest will be placed in the waste rock piles located west of the mining area (Fig. 7). (Vulcan Resources 2006).

Two talc pits are located north of the Kylylahti mining site, which were part of the Vasarakangas mine district and operational in 1977-1982. The present owner of that site (Mondo Minerals Oy) has been planning to restart the talc production. (Vulcan Resources 2006).

Fig. 7. The Kylylahti mining site (Vesanto 2010).



3. Geological Survey of Finland, Mineral processing laboratory (Mintek)

Teemu Karlsson
Geological Survey of Finland

Target guide: Markku Klemetti (Geological Survey of Finland)

The geolaboratory of the Geological Survey of Finland (GTK) is a leading European facility hosting chemical, isotope, mineral research and mineral processing laboratories and a pilot plant (Fig. 8), which are rare in the world in the scale and variety GTK has them. The Mineral Processing laboratory (MINTEK) and the pilot plant are located in Outokumpu municipality (GTK 2011). They were earlier part of the Technical Research Centre of Finland (VTT) but were attached to GTK in 2004 (Kauranne et al. 2010).

In ore evaluation projects a full study including mineralogical work, bench scale tests and a pilot campaign can be undertaken. To assess the commercial exploitability of a mineral deposit a properly conducted pilot scale research is the most reliable method. The pilot plant is a modern research resource, where various mineral processing unit operations can be studied using alternative methods and a combination of these. During the feasibility studies, data can also be collected for basic engineering purposes, like equipment sizing and preliminary layout design of the planned processing plant. (GTK 2011)

The Mineral Processing laboratory and research group is dedicated to size reduction and processing different kinds of ores and raw materials in close cooperation with companies, universities and other research institutes. The mission is to improve the results of different unit operations and the competitiveness of the clients. Every project caters also the environmental aspects. Research covers the traditional mining industry as well as solutions for other chemical technologies, recycling of waste materials and cleaning of contaminated soils. (GTK 2011)

Fig. 8. The Mineral Processing Laboratory at Outokumpu, a part of the pilot plant. Photo by GTK.

4. Outokumpu

Teemu Karlsson
Geological Survey of Finland

Target guides: Marja Liisa Räisänen (Centre for Economic Development, Transport and the Environment), Päivi Kauppila (Geological Survey of Finland)

A large peculiar boulder, which was at first thought to be a meteorite, was found in the winter of 1907-1908 during a dredging of a canal at Kivisalmi some 50 km SE of Outokumpu. A sample was sent to the Geological Commission of Finland, where the importance of the finding was realized; the boulder proved on analysis to assay 3.74 % copper. After two years of tough prospecting led by Otto Trustedt, the Outokumpu deposit was found on the 16th of March 1910 (Saksela 1948, Loukola-Ruskeeniemi and Sorjonen-Ward 1997). Several massive sulphide deposits are known in the area. Another major ore body is called Vuonos, which was located in 1965. The Vuonos deposit is one of the few blind ore bodies lacking surface manifestation to have been found in Finland, its discovery being based on scientific principles. (Loukola-Ruskeeniemi and Sorjonen-Ward 1997).

The Outokumpu deposit is located within the NE trending about 2 km wide folded horizon of mica and black schists and ultramafic massifs (Fig. 9). The deposit is located along the western margin of an over 10 km long, tubular (< 1.2 x < 1.5 km in cross-section) tightly folded package of serpentinites and enveloping carbonate-skarns-quartz rocks a few meters in thickness. Unpacked from folding the Outokumpu serpentinite body comprises a ~150-200 m thick, ~5 km wide and over 10 km long ultramafic lens. On its hanging wall, the SE-dipping ore plate is in contact against serpentinite and skarn-carbonate rocks, and the footwall of the ore is dominantly against quartz rocks. The contacts of the ore with the wall rocks are frequently very sharp. (Peltonen et al. 2008).

The Outokumpu mine was operational during 1913-1988 and produced a total of 50 Mt of sulphide ore at the average concentrations of 2.8% Cu and 0.2% Co (Loukola-Ruskeeniemi and Sorjonen-Ward 1997). The Outokumpu mining district consists of the Old Mine and the Keretti mine, which was opened in 1954 (Kuusisto 1991).

During the years 1967-1980 the Outokumpu enrichment plant processed so called waste-ore, material from the older waste areas. The tailings area is altogether 140 ha and contains 9.5 Mt of waste. The waste is acid because of the oxidized pyrrhotite and consists of 0.143% Cu, 0.106% Zn, 0.060% Co, 4.0% S, 6.3% Fe, 0.059 ppm Au, 2.06 ppm Ag and 5.9 ppm Se (measured in 1981, Kuusisto 1991). The mineralogy of the tailings impoundments consist mainly of quartz, plagioclase, amphibole, serpentine, talc and Fe-sulphides (P. Kauppila 2011, spoken communication). During the so called Old Mine the groundwater was extensively polluted, which led to long lasting legal transactions and economical compensations. As a result, the environmental issues were better taken into account in the Keretti mine (Kuusisto 1991).

The dust from the tailings impoundment used to be a problem of the Outokumpu mine. Some attempts to cover the area with plants were made in the 1970s, but without much success (Kuusisto 1991). In 1991 the area was bought by a private entrepreneur and the tailings impoundments were covered with about 20 cm of gravel, overlain by some 10 cm of peat mixed with sand at a ratio of 20:1. Vegetation cover was initially established by sowing a so-called TVL seed mixture, with addition of fertilizer. Parts of the waste area were turned into a golf course (Fig. 3). (Heikkinen et al. 2008. The Outokumpu mine district is presented in Fig. 10.

The drainage is collected and channeled to wetlands for treatment. The quality of the drainage produced by the mine site is hard to measure because the waters from the municipal landfill in the west of the mine site are also conducted via the same route. From the wetland the waters run to the small lake Alimmainen Hautalampi as seen in Fig. 2. (P. Kauppila 2011, spoken communication)

The water quality of the 6.5 ha Lake Alimmainen Hautalampi is poor. Normally there is a 2-3 m oxygen containing water body on the surface. In spring time after the breaking up of ice the whole water body mixes and is depleted in oxygen. The water quality of the other small lakes south of the tailings impoundment is surprisingly good. (J. Mäkinen 2011, spoken communication)

The Outokumpu mine is an example of mine buildings and infrastructure being of cultural and historical significance. The Old Outokumpu mine is maintained as a museum and the Keretti head frame (Fig. 11) has heritage listing under the Finnish Building Protection Act. (Heikkinen et al. 2008).

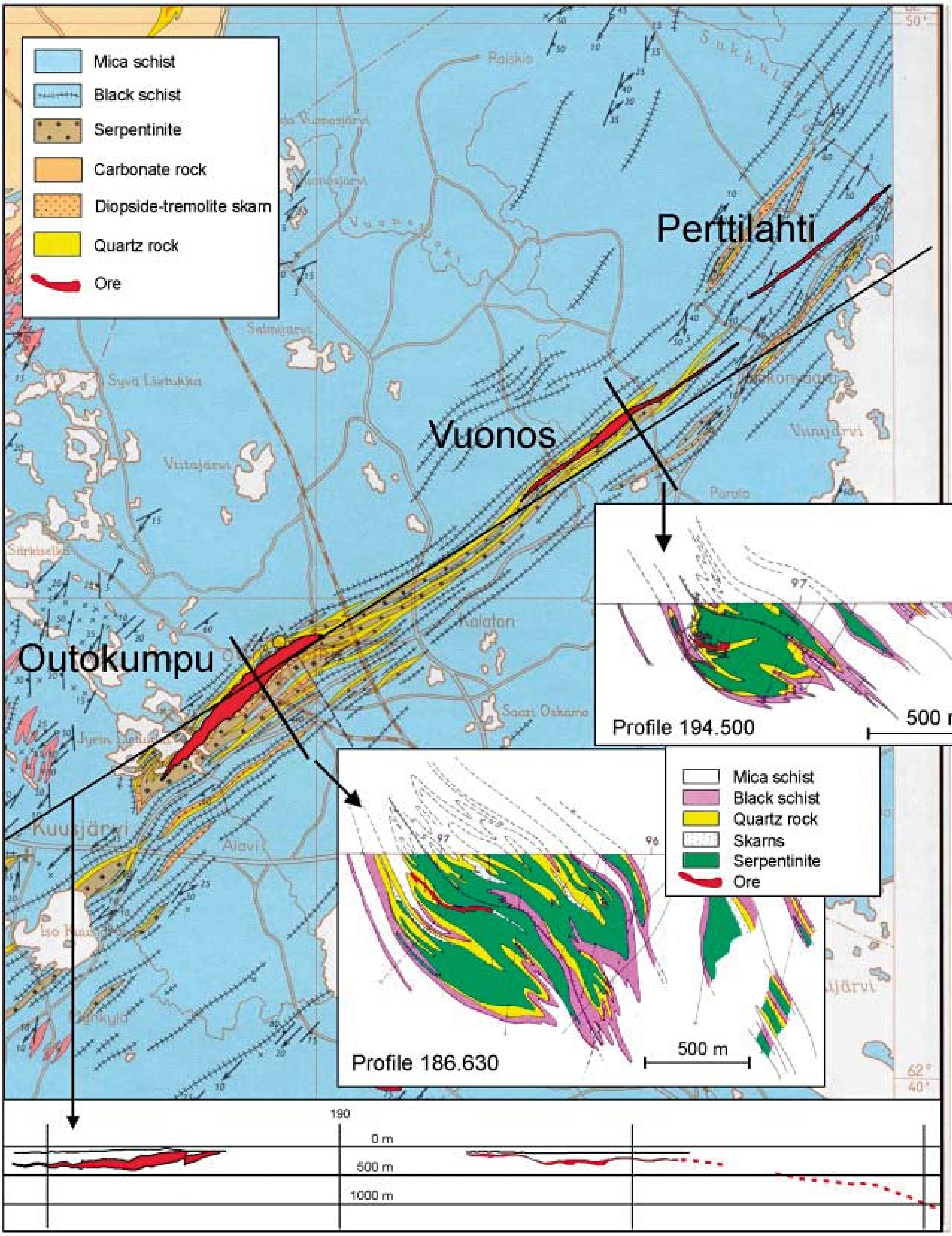


Fig. 9. Geological map of the Outokumpu area and the surface projections of the known ore bodies. The longitudinal projections of the ore bodies are given in the lowermost diagram. The two inset diagrams provide cross-sections over the thickest parts of the Outokumpu and Vuonos serpentinities. (Peltonen et al. 2008).

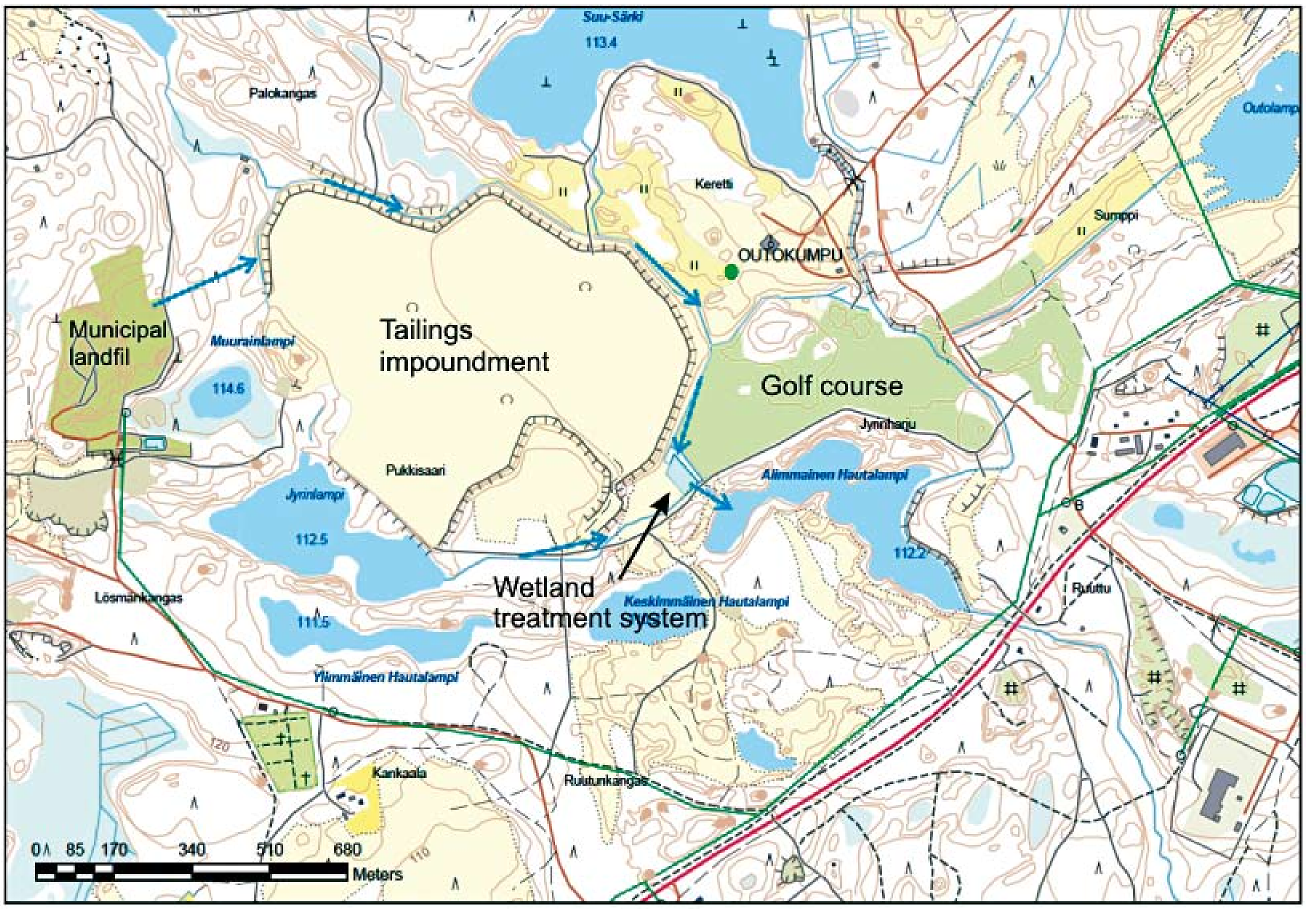


Fig. 10. The Outokumpu mining district. The blue arrows indicate the surface water flow. Basemap: © National Land Survey of Finland, licence no 13/MML/11, Logica Suomi Oy

Fig. 11. The head frame of the Keretti mine and tailings area landscaped into golf course. Photo: P. Kauppila / GTK.

5. Talvivaara

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Target guide: Jukka Pitkäjärvi (Talvivaara Mining Company)

The Talvivaara mine is situated in Sotkamo in the province of Kainuu, between the lakes Kolmisoppi and Kuusilampi, close to the small village of Tuhkakylä. The name Talvivaara ("winter hill") refers to a prominent quartzite hill southwest of the black schist occurrence. (Loukola-Ruskeeniemi and Sorjonen-Ward 1997). In the 1930s, elevated Ni, Cu and Zn values were found in glacial erratics of black schist from the Sotkamo municipality. In the 1960s Suomen Malmi Ltd. drilled four holes into black schist about 3 km northeast of the present mine, but with the methods of that time the results did not justify continued drilling. In the 1970s the Geological Survey of Finland began exploration in the Talvivaara area and found an interesting resource within black schists in 1977. (Loukola-Ruskeeniemi and Heino 1996). The mining operations were not started until the Talvivaara Mining Company Plc. got the permits to open a mine. In 2008 the company started the production at the mine with the precipitation of the first metal sulphides. (Talvivaara 2011).

The Talvivaara deposit is located in the roughly 1.97-1.96 Ga old Paleoproterozoic Kainuu Schist Belt (KSB) in a 15 km long and 1-2 km wide unit characterized by metamorphosed black shales within a 100 km long turbidite formation. (Loukola-Ruskeeniemi and Heino 1996). The deposit consists of two different mineralisations, Kolmisoppi and Kuusilampi. The geological map of the Talvivaara area is presented in Fig. 12.

The Talvivaara deposit is in terms of total tonnage one of the largest black schist -hosted deposits in the world. It is exploited as an open cut mining operation due to its resource geometry and its topographically elevated terrain. This is rather unusual because this type of black schists are generally easily weathered. The original formation seems to have been so thick that even intense glacial erosion was unable to level the landscape. (Loukola-Ruskeeniemi and Sorjonen-Ward 1997).

Pyrite and pyrrhotite are the dominant sulphide minerals in the Talvivaara deposit and they occur both as fine grained disseminations (< 0.01 mm) and as coarser grains in quartz-sulphide veins. The precursors of the Talvivaara black schists were deposited on the seafloor as organic-rich muds in anoxic conditions. The elevated nickel, copper and zinc concentrations originated in hydrothermal processes. (Loukola-Ruskeeniemi and Heino 1996).

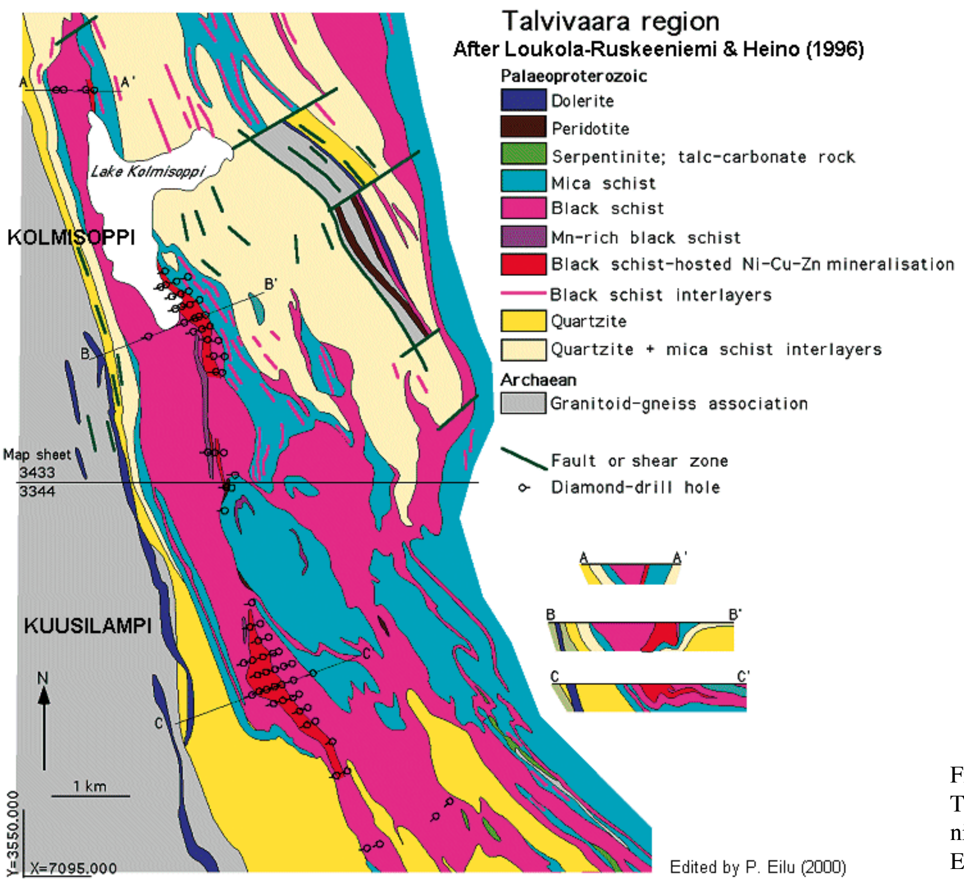

Fig. 12. The geological map of the Talvivaraa area. (Loukola-Ruskeeniemi and Heino 1996, edited by P. Eilu 2000)

The dominant soil type of the Talvivaara area is 1-5 m thick sandy till which is in places covered with peat. There are no eskers in the area, but some small units of sorted beach material have been discovered (Lapin Vesi 2005). The natural baseline values of Ni, Cu and Zn around the Talvivaara area are in some places anomalously high. The spring waters underlain by the Ni-Cu-Zn-rich black schists are suitable for human consumption, but wells where water is in direct contact with the bedrock have yielded values with excessive amounts of nickel. (Loukola-Ruskeeniemi and Sorjonen-Ward 1997). Because of the till material and its shallow depth, the area is not an important ground water resource. The amount of forming ground water and its velocity is small. (Lapin Vesi 2005). According to Einsalo (2005) the ground water pH varies between 5.6 – 6.8 and it contains 25.1 µg/l Ni, 168 µg/l Zn, 1.32 µg/l Co and 13.9 µg/l Cu (the median of nine samples).

The targeted full scale annual production of the Talvivaara mine (from 2012) is 50 000 t Ni, 90 000 t Zn, 15 000 t Cu, 1 800 t Co and 350 t U. The total resources of the Kolmisoppi and Kuusilampi deposits are 1 550 Mt at the average metal grades of 0.22% nickel and 0.49% zinc. The mine uses advanced technologies as bioheapleaching. Uranium is planned to be extracted as a by-product of the present leach solution. The mineralisations and the mining district are presented in Fig. 13, an aerial photo in Fig. 14. (Talvivaara 2011).

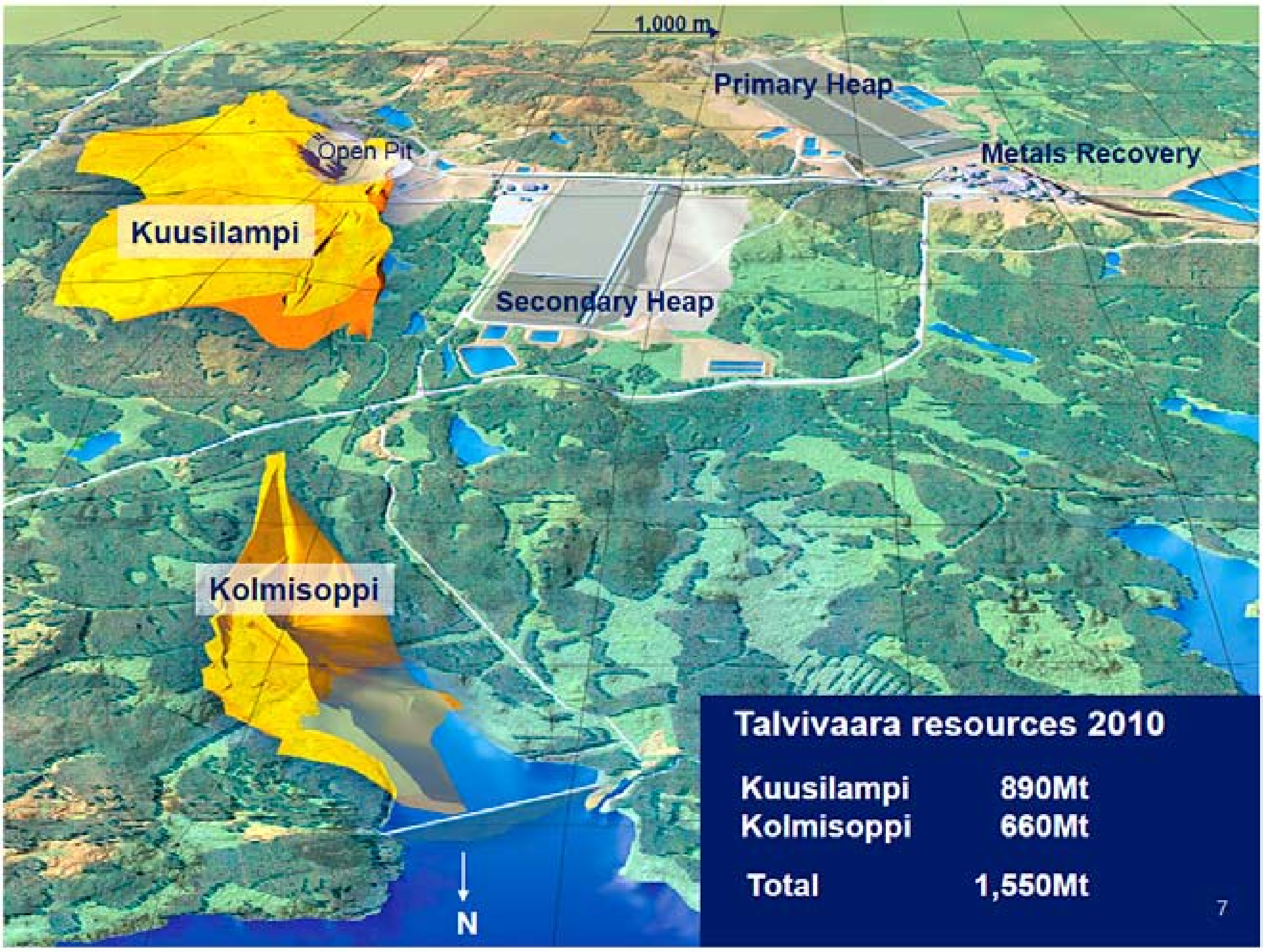

Fig. 13. The mineralisations of Kolmisoppi and Kuusilampi, and the mining district of the Talvivaara mine by the Lake Kolmisoppi (Talvivaara 2011).

The waste material produced by the Talvivaara mine consists of waste rock, crushed and bioleached ore, and precipitates. The most common waste rock type is black schist, which contains e.g. 159 mg/kg As, 413 mg/kg Cu, 358 mg/kg Ni, 2283 mg/kg Zn and 101 mg/kg Cr and will potentially produce acidity. The drainage from the waste rock piles is collected and pumped to the bioheaps. The crushed and bioleached ore will be left in the secondary leaching piles. Based on pilot tests, the heavy metals remaining after leaching will be relatively immobile. The precipitates formed in the processes are mainly gypsum and metal hydroxides, which will be stored in a 140 ha basin. (Pohjois-Suomen ympäristölupavirasto 2007).

The closure of the Talvivaara mine has been planned. The production will stop at the earliest in 25 years, probably much later (estimated mine life > 45 years in 2011). It is objective that the environmental impacts will be minimized as efficiently as possible and the rehabilitation phase will last approximately two years. (Pohjois-Suomen ympäristölupavirasto 2007).

Fig. 14. Aerial photo of the Talvivaara mining district (a photo from the Talvivaara Gallery).

6. Lahnaslampi

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Erkki Kuronen
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The Lahnaslampi talc mine is situated in Sotkamo in the province of Kainuu, near the southern shore of Lake Nuasjärvi. The early exploration history of the Lahnaslampi talc mineralisation is not known, but according to the local people the deposit has been known at least since the beginning of the 20th century. At that time the Lahnaslampi soap stone was tried to be used as building material for stoves but without success; the strongly carbonated soapstone was too fragile for heating. After the failed stove attempts the deposit was left alone until 1955, when the Suomen Malmi Ltd. became interested in producing filler for the paper industry. The geological investigations in Lahnaslampi proved to be promising and pilot studies with the ore produced material suitable for making paper. The process was however so slow that the production started in only 1969. (Juntunen 1971) Above Jatulian quartzites lying Lahnaslampi talc deposit is associated with the black schists and skarn rocks of the Kainuu Schist Belt. The deposit was formed by the hydrothermal alteration of an ophiolitic ultramafite (Niemelä 2001) and it correlates with the ophiolites of Jormua and Outokumpu area (Tuokko 1991). The ultramafite is located in the middle of mica schists and sulphide-bearing black schists, which belong to the same lithological unit as those in Talvivaara (Mäkinen et al. 2010). The geological map of the mine site is presented in Fig. 15.

The Lahnaslampi deposit consists of three mineral components; slightly over 50% talc, slightly under 50% magnesiumcarbonate, some chlorite and 1-2% metal sulphides. The ore body is a vertical vein with an average width of 200 m and a surface outcrop of about 10 ha, for what it is to extract as open pit mining (Juntunen 1971). Until the year 2009 the mining of the ore has been 17.3 Mt (Vuorimiesyhdistys 1961-2009).

The topography of the Lahnaslampi area is quite flat, as seen in Fig. 16. The natural landscape has changed due to mining activities and the most notable feature along the waste rock piles and tailings impoundments is the almost 1 km long, 400 m wide and over 100 m deep open pit. (Saarelainen and Räisänen 2001)

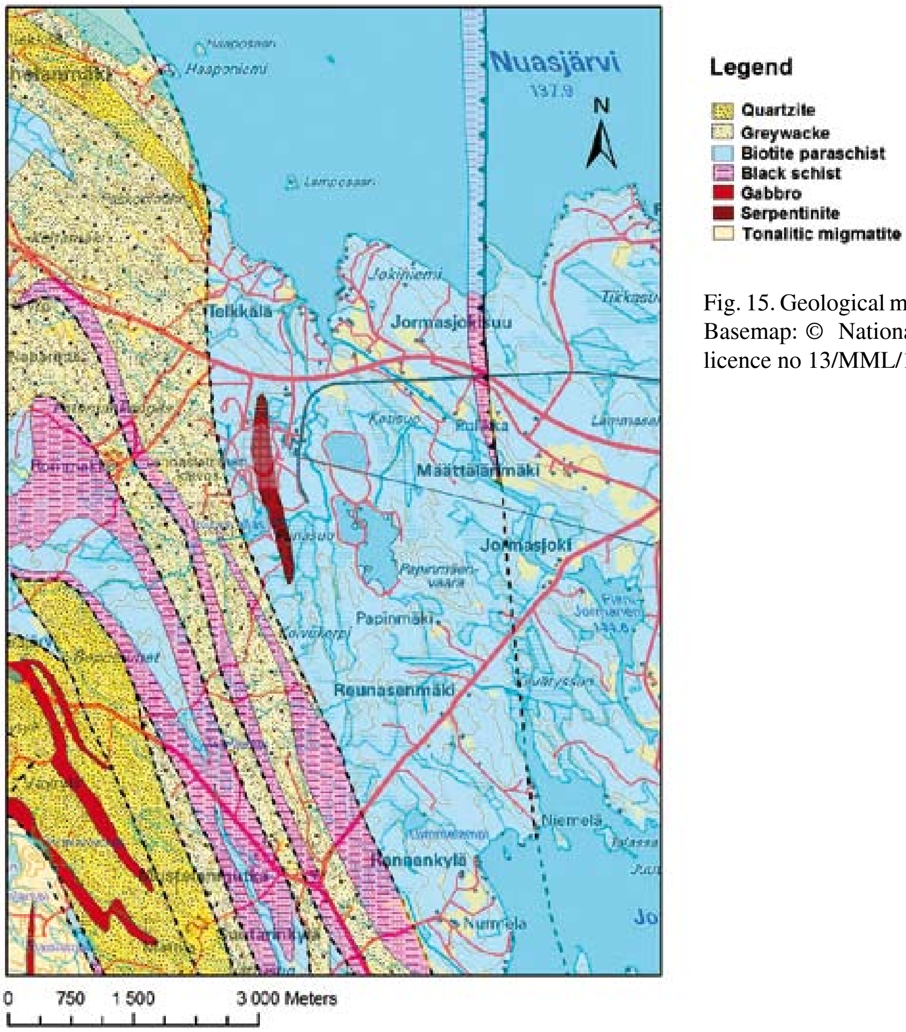

Fig. 15. Geological map of the Lahnaslampi area. Basemap: © National Land Survey of Finland, licence no 13/MML/11, Logica Suomi Oy

Fig. 16. An aerial photo of the Lahnaslampi mine district. (Mondo Minerals photo gallery)

The soil types of the Lahnaslampi mine area consists of till (41.6%), peat (9.2%), and sandy and fine-sandy formations. The Quaternary deposits of the mine site are presented in Fig. 17. The bedrock topography is quite strong due to the valleys formed by the shear zones, but the soil flattens the overall landscape. One shear zone cuts through the open-pit mine. In general the Lahnaslampi mine site is not an important ground water zone. (Saarelainen and Räisänen 2001)

The geochemical properties of soil and ground water reflect the changes in bedrock rock type. The ground water quality is good, except the drainage in the NE corner of the waste rock pile (Fig. 17), where the water is slightly acid and contains high concentrations of Al, Ca, K, Mg, Cd, Mn, Ni, S, and Zn. The most problematic rock type in the waste rock pile is black schist, which contains notable amounts of sulphides (Jaakko Pöyry 2005). The surface water quality around the mine is weakened by the acid effluents from the waste rock piles, oxidation of the sulphide-rich rocks by the road banks, and nutritious effluents from the tailings impoundments. The water quality of the rivers Juuanpuro and Lahnasjoki is dependent on the diluting effect of the natural surface waters, e.g. small amount of precipitation in the summer 2001 caused an increase in acidity and heavy metal content (Saarelainen and Räisänen 2001). The effects of mining can be seen in the sediments of the southern part of Lake Nuasjärvi as increased metal and sulphur concentrations (Mäkinen et al. 2010).

The drainage waters from the waste rock pile are nowadays treated in a neutralization unit before entering River Lahnasjoki and Lake Nuasjärvi. In addition, covering of potential contamination sources e.g. waste rock pile, tailings impoundment dams and road banks has been used to decrease the amount of effluents. In a long run the open pit will be filled with waste rocks and tailings material. To control harmful effects on nature after the closure of the Lahnaslampi mine, wetlands and different kinds of covering options (water and dry) will be used. (Jaakko Pöyry 2005)

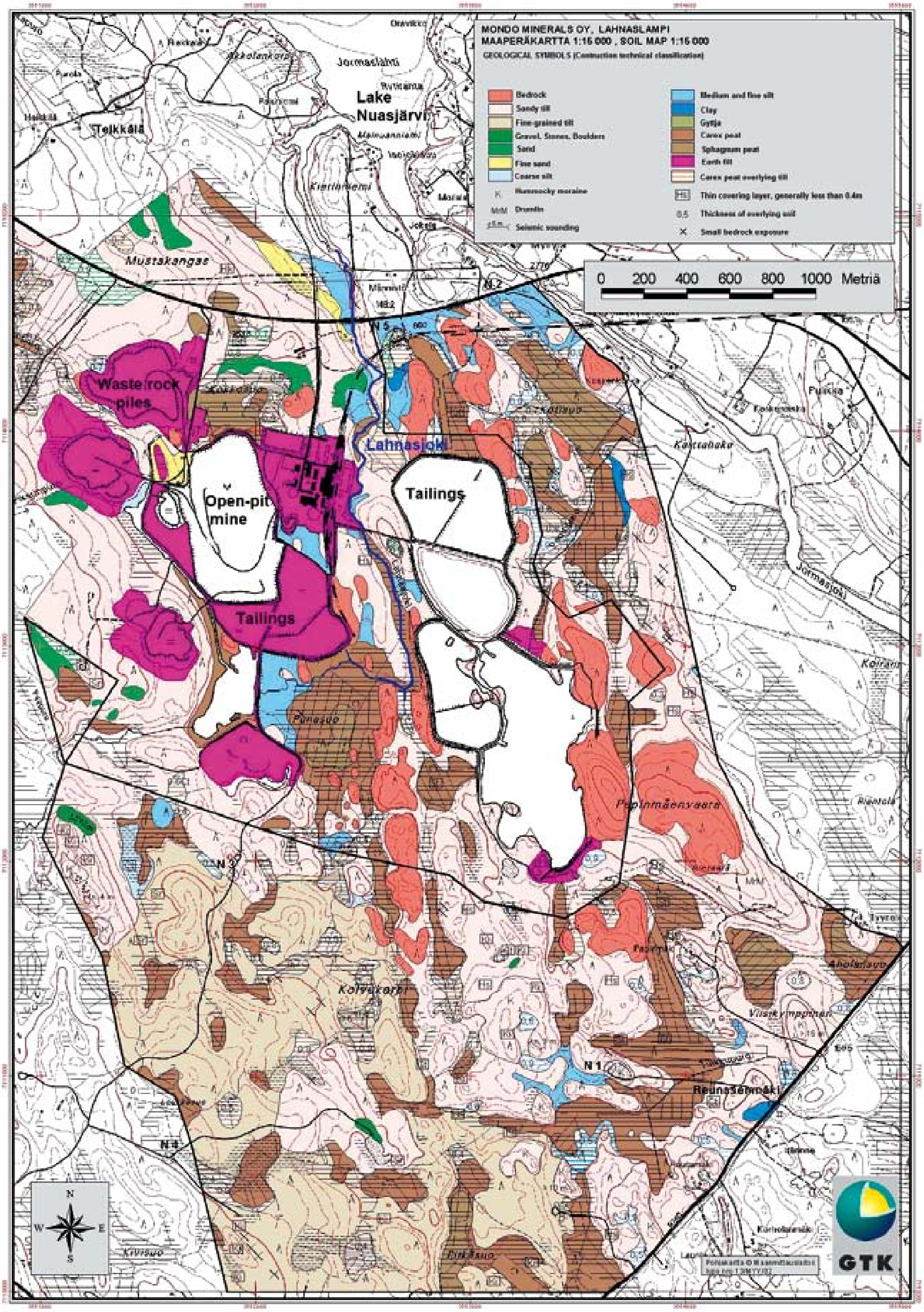

Fig. 17. The Lahnaslampi mine district and Quaternary deposits. Basemap: © National Land Survey of Finland, licence no 13/MML/11, Logica Suomi Oy (Modified from Saarelainen and Räisänen 2001)

7. Mustavaara

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Tuomo Karinen
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Target guides: Marja Liisa Räisänen (Centre for Economic Development, Transport and the Environment), Aarre Juopperi, Tuomo Karinen (Geological Survey of Finland)

The Mustavaara Vanadium Mine is located in the Koillismaa Intrusion in the eastern Finland, ca. 150 km northeast of the city of Oulu (Fig. 18). The intrusion is a part of the Koillismaa-Näränkävaara Complex, which comprises the Koillismaa Intrusion, the Näränkävaara Intrusion and a strong positive gravity anomaly (regarded as unexposed dyke) that connects these distant western and eastern parts of the complex. The westernmost part of the complex, i.e. the area of the Koillismaa Intrusion consists of separate bodies that represent blocks of a single, sheet-like layered intrusion. These blocks appear to straddle along 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. 2.45 Ga (Alapieti 1982).

The Koillismaa-Näränkävaara Complex hosts two principal types of metallic mineralisation. Both types are located in the Koillismaa Intrusion:

- Orthomagmatic V(-Ti-Fe)-rich layer, the 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 presently is the only deposit that has been mined (1975-1985) in the complex area.
- 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 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.

The Mustavaara Vanadium Mine represents the magnetite gabbro layer in the upper part of the layered series of the Koillismaa Intrusion. The layer is uniform and can be traced almost in every block of the Koillismaa Intrusion. In the mine area, the magnetite gabbro layer is ca. 240 m thick, striking nearly east-west and generally dipping some 40° to the north (Juopperi 1977; Alapieti 1982; Karinen 2010).

Vanadium grades of the magnetite gabbro correlate with the amount of the ilmenomagnetite, which is a oxide phase that originally crystallized as titaniferous magnetite, but which later during subsolidus phase reacted to composite grains of fine ilmenite lamellae and V-bearing magnetite host. At 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 ca. 5 m thick and contained 25-35 vol-% oxide minerals and 0.38 w-% V (0.68 w-% V_2O_5), while the middle layer, 15-50 m in thickness, was poorest in oxide mineral content at near 15 vol-% with 0.22 w-% V (0.39 w-% V_2O_5). The upper layer of ore varied from 10 to 40 m in thickness and contained 0.26 w-% V (0.46 w-% V_2O_5). During the operation of the mine, one significant challenge to overcome was the optimization of the production line to gain the maximum V-grade with minimum amount of ilmenite lamellae in the magnetic concentrate.

The construction work of the Mustavaara mine began in 1973 and the production started in 1976. At the end of the 1970s the Mustavaara mine was the biggest producer of vanadium pentoxide in Europe. The production was stopped in 1985 for economic reasons as the price of vanadium was low (Juopperi 1977, Pöyry 2008). An open pit 1800 m in length, varying in widths from 130 to 290 m and in depth from 50 to 135 m was designed. (Juopperi 1977). The mine produced 13.446 Mt ore at 0.2 w-% V (0.36 w-% V_2O_5). (Puustinen 2003, Adriana Resources 2006).

At present there can be seen an open pit, waste rock heaps, a large tailings impoundment and remains of the vanadium pellet heap (Fig. 19). Vanadium pellets are excavated and transported to the Raahe steel works of Rautaruukki Oyj (also known as Ruukki), located in western coast. The tailings impoundment is partly covered by water (settling pond) and composted manure (western part), and is partly uncovered. The covered area grows barley and in turns oat sowed by a local farmer. (Pöyry 2008).

The soil of the Mustavaara area consists mostly of sandy till or silty sandy till and the thickness varies from < 1 m to 10-15 m. The area is not on an important ground water zone. During the mining operations the surface water quality of the water systems declined remarkably, but since the year

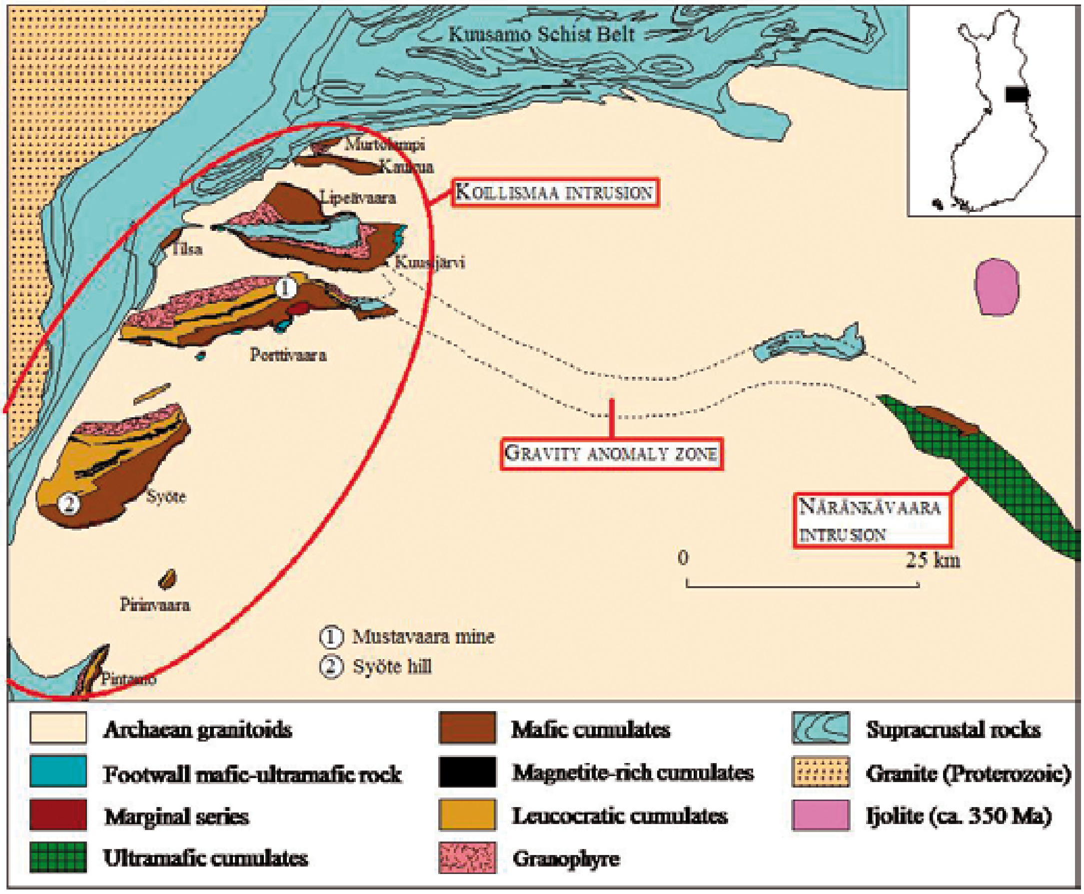

Fig. 18. Geological map of the Koillismaa layered intrusions. (Juopperi 1977)

1985 the concentration levels have decreased and at present the water quality is good. The 120 ha tailings impoundment is partly covered by water and some minor dust emissions have occurred. (Pöyry 2008). The Mustavaara area is presented in Fig. 19.

At present, mining impacts are detected by elevated V concentrations of lake sediments and surface waters (140-300 µg/L, background <10 µg/L) in the Sirniönlampi lake and creeks downstream (Pohjois-Pohjanmaan Ely-keskus, Monitoring data 2008-2009). According to the monitoring data, vanadium concentrations of the lake sediments have decreased to tenth part from 2000 to 2008 (Pöyry 2008). Originally, V bearing waters were discharged from drainage waters from the pit and waste waters from pellet plant. Furthermore, the second potential source for V contamination can be the area of the old Fe-V pellet stockpile, which will be exhausted during near years and remediated by the Rautaruukki Oyj. The research and planning of the remediation is under way.

The buildings of the old mine have been taken apart in 2001-2004. Soil polluted by oil and sulphuric acid has been cleaned up in 2001-2002. The tailings impoundment has been in agricultural use and also as a reindeer round-up area. There have been plans to open the mine again. (Pöyry 2008)

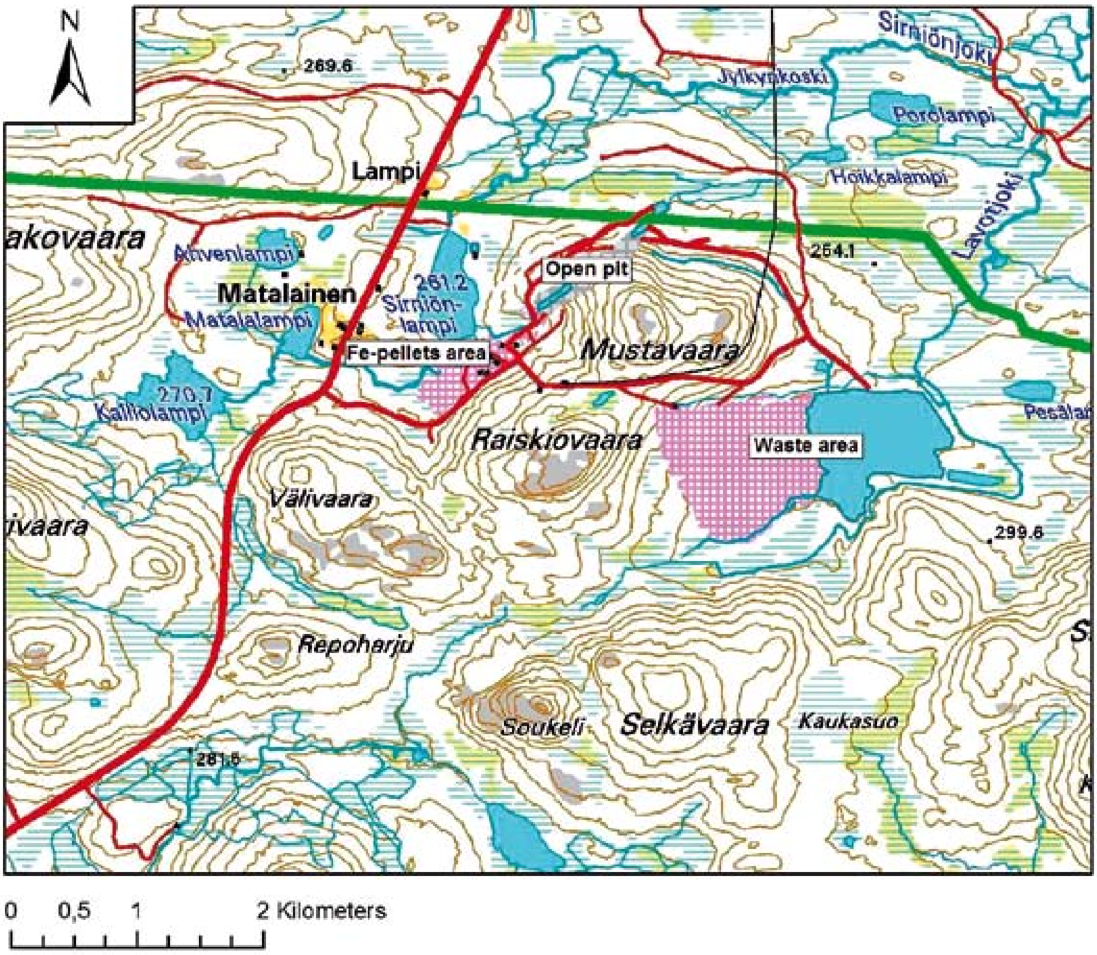

Fig. 19. Map of the Mustavaara area. Basemap: © National Land Survey of Finland, licence no 13/MML/11, Logica Suomi Oy

8. Syöte National Park and the geological outdoor maps

Peter Johansson
Geological Survey of Finland

Target guide: Peter Johansson (Geological Survey of Finland)

Nature tourism, including all the various activities it encompasses, is one of the most rapidly growing types of tourism in the world. This is clearly reflected in northern Finland, where backpacking excursions, hiking and other experiences in nature are steadily gaining in popularity. Its Arctic scenery and wilderness are also one of the main reasons why people from outside Finland choose Lapland as their destination.

Geological Survey of Finland has published nine geological outdoor maps and accompanying guidebooks from different parts of the country in the series that was launched in 1994. The newest map of the Syöte area was published in 2010. The previous maps cover the Urho Kekkonen, Nuuksio, Pyhä-Luosto and Koli National Parks, the Pallas-Ounastunturi fell area as well as the Ivalojoki and Lemmenjoki placer gold areas. Mapping is based on landform surveys that have been made from aerial photographs and supplemented by field surveys. Rock types and various glacial and postglacial formations and deposits are indicated on the map with different colours and symbols. In addition, the map contains selected geological excursion sites, such as the mighty quartzite mountain ranges and the deep channels that have been cut through them by meltwater streams from the glacier, eskers covered by ancient pine forests and vast aapa mires.

The guidebook also provides detailed information about geological formations and other natural sights, as well as the origins and development of Lapland's landscapes. Some of the destinations are located near marked paths and can be easily reached even during brief visits. The outdoor map is based on a topographical map scaled at 1:50,000. Fell huts, marked paths and campfire sites are also indicated on the map in order to help in planning hiking routes and day trips. Accordingly, it includes cycling and canoe routes and other hiking-related information. Equipped with the geological outdoor map the visitor will understand the significant role geology has played in Finland's landscapes.

The Syöte National Park is located on part of a range of hills running from the Kainuu region to southern Lapland. The landscape is marked by a mosaic of old spruce-dominated hill forests in their natural state and mires. The Syöte National Park (299 km²) was established in 2000 mainly in areas included in the conservation programme for old-growth forests. It is also part of the Natura 2000 network. The park consists of four sections, the largest of which is located north of the Syöte tourist centre and the Iso-Syöte hiking area.

The bedrock of the Syöte area is composed of diverse lithologies with an age span of over 1 billion years. The oldest rocks in the area are tonalitic migmatites and gneisses over 2 800 million years in age. These rocks form the oldest continental crust in Europe. 2 500 million years ago the old continent started to fracture, inducing volcanic activity in the Syöte area. Mafic magma from the Earth's mantle intruded in the crust between the old continent and the overlying mafic and felsic volcanic rocks, forming the Koillismaa intrusion. Younger tectonic events fragmented the Koillismaa intrusion into the Syöte, Porttivaara and Pirinvaara blocks (see Fig. 18 of the excursion target 7, Mustavaara). The Syöte area is cross-cut in the N-S direction by deep water mica gneisses and overlying shallow water quartzites. These sedimentary rocks were deposited over the old continent 2 500–2 000 million years ago. Volcanic activity continued during the sedimentation, resulting in volcanic layers in the sediment pile and diabase dykes cross-cutting the other rock types in the area. The youngest rock type is the voluminous pegmatite granite found in the NW part of the area. The granites were formed during a continental collision ca. 1 800 million years ago, when the crust thickened and melted. The other rock types in the area were folded and metamorphosed during the same collision (Räisänen et al. 2010).

The most typical features of the topography of the Syöte area are high hills covered with till. In many places, there are boulder fields on the rocky tops and slopes of the hills. They are the result of frost weathering. The magnificent gorges and channels carved in the bedrock are created by melt waters during the Ice Age. The channels run more than 20 metres deep in places. The valleys between the hills are usually covered by extensive aapa mires. The area is also characterized by impressive mires on the slopes and tops of hills, which may be situated at an altitude of up to more than 300 metres. Mires are a very impressive part of the landscape. They are in their natural state and can be admired from the hiking trails crossing the area (Räisänen et al. 2010). An overall view of the Syöte area is presented in Figure 20.

Fig. 20. A landscape of the Syöte National Park. Photo: P. Johansson / GTK.

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