Stop 2 The Kevitsa intrusion and associated Ni-Cu-PGE deposit

Tuomo Törmänen and Markku Iljina
Geological Survey of Finland, Rovaniemi, Finland

Preface

The following description is mostly based on the works of Mutanen (1997, 2005) unless otherwise indicated. For a more detailed description see those extensive reports.

Location and exploration history

The Kevitsa mafic layered intrusion is located in Central Lapland, some 35 km north of Sodankylä, 0.8 km from the southern margin of the 2.44 Ga Koitelainen intrusion. It forms the western part of the larger Kevitsa-Satovaara Complex (Fig. 1).

The Kevitsa intrusion was explored by the Geological Survey of Finland between the years 1984 and 1995, in three phases. The presence of magmatic sulphides within the intrusion was indicated by early drilling in 1984 which intersected several meters of pyrrhotite-rich sulphides with low base and precious metal values, near the basal contact. The discovery hole (R326) was drilled in 1987 to the western part of the currently known mineralised domain, where it intersected about 30 meters of disseminated sulphides. Subsequent drilling programs delineated a large, low-grade Ni-Cu-PGE-Au occurrence, the Kevitsa deposit (formerly known by the names Keivitsa and Keivitsansarvi). The deposit was subsequently held and evaluated by the Outokumpu Company (1995–1998). In 2000, Scandinavian Gold Prospecting AB (subsidiary of Scandinavian Minerals Ltd) acquired the deposit.

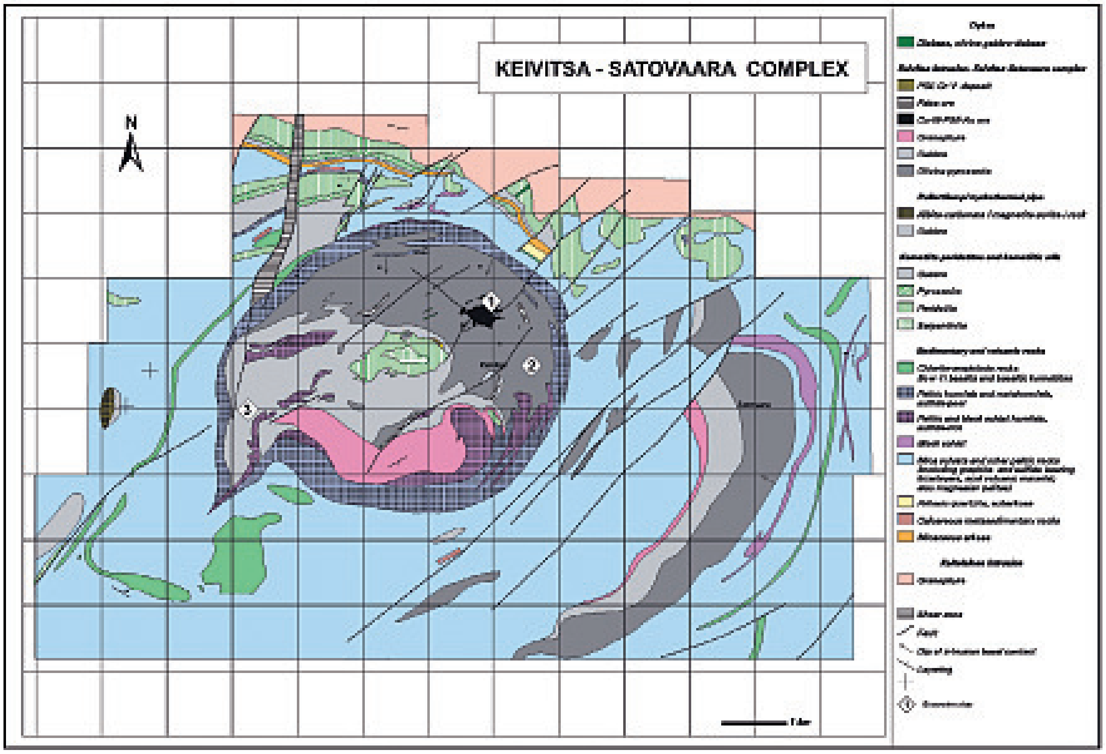

Fig. 1. Geological map of the Kevitsa area, with excursion stops indicated by numbers. From Mutanen (2005).

General geology

The rocks in the vicinity of the Kevitsa intrusion belong to the 2.0–2.2 Ga old Savukoski Group (SKG) of Central Lapland. The Savukoski Group is subdivided into four formations; Matarakoski (MkF), Linkupalo (LpF), Sotkaselkä (SoF), and Sattasvaara (SaF) Formation, where MkF is the lowermost and SaF the uppermost unit (Fig. 2 in the Introduction; Lehtonen et. al 1998). The Kevitsa intrusion is surrounded by mica schists with graphite- and sulphide bearing interlayers, felsic volcanic rocks, magnesian metapelites and calcareous metasediments of the Matarakoski Formation (Fig. 1). These are overlain by komatiitic volcanic rocks intercalated with sulphide-rich Mg-pelites. Differentiated komatiitic sills occur close to the base of the intrusion and on the northern side of the intrusion. Pelitic rocks near the intrusion contacts were altered to hornfels due to thermal metamorphism caused by the intrusion. Regional metamorphism reached amphibolite facies grade and affected especially the country rocks and the upper parts of the intrusion the central part of the intrusion being less metamorphosed.

Kevitsa intrusion, age and structure

The zircon U-Pb age of the Kevitsa intrusion is 2.057±5 Ga (Huhma et al. 1996, Mutanen & Huhma 2001). This correlates well with the Sm-Nd age of 2.05 Ga determined from primary igneous minerals (Huhma et al. 1996).

The 4x5 km^2 sized Kevitsa intrusion is funnel-shaped and dips to S-SW. The contacts cut across the surrounding metasedimentary strata, with basal contact dipping 45–50° to the S. Contacts are commonly interfingered with the country rocks. Igneous layering is parallel to the basal contact in the lower parts of the intrusion, 20–30° in the upper part of the ultramafic zone, and almost horizontal in the gabbro and granophyre zones. The intrusion has

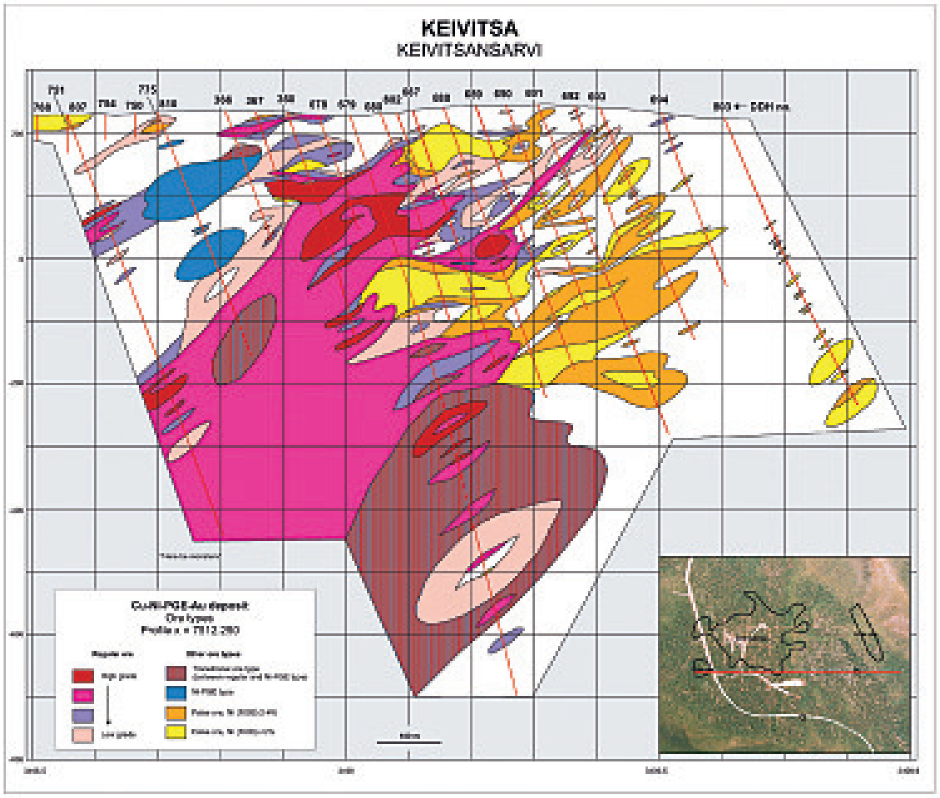

Fig. 2. Cross section of the Kevitsa deposit, with different ore types indicated. DDH profile x=7512.250. From Mutanen (2005).

been divided into four zones (from base upwards): 1) marginal zone, 2) ultramafic zone, 3) gabbro zone, and 4) granophyre zone (Fig. 1).

The marginal (chill) zone is 0–8 m thick and consists of microgabbro, contaminated quartz gabbros and quartz-rich pyroxenites which grade rapidly to olivine pyroxenites of the ultramafic zone.

The ultramafic zone is most prominent in the NE part of the intrusion. The thickness of the zone is not known but is at least 1000 meters, possibly 2000 meters or more. The rocks are mostly olivine-augite mesocumulates (wehrlites and olivine websterites, here generally named as olivine pyroxenites), locally with plagioclase and/or orthopyroxene as cumulus or intercumulus phases with minor hornblende and phlogopite. Altered counterparts of olivine pyroxenites are named as metaperidotites which are composed of amphibole, serpentine, chlorite and talc. Within the ultramafic zone, there are discontinuous layers of pyroxenites and gabbros. Various types of komatiitic xenoliths are common in the ultramafic zone, especially within the mineralised part, whereas pelitic xenoliths are common closer to the contacts of the intrusion.

Rocks belonging to the gabbro zone are most prominent in the SW-part of the intrusion. They consist mainly of pyroxene gabbro, ferrogabbro (with pigeonite and fayalite), magnetite gabbro (with V-rich magnetite), and their metamorphic (hydrated) equivalents. Discontinuous units of Fe-rich, Mg-, Ni-, Cr-poor olivine pyroxenites occur in the upper parts of the gabbro zone. The gabbro zone contains large pelitic and minor komatiitic xenoliths. The thickness of the gabbro zone is not known, but drilling indicates that it is at least 500 m thick.

The magnetite gabbro of the upper part of the gabbro zone rapidly grades into the granophyre which represents the uppermost magmatic unit of the Kevitsa intrusion. The granophyre is mainly composed of sodic plagioclase, quartz, and secondary amphibole, with abundant magnetite, ilmenite, fluorapatite and sulphides. The granophyre contains small pelitic xenoliths.

As can be seen from the above, various types of xenoliths are common and they are encountered in various parts of the intrusion. The most common types are komatiitic and pelitic xenoliths. Komatiitic xenoliths occur as massive, banded, or layered rocks that have been mechanically disintegrated to a variable degree. They are composed of variable amounts of olivine, clinopyroxene, orthopyroxene and chromite. Komatiitic xenoliths are especially common in the ore zone and there is a 4–10 m thick xenolith-rich layer in the upper part of the ore that has been traced for 300 m from north to south. It is interesting to note that komatiitic xenoliths within the ore zone contain fine-grained disseminated sulphides, while those from the barren parts of the intrusion do not contain sulphides. Pelitic rocks, now pyroxene-plagioclase hornfels, occur as large xenoliths which are often partially digested ("rotten" xenoliths). Small (5–10 cm across) graphitic xenoliths indicate assimilation of graphite-rich black schist material. Graphite-rich pelitic hornfels xenoliths are also associated with pyrrhotite-rich sulphides 2 km west of the Kevitsa deposit.

Various types of dyke rocks cut the Kevitsa intrusion. They can be broadly classified into three categories: gabbro, diorite-felsite, and diabase. Porphyric gabbroic veins with sharp contacts represent the earliest phase. They have been interpreted as local evolved intercumulus liquids, based on chemical and mineralogical composition. The diorite-felsite veins show a paragenetic and compositional continuum and, indeed, form also composite veins with felsite occurring in the middle of diorite veins. These rocks are made of variable amounts of plagioclase, hornblende, and quartz. U-Pb zircon gives a comagmatic age of 2.054±5 Ga (Mutanen & Huhma 2001). Diabase and related olivine gabbro-diabase dykes are younger than the intrusion with a Sm-Nd mineral age of 1.916 Ga (Mutanen 2005). The ENE-striking dykes have fine-grained chilled contacts with the intrusion rocks. A typical feature of the olivine gabbro-diabase dykes is the presence of coarse-grained (up to 2 cm) olivine crystals in the mid-parts of the dykes.

The Kevitsa Cu-Ni-PGE deposit

The Kevitsa deposit is a large, low-grade disseminated sulphide deposit located in the upper part of the ultramafic zone, in the NE part of the intrusion (Fig. 1). The surface cross-section of the ore body is about 13.4 hectares and it extends to the depth of >400 meters. The host rocks are olivine pyroxenites and their metamorphic equivalents (metaperidotites). The deposit has been divided into two bodies, the main ore body (or Main Ore) and the overlying Upper Ore. There are four main ore types, based on the metal and sulphur contents: 1) regular ore, 2) false ore, 3) Ni-PGE ore, and 4) transitional ore. As distribution of Cu, Ni, PGE+Au, and S within the deposit is complex and variable, the different ore types tend to grade into another. Figure 2 shows a section trough the Kevitsa deposit and gives some indication on the distribution of different ore types: Regular ore makes up most of the main ore, whereas the false ore mainly occurs in the eastern part of the deposit. The Ni-PGE type mostly occurs in the upper parts of the ore, forming N-S trending pipe-like bodies, 30–50 m long, 10–30 m wide and extending to a depth of up to 400 m (Gervilla et al. 2003, Kojonen et al. 2004). The Ni-PGE ore is shown in blue in the centre of the open pit model in Fig. 3 (by J. Parkkinen, courtesy of Scandinavian Minerals Ltd).

The regular ore typically contains 0.4–0.6 % Cu, 0.2–0.4 % Ni, 0.015 % Co, 0.5–3.0 % S, and about 0.5–1.0 ppm of combined Pt+Pd+Au, giving an average Ni/Cu ratio of 0.6–0.8 and Ni/Co ratio of 15–25. The Ni content of the sulphide fraction typically is 4–7 %. Precious metals show fairly good positive correlation with the Cu+Ni values. Compared to the regular ore, the *false ore* typically is much more sulphur-rich (>5 % S) and grades locally into sulphide vein network. However, the metal contents are much lower, for example Ni is generally less than 0.1 % (< 4 % Ni in sulphide fraction). In the leanest false ore (0.3–0.5 % Ni in sulphide fraction), the Ni/Co ration is 1–2 which is similar to sulphides in the metasedimentary rocks surrounding the intrusion. The *Ni-PGE type* has a variable but generally fairly low sulphur content of about 0.5–1 % S, high nickel (>0.5 % Ni, 40–60 % Ni in sulphide fraction), high PGE (>1 ppm, up to 26.75 ppm (Gervilla et al. 2003)), and low copper (<0.1 % Cu) and gold contents (max. 0.13 ppm Au). The high Ni and low Cu contents give rise to high Ni/Cu ratio (generally >5, up to 50–90) and Ni/Co ratio (25–80).

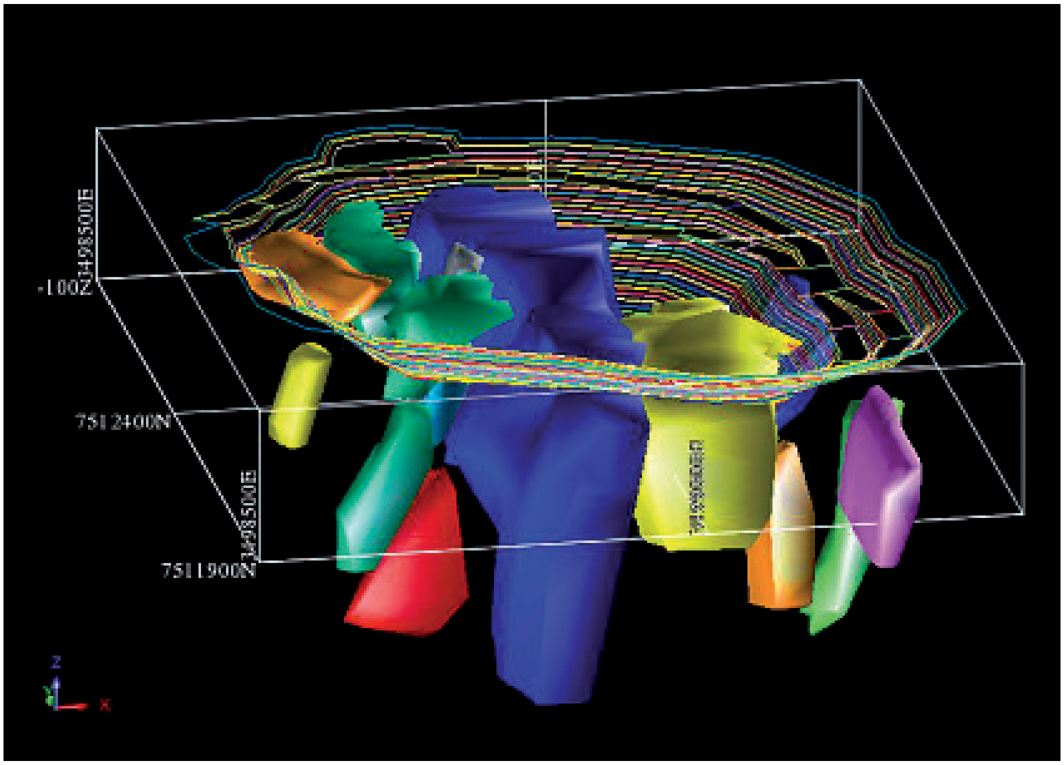

Fig. 3. 3D block model of the Kevitsa deposit with Ni-PGE ore depicted in blue. Image by J. Parkkinen, Kevitsa Mining Oy.

The *transitional ore* represents an intermediate ore type which is gradational in metal content to both the regular ore and the Ni-PGE ore. Its Ni/Cu ratio normally is 1.5–2.5 or higher and sulphide fraction nickel content 15–23 %. The changes in precious metal and sulphur contents between the different ore types is depicted in the sulphur vs. PGE+Au diagram, along with other data in Fig. 4.

Ore mineralogy

The main sulphide minerals at Kevitsa are troilite, hexagonal pyrrhotite, pentlandite, and chalcopyrite, with subordinate amounts of cubanite, talnakhite and magnetite, and a number of minor to trace mineral phases (Table 10 in Mutanen 1997). The Ni-PGE type of ore has a somewhat different paragenesis with pentlandite, pyrite, and chalcopyrite as the main phases, with subordinate, but locally abundant pyrrhotite, millerite, heazlewoodite, nickeline, maucherite and gersdorffite. The Ni-PGE type also contains graphite, whereas magnetite is rarer.

Altogether, about 40 platinum group minerals (PGM) have been identified from the deposit. The PGE mineralogy is dominated by various Pd-Pt-Te-Bi phases and speryllite, whereas PGE sulphides such as cooperite and braggite are more rare. However, the distribution of the PGMs is quite heterogeneous, as is evident from the study of Gervilla et al. (2003). They studied the PGE mineralogy of Ni-PGE ore from four different drill cores which intersected the ore at different depths. In their study, braggite was the most abundant PGE mineral and also geversite ($Pt(Sb,Bi)_2$) was locally abundant, with highly variable distribution of PGMs form hole to hole. About 55 % of the PGE minerals occur as inclusions in silicates (amphibole, serpentine, chlorite, pyroxene), 8–13 % as inclusions in sulphides, and 32–39 % are at silicate-sulphide grain boundaries.

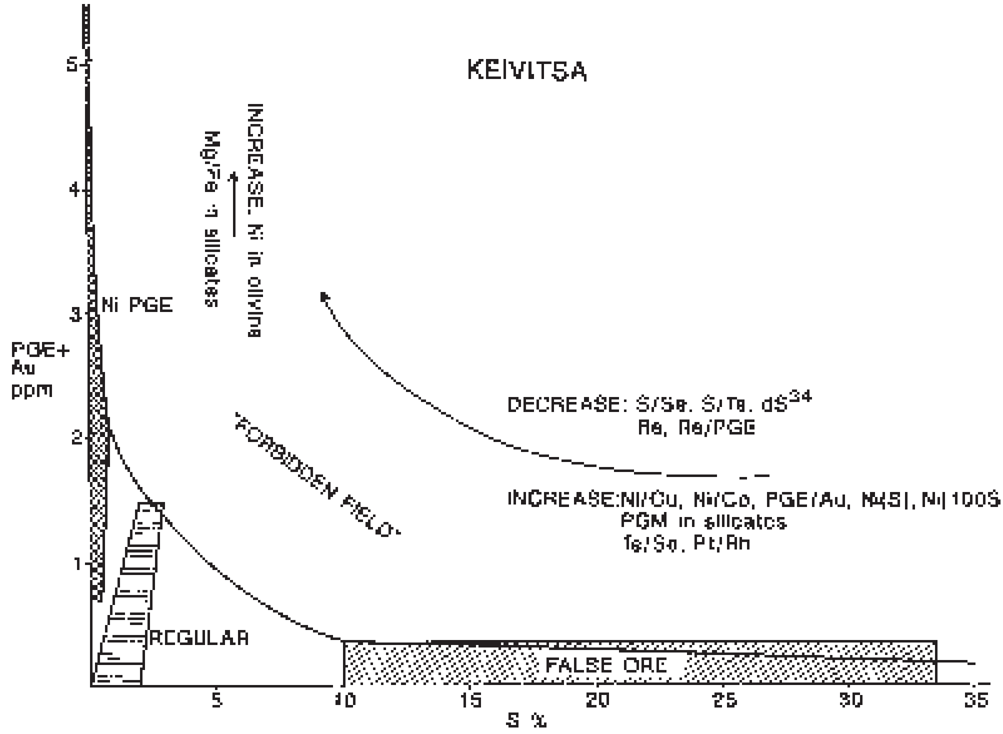

Fig. 4. Precious metals vs. sulphur diagram showing geochemical trends between different ore types. From Mutanen (2005).

Contamination and ore genesis

The abundance of various supracrustal xenoliths attest to strong contamination by country rocks during the emplacement of the intrusion. Contamination is reflected in the isotope composition of the magma and different ore types. The initial epsilon Nd value of -3.5 and gamma Os value of +19.1 indicate substantial crustal contamination (Huhma et al. 1995). The average δ^{34}S value for regular ore is +4.0 ‰, for false ore it is +8.9 ‰, and for Ni-PGE ore it is +6.0 ‰ (Hanski et al. 1996). One analysis from a sulphur-rich sample in the marginal zone has δ^{34}S at +6 ‰. Gabbroic rocks have highly variable δ^{34}S values ranging from +5 ‰ in lower gabbros to a high of +24.4 ‰ in overlying graphite-bearing gabbros and ferrogabbros. Dunite inclusions have δ^{34}S between +5 to +9 ‰, whereas various metasediments have values between +1 to +24.4 ‰, with most values clustering between +17 to +20 ‰. All the intrusion rocks have high positive δ^{34}S values that are outside the range of values for typical mantle-derived sulphur, indicating variable contamination by heavy crustal sulphur. Of the different ore types, the false ore has the highest positive δ^{34}S values indicating the most substantial contamination by sedimentary country rocks (Fig. 4). Contamination is also reflected in the high Cl content of all of the ore types as well as barren ultramafic rocks and the presence of primary Cl apatite and Cl amphibole (dashkesanite).

Two models have been proposed for the ore genesis. Mutanen (1997) attest the formation of the regular and false ore to contamination by variable amounts of komatiitic material and S- and C-rich metasediments, wherein the regular ore received some additional sulphur from the metasediments and additional nickel from the komatiitic material, whereas the false ore was more heavily contaminated by S-rich metasediments, which led to dilution of the ore (Fig. 4). The Ni-PGE ore type has many peculiar features, such as a high REE content (Fig. 5), high Ni content both in sulphide fraction and in olivine (about 1.5 % NiO in olivine, Fig. 6), low S, and a very low Cu content, which make the origin of this ore type more enigmatic. Furthermore, the Ni-PGE ore type formed in a highly reducing, S-poor environment caused by assimilation graphite-rich metasediments, with also some S coming from metasedimentary material (reflected in the S isotopes), and residual olivine from disintegrated komatiites contributing most of the Ni in the ore. The high olivine Ni content is explained by olivine equilibrium with metallic Ni in a highly reducing environment. A different kind of genetic model was proposed by Gervilla et al. (2003), whereby the Ni-PGE ore type is the product of leaching of S and Cu and/or remobilisation of PGE and Ni by metamorphic Cl-rich fluids resulting in the deposition of Ni-rich sulphides and, for instance, unusually Ni-rich braggite.

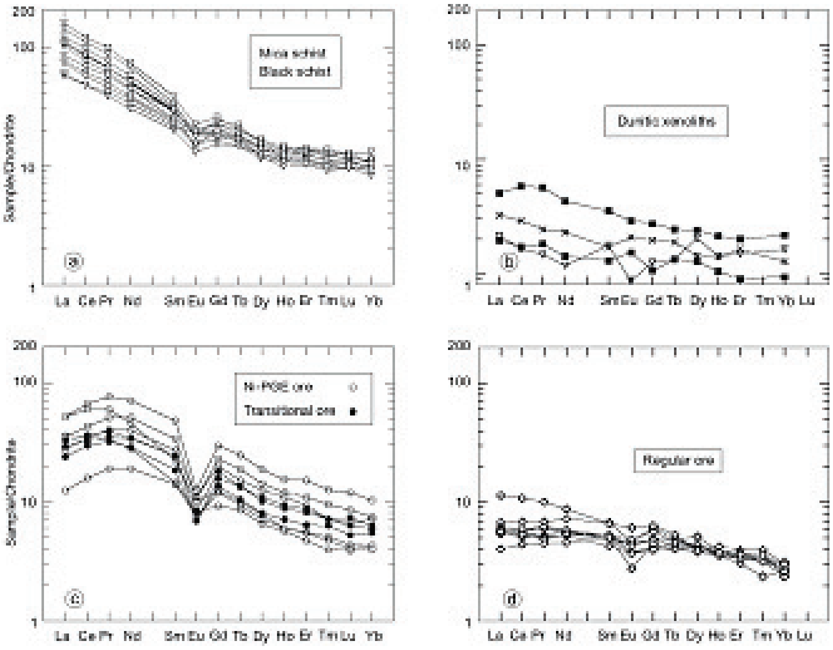

Fig. 5. Chondrite-normalised REE diagram for various rock types of the Kevitsa complex. From Mutanen (2005).

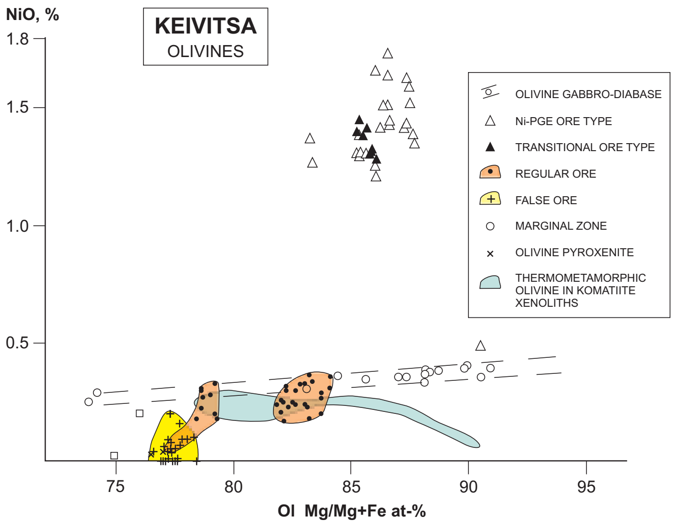

Fig. 6. Kevitsa intrusion olivine NiO (%) content vs. olivine Mg/Mg+Fe (at-%) ratio. From Mutanen (2005).

Mineral resources of the Kevitsa intrusion

Table 1 shows the current mineral resource of the Kevitsa deposit, to a depth of 400 meters, based on the pre-feasibility study of 2006. A full bankable feasibility study is currently underway.

Acknowledgements

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Excursion stops

Stop 1. Kevitsa Cu-Ni-PGE deposit

Variably mineralised olivine pyroxenite and metaperidotite are visible in the recent test pit and rock piles. We will also see some drill core of the various rock and ore types.

Stop 2 Pitted peridotite

Pitted, heterogeneous feldspathic olivine websterite. Orthopyroxene, biotite and sulphide containing parts are eroded into pits, whereas cpx-rich parts are preserved as knobs.

Optional stop

Stop 3. Hanhilehto Hill. Gabbro and roof hornfels

Strongly altered, medium-grained rocks of the gabbro zone. Also pelitic and black schist metahornfels of the roof rocks of the intrusion.

Table 1. Mineral reserve to 400 meters depth at 0.18 % Ni cut-off, July 2006 (Scandinavian Minerals 2007).

	Tonnage	Ni %	Cu %	Co %	Au ppm	Pd ppm	Pt ppm
Proven	56.2 Mt	0.295	0.415	0.014	0.141	0.201	0.310
Probable	10.6 Mt	0.295	0.492	0.015	0.142	0.171	0.267
Total	66.8 Mt	0.295	0.427	0.014	0.141	0.196	0.303