**Finnish historical and current Ni-Cu-PGE deposits highlight country-wide exploration potential**

**Introduction**

In 2017, Finland celebrates its 100 years of independence, but the mining industry has played an even longer important role in its history. Presently, the most significant magmatic Ni-Cu-Cu-PGE (Fig. 1) and Cr-Ti-Pt-V deposits of the European Union are located in Finland, within the Fennoscandian Shield. Historical deposits like the Pechenga and Outokumpu deposits were previously the most important sources of nickel, copper, and cobalt in Finland. Several Paleoproterozoic orogenic intrusion-hosted Ni-Cu deposits in these areas and southern parts of Finland were important metal sources for the Finnish smelters. The intrusion-related Kevitsa Ni-Cu-PGE, black shale-hosted Taltavaara Ni-Cu-Cu, and layered intrusion-related Kemi Cr deposits include significant metal resources. Finland's EEA (European Economic Area) agreement in 1994 and entry into the European Union in 1995 opened exploration and mining opportunities for international companies. They have launched several exploration and mining projects in Finland. However, only a limited amount of exploration has been carried out in Finland compared to Canada and Australia. The recently discovered Sakatti Cu-Ni-PGE deposit has highlighted the good exploration potential of Finland. In addition, the geodata of good quality, available through the Geological Survey of Finland, plays important role in exploration success. Active Ni-Cu-PGE exploration, research and mining, as well as Ni-Cu production in the stainless steel industry, form a comprehensive value chain in Finland.

**Finnish Ni-Cu-PGE deposit types**

The main Ni-Cu-PGE deposit types in Finland are related to komatiite-related Ni-Cu-PGE, intrusion-related Ni-Cu deposits, Paleoproterozoic metamorphosed black shales of the Talvivaara type, and the ultramafic and metasomatic calc-silicate rocks of the ophiolitic Outokumpu association. Several komatiite-hosted Ni-Cu-PGE deposits have been discovered in the Archean and Paleoproterozoic greenstone belts in northern and eastern Finland. Many 2.45 Ga mafic-ultramafic layered intrusions in Finland host contact-type PGE-Ni-Cu deposits and significant reef-type PGE deposits; their Ni resources typically are of low grade but large tonnage. Mafic-ultramafic magmatism at ca. 2.06 Ga produced significant Ni-Cu-PGE resources in the Central Lapland greenstone belt, including the Kevitsa and Sakatti deposits. The Svecofennian domain in central and southern Finland contains hundreds of small, ca. 1.88 Ga, mafic-ultramafic intrusions; many of these host nickel mineralisation (Fig. 1).

![Ni-Cu-PGE exploration potential](image)

**Ni-Cu-PGE exploration potential**

Significant exploration potential exists in the Fennoscandian Shield, which shares a similar geology and metallogeny with the ancient shields in globally (e.g., Canada and Australia). The Archean provinces in eastern and northern Finland include komatiites (ca. 2.8–2.9 Ga) and other rocks of mafic-ultramafic rocks potential for nickel deposits. In the northern Fennoscandian Shield, rifting with mafic-ultramafic magmatism took place in multiple stages during 2.45–2.0 Ga (e.g., Lahitinen et al. 2008). The rifted Archean–Proterozoic boundary hosts several 2.45 Ga layered intrusions hosting mainly PGE-dominant sulphide deposits in the eastern and northern parts of Finland. Rift-related greenstone belts of central Lapland host extensive mafic-ultramafic formations with potential for nickel (e.g., Kevitsa intrusion). From the exploration point of view, formations with potential for nickel deposits are still poorly understood, as the exploration focus has historically been on the outcropping part of the bedrock. Exploration potential has also been highlighted by the GTK in permissive tracts (i.e., Ni-Cu-PGE potential areas and belts) and in the assessments of undiscovered Ni-Cu-PGE resources in Finland (Fig. 2; Rasilainen et al. 2011a, 2010b, 2012).

![Ni-Cu-PGE research](image)

**Ni-Cu-PGE research**

Magnetic sulphide ore research in Finland has developed along with the exploration and mining industry. Exploration and research for the Svecofennian (1.88 Ga) nickel deposits began during the 1930 and continued actively several decades (Papunen and Vorma 1985; Makkonen 2015). In 1960, the Outokumpu Company commenced the Nickel Programme in order to collect extensive petrological database on Finnish mafic-ultramafic rocks, to be used to enhance nickel exploration. One of the most important tools developed within the programme was the use of nickel content in mafic silicates to discriminate between barren and nickel-potential formations (Häkli 1971). A following project produced lithogeochemistry models for nickel exploration (Lamberg 2005).

Extensive magmatic sulphide ore research has also been carried out in numerous projects by the Turku and Oulu universities since the late 1960s and by the GTK (Makkonen 2015 and references therein).

**GTK’s role in Ni-Cu-PGE exploration**

Throughout its history, the GTK has evaluated potential related to magmatic deposits across the country. GTK’s digital databases are well organized, and regarded the best in the World (e.g., Jackson and Green 2016). Country-wide airborne low-altitude geophysical data, till-geochemical data, and the extensive datasets from mafic and ultramafic rocks and related deposits are available online (Mineral Deposits and Exploration, 2017). Exploration reports and GTK and Finnish exploration companies such as Outokumpu Oy are also available through the GTK online services (online spatial data product database - HAKLU). Also available for the private sector are the National Drill Core Archive, GTK’s Mineral Processing Laboratory with the pilot plant (i.e., MINTEC), research facilities, and the services by several experts specialised in Ni-Cu-V deposits.

GTK’s main focus is to support the exploration and mining sector in Finland. As a part of this activity, GTK’s current nationwide Ni-Cu exploration project is focused on poorly explored areas and produces new geodata from prospective areas.

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**Geological Survey of Finland**

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**Figure 1. Distribution of Ni-Cu-PGE deposits in Finland, and Ni and PGE deposits in other parts of the Fennoscandian Shield. Yellow stars show location of the Kevitsa, Kevitsa and Pechenga deposits. Base map: combined gravimetric + magnetic (red = high gravity, blue = low gravity). Source: Fennoscandian Ore Deposit Database (FODD 2016)**

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**Figure 2. The mean estimate of undiscovered Ni-(Cu-PGE) resources in the Ni-Cu-PGE exploration potential**

<table>
<thead>
<tr>
<th>Deposit Type</th>
<th>Archean</th>
<th>Proterozoic</th>
<th>Phanerozoic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maturity</td>
<td>0.0 - 0.1</td>
<td>0.1 - 0.2</td>
<td>0.2 - 0.3</td>
</tr>
<tr>
<td>Resource estimation (t)</td>
<td>0.3 - 0.4</td>
<td>0.4 - 0.5</td>
<td>0.5 - 0.6</td>
</tr>
<tr>
<td>Potential index</td>
<td>0.6 - 0.7</td>
<td>0.7 - 0.8</td>
<td>0.8 - 0.9</td>
</tr>
</tbody>
</table>

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**Legend**

- Blue = Archean deposits
- Green = Proterozoic deposits
- Red = Phanerozoic deposits

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Reading the GTK geological map database (Bedrock of Finland–DigiKP)
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Introduction

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Finland’s EEA (European Economic Area) agreement in 1994 and entry into the European Union in 1995 opened exploration and mining opportunities for international companies. They have launched several exploration and mining projects in Finland. However, only a limited amount of exploration has been carried out in Finland compared to Canada and Australia. The recently discovered Sakatti Cu-Ni-PGE deposit has highlighted the good exploration potential of Finland. In addition, the geodata of good quality, available from Geological Survey of Finland, plays important role in exploration success. Active Ni-Cu-PGE exploration, research and mining, as well as Ni-Cu production in the stainless steel industry, form a comprehensive value chain in Finland.

Finnish Ni-Cu-PGE deposit types

The main Ni-Cu-PGE deposit types in Finland are related to Archean magmatic-ultramafic intrusions. Paleoproterozoic metamorphosed black shales of the Talvivaara type, and the ultramafic and metasomatic calc-alkaline complexes of the Outokumpu association. Several komatiite-hosted Ni-Cu-PGE deposits have been discovered in the Archean and Paleoproterozoic greenstone belts in northern and eastern Finland. Many 2.45 Ga mafic-ultramafic layered intrusions in Finland host contact-type PGE-Ni-Cu deposits and significant reef-type PGE deposits; their Ni resources typically are of low grade but large tonnage. Mafic-ultramafic magmatism at ca. 2.06 Ga produced significant Ni-Cu-PGE resources in the Central Lapland greenstone belt, including the Kevitsa and Sakatti deposits. The Svecofennian domain in central and southern Finland contains hundreds of small, ca. 1.88 Ga, mafic-ultramafic intrusions; many of these host nickel mineralisation (Fig. 1).

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Geological Survey of Finland

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Ni-Cu-PGE research

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Extensive magnetic sulphide ore research has also been carried out in numerous projects by the Turku and Oulu universities since the late 1960s and by the GTK (Makkonen 2015 and references therein).

Comprehensive compilations of Finnish nickel deposits include the work by Papunen and Gorbonov (1985), where the nickel-copper deposits of the Fennoscandian Shield and Scandinavian Caledonides were described, the work by Puustinen et al. (1995), the public FINNICKEL data base (Makkonen et al. 2009), the nickel chapters in Eilu et al. (2012), the assessment of undiscovered Ni-Cu-PGE resources in Finland (Rasilainen et al. 2010a, 2010b, 2012, 2014) and chapters in Mineral deposits of Finland (Maier et al. 2015).

GTK’s role in Ni-Cu-PGE exploration

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Processing Laboratory with the pilot plant (i.e., MINTEC), research facilities, and the services by several experts specialised in Ni-Cu-PGE research.

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