Exploration potential of Finland

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Mining & Metals in Finland

- **42 mines reported production in 2016:**
  - 12 metal, 30 industrial minerals

  - 242 M€ in 2016

- Estimated investments 2016–2025: **3000 M€**

- Turnover 1500 M€ in 2015

- Mining and metal-related exports 6700 M€ in 2014

### 2015 ore output (Mt)

- **> 10**
- **1.0 - 10**
- **0.5 - 1.0**
- **0.1 - 0.5**
- **< 0.1**

- **Metals**
- **Industrial minerals**
Finland: mining history milestones, selected mines

Value of past production and remaining mineral resources

Operating years of the mines with the highest total value

Commodity values calculated as the mean of annual mean prices between 2003–2012.
Source: Fennoscandian Ore Deposit Database (FODD)
Mine development projects in Finland

<table>
<thead>
<tr>
<th>Project</th>
<th>Commodity</th>
<th>Resource/Reserve</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sakatti</td>
<td>Ni, Cu, PGM</td>
<td>TBA, World class discovery</td>
<td>Anglo American</td>
</tr>
<tr>
<td>Suhanko</td>
<td>PGM, Ni, Cu, Au</td>
<td>208 Mt¹ @1.83 g/t 2PGM</td>
<td>Goldfields</td>
</tr>
<tr>
<td>Mustavaara</td>
<td>V, Fe, Ti</td>
<td>99 Mt² @14% Fe₂O₄</td>
<td>Mustavaaran Kaivos Oy</td>
</tr>
<tr>
<td>Kolari</td>
<td>Fe, Cu, Au</td>
<td>115 Mt⁵ @30.5% Fe</td>
<td>Hannukainen Mining Oy</td>
</tr>
<tr>
<td>Otanmäki</td>
<td>V, Ti, Fe</td>
<td>36.6 Mt³ @0.26% V</td>
<td>Vuorokas</td>
</tr>
<tr>
<td>Kaustinen</td>
<td>Li, Ta</td>
<td>4.49 Mt⁵ @1.1% Li₂O</td>
<td>Keliber</td>
</tr>
<tr>
<td>Koillismaa</td>
<td>PGM, Cu, Ni, Au</td>
<td>46.8 Mt³ @0.43-0.99 g/t 2PGM, two deposits</td>
<td>Nickel One/Nortec</td>
</tr>
<tr>
<td>Taivaljärvi</td>
<td>Ag, Au, Pb, Zn</td>
<td>2.76 Mt³ @124 g/t Ag</td>
<td>Sotkamo Silver</td>
</tr>
<tr>
<td>Sokli</td>
<td>P, Fe, (REE, Nb)</td>
<td>120 Mt³ @14.3% P₂O₅</td>
<td>Yara</td>
</tr>
<tr>
<td>Kuusamo</td>
<td>Au, Co, U, REE</td>
<td>3.9 Mt¹ @4.1 g/t Au</td>
<td>Nero Projects</td>
</tr>
<tr>
<td>Kuotko</td>
<td>Au</td>
<td>1.9 Mt¹ @2.89 g/t Au</td>
<td>Agnico Eagle</td>
</tr>
</tbody>
</table>

¹ Measured, Indicated and Inferred, ² Measured and Indicated, ³ Indicated and Inferred, ⁴ Inferred, ⁵ Proven and Probable
## Exploration projects
### Emerging projects and project opportunities

<table>
<thead>
<tr>
<th>Project</th>
<th>Resource/Intercepts/Assays</th>
<th>Investigated by</th>
</tr>
</thead>
</table>
| Rompas–Palokas | 3/6/2017:  
• A new style of gold-bearing system at South Rajapalot, 900 m along strike and 400 m in width that remains open  
• 56 m of gold-bearing mineralization, incl. 2.0 m @ 3.6 g/t Au and 4.0 m @ 3.7 g/t Au  
• 2.2 m @ 7.7 g/t Au  
• 10.0 m @ 11.6 g/t Au (2/21/2017) | Mawson Resources                  |
| Risti       | 36 rock samples which assayed greater than 31 g/t Au (1 ounce/t)                                                                                                                                                           | Aurion Resources Ltd.            |
| Kiviniemi   | 2 180 t Sc; 1 080 t Y; 23 100 t Zr                                                                                                                                                                                        | GTK¹                             |
| Kitinen, Pelkosenniemi, Pulju | Ni, Ni-Cu, Ni-Cu-PGM, Au  
Promising greenfield projects throughout Finland                                                                                                                      | Magnus Minerals                 |

¹ Exploration permits no longer held by GTK
Mines, exploration tenements, main targets

tenements as of 15 May 2016
GTK has discovered 21 past-producing and producing deposits

2015 turnover
Kittilä ≈ 160 M€
Kevitsa ≈ 150 M€
Outokumpu Cr ≈ 350 M€
GTK’s role in mineral potential mapping

Main aim to increase the interest of industry to invest in Finland

- New information for society and exploration companies
- Methodical, cost-effective and persistent production of new field data
- Collection, organization and interpretation of existing data; maximal utilization of data produced by others
  - TUKES-GTK data flow, reformation of layman sampling procedures
- Mapping of new geological zones for recognizing their mineral potential; application and testing of exploration models
- Validation of exploration models via drilling in selected locations
- Protecting the testing locations by exploration licences (if necessary) for impartiality – not for competing with companies
Mineral potential mapping in GTK

Industrial Minerals

Mineral Resources

Ore Geology and Mineral Economics
Mineral System

1 ENERGY

2 LIGANDS

3 SOURCE

4 TRANSPORT

5 TRAP

6 OUTFLOW/SINK

- From traditional geological datasets to mappable expressions of mineral systems
- Need to revive the old concept of metallogenic maps with new ideas
Mineral System

- All geological factors that control the generation and preservation of mineral deposits” (Wyborn et al., 1994)
- Traditional geological maps are insufficient
- Need consistent maps of essential metallogenic information that would adequately characterise mineral systems:
  - Geochronology and genetic links of mineralisation
  - Lithospheric to local-scale domains and damage zones
- The general concepts are translated into mappable targeting criteria and used in exploration targeting
Research in different scales

- Critical mappable geological, geochemical and geophysical indications of mineral forming processes
- 2D-3D-4D modelling: Geological features indicating the age and location of the critical processes
- Mineral prospectivity mapping: Evaluation of the mineral potential and selection of target areas for exploration

Legend:
- IOCg deposits shown in red
- Fuzzy membership

Scale:
- nm
- µm
- mm
- m
- km
Undiscovered resources

- Assessments of undiscovered mineral resources in Finland since 2008, by GTK
  - PGE, Ni, Cu, Zn, Au, Cr completed
  - V, Fe, P, REE, Li coming
- USGS Three-part quantitative assessment method used:
  - Permissive tracts defined (and ranked)
  - Probability estimates on undiscovered resources
Orogenic gold - Permissive tracts and number of undiscovered deposits

- **Permissive tracts**
  - 32 tracts, 110,000 km² (35% of area)
    - **Archaean** tracts: 8
      - Area: 28,800 km²
      - Known deposits: 5
      - Expected undiscovered deposits: 18
    - **Karelian** tracts: 13
      - Area: 61,000 km²
      - Known deposits: 2
      - Expected undiscovered deposits: 45
    - **Svecofennian** tracts: 11
      - Area: 25,000 km²
      - Known deposits: 8
      - Expected undiscovered deposits: 27
- 90 undiscovered deposits
Undiscovered resources (Ni & PGE)

Median undiscovered resources

Ni (t)
- < 10,000
- 10,000 - 50,000
- 50,000 - 100,000
- 100,000 - 500,000
- > 500,000

Phanerozoic
Proterozoic
Archaean

Median undiscovered resources

Pt + Pd (t)
- < 50
- 50 - 100
- 100 - 500
- 500 - 1000
- > 1000

Phanerozoic
Proterozoic
Archaean
Ni-Cu and ± PGE deposits in Finland

- Ni-Cu in 1.89–1.87 Ga synorogenic mafic-ultramafic intrusions: 35 known deposits, >80 occurrences, 10 mines
- Ni-Cu in ~2.8 Ga and ~2.05 Ga komatiitic rocks: 6 known deposits, 26 occurrences, 1 mine
- Ni-Cu-PGE in ~2.45 Ga layered intrusions: 6 known deposits, 34 occurrences, no mines
- Ni-Cu-PGE in the Sakatti deposit
  - Potential of ca 2.05 Ga (?) mafic-ultramafic magmatism
How mature are the active exploration districts in Finland?

Recent discoveries

Sakatti, Sodankylä (Anglo American)

Romiaps-Rajapalot, Peräpohja (Mawson Resources)

Risti-Aamurusko (Aurion Resources)

Photo: www.aurionresources.com
Case Central Lapland Greenstone Belt (CLGB)

- Paleoproterozoic greenstone-schist belt deposited on an Archean basin
- Metamorphosed and deformed during 1.91-1.80 Ga Svecofennian events
- Active gold exploration started in 1980’s
  - One world class (>3 Moz) deposit, few economic, but small deposits, a number of known occurrences
  - Orogenic gold, IOCG, massive sulfide-hosted Au, paleoplacer
- Known orogenic gold deposits bear similar characteristics as in other gold districts around the world
Orogenic Au deposits of CLGB

- Total known Au ≈ 10 Moz
- One world class deposit (Kittilä, almost in “giant” category, 8.9 Moz, 12/2015)
- Rest of the significant deposits in size range between 0.15 to 0.35 Moz
- Almost 90% of reported Au hosted by a single deposit!
Norseman-Wiluna belt, WA

- Archean greenstone-schist belt
- Most of the gold deposits orogenic-Au-type
- 100+ years of active gold exploration

Data: Gosselin & Dubé (2006)
Abitibi belt, Canada

• Archean greenstone-schist belt with 100+ years active exploration
• Very rich in gold; total Au endowment c. 170 Moz (Orogenic-Au + IR-Au)

Data: Gosselin & Dubé (2006)
Zimbabwe Craton

- Archean greenstone-schist belts
- Orogenic Au dominates
- 100+ years exploration

Data: Gosselin & Dubé (2006)
Comparison

• No direct correlation between the size of the belt and total gold endowment
• There appears to be a fractal pattern in size distribution of the orogenic gold districts with prolonged exploration history
• CLGB data is very skewed compared to the other belts due to Suurikuusikko

“Watson, I smell something fishy in here!”
All these histograms made me to think about... broccoli (Roman couliflower)!

Fracture patterns in deformed rocks and their potential connection to orogenic gold deposits

Kittilä Mine Suurikuusikko Au-ore
The seismic events and magnitude of these events in seismic region follow near logarithmic relationship of:

$$\log_{10} N = a - bM$$

where $N$ is number of events having magnitude $> M$, and $a$ and $b$ are constants
- $b$ is typically close to 1 (0.5 – 1.5)
- $a$ reflects the total seismicity rate of the region

Similar correlations has been discovered in multiple natural systems -> link to the theories of Self Organized Criticality (SOC), eg. fractal geometry
Testing GR-law to size distribution of orogenic gold deposits in well known gold districts

- Near logarithmic correlation between deposit size and number of deposits
- Good correlation in each data sets, $b$ between 0.620 and 0.944
- $a$ does indeed appear to correlate to total gold endowment of the data sets
What about CLGB?

- Poor correlation
  - sample set too small
  - small (< 0.1 Moz) deposits included

- Either the OG deposits in CLGB follow completely different size distribution
  OR
- The data reflects the low exploration history and hence the high amount of undiscovered orogenic gold deposits in the district

- correlates well with other data sets in small deposit sizes – emphasizes the abnormal size of Suurikuusikko

- more deposits are needed in here and here for data set to fit the gray area!
The key message:

• The size of the orogenic gold deposits in gold districts with long exploration history appear to follow near logarithmic distribution similar to GR-law
  – Links to the seismic activity of the shear zones hosting the gold?
  – Links to the self organized criticality and/or self similarity? - do mineralizing systems follow fractal behaviour?
  – Can GR-law be used to predict metal endowment of less explored districts?

• The known orogenic gold deposits within CLGB follow highly skewed size distribution compared to districts with long exploration history

• **Much of the CLGB is ”green fields” in respect to exploration of orogenic gold. It is very likely that considerable amount of undiscovered gold remains within the district, including deposits in >1 Moz category**
Summary:

• Proven potential in several districts
• GTK’s role in exploration:
  – National geodata center
  – More emphasis in outlining prospective districts – less direct exploration of targets
• New discoveries in districts with *relatively* active exploration history + expertise and statistics based assessments ->

Exploration potential is high in several districts in Finland
Much of the known high-potential districts are still ”green fields”