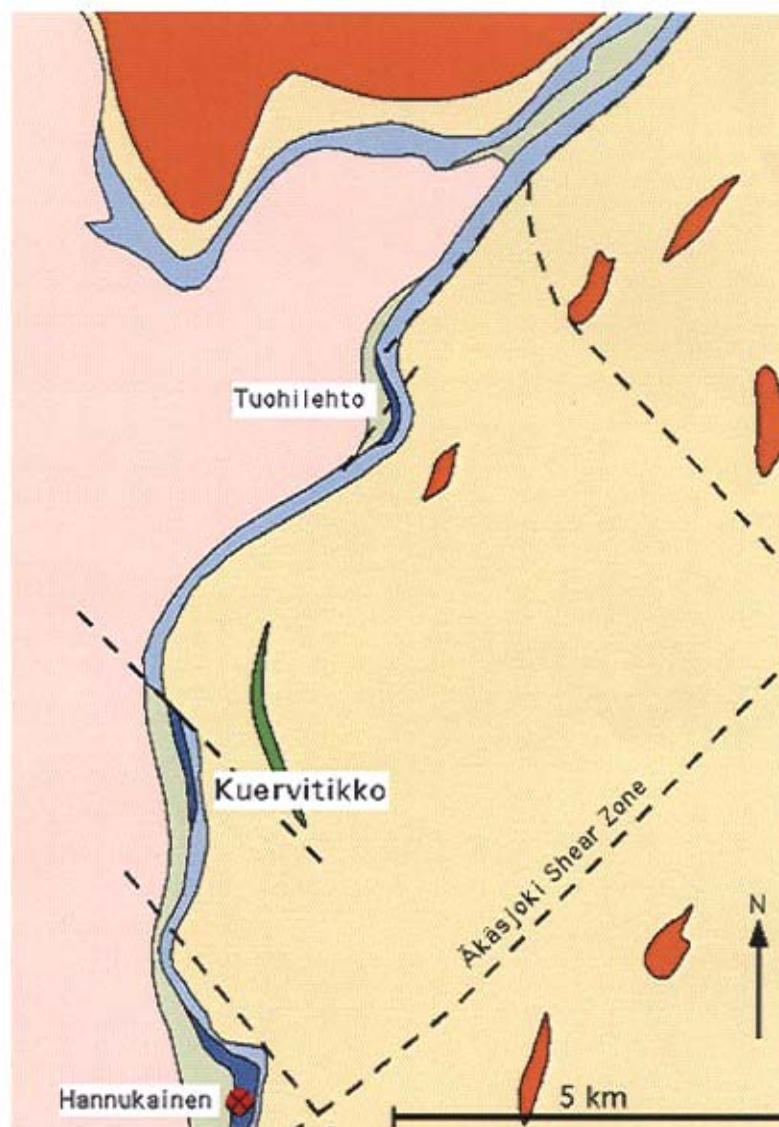


## Iron oxide-copper-gold deposits in Finland



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<b>Title of report</b> Iron oxide-copper-gold deposits in Finland			
<b>Abstract</b> <p>Iron oxide-copper-gold deposits (IOCG) probably occur in several areas in northern Finland. the most obvious members of this group are the Vähäjoki deposit in Tervola, Peräpohja schist belt and deposits in Kolari, in the westernmost part of the Central Lapland greenstone belt. Also, the auriferous quartz haematite veins in the Vuotso-Ivalo area can be included into the IOCG class <i>sensu lato</i>. The Au-Co Cu±U in the Kuusamo schist belt apparently represent a transitional type between orogenic and IOCG type. In the Misi area, several features suggest IOCG style of mineralization, but no significant gold or copper occurrence has so far been detected.</p> <p>Northern Finland is potential for the IOCG style of mineralization, because: 1) the main Proterozoic orogeny in the area took place at 1.9-1.8 Ga (globally favourable timing); 2) styles of regional alteration (extensive albitization and scapolitization); 3) styles of Au-Cu-Fe mineralization: multi-stage Fe±Ca±Mg±K±Na alteration, mineral association magnetite-chalcopyrite-pyrite-pyrrhotite-gold, metal association Fe-Au-Cu ± As, Bi, Co, K, Li, LREE, Mo, Se, Te, U, W, Y; 4) abundance of early- to late orogenic intrusions (potential heat, metal and fluid sources); 5) apparently extensive evaporates (potential source for saline fluid); 6) abundant sulphidic shales (potential metal and sulphur source); 7) extensive rifting (extensional tectonics).</p>			
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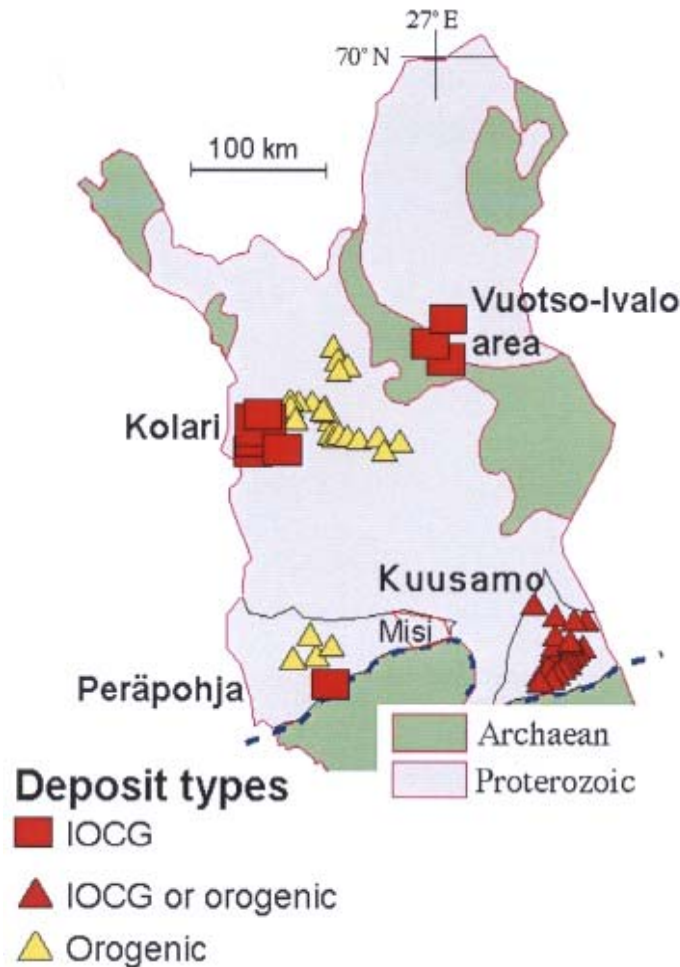
### Summary

*Iron oxide-copper-gold deposits (IOCG) probably occur in several areas in northern Finland. The most obvious members of this group are the Vähäjoki deposit in Tervola, Peräpohja schist belt, and magnetite-hosted deposits in Kolari, in the westernmost part of the Central Lapland greenstone belt. Also, the auriferous quartz-haematite veins in the Vuotso Ivalo area can be included into the IOCG class sensu lato. The Au-Co-Cu±U occurrences in the Kuusamo schist belt may represent a transitional type between orogenic gold and IOCG type. In the Misi area, central southern Lapland, several features suggest IOCG style of mineralization, but no significant gold or copper occurrence has so far been detected.*

### Introduction

Northern Finland is potential for the IOCG style of mineralization because of a number of favourable or characteristic factors for the deposit category (Hiltunen 1982, Liipo & Laajoki 1991, Pankka & Vanhanen 1992, Eilu 1994, Frietsch et al. 1997, Lehtonen et al. 1998, Vanhanen 2001): 1) the main Proterozoic orogeny in the area took place at 1.9-1.8 Ga (globally favourable timing); 2) styles of regional alteration (extensive albitization and skapolitiization); 3) style of the discovered Au-Cu-Fe mineralization: local multi-stage Fe±Ca±Mg±K±Na alteration, ore mineral association magnetite-chalcopyrite-pyrite-pyrrhotite-native gold, metal association Fe-Au-Cu ± As, Bi, Co, K, Li, LREE, Mo, Se, Te, U, W, Y; 4) abundant early- to late-orogenic intrusions (potential heat, metal and fluid sources for all stages of deformation); 5) apparently extensive evaporates (potential source for saline fluid); 6) abundant sulphidic shales (potential metal and sulphur source); 7) extensive rifting (extensional tectonics).

Greenstone belts and other regions potential for IOCG mineralization in Finland include the Peräpohja schist belt, westernmost part of the Central Lapland greenstone belt (the Kolari area), Kuusamo schist belt, and the Vuotso-Ivalo area (Fig. 1). Their IOCG features are presented below. More details and figures of the deposit is presented in the FINGOLD database; see: [www.gsf.fi/explor/gold](http://www.gsf.fi/explor/gold).



**Figure 1.** Gold occurrences and potential IOCG areas in northern Finland. Based on the FINGOLD database and references therein (see the Gold Page at: [www.gsf.fi/explor](http://www.gsf.fi/explor)). The Misi area, where no significant gold occurrences have yet been discovered, forms the easternmost part of the Peräpohja schist belt.

## Peräpohja schist belt

Main target: Vähäjoki in the municipality of Tervola. This is the rectangle marked in the Peräpohja belt domain in Figure 1. The list below shows the IOCG-characteristics of the Vähäjoki deposit.

1. Metal association As-Au-Co-Cu-Fe; no analytical data on other elements (Korvuo 1982). Main ore minerals are magnetite, pyrite, chalcopyrite, and cobaltite. Ilmenite, haematite, arsenopyrite, sphalerite, galena, mackinawite, linneaite, bornite, marcasite, pyrrhotite, and native gold are detected in minor to trace amounts (Vornanen 1963, Korvuo 1982). Native gold occurs as free among gangue and arsenides and as inclusions in cobaltite.
2. The ore bodies comprise magnetite with skarnoid gangue dominated by tremolite-actinolite, cummingtonite, and hornblende. Magnetite forms breccia matrix, veins, blobs and irregular masses. The volume of magnetite is much higher than that of sulphides which form <1-5 vol.% of ore.

3. Sulphide mineralization is in all cases hosted by the ironstone.
4. Structural control is not well defined, but the magnetite bodies seem to be within shear zones. According to Vesa Perttunen (pers. comm. 2001), the deposit is in a fold hinge, near a major fault.
5. Local alteration is characterised by formation of magnetite and Ca metasomatism (formation of tremolite, hornblende and cummingtonite; Liipo & Laajoki 1991). In addition, there is low-degree albitization and skapolitization around the magnetite bodies. No extensive albitization has been detected.
6. Fluids: preliminary studies suggest two fluid stages. High-salinity brine (H<sub>2</sub>O-NaCl fluid) associated with precipitation of magnetite. Low-salinity H<sub>2</sub>O-CO<sub>2</sub> fluid associated with AuCo-Cu mineralization.
7. Sources for fluid, ligands and metals are present. There is a supracrustal sequence with evaporates (extensive dolomites). No synorogenic intrusions exist in the area. Only minor pegmatite dykes have been detected in drill core. These could be related to a hidden intrusion below the deposit - this could also explain the synmetamorphic thermal high characterizing the Vähäjoki area.
8. Temperature during magnetite mineralization was between 400-500°C (Liipo & Laajoki 1991).
9. Extensional tectonics has taken place the region.
10. Timing of mineralization is unclear. In any case, there seems to be a time gap between magnetite and sulphide-gold mineralization.

### Misi area

The Misi area forms the easternmost part of the Peräpohja schist belt. It contains more than ten magnetite deposits four of which have been mined for iron during 1958-1975 (Nuutilainen 1968, Siirama 1976). Although the iron deposits of the area only show uneconomical Cu and Au values many features of them fit to the IOCG style of mineralization. These are (Niiranen et al. *submitted*):

1. Metal association Fe ± As, Au, Co, Cu, Te. However, no significant correlation between the commodity metals has been detected. Ore mineral assemblage magnetite ± pyrite ± chalcopyrite ± bornite.
2. The ore bodies essentially comprise magnetite. Sulphides typically form <1 vol.% of bulk ore.
3. Albite rocks are closely associated with the iron deposits. All magnetite masses and albitites are epigenetic and have a distinct structural control being sited in E-W trending structures. This trend clearly departs from the dominant NW-trend of the lithological units in the region.
4. Alteration is characterized by regional skapolitization and albitization with overprinting, structurally-controlled, intense albitization. Sequence of alteration is, from the earliest to the youngest: 1) regional albitization and skapolitization of variable intensity; 2) local intense albitization; 3) formation of magnetite and Ca-Mg-H<sub>2</sub>O-metasomatism (formation of tremolite, serpentine, talc, chlorite), and sulphide precipitation; 4) low-degree carbonation.
5. Highly saline H<sub>2</sub>O-NaCl+CO<sub>2</sub>±NH<sub>3</sub> fluids are associated with albitization and formation of the magnetite deposits.

6. Several potential sources for fluid, ligands and metals are present: a supracrustal sequence with evaporates (extensive dolomites), abundant syn- or late-orogenic granitoids.
7. Temperature during magnetite mineralization probably was between 350-500°C.
8. Possibly, extensional tectonics.
9. Timing between 2.14 and 1.8 Ga.

For the Misi area, it must be noted that the locations characterized by sulphides have not been drilled in any significant extent. Rather, they were avoided during the previous iron exploration campaigns. Also, the ore potential of the intensely albitised rocks has not been investigated in any detail; the albitites are in many locations the most competent lithological units and, hence, also potential for epigenetic Au-Cu mineralization.

### **Kolari area**

Main IOCG targets are located along the contact of a large, synorogenic monzonite: Kuervitikko, Laurinoja and other magnetite bodies at Hannukainen, and Cu-Rautuvaara (Hiltunen 1982, 1989, Keinänen 1995).

1. Metal association Au-Cu-Fe-Te ± Ag, Bi, Co, Mo, LREE, Se. No data on fluorine. No distinct enrichment in Ba, Sb, U or W. Main ore minerals are magnetite, pyrite, chalcopyrite, and pyrrhotite. Native gold has been detected in close association with chalcopyrite.
2. The ore bodies comprise magnetite with skarnoid gangue dominated by diopside and hornblende. Sulphides form <1-5 vol.% of ore.
3. Sulphide mineralization is hosted by the ironstone and albitised monzonite.
4. Structural control: the magnetite bodies are in locations where a fault seems to cut across the contact between the monzonite and its country rocks.
5. Multi-stage alteration: regional albitization and skapolitization, local biotitisation and Ca-metasomatism (diopside + hornblende).
6. No data on fluids available.
7. Multiple potential source for fluid, ligands and metals: the synorogenic intrusion + late-orogenic(?) intrusion + a supracrustal sequence with evaporates (extensive dolomites).
8. Temperature during magnetite mineralization was between 500-600°C. 9. Extensional tectonics has taken place.
10. Timing 1.86-1.75 Ga; there seems to be a time gap between magnetite and sulphide-gold mineralization.

In addition to the deposits mentioned above, there are Au-Cu occurrences (e.g., Lauttaselkä, Akäsaivo; Hiltunen 1989, Keinänen 1996) in structurally controlled locations several kilometres away from the detected magnetite bodies and synorogenic granitoid intrusions. These are hosted by metavolcanic and metasedimentary rocks. They contain disseminated magnetite and their gangue is characterized by albite, carbonates, diopside and Ca amphibole.

### Kuusamo schist belt

More than 20 Au±Cu±Co±U deposits and occurrences have been discovered in the Kuusamo schist belt. Their characteristic features are (Pankka & Vanhanen 1992, Vanhanen 2001).

1. Metal association Au-Cu-Co ± Ag, As, Ba, Bi, Co, Cu, Fe, K, Li, LREE, Mo, Pb, Rb, Se, Te, Th, U, V, W, Y. Main ore minerals are pyrrhotite, pyrite, chalcopyrite, cobaltite, cobaltian pentlandite, native gold and uraninite.
2. Fe-oxides are present in the ores, but in relatively low amounts, less than or at the same amount as total sulphides. The volume of sulphides typically is 1-5 vol.%.
3. Deposits are typically hosted by albitised metasedimentary rocks (albitization predates sulphidation). There are no deposits hosted by ironstones.
4. Structural control is distinct: nearly all occurrences are at intersections between two major antiforms of the belt and shear and fault zones. Note that this is a feature which also is characteristic for the orogenic style of gold mineralization.
5. Multi-stage alteration is detected in all cases investigated in detail: early regional albitization and skapolitization is followed by local intense (even total) albitization, and local multi-stage Fe-K-S-H<sub>2</sub>O-CO<sub>2</sub>±Mg metasomatism.
6. Fluids related to albitization and skapolitization probably were highly saline. Later fluids were either brines or of low salinity.
7. Sources for fluid, ligands and metals are extensively present: a supracrustal sequence with evaporates (extensive dolomites with clear evidence of salt deposits) + syn-orogenic granitoids to the west and northwest of the schist belt.
8. Temperature during alteration and sulphide mineralization was between 300-500°C. 9. Extensional tectonics is typical for the region.
10. Timing: between 1.89 and 1.80 Ga.

### Vuotso-lvalo area

There are a number of quartz-haematite veins in the area. These contain magnetite, carbonates, albite, baryte, pyrite and native gold in variable amounts. The best known veins are at Hirvasselkä, Mäkärärova and Palokiimanselkä (Härkönen 1987, Ollila 1976, Kinnunen 1980).

1. Metal association Au-Fe ± Ba, Bi, Cu, Te, W. Main ore minerals are haematite, pyrite, chalcopyrite and native gold.
2. The dominant Fe-oxide is haematite; the volume of sulphides is variable, but smaller than that of haematite.
3. There are no ironstones. The style of mineralization is in all cases a vein. The veins are hosted by Archaean and Palaeoproterozoic rocks with no obvious genetic relationship with the veins. 4. As the deposits are veins, there has to be a structural control, but this aspect has not been investigated. The veins were obviously formed during brittle stage(s) of deformation.
5. Alteration is reported to be single-stage, low-degree hydration and carbonation of the wallrocks of the veins only extending up to 5 metres away from the veins.
6. Fluid inclusion data from Palokiimanselkä: 24% NaCl eq., oxidising fluid, p = 2.0 kbar if T = 280°C (this is a minimum temperature estimate).

7. Sources for fluid, ligands- and metals: the local supracrustal association, syn- and late-orogenic granitoids. There are no known indications of evaporates in the region.
8. Temperature during vein mineralization possibly was between 250-350°C. 9. Presence of extensional tectonics not well established.
10. Predate(?) the late- or post-orogenic Nattas-granites, hence older than 1.80-1.77 Ga?

## **Conclusions**

In Finland, the most potential areas for IOCG mineralization are the Kolari region in the westernmost Central Lapland, and parts of the Peräpohja and Kuusamo schist belts. Especially, the chalcopyrite-gold deposits hosted by magnetite rocks in Kolari and Peräpohja share nearly all of the features held typical for the deposit category. Metal association, styles of alteration, close spatial relationship with possible evaporates, and tectonic setting of the Kuusamo Au deposits are similar to that in the IOCG category. On the other hand, their structural setting, metamorphic grade, absence of major masses of Fe oxides and absence of any obvious genetic relationship with intrusion better fit with the orogenic mesothermal category, although these features do not exclude the deposits in Kuusamo from the IOCG category.

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