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Gold Prospectivity of Finland:

Workshop & Fieldtrip Notes 07.05.2006 – 19.05.2006

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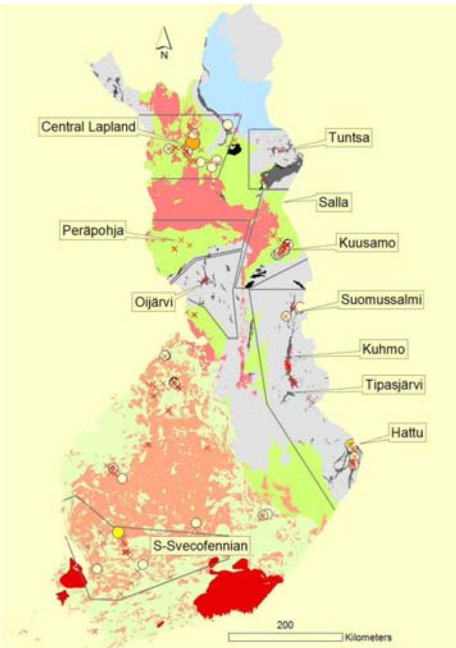

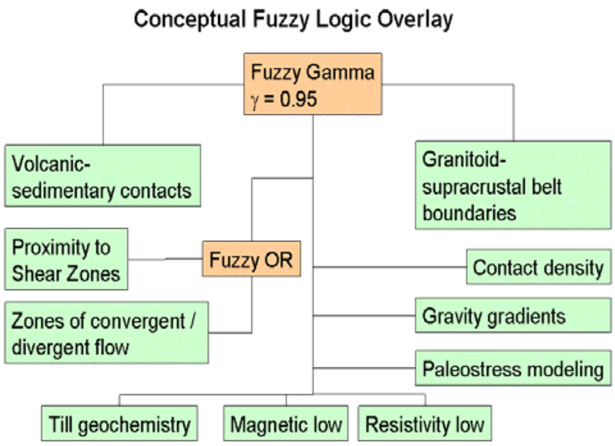

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Abstract

Gold prospectivity of Finland was assessed to refine exploration criteria for future work on different deposit classes or styles. For the prospectivity assessment, Finland was divided into geologically different terrains, and these included SW Finland, the Tampere Schist Belt, the Ilomantsi Belt (Hattu Schist Belt), the Kuhmo and Suomassalmi greenstone belts, the Kuusamo Schist Belt, the Peräpohja Schist Belt, and the Central Lapland Area. The specific modelling criteria suggested for each type of mineralisation are summarised at the end of the report. The general criteria and comments regardless of mineralisation type include:

- a suitable seal/trap, a suitable fluid conduit exists, and a suitable element source should be present
- regional contacts between volcanic and sedimentary rocks should be included in all models
- structural data should be incorporated into most data sets
- geochemical gradients should be used in preference to actual anomaly values
- classification of the deposits is important as empirical GIS models should only use similar deposits as learning points
- schist areas can probably be excluded from modelling, with emphasis instead placed on sediment/volcanic belts and contacts
- dating of deposits is required to compare mineralisation ages to the age ranges of crustal formation events
- tectonic settings helps to define the likely deposit types to exist
- areas with thin lithosphere and major boundaries important
- distribution of anomalous intrusion types to help identify tectonic environments and crustal depths exposed

Keywords

Gold, GIS, prospectivity, modelling

Geographical area

Finland, Tampere, Outokumpu, Ilomantsi, Kuhmo, Kuusamo, Lappi

Map sheet

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Tiivistelmä

Työpajan tarkoituksena oli arvioida kullan esiintymisen otollisuutta Suomessa, jotta eri kultamalmityyppien malminetsintä kriteerejä voitaisiin parantaa. Työssä Suomi jaettiin geologian perusteella seuraaviin osa-alueisiin: Lounais-Suomi, Tampereen liuskejakso, Hatun liuskejakso, Kuhmo-Suomussalmen vihreäkivivyöhyke, Kuusamon liuskejakso, Peräpohjan liuskejakso ja Keski-Lapin alue. Eri malmityyppeille ehdotetut mallinuskriteerit on listattu raportin lopussa. Yleisiä kaikille malmityypeille huomioon otettavaksi ehdotettuja kommentteja:

- metallin lähde, sopiva kulkutie ja malmiutumispaikka pitäisi olla määritettävissä
- alueelliset sedimenttikivien ja vulkaniittien kontaktit ovat tärkeitä
- rakennegeologinen data pitäisi pystyä sisällyttämään malleihin
- geokemialliset gradientteja pitäisi käyttää mieluummin kuin anomalia arvoja
- esiintymien luokittelu on erityisen tärkeää jos GIS mallinuksessa käytetään opetuspisteitä
- liuskealueet, joissa ei ole vulkaniitteja, voidaan pitää toissijaisina vulkaniittijaksoihin verrattuna
- esiintymien iätys on tärkeää, että voidaan verrata mineralisaatioita tektoniseen kehitykseen
- tektonisten ympäristöjen ja niissä mahdollisten malmityyppien tunnistaminen
- ohuen litosfäärin alueet ja suuret rakenteet tärkeitä
- epätavalliset intruusiot ja niiden sijainti voivat auttaa tektonisten ympäristöjen ja eroosiotason määrittämisessä

Asiasanat (kohde, menetelmät jne.) Kulta, GIS, malmiennuste, mallinnus,			
Maantieteellinen alue (maa, lääni, kunta, kylä, esiintymä) Suomi, Tampere, Outokumpu, Ilomantsi, Kuhmo, Kuusamo, Lappi			
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Contents

1 INTRODUCTION

The purpose of the workshop was to assess the gold prospectivity of Finland, and to develop and refine exploration criteria for future work on different deposit classes or styles. For the prospectivity assessment, Finland was divided into geologically different terrains, and these included SW Finland, the Tampere Schist Belt, the Ilomantsi Belt (Hattu Schist Belt), the Kuhmo and Suomassalmi greenstone belts, the Kuusamo Schist Belt, the Peräpohja Schist Belt, and the Central Lapland Area. The status of exploration, tectonic setting, genetic models, and the likely prospectivity of each area were considered. It is reminded that these notes are based on the public data, and other reports, which were on hand during the workshop and excursion.

Provided below are details of:
1. The workshop participants and programme
2. Outcomes
3. Recommendations for future work

The text below incorporates the suggestions made by all participants. Diagrams have been included where relevant.

1.1 Participants

David Groves, Emeritus Professor, University of Western Australia (07.05 – 19.05)
Stephen Gardoll, Associate Research Fellow, University of Western Australia (07.05 – 11.05)
Juhani Ojala, GTK (07.05 – 19.05)
Pasi Eilu, GTK (07.05 – 19.05)
Vesa Nykänen, GTK (07.05 – 19.05)
Nicole Patison, GTK (07.05 – 17.05)
Peter Sorjonen-Ward, GTK (08.05 – 11.05, and 15.05)
Kerstin Saalmann, GTK (07.05 – 11.05)
Saku Vuori, GTK (08.05)
Niilo Kärkkäinen, GTK (08.05)
Raimo Lahtinen, GTK (10.05)
Hugh O'Brien, GTK (12.05)
Asko Kontinen, GTK (15.05)

1.2 Programme

Date	Topics
07.05.2006	Review of earlier prospectivity analyses Review of current exploration criteria/GIS modelling criteria for gold deposits Review of deposit types found in Finland
08.05.2006	Review of exploration in Pohjanmaa, the Tampere Schist Belt, and SW Finland
09.05.2006	Prospectivity of amphibolite areas Orogenic Au GIS model parameters Potential for other deposit types (VMS, intrusion-related gold) and possible GIS parameters for these deposit types Review of the Ilomantsi belt
10.05.2006	Review of the tectonics of southern and central Finland Review of the Kuhmo and Suomassalmi greenstone belts Review of the Kuusamo Schist Belt Review of the Peräpohja Schist Belt
11.05.2006	Review of Central Lapland Au and Fe-oxide Cu-Au (IOCG) occurrences Review of the mantle stratigraphy of Finland and relevance to exploration models

	Review of FIRE data Summary and discussion
12.05.2006	Discussion of drill core from Outokumpu, Kylylahti, Jormasuo, Pampalo, Kuhmo, Hirvil-vanmaa, Pahtavaara, Rautavaara, Suurikuusikko (at Loppi)
13.05.2006	Visit to Jokisivu and Haveri deposits
14.05.2006	Visit to Orivesi deposit
15.05.2006	Overview of GTK's Outokumpu research Discussion of Kylylahti drill core Visit to Pampalo deposit
16.05.2006	Visit to Timola, Mataralampi and Kuikkapuro prospects Visit to Jormasuo deposit
17.05.2006	Visit to Pahtavaara mine and Suurikuusikko deposit
18.05.2006	Visit Soretia and Hanhimaa Au prospects
19.05.2006	Kolari IOCG core

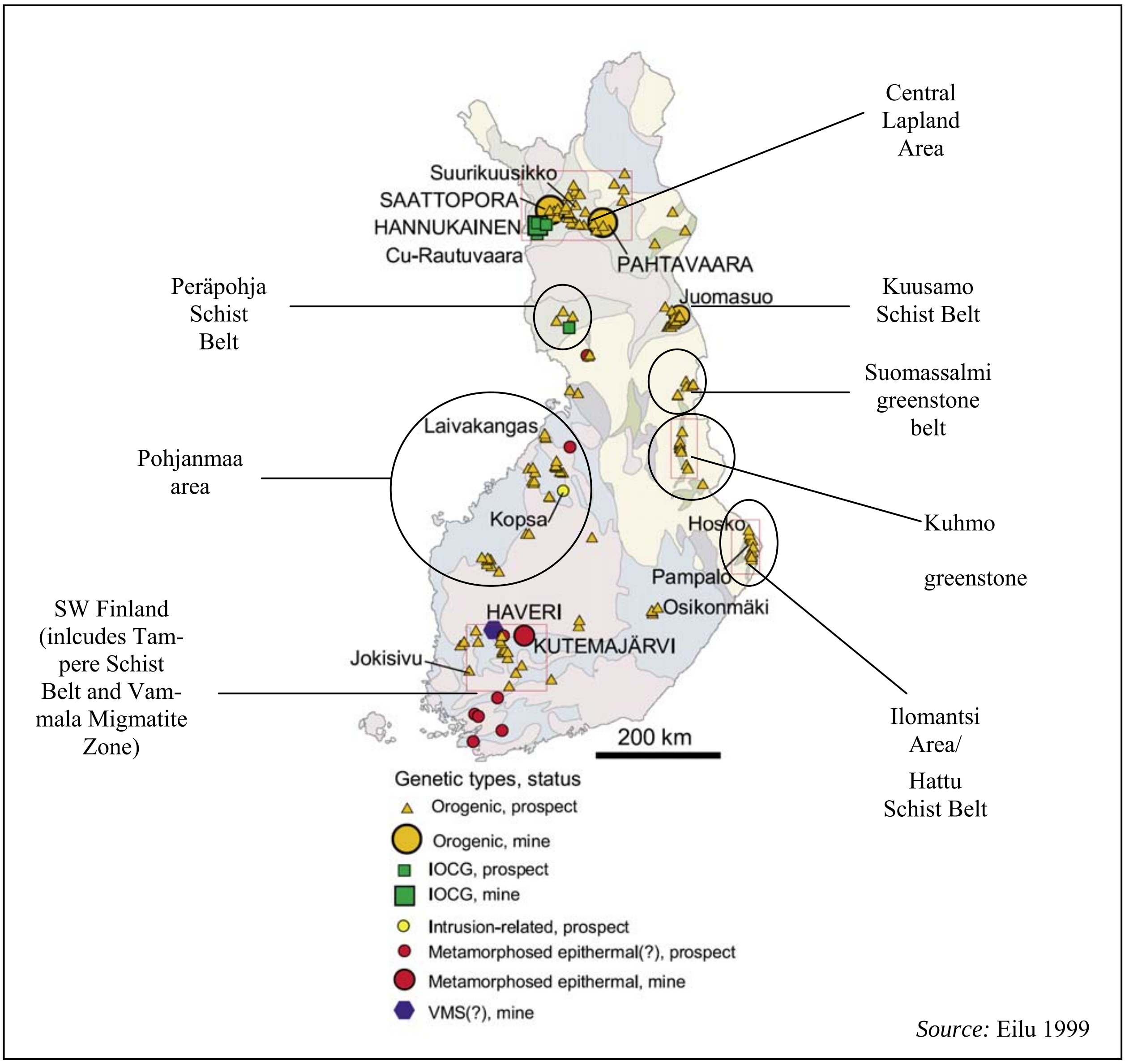


Figure 1. Reference map for target locations (genetic types assigned prior to workshop)

2 OUTCOMES

2.1 General comments relevant to exploration models

2.1.1 Integrate 'whole fluid system' criteria into exploration models

For GIS modelling and belt-scale targeting, prospectivity criteria from the oil industry are equally applicable to metal exploration. Questions to ask include:

- Is there evidence for a suitable fluid source and/or heat generator (to drive hydrothermal systems)?
- Is the rock or belt mechanically and compositionally heterogeneous enough to have traps for mineralising fluids?
- Has fluid flow been constrained by impermeable capping cover sequences that may also aid preservation of deposits?

GIS and structure-based exploration models for orogenic gold deposits often fail to include these criteria.

In the absence of direct preservation of these features, proxy parameters might be used; for example, distance from preserved quartzite cover, stratigraphic level of known ore-bearing rocks, and relative stratigraphic distance from potential cover horizons, structural facing/position and relation to cover rocks (e.g., weathered anticlines as host sites). The presence of overlying conglomerates can also be used to identify structures that have undergone the greatest movement.

Faults should be considered beyond their potential as host structures. It could also be true that these structures only act as drains for mineralising fluids. They may not be themselves be mineralised because the wall rocks of these structures may have chemically equilibrated with the fluids being transported and no longer have the compositional contrast with the fluid required to initiate metal deposition.

2.1.2 Criteria incorporating crustal boundaries and structures

Regional tectonic filters can also aid GIS analysis. For example, major orogenic gold provinces are typically located <500 kilometers inboard of subduction zones (e.g., Western Australia, Canada). Changes in subduction processes may also create new geometries that are more favourable for trapping fluids. Beyond 500 kilometers, other gold deposit types are more likely (e.g.. Carlin types, Sn-bearing deposits).

In contrast, there is no documented relationship between subduction zones and Fe-oxide Cu-Au occurrences. These are typically constrained to with 150 kilometers of terrane boundaries, and evidence for metasomatised lithosphere is required to provide volatile rich magmas. Thin, primitive crust is also favourable for VMS deposits. It could be possible to examine the nature of barren and mineralised lithosphere using information from diamond research (sub-lithospheric mantle 'stratigraphies') and use this as a county-scale filter (discussed later).

Areas of thin crust are considered to be more prospective for orogenic gold deposits. In these terrains, the lithospheric evolution prior to gold mineralisation has typically been short (e.g., Bierlein et al. 2006). For Archean areas, the variation in ages preserved within individual belts can be used as a proxy for examining crustal evolution times. In Proterozoic areas, a lack of mantle xenoliths in granites and of Archean zircons in sediments could also indicate a short period of lithosphere evolution. Gold mineralisation is also thought to form 30 to 40 million years before cratonisation ends, and so the age of younger granites with deep formation depths may also be used to infer the timing of cratonisation.

Finally, can the nature of the lithosphere be inferred from the metallogeny of belts? For example, are wide spread gold anomalies in till indicative of rift or platform greenstone belts, rather than allochthonous blocks?

2.1.3 Criteria relating to belt geometry and composition

Apart from the Central Lapland Area, the shapes of the Finnish gold belts differ from the major gold belts in other regions. Most belts resemble the Southern Cross Belt of Western Australia in that the granites within each belt control the present shape of the greenstone belt. Volcanic rocks appear to be the more favourable host rocks, followed by sedimentary rocks. However, many belts (e.g., in SW Finland) have very complex tectonic and metamorphic histories. The preservation of intact cratons is also poor due to a history of amalgamating many small elements. These events have disrupted the linearity of belts, and linearity is a favourable characteristics of most gold-bearing belts. High metamorphic grades have also produced rock with fairly uniform fabrics, and this may decrease the potential for focused dilation during deformation. It is likely that belts with strong, uniformly developed deformation fabrics and non-linear shapes are less prospective (at least for orogenic gold deposits).

Granite-influenced geometries are important because of the role granite bodies play in controlling stress fields and, consequently, fluid flow. It is suggested that fluid flow will converge between granitoid bodies, and diverge in triple-points (volcano-sedimentary belts between three granitic bodies), providing a suitable ‘outflow’ zone exists. Studies in other terranes have found a good correlation between divergent zones and gold mineralisation. Granite mid-point processing has been incorporated into GIS modelling for Finland, and there appears to be a correlation between mineralisation and triple-points at both country- and belt-scale. There is scope for improving this modelling, and given the geometry of the Finnish belts it is worth using triple-points as first-pass prospectivity analysis criteria. It was also noted that gold anomalies in such zones might occur on outflow zones that are adjacent to the modelled triple point.

In belts lacking linearity and granite-related shapes, stratigraphic boundaries may be useful as prospectivity criteria. In belts (e.g., schist belts) containing small gold occurrences with characteristics anomalous for orogenic gold, it might be useful to consider rock type contacts as potential redox boundaries where larger deposits might occur.

The orientation of target belts to the inferred or known regional compression field at the time of mineralisation is also important. Many belts are orthogonal, which is favourable for producing rock failure during deformation.

2.1.4 Use of till geochemistry

Given the large number of gold and its pathfinder element till anomalies present within Finland, ranking of geochemical targets is required before anomaly testing. Current regional till geochemistry identifies extended geochemical trends rather than constrained targets.

It may also be useful to experiment with gradients and patterns rather than absolute anomaly values. For example, the largest gold deposit of Western Australia (Golden Mile) has a complexity gradient (defined by fractal number) several orders of magnitude larger than others along the same host structure, and many large gold deposits lie on similar gravity gradients.

2.1.5 General comments on GTK exploration practices

The data available to GTK are equivalent in volume and quality to the databases of large companies. One advantage of GTK’s dataset is that data are available also on small deposits that allow genetic types to be assessed. However, more focus is required in using this information, and the skills of specialised individuals should be applied where these can be used for maximum benefit.

2.2 Belts and individual deposits

2.2.1 SW Finland

The locations of the main occurrences in SW Finland are shown in Figure 2. This area is immediately south of the Vammala Migmatitie Zone and Tampere Schist Belt.

Forssa (Forssa-Somero) Area

Interpretations of the regional structure of this area (by Saalmann) identify thrust faulting and associated transfers, with gold occurrences located within overthrust blocks.

Further north, the deposits in SW Finland and the adjacent Tampere Schist Belt appear to concentrate at a regional contact between volcanic and sedimentary rocks (Figure 3). It is possible that this boundary operates as a geochemical control or a regional seal. The area contains some coherent structures (NW-trending, as are till Au and As anomalies), but most are generally difficult to follow.

Ritakallio Prospect

Current drilling has targeted to test geochemical and heavy mineral anomalies and to map the extents and geometry of gabbro bodies in metasedimentary rocks to aid geophysical interpretation. The results indicate two styles of mineralisation: 1) mineralisation in shear zones between rock types of different competency (gabbros and metasediments/mica schist) and 2) competent rock (gabbro) hosted. If the current gabbro body geometry mapped and interpreted from aeromagnetics is correct, a geometrical target with an orthogonal relationship to regional principal compression can be identified (Figure 4). This area has the correct rock types (same as known mineralisation), but also the potential for bulk rock failure rather than margin-related shearing. ‘Rock-hosted’ mineralisation (*within* a fractured rock mass) is typically more extensive than shear-hosted mineralisation. Current drill profiles do not transect this entire gabbro body.

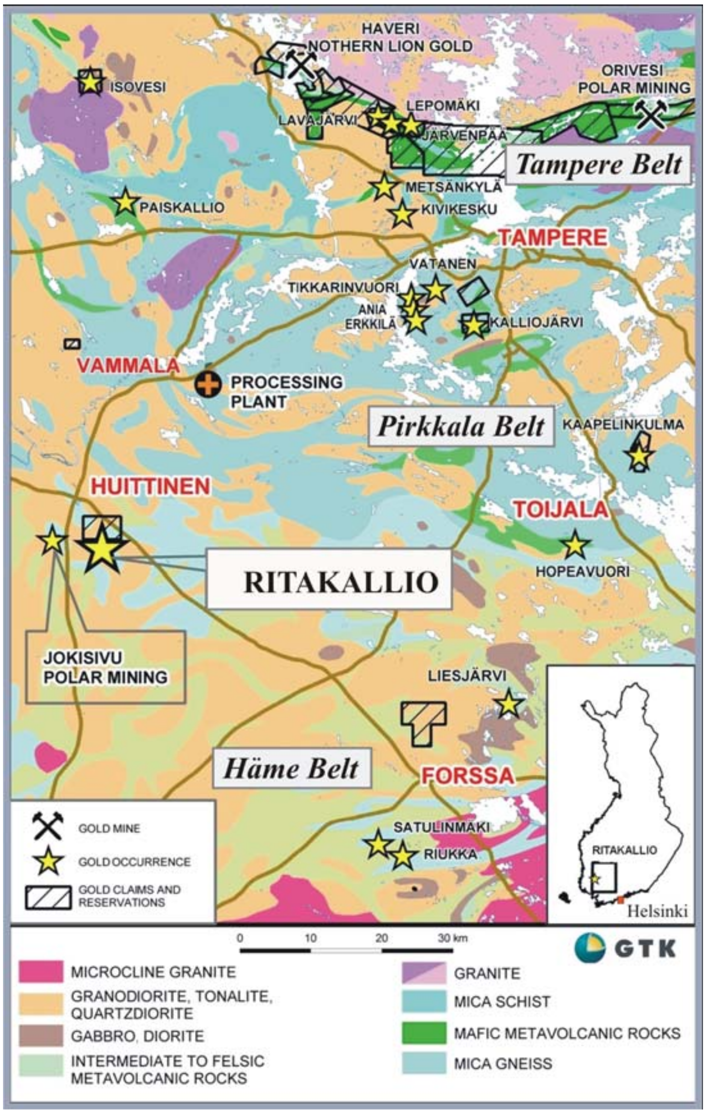


Figure 2. Location diagram for targets in SW Finland (Vuori et al. 2005)

Jokisivu (Vammala Migmatite Zone)

The Jokisivu gold mineralisation occurs at a contact between diorites and tonalitic gneisses (Figure 5). The contact is also conductive, which could suggest the presence of black schists. The test pit area is within a fold hinge, but may also be located on a secondary stratigraphic contact. There may be potential for a better ore zone at a major stratigraphic contact.

This and nearby occurrences probably formed at amphibolite facies because there is no metamorphosed alteration halo surrounding mineralised veins, no hydrous phases surrounding veins, and there are examples of in-situ melting initiated by water input (good examples in the Arpola lode area, Fig. 5).

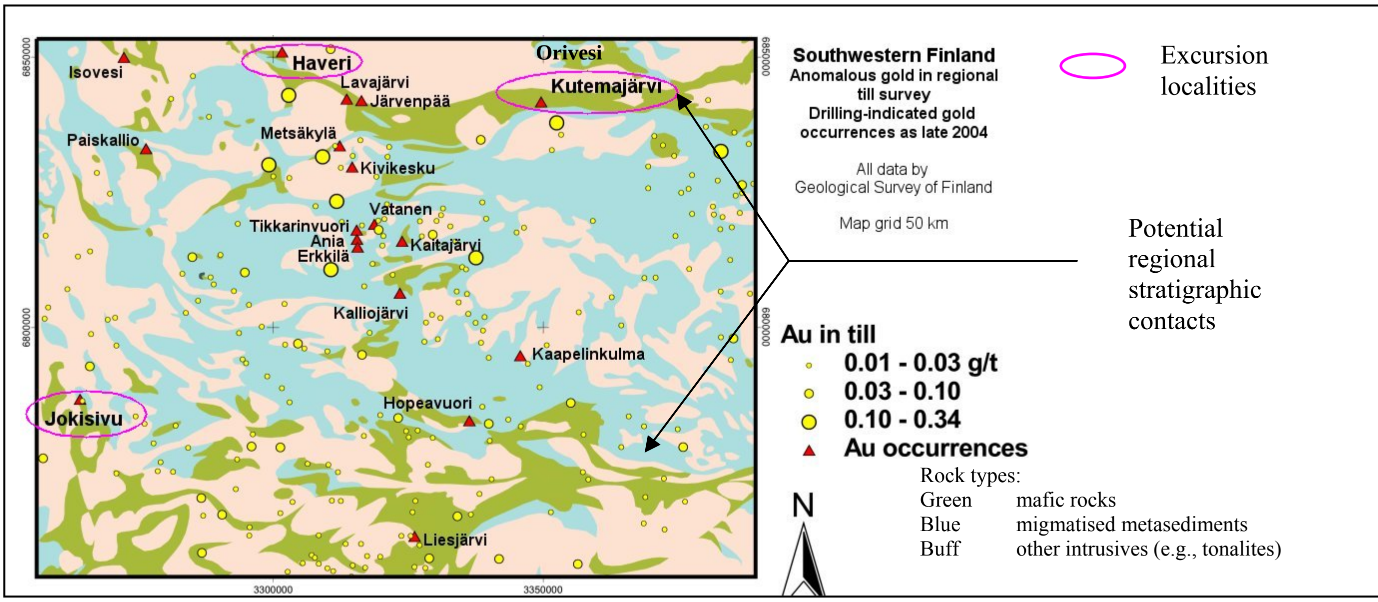
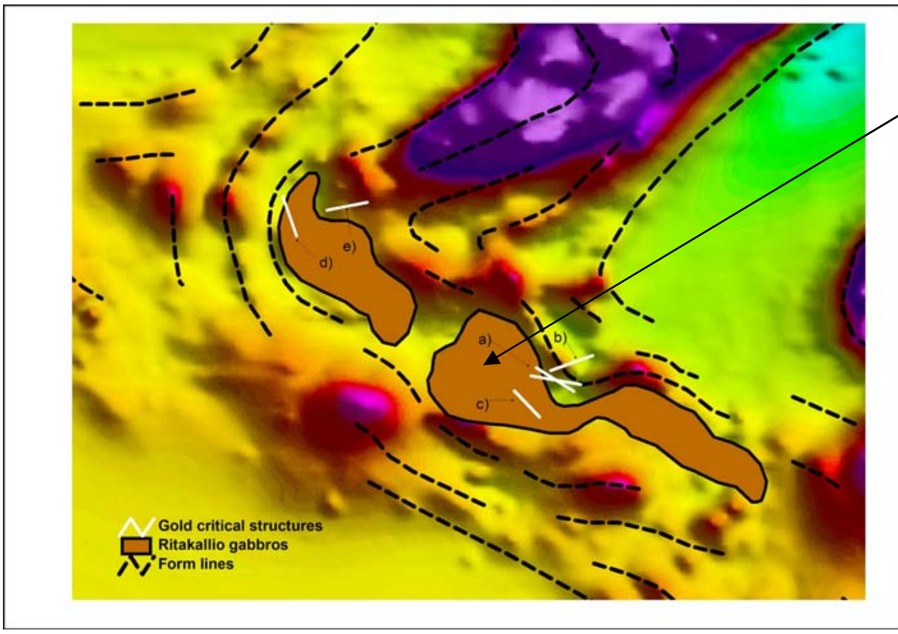


Figure 3. Vammala Migmatite Zone and Tampere Schist Belt



Possible target - drill out competent gabbro body where potential for rock-mass hosted deposits may be greater

Source: Vuori et al. (2005)

Figure 4. Ritakallio prospect

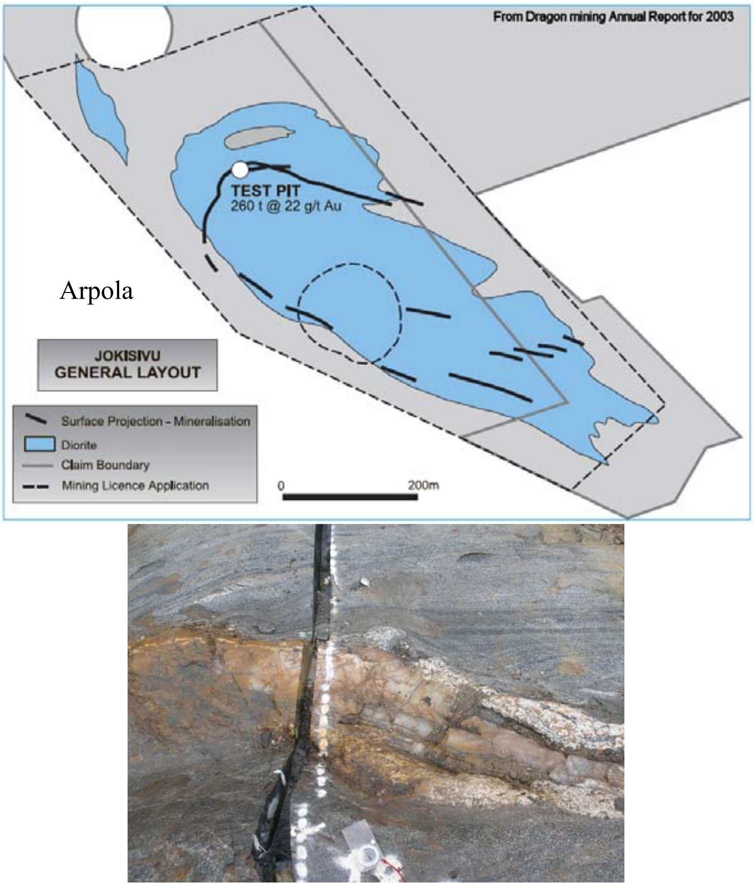


Figure 5 a) Jokisivu area, **b)** Pegmatitic material interpreted as an in situ melting zone surrounding a gold rich quartz vein (Arpola)

Haveri (Tampere Schist Belt)

The geology at this location is complicated and careful interpretation of existing data is needed to increase understanding of the mineralisation. There are a large amount of data available for interpretation. The geology map of the immediate area could not be correlated with geophysical data, and probably represents a map of alteration. It is possible that the deposit has a connection with a porphyry intrusion (granodiorite, Fig. 6). The mine area occupies a NNW-trending magnetic low (the porphyry?). Spot lows at an angle to this anomaly could be porphyry ‘fingers’.

Rock types in the mine pit area resemble a typical greenschist pillow margin and sediment sequence +/- mafic tuffs. Euhedral pyrite is abundant in hyaloclastic breccias at pillow margins. The porphyry is not exposed in the area that could be accessed. Stratigraphic contacts in the pit area have a consistent strike of 060º. The dominant tectonic foliation and strike of minor fold hinges is 010º-020º. Similar rocks were seen in drill core (typical greenschist-facies mafic rocks).

In the presented drill core, free Au was in narrow quartz veins. Higher gold grades were described as associated with silicified intervals. Massive pyrite sections are present but it is unclear if these contain gold. The veins and silicification resemble quartz-sulphide stringers, and an association between gold, copper, and magnetite was mentioned.

Given the sea-floor environment in the area and the (assumed?) intrusion, a VMS association could be considered. A possible sub-volcanic sill occurs to the SW, within 2 kilometers of the deposit area. This sill could be the heat source for such a system except that stratigraphic facing may be incorrect for this relationship. What type of deposit Haveri is could not be resolved without better local geological information. Suggested work includes:

- assessing the geochemical associations of host rocks, and better identifying local rock types by use of trace element ratios (an extensive company geochemistry database exists)
- identifying the stratigraphic facing of the host rock sequence to assess the possibility that an intact seafloor sequence with an underlying heat source might be present
- further modelling of geophysics to clarify the nature of the magnetic lows in the area
- establishing if and which pyrite phases contain gold (mine production shows very good correlation between Cu and Au, but very high grade museum samples have very little sulphides)
- obtaining a clearer idea of the shape of ore zones by logging the silicified high-grade ore zones or extracting them from core data and turning them into 3D solid models
- carrying out detailed variographic analysis of the assay data to reveal the real orientations and continuations of ore zones (there appears to be two dominant orientations)
- dating the porphyry

Haveri demonstrates that there may also be potential in this area for other deposit types (e.g., VMS deposits, intrusion-related gold). It could be a useful exercise to attempt a prospectivity analysis of the region using VMS criteria rather than orogenic gold criteria (see part 4).

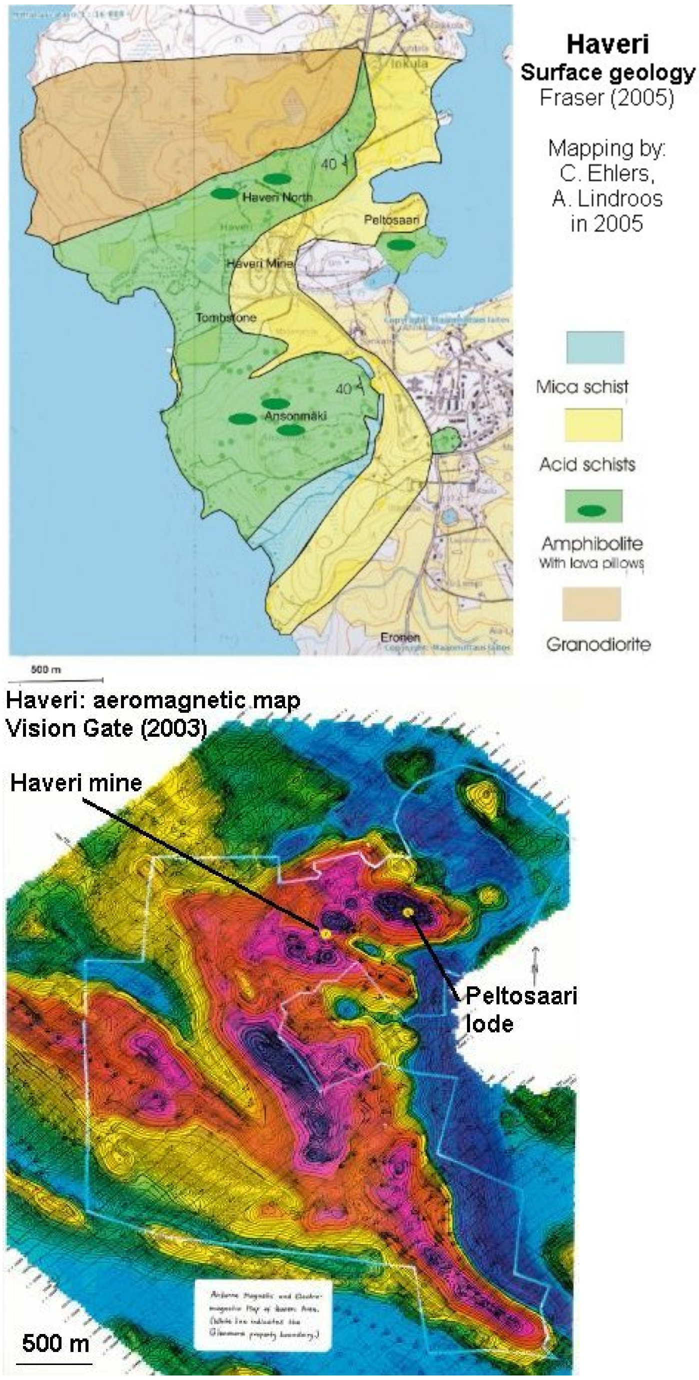


Figure 6. Haveri surface geology and aeromagnetic map

Orivesi (or Kutemajärvi; Tampere Schist Belt)

Figure 7 shows a geological map of the Orivesi mine area and it is likely that this is at least partly an alteration map. The ore pipes (black dots) have two host-rock assemblages - andalusite-quartz (northernmost pipes) and quartz pipes, the former containing high bismuth suggesting high formation temperatures. The trend of pipes of similar composition approximates the orientation of the more obvious structures present in the area (~NW strike – a strong foliation in the pit area also has a strike of 300º). The compositional variation between the pipe rocks may also reflect a stratigraphic orientation. Other mine maps (projected to surface) show that some ore pipes parallel stratigraphic contacts, while others have a NE trend and are drawn in a way suggesting *en-echelon* distributions.

Ore pipe pathfinder minerals suggested were apatite, topaz, pyrophyllite, amorphous carbon and tellurides. There are some mineralogical differences between different ore pipes, and pathfinder elements have different trends in cross section from north to south. A previous publication (Poutiainen and Gröholm 1996) has suggested that much of the alteration at Orivesi is sea floor epithermal alteration. Gold mineralisation is argued to be a later orogenic overprint based on fluid inclusion studies. Alteration in the mine area was described as having an irregular pattern and not easy to map, as expected from telescoped epithermal alteration. If the alteration were of similar timing to the late orogenic gold mineralisation, it would be reasonable to expect alteration distribution to be easier to understand.

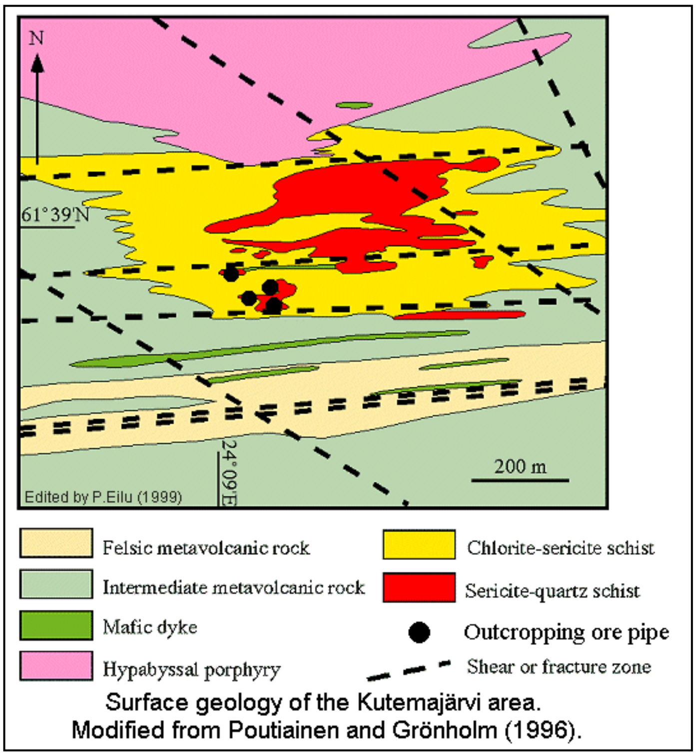


Figure 7. Orivesi mine area geology map.

Core and other samples indicate that a structural control might also operate. Ore pipes are parallel to the stretching lineation orientation and ore minerals (Au-bearing tellurides?) in hand samples appear to be parallel to the plunge of rodding/lineations. Lineated zones in drill core were spatially limited, with the remaining core foliated and kinked. A controlling intersection lineation would be consistent with the narrow and distinctly plunging nature of modeled ore zones. It is possible that the ore bodies are not randomly distributed in the proximal alteration zone, as is currently suggested, and are instead located at an intersection that may be predicted. A potential intersection to test as a control would be the intersection between the NW-trending faults and stratigraphic contacts. The assay model also allows grade changes in vertical steps. Understanding how this change relates to structures could also resolve structural controls. Although metamorphosed sea-floor epithermal alteration of the host rocks is clear, dating of gold mineralisation would help to resolve if the gold mineralisation is a later, structurally overprinting event.

2.2.2 General exploration guidelines for SW Finland

The gold occurrences of SW Finland (at least the larger deposits) seem to have a regional-scale correlation with the stratigraphic contact between mica schists and mafic volcanic rocks adjacent to granitic/tonalitic rocks (marked in Figure 3). GIS-based prospectivity modelling for this region could include an enveloping surface of the regional stratigraphic contact as a limit area within which further criteria could be tested. A second-order filter could be proximity to a local stratigraphic contact (structurally superimposed contact between volcanic and sedimentary rocks), as these are present at all visited occurrences. This method is recommended because it appears that this area may contain multiple deposit types, and because stratigraphic limits are not specific to any particular type of deposit.

The granitoid triple-point approach could also be trialed independently in this area (although this seems to be less significant for southwestern Finland). This method is also biased towards identifying target areas for orogenic gold deposits rather than other deposit types, and few of the occurrences in this area appear to be clearly orogenic.

A general problem for southwestern Finland is the potential for multiple deposit types. The large number of identified anomalies should be reclassified into subsets of deposits that might have similar origins before GIS modelling.

2.2.3 Pohjanmaa Area

Some occurrences in this area (e.g., Kopsa) have been described as resembling stockwork vein systems. These and high temperature element associations (e.g., bismuth) at other occurrences have led to the suggestion that the area could contain intrusion-related gold systems. However, the tectonic environment of this area could be incorrect for this deposit type. The high amount of granitoid material exposed in this area suggests an exposed crustal depth too deep for significant intrusion-related gold mineralisations. The area also lacks the shelf sequences characteristically associated with intrusion-related gold systems. Some of the deposits examined may cluster in granite triple points.

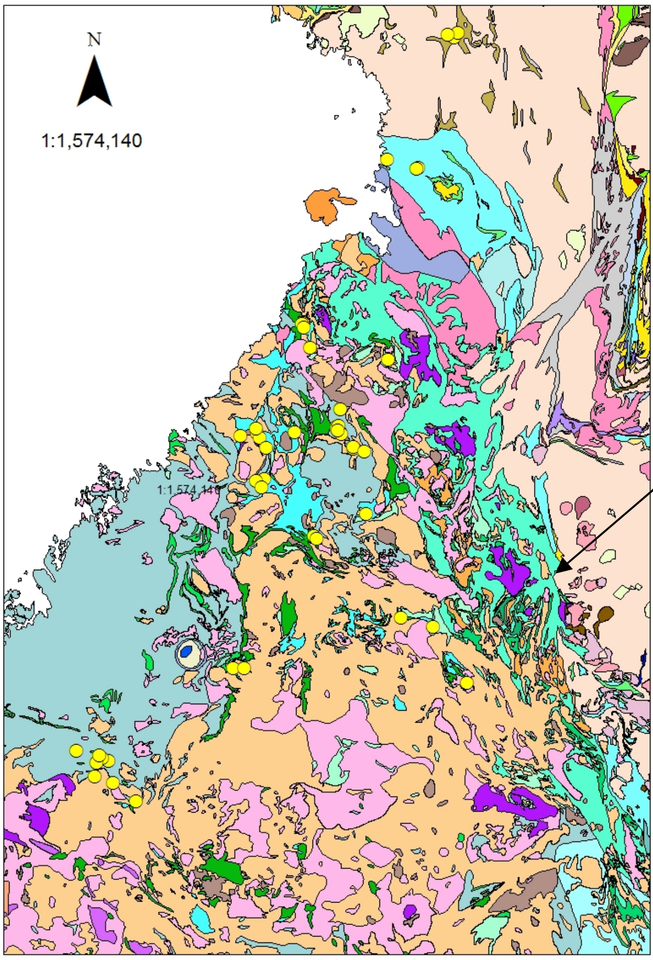


Figure 8 Map of Pohjanmaa with occurrences shown as yellow dots.

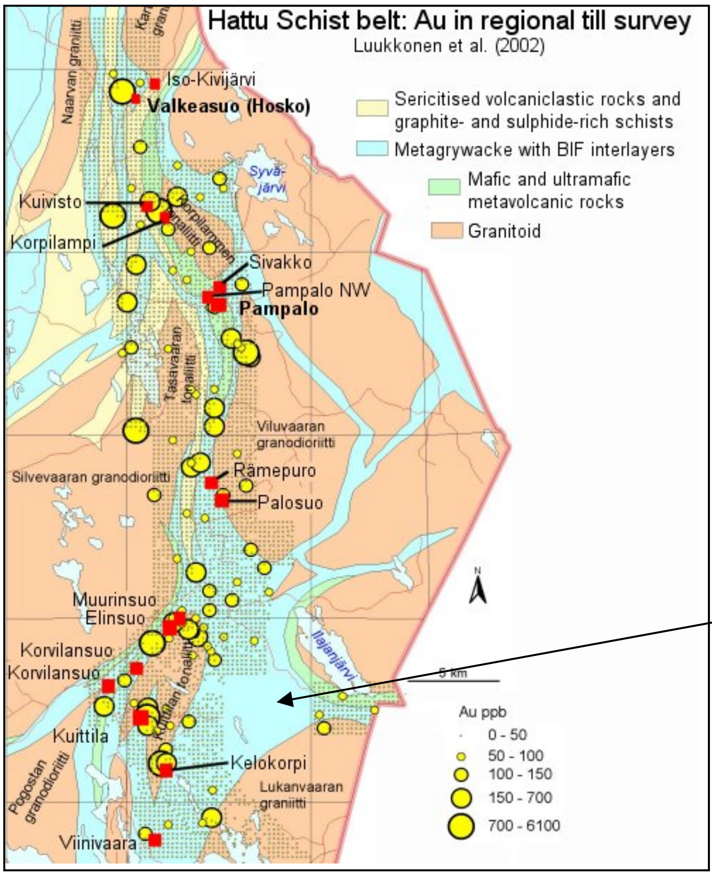
Pinks/purples/sand – granitoids, granodiorites; blue/greys – schists, gneisses; green – mafic rocks

Archean (north)/Proterozoic boundary

Source: GTK GIS database

2.2.4 Ilomantsi/Hattu Schist Belt

Questions about the possible nature of the Archean lithosphere in this area were raised. The presence of BIF in the belt may also indicate a shelf or slope environment. This may in turn indicate that some sub-continental lithosphere was present and that the greenstone sequences here formed in platform environments. This may make the potential for VMS mineralisation in this belt low.



Better position for outflow zone related to granitoid triple-points?

Figure 9. Simplified geological map of the Hattu Schist Belt with Au till geochemistry

Pampalo

This deposit has a higher metamorphic grade (described as greenschist-amphibolite facies transition, and biotite in the proximal alteration assemblage) than the Central Lapland deposits. Metamorphic reaction rims between felsic and mafic rock units are developed, and possible melting as indicated by pegmatitic material in *boudin* necks. The ore occurs in a volcanoclastic rock of intermediate composition, but is also thought to be located within the hanging wall of the Kuittila tonalite pluton. Talc-chlorite schist underlies ore zones. The area has a strong, uniformly developed tectonic fabric that may create lower potential for larger deposits.

A folded area to the WNW of the Kuittila tonalite appears broken by faulting and may be the more prospective area (check for the presence of a gravity gradient in this area). The immediate area of the Pampalo deposit has a NW trend compared to the typical N trend of the Hattu Schist Belt. This highlights the importance of capturing structural data and combining that with till geochemistry.

Similar criteria to that suggested for SW Finland could be applied to Ilomantsi. However, there are also clear granitoid triple points present. Prospectivity criteria should include:

· granitoid triple-point zones (potential divergent zones)

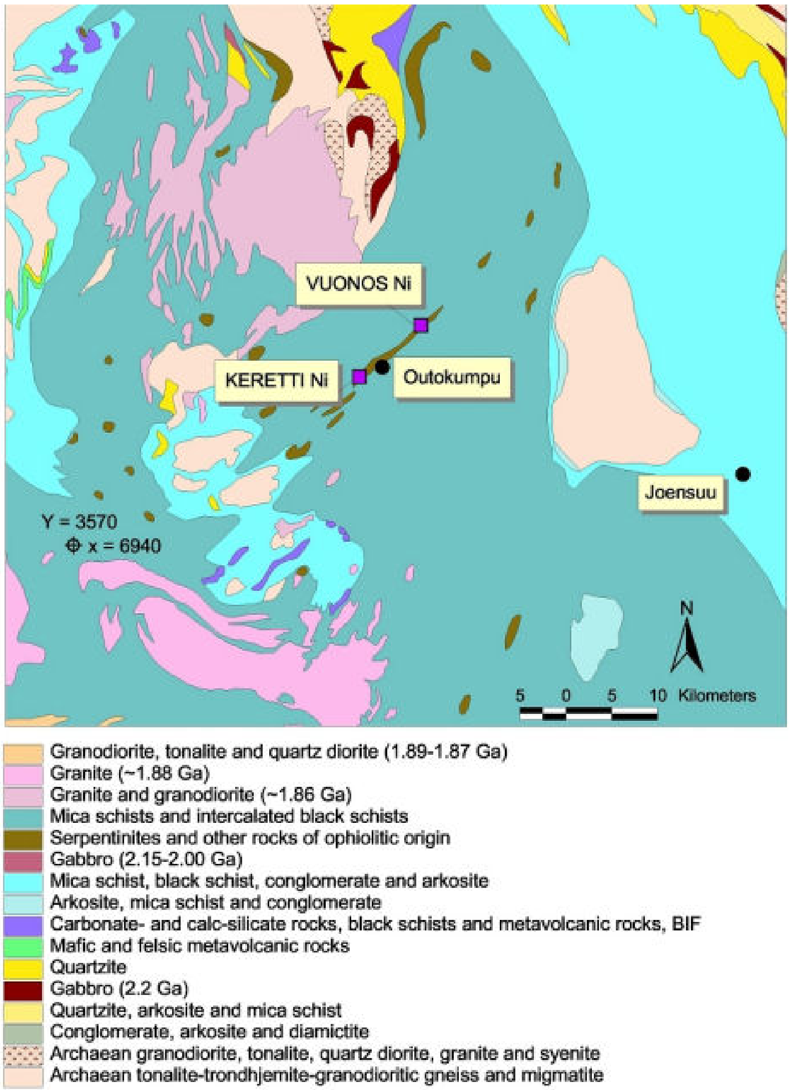
· conduit presence (some sections of the regional shear zone in this belt appear mineralised). Compare structures to till geochemistry to see which are gold-bearing/favourable orientations. The proposed better orientations could be selected using filters for dips <70 degrees and strike orientations at >30 degrees from the regional trend N-S (define fractal parameters for structures)

· volcanic/sedimentary rock contacts or other zones of rheological/chemical contrast

· distance to magnetic highs (and use of magnetics to locate BIF units)

Till geochemistry may be excluded, or use gradients, from most models as it delineates a large trend rather than specific targets.

2.2.5 Outokumpu area



Lithology of the Outokumpu area after Korsman et al. (1997).

Figure 10. Simplified geological map of the Outokumpu area

The Outokumpu area was considered, as it has been significant gold producer. Ores in the Outokumpu area are argued to be hosted by an allochthonous package of sulfidic black shale, greywackes and serpentinites. This sequence resembles a seafloor sequence but does not contain sheeted dykes, and contains few pillow sequences. Deposits are metamorphosed and grade increases from lower-amphibolite to sub-granulite faces east to west. All mineral assemblages are metamorphosed. The allochthonous interpretation is made because the serpentinites are interpreted as mantle peridotites, and dating of the surrounding greywacke indicates that the sediment material is younger. The regional stratigraphic trend is NE, and NE-SW compression is implied. The Outokumpu lens is also thought to occupy a duplex position.

Ores are typically located on a ‘quartz' rock/serpentinite boundary (on the margins of the serpentinite bodies, Figure 10 and 11). The immobile element distribution within the ‘quartz rock’ is the same as that within the surrounding ultramafic rock and has similar cromite grains. The ores lacks the Cr present in adjacent rocks, and have no PGE enrichment. Both would be expected to be present if the ore was produced by magmatic segregation or by a magmatic fluid.

One possibility that should be considered is that the ‘quartz’ rock is a product of extreme seafloor Ca metasomatism (high CO_2 activity during serpentinisation), during which skarn-like rocks were created as fronts of Ca/Mg exchange between serpentinites and adjacent Si-rich rocks. The Ni may also be sourced from host-rock leaching during serpentinisation, as could cobalt. Alternatively, the ‘quartz’ rock surrounding lodes may be preserved quartz-dolomite shear zones (e.g., as described for the Mt Keith deposit of Western Australia).

Sediments could provide the copper source if the feeders for ultramafic rocks intruded wet sediment (look for peperitic textures). Due to the 600º C+ temperature of intrusions associated with ultramafic feeder pipes, all metals except copper would remain soluble. However, no oblique feeder pipes have been recognized in the area (but they are not typically found).

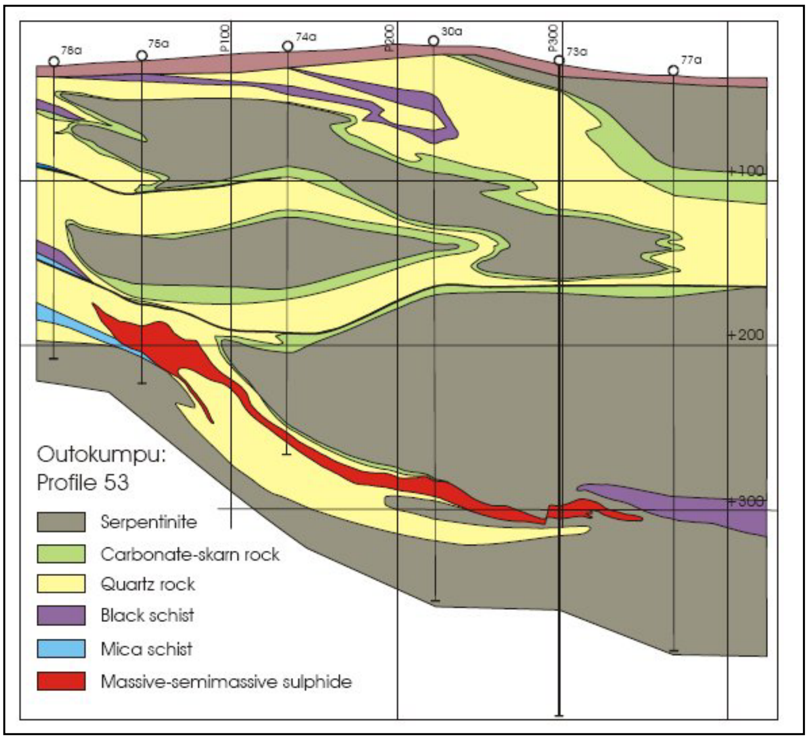


Figure 11 Simplified stratigraphic cross section of the Outokumpu area (after Kontinen et al. 2006)

In drill core, the quartz/skarn rock has a cyclic appearance that could indicate that the rock was originally a reactive layer (e.g., a dolomite). However, (visible) sulfide content increases towards the ore zone irrespective of rock type. This suggests that the quartz rock is not related to the mineralising event. Greywackes also appear to be part of the sulfide ore halo.

A conclusion for this deposit is that it is only the age data for the greywacke that prevents interpreting sulfide formation at the seafloor. Therefore, despite the structural location of the ore, there is some evidence that a primary stratigraphic control also operated. Obduction dates obtained from dykes restricted to serpentinite bodies could also be questioned, as it is possible that the dykes selectively intruded the silicified serpentinite body. Hardening of this body prior to dyke intrusion would have increased the potential for brittle failure in this body compared to adjacent rocks.

Prospectivity criteria for the Outokumpu area should include (assuming that the original stratigraphic position of the ores has been maintained during deformation):

- a NNW trend for host rocks (orthogonal to the belt trend) appears to be generally favourable, and could be targeted using magnetic and gravity gradients. Target ultramafic rocks oblique to the stratigraphic trend (potential feeders) in the thickest parts of the ultramafic sequence (or, thick ‘quartzites’ that could indicate the zones most extensively altered)
- try to identify a heat source
- Co/Ni ratios have been successfully used as an exploration tool in this area, and so should be included in future GIS models
- Look for structural traps that may preserve larger zones of mineralisation. One such target exists in the Laitasaari area (Figure 12), an area with a folded sequence of favorable stratigraphy. Folding increases the chances of preserving a deposit, and it is also possible that folds may nucleate in previously altered areas, such as hardened alteration zones above massive sulfide ores. This target is partly within the tenure areas of Kylylahti Cu Oy.

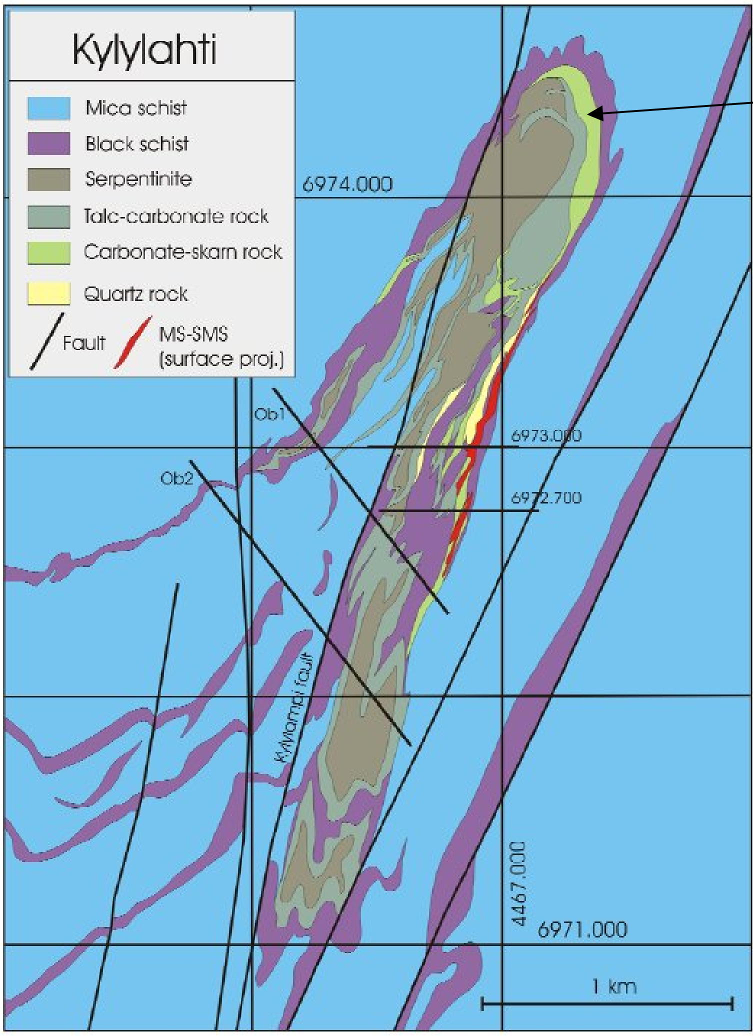


Figure 12 Potential target in the Outokumpu region

2.2.6 Kuhmo/Suomussalmi Belt

In general, the Kuhmo/Suomassalmi belt may have more exploration potential than the Ilomantsi Belt because the former has greater strain variation within the belt. The belt consists of steeply dipping ~2.75 Ga greenstone (ca. 50 million years older than Ilomantsi greenstones) surrounded by 2.9 – 2.65 Ga gneiss-granitoid terrane.

Known deposits occur at a sheared contact between two units with different mafic lava geochemistry. Other targets with potential stratigraphic controls and/or granitoid triple point locations include Jumalisjärvi and Saarijärvi (these also correlate with stress modelling anomalies at these and other locations circled in Figure 13).

The main structural trends in this area appear to follow granitoid contacts. The existing stress modelling could be modified and tested using fewer structures (eg stiffening faults in granitoid area), reclassifying some of the lithological boundaries, and increasing the rock strength assigned to the granitoids.

Härmänkylä: Timola and Mataralampi

A series of outcrops (regional and prospects) shows the possible relationship between map-scale structures and mineralisation. An outcrop of rocks typical for the belt (at Timola) shows Au-bearing quartz veins in komatiite. These rocks have an unusual fracture pattern resembling modelled orientations for conjugate shear zones associated with large bulk strains. The veins strike 015º or less and are parallel to a localised shear fabric.

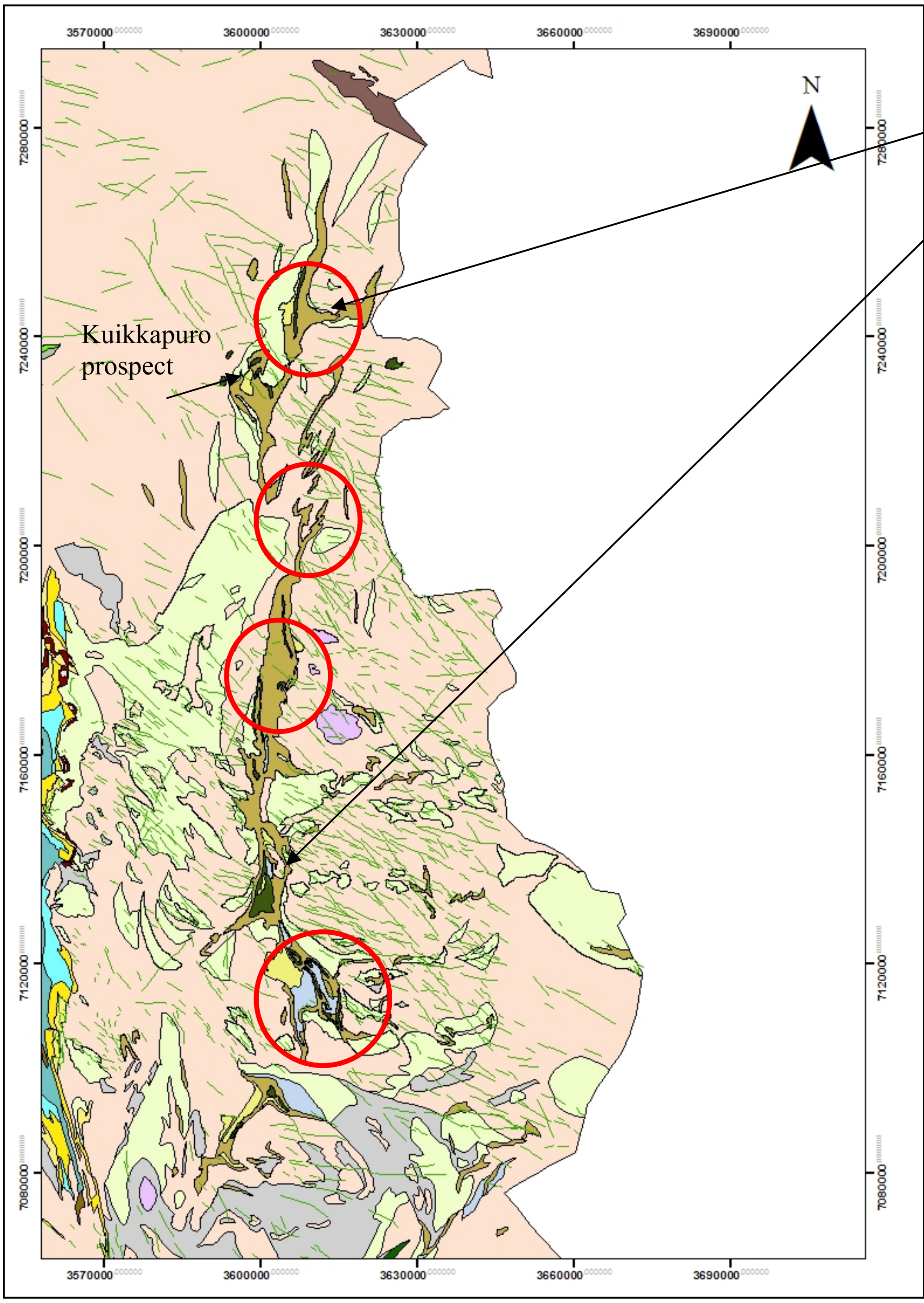


Figure 13

Suomussalmi
&
Kuhmo
greenstone belts

Preferred target areas shown by red circles

Source: GTK GIS database

Amphibolite-facies mafic volcanic rocks host the Mataralampi prospect. Some localised biotite alteration occurs. More intense biotite-chlorite altered rocks are interpreted as komatiites (not proven). The deformation fabrics are mostly brittle small-scale orthogonal conjugate (Fig. 14) shears, and resemble those at Timola, but quartz infill occurs within stepped (dextral) dilations at an angle to (but perhaps related to) the brittle fractures. The enveloping shears of the steps strike 340º. The dilational steps strike 020º. Mafic dykes and possible pegmatitic melt zones are also present, and have a similar strike to the quartz-filled steps. Outside of the reported gold-bearing zone in trenches, the fabric orientation becomes closer to N-S. A sulfidic zone in trench with no to low associated gold strikes 340º.

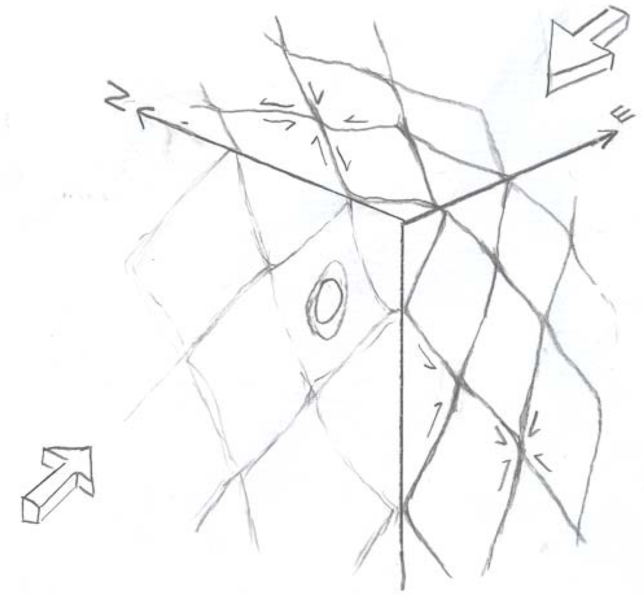


Figure 14. Sketch of conjugate orthogonal brittle-ductile shear relationship in the Mataralampi area. Conjugate shear bands form a fracture mesh, which could provide a rock confined fluid pathways in a more brittle host rock.

The above structural trends can be correlated back to the regional map and may aid in defining prospectivity (Figure 15). The trend of shears and quartz veining at Timola resembles the overall trend of the greenstone belt. The host shear for the dilational steps at Mataralampi is equivalent to the dominant cross fault orientation expressed on the regional map (NW strike; parallel to fold hinges in NW area). The trend of the quartz-filled steps has few equivalents on the regional map. However, one stratigraphic contact (between sericitic quartzites and mafic volcanic rocks) has this orientation and could be considered as a favourable site (circled in Figure 16).

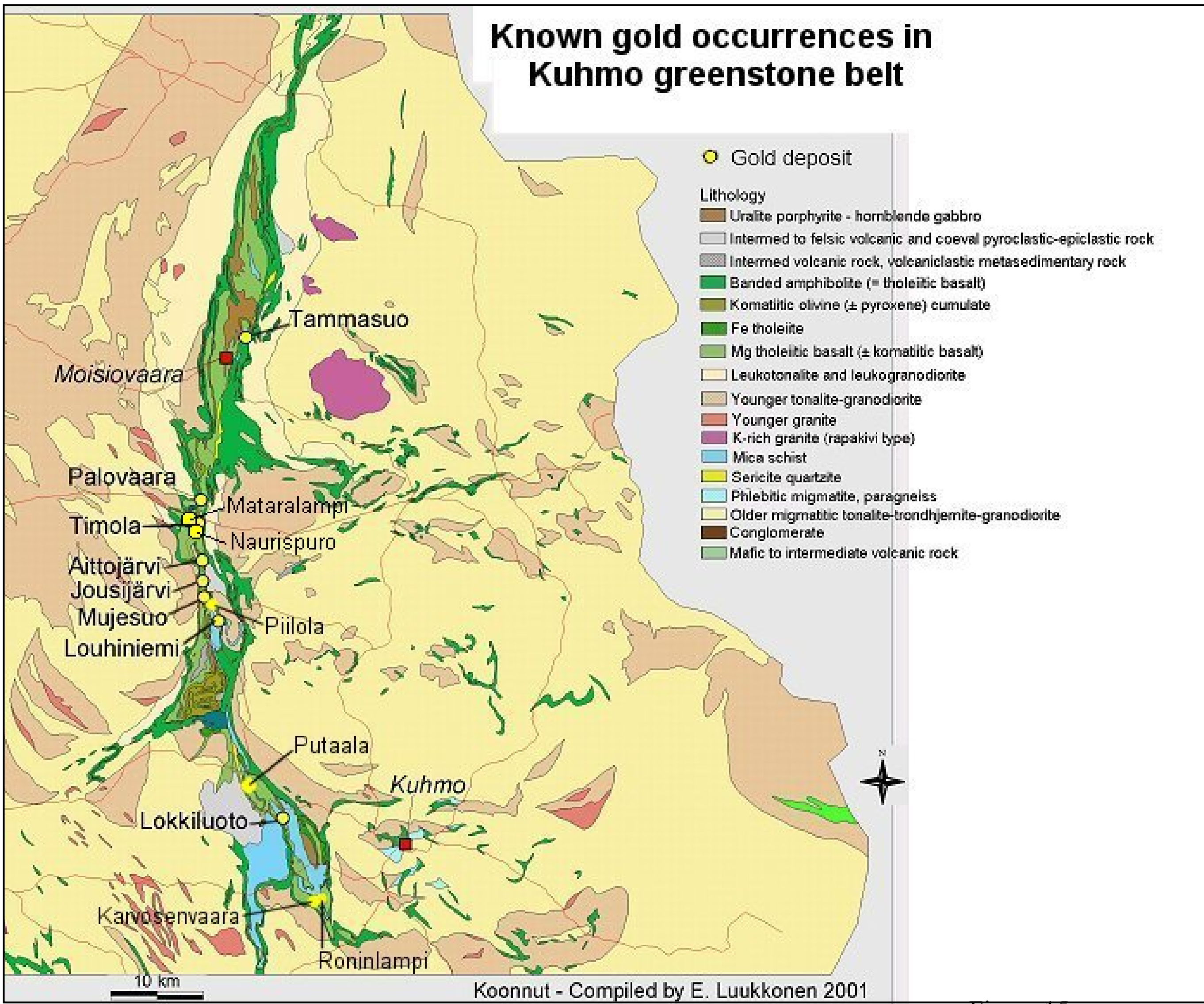


Figure 15

Figure 15. Geological map of the Kuhmo greenstone belt.

Kuikkapuro

At the Kuikkapuro prospect further north (Suomussalmi greenstone belt, Figure 13) high-grade gold intersections occur in a biotite alteration zone between mafic volcanic and garnet-biotite altered rocks. A sub-vertical to north-dipping layering is present, striking 100º. The fabric could be sheared bedding, indicating a regional limb position for the quartz veins. Quartz pods have moderate to steep plunges to 020º. This orientation is the same as the strike plane for the quartz-bearing dilations at Mataralampi.

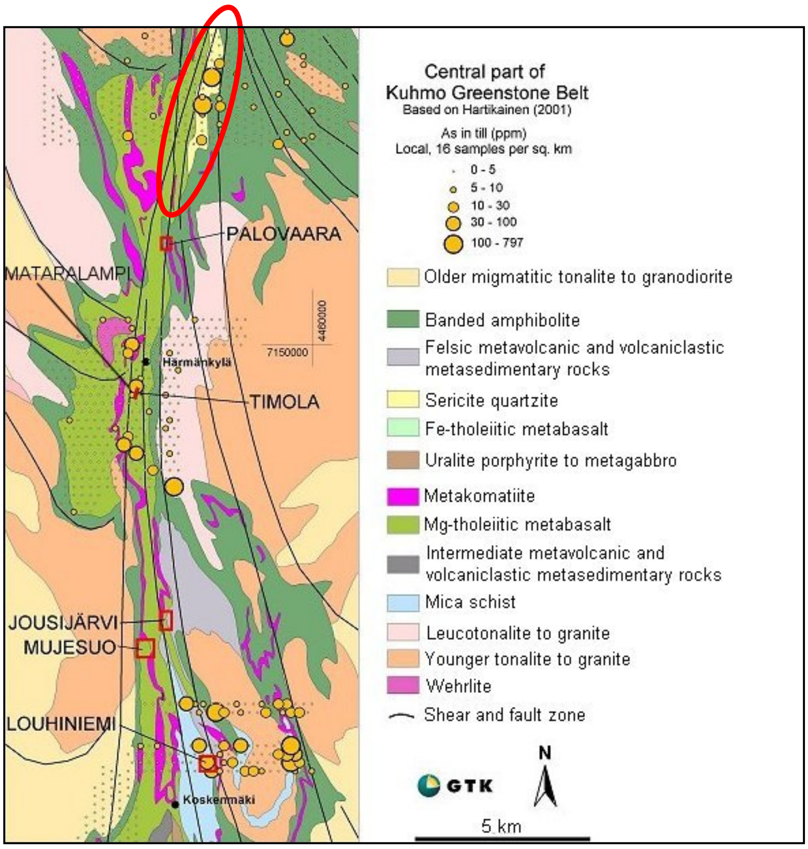


Figure 16

Visited localities in the Kuhmo Greenstone Belt

Potentially favourable rock contact orientation circled

2.2.7 Kuusamo Schist Belt

Interpretations of this belt include a foreland area for the Lapland Granulite Belt and/or a continental shelf sequence. Eutectic melts are present at the NW margin (PSW – possibility of granite-related hydrothermal gold mineralisation?). Possible redox-related targets could be considered at stratigraphic boundaries, particularly in the northeastern corner of the belt where folding affects the sedimentary rocks.

Juomasuo

This deposit has experienced very low strain. Syn-sedimentary structures, including dissolution features/fluid escape channels are preserved in pit exposures, as is albitic layering containing relict crystal shapes interpreted as ferrodolomites (Vanhanen 2001) but may also be evaporate minerals (eg gypsum). The possibility that these sedimentary rocks are karsted shelf sequences with interlayered black schist could be explored, as could a sedimentary replacement origin for the mineralisation. The Ti content of ‘albitic’ layers could also suggest a tuffitic composition. Elsewhere in the pit area, patchy albite alteration has a similar appearance to the syn-seafloor (?) albitisation present at some deposits in Central Lapland (e.g., Kaaresselkä). The geochemistry of the Juomasuo deposit is also anomalous for an orogenic gold deposit. Vanhanen 2001 suggested it to have similarities to IOCG group of deposits, but it resembles also the geochemistry of the black shale deposits (Coveney and Pašava 2004). It is suggested that Juomasuo is a highly anomalous style of mineralisation which is very unlikely to be orogenic.

Targeting criteria should include exploring along the strike at shale/’albitised’ rock contact.

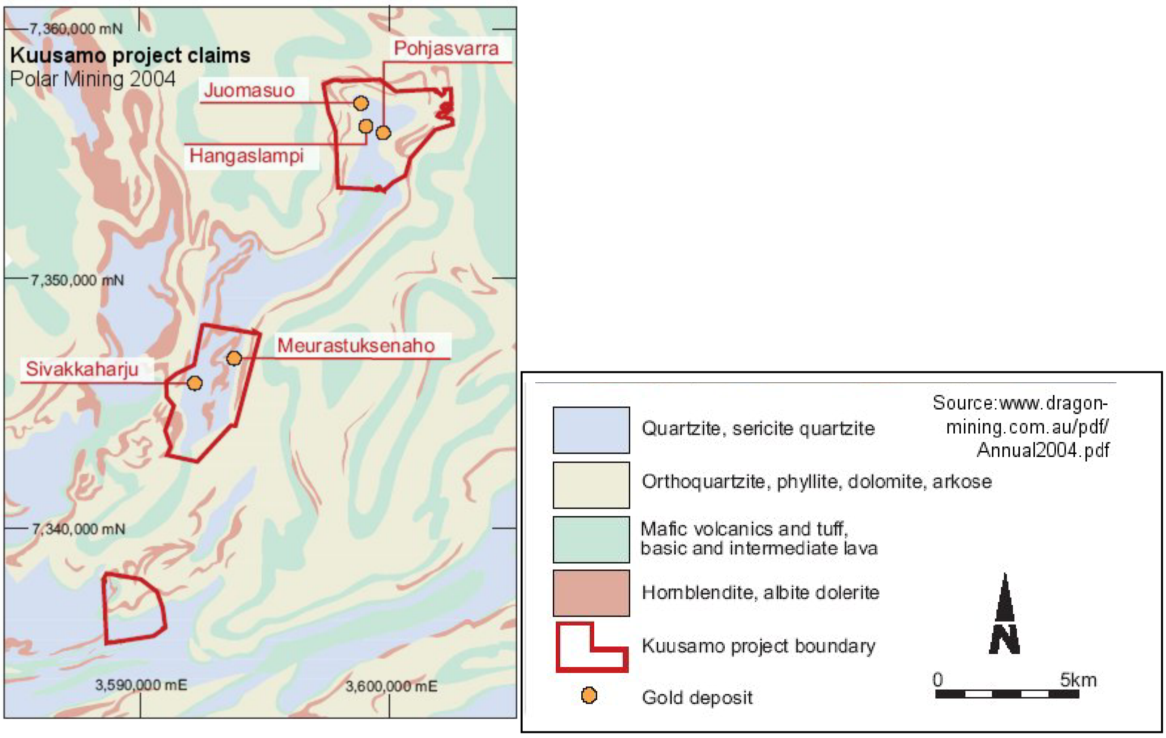


Figure 17. Simplified map of the Kuusamo Schist Belt

2.2.8 Peräpohja Schist Belt

This belt contains gold occurrences associated with cobaltite and with amphibole alteration halos. Mineralisation is in many places found at dolerite contacts. Low Au-Cu ratios and high sulphide abundances suggest that these are not typical orogenic gold occurrences, some have similarities to IOCG group of deposit (Eilu et al. 2007), and the correct deposit type should be identified before prospectivity criteria can be proposed.

2.2.9 Central Lapland

The gross orientation of this belt (Fig. 18. E-W, to NW-SE if the Salla area is considered as tectonically and stratigraphically continuous with Central Lapland) is perpendicular to the likely dominant compression direction (SW-NE). Due to this relationship, any structure that diverges from the trend of the belt has the potential for extensional or contractional reactivation. Structural orientation should be included in prospectivity models.

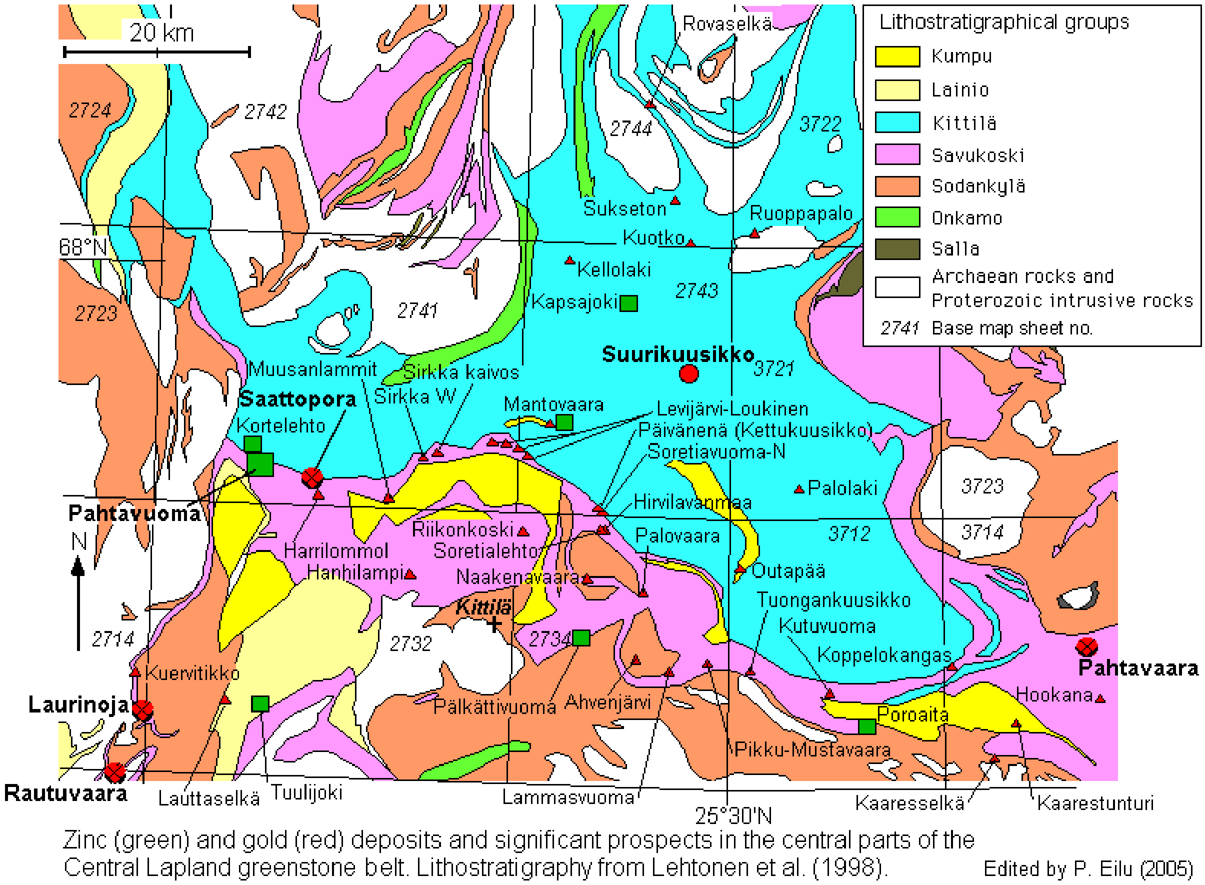


Figure 18. Very simplified map of Central Lapland. Red and green symbols show the location of occurrences in this belt.

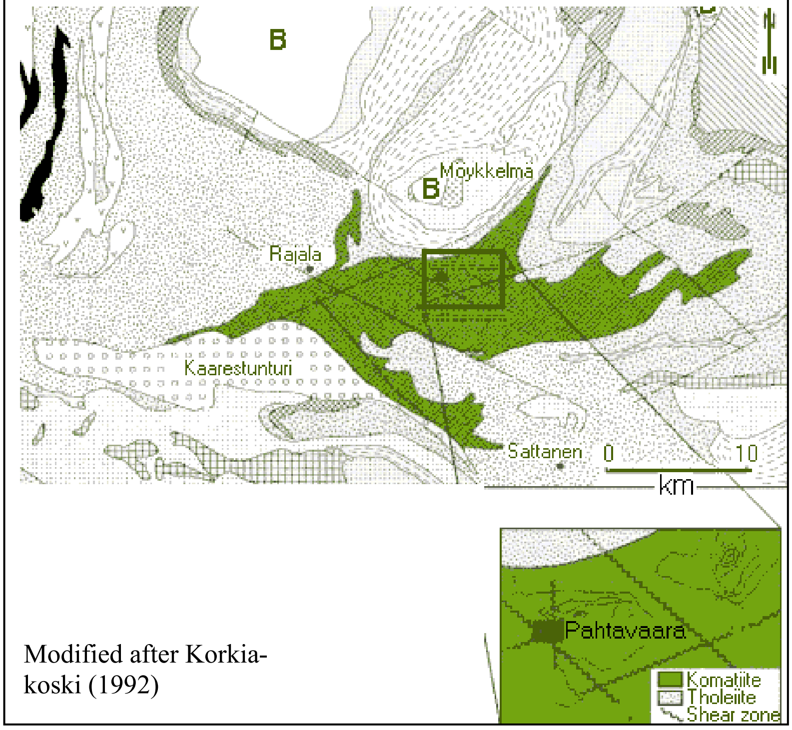
It is also possible that the younger sedimentary sequences (e.g., Kumpu Group) act as capping layers that may aid preservation of mineralisation. Other flat-lying layers may act similarly, and a model incorporating low angle dip measurements could be considered. Granite triple-points may also operate at regional scale for Central Lapland.

Hirvilavanmaa

Mineralisation may be hosted by a differentiated dolerite as abundant coarse leucoxene alteration suggests that the rock was originally coarse-grained (i.e., contained coarse ilmenite). The cyclic appearance of leucoxene could indicate internal compositional variations or grain size changes in the original lavas or sills (e.g., mineralisation could occur at the contact between a differentiated sill (e.g., Fe tholeiite) and a 'normal' mafic lava). Differentiated sills should be examined as a possibility for many deposits in this area that have been described as lava-hosted.

Pahtavaara

This deposit is unlike the other known gold occurrences in Central Lapland. The unusual features of the deposit include barite in the ore assemblage, high gold fineness (>99.5 % Au), and ore breccias demonstrating unimpeded crystal



Modified after Korkiakoski (1992)

Figure 19

Distribution of Sattasvaara komatiites hosting the Pahtavaara deposit

growth (e.g., pyrite hedrons instead of cubes, randomly oriented tremolites). The presence of euhedral crystals suggests a formation depth less than five kilometres. This conflicts with the apparent upper greenschist-facies metamorphic grade of the deposit.

The vuggy textures appear to be associated with higher gold grades. In underground exposures, at least some of the vuggy veins have low angle to moderate dips E and are perpendicular to the biotite-carbonate banding present in host rocks.

High-grade ore is visually identified by the presence of quartz, barite and grey dolomite constituting rock that has no recognisable fabric. The mineralised rock is normally but not everywhere a tremolite-biotite rock, with the highest gold grades associated with the quartz-barite-dolomite association alone. Schistose tremolite-biotite rock is described as having a negative correlation with gold. Red phases (possibly magnesite and albite?) in places accompany ore-related alteration, as do tremolite and fuchsite alteration. However, none of these phases are definitive of ore zones. Many of the amphibolite phases appear to be reaction-related.

The ore shoots are thin and discontinuous (20 – 30 metres long). The assay block model gives an impression of an ore envelope plunging SW. Secondary ore in quartz veins also occurs. Thick quartz-dominated veins in tremolite rock normally contain <1 g Au. These can have high gold grades if the veins are thin and irregular, and have sugary textures and accompanied by barite. This vein type is not developed in the higher-grade ore zones dominated by the vuggy vein types. The quartz veins have low to moderate dips to 230º at the face visited but the orientation of this vein type is probably variable.

It has been suggested that the deposit may occupy a contact between komatiitic and mafic rocks. Primary volcanoclastic textures have also been suggested. The primary clastic texture (where present) is developed in alteration adjacent to ore zones, but no primary texture is preserved within ore sections. The deposit may also be located in an isoclinal fold closure.

The deposit type represented by Pahtavaara could not be resolved. The lack of a tectonic fabric or brecciation in the ore zone suggests the deposit is not an orogenic gold deposit. The deposit also has low silver and arsenic concentrations, which is atypical for orogenic gold, as are the high barium and cobalt values. The low REE content of the deposit is unlike Fe-oxide Cu-Au, and there is no evidence of an intrusive origin. Other types of barite-bearing deposits should be examined (e.g., barite in low and high sulfidation systems?). The possibility that Pahtavaara is a metamorphosed deposit should also be considered (e.g., like metamorphosed altered ultramafic rocks in Soretia, Kittilä; commercially marketed as "chromium marble").

Suurikuusikko

This deposit is a more typical example of an orogenic gold deposit. Gold is refractory, primarily within arsenopyrite that has a disseminated appearance. It occurs within a shear zone passing through a local stratigraphic contact. The shear zone is associated with amorphous carbon alteration that is probably remobilised from adjacent sedimentary rocks. The contact is a zone of intermediate lavas and minor sedimentary rocks that is between two thicker packages of mafic lava. Most of the mineralised rocks are hyaloclastic lava breccias, and lesser volumes of mafic to felsic pyroclastic rocks are also mineralised.

Remaining questions for this deposit include why such a long section of the host shear is mineralised (several kilometers, as separate north-plunging lenses), and why the stratigraphic contact can be traced for some distance despite the regional folding in the belt. The possibility that stratigraphy is duplicated by shearing of a regional fold hinge should be considered. There is currently no identified stratigraphic repetition on either side of the host shear that would suggest this, but the area available for direct observation is still limited.

2.2.10 Western Lapland (Fe-oxide-Cu-Au occurrences)

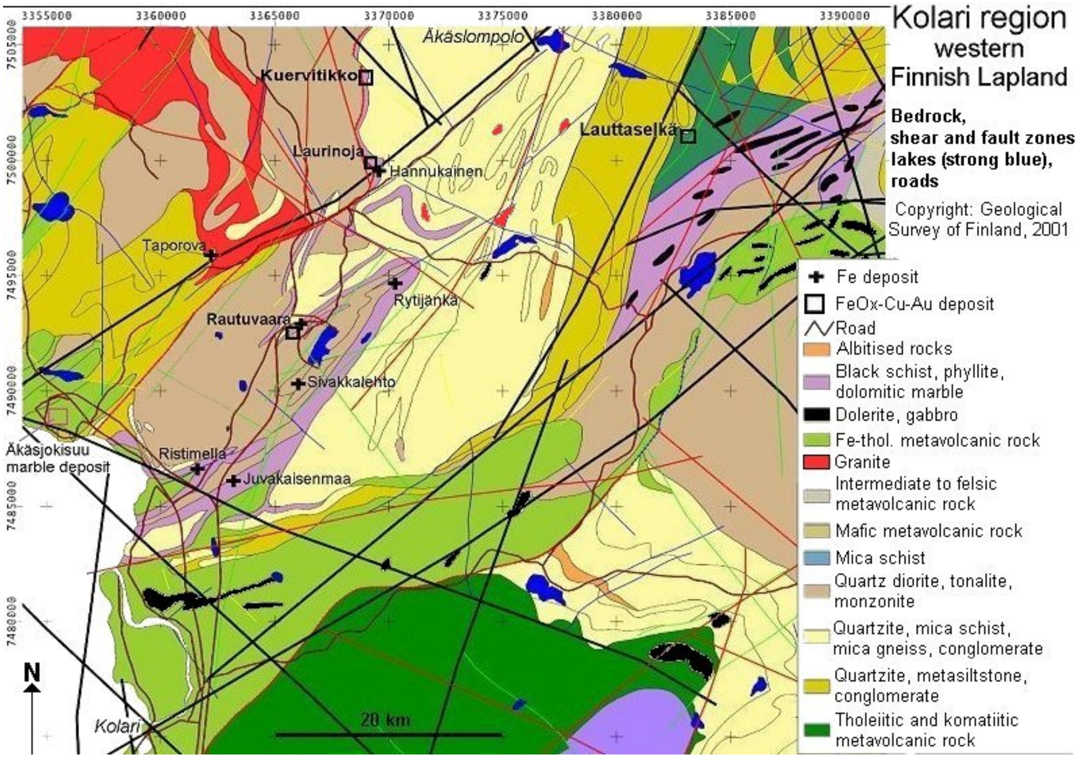


Figure 20. Geological map of Kolari region and location of potential Fe-oxide Cu-Au occurrences.

At the western edge of the Central Lapland Greenstone Belt, a series of iron deposits containing some copper and gold occur. These have been described as Fe-oxide Cu-Au deposits.

Rautuvaara area

Five of the known deposits and prospects in the Kolari region contain significant amounts of copper and/or gold: Cu-Rautuvaara, Hannukainen, Kuervitikko, Rautuoja, and Lauttaselkä. These deposits have many but not all the characteristics of classic Fe-oxide Cu-Au deposits. Most REE profiles for the mineralisation are characteristic of sedimentary rocks. However, magnetite ore analysis resembles an Fe-Ox-Cu-Au profile (from the centre of the Cu rich magnetite ore body) although this sample is higher in SiO2 than is typical for this type of deposit. Magnetite bodies could represent a sedimentary iron formation (stratiform seafloor), into which an Fe-oxide-Cu-Au type of intrusive plug has been injected after metamorphism. However, there is no stratigraphic control on magnetite bodies and a metasomatic replacement type controlled by Kolari shear zone structures is a feasible interpretation.

During the visit new large diameter core from the Haunnukainen deposit was available and showed the intimate relationship of magnetite and sulphides. Typical ore mineral association at is magnetite-chalcopyrite-pyrite±pyrrhotite. In places, the amount of pyrrhotite exceeds that of pyrite. Alteration styles described at Hannukainen are sodic to calcic in the hanging wall diorite, Ca-Fe in the ore-skarn zone, and potassic to calcic in the footwall.

Tero Niiranen presented his PhD results and it was concluded that the general characteristics of the Kolari deposits do fit into the IOCG category; they display similar element association, alteration pattern, and fluid inclusion characteristics (Niiranen et al 2007). Niiranen et al. (2007) proposed 1.80 Ga age for the

Kolari deposits and this age is contemporaneous to a thermal event related to the intrusion of the voluminous S-type potassic granitoids throughout northern Finland and Sweden (e.g. Hanski et al., 2001). In addition, the Kolari deposits are related to a major crustal scale shear zone system (Pajala shear zone or Bothian mega shear, Berthelsen and Marker 1986) that is considered to represent the continent-continent collisional boundary between the Norrbotten and Karelian cratons.

2.2.11 Criteria for Fe-oxide Cu-Au deposits

The classification of this deposit type was reviewed throughout this workshop. Many deposits appear to be misclassified as belonging to this type. This seems to arise from using alteration assemblages and element trends to classify deposits, which is misleading because fluid-rock interactions in different environments can ultimately produce the same final alteration or element trend.

It was suggested that the scale of the fluid system associated with these deposits is critical to forming genuine Fe-oxide-Cu-Au deposits. Large type examples form above Archean lithosphere and are associated with breccia pipes (e.g., breccia within maar hosting the Olympic Dam deposit). The pipes are associated with alkaline intrusion at depth, but do not necessarily show a spatial relationship with intrusions at surface.

The host pipes are probably analogous in structure to diamond pipes (a deep hyperabyssal intrusion overlain by a breccia pipe/diatreme with a crator and tuff ring at surface). Variety in occurrences may result because of the location of the mineralisation relative to the intrusion, pipe or crator. Hyperabyssal mineralisation associated with feeder intrusions may be small but higher grade, whereas crater-related mineralisation formed closer to the surface would be lower grade and more extensively distributed.

In Finland, diamond-related research has defined diatreme material in the Kuusamo area. To the south (e.g: Kaavi-Kuopio), a three-layer mantle stratigraphy has been defined (layers to depths of 110 kilometers, 110-180 kilometers, and >180 kilometers). The third layer resembles Proterozoic or metasomatised Archean mantle that has been altered by the addition of mantle melts. However, the Kuhmo (and Kuusamo) mantle appears to be intact and does not show the layer stratification of other areas (information from presentation given by Hugh O'Brien). It could also be possible to do a global (craton) comparison of mantle stratigraphy to see if there are regular patterns for mineralised and unmineralised belts (e.g., utilising data of Griffin et al.) and for belts where alkaline magmatism is present.

Iron-oxide Cu-Au deposits commonly occur within about 150 kilometers of cratonic margins (e.g., Carajas occupies the edge of a rifted Archean craton, where regional faults orthogonal to the craton edge act as conduits). In Finland, the extent of Archean rocks could be used as a proxy for locating craton edges (assuming Archean lithosphere is difficult to destroy).

Mineralisation associated with A-type granites is commonly misclassified into the Fe-oxide-Cu-Au class. These deposits are usually small and have irregular geochemical trends. Fluid interaction with local iron formations may explain the chemical anomalies. Specific evidence for Fe metasomatism is required for classification of occurrences as Fe-oxide-Cu-Au.

The current, first pass regional 'fuzzy logic model' for this deposit type includes many elements, resulting in signals from many sources appearing as anomalies. For example, U-rich shales are identified. A method to filter out sediment-related anomalies is required. Suitable elements for Fe-oxide-Cu-Au modelling could include Au, Cu, Co, and P. Incorporating Na alteration into the model is also misleading, as it may be too widespread to be related to a mineralising system. It may be that the presence of phlogophite could also be used to indicate a suitable metasomatic history.

3 RECOMMENDATIONS

The specific modelling criteria suggested for each type of mineralisation are summarised below. General criteria regardless of mineralisation type include:

- positive modelling scores are needed to indicate that a suitable seal/trap is or was present, that a suitable fluid conduit exists, and that a suitable element source is present
- bias in data sets needs to be identified (e.g., bias towards structure or geochemistry, incompatible analytical data sets, etc.)
- including stratigraphic contacts (particularly regional contacts between volcanic and sedimentary rocks) should be included in all models because favourable stratigraphic sites are a requirement for all deposit types
- structural data such as dips could be incorporated into most data sets (current models have a strong geochemical/geophysical bias)
- geochemical gradients should be used in preference to actual anomaly values
- current GIS models could be re-run using only characteristics related to mineable deposits
- classification of the deposits is important as empirical GIS models should only use similar deposits as learning points
- schist areas can probably be excluded from modelling, with emphasis instead placed on sediment/volcanic belts and contacts. The only significant Proterozoic deposits in the Fennoscandian Shield occur in volcano-sedimentary sequences
- alteration in amphibolite facies terranes is likely to be subtle and is probably not detectable using regional alteration maps
- the individual model types below should be re/applied to all areas
- dating of deposits is required to compare mineralisation ages to the age ranges of crustal formation events

3.1 Identifying suitable tectonic locations and lithosphere composition

Criteria relating to tectonic setting should also be included in modelling regardless of deposit type. This should include:

- measuring distance to crustal boundaries (filters: <500 kilometers from boundary for gold deposits; <150 kilometers for Fe-oxide-Cu-Au)
- analysing of the tectonic settings present in Finland and compiling the likely deposit types to be located in each. Additional tectonic criteria (e.g., rapid changes to subduction patterns) may also be used in well-known areas
- identifying areas with thin lithosphere and locating major boundaries (proxies: Proterozoic intrusions lacking Archean xenoliths, Proterozoic sedimentary rocks without Archaean zircons; xenolith populations in intrusions for terrane identification)
- gridding of crustal age range data to improve the resolution available from current models
- assembling lithospheric profiles based on diamond/mantle research to see if trends are apparent between mineralised and unmineralised cratons
- locating and assessing the distribution of anomalous intrusion types to help identify tectonic environments and crustal depths exposed

3.2 Orogenic gold prospectivity modelling

In addition to the general recommendations listed above, the following should be completed:

- identify areas where mineralisation occurred 30-40 million years before the end of cratonisation (using the age of younger granitoids). Problem: insufficient age dates for mineralisation
- calculate grids from the U-Pb age and Rb/Sr data to estimate the rate of cooling.

- test granitoid triple-point model for all belts. Results could be filtered using gravity gradients, with gradient/triple-point combinations indicating target areas of higher priority. In Central Lapland, it is necessary to rely on gravity inversion to identify potential granitoids below surface
- identify deposits that are not likely to be orogenic gold deposits and not included in modelling data sets
- complete prospectivity maps for the Kuhmo belt (using Outokumpu Mining/Polar Mining data when it is released)
- incorporate the updated map of Central Lapland showing additional blocks identified from seismic data should be incorporated into future modelling
- identify the likely orientation of conduits/favourable structures (NE- and ENE-striking structures appear to be significant)
- define belts or parts of belts that are oriented orthogonally to regional compression appear to be more favourable
- for SW Finland, use the updated geology maps. Anomalously thick stratigraphic zones could also be used to aid identifying duplex zones associated with deposits
- define proximity to sediment/volcanic contacts or to permeable stratigraphic units, particularly for the non-linear gold belts. This should be done at regional (kilometers) and deposit (100s to 10s of meters) scales
- identify terranes with incoherent structural trends as these are likely to be less prospective

3.3 VMS prospectivity modelling

In addition to the general recommendations listed above, the following should be completed:

- the orientation of ore zone stratigraphy may identify VMS deposits from other mineralisation styles (e.g., epithermal, VMS)
- radiometric data could be assessed for potassium anomalies
- resistivity gradients could be assessed for anomalies that may indicate quartz-sericite alteration zones
- magnetic gradients could potentially indicate redox boundaries
- fluid conduits for VMS systems should be identified (probably not possible)
- a change in volcanism could be identified as it increases VMS potential (e.g., late shoshonitic volcanism may cap and preserve VMS sequences), with felsic volcanic rocks in sequences dominated by mafic volcanic rocks particularly favourable
- anomalously planar intrusions (e.g., stratiform granitoids, gabbro sills in felsic rock) could identify potential heat sources for VMS systems, and could be used to identify prospective areas if these are within 2 to 3 kilometers of a recognised seafloor sequence. In estimating this distance, corrections should be made for tectonic thickening and/or thinning. For identified heaters, zones of elemental depletion should be verified
- granitoid pressure shadows should be considered as these are still relevant locations for this deposit type
- VMS model on all belts previously targeted for gold should be run, as some gold deposits (e.g., Haveri) display VMS characteristics)

3.4 Fe-oxide-Cu-Au prospectivity modelling

In addition to the general recommendations listed above, the following should be completed:

- look for evidence for suitable volcanic host rocks (feeder intrusions, breccia pipes, volcanoclastic deposits)
- look for evidence for Fe-metasomatism
- reduce the modelled elements to Au, Cu, Co and P, and used with a filter for sediment-related anomalies
- look for characteristic rare earth element trends in existing analyses
- ignore Na anomalies as these may not be useful as it appears that a distinction cannot be made between regional and local alteration events

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