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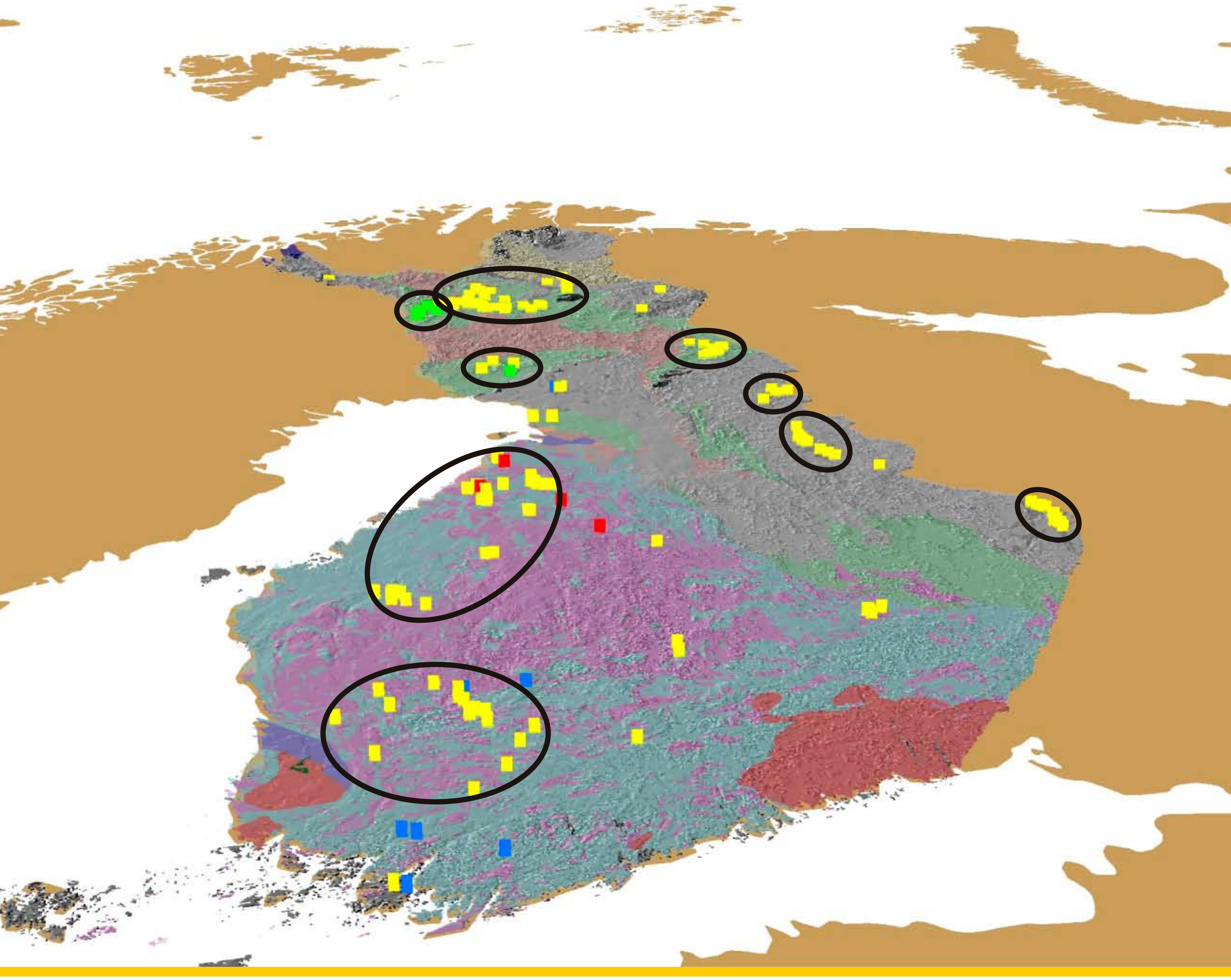

Gold Prospectivity of Finland

Patison, Nicole, Ojala, V. Juhani, Nykänen, Vesa, Eilu, Pasi,
Groves, David I. and Gardoll, Stephen

GTK

GEOLOGIAN TUTKIMUSKESKUS

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Nicole Patison, V. Juhani Ojala, Vesa Nykänen, Pasi Eilu, David I. Groves and Stephen Gardoll

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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 which are SW Finland (including Tampere Schist Belt and Vammala Migmatite Zone), Ilomantsi (Hattu Belt), Pohjanmaa, Kuhmo and Suomussalmi greenstone belts, Kuusamo Schist Belt, Peräpohja Schist Belt, and Central Lapland. 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: 1) A suitable seal/trap, a suitable fluid conduit exists, and a suitable element source should be present. 2) Regional contacts between volcanic and sedimentary rocks should be included in all models. 3) Structural data should be incorporated into most data sets. 4) Geochemical gradients should be used in preference to actual anomaly values. 5) Genetic classification of the deposits is important as empirical GIS models should only use similar deposits as learning points. 6) Schist areas can probably be excluded from modelling, with emphasis instead placed on sediment/volcanic belts and contacts. 7) Dating of deposits is required to compare mineralisation ages to the age ranges of crustal formation events. 8) Defining tectonic settings helps to define the likely deposit types to exist. 9) Areas with thin lithosphere and major boundaries are important. 10) Defining the distribution of anomalous intrusion types to help identify tectonic environments and crustal depths exposed.

Key words: (GeoRef Thesaurus, AGI): mineral exploration, gold ores, IOCG deposits, greenstone belts, schist belts, geographic information systems, models, Precambrian, Proterozoic, Paleoproterozoic, Archean, Finland

Nicole Patison, Juhani Ojala, Vesa Nykänen
Geological Survey of Finland
P.O. Box 77
FI-96101 ROVANIEMI
FINLAND

Pasi Eilu
Geological Survey of Finland
P.O. Box 96
FI-02151 ESPOO
FINLAND

David Groves, Stephen Gardoll
Department of Geology
University of Western Australia
35 Stirling Highway
Crawley WA 6009
AUSTRALIA

E-mail: pasi.eilu@gtk.fi

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Työn tarkoituksena oli arvioida kullan esiintymisen otollisuutta Suomessa, jotta eri kultamalmityyppien etsintäkriteerejä voitaisiin parantaa. Työssä Suomi jaettiin geologian perusteella seuraaviin osa-alueisiin: Lounais-Suomi (sisältäen Tampereen liuskejakson ja Vammalan migmatiittivyöhykkeen), Hatun liuskejakso, Pohjanmaan, Kuhmo-Suomussalmen vihreäkivivyöhyke, Kuusamon liuskejakso, Peräpohjan liuskejakso ja Keski-Lapin alue. Eri malmityypeille ehdotetut mallinnuskriteerit on listattu raportin lopussa. Yleisiä kaikille malmityypeille huomioon otettavaksi ehdotettuja kommentteja ovat: 1) Metallin lähde, malmiliuokselle sopiva kulkutie ja malmiutumispaikka pitäisi olla määritettävissä. 2) Alueelliset sedimenttikivien ja vulkaniittien kontaktit ovat tärkeitä. 3) Rakennegeologinen tieto pitäisi pystyä sisällyttämään malleihin. 4) Geokemiallisia gradientteja pitäisi käyttää mieluummin kuin geokemiallisia anomalia-alueita. 5) Esiintymien geneettinen luokittelu etukäteen on erityisen tärkeää jos GIS-mallinnuksessa käytetään opetuspisteitä. 6) Liuskealueita, joissa ei ole vulkaanisia kiviä, voidaan pitää toissijaisina malminetsintäkohteina vulkaniittijaksoihin verrattuna. 7) Esiintymien iätys on tärkeää, jotta voidaan verrata malmeja ja malmiaiheita alueen tektoniseen kehitykseen. 8) Tektonisten ympäristöjen ja niissä mahdollisten malmityyppien tunnistaminen. 9) Ohuen litosfäärin alueet ja suuret rakenteet ovat tärkeitä. 10) Koostumukseltaan epätavalliset intruusiot ja niiden sijainti voivat auttaa tektonisten ympäristöjen ja eroosiotason määrittämisessä.

Julkaisu on englanninkielinen.

Asiasanat (Geosanasto, GTK): malminetsintä, kultamalmit, IOCG-esiintymät, vihreäkivivyöhykkeet, liuskevyöhykkeet, paikkatietojärjestelmät, mallit, prekambri, proterotsooinen, paleoproterotsooinen, arkeeinen, Suomi

Nicole Patison, Juhani Ojala, Vesa Nykänen
Geologian tutkimuskeskus
PL 77
96101 ROVANIEMI

Pasi Eilu
Geologian tutkimuskeskus
PL 96
02151 ESPOO

David Groves, Stephen Gardoll
Department of Geology
University of Western Australia
35 Stirling Highway
Crawley WA 6009
AUSTRALIA

Sähköposti: pasi.eilu@gtk.fi

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Front cover:
Gold deposits and occurrences in Finland, and regions assessed in this study. Deposit classification according to Eilu et al. (2003) and Eilu (2007), bedrock from GTK GIS database. Digital elevation model (c) National Land Survey of Finland license number 13/MML/08.

INTRODUCTION

The purpose of this work is to assess the gold prospectivity of Finland, and to develop and refine exploration criteria for future work on different deposit classes and styles. All comments and suggestions given in this report are based on the work we did during the workshop and field trip in May 2006, with a update to the most recent literature on gold metallogeny and exploration. It is up to more detailed work to prove the conclusions below right or wrong, for the benefit of economic geology research and metals exploration in Finland.

For the prospectivity assessment, Finland was divided into geologically different terrains, which are SW Finland (including Tampere Schist Belt and Vammala Migmatite Zone), Pohjanmaa Area, Ilomantsi Belt (Hattu Belt), Kuhmo and Suomussalmi greenstone belts, Kuusamo Schist Belt, Peräpohja Schist Belt, and Central Lapland Area (Fig. 1). The status of exploration, tectonic setting, genetic models, and the likely prospectivity of each area are considered. It is reminded here that this report is based on the public data, and other reports which were on hand during the our work.

Provided below are details of participants, programme and outcomes of this work, and recommendations for future research and exploration. The text below incorporates the suggestions made by all participants. Figures have been included where we saw that relevant.

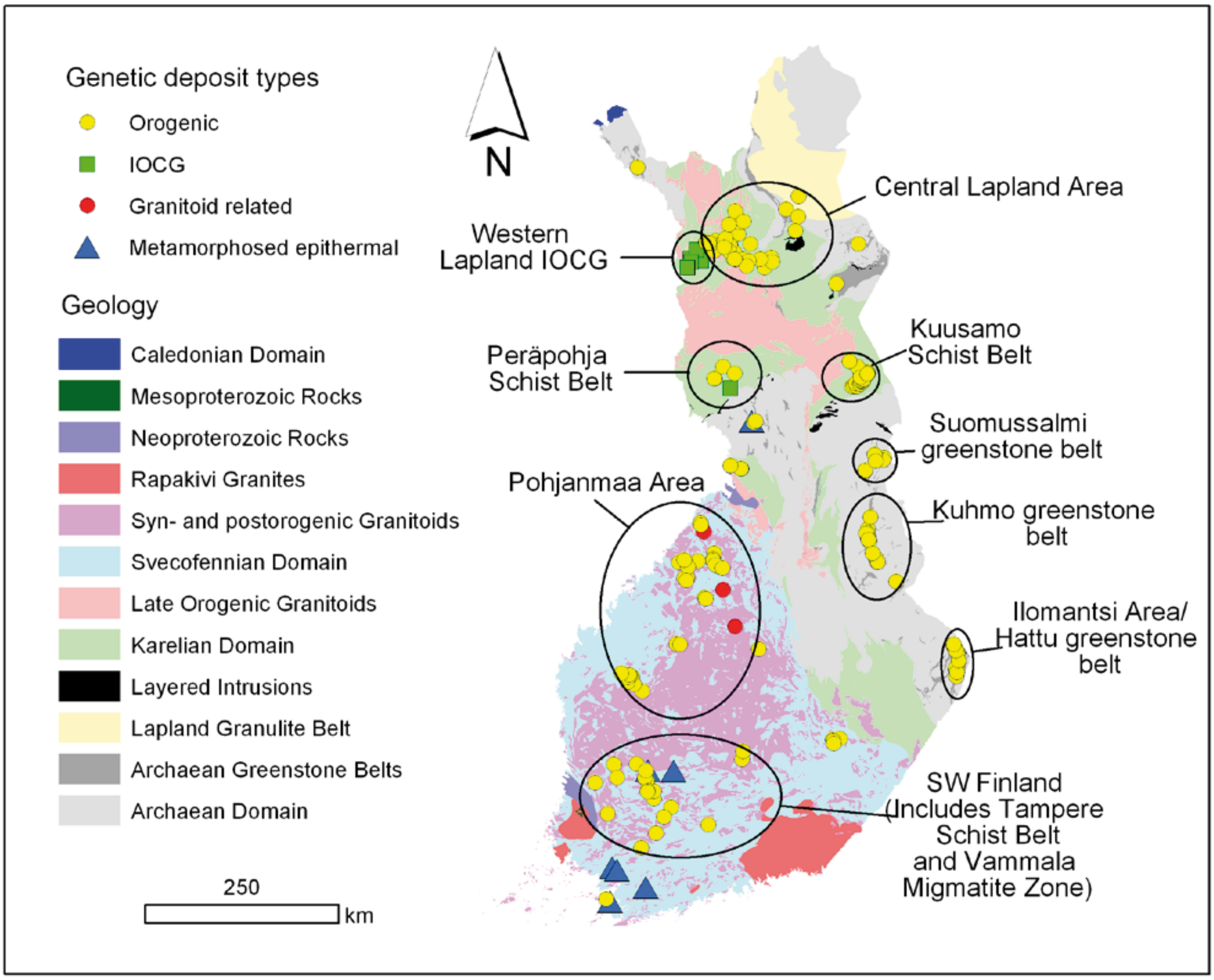

Figure 1. Reference map for target locations (genetic types according to Eilu et al. 2003 and Eilu 2007).

Participants

The following people participated on the workshop and field trip (in 2006) on which this report is based on; dates indicate the time when the person participated:

David Groves, Emeritus Professor, University of Western Australia (07–19 May)
Stephen Gardoll, Associate Research Fellow, University of Western Australia (07–11 May)
Juhani Ojala, GTK (07–19 May)
Pasi Eilu, GTK (07–19 May)
Vesa Nykänen, GTK (07–19 May)
Nicole Patison, GTK (07–17 May)
Peter Sorjonen-Ward, GTK (08–11 May, and 15 May)
Kerstin Saalmann, GTK (07–11 May)
Saku Vuori, GTK (08 May)
Niilo Kärkkäinen, GTK (08 May)
Raimo Lahtinen, GTK (10 May)
Hugh O'Brien, GTK (12 May)
Asko Kontinen, GTK (15 May)

Programme

Table 1. Workshop and field trip 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 Suomussalmi 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, Juomasuo, Pampalo, Kuhmo, Hirvilavanmaa, 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 Juomasuo 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*

OUTCOMES

General comments relevant to exploration models

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 (Bierlein et al. 2008, Hronsky & Groves 2008). 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 (Groves et al. 2000, Hronsky & Groves 2008) 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 (Beaudoin et al. 2006). 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.

Criteria incorporating crustal boundaries and structures

Regional tectonic filters can also aid GIS analysis. For example, major orogenic gold provinces are typically located <500 kilometres inboard of subduction zones (e.g., Western Australia, Canada; Goldfarb et al. 2001, Groves et al. 2003). Changes in subduction processes may also create new geometries that are more favourable for trapping fluids. Beyond 500 kilometres of a crustal boundary, other gold deposit types are more likely (e.g., Carlin-style gold, Sn and W deposits; Goldfarb et al. 2001, Emsbo et al. 2006, Mair et al. 2006).

In contrast, there is no documented relationship between subduction zones and Fe-oxide Cu-Au occurrences. These are typically constrained to with 150 kilometres of terrane boundaries, and evidence for metasomatised lithosphere is required to provide volatile rich magmas (Williams et al. 2005, Groves & Bierlein 2007). Thin, primitive crust is also favourable for volcanic-hosted massive sulphide (VMS) deposits (Goldfarb et al. 2001). 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 (Groves et al. 2005). In these terrains, the lithospheric evolution prior to gold mineralisation has typically been short (e.g., Bierlein et al. 2006). For Archaean 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 (Goldfarb et al. 2001, Groves et al. 2003), 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 widespread gold anomalies in till in Central Lapland indicative of rift or platform greenstone belts, rather than allochthonous blocks?

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 in Finland resemble the Southern Cross Belt of Western Australia in that the granites within each belt control the present shape of the greenstone belt (Luukkonen 1992, Dalstra 1995, Papunen et al. *submitted*). Volcanic rocks appear to be the more favourable host rocks, followed by sedimentary rocks (Eilu 2007). 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 (Lahtinen et al. 2005). These events have disrupted the linearity of belts, and linearity is a favourable characteristics of most gold-enriched 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 (de Ronde et al. 1992, Pitfield & Campbell 1996, Weinberg et al. 2005). 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 (Nykänen et al. 2008b). 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 in this work 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 (Goldfarb et al. 2001).

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 (e.g., Koljonen 1992, Salminen 1995) 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 structural 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 (Weinberg et al. 2004, Hodkiewicz et al. 2005, Morey et al. 2007).

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.

Belts and individual deposits

SW Finland

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

Forssa (Forssa-Somero) Area

Interpretations of the regional structure of this area (Saalmann 2007), forming the western part of the Häme Volcanic Belt, identify thrust faulting and associated transfers, with gold occurrences located within overthrust blocks. Further north, the deposits in SW Finland (Vammala Migmatite Zone) and the adjacent Tampere Schist Belt appear to concentrate at the regional contacts between volcanic and sedimentary rocks (Figure 3). It is possible that these boundaries operate as geochemical controls or regional seals. The area also contains some coherent structures (NW-trending, as are till Au and As anomalies), but most are generally difficult to follow.

Ritakallio (Vammala Migmatite Zone)

Current drilling at Ritakallio has targeted to test geochemical and heavy mineral anomalies in a shear zone suggested by aeromagnetic survey. The aim was

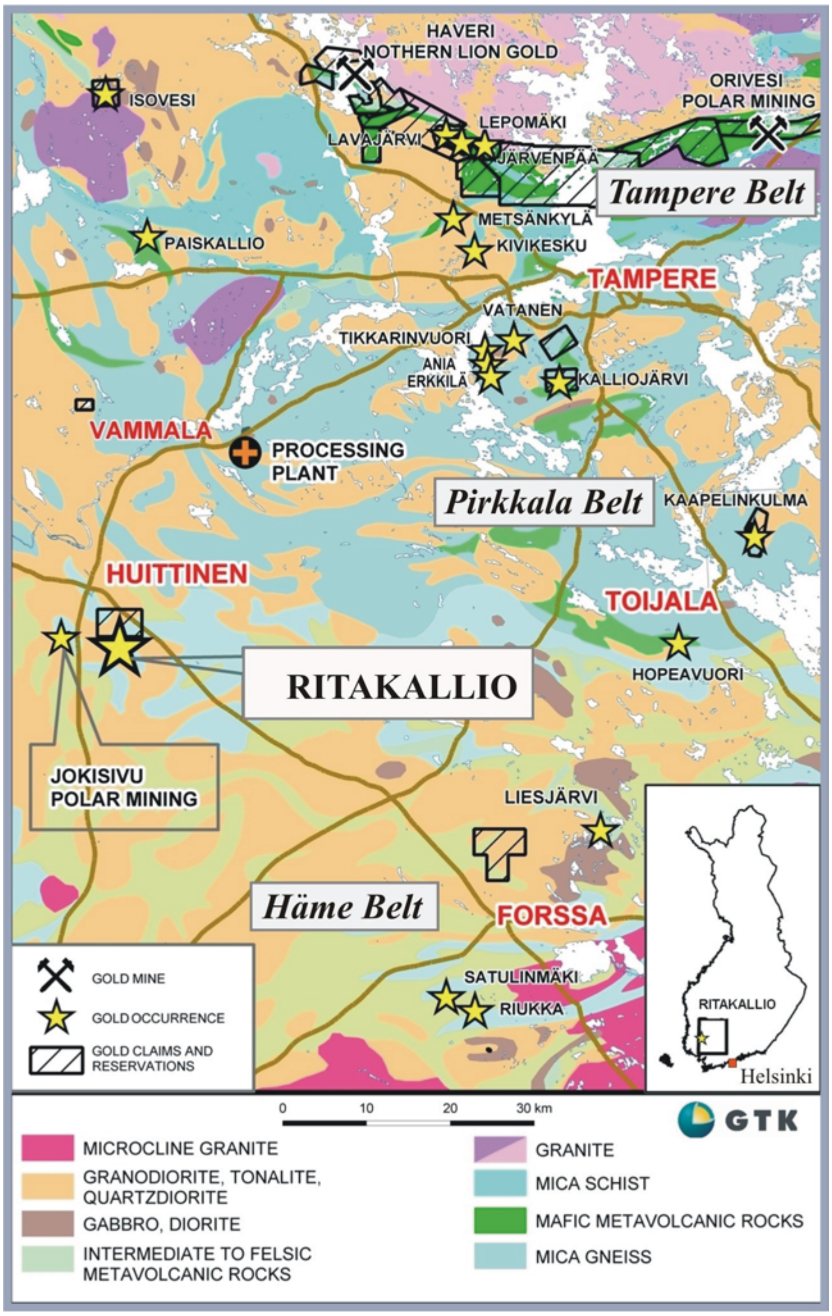

Figure 2. Location for gold targets in SW Finland (Vuori et al. 2005).

to map the extents and geometry of gabbro bodies hosted by metasedimentary rocks to aid geophysical interpretation of structures potentially hosting gold mineralisation. The results (Vuori et al. 2005) 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 aero-magnetics is correct, a geometrical target with an orthogonal relationship to regional principal compression can be identified (Fig. 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 the entire gabbro body.

Jokisivu (Vammala Migmatite Zone)

The Jokisivu deposit is close to a contact zone between diorites and tonalitic gneisses (Fig. 5; Luukkonen 1994). The contact is also conductive, which suggests the presence of black schists. The test pit area is within a fold hinge, but may also be located

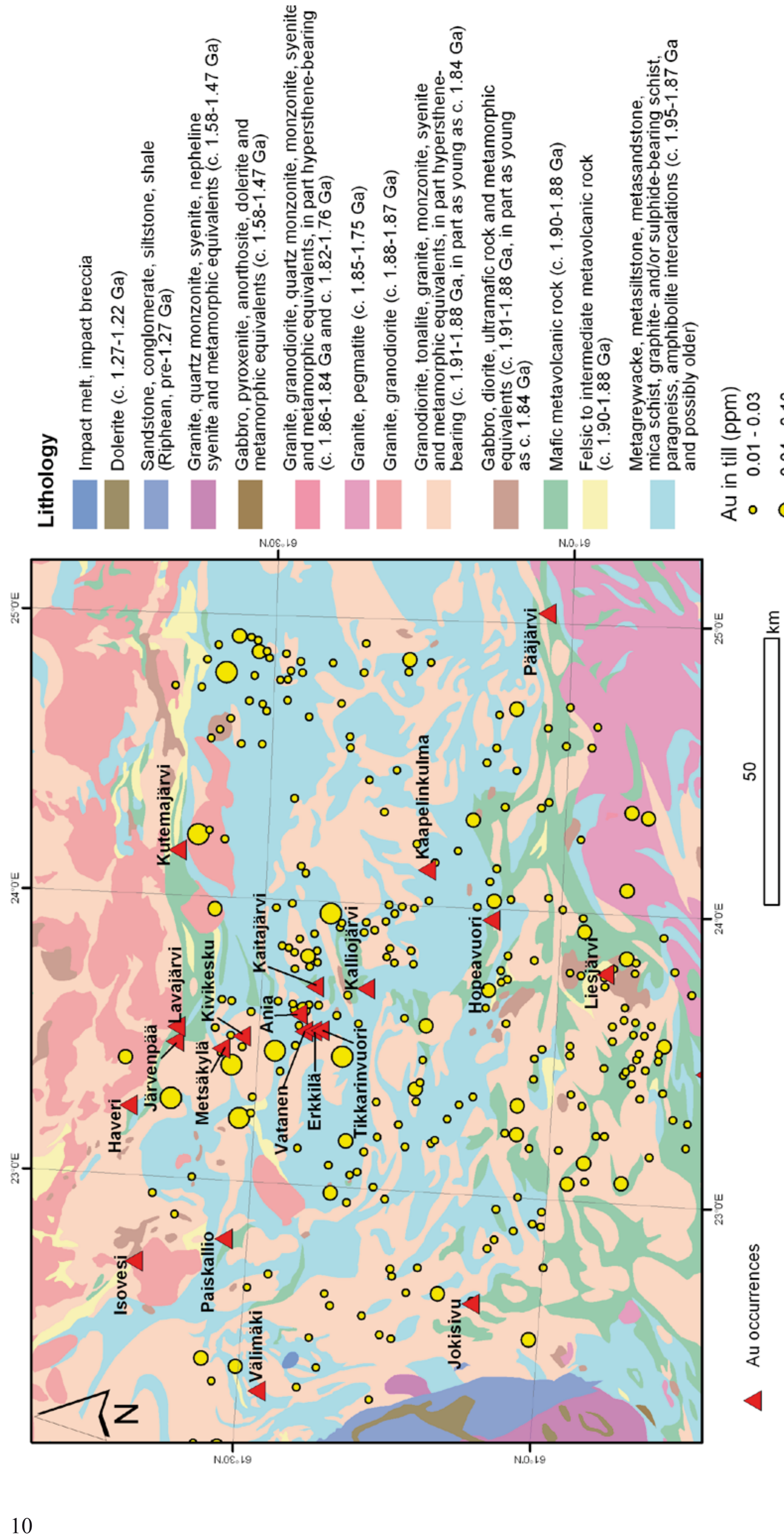

Figure 3. Gold in till in SW Finland. Tampere Schist Belt (green at north), Vammala Migmatite Zone (Pirkkala Belt; blue in the middle), and Häme Volcanic Belt (green at south).

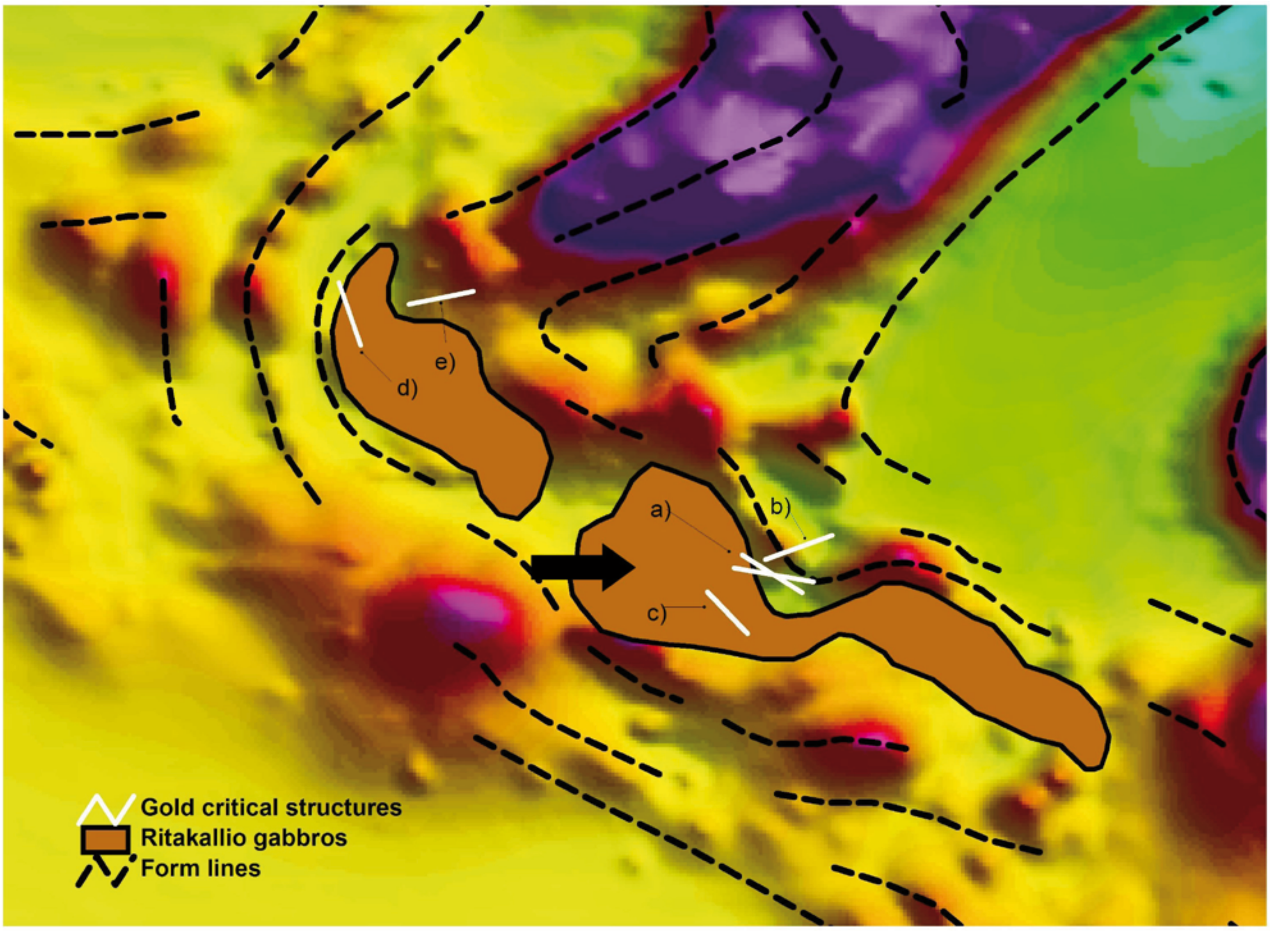

Figure 4. Ritakallio prospect (Vuori et al. 2005). Possible target marked by arrow: drill out the competent gabbro body where the potential for a rock mass-hosted deposits may be greater. Base map a low-altitude high-resolution airborne magnetic map. Field of view 3 km, north up.

on a secondary stratigraphic contact. There may be potential for a better ore zone at a major stratigraphic contact.

This and the nearby occurrences probably formed at amphibolite facies PT conditions because there is no metamorphosed alteration halo surrounding the mineralised veins, no hydrous phases around the veins, diopside is the most proximal alteration product next to auriferous quartz veins, and there are indications of in-situ melting around quartz veins, initiated by water input by hydrothermal fluids (good examples in the Arpola lode area, Fig. 5).

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 (Fig. 6), especially company data since 2007 held by the company Lappland Goldminers Ab. The geology maps of the immediate area (Figs. 6A, 6B) could not be correlated with geophysical data (Fig. 6C; Eilu et al. 2004), and probably partially represent maps of alteration. It is possible that the deposit has a connection with a porphyry intrusion (granodiorite in Fig. 6A) as is presented in Figure 6B. The mine area occupies a NNW-trending magnetic low (the porphyry ± granodiorite?). 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 (Mäkelä 1980). 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 (Northern Lion Gold Corp. 2005, 2006). 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.

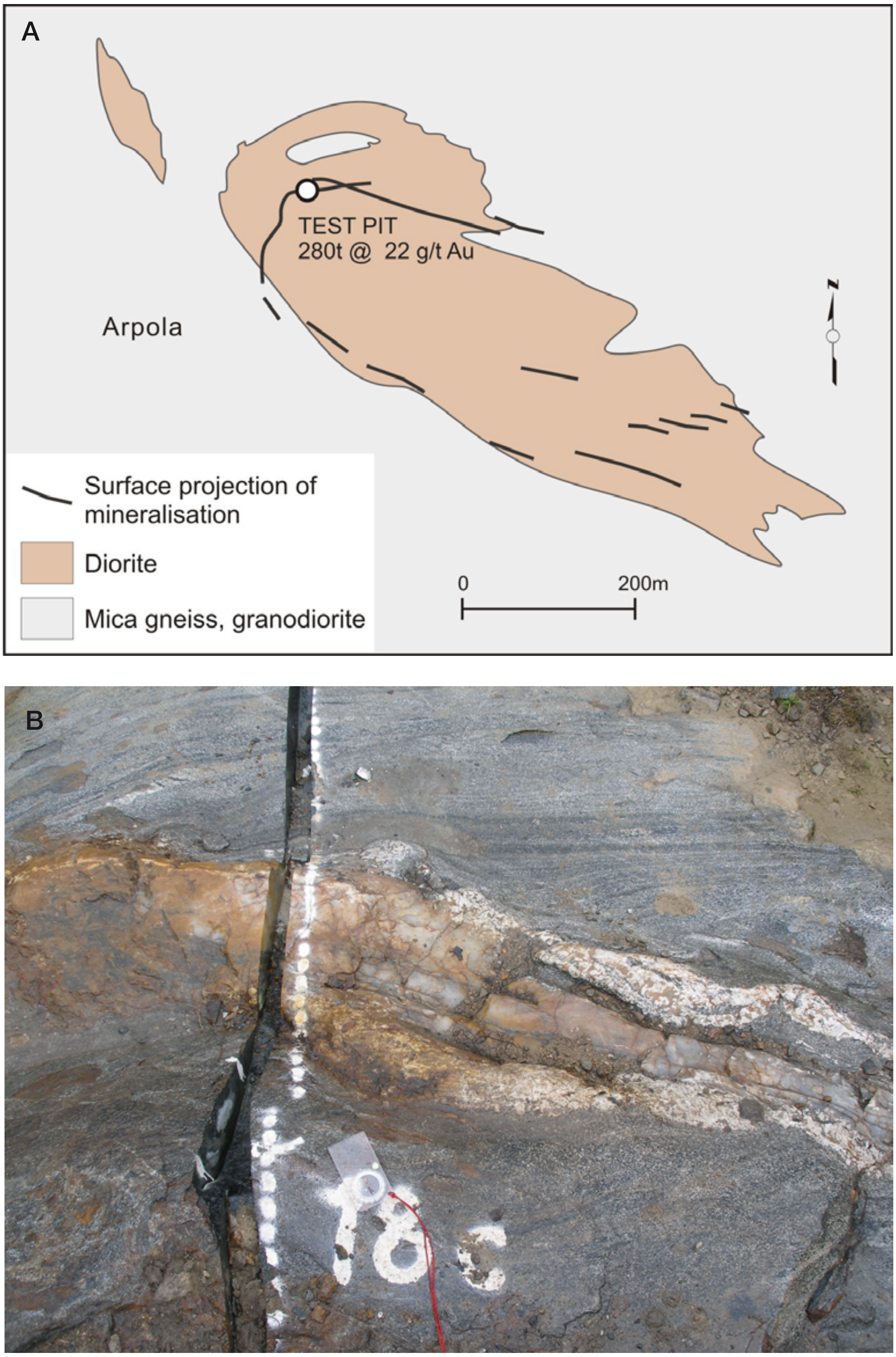

Figure 5. A) Jokisivu area (Dragon Mining 2004). B) Pegmatite-like material around a quartz vein, in diorite, interpreted as an in situ melting zone surrounding a gold-rich quartz vein (Arpola lode); the compass plate is 11 cm long; photo Pasi Eilu.

Given the sea-floor environment in the area and the assumed intrusion, a VMS association could be considered, as suggested by Mäkelä (1980) and Eilu et al. (2004). A possible major subvolcanic sill occurs to the SW, within 2 kilometres of the deposit area, and it may have a connection to the immediate deposit area (Fig. 6B). 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 additional 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).

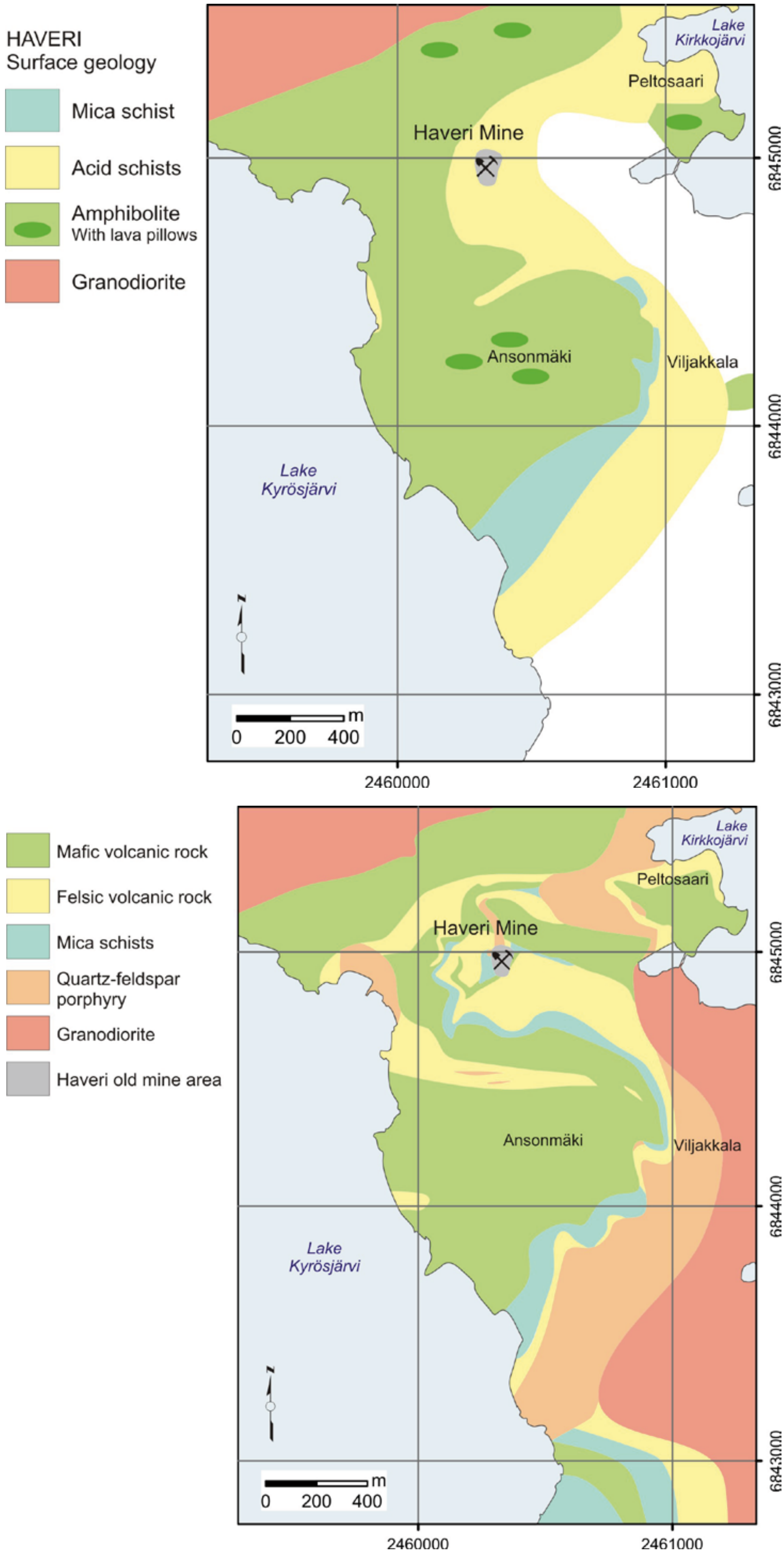

Figure 6. A) Haveri surface geology by Lindroos (2005) and B) by Forss (2006).

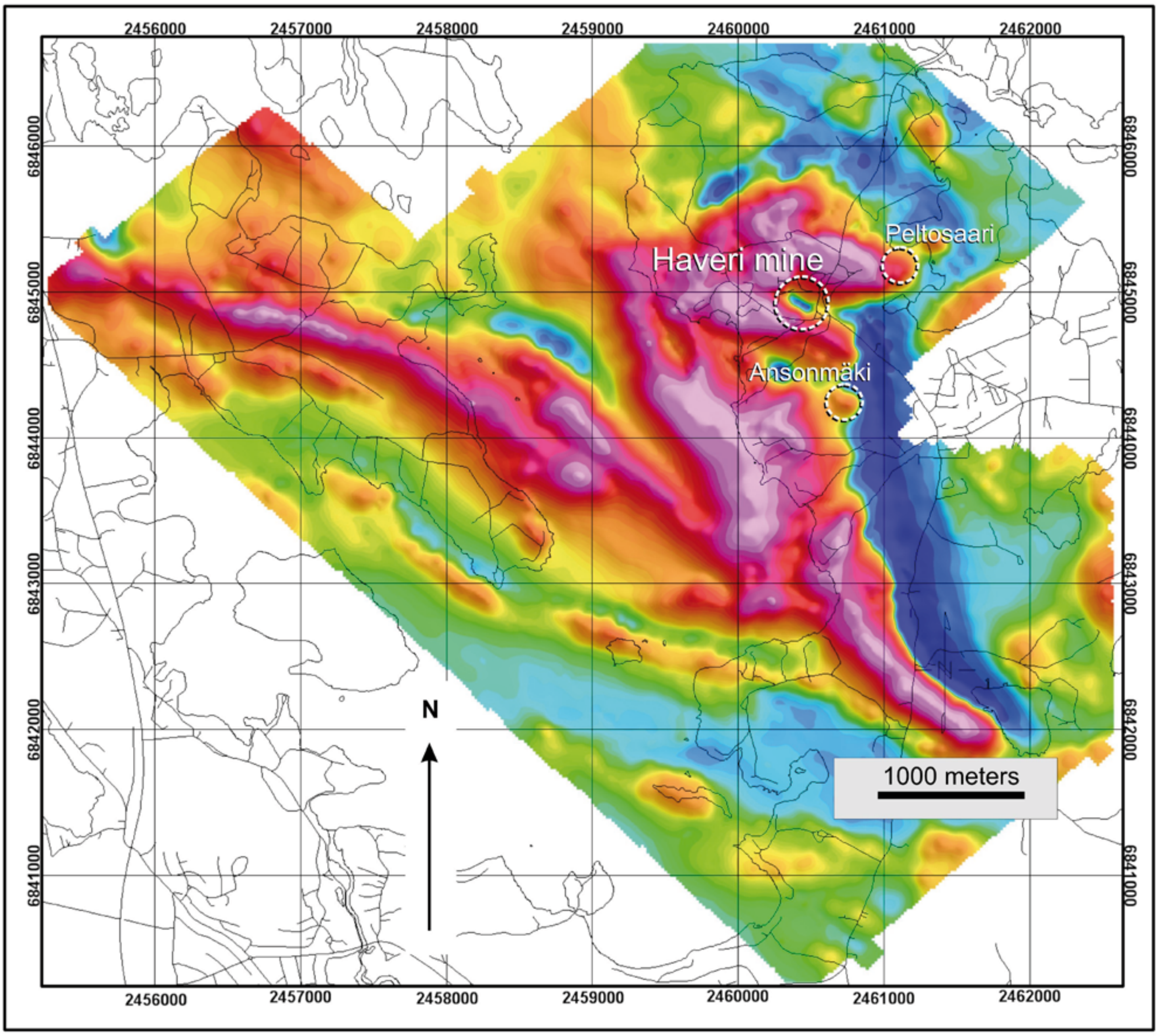

Figure 6. C) Aeromagnetic map of the Haveri region (original map image received from Northern Lion Gold, edited by Tapio Ruotoistenmäki).

- 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 a 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 felsic porphyry.

Haveri demonstrates that there may also be potential in this area for other deposit types (e.g., VMS or 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 Recommendations).

Orivesi (or Kutemajärvi; Tampere Schist Belt)

Figure 7 shows a geological map of the Orivesi mine area; this figure is partly a rock type, partly an alteration map. The ore pipes (black dots) have two hosting mineral assemblages: andalusite-quartz (northernmost pipes) and quartz pipes, the former containing high bismuth suggesting relatively 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

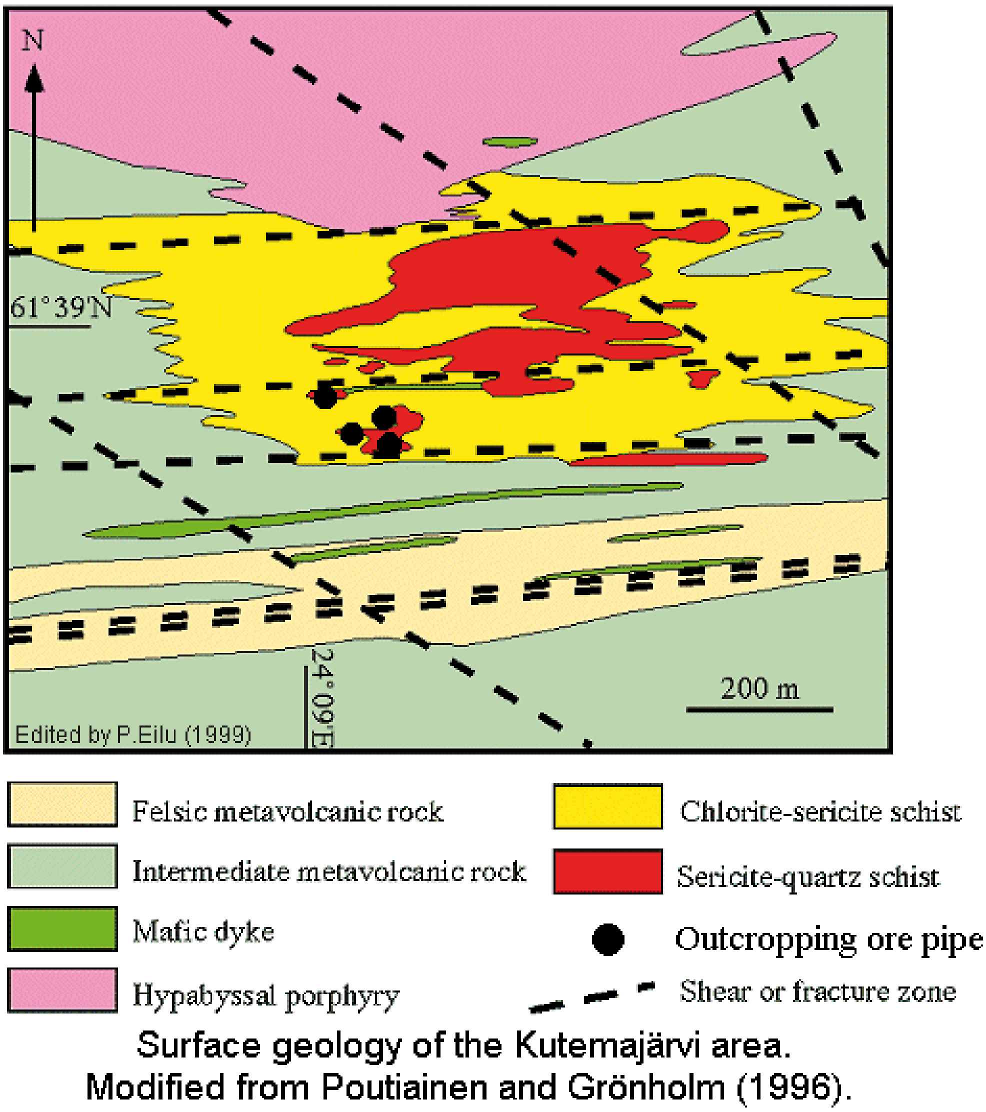

Figure 7. Orivesi mine area geology map (modified from Poutiainen & Grönholm 1996).

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, whereas others have a NE trend and are drawn in a way suggesting *en echelon* distribution.

Ore pipe pathfinder minerals suggested by the mine geologist at site in 14 May 2006 were apatite, topaz, pyrophyllite, amorphous carbon and tellurides. There are some mineralogical differences between the ore pipes, and pathfinder elements have different trends in cross section from north to south. A previous publication (Poutiainen & Grönholm 1996) has suggested that much of the alteration at Orivesi is produced by a pre-metamorphic system. Gold mineralisation in the same paper was suggested 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 map and understand.

Core and other samples indicate that a structural control might also operate. Ore pipes are parallel to the stretching lineation orientation and ore minerals in hand samples (Au-rich tellurides?) 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 modelled ore zones. It is possible that the ore bodies are not randomly distributed in the proximal alteration zone, as is currently suggested, but 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 high-sulphidation 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.

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 and 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 the region 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 trialled 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 modelling the 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.

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., with bismuth) at other occurrences (Fig. 8) have led to the suggestion that the area could contain intrusion-related gold systems of porphyry copper and other styles (e.g., Gaal & Isohanni 1979,

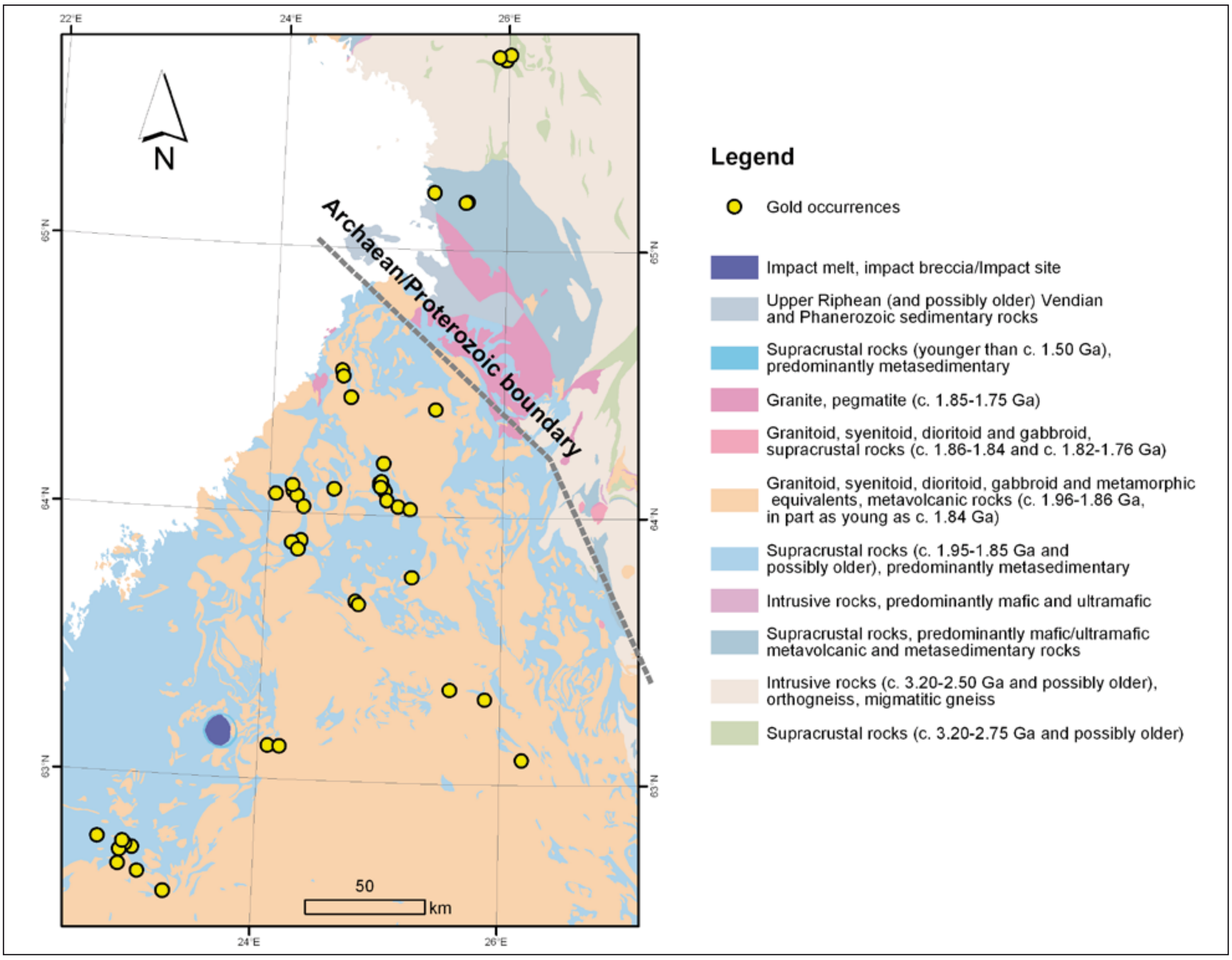

Figure 8. Map of Pohjanmaa with occurrences shown as yellow dots. Pink, purple, light yellow: granitoids, granodiorites; blue, grey: schists, gneisses; green: mafic rocks. The boundary between Archaean and Palaeoproterozoic is marked by a dashed line. Bedrock from GTK GIS database, gold occurrences from the FINGOLD data base (http://en.gtk.fi/ExplorationFinland/Commodities/Gold/gtk_gold_map.html).

Eilu et al. 2003). 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 deposits. 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. On the other hand, one should keep in mind that the enormous Aitik Cu-Au deposit in northern Sweden, at similar crustal level and potentially in the same plate-tectonic domain as much of Pohjanmaa, has recently been indicated to probably be a porphyry-style deposit (Wanhainen et al. 2005).

Ilomantsi/Hattu Schist Belt

Questions about the possible nature of the Archean lithosphere in this area (Fig. 9) 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 during Neoarchaean, as also is suggested by isotope data in O'Brien et al. (1993), and that the greenstone sequences here formed in platform environments. This may make the potential for VMS mineralisation in this belt low.

The Pampalo 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 melting has possibly taken place as indicated by pegmatitic material in boudin necks. The ore is mostly hosted by a volcaniclastic rock of intermediate composition, but also by intermediate to felsic porphyry dykes (Nurmi & Sorjonen-Ward 1993). 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 (Fig. 9) appears broken by faulting and may be the more prospective area (check for the presence of a gravity gradient in this area). The immediate surroundings of the Pampalo deposit have 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 also are 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 or favourable orientations. The proposed better orientations could be selected using filters for dips <70° and strike orientations at >30° from the regional trend of N-S (define fractal parameters for structures).
- Check the volcanic-sedimentary rock contacts or other zones of rheological/chemical contrast.
- Define 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 anomalous region rather than specific targets.

Kuhmo and Suomussalmi Greenstone Belts

In general, the Kuhmo and Suomussalmi belts may have more exploration potential for gold than the Ilomantsi Belt because the former have a greater strain variation within the belt. The belts consist of steeply dipping ~2.8 Ga greenstones (Hyppönen 1983; ca. 40 million years older than Ilomantsi greenstones) surrounded by 2.9–2.65 Ga gneiss-granitoid terrane (Luukkonen 1992, Papunen et al. *submitted*).

Most of the known deposits occur at a sheared contact between two units with different mafic lava geochemistry (Luukkonen et al. 2002). Other targets with potential stratigraphic controls and/or granitoid triple point locations include Jumalisjärvi and Saarijärvi (they also show a positive correlation with stress modelling anomalies at these and other locations circled in Figure 10).

The main structural trends in this area appear to follow granitoid contacts. The existing stress modelling could be modified and tested using fewer structures (e.g., by 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 visited during this work, in the central parts of the Kuhmo belt, shows the possible relationship between map-scale structures and mineralisation. An outcrop of rocks typical for the belt, at Timola, shows Au-rich 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.

Lower-amphibolite facies felsic to intermediate porphyries host the Mataralampi prospect. Localised biotite-calcite alteration occurs in mafic wall rocks,

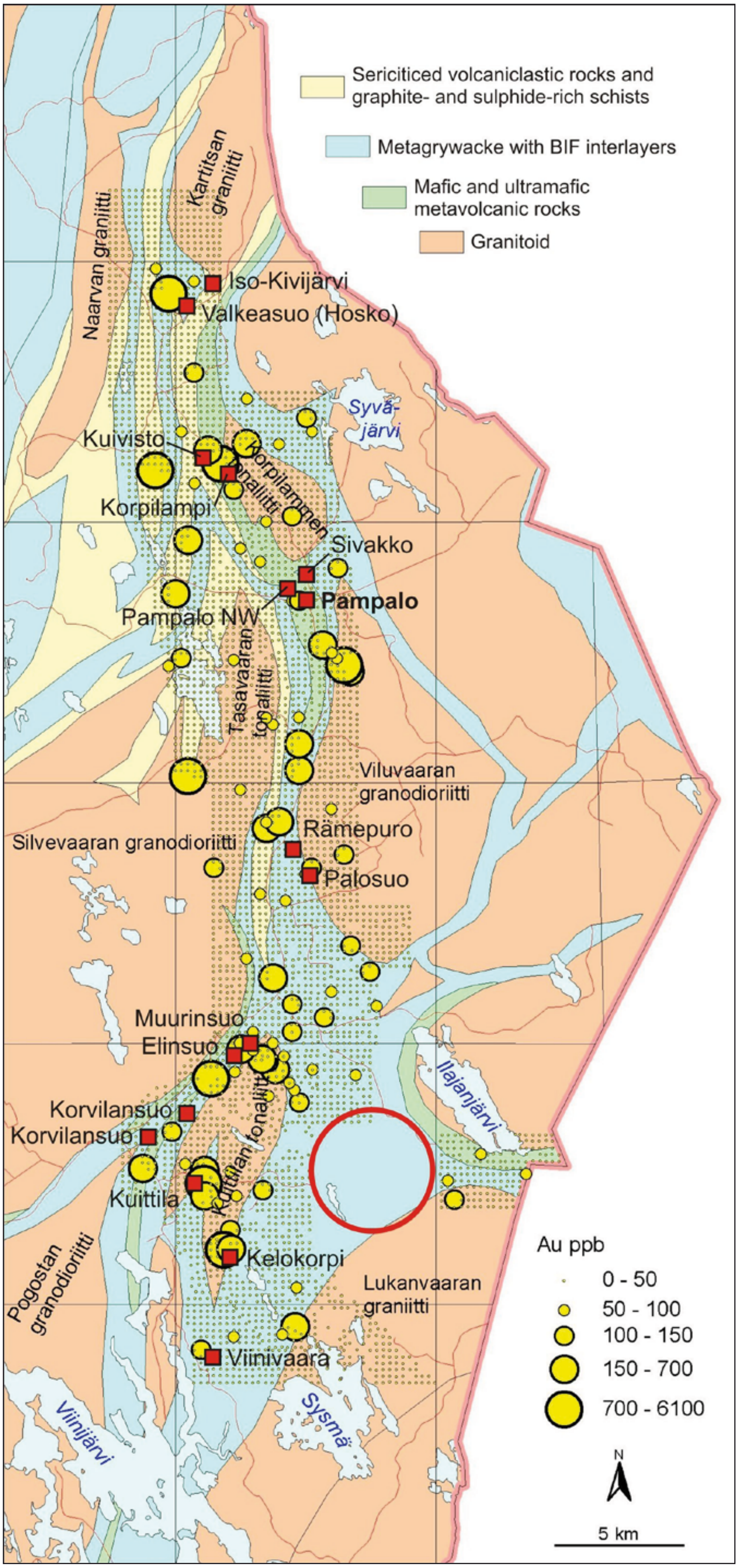

Figure 9. Simplified geological map of the Hattu Schist Belt with Au till geochemistry and gold occurrences (Luukkonen et al. 2002). A preferred exploration target area is indicated by red circle.

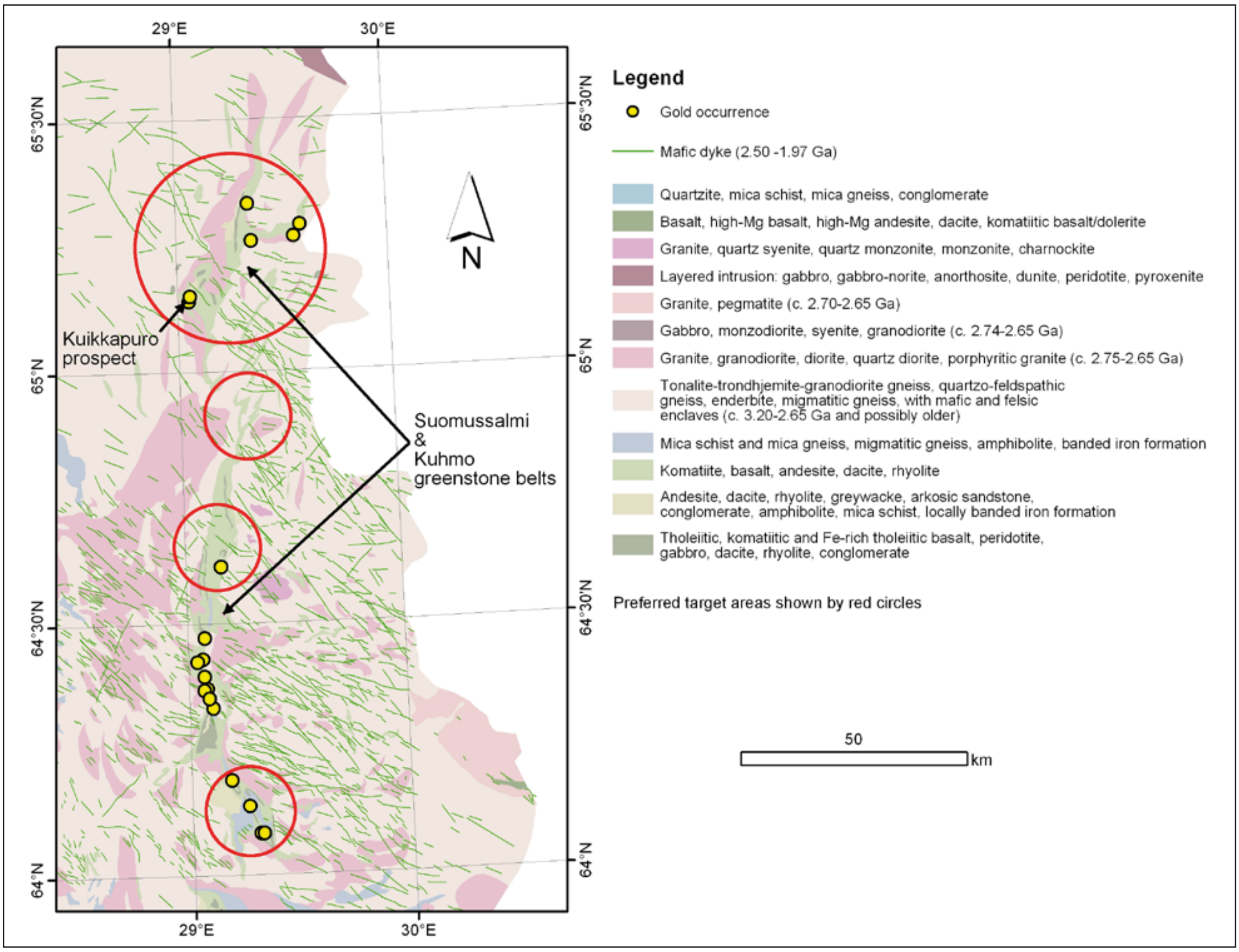

Figure 10. Kuhmo and Suomussalmi greenstone belts and their surroundings. Preferred target areas shown by red circles. Source: GTK GIS database.

but sericite-calcite alteration characterises the mineralised hosts. The deformation fabrics are mostly brittle small-scale orthogonal conjugate (Fig. 11) shear bands, 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 dilatational 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 gold mineralisation detected in exploration trenches, the fabric orientation becomes closer to N-S. A sulphidic zone in the trenches with no to low associated gold strikes 340º.

The above structural trends can be correlated back to the regional map and may aid in defining prospectivity (Fig. 12). The trend of shear bands and quartz veining at Timola (Fig. 13) resemble the overall trend of the greenstone belt. The host shear for the dilatational 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

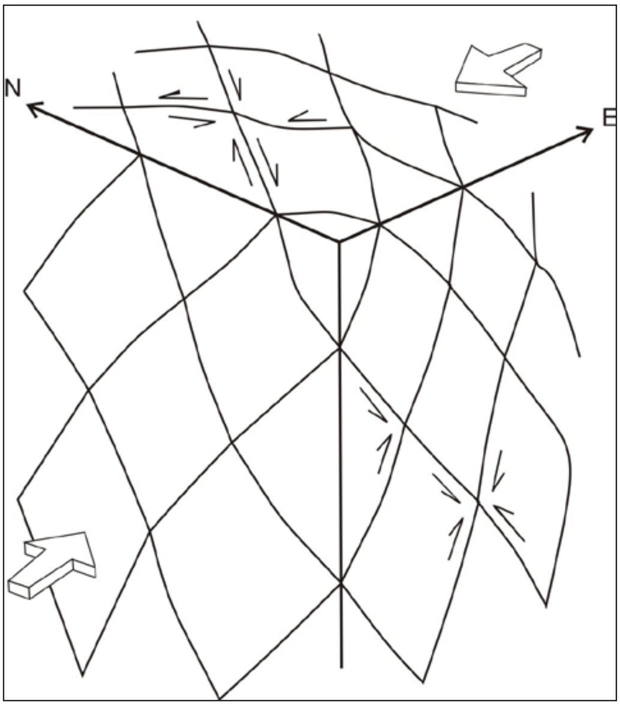

Figure 11. Sketch of conjugate orthogonal brittle-ductile shear relationship in the Mataralampi area. Conjugate shear bands form a fracture mesh which could provide rock-confined fluid pathways in a brittle host rock, such as the quartz porphyry host at the Mataralampi gold occurrence.

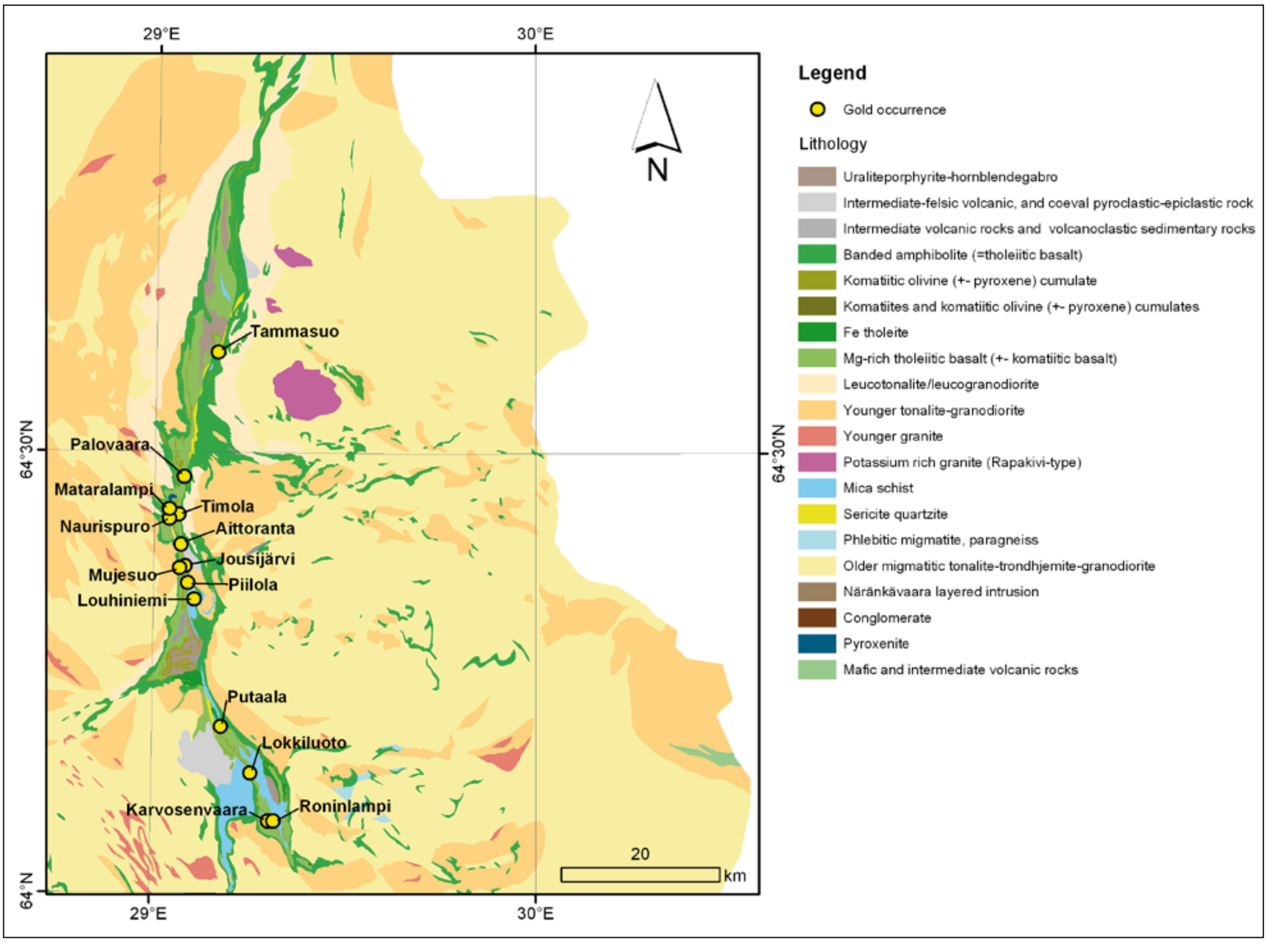

Figure 12. Geological map of the Kuhmo greenstone belt. Geology from Luukkonen et al. (2002), gold occurrences from the FINGOLD data base (http://en.gtk.fi/ExplorationFinland/Commodities/Gold/gtk_gold_map.html).

stratigraphic contact (between sericitic quartzites and mafic volcanic rocks) has a 015–020° orientation and could be considered as a favourable site (circled in Figure 13).

Kuikkapuro

At the Kuikkapuro prospect further north (Suomussalmi Greenstone Belt, Figure 10) high-grade gold intersections occur in a quartz-veined biotite-calcite alteration zone between mafic volcanic and garnet-biotite altered rocks (Pietikäinen et al. 2001, Luukkonen et al. 2002). It is obvious now, that the present mineral assemblages and textures also represent originally different rock types at Kuikkapuro. 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. Auriferous quartz pods have moderate to steep plunges to 020º. This orientation is the same as the strike plane for the quartz-veined dilations at Mataralampi.

Kuusamo Schist Belt

Interpretations of the Kuusamo Schist Belt (Fig. 14) include a foreland area for the Lapland Granulite Belt and/or a continental shelf sequence at an intracratonic, failed rift filled by a subaerial to shallow-water volcanosedimentary sequence deposited on late Archaean (2.6–2.8 Ga) basement (Pankka & Vanhanen 1992, Vanhanen 2001, Laajoki 2005). Felsic rocks representing eutectic melts are present at the NW margin (possibility of granite-related hydrothermal gold mineralisation suggested by P. Sorjonen-Ward, pers. comm. 10 May 2006). 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 and possible fluid escape channels are preserved in

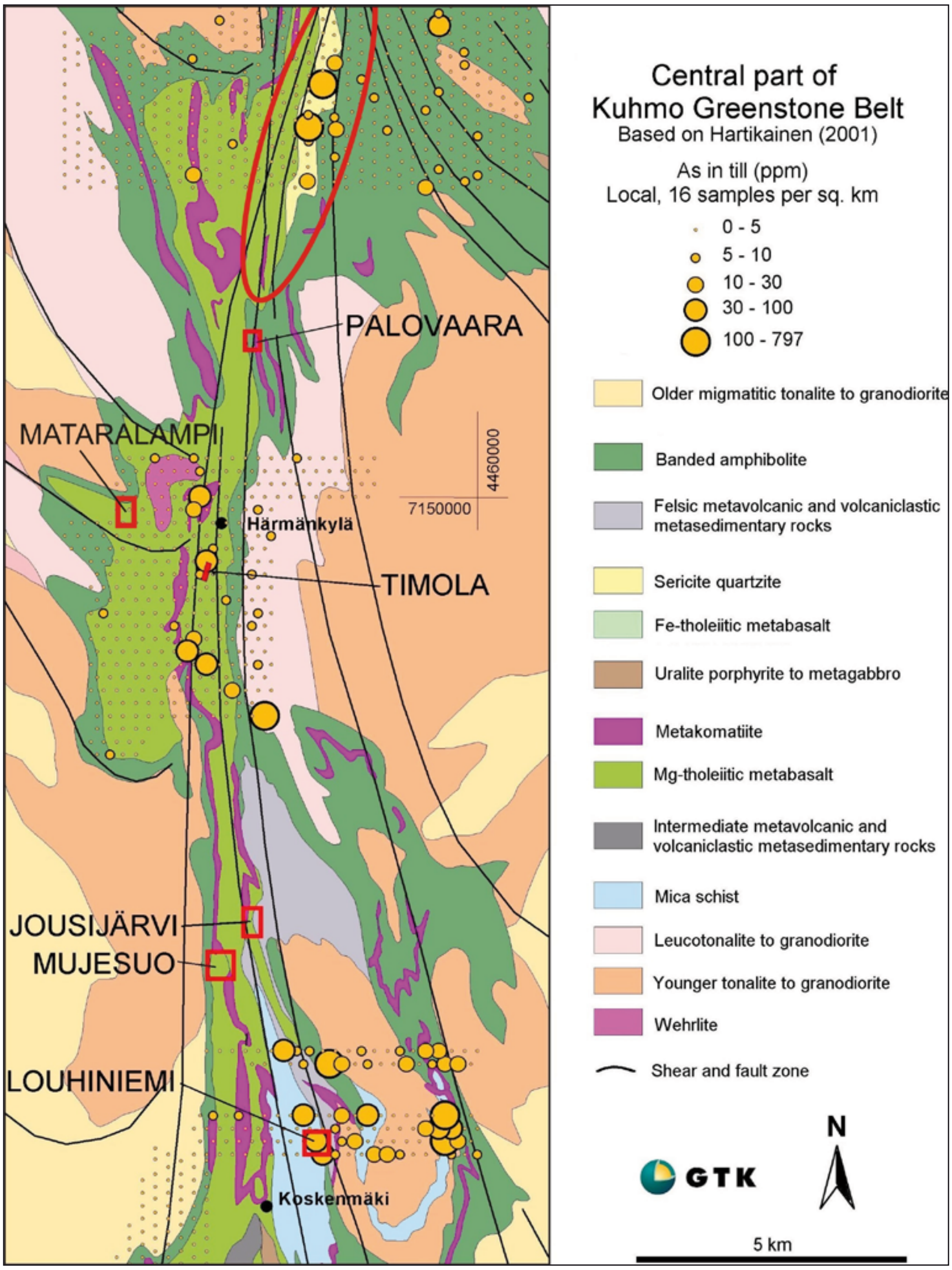

Figure 13. Gold occurrences in the central part of the Kuhmo Greenstone Belt. Potentially favourable rock contact orientation circled. Geology and gold in till from Hartikainen (2001).

open pit exposures, as is albitic layering containing relict crystal shapes now ferrodolomite (Vanhanen 2001) possibly as pseudomorphs after evaporate minerals (e.g., gypsum). The possibility that these sedimentary rocks are karsted shelf sequences with interlayered black schist should be explored, as should a pre-metamorphic sedimentary replacement origin for the mineralisation. The Ti content of albitic layers may also suggest a tuffitic composition, with originally abundant zeolites being the reason or one of the main reasons for the presently high albite content.

Elsewhere in the Juomasuo open 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 the iron oxide-copper-gold group of deposits, but it resembles also the geochemistry of the black shale deposits (Coveney and Pašava 2004). We suggest that Juomasuo represents a highly anomalous style of mineralisation which is unlikely to belong to the orogenic gold category.

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

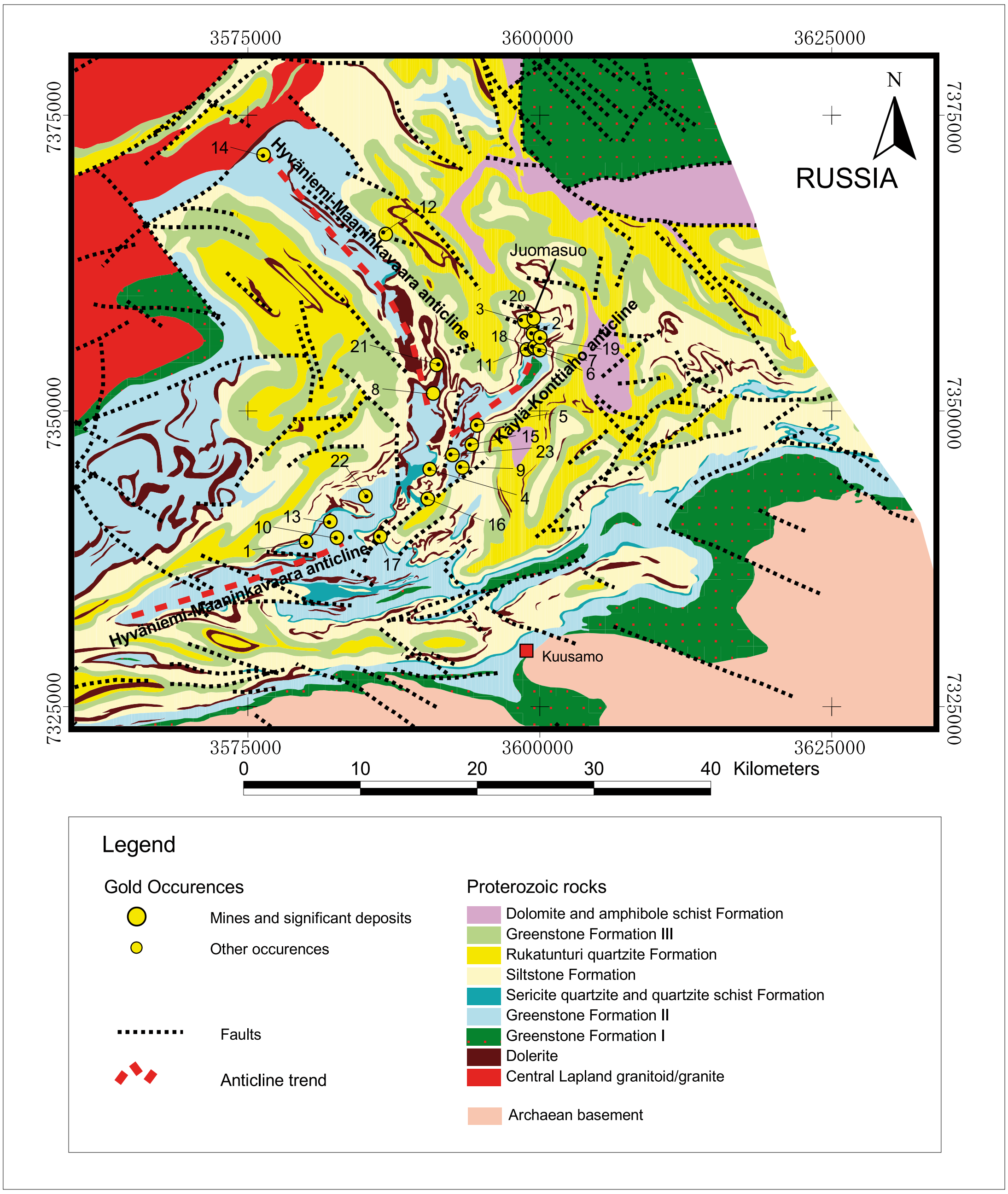

Figure 14. Simplified map of the Kuusamo Schist Belt. Numbers refer to gold occurrences listed in Eilu et al. (2007).

Peräpohja Schist Belt

This belt (Fig. 15) contains gold occurrences associated with chalcopyrite ± cobaltite and with biotite-calcite and amphibole-calcite 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.

Central Lapland Area

The gross orientation of this belt (Fig. 16.; 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. It is also possible that the younger sediment-dominated sequences (Lainio and

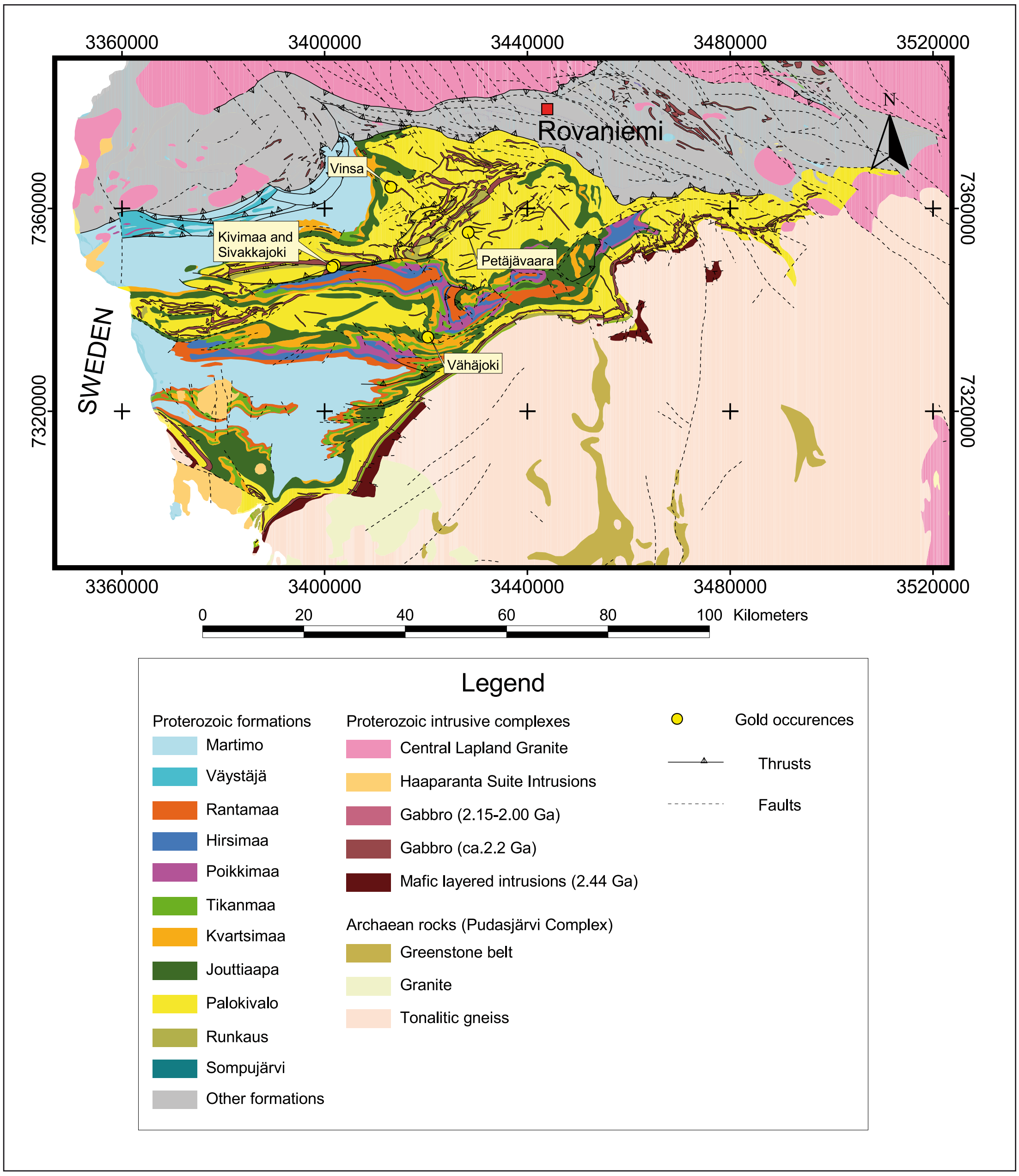

Figure 15. Gold occurrences in the Peräpohja Schist Belt. Geology after Perttunen (1989, 2002, 2003). The grey areas ('Other formations' in the legend) contain no signs of gold mineralisation. Coordinates according to Finnish National Grid (ykj-grid) metric values.

Kumpu Groups) acted as capping layers that may have aided preservation of mineralisation. Other flat-lying units may have acted 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

According to Hulkki and Keinänen (2007), the Hirvilavanmaa deposit is mainly hosted by komatiite. Some of the whole-rock geochemical and alteration mineral assemblage data indicate that, at least, part of the ore-grade material indeed is hosted by komatiite (Nurmi et al. 1991, Hulkki & Keinänen 2007). However, the drill core viewed during this work suggests that the main host is a differentiated dolerite, as abundant coarse leucoxene alteration (aggregates of small rutile grains as pseudomorphs after ilmenite) suggests that the rock was originally coarse-grained and has a Ti content more typical for a mafic than a ultramafic rock. The cyclic appearance of rutile

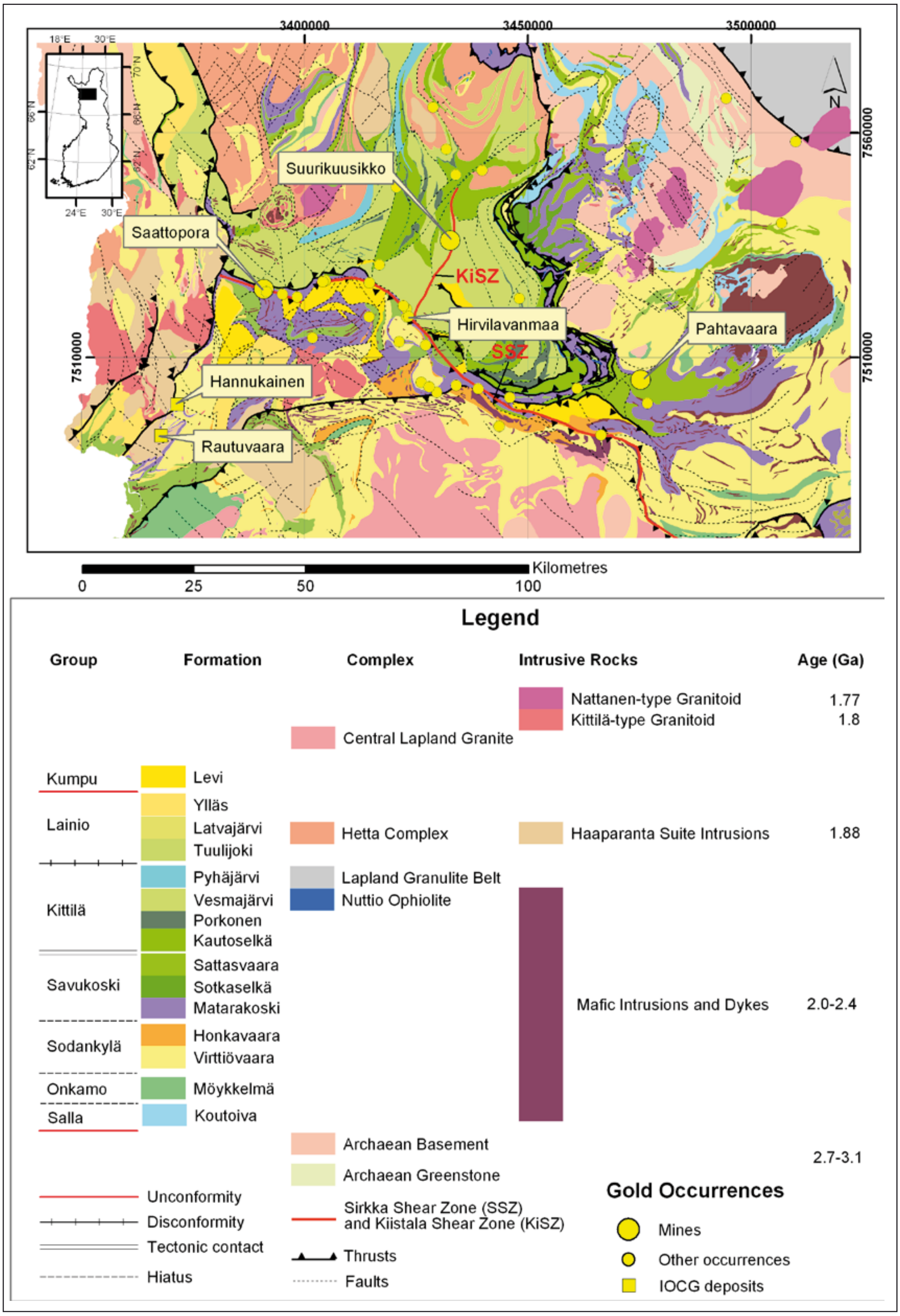

Figure 16. Formation map of the Central Lapland Greenstone Belt (after Lehtonen et al. 1998) showing the location of the gold deposits and occurrences in the area, with the deposits discussed named.

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 fine-grained mafic lava). Differentiated sills should be examined as a possibility for many deposits in this area that have been described as lava-hosted.

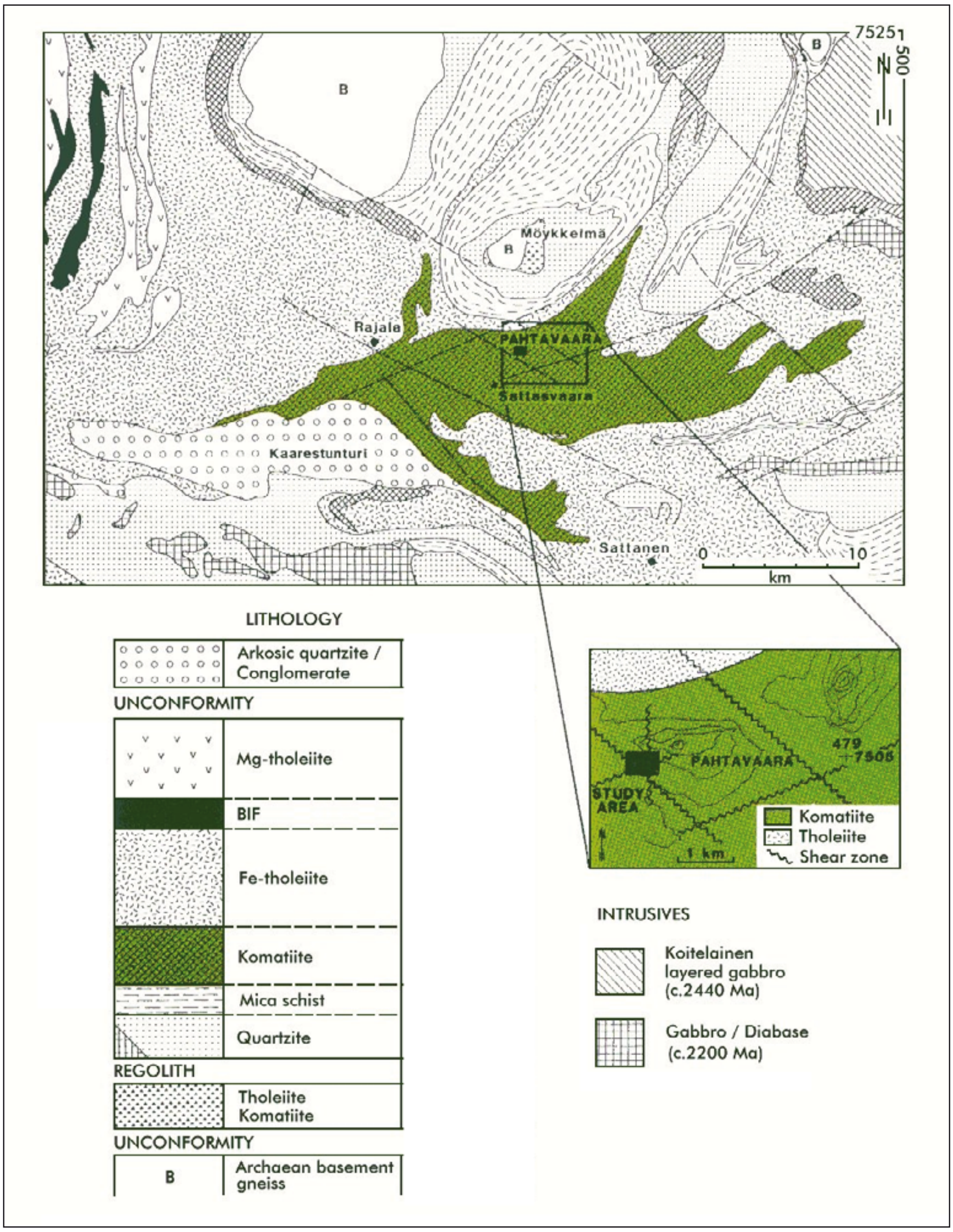

Figure 17. Distribution of Sattasvaara komatiites (green) hosting the Pahtavaara deposit (Korkiakoski 1992). Coordinates according to Finnish National Grid (kkj-grid) metric values.

Pahtavaara

The Pahtavaara gold deposit at Sodankylä (Figs. 17 and 18) is unlike the other known gold occurrences in Central Lapland. The unusual features (Korkiakoski 1992, Ojala et al. 2007) of the deposit include barite in the ore assemblage, high gold fineness (>99.5 % Au), and ore breccias demonstrating unimpeded crystal growth (e.g., pyrite hedrons instead of cubes, randomly oriented tremolites). The presence of euhedral pyrite 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 a low to moderate dips to the 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 commonly, 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 indicating low-grade mineralisation. Red mineral phases (possibly magnesite and albite?) in places accompany

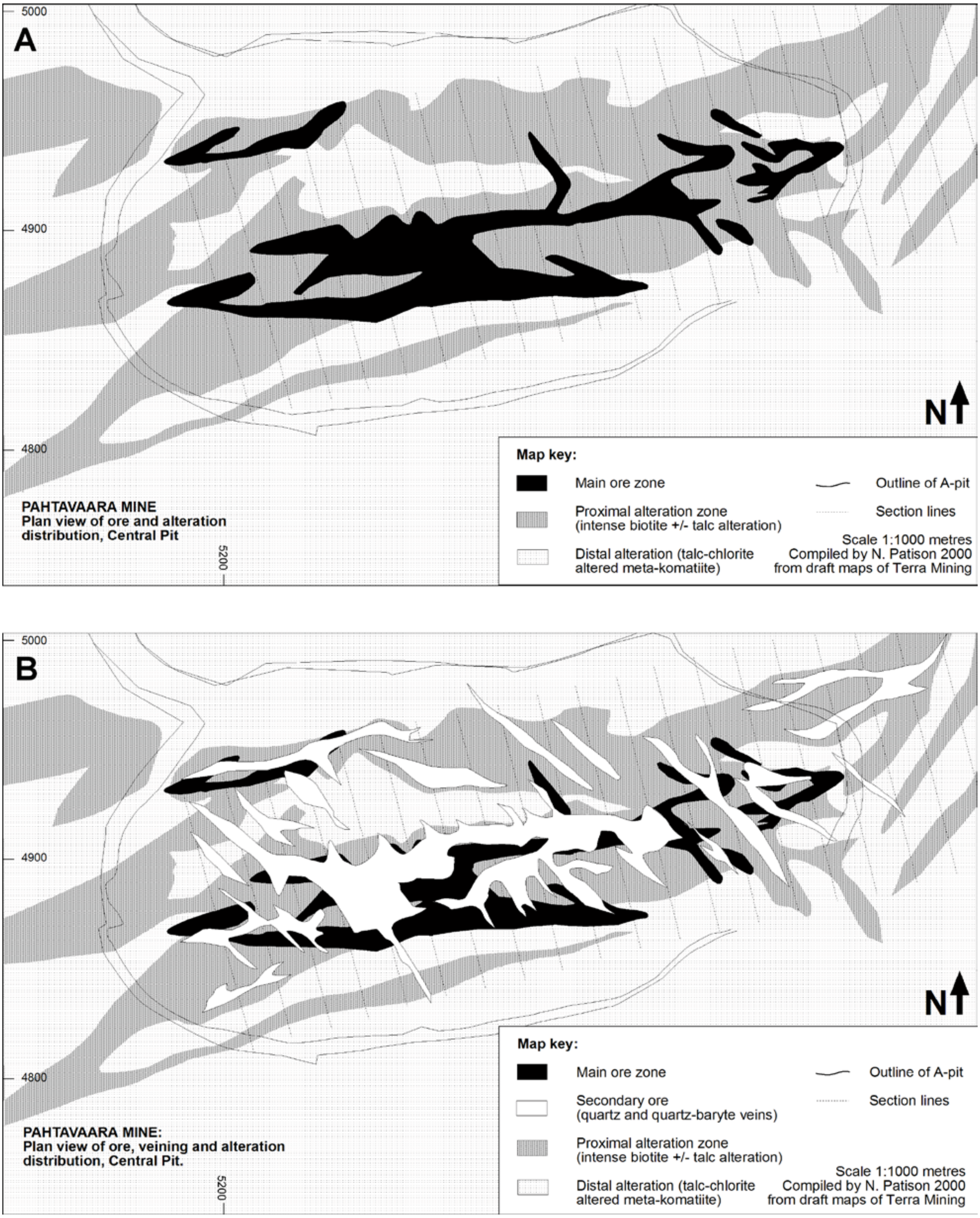

Figure 18. Geological plan maps from the Pahtavaara Mine open pit area. A) The main ore zone. B) distribution of the secondary ore (from Ojala et al. 2007). North up.

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 lenses within a 300 m long zone; Fig. 18a). 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 ppm Au. However, high gold grades can be present, 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 a komatiitic pyroclastic and a komatiitic lava unit (Korkiakoski 1992). The primary (pyro)clastic texture is present in the alteration halo adjacent to ore zones, but no primary texture is preserved within the 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 very low silver and arsenic concentrations, which is uncommon for orogenic gold, as are the high barium and cobalt values. The low REE content of the deposit is unlike Fe oxide-Cu-Au style of mineralisation, and there is no evidence of an intrusive origin. Other types of barite-bearing deposits should be examined (e.g., barite in high-sulphidation epithermal and VMS 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 than Pahtavaara (Patison 2007, Patison et al. 2007). Gold is refractory, primarily within arsenopyrite that has a disseminated appearance. The deposit is within a shear zone passing through a local stratigraphic contact. The shear zone is associated with amorphous carbon that is probably remobilised from adjacent sedimentary rocks. The deposit is in 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 kilometres, 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.

Western Lapland Fe oxide-copper-gold

A group of iron deposits containing variable concentrations of copper and gold are present at the western edge of the Central Lapland Greenstone Belt (Fig. 19).

Hannukainen-Rautuvaara area

Five of the known deposits and prospects in the Kolari region contain, at least locally, significant amounts of copper and gold: Cu-Rautuvaara, Hannukainen, Kuervitikko, Rautuoja, and Lauttaselkä (Hiltunen 1982). These deposits have many, but not all, the characteristics of classic IOCG deposits (Niiranen et al. 2007). Similar deposits also occur immediately across the international border, at Pajala in Sweden. Most REE profiles for the mineralisation are typical for sedimentary rocks. However, the REE from a magnetite ore sample defines a typical IOCG profile (from the centre of a Cu-rich magnetite ore body), although this sample is higher in SiO_2 than is typical for this type of deposit. Magnetite bodies could represent a sedimentary iron formation (stratiform seafloor), into which an IOCG type of intrusive plug has been injected after metamorphism. However, there is no stratigraphic control on the magnetite bodies and a metasomatic replacement controlled by Kolari shear zone structures is much more feasible interpretation than that of deformed BIF.

During our visit to the area, new large-diameter diamond-drill core from the Hannukainen deposit was available and showed the intimate relationship of magnetite and sulphides. Typical ore mineral association is magnetite-chalcopyrite-pyrite±pyrrhotite (Niiranen et al. 2007). In places, the amount of pyrrhotite exceeds that of pyrite. Alteration styles described at Hannukainen (Niiranen et al. 2007) 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 to us, 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 a 1.80 Ga age for the Kolari deposits. This age is contemporaneous with 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, Weihed et al. 2005). In addition, the Kolari deposits are related to a major crustal scale shear zone system (Pajala shear zone or Bothnian mega shear) that is considered to represent the continent-continent collisional boundary between the Norrbotten and

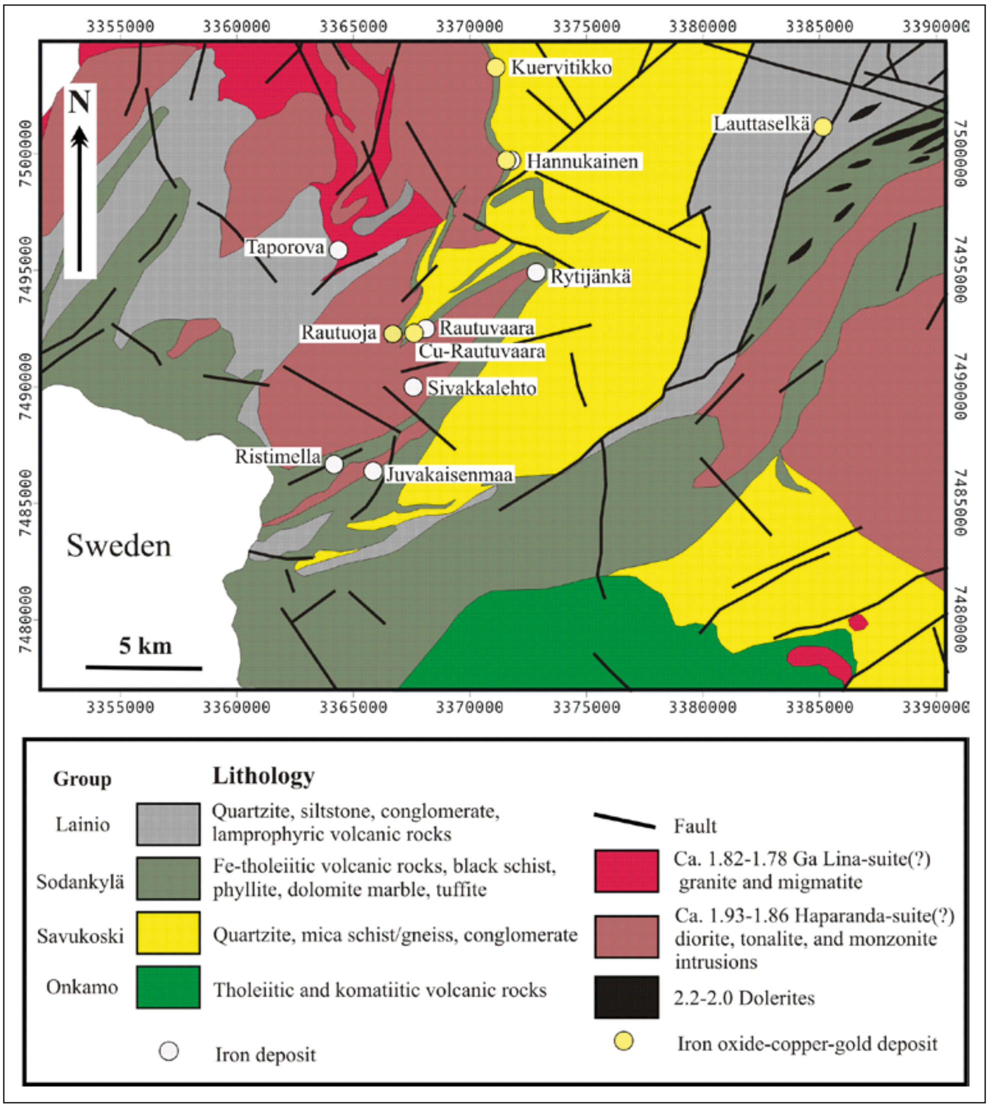

Figure 19. Geological map of Kolari region and location of potential Fe-oxide Cu-Au occurrences. Geology map from GTK GIS database, deposits from the FINGOLD data base (http://en.gtk.fi/ExplorationFinland/Commodities/Gold/gtk_gold_map.html; Eilu 2007).

Karelian cratons, to the west and east, respectively (Berthelsen & Marker 1986, Lahtinen et al. 2005).

Criteria for Fe oxide-copper-gold deposits

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

It was suggested during the workshop that the scale of the fluid system associated with the mineralisation process is critical to forming genuine IOCG deposits. Large type examples form above Archean lithosphere and are associated with breccia pipes (e.g., breccia within a maar hosting the Olympic Dam deposit; Reynolds 2000). 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 hypabyssal intrusion overlain by a breccia pipe and/or diatreme with a crater and tuff ring at surface). Variation between occurrences may result because of the location of the mineralisation relative to the intrusion, pipe or crater. Hypabyssal mineralisation associated with feeder intrusions may be small but higher grade, whereas crater-related mineralisation formed closer to the surface would be of lower grade but much larger.

In Finland, diamond-related research has defined diatreme material in the Kaavi–Kuopio and Kuusamo areas (O'Brien et al. 2005, 2006). To the south (e.g., at Kaavi–Kuopio area), a three-layer mantle stratigraphy has been defined (layers to depths of 110 kilometres, 110–180 kilometres, and >180 kilometres). 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 (Hugh O'Brien, pers. comm. 12 May 2006). 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. 2003) and for belts where alkaline magmatism is present.

IOCG deposits commonly occur within about 150 kilometres of cratonic margins (Groves & Vielreicher 2001). For example, the large Carajas deposits in Brazil are at the edge of a rifted Archean craton, where regional faults orthogonal to the craton edge act as conduits (Groves et al. 2005). In Finland, the extent of Archean rocks could be used as a proxy for locating craton edges assuming that the Archean lithosphere is difficult to destroy.

Mineralisation associated with A-type granites is commonly misclassified into the IOCG 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 into the IOCG category.

The current, first-pass regional 'fuzzy logic model' for this deposit type includes many elements, resulting in signals from many sources appearing as anomalies (Nykänen et al. 2008a). For example, U-rich shales are identified. A method to filter out sediment-related anomalies is required. Suitable elements for IOCG modelling could include Au, Cu, Co, and P. Incorporating Na alteration into the model is also misleading, as it may be too widespread to closely enough relate to any mineralising system. Possibly also the presence of phlogopite could also be used to indicate a suitable metasomatic history.

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 and trap are or were 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 or 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 volcano-sedimentary belts and sediment-volcanic unit contacts. The significant Proterozoic deposits in the Fennoscandian Shield only 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.

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 km from boundary for gold deposits; <150 km for Fe oxide-Cu-Au deposits).
- Analysing 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 and 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.

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, by using the age of younger granitoids. Problem: insufficient age dates for mineralisation.
- Calculate grids from the U-Pb and Rb-Sr age 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; such cases should not to be included into the modelling data sets.
- Complete the prospectivity maps for the Kuhmo belt. Use the Outokumpu Mining and Polar Mining data when these are released.
- The updated map of Central Lapland showing additional blocks identified from seismic data should be incorporated into the future modelling.
- Identify the likely orientation of fluid conduits and favourable structures (NE- and ENE-striking structures appear to be significant).
- Define belts or parts of belts that are oriented orthogonally to regional compression; these appear to be more favourable for mineralisation.
- 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 unit contacts or to permeable stratigraphic units, particularly for the non-linear gold belts. This should be done at regional (kilometres) and deposit (100s to 10s of meters) scales.
- Identify terranes with incoherent structural trends as these are likely to be less prospective.

VMS prospectivity modelling

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

- The orientation of the ore zone stratigraphy may identify VMS deposits from other mineralisation styles (e.g., epithermal, orogenic).
- Radiometric survey data should be assessed for potassium anomalies.
- Resistivity gradients should be assessed for anomalies that may indicate quartz-sericite alteration zones.
- Magnetic gradients could potentially indicate redox boundaries.
- Fluid conduits for VMS systems could be identified (probably not possible).
- A change in the style of volcanism should 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 being 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 kilometres 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.

Fe oxide-copper-gold 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, volcaniclastic deposits).
- Look for evidence for Fe metasomatism.
- Reduce the modelled elements to Au, Cu, Co and P, and use 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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This report presents results of a country-wide assessment of gold prospectivity in Finland. The assessment is based on a workshop and field trip in May 2006, but has been updated with the most recent literature on gold metallogeny and local exploration. Specific modelling criteria are suggested for the main types of gold mineralisation detected and for the main gold belts of the country. The results of the work are expected to benefit exploration both in Finland and globally in other Precambrian shield areas.

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