GEOLOGICAL SURVEY OF FINLAND
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# Quantitative assessment of undiscovered resources in volcanogenic massive sulphide deposits, porphyry copper deposits and Outokumpu-type deposits in Finland

Rasilainen, K., Eilu, P., Halkoaho, T., Karvinen, A., Kontinen, A., Kousa, J., Lauri, L., Luukas, J., Niiranen, T., Nikander, J., Sipilä, P., Sorjonen-Ward, P., Tiainen, M., Törmänen, T. and Västi, K.

**GEOLOGIAN TUTKIMUSKESKUS** **GEOLOGICAL SURVEY OF FINLAND**

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# QUANTITATIVE ASSESSMENT OF UNDISCOVERED RESOURCES IN VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS, PORPHYRY COPPER DEPOSITS AND OUTOKUMPU-TYPE DEPOSITS IN FINLAND

Front cover: The Pyhäsalmi mine in 2007. The Pyhäsalmi deposit is one of the most important copper-zinc deposits of all time in Finland.
Photo: Pyhäsalmi Mine Oy.

Unless otherwise indicated, the figures have been prepared by the authors of the publication.

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Undiscovered resources of copper, zinc, lead, gold and silver in volcanogenic massive sulphide (VMS) deposits, undiscovered resources of copper, molybdenum, gold and silver in porphyry copper deposits, and undiscovered resources of copper, zinc, nickel and cobalt in Outokumpu-type deposits were estimated down to the depth of one kilometre in the bedrock of Finland using the three-part quantitative assessment method. Grade-tonnage models were constructed for felsic, bimodal-mafic and mafic VMS deposits using data from known Fennoscandian deposits. A grade-tonnage model for porphyry copper deposits was constructed using global data from Precambrian deposits. For the Outokumpu-type deposits, a grade-tonnage model was developed using data from well-known deposits within the Outokumpu area. Thirty-one permissive tracts were delineated for VMS deposits, 10 for porphyry copper deposits, and one for Outokumpu-type deposits. The VMS tracts cover an area of 41,600 km$^2$, the porphyry copper tracts cover 38,400 km$^2$, and the Outokumpu tract covers 9800 km$^2$. The mean estimates of the numbers of undiscovered VMS, porphyry copper and Outokumpu-type deposits within the permissive tracts are 45, 11 and 6, respectively. At 50 % probability, the undiscovered VMS deposits are estimated to contain at least 730,000 t Cu, 1.6 Mt Zn, 150,000 t Pb, 1100 t Ag and 16 t Au, and the undiscovered porphyry copper deposits are estimated to contain at least 2.4 Mt Cu, 100,000 t Mo, 1000 t Ag and 170 t Au. The estimated median undiscovered resources in Outokumpu-type deposits are at least 580,000 t Cu, 220,000 t Zn, 53,000 t Co and 41,000 t Ni. About 71 % of the copper and 68 % of the zinc endowment in VMS and Outokumpu-type deposits, and at least 98 % of the copper endowment in porphyry copper deposits in Finland occurs in poorly explored and undiscovered deposits. The undiscovered VMS resources are estimated to be distributed between several permissive tracts, with the Vihanti and Pyhäsalmi tracts having the largest undiscovered resources. Felsic deposits are estimated to contain 53 % of the undiscovered VMS-type copper-zinc resources and 95 % of the undiscovered VMS-type lead resources in Finland. The undiscovered porphyry copper resources are estimated to be concentrated in the Central Ostrobothnia, Tampere, Häme and Haaparanta tracts, with 86 % of the resources in central and southern Finland. At the 50 % level of probability, the undiscovered copper-zinc resources in VMS, porphyry copper and Outokumpu-type deposits in Finland are at least 3.7 Mt of copper and 1.8 Mt of zinc. This is 38 % of the total estimated undiscovered copper resources and 100 % of the total estimated undiscovered zinc resources in Finland.

Keywords (GeoRef Thesaurus, AGI): copper, zinc, massive sulfide deposits, porphyry copper, undiscovered resources, evaluation, ore grade, tonnage, quantitative analysis, intrusions, Proterozoic, Archean, Finland

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Vulkanogeenisiin massiivisiin sulfidimalmeihin (VMS) liittyvät löytämättömät kupari-, sinkki-, lyijy-, kulta- ja hopeavarannot, porfyyrikupariesiintymiin liittyvät löytämättömät kupari-, molybdeeni-, kulta- ja hopeavarannot sekä Outokumpu-tyyppisiin esiintymiin liittyvät löytämättömät kupari-, sinkki-, nikkeli- ja kobolttivarannot Suomen kallioperässä arvioitiin yhden kilometrin syvyyteen asti käyttäen kolmivaiheista kvantitatiivista menetelmää. Felsisille, bimodaalis-mafisille ja mafisille VMS-esiintymille rakennettiin tonnimäärä-pitoisuusmallit tunnettujen Fennoskandian kilvellä sijaitsevien esiintymien perusteella. Porfyyrikupariesiintymille tehtiin tonnimäärä-pitoisuusmalli käyttäen maailmanlaajuista aineistoa prekambrisista esiintymistä. Outokumpu-tyypin esiintymien tonnimäärä-pitoisuusmalli koottiin käyttäen hyvin tunnettuja esiintymiä Outokumpu-alueelta. VMS-esiintymille määritettiin 31 sallittua esiintymisaluetta, porfyyrikupariesiintymille kymmenen ja Outokumpu-tyypin esiintymille yksi. VMS-tyypin alueet kattavat 41 600 $km^2$, porfyyrikuparityypin 38 400 $km^2$ ja Outokumpu-tyypin 9 800 $km^2$. Sallituilla esiintymisalueilla sijaitsevien löytämättömien VMS-esiintymien, porfyyrikupariesiintymien ja Outokumpu-tyypin esiintymien arvioitujen lukumäärien keskiarvot ovat 45, 11 ja 6. Löytämättömien VMS-esiintymien arvioidaan sisältävän 50 %:n todennäköisyydellä ainakin 730 000 t Cu, 1,6 Mt Zn, 150 000 t Pb, 1 100 t Ag ja 16 t Au. Löytämättömien porfyyrikupariesiintymien arvioidaan sisältävän 50 %:n todennäköisyydellä ainakin 2,4 Mt Cu, 100 000 t Mo, 1 000 t Ag ja 170 t Au. Mediaaniarvion mukaan löytämättömien Outokumpu-tyypin esiintymien mineraalivarannot ovat vähintään 580 000 t Cu, 220 000 t Zn, 53 000 t Co ja 41 000 t Ni. Ainakin 71 % Suomen VMS- ja Outokumpu-tyypin esiintymien kuparisisällöstä ja 68 % niiden sinkkisisällöstä sekä ainakin 98 % Suomen porfyyrikuparityypin esiintymien kuparisisällöstä on heikosti tutkituissa ja löytämättömissä esiintymissä. Löytämättömien VMS-tyypin mineraalivarantojen arvioidaan jakautuvan monelle sallitulle alueelle, ja Vihanti- ja Pyhäsalmi-alueilla ovat suurimmat löytämättömät varannot. Felsiset esiintymät sisältävät arviolta 53 % Suomen löytämättömistä VMS-tyyppisistä kupari-sinkkivarannoista ja 95 % löytämättömistä lyijyvarannoista. Löytämättömien porfyyrikuparivarantojen arvioidaan keskittyneen Keski-Pohjanmaan, Tampereen, Hämeen ja Haaparannan sallituille alueille, ja 86 % varannoista sijaitsee Keski- ja Etelä-Suomessa. Löytämättömät kupari-sinkkivarannot Suomen VMS-, porfyyrikupari- ja Outokumpu-tyypin esiintymissä ovat 50 %:n todennäköisyydellä ainakin 3,7 Mt kuparia ja 1,8 Mt sinkkiä. Tämä on 38 % kaikista arvioiduista löytämättömistä kuparivarannoista ja 100 % kaikista arvioiduista löytämättömistä sinkkivarannoista Suomessa.

Julkaisu on englanninkielinen.

Asiasanat (Geosanasto, GTK): kupari, sinkki, massiiviset sulfidiesiintymät, porfyyrikupari, löytämättömät varannot, arviointi, malmipitoisuus, tonnimäärä, kvantitatiivinen analyysi, intruusiot, proterotsooinen, arkeeinen, Suomi

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**CONTENTS**

1 INTRODUCTION ..... 7
1.1 The Geological Survey of Finland assessment project ..... 7
1.2 Terminology ..... 9

2 Cu-Zn DEPOSIT TYPES IN FINLAND ..... 9
2.1 Volcanogenic massive sulphide deposits ..... 11
2.1.1 Felsic type: The Pyhäsalmi deposit ..... 12
2.1.2 Bimodal-mafic type: The Rauhala deposit ..... 15
2.1.3 Mafic type: The Hällinmäki deposit ..... 17
2.2 Porphyry copper deposits ..... 21
2.2.1 The Kopsa deposit ..... 21
2.3 Outokumpu-type Cu-Zn-Co deposits ..... 23
2.3.1 The Kylylahti deposit ..... 23

3 THE THREE-PART QUANTITATIVE RESOURCE ASSESSMENT METHOD ..... 27
3.1 Deposit models ..... 27
3.1.1 Descriptive models ..... 27
3.1.2 Grade-tonnage models ..... 27
3.2 Permissive tracts ..... 28
3.3 Estimation of the number of undiscovered deposits ..... 28
3.4 Statistical evaluation ..... 29

4 ASSESSMENT OF Cu-Zn RESOURCES IN FINLAND ..... 29
4.1 Resources covered by the assessment ..... 29
4.2 GTK assessment process ..... 29
4.3 Data used ..... 30
4.3.1 Geology ..... 30
4.3.2 Known mineral deposits and occurrences ..... 30
4.3.3 Geophysical and geochemical data ..... 30
4.3.4 Exploration history ..... 30
4.4 Deposit models ..... 30
4.4.1 Volcanogenic massive sulphide (VMS) deposits ..... 30
4.4.2 Porphyry copper deposits ..... 34
4.4.3 Outokumpu-type Cu-Zn-Co deposits ..... 35
4.5 Tract delineation ..... 36
4.6 Estimation of the number of undiscovered deposits ..... 36
4.7 Assessment of metal tonnages ..... 39

5 RESULTS AND DISCUSSION ..... 39
5.1 Permissive tracts delineated ..... 41
5.2 Undiscovered resources in VMS deposits, Outokumpu-type deposits and porphyry copper deposits ..... 41
5.3 Finnish Cu-Zn endowment in the global context ..... 50

5.4 Reliability and usability of the estimates ..... 51

6 SUMMARY ..... 52

ACKNOWLEDGMENTS ..... 54

REFERENCES ..... 54

APPENDICES ..... 61

Appendix 1 ..... 61
Descriptive model of volcanogenic massive sulphide (VMS)

Appendix 2 ..... 65
Grade-tonnage model of Fennoscandian volcanogenic massive sulphide (VMS)

Appendix 3 ..... 76
Descriptive model of porphyry copper (gold, molybdenum)

Appendix 4 ..... 79
Grade-tonnage model of Precambrian porphyry copper

Appendix 5 ..... 83
Descriptive model of Outokumpu-type Cu-Zn-Co

Appendix 6 ..... 88
Grade-tonnage model of Outokumpu-type Cu-Zn-Co

Appendix 7 ..... 91
Assessment results for VMS, porphyry copper and Outokumpu-type Cu-Zn-Co permissive tracts in Finland

# 1 INTRODUCTION

Throughout the history of humankind, the demand for mineral resources has increased with the continuing growth of the world population and the rise in the average material standard of living. In tandem with this trend, exploration for and the development of new mineral resources all over the world have faced increasing competition from other land uses (e.g., Briskey et al. 2007, Cunningham et al. 2007, Hitzman 2007, Idman et al. 2007). Concerns about the environmental effects of mining are also having a growing influence on the cost and pace of development of new natural resources. In the modern world, Finland can no longer rely on the ready availability of imported raw materials for manufacturing and other industries. This applies to the entire European Union, which is globally a major net importer of nearly all metallic ores and concentrates (Kauppa- ja teollisuusministeriö 2006, Commission of the European Communities 2008, European Commission 2011). We need to know our mineral resources and how they might be expanded. Essential information includes the location of known resources, the location and amount of the possibly existing, yet undiscovered resources, and the uncertainty related to their existence. Furthermore, it is important to know how the development of mineral deposits will affect other surrounding resources, such as biological diversity, arable land, air and water.

This report aims to answer the questions 'where' and 'how much' we could still expect to find, given all that we have already discovered and used. We describe the process and results of a quantitative assessment of copper (Cu), zinc (Zn), lead (Pb), silver (Ag), and gold (Au) resources in undiscovered volcanogenic sulphide (VMS), Outokumpu-type polymetallic and porphyry copper deposits in Finland. The report comprises two parts. The first part reviews the types of VMS, Outokumpu and porphyry copper deposits in Finland and their geological environments, the assessment method, the data used, and the assessment process itself. A summary of the assessment results is given and the results are discussed. The second part comprises the Appendices, which include the deposit models employed and detailed information on each permissive tract delineated.

The information provided here on the location and amount of undiscovered mineral resources is expected to be valuable for effective land use planning and the sustainable development of mineral resources, and also in evaluating the long-term productivity of investments in exploration and related research and education.

## 1.1 The Geological Survey of Finland assessment project

The demands defined above, and requests of various stake holders (including the National Audit Office of Finland) to produce exact information on potential resources, resulted in the initiation of the project "National resources of useful minerals" at the Geological Survey of Finland (GTK) in 2008. The project was established to produce unbiased information on undiscovered mineral resources for national and regional planning of land use, natural resources management and environmental actions, as well as to develop assessment tools and enhance their proper application in the conditions of Finnish bedrock. The work done and results produced will enable accounting of metallic natural resources according to the principles of sustainable development. The project provides new information for metallogenic and lithological research and for national-level planning of mineral exploration.

The project started in 2008 with the selection of the working methods. The assessment of platinum-group element (PGE) resources was completed and published in 2010 (Rasilainen et al. 2010a, b), and the results for nickel (Ni) resources were published in 2012 (Rasilainen et al. 2012). At the beginning of 2011, the name of the project was

changed to "Mineral raw materials in Finland and Fennoscandia". The results of the assessment of Cu, Zn, Pb, Ag and Au resources in VMS, Outokumpu-type and porphyry deposits are presented in this report, and the Au resources in orogenic gold deposits will be assessed in a report later in 2014. The outputs of the project include national and areal mineral resource estimates, and a final report containing a summary of the results for all metals assessed, a description of the methods and international reference materials used, and an evaluation of the quality of the results.

The procedure selected for the GTK assessments is based on the three-part quantitative assessment method developed by the U.S. Geological Survey (USGS) starting from the mid-1970s (Singer 1993, Singer and Menzie 2010). It must be emphasized that the method does not provide mineral resource or reserve estimates concordant with the present industrial standards such as the JORC, CRIRSCO, NI 43-101, PERC and UNFC codes (United Nations Economic Commission for Europe 2009, National Instrument 43-101 2011, Joint Ore Reserves Committee of the Australasian Institute of Mining and Metallurgy, Australian Institute of Geosciences and Mineral Council of Australia 2012, Committee for Mineral Reserves International Reporting Standards 2013, Pan-European Reserves and Resources Reporting Committee 2013). The results of undiscovered resource assessments should never be confused with proper reserve or resource estimates based on international standards. Rather, the assessment process produces probabilistic estimates of the total amount of metals in situ in undiscovered deposits down to the depth of one kilometre. The modification of the process used in GTK assessments does not take into account the economic, technical, social or environmental factors that might in the future affect the potential for economic utilisation of a resource. Hence, part of the estimated undiscovered resources may be located in subeconomic occurrences (Fig. 1), and it might be more appropriate to use the term 'metal endowment', which is not directly dependent on economic or technological factors (Harris 1984).

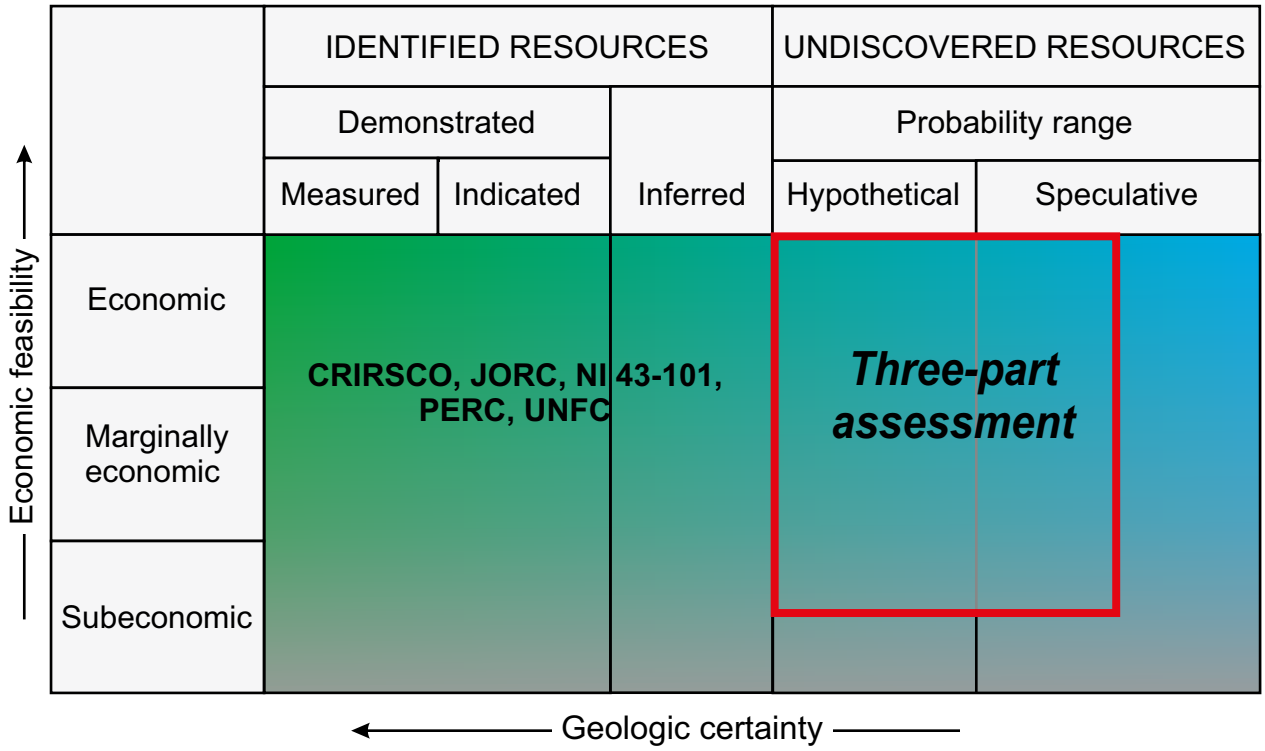


Fig. 1. Classification of mineral resources used in GTK assessments (modified from U.S. Geological Survey National Mineral Resource Assessment Team 2000). Economic feasibility increases upwards and geological uncertainty increases to the right.

### 1.2 Terminology

Some terms essential to the proper understanding of this report are briefly described below. The definitions follow the usage by the minerals industry and the resource assessment community (U.S. Bureau of Mines and U.S. Geological Survey 1980, U.S. Geological Survey National Mineral Resource Assessment Team 2000, Committee for Mineral Reserves International Reporting Standards 2013).

*Mineral deposit*
A mineral occurrence of sufficient size and grade that it might, under the most favourable circumstances, be considered to have economic potential.

*Well-known mineral deposit*
A completely delineated mineral deposit, for which the identified resources and past production ore known.

*Undiscovered mineral deposit*
A mineral deposit believed to exist less than 1 km below the surface of the ground, or an incompletely explored mineral occurrence within that depth range that could have sufficient size and grade to be classified as a deposit.

*Mineral occurrence*
A concentration of any useful mineral found in bedrock in sufficient quantity to suggest further exploration.

*Mineral resource*
A concentration or occurrence of material of economic interest in or on the Earth's crust in such a form, quality and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade, continuity and other geological characteristics of a mineral resource are known, estimated or interpreted from specific geological evidence, sampling and knowledge.

*Identified resources*
Resources whose location, grade, quality and quantity are known or can be estimated from specific geological evidence.

*Well-known resources*
Identified resources that occur in completely delineated deposits included in grade-tonnage models.

*Discovered resources*
The total amount of identified resources and cumulative past production.

*Undiscovered resources*
Resources in undiscovered mineral deposits whose existence is postulated based on indirect geological evidence.

*Hypothetical resources*
Undiscovered resources in known types of mineral deposits postulated to exist in favourable geological settings where other well-explored deposits of the same types are known.

*Speculative resources*
Undiscovered resources that may occur either in known types of deposits in favourable geological settings where mineral discoveries have not been made, or in types of deposits as yet unrecognized for their economic potential.

## 2 Cu-Zn DEPOSIT TYPES IN FINLAND

Copper and zinc are the main or minor commodities in several types of ore deposits in Finland. This report covers three important deposit types where copper, zinc or both occur as main commodities: volcanogenic massive sulphide (VMS) deposits, porphyry copper deposits and Outokumpu-type Cu-Zn-Co deposits. VMS and Outokumpu-type deposits have produced 1.8 Mt copper and 3.2 Mt zinc, which is over 90 % the total cumulative production of these metals in Finland. These two deposit types are estimated to contain about 538,000 t of copper and 859,000 t of zinc in well-known resources, which is respectively 11 % and 8 % of all the well-known copper and zinc resources in Finland (Table 1). Porphyry copper deposits are included in this assessment due to recent discoveries indicating the potential for this deposit type in Finland. The VMS, porphyry copper and Outo-

Table 1. Well-known resources and cumulative production of copper and zinc for VMS, Outokumpu and porphyry Cu deposits in Finland.

| | Well-known resources | | Cumulative production | |
|---|---|---|---|---|
| **Deposit type** | **Cu (t)** | **Zn (t)** | **Cu (t)** | **Zn (t)** |
| VMS | 341,000 | 745,000 | 637,000 | 2,830,000 |
| Outokumpu | 197,000 | 114,000 | 1,161,000 | 334,000 |
| Porphyry Cu | 45,000 | - | - | - |
| Total | 583,000 | 859,000 | 1,798,000 | 3,164,000 |

- : Not present in significant amounts.
Resources and production as of the end of 2012.
The resource and production figures are rounded to full thousands.
Data sources: Puustinen (2003) and those listed in Appendices 2, 4 and 6. For mines operated after 2001, company reports and news releases were used.

kumpu-type deposits are described in more detail in the following subsections.

The single most important resource of copper and zinc in Finland is the giant Talvivaara disseminated to semi-massive strata-bound Ni-Zn-Cu-Co deposit in Palaeoproterozoic (2.1–1.90 Ga) carbonaceous metasedimentary rocks of the Kainuu schist belt in eastern Finland (Loukola-Ruskeeniemi & Heino 1996, Loukola-Ruskeeniemi 1999). Talvivaara contains an identified resource of 2.7 Mt of copper and 10 Mt of zinc. Another major source of copper is the Kevitsa Ni-Cu-PGE deposit hosted by a Palaeoproterozoic (~2.05 Ga) layered intrusion in northern Finland (Mutanen 1997, Gregory et al. 2011). Kevitsa contains an identified resource of 1.1 Mt of copper. These two deposits are unique in style; no other deposits of either type are known. Hence, it was not possible to construct grade-tonnage models for Talvivaara- or Kevitsa-type deposits, which in turn made it impossible to quantitatively assess the possible undiscovered resources of these two deposit types.

Copper also occurs in Ni-Cu deposits associated with Svecofennian (~1.89–1.87 Ga) mafic-ultramafic intrusions in central and southern Finland, in Ni-Cu deposits associated with Archaean (~2.8 Ga) komatiitic rocks in eastern and northern Finland and Palaeoproterozoic (~2.05 Ga) komatiitic rocks in northern Finland, and in Ni-Cu-PGE deposits associated with Palaeoproterozoic (~2.45 Ga) mafic-ultramafic layered intrusions in northern Finland. The copper resources in these deposit types have previously been assessed (Rasilainen et al. 2010a,b, 2012).

Several other deposit types having copper as a major or minor commodity were excluded from the assessment for a variety of reasons. A number of small Ni-Cu deposits associated with Jatulian-age diabase dykes are known in SW Finland (Puustinen et al. 1995). Since these deposits are small and few in number, their importance for the total copper endowment in Finland is negligible and they were not included in this assessment. There are some indirect indications for sediment-hosted stratiform copper as well as subaerial volcanic-hosted (red bed type?) copper in the Peräpohja schist belt, in Kuusamo and in other Karelian schists, especially in northern Finland (Kyläkoski 2007, 2009, Kyläkoski & Eilu 2012). However, no obvious examples of these deposit types are known in Finland and they were excluded from the assessment. The possible iron oxide-copper-gold (IOCG) deposits in northern Finland (Eilu & Pankka 2009) are mostly iron deposits where copper and gold form less than 10 % of the in situ value of a deposit. Hence, undiscovered IOCG deposits were not assessed. The Kuusamo-type Au-Co±Cu deposits in the Kuusamo area and the Au-Cu occurrences in the Peräpohja schist belt in northern Finland contain copper only as a minor commodity and were not considered important for the copper assessment. These two mineralisation styles were included in the assessment of gold deposits in Finland (Eilu et al. 2014).

## 2.1 Volcanogenic massive sulphide deposits

VMS deposits have historically been the most important source for zinc in Finland and the second most important source for copper after the Outokumpu-type deposits. By the end of 2012, VMS deposits had produced about 0.64 Mt Cu and 2.8 Mt Zn in Finland (Table 1). However, the well-known VMS resources were only 0.34 Mt Cu and 0.75 Mt Zn, which are small compared to the total well-known resources of 4.9 Mt of Cu and 11 Mt of Zn in Finland.

Based on the associated lithology, VMS deposits can be classified into mafic-ultramafic, siliciclastic-mafic, bimodal-mafic, bimodal-felsic and siliciclastic felsic types (Franklin et al. 2005, Galley et al. 2007, Shanks & Thurston 2012). In this assessment, we follow the simplified threefold classification of VMS deposits (Mosier et al. 2009) into mafic, bimodal-mafic and felsic types. This classification is based on the observed differences in ore tonnage and metal grades between the mafic, bimodal-mafic and felsic types. Finnish examples of the three types of VMS deposits are briefly described in the following sections (Figs 2–12). A descriptive model for VMS deposits is presented in Appendix 1 and grade-tonnage models for Fennoscandian VMS deposit types are given in Appendix 2.

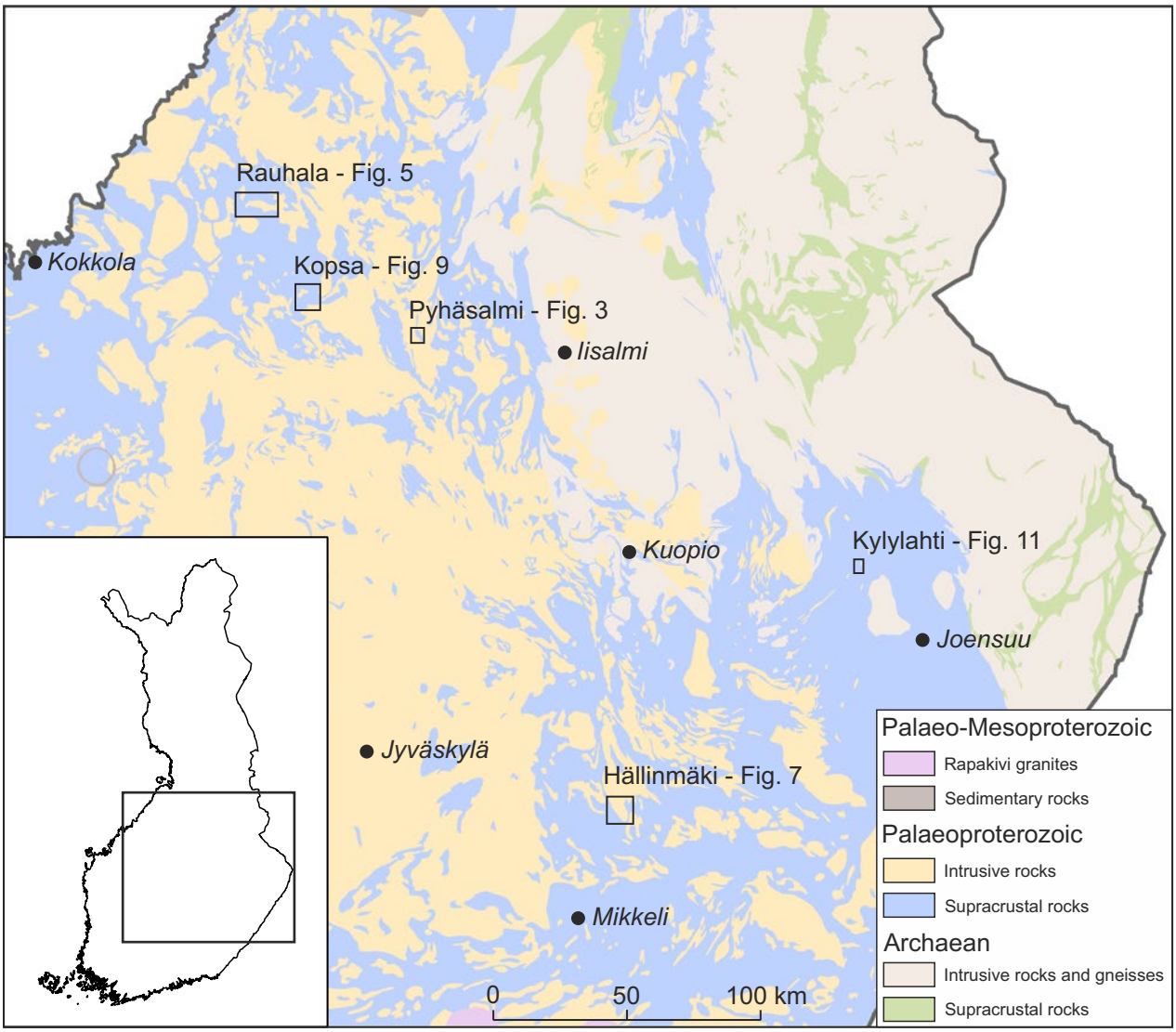


Fig. 2. Index map showing the locations of the Pyhäsalmi, Rauhala, Hällinmäki, Kopsa and Kylylahti deposits and the areas covered by Figs. 3, 5, 7, 9 and 11.

### 2.1.1 Felsic type: The Pyhäsalmi deposit

The Pyhäsalmi deposit is an example of the bimodal-felsic type, which falls into the felsic category in the simplified threefold classification used in this assessment. Sixteen of the 20 well-known VMS deposits in Finland belong to the felsic type, which makes it by far the most common and important category of VMS deposits in the country.

The Pyhäsalmi deposit is located in the village of Ruotanen in Pyhäjärvi municipality, 120 km northwest of the city of Kuopio (Fig. 2), and it was discovered in 1958 on the basis of a layman sample. The mine started as an open pit operation in 1962, and from 1976 onwards, all production has been from underground. A deep continuation of the orebody was discovered in 1996, which extended the mine life by approximately 20 years. Cumulative production at the end of 2012 was 51 Mt of ore containing 0.45 Mt Cu and 1.2 Mt Zn, whereas the known remaining resources were 17 Mt containing 0.14 Mt Cu and 0.20 Mt Zn (Puustinen 2003, Inmet Mining Corporation 2013, T. Mäki 2010 pers. comm.). The estimated remaining mine life in 2014 was five years (T. Mäki pers. comm. 2014). The Pyhäsalmi deposit and its surroundings are described in Helovuori (1979), Huhtala (1979), Mäki (1986), Ekdahl (1993), Lahtinen (1994), Kousa et al. (1994, 1997), Balint & Boaro 2002, Mäki & Puustjärvi (2003) and Rasilainen et al. (2003).

The Svecofennian bedrock in the Pyhäsalmi area belongs to the Savo belt, which trends northwest between an Archaean basement in the east and rocks of the Central Finland granitoid complex in the southwest (Kähkönen 2005). The area is characterised by crustal-scale tectonic blocks of differing lithological and metamorphic features, produced by the overlapping of the northwest-trending Raahe-Ladoga zone and the southwest-trending Oulujärvi shear zone. The Savo belt mainly consists of moderately to highly metamorphosed and migmatised turbiditic mica gneisses with intercalations of volcanic rocks, graphite-bearing schists and minor carbonate rock, skarn and uranium-bearing phosphate beds (Huhtala 1979, Äikäs 1989, Ekdahl 1993). The composition of intrusive rocks mainly varies from quartz diorite to granite; mafic and ultramafic intrusions are subordinate.

Volcanic rocks in the northwestern part of the Savo belt are divided into two major units based on age and compositional differences (Kousa et al. 1994). The younger unit, to the west and northwest of the Pyhäsalmi area, contains the 1.85–1.89 Ga Ylivieska group calc-alkaline basalts to potassium rhyolites with island arc affinity and well-preserved primary structures indicating a subaerial or shallow-water depositional environment (Kousa et al. 1994, Mäki & Puustjärvi 2003). The older unit, which contains all the known VMS deposits in the area, mostly consists of a 1.92–1.93 Ga bimodal association of low-K basalts, basaltic andesites and rhyolites with arc affinity (Kousa et al. 1994), interpreted to have formed on an island arc crust that had been attached to the Keitele microcontinent prior to 1.92 Ga (Lahtinen et al. 2005).

The 1.92–1.93 arc assemblage consists of the Pyhäsalmi group volcanic rocks and the stratigraphically overlying Vihanti group volcanic rocks (Fig. 3). The Pyhäsalmi deposit is hosted by altered felsic volcanic rocks of the Pyhäsalmi group, whereas the Mullikkoräme deposit seven kilometres to the northeast occurs within the Vihanti group rocks. The lowest part of the volcanic sequence in the Pyhäsalmi area consists of felsic mass flows and tuffaceous and pyroclastic rocks with minor mafic intercalations. Mafic massive lavas, pillow lavas, pillow breccias and pyroclastic rocks become more abundant towards the stratigraphic top. The rocks were metamorphosed in upper amphibolite facies conditions, but retrograde metamorphic mineral assemblages are seen in $D_4$ shear zones (Mäki & Puustjärvi 2003). Much of the original volcanic textures has been destroyed by hydrothermal alteration and later tectonic events, but locally the metavolcanic rocks are well preserved.

Most of the felsic volcanic rocks of the Pyhäsalmi group are low- to medium-K rhyolites, transitional between tholeiitic and calc-alkaline affinity (Rasilainen et al. 2003). The mafic metavolcanic rocks are sub-alkaline low- to medium-K tholeiitic basalts and basaltic andesites. Trace element chemistry of the Mukurinperä member basaltic rocks in the upper part of the stratigraphic sequence and overlying the Pyhäsalmi deposit indicates a mature island arc setting (Rasilainen et al. 2003), although felsic volcanic and subvolcanic rocks at a stratigraphically lower position below the Pyhäsalmi deposit have a juvenile Nd isotope signature (Lahtinen 1994).

Although most of the Pyhäsalmi orebody has now been excavated, we describe it here using the present tense. The orebody forms a roughly north-

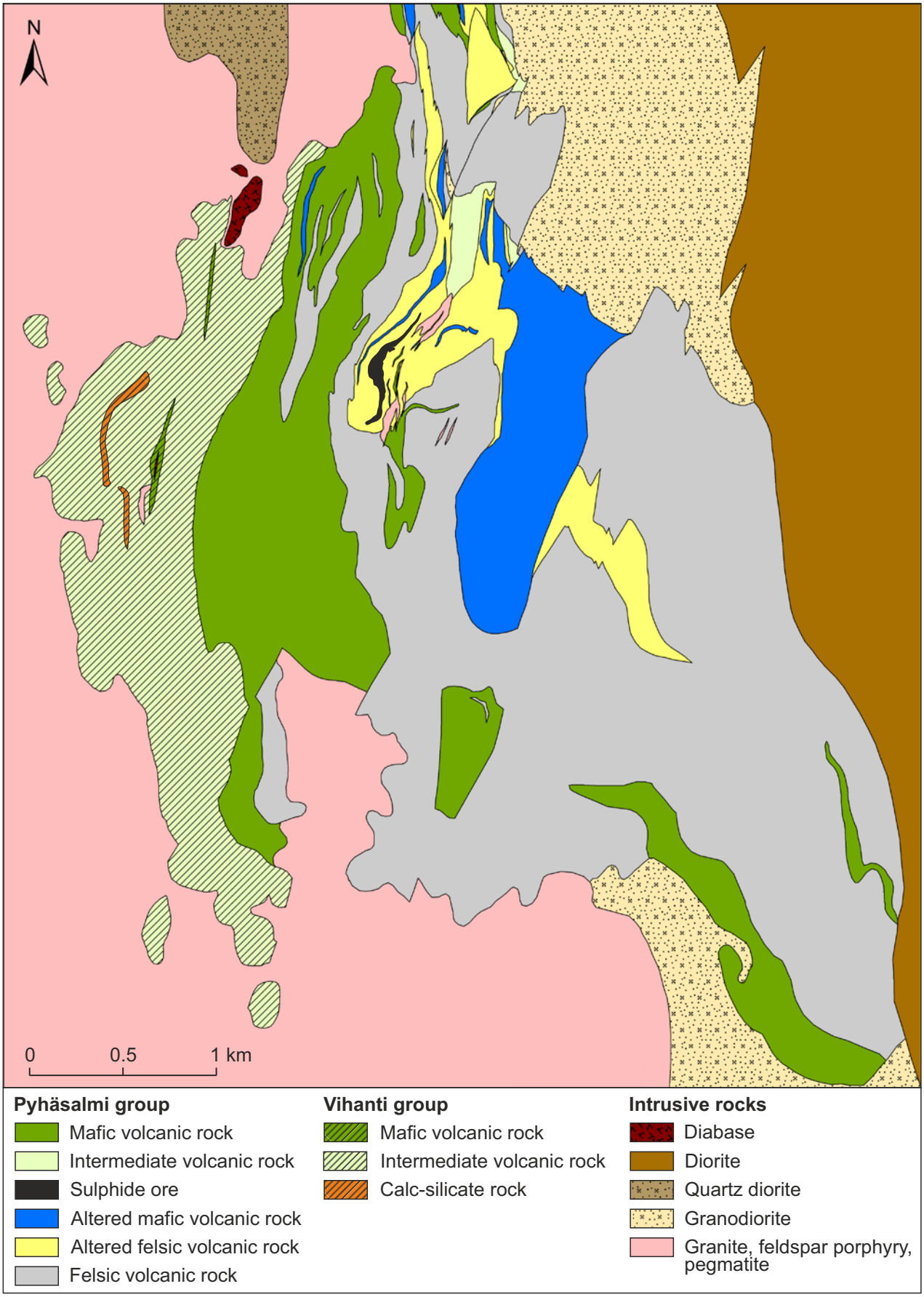


Fig. 3. Simplified geology around the Pyhäsalmi deposit. Map based on Geological Survey of Finland (2010a).

east-trending, S-shaped, 650-m-long and up to 75-m-wide intersection with the surface (Fig. 3). The orebody shortens as it continues almost vertically down to the depth of 1416 m, where it ends in a tight fold (Fig. 4). The deep orebody occurs below the depth of 1050 m from the surface, and it contains approximately 35 Mt of sulphides (Mäki & Puustjärvi 2003). The deep orebody is zoned and consists of a core of massive pyrite with low copper and zinc grades, a surrounding zone of massive chalcopyrite-pyrite ore and an outer rim of massive to semimassive sphalerite-pyrite ore. A discontinuous area of galena-chalcopyrite mineralisation containing relatively high gold and silver grades occurs outside of the massive sulphides (Balint & Boaro 2002).

The coarse-grained Pyhäsalmi massive sulphide ore contains 75 % sulphides with pyrite, chalcopyrite, sphalerite and pyrrhotite as the main minerals. Accessory minerals include galena, magnetite, arsenopyrite and various sulphosalts (Mäki & Puustjärvi 2003). Barite, carbonate, mica and quarts occur as the main gangue minerals. Host rock inclusions in the sulphide ore are common and consist mainly of calcareous rocks as well as felsic and mafic volcanic rocks. The average chemical composition of the total deposit is 0.90 % Cu, 2.18 % Zn, 0.4 g/t Au and 14 g/t Ag (Appendix 2, Table 1).

Several types of sulphide ore can be recognized, including massive pyrite, massive chalcopyrite-pyrite, massive chalcopyrite-sphalerite-pyrite, massive banded sphalerite-pyrite, semi-massive breccia sphalerite-barite-carbonate-pyrite, breccia chalcopyrite in host rock inclusions, and pyrrhotite-bearing varieties (Balint & Boaro 2002). The orebody can be roughly classified in two types, copper-pyrite ore and zinc ore. The copper-rich parts mostly consist of massive pyrite-chalcopyrite. No clear feeder zones have been discovered, but host rock inclusions occasionally contain breccia-type mineralisation with high copper contents. The zinc-rich pyrite-sphalerite ore is either massive or semi-massive with high barite and carbonate contents (Mäki & Puustjärvi 2003). The distribution of copper- and zinc-rich ore types is variable in the upper parts of the deposit, but a clearer zoning is present in the deep orebody.

The Pyhäsalmi orebody is surrounded by a deformed north-trending alteration zone, which is four kilometres long and up to one kilometre wide at the surface. The length and width of

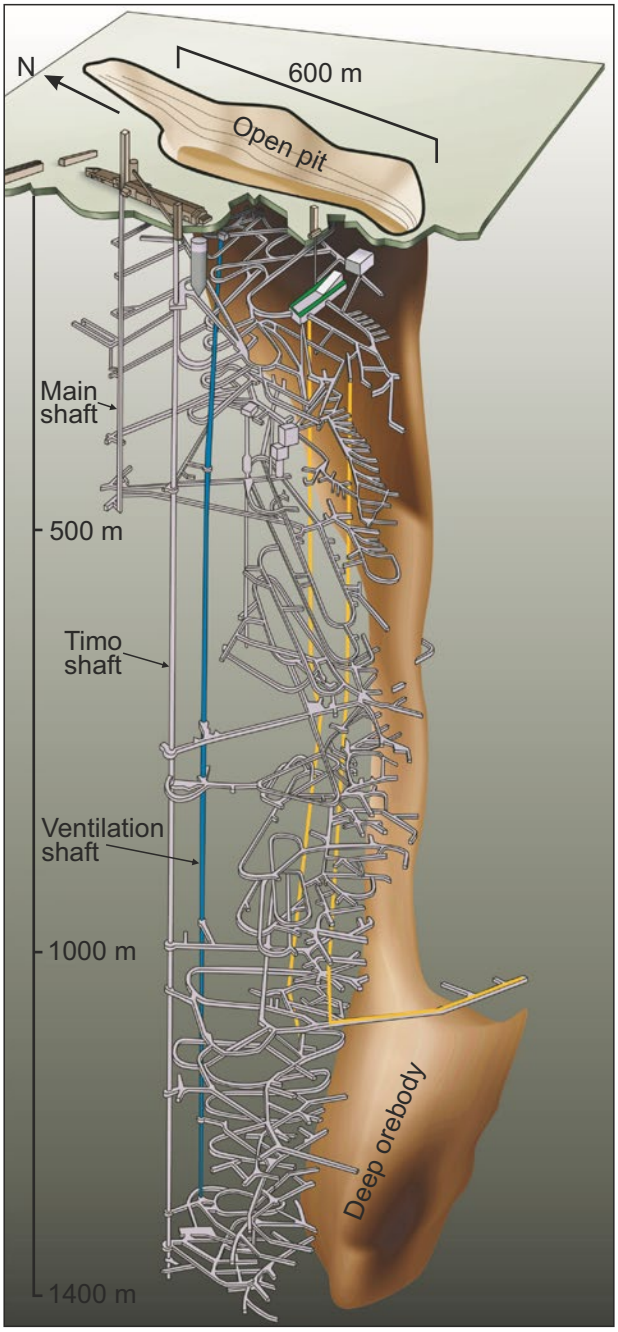


Fig. 4. Vertical 3D sketch of the Pyhäsalmi orebody showing shafts and declines. Modified from a picture received from T. Mäki (pers. comm. 2014).

the alteration zone decrease with depth, until the whole zone gradually disappears below the depth of 1150 m. At deeper levels, altered rocks occur only as inclusions within the orebody. Altered felsic volcanic rocks contain sericite- and cordierite-bearing mineral assemblages, whereas cordierite, anthophyllite and garnet characterise altered mafic volcanic rocks.

The contact between the ore and wall rocks is sharp and sheared, and in places pegmatite dykes have intruded the contact zone, indicating that $D_4$ deformation had a strong influence on the final emplacement of the massive sulphides (Mäki & Puustjärvi 2003). The overall form and contacts of the orebody indicate a ductile deformation history (Balint & Boaro 2002).

### 2.1.2 Bimodal-mafic type: The Rauhala deposit

Rauhala is the only well-known bimodal-mafic VMS deposit in Finland. The deposit is located in western Finland, approximately 90 km east-northeast of the town of Kokkola (Fig. 2). It was discovered in 1985 after a three-year period of exploration initiated by an anomalously high zinc concentration in a regional geochemical sample (Iisalo 1989). The Rauhala mining concession is presently held by Pyhäsalmi Mine Oy, but the deposit has not been mined. The known resources of the deposit are 1.7 Mt of ore containing 0.023 Mt of copper and 0.081 Mt of zinc (Västi 1989). The Rauhala deposit and its surroundings are described in Kojonen et al. (1987, 1989), Puustjärvi (1988), Västi (1988, 1989, 1993), Iisalo (1989), Jokinen et al. (1989), Rasilainen & Västi (1989), Vaasjoki (1989), Korkalo (1991), Poutiainen (1992) and Kousa et al. (1997).

The Svecofennian supracrustal rocks in the Rauhala area belong to the 1.87–1.90 Ga Ylivieska group within the Pohjanmaa belt (Kähkönen 2005, Geological Survey of Finland 2010a). The volcanic rocks range from basalts to K-rhyolites and have a calc-alkaline, mature island-arc affinity (Kähkönen 2005). Well-preserved primary structures indicating a subaerial or shallow-water depositional environment are common (Kousa & Lundqvist 2000). The sedimentary rocks are characterized by sandstones, conglomerates and silty mudrocks with volcanic provenance. The composition of intrusive rocks mainly varies from quartz diorite to granite, but gabbroic intrusions and intermediate to mafic hypabyssal rocks also occur in the area. Regional metamorphism in the area culminated in amphibolite facies conditions, and later retrograde metamorphism caused the alteration of andalusite into sericite and quartz (Västi 1989).

The stratiform Rauhala massive sulphide deposit is hosted by a metasedimentary sequence consisting of metaturbidites and mica schists with black schist, quartz-feldspar schist, cordierite gneiss and tuffitic hornblende schist interlayers (Figs 5 and 6). Locally well-preserved graded bedding structures indicate that the metasediments are facing upwards. The metasediments are intruded by a subvolcanic quartz diorite and thin conformable tholeiitic uralite porphyrite dykes, which are younger than the ore deposit (Västi 1989). The deposit occurs as a thin concordant sheet in the metasedimentary host rocks. The folded outcrop can be traced at the surface for about 650 m. The orebody consists of two parts (Fig. 6). The western main orebody, which contains most of the massive sulphides, is gently folded with a fold axis dipping at 25° to the northeast. The small eastern orebody is only intersected by one drill hole. The deposit continues down to the depth of 190 m, where it is only a few tens of centimetres thick. The maximum dimensions of the main orebody are 590 m from east to west and 350 m from north to south. The thickness of the orebody varies from 0.2 m to 5.9 m, with an average of 2.1 m (Västi 1989). The deposit consists of massive and disseminated ores. The massive ore forms a 0.20–3.75-m-thick continuous sheet having an average thickness of 1.35 m. The disseminated ore has an average thickness of 0.75 m, and it mostly occurs in sericite schist below the massive orebody. A narrow zone of net- or breccia-textured sulphides occasionally occurs in the lower part of the massive orebody.

The main ore minerals are pyrrhotite, sphalerite, chalcopyrite, galena and pyrite. Accessory ore minerals include arsenopyrite, marcasite, tetrahedrite, boulangerite, stannite, kesterite, electrum, Au-Ag amalgam, native bismuth, cassiterite and rutile (Kojonen et al. 1989). Pyrrhotite is the predominant iron sulphide mineral in the orebody, but pyrite and marcasite prevail along the western and southern margins of the orebody. Hematite and ilmenite occasionally occur in the disseminated ore, and bornite, chalcocite, covelline and native copper occur together with marcasite and goethite in the weathered margin of the orebody. Quartz, muscovite, iron-bearing serpentine and chlorite occur as gangue minerals in the massive

ore area (Kojonen et al. 1989). The average chemical composition of the Rauhala deposit is 1.33 % Cu, 4.79 % Zn, 0.96 % Pb, 0.4 g/t Au and 53 g/t Ag (Appendix 2, Table 1).

Although the contents of all the ore metals are highest in the massive orebody, average relative concentrations reveal a vertical zonation, in which copper and arsenic are concentrated in the footwall mineralised rocks, zinc in the massive ore, and lead in the hanging-wall mineralised rocks (Rasilainen & Västi 1989). The massive orebody also shows semiconcentric lateral zonation, (arsenic, gold) - copper - zinc - (lead, silver, antimony), from the southwestern part towards the northeast.

Hydrothermal alteration of the mica schists, presumably related to mineralisation, is manifested by sericitisation and silicification of the footwall rocks of the massive sulphide orebody at a distance of 0.5–8 m. Much weaker alteration of the hanging-wall rocks is seen as localized sericitisation. The characteristics of the sulphide orebody, the alteration features and the geochemical zonation of the ore metals are considered to be consistent with the interpretation that the Rauhala deposit is a massive sulphide deposit occurring in its primary location and position (Rasilainen & Västi 1989).

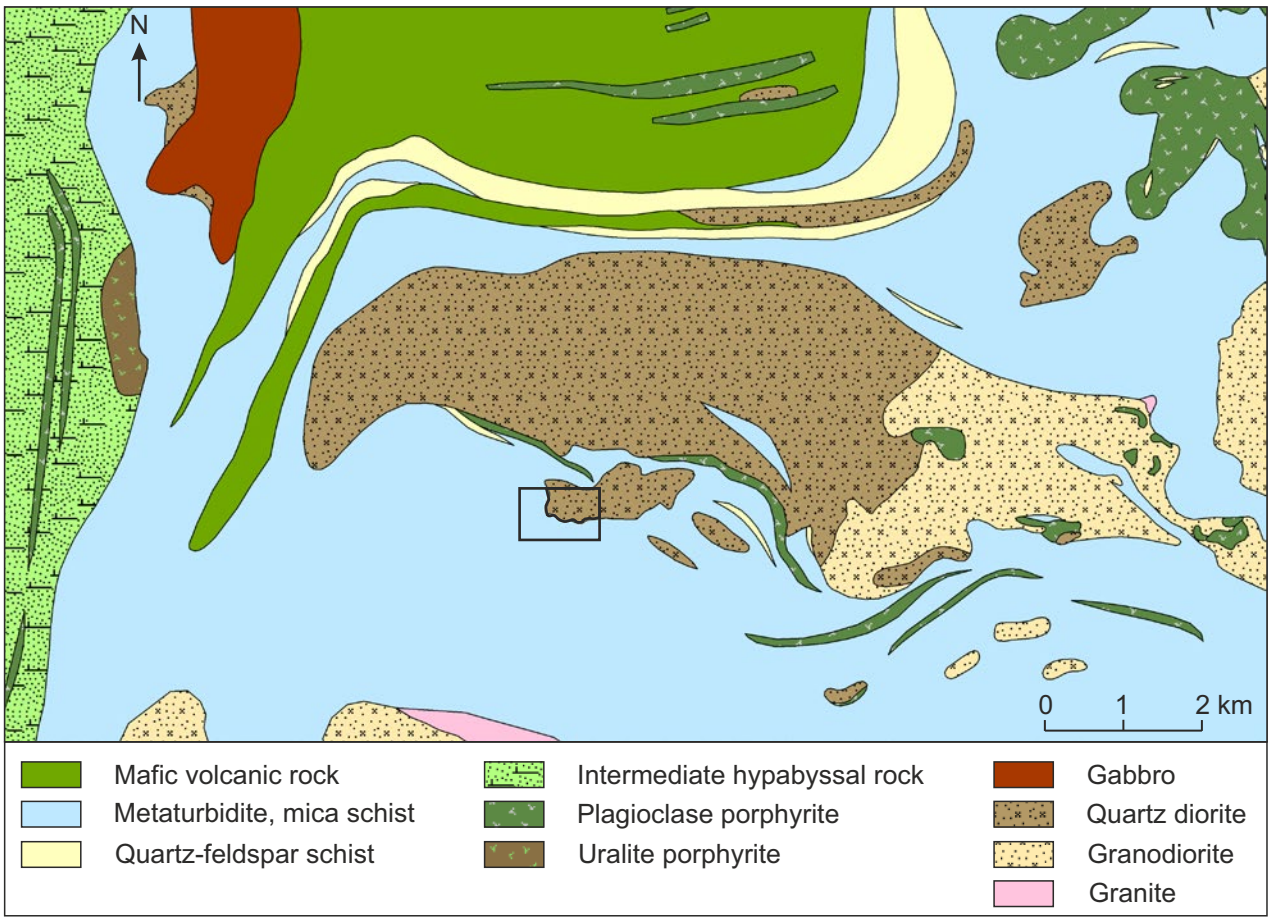


Fig. 5. Simplified geology around the Rauhala deposit. The rectangle indicates the area of Fig. 6. Map based on Geological Survey of Finland (2010a).

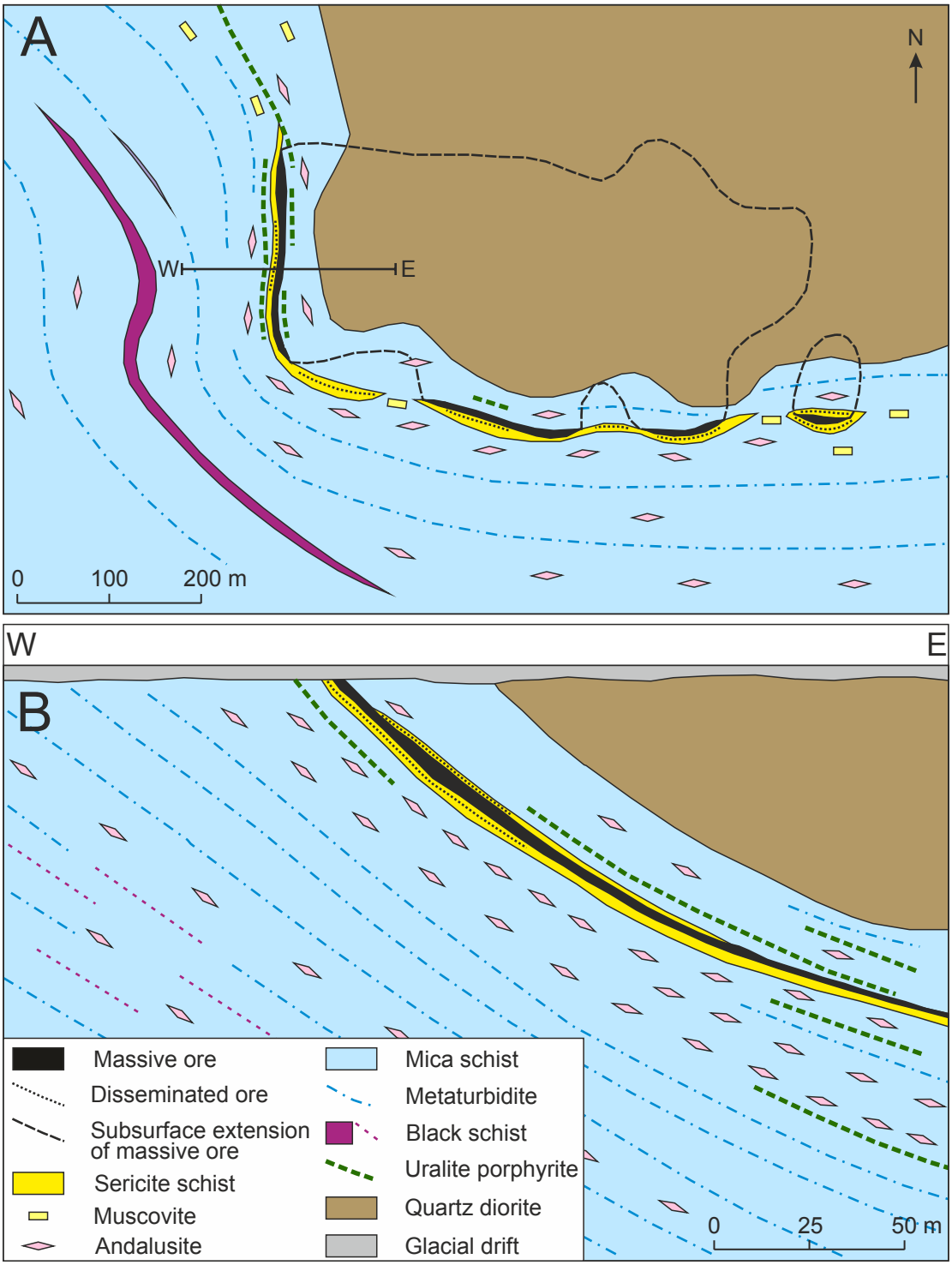


Fig. 6. Plan (A) and vertical (B) sections of the Rauhala deposit. Modified from Västi (1989).

### 2.1.3 Mafic type: The Hällinmäki deposit

There are three well-known mafic VMS deposits in Finland (see Appendix 2, Table 1), and Hällinmäki is the only one of these to have been mined. The deposit is located in southeastern Finland, 45 km north-northeast of the city of Mikkeli (Fig. 2). The Hällinmäki deposit was discovered in 1964 after intensive exploration prompted by several layman samples from the area. Open pit mining of the deposit in the Virtasalmi mine started in 1966 and underground mining was carried out in 1972–1983. The mine was closed in 1984 due to the exhaustion of resources. Cumulative produc-

tion was 4.2 Mt of ore containing 32,000 t of copper (Puustinen 2003). The Hällinmäki deposit and its surroundings have been described by Kahma (1965), Hyvärinen (1966, 1969), Siikarla (1967), Vaajoensuu et al. (1978), Pulkkinen (1985), Lawrie (1987, 1992) and Pekkarinen (2002).

The Virtasalmi area is located at the southern end of the Savo belt (Kähkönen 2005). The area is characterised by mafic volcanic rocks of the Virtasalmi suite, mica gneisses of the Häme migmatite suite and granodiorites, quartz diorites and gabbros of the Southern Finland plutonic suite (Geological Survey of Finland 2010a). Graphite-bearing schists, sedimentary carbonate rocks, calc-silicate rocks, cherts, iron-rich strata, uranium-phosphorus-bearing horizons and minor felsic volcanic rocks occur within the mafic volcanic rocks and mica gneisses (Lawrie 1992, Reinikainen 2001, Pekkarinen 2002). Several copper occurrences, in addition to the Hällinmäki deposit, are located in the area. The mafic volcanic rocks are subalkaline, mainly medium-K, tholeiitic basalts and andesites, which probably erupted 1.92–1.905 Ga ago in relatively shallow water, possibly in a rift-related or marginal basin setting (Lawrie 1992, Korsman et al. 1997, Pekkarinen 2002, Kähkönen 2005). The mafic volcanic rocks in the Hällinmäki deposit area are intruded by diorites and tonalities, as well as minor leucogabbros, mafic dykes and pegmatites (Fig. 7).

The Hällinmäki deposit is enclosed in mafic volcanic rocks (amphibolites) with a probably pyroclastic origin (Lawrie 1987) at the contact of a dioritic plutonic rock to the southwest. The immediate wall rocks of the orebody are garnet (andradite) skarns and diopside-bearing mafic volcanic rocks. The andradite skarns occur as irregular lenses or commonly boudinaged interlayers. The main minerals are usually andradite and hedenbergite, but in places epidote, plagioclase, scapolite, chalcopyrite, cubanite, pyrrhotite and magnetite also occur as major minerals. Accessory minerals include sphene, apatite, carbonate, quartz, hornblende and pyrite. The diopside-bearing mafic volcanic rocks are usually banded with light green bands rich in diopside and plagioclase, and dark green bands dominated by hornblende and plagioclase. Carbonate, epidote, biotite, scapolite, sphene, apatite, sulphides and magnetite occur as minor minerals (Lawrie 1987, Hyvärinen 1969, Pekkarinen 2002). The host rocks and orebody have suffered polyphase deformation and metamorphism in amphibolite–granulite facies conditions (Lawrie 1987, 1992, Pekkarinen 2002).

The Hällinmäki deposit consists of five ore bodies within a west–northwest-trending zone 500 m long and up to 50 m wide at the surface (Fig. 8). The ore bodies dip almost vertically to the north-northeast and continue down to the depth of 350 m (Vaasjoensuu et al. 1978). The Hällimäki orebodies contain disseminated and brecciated ore types. Disseminated ore mainly occurs as evenly distributed or as poorly developed layers or bands in the diopside-bearing mafic volcanic rocks. The main ore minerals are chalcopyrite, pyrite, pyrrhotite and magnetite. Brecciated ore occurs chiefly within or adjacent to the andradite skarn rocks. The sulphides form a coarse-grained network structure, and the breccia ore has been interpreted to represent a stockwork zone below the Hällinmäki deposit (Lawrie 1987). The main ore minerals are chalcopyrite, cubanite and pyrrhotite, with minor amounts of pyrite and magnetite (Hyvärinen 1969, Mikkola & Rouhunkoski 1980). Gangue minerals in the sulphide ore include diopside, hedenbergite, andradite, plagioclase, scapolite, hornblende, actinolite, epidote/zoisite, quartz and sphene (Lawrie 1987, Hyvärinen 1969). The average chemical composition of the Hällinmäki deposit is 0.78 % Cu and 0.1 g/t Au (Appendix 2, Table 1).

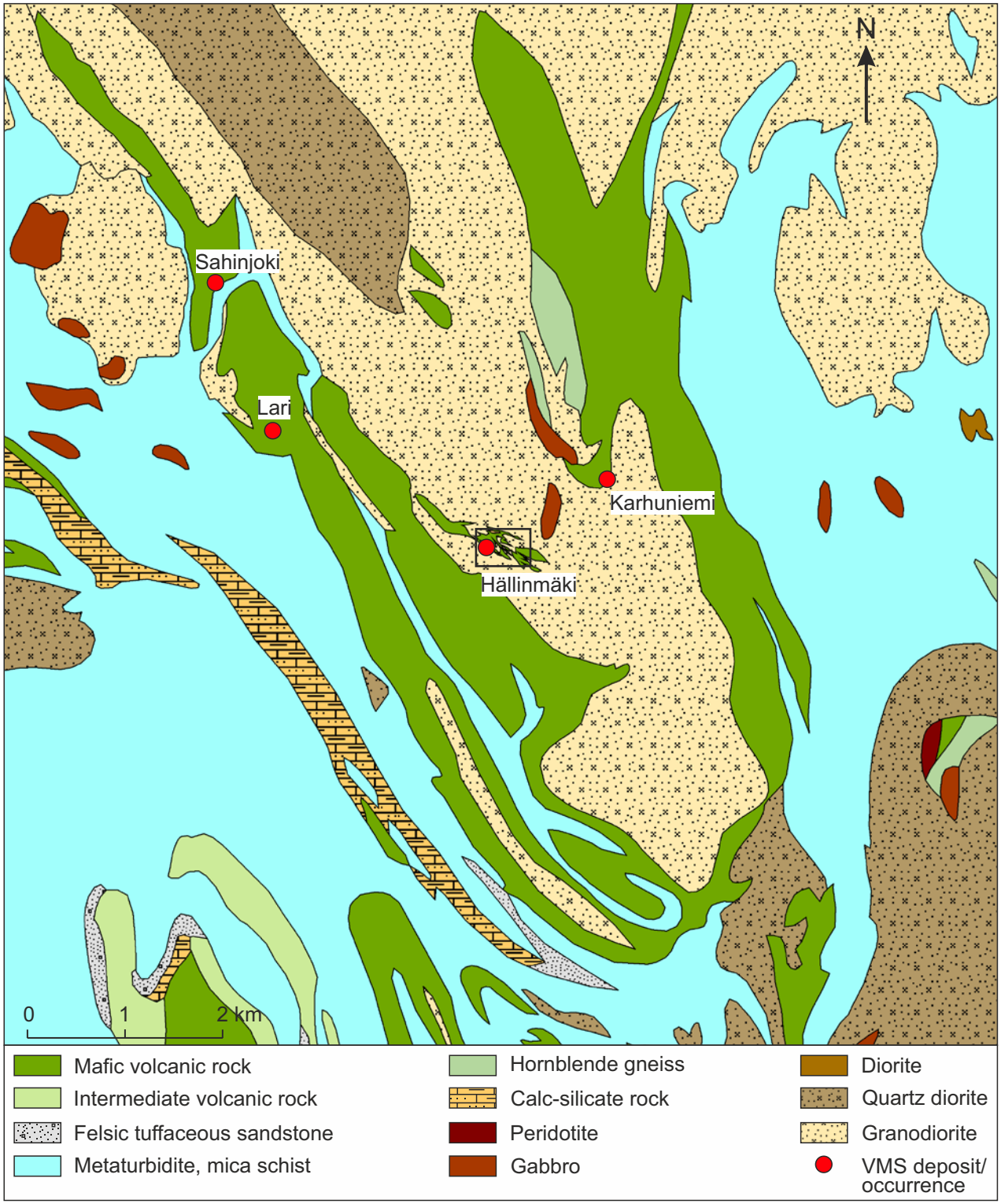


Fig. 7. Simplified geology around the Hällinmäki deposit. The rectangle indicates the area of Fig. 8. Map based on Geological Survey of Finland (2010a).

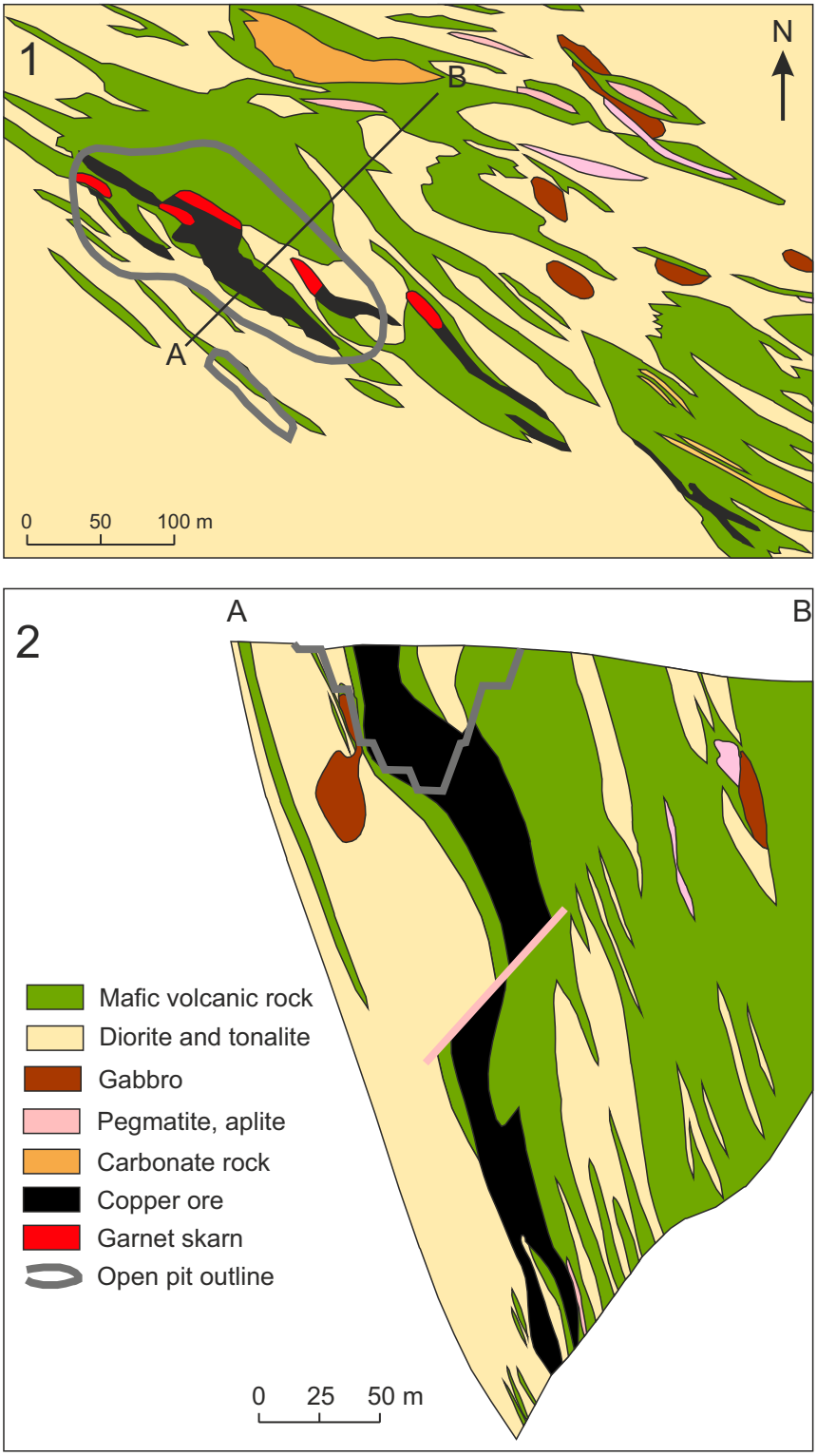


Fig. 8. Plan (1) and vertical (2) sections of the Hällinmäki deposit. Modified from Pekkarinen (2002) and Vaajoensuu et al. (1978).

## 2.2 Porphyry copper deposits

No mining has taken place in porphyry copper deposits in Finland. Known resources in the Finnish porphyry-type deposits are 45,000 t Cu, 14 t Au and 100 t Ag (Appendix 4, Table 1). A descriptive model for porphyry copper deposits is given in Appendix 3 and a grade-tonnage model for Precambrian deposits in Appendix 4.

### 2.2.1 The Kopsa deposit

The Kopsa deposit is described here as an example of porphyry-type deposits in Finland. Actually, the deposit has variably been classified as a Proterozoic porphyry copper, an orogenic gold, and an intrusive-related deposit (Pym et al. 2012). The evidence for a porphyry style is largely based on the potassic alteration and the association of copper and gold. On the other hand, the evidence for an orogenic gold type is mostly based on the association of gold with quartz veins. At present, Belvedere geologists consider Kopsa to be an intrusive-related deposit, but no conclusive classification can be performed without further studies. Several other prospects and occurrences in Finland have been interpreted to belong to the porphyry class, but because Kopsa is the best known of these, it is described here.

The Kopsa deposit is located in the Haapajärvi municipality, central Ostrobothnia, about 110 km east-southeast of the city of Kokkola (Fig. 2). The deposit was discovered in 1939 based on layman samples sent to the Geological Commission of Finland (Gaál 1978). The deposit has been studied in several periods since 1939 by the Geological Commission of Finland (1939), the North Finland Research Foundation (1943–1954), Outokumpu Oy (1940–1941, 1964–1966, 1971–1973, 1977–1978, 1981–1982), the Geological Survey of Finland (1961, 1983–1985), Baltic Minerals Finland (1995–1999) and Belvedere Resources Ltd (2002–). The deposit has never been mined, but a positive preliminary economic assessment was published in 2013 (SRK Consulting Ab 2013). A recent resource estimate gives a total tonnage of 16.3 Mt of ore containing 25,800 t of copper, 13 t of gold and 36 t of silver (SRK Consulting Ab 2013). However, the historic resource estimate of Gaal & Isohanni (1979) was used in this assessment. The geology of the Kopsa deposit and its surroundings has been described by several authors, including Gaál (1978), Gaál & Isohanni (1979), Isohanni (1982), Nurmi et al. (1984), Nurmi (1985), Nikander (1986), Strauss (1999), Pym et al. (2012) and SRK Consulting (2013).

The supracrustal rocks in the area belong to the Pohjanmaa belt (Kähkönen 2005) and mostly consist of migmatised mica gneisses and minor intercalated quartz-feldspar gneisses, graphite schists, mica schists and volcanic amphibolites, which locally contain dolomite and skarn (Pym et al. 2012). The Kopsa gold-copper deposit is located within the late orogenic Kopsa tonalite, which intrudes a turbidite sequence consisting of metagraywackes, mica schists and intermediate pyroclastic volcanic rocks (Fig. 9). A suite of 1.88–1.87 Ga igneous rocks ranging from gabbro to granodiorite intrude the ~1.92 Ga turbidite sequence (Pym et al. 2012, SRT Consulting 2013).

The Kopsa tonalite is grey, medium-grained and mostly isotropic and non-foliated. Within most of the Kopsa outcrop, the tonalite shows a bleached surface due to silicification and potassium feldspar alteration (Pym et al. 2012). A few xenoliths of dark grey, fine-grained and isotropic tonalite occur within the outcrop.

A plagioclase porphyry is in a few locations intersected by drill holes within the Kopsa tonalite. The porphyry can be over 10 m thick, and it has a dark fine-grained matrix with plagioclase crystals up to 8 mm in size. The relationship between the Kopsa tonalite and the plagioclase porphyry is unclear due to the lack of outcrop observations. Mineralisation has not been observed in the plagioclase porphyry. On the other hand, it has only been intersected outside of the main mineralised body (Pym et al. 2012).

The mineralised volume of rock is approximately 700 m long along strike (approximately east–west), 200 m wide down dip towards the south (Fig. 10), and has a maximum thickness of 50 m (Pym et al. 2012, SRK Consulting 2013). The gold-copper mineralisation is associated with quartz and arsenopyrite veining (SRK Consulting 2013). The mineralised material consists of compact sulphide veins, stringers and blebs in connection with quartz veining and silicification, which form a stockwork zone in the higher-grade areas. Outside the main veins, fine-grained sulphide dissemination occurs in the altered host rock. The main sulphide minerals are arsenopyrite, chalcopyrite and

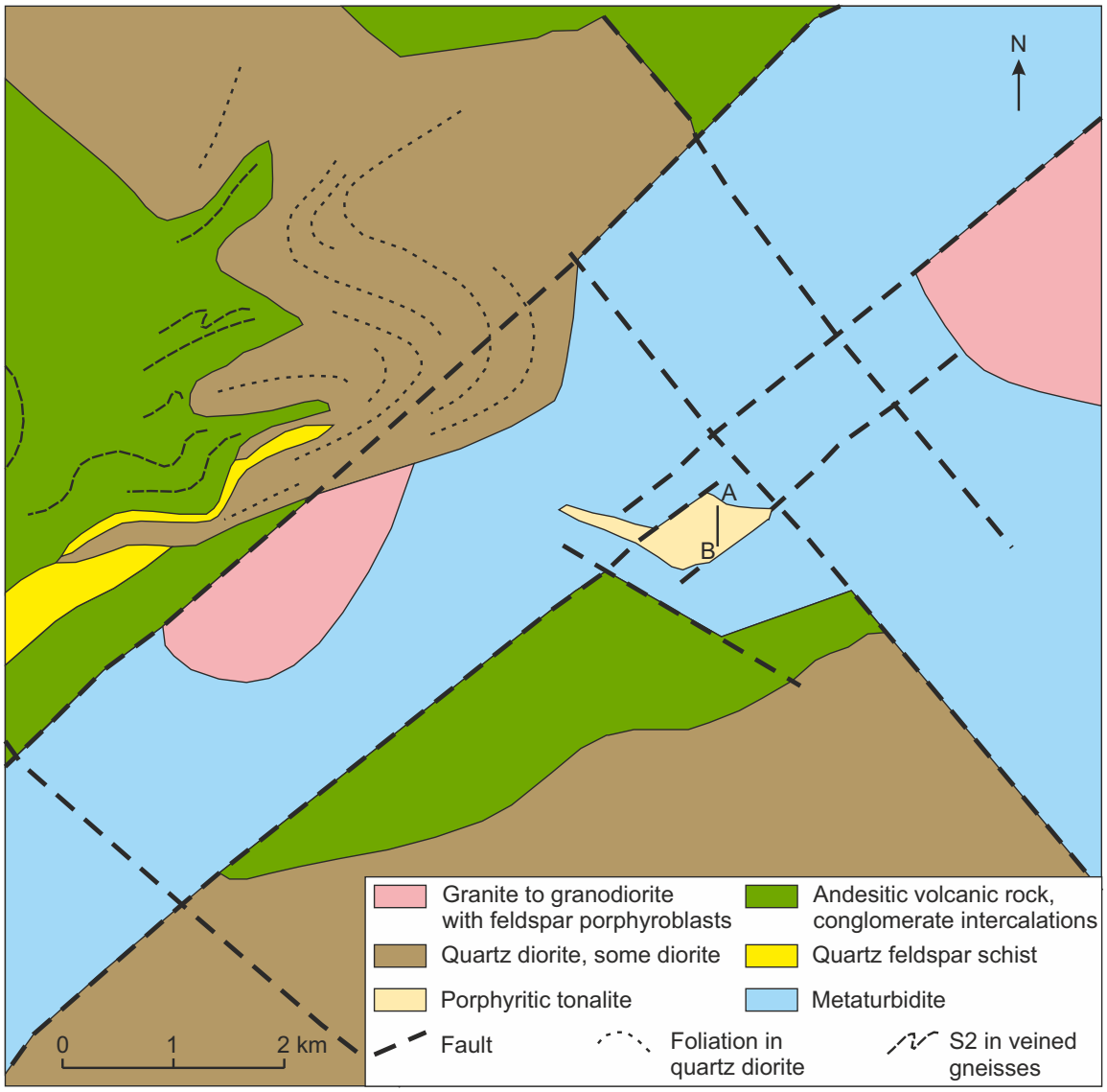


Fig. 9. Simplified geology around the Kopsa deposit. The approximate location of the vertical section in Fig. 10 is indicated. Modified from Strauss (1999).

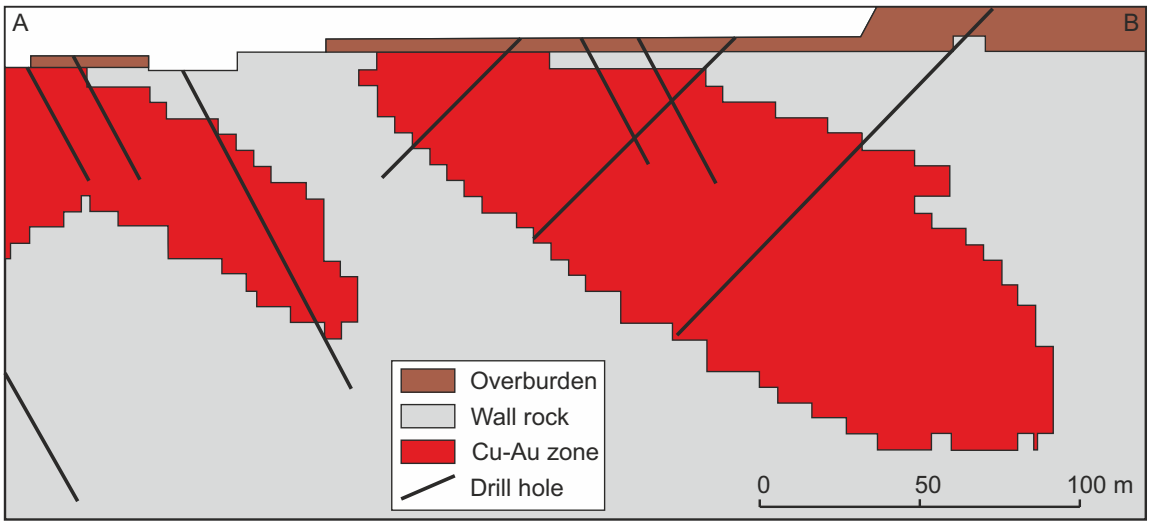


Fig. 10. Vertical section of the Kopsa deposit showing the zone of combined copper and gold mineralisation. Modified from SRK consulting (2013).

pyrrhotite (Pym et al. 2012). Löllingite and pyrite occasionally occur as main minerals, and minor sulphides and oxides include stannite, bornite, ilmenite, rutile, and occasionally hydrothermal graphite. Gold occurs as free gold (non-refractory) with a close association with bismuth (SRK Consulting 2013). The average chemical composition of the Kopsa deposit is 0.18 % Cu, 0.57 g/t Au and 4 g/t Ag (Appendix 4, Table 1).

## 2.3 Outokumpu-type Cu-Zn-Co deposits

All the known Finnish Outokumpu-type deposits occur in a rather restricted area in eastern Finland. The deposits had produced 1.2 Mt Cu and 0.33 Mt Zn by the end of 2012 (Table 1). Well-known resources in the Outokumpu-type deposits were 0.20 Mt Cu and 0.11 Mt Zn.

A descriptive model for Outokumpu-type Cu-Zn-Co deposits is given in Appendix 5, and a grade-tonnage model for this deposit type is given in Appendix 6.

### 2.3.1 The Kylylahti deposit

Although the Outokumpu area has a long history of mining with three exhausted deposits (Outokumpu, Luikonlahti, Vuonos), Kylylahti is presently the only operating mine excavating an Outokumpu-type deposit. The Kylylahti deposit is located in southeastern Finland, 35 km to the northwest of the city of Joensuu (Fig. 2). The first indications of mineralised rocks at Kylylahti were given by reconnaissance exploration diamond drilling in 1984, and the economically most interesting part of the deposit was intersected in 1985 (Kontinen 2005). The mine started production in 2012, and by the end of the year, it had processed 0.37 Mt of ore and produced 4800 t copper and 0.14 t gold (Altona Mining Limited 2012, 2013). The Kylylahti deposit and its surroundings have been described, among others, by Ahokas (1984a,b), Hakanen et al. (1986), Koistinen (1986), Huhtelin & Sotka (1994), Pekkarinen et al. (1998), Kontinen (2005), Kontinen et al. (2006), Glacken et al. (2008) and Peltonen et al. (2008). In addition to Cu-Co sulphides, there is a considerable talc potential at Kylylahti in soapstones, which were briefly mined during the seventies (Kontinen et al. 2006).

The Outokumpu mining camp is located within the North Karelia Schist Belt in eastern Finland. The schist belt rests on a late Archaean gneiss–granitoid basement, east of the suture zone between the Archaean Karelian Craton and the 1.93–1.80 Ga Palaeoproterozoic Svecofennian island arc complex. The dominantly metasedimentary rocks of the North Karelia Schist Belt consist of autochthonous 2.5–2.0 Ga shallow-water deposits (mainly quartzitic sands) resting discordantly on the Archaean basement, and younger, <1.92–2.0 Ga parautochthonous and allochthonous deeper water deposits that were thrust from the west onto the Archaean basement complex during the early stages of the Svecofennian Orogeny (Kontinen 2005, Peltonen et al. 2008). The younger assemblage consists of two tectonostratigraphic units (Kontinen 1987). The probably parautochthonous "Lower Kaleva" unit mainly consists of metaturbiditic greywackes that have thin intercalations of low-Ti tholeiitic metabasalts and black schists in its upper part. The "Upper Kaleva" unit is mainly composed of deep marine metaturbiditic greywackes with up to tens of metres thick intercalations of black schists, commonly in the basal parts of the unit. These black schists commonly enclose fragmented ophiolite bodies and associated ore deposits (Kontinen 2005, Peltonen et al. 2008).

The following description of the Kylylahti deposit is based on Kontinen (2005), unless otherwise specified. The Kylylahti deposit is located at the eastern margin of a poorly exposed, large ultramafic talc-carbonate-serpentinite body with surface dimensions of 300 x 3300 m (Fig. 11). Outokumpu-type copper-zinc-cobalt deposits are invariably associated with rocks of the so-called Outokumpu association or Outokumpu assemblage (Gaál et al. 1975, Park 1984, 1988): serpentinised mantle peridotites with thin alteration selvages consisting of carbonate rocks, skarns and quartz rocks (Peltonen et al. 2008). This is also the case with Kylylahti; the mineralised rocks are confined to the north-trending eastern limb of the massif, where ultramafic rock is bordered by a zone of carbonate–skarn–quartz rocks in contact with a thick unit of sulphide-bearing black schists (Peltonen et al. 2008).

The ultramafic body at Kylylahti mostly consists of metaserpentinite altered by metamorphic hydrothermal processes to talc-carbonate rock along the margins (Fig. 11). Basaltic dykes and gabbro stocks intruding the serpentinite form 5–10 volume per cent of the whole ultramafic body. Sodium-rich quartz-plagioclase rocks resembling oceanic plagiogranites occur associated with metagabbros at the western margin of the massif.

The purest carbonate rocks are grey, massive and medium–coarse-grained, and they have a massive or irregularly banded (tremolite) structure. The main minerals are calcite ± dolomite; tremolite usually also occurs as a main component. Tremolite skarns, consisting of tremolite, dolomite ± calcite and quartz, are typically nematoblastic, schistose rocks that occur as irregular layers between carbonate and quartz rocks or as thin layers and bands in the quartz rocks. However, a significant part of the skarn material within the mineralised zone at the eastern contact of the Kylylahti massif occurs as veins and breccia-type networks of massive carbonate-tremolite skarn. These cut and replace the carbonate and quartz rocks as well as the more normal skarn rocks, and host most of the disseminated copper-cobalt-zinc sulphides at Kylylahti. The purest quartz rocks at Kylylahti are dark to pale grey, fine-grained, schistose and almost monomineralic. They resemble quartzite or metachert but are alteration products of ultramafic rocks. Varying amounts of tremolite ± carbonate are always present, and there is a gradation between quartz rock and tremolite skarn.

The mica schists at Kylylahti are medium–fine-grained biotite-quartz-plagioclase schists with locally preserved primary sedimentary features. The black schists are usually fine-grained, schistose rocks heavily stained by fine-grained graphite dust. Quartz, plagioclase, biotite and some muscovite occur as the main silicate minerals. The main sulphide mineral is pyrite, and the pyrite content of the black schists can be very high, up to 50 volume per cent. Pyrrhotite occurs in variable amounts, and sphalerite and chalcopyrite are minor components. Thin (<5 cm) dark layers rich in fine-grained graphite and apatite occur in the black schists, especially adjacent to the mineralised zone. In many parts of the Kylylahti deposit, a black to grey carbonate rich schist occurs as a wall rock to the sulphide ore. Several overprinting generations of ductile to brittle quartz, carbonate, phlogopite or sulphide veins are a common feature in the Kylylahti black schists.

Two main types of sulphide mineralisation are present at Kylylahti: semimassive to massive quartz-sulphide lenses in the contact between the carbonate-skarn-quartz rocks and the black schists, and sulphide dissemination, as well as minor veinlets, blotches and semimassive lenses, in the skarn rocks (Fig. 12).

Semimassive to massive, subvertical, quartz-sulphide lenses occur between the skarn-quartz rocks and black schists within a ~1.3-km-long interval along the eastern margin of the ultramafic massif (Fig. 11). In the northern part of the zone, the lenses are only five metres thick and up to 50 m high, whereas in the southern part, the orebody is up to 30 m thick and 170 m high. The contacts between the ore lenses and their wall rocks are sharp. The main sulphide minerals are pyrite, pyrrhotite, chalcopyrite and sphalerite. Quartz is the main gangue mineral; other gangue minerals include amphibole, calcite, mica, rutile, titanite and tucholite (carbon-rich organic material + uraninite + sulphides). Five main textural-mineralogical ore types in the semimassive quartz-sulphide lenses can be distinguished: banded pyrite ore, blebby pyrite ore, pyrrhotite ore, pyrrhotite–magnetite ore, and cobalt–arsenic-rich pyrite ore. The average chemical composition of the Kylylahti deposit is 1.25 % Cu, 0.54 % Zn, 0.24 % Co and 0.20 % Ni (Appendix 6, Table 1).

Sulphide dissemination as well as minor veinlets, blotches and semimassive lenses occur in the skarn rocks. The main sulphide phase is pyrrhotite, and pyrite, chalcopyrite, sphalerite, pentlandite and cobaltite occur in variable amounts. Due to the peridotitic origin of the Kylylahti massif, chromite occurs as a minor component.

The peak metamorphic temperature of ~500 °C at Kylylahti indicates a lower regional metamorphic grade than at any other Outokumpu-type deposit in the area. The location of the massive sulphides in a late fault zone suggests pervasive syntectonic reworking of the deposit (Peltonen et al. 2008).

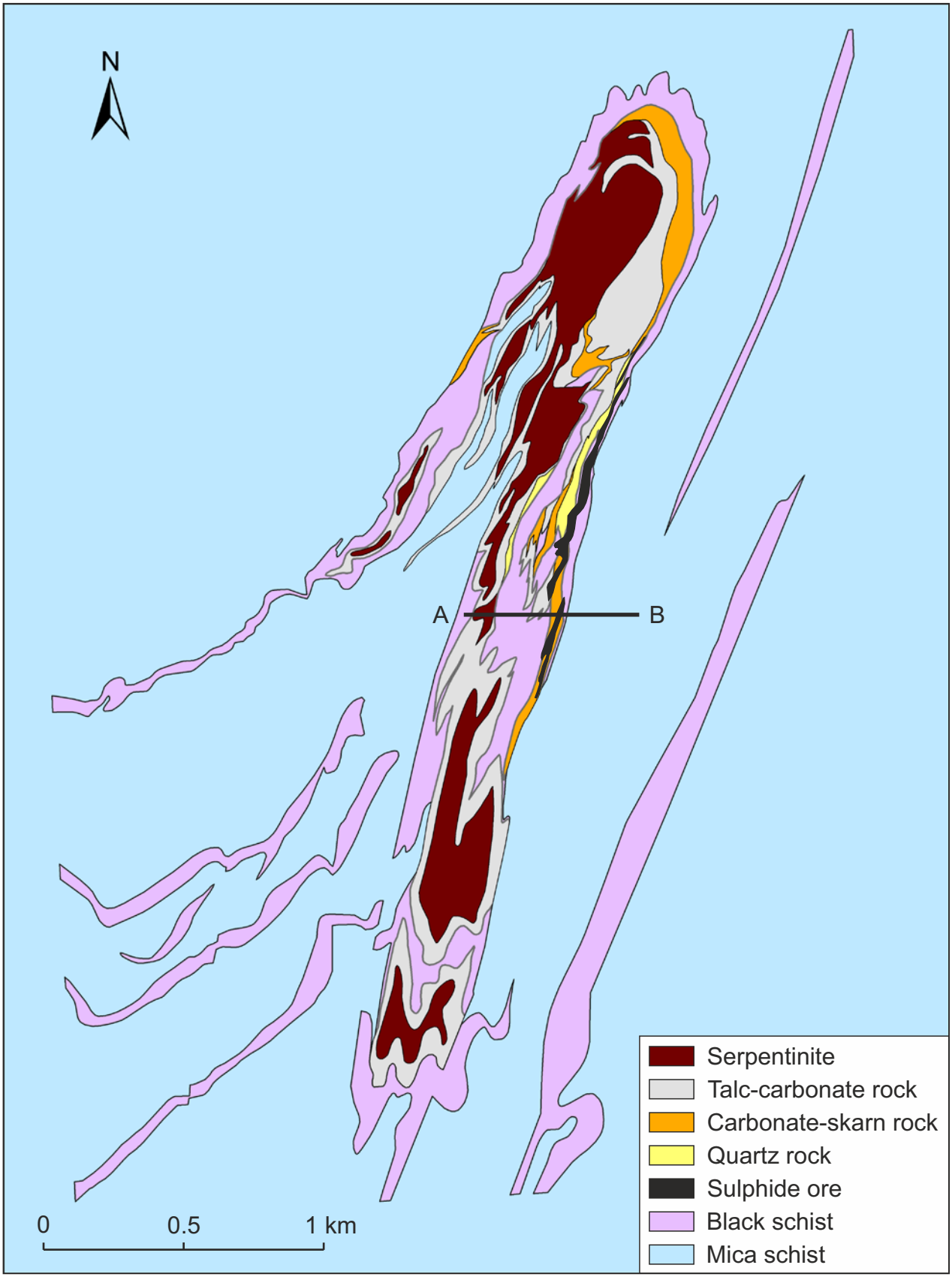


Fig. 11. Simplified geology around the Kylylahti deposit. The location of the vertical section in Fig. 12 is indicated. Map based on Geological Survey of Finland (2010a) and Kontinen et al. (2006).

Fig. 12. Vertical section of the Kylylahti deposit. Modified from Kontinen et al. (2006).

# 3 THE THREE-PART QUANTITATIVE RESOURCE ASSESSMENT METHOD

Numerous methods have been developed and applied to the estimation of undiscovered mineral resources during the past decades, but the task still remains challenging and there are no universally accepted, definitive procedures (e.g., Lisitsin et al. 2007 and references therein). The procedure we selected is based on a three-part quantitative assessment method developed at the USGS starting from the mid-1970s (Singer 1975, Cox & Singer 1986, Root et al. 1992, Harris et al. 1993, Singer 1993, Barton et al. 1995, Drew 1997, Singer & Menzie 2010) and increasingly used by the USGS and others since 1975 (e.g., Richter et al. 1975, Singer & Overshine 1979, Drew et al. 1984, Bliss 1989, Brew et al. 1992, Box et al. 1996, U.S. Geological Survey National Mineral Resource Assessment Team 2000, Kilby 2004, Lisitsin et al. 2007, Cunningham et al. 2008, Hammarstrom et al. 2010, Mihalasky et al. 2011, Rasilainen et al. 2010a, 2012, Box et al. 2012, Ludington et al. 2012a,b, Hammarstrom et al. 2013, Sutphin et al. 2013, Zientek et al. 2014). The method was considered well suited to accomplishing the goal of the GTK assessment project to estimate the undiscovered mineral endowment in Finland. The assessment is based on statistical methods of data analysis and integration and it treats and expresses uncertainty. The method enables the use of varying amounts of objective geological data and subjective expert knowledge, and it generates reproducible assessment results.

The three-part method consists of the following components: (1) evaluation and selection or construction of descriptive models and grade-tonnage models for the deposit types under consideration, (2) delineation of areas according to the types of deposits permitted by the geology (permissive tracts), and (3) estimation of the number of undiscovered deposits of each deposit type within the permissive tracts. The estimated number of deposits is combined with the grade and tonnage distributions from the deposit models to assess the total undiscovered metal endowment.

## 3.1 Deposit models

Deposit models designed for quantitative assessments are the cornerstone of the method. They are used to classify mineralised and barren environments, as well as types of known deposits, and to discriminate mineral deposits from mineral occurrences (Singer & Berger 2007). Deposit models that can be used in the three-part assessment method include descriptive models, grade-tonnage models, deposit density models, economic models and quantitative descriptive models. Descriptive models and grade-tonnage models are an essential component of the three-part method and they are used in all GTK assessments. Deposit density models, when available, can be used in the estimation of the number of undiscovered deposits for an area. Economic models and quantitative descriptive models have not been used in the GTK assessment project.

### 3.1.1 Descriptive models

A descriptive model consists of systematically arranged information describing all of the essential characteristics of a class of mineral deposits (Barton 1993). A descriptive model usually consists of two parts. The first part describes the geological environments in which the deposits occur. It contains information on favourable host rocks, possible source rocks, age ranges of mineralisation, the depositional environment, tectonic setting, and associated deposit types. This part of the descriptive model plays a crucial role in the delineation of permissive tracts, i.e., areas where the geology permits the occurrence of deposits of the type under consideration.

The second part of a descriptive model lists the essential identifying characteristics by which a given deposit type might be recognized. These include ore textures and structures, mineralogy, alteration, and geochemical and geophysical signatures. The second part of the model is used to classify known deposits and occurrences. Identifying the types of known deposits is important for the tract delineation process, and it can sometimes help to delineate geological environments not indicated on geological maps.

### 3.1.2 Grade-tonnage models

A grade-tonnage model consists of data on average metal grades and the associated total tonnage of well-studied and completely delineated deposits

of a certain type (Singer 1993, Singer & Menzie 2010). The total tonnage combines total past production and current resources (including reserves) at the lowest possible cut-off grade. Grade-tonnage models are usually presented as frequency distributions of tonnage and average metal grades. These distributions are used as models for grades and tonnages of undiscovered deposits of the same type in geologically similar settings. They also help in differentiating between a deposit and a mineral occurrence, and in judging whether a deposit or group of deposits belongs to the type represented by the model.

It is very important to use the same sampling unit criteria for all deposits in the grade-tonnage model. Mixing old production data from some deposits with resource data from other deposits is among the most common errors in the construction of grade-tonnage models and will produce biased models (Singer & Berger 2007). Spatial aspects of the sampling unit must also be considered. A spatial rule identifying the minimum distance between two separate deposits of a given type should be defined and deposits closer to each other than the minimum distance should be combined in the grade-tonnage model.

### 3.2 Permissive tracts

A permissive tract is an area within which the geology permits the existence of mineral deposits of the type under consideration (Singer 1993, Singer & Menzie 2010). It is important to distinguish between areas favourable for the existence of deposits and permissive tracts: the former are a subset of the latter. The existence of a permissive tract in an area does not indicate any favourability for the occurrence of deposits within the area; neither has it anything to do with the likelihood of discovery of existing undiscovered deposits in the area.

In the three-part assessment method, permissive tracts should be based on criteria derived from descriptive models. Tract boundaries should be defined so that the likelihood of deposits occurring outside of the tract is negligible. The boundaries of the tracts are first defined based on mapped or inferred geology. Tracts may or may not contain known deposits. The existence of deposits is used to confirm and extend the tracts, but the lack of known deposits is not a reason to exclude any part of a permissive area from the tract. Original tract boundaries should only be reduced where it can be firmly demonstrated that a deposit type could not exist. This evidence could be based on geology, knowledge of unsuccessful exploration, or the presence of barren overburden exceeding the predetermined delineation depth limit.

### 3.3 Estimation of the number of undiscovered deposits

The third part of the three-part assessment method is the estimation of the number of undiscovered deposits of the type(s) that may exist in the delineated tracts (Singer 1993, Singer & Menzie 2010). The estimates represent the probability that a certain fixed but unknown number of undiscovered deposits exist in the delineated tracts. The estimates are carried out according to deposit type and they must be consistent with the grade-tonnage models. This means that, for example, about half of the estimated undiscovered deposits should be larger than the median tonnage given by the grade-tonnage model and about 10 % of the estimated deposits should be larger than the upper $10^{th}$ quantile of the model. The spatial rule used to define a deposit in the grade-tonnage model must be respected in the estimates. Well-explored and completely delineated deposits, for which published grade and tonnage values exist, are considered as discovered deposits, whereas deposits without publicly available grade and tonnage information, partly delineated deposits, and known occurrences without reliable grade-tonnage estimates are counted as undiscovered.

Several methods can be used either directly or as guidelines to make the estimates. These include the frequency of deposits in well-explored geologically analogous areas (deposit density models), local deposit extrapolations, counting and assigning probabilities to geophysical and/or geochemical anomalies, process constraints, relative frequencies of associated deposit types, and limits set by the total available area or total known metal (Singer 2007). Some of these methods produce a single estimate of the expected number of deposits; others produce a probability distribution

of the expected number of deposits. In the latter case, the spread of the estimates for the number of deposits associated with high and low quantiles of the probability distribution (for example, the 90 % and 10 % quantiles) indicates the uncertainty of the estimate. The expected number of deposits, or the estimated number of deposits associated with a given probability level, measures the likelihood of the existence of a deposit type.

The estimates are typically made subjectively by a team of experts knowledgeable about the deposit type and the geology of the region. The process follows the Delphi technique (Chorlton et al. 2007), in which each expert makes an estimate independently and all the estimates are then discussed to possibly reach a final consensus estimate.

### 3.4 Statistical evaluation

The three parts of the assessment method described above produce consistent estimates of the number of undiscovered deposits for the delineated areas and of the probability distribution of grades and tonnages of the deposit type (Singer & Menzie 2010). As the final step of the assessment, these estimates are combined using statistical methods to achieve probability distributions of the quantities of contained metals and ore tonnages in the undiscovered deposits. Software using Monte Carlo simulation has been developed for this purpose (Root et al. 1992, Duval 2012).

## 4 ASSESSMENT OF Cu-Zn RESOURCES IN FINLAND

### 4.1 Resources covered by the assessment

This report contains the results of the assessment of undiscovered resources of copper and zinc in VMS-type, Outokumpu-type and porphyry-type deposits. The other deposit types listed in Chapter 2 were not included either because they are covered in other reports, they were considered insignificant for the copper-zinc endowment in Finland, or a grade-tonnage model could not be constructed due to the lack of reliable data.

### 4.2 GTK assessment process

The assessment process started with the selection of experts for the assessment team. As the work was conducted as a GTK internal project, only persons employed by GTK were assigned. Scientists from the northern, eastern and southern regional offices of GTK were included in the assessment team to ensure first-hand knowledge of all covered areas. The work started with a two-day workshop on 2–3 February 2010, at which the participants were introduced to the three-part assessment method. The types of known copper and zinc deposits in Finland and their characteristics were reviewed and deposit types to be included in the assessment were selected. Three types of deposits were included in the assessment: VMS deposits, Outokumpu-type deposits and porphyry copper deposits. Responsibilities for the delineation and documentation of initial permissive tracts and for reviewing the existing grade-tonnage data for the selected deposit types were assigned to the assessment team members.

After the workshop, the work continued with the delineation of preliminary permissive tracts, the preparation of tract description documents and the development of descriptive and grade-tonnage models for the deposit types. Grade-tonnage models were constructed for Finnish VMS deposits, Outokumpu-type deposits and porphyry copper deposits. The finalising of the permissive tracts and the estimation of the number of undiscovered deposits was carried out in a series of workshops in 2010–2013.

After the deposit models were finalised, Monte Carlo simulations were run to estimate the metal abundances in undiscovered deposits for each tract. Finally, the tract reports and other parts of the present report were combined.

## 4.3 Data used

The assessment team used geological maps in digital and paper format, databases of mineral deposits and occurrences, technical reports on deposits and occurrences, mining company websites, and published geological literature. The personal experience and knowledge of the assessment team members concerning the areas assessed was a valuable addition to the publically available information. All data used in the assessment work for any permissive tract are listed in the respective tract description document in Appendix 7.

### 4.3.1 Geology

The GTK in-house GIS map database of Finnish bedrock (Geological Survey of Finland 2010a) formed the main source of lithological data for this work. The multi-scale database covers the whole of Finland and is regularly updated. A version of the database at the 1:200,000 scale can be viewed at http://en.gtk.fi/informationservices/map_services. Detailed maps produced by exploration and research campaigns by various parties were also available for many areas.

### 4.3.2 Known mineral deposits and occurrences

The FINCOPPER database (Västi 2009), the FINZINC database (Eilu & Västi 2009), the Fennoscandian Ore Deposit Database (FODD 2012) and a recent report on mineral deposits and metallogenic belts in the Fennoscandian Shield (Eilu 2012) were the main sources of data for known zinc and copper deposits and occurrences in Finland and the Fennoscandian Shield. Where possible, the grade and tonnage data were checked and updated from company reports and publications. The GTK in-house GIS database of mineral occurrences in Finland was also used for information on known occurrences. Reports in GTK report databases, published literature on known deposits, prospects and occurrences, and mining company websites were used as additional sources of information on Finnish deposits and occurrences. For global data from outside of the Fennoscandian Shield, the recently published grade-tonnage data of Mosier et al. (2009) were used for VMS deposits and data published by Singer et al. (2005) and Sinclair (2007) were used for porphyry copper deposits.

### 4.3.3 Geophysical and geochemical data

Low-altitude airborne magnetic survey data of GTK (Hautaniemi et al. 2005) covering the whole of Finland were used in the delineation of permissive tracts. Gravimetric maps, based on data provided by the Finnish Geodetic Institute (Kääriäinen & Mäkinen 1997) or on regional gravity measurements by GTK where available (Elo 2003), were also occasionally utilised. The Rock Geochemical Database of Finland (Rasilainen et al. 2007) was occasionally used to verify rock types when delineating permissive tracts. The igneous rock age database of GTK (Geological Survey of Finland 2009) was used to check the ages of rock units.

### 4.3.4 Exploration history

The location of effective and recently expired claims as well as claim reports from GTK databases (Geological Survey of Finland 2010b, 2011a, b) were used to estimate exploration activities for copper and zinc in various areas in Finland. Internal GTK GIS maps of the coverage of geophysical measurements, geochemical sampling, and diamond drilling by GTK as well as Outokumpu Oy and other exploration companies, were used to estimate the intensity and coverage of exploration activities in permissive tracts. Information on exploration and mining company web sites were also examined for exploration data, and the assessment team members contributed personal knowledge of exploration activities.

## 4.4 Deposit models

### 4.4.1 Volcanogenic massive sulphide (VMS) deposits

Descriptive and grade-tonnage models developed especially for the three-part assessment method were recently published for VMS deposits (Mosier et al. 2009, Shanks & Thurston 2012). The existing descriptive model for VMS deposits (Shanks & Thurston 2012) was considered to adequately characterise the Finnish VMS deposits. A sum-

mary descriptive model for felsic, bimodal-mafic and mafic VMS deposits is given in Appendix 1.

An initial comparison of grade and tonnage data from Finnish VMS deposits with the global data (Mosier et al. 2009) indicated that local grade-tonnage models are required for the Finnish VMS deposits. Data sources used in updating the existing grade-tonnage data and gathering of new data for Fennoscandian VMS deposits are listed in chapter 4.3.2. Only deposits with a total ore tonnage exceeding 10,000 t were included in the collected dataset. A spatial rule was applied according to which deposits were combined into one if the distance between them was less than 500 m. This was done to assure comparability with the global models of Mosier et al. (2009). Well-known VMS deposits within the Fennoscandian Shield with representative grade-tonnage data were included in our dataset (Appendix 2) from Finland (20), Norway (38) and Sweden (76). These grade-tonnage data from Fennoscandian VMS deposits were compared with global data of Mosier et al. (2009), from which deposits within the Fennoscandian Shield had been excluded.

There are significant differences both in tonnage and metal grades between the felsic, bimodal-mafic and mafic subgroups in the global data (Mosier et al. 2009). To enable the comparison with global data, the Fennoscandian deposits were classified into felsic, bimodal-mafic and mafic types, based on the lithologies of the surrounding rocks within up to five kilometres away from the deposit. Missing (not reported) values in the metal grade data were estimated separately for the felsic, bimodal-mafic and mafic deposits using the robust ROS method (Helsel 2005) and assuming a log-normal distribution. A similar procedure was undertaken for the global data. The process of estimating the missing grade values was necessary to make the comparison between the Fennoscandian and global data possible. The grade values of lead, silver and gold are missing for a large proportion of the deposits, especially in the global dataset (Table 2). Without the estimation of missing value data, different proportions of missing values in the Fennoscandian and global datasets could bias the comparison between the datasets.

Comparison of the Fennoscandian data with the global data revealed the following differences, which are statistically significant at the one per cent level (Fig. 13, Table 2):

1. The Fennoscandian deposits have smaller tonnages for the felsic and bimodal-mafic types;
2. The Fennoscandian deposits have lower copper grades for the felsic type;
3. The Fennoscandian deposits have higher zinc grades for the mafic type;
4. The Fennoscandian deposits have higher lead grades for the mafic type;
5. The Fennoscandian deposits have lower gold grades for the bimodal-mafic type;
6. The Fennoscandian deposits have lower silver grades for the bimodal-mafic type and higher silver grades for the mafic type.

Analysis of variance tests on the means of ore tonnages and metal grades for the Fennoscandian data indicate that the following differences between the deposit types are significant at the one per cent level (Appendix 2):

1. The felsic type has lower copper grades than both the bimodal-mafic and mafic types;
2. The mafic type has lower zinc grades than both the bimodal-mafic and felsic types;
3. The felsic type has higher lead grades than both the bimodal-mafic and mafic types;
4. The felsic type has higher gold grades than both the bimodal-mafic and mafic types;
5. The felsic type has higher silver grades than both the bimodal-mafic and mafic types.

Some differences also exist between deposits of different ages, but the small number of Precambrian mafic and bimodal-mafic deposits in the Fennoscandian dataset makes these comparisons uncertain (Appendix 2).

Final grade-tonnage models were created for the Fennoscandian felsic, bimodal-mafic and mafic deposit types. The models are summarised in Table 2 and explained in greater detail in Appendix 2.

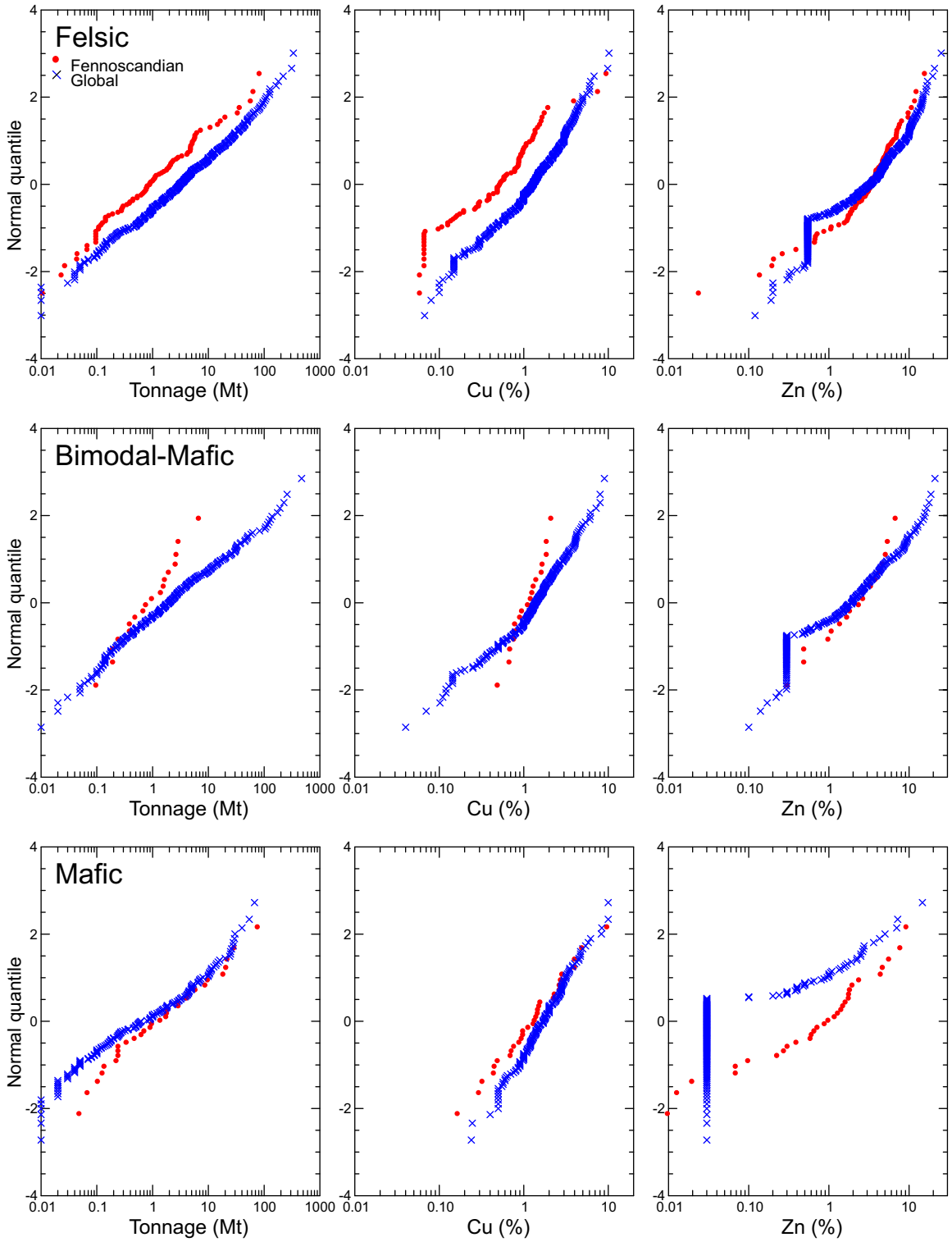


Fig.13. Normal probability plots of tonnage and metal grades for the Fennoscandian and global VMS deposits.

Table 2. Summary statistics for the Fennoscandian and global VMS deposit data sets.

| **Fennoscandian felsic subclas** | | | | | | | **Global felsic subclas** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tonnage (Mt) | Cu (%) | Zn (%) | Pb (%) | Au (g/t) | Ag (g/t) | | Tonnage (Mt) | Cu (%) | Zn (%) | Pb (%) | Au (g/t) | Ag (g/t) |
| N of cases | 85 | 76 | 85 | 65 | 62 | 72 | N of cases | 383 | 373 | 314 | 246 | 243 | 264 |
| 90% | 0.100 | 0.075 | 0.69 | 0.023 | 0.056 | 4.3 | 90% | 0.178 | 0.30 | 0.48 | 0.041 | 0.028 | 1.7 |
| 50% | 0.930 | 0.54 | 3.5 | 0.36 | 0.30 | 27 | 50% | 3.100 | 1.3 | 3.3 | 0.50 | 0.40 | 24 |
| 10% | 11.205 | 1.5 | 7.6 | 3.5 | 1.4 | 100 | 10% | 39.284 | 3.3 | 10 | 3.3 | 2.6 | 130 |
| Mean | 5.520 | 0.86 | 4.0 | 1.2 | 0.66 | 43 | Mean | 14.637 | 1.6 | 4.4 | 1.2 | 1.3 | 48 |
| St dev | 14.051 | 1.4 | 3.0 | 2.9 | 1.1 | 48 | St dev | 34.610 | 1.4 | 4.2 | 1.9 | 3.0 | 66 |
| T-S t-T p | 0.000 | 0.000 | 0.644 | 0.092 | 0.562 | 0.040 | | | | | | | |

| **Fennoscandian bimodal-mafic subclas** | | | | | | | Global bimodal-mafic subclas | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tonnage (Mt) | Cu (%) | Zn (%) | Pb (%) | Au (g/t) | Ag (g/t) | | Tonnage (Mt) | Cu (%) | Zn (%) | Pb (%) | Au (g/t) | Ag (g/t) |
| N of cases | 18 | 18 | 18 | 8 | 7 | 5 | N of cases | 232 | 227 | 185 | 63 | 150 | 162 |
| 90% | 0.200 | 0.69 | 0.65 | 0.0018 | 0.059 | 0.51 | 90% | 0.140 | 0.34 | 0.25 | 0.00016 | 0.035 | 1.1 |
| 50% | 0.890 | 1.2 | 2.6 | 0.027 | 0.18 | 3.1 | 50% | 1.965 | 1.4 | 1.9 | 0.0087 | 0.41 | 14 |
| 10% | 2.925 | 1.8 | 5.4 | 0.75 | 0.71 | 20 | 10% | 32.150 | 3.9 | 8.7 | 0.82 | 2.7 | 73 |
| Mean | 1.477 | 1.2 | 2.8 | 0.17 | 0.27 | 8.2 | Mean | 15.304 | 1.8 | 3.2 | 0.30 | 0.99 | 34 |
| St dev | 1.651 | 0.49 | 2.0 | 0.30 | 0.24 | 13 | St dev | 45.680 | 1.5 | 3.8 | 1.0 | 1.4 | 72 |
| T-S t-T p | 0.007 | 0.407 | 0.432 | 0.057 | 0.008 | 0.003 | | | | | | | |

| **Fennoscandian mafic subclas** | | | | | | | **Global mafic subclas** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tonnage (Mt) | Cu (%) | Zn (%) | Pb (%) | Au (g/t) | Ag (g/t) | | Tonnage (Mt) | Cu (%) | Zn (%) | Pb (%) | Au (g/t) | Ag (g/t) |
| N of cases | 31 | 30 | 30 | 11 | 11 | 16 | N of cases | 155 | 154 | 46 | 7 | 65 | 64 |
| 90% | 0.121 | 0.40 | 0.050 | 0.00022 | 0.0063 | 1.2 | 90% | 0.030 | 0.62 | 0.0041 | 8E-14 | 0.0025 | 0.14 |
| 50% | 1.415 | 1.4 | 1.0 | 0.0052 | 0.037 | 3.8 | 50% | 0.620 | 1.7 | 0.071 | 0.0000000035 | 0.059 | 1.8 |
| 10% | 21.821 | 4.1 | 5.1 | 0.24 | 0.23 | 18 | 10% | 13.600 | 3.8 | 1.6 | 0.000055 | 1.8 | 31 |
| Mean | 7.221 | 1.9 | 1.8 | 0.054 | 0.088 | 7.5 | Mean | 4.670 | 2.1 | 0.58 | 0.073 | 0.70 | 15 |
| St dev | 15.376 | 1.9 | 2.3 | 0.11 | 0.13 | 7.3 | St dev | 9.684 | 1.6 | 1.6 | 0.58 | 1.8 | 65 |
| T-S t-T p | 0.093 | 0.072 | 0.000 | 0.000 | 0.031 | 0.001 | | | | | | | |

N of cases: Number of available data values; 90 %, 50 %, 10 %: Percentile values; Mean: Arithmetic mean; St dev: Standard deviation; T-S t-T p: p-value for the two-sample t-test for equality of two means. The statistical tests are calculated using logatithmic values. Tonnages are rounded to full thousands and grades to two significant digits. When the number of available data values is smaller than the one shown for tonnage, the mean, standard deviation and percentiles for Cu, Zn, Pb, Au and Ag are estimated using the robust ROS method (Helsel 2005) assuming a log-normal distribution. The T-S t-T statistic is calculated using data where missing metal grade values were first replaced by the median of the ROS-estimated missing values.

### 4.4.2 Porphyry copper deposits

Descriptive and grade-tonnage models especially developed for the three-part assessment method have been published for porphyry copper deposits (Singer et al. 2002, 2005, 2008, John et al. 2010). The existing descriptive model for porphyry copper deposits (John et al. 2010) was considered to adequately characterise the Finnish deposits. A summary descriptive model is given in Appedix 3.

Only five well-known porphyry copper deposits are located in the Fennoscandian Shield. Initial comparison of these Precambrian deposits to the global data indicated that a model for Precambrian porphyry copper deposits might be needed. Grade and tonnage data for Precambrian and younger porphyry copper deposits were gathered from the databases of Singer et al. (2005), Sinclair (2007) and FODD (2012). Only deposits with no missing data for tonnage and copper grade were accepted. A spatial rule was applied, according to which deposits less than 2000 m from each other were combined. This was done to ensure comparability with the global model of Singer et al. (2005). Altogether, the constructed dataset contains 489 deposits with age information. Of these, the majority are Cenozoic (266) or Mesozoic (142), and only 27 deposits are Precambrian.

Statistical testing revealed that the ore tonnage and metal grade data for the Precambrian deposits do not differ significantly from log normality. For the younger deposits, only molybdenum grade data are approximately log-normally distributed (Table 3). The Precambrian porphyry copper deposits have a smaller average tonnage and copper grade and higher average molybdenum and gold grades compared to the Phanerozoic porphyry copper deposits in the dataset (Fig. 14, Table 3). Non-parametric statistical tests indicated that the differences in tonnage and copper grade are significant at the one per cent level, whereas a parametric test suggested a marginal significance. The

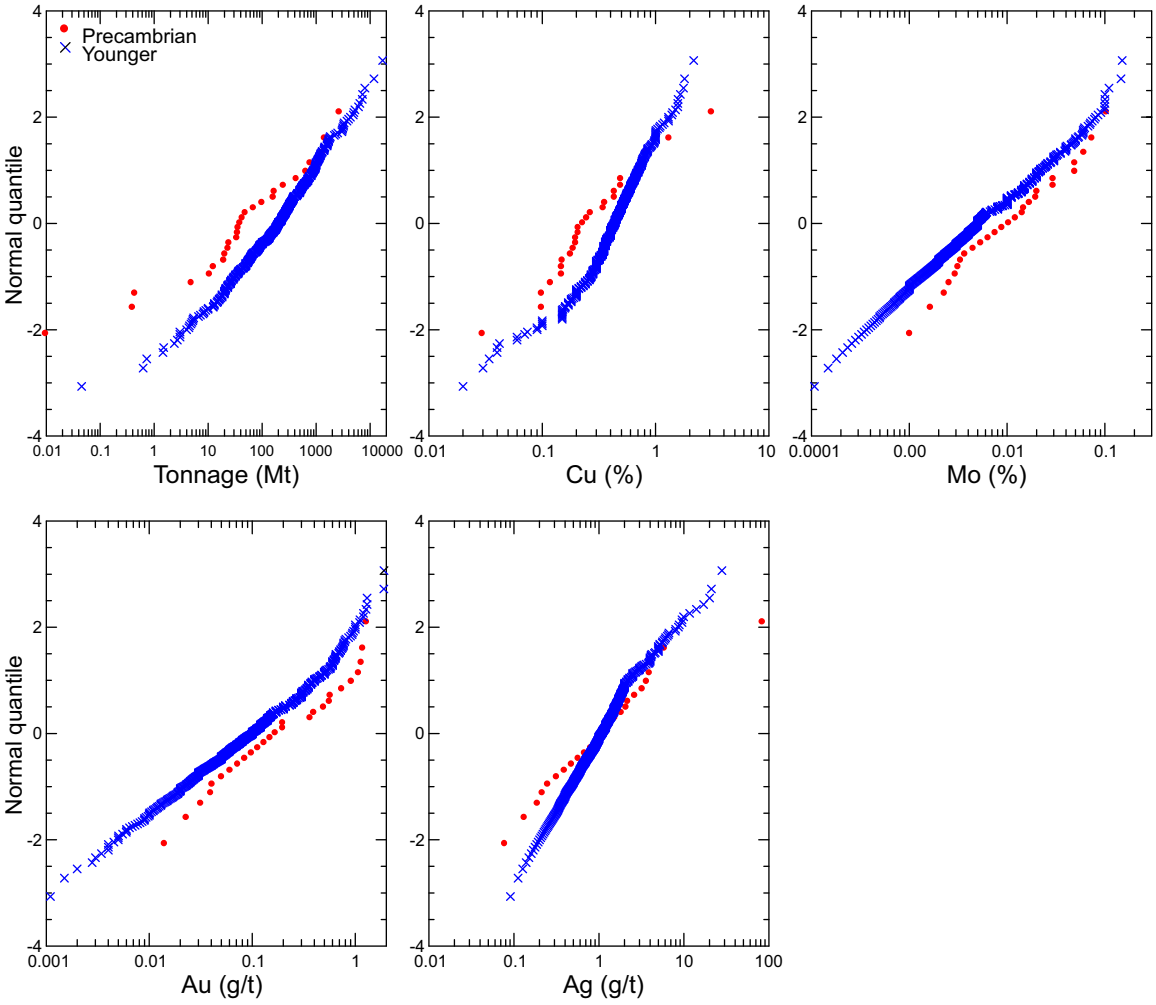


Fig. 14. Normal probability plots of tonnage and metal grades for the Precambrian and Phanerozoic porphyry copper deposits.

Table 3. Summary statistics for the Precambrian and younger porphyry copper deposit data sets.

| **Precambrian deposits** | | | | | |
|---|---|---|---|---|---|
| | Tonnage (Mt) | Cu (%) | Mo (%) | Au (g/t) | Ag (g/t) |
| N of cases | 27 | 27 | 12 | 15 | 8 |
| 90% | 1.4 | 0.10 | 0.0024 | 0.034 | 0.20 |
| 50% | 40 | 0.23 | 0.011 | 0.17 | 1.1 |
| 10% | 1,200 | 0.82 | 0.060 | 1.1 | 4.1 |
| Mean | 320 | 0.45 | 0.021 | 0.38 | 4.7 |
| St dev | 630 | 0.61 | 0.026 | 0.42 | 16 |
| S-W p | 0.025 | 0.498 | 0.765 | 0.250 | 0.261 |
| **Phanerozoic deposits** | | | | | |
| | Tonnage (Mt) | Cu (%) | Mo (%) | Au (g/t) | Ag (g/t) |
| N of cases | 462 | 462 | 237 | 262 | 161 |
| 90% | 20 | 0.20 | 0.00094 | 0.014 | 0.41 |
| 50% | 200 | 0.43 | 0.0050 | 0.10 | 1.2 |
| 10% | 1,200 | 0.80 | 0.032 | 0.60 | 3.3 |
| Mean | 580 | 0.49 | 0.013 | 0.21 | 1.8 |
| St dev | 1,400 | 0.28 | 0.020 | 0.27 | 2.5 |
| S-W p | 0.000 | 0.000 | 0.176 | 0.001 | 0.000 |
| T-S t p | 0.014 | 0.039 | 0.014 | 0.011 | 0.818 |
| K-W p | 0.003 | 0.002 | 0.019 | 0.019 | 0.759 |

N of cases: Number of available data values; 90 %, 50 %, 10 %: Percentile values; Mean: Arithmetic mean; St dev: Standard deviation; S-W p: Shapiro-Wilk normality test p-value; T-S t p: Two-sample t-test p-value for comparison of means between the Precambrian and Phanerozoic data sets; K-W p: Kruskal-Wallis nonparametric test p-value for comparison between the Precambrian and Phanerozoic data sets. The statistical tests are calculated using logatithmic values. Tonnage and grade statistics are rounded to two significant digits. The mean, standard deviation and percentiles for Mo, Ag and Au are estimated using the robust ROS method (Helsel 2005) assuming a log-normal distribution.

differences in molybdenum and gold grades are marginally significant according to both parametric and non-parametric tests. These results are taken to indicate real differences between the Precambrian and younger porphyry copper deposits, and only Precambrian deposits were consequently included in the grade-tonnage model to be used in the assessment of Finnish undiscovered porphyry copper deposits.

Based on Au and Cu grades, porphyry copper deposits can be classified into three categories: Cu-Au (Au/Mo ≥ 30), Cu-Mo (Au/Mo ≤ 3) and Cu (3 < Au/Mo < 30), where Au is gold grade in g/t and Mo is molybdenum grade in weight % (Cox & Singer 1992). The Precambrian grade-tonnage model includes 12 Cu-Au deposits, 8 Cu-Mo deposits and 7 Cu deposits. Analysis of variance tests indicated that the three deposit types (Cu, Cu-Au, Cu-Mo) do not differ significantly in tonnage or copper grade. They are expected to differ in Mo and Au, but there are insufficient Mo and Au values to quantify the differences. Hence, no Precambrian porphyry copper grade-tonnage submodels were constructed.

The final Precambrian grade-tonnage model is summarised in Table 3 and explained in greater detail in Appendix 4.

### 4.4.3 Outokumpu-type Cu-Zn-Co deposits

No previously published grade-tonnage model exists for Outokumpu-type deposits. Close analogies for the Outokumpu-type deposits are very uncommon (Peltonen et al. 2008), and no deposits outside of the Outokumpu area have been classified with certainty as being of the Outokumpu type. Hence, only data from well-known deposits in the Outokumpu area were available for the construction of a grade-tonnage model. A descriptive model was created based on recently updated ideas concerning the genesis of the deposit type (Kontinen et al. 2006, Peltonen et al. 2008). The descriptive model is provided in Appendix 5.

The grade-tonnage model for Outokumpu-type

Table 4. Summary statistics for Outokumpu-type deposits.

| | Tonnage (Mt) | Cu (%) | Zn (%) | Co (%) | Ni (%) |
|---|---|---|---|---|---|
| N of cases | 10 | 10 | 10 | 10 | 10 |
| Minimum | 0.2 | 0.44 | 0.09 | 0.04 | 0.03 |
| Maximum | 31.66 | 3.46 | 1.89 | 0.24 | 0.2 |
| Mean | 6.0 | 1.3 | 0.74 | 0.13 | 0.13 |
| St Dev | 9.6 | 0.97 | 0.59 | 0.065 | 0.057 |
| 10% | 0.27 | 0.47 | 0.095 | 0.055 | 0.04 |
| 50% | 2.4 | 0.96 | 0.64 | 0.13 | 0.15 |
| 90% | 20 | 2.8 | 1.6 | 0.24 | 0.19 |
| S-W p | 0.623 | 0.505 | 0.051 | 0.733 | 0.023 |

N of cases: Number of available data values; Mean – Arithmetic mean; St dev – Standard deviation; 90 %, 50 %; 10 % – Percentile values; S-W p – Shapiro-Wilk normality test p-value (calculated for logatithmic values). The mean, standard deviation and percentiles are rounded to two significant digits.

Cu-Zn-Co deposits contains data from 10 Outokumpu-type 1.95–1.91 Ga deposits in the Outokumpu area in Finland. A spatial rule was applied, according to which deposits less than 500 m from each other have been combined. Four of the deposits have been mined in the past; at present, only the Kylylahti mine is in operation. The remaining six deposits in the model have not been developed into mines.

The Outokumpu-type grade-tonnage model is summarised in Table 4 and explained in greater detail in Appendix 6.

### 4.5 Tract delineation

Permissive tracts were delineated separately for the VMS deposits, porphyry copper deposits and Outokumpu-type Cu-Zn-Co deposits (Fig. 15, Table 5), based on the information described in section 4.3. For each area, the member or members of the assessment team most familiar with the geology and Cu-Zn mineralisation of the region drew the tracts. On a map, a permissive tract is a projection to the surface of the domain where geology allows the existence of the deposit type assessed. The permissive volumes of rock were delineated down to the depth of one kilometre, unless there was clear evidence (typically from drilling or geophysical data) that the permissive rock unit terminates at a shallower depth. In the latter cases, the permissive domain was delineated down to the estimated or known depth of the permissive rock unit.

Maps of the individual permissive tracts, criteria for their delineation and information on known deposits and occurrences as well as exploration performed are given in the tract reports in Appendix 7.

### 4.6 Estimation of the number of undiscovered deposits

The number of undiscovered Cu-Zn deposits of each type was estimated separately for each permissive tract in a series of workshops by the members of the assessment team and a few other GTK experts. The names of the estimators for each permissive tract are provided in the tract reports in Appendix 7. Each estimator independently assessed the number of undiscovered deposits at the 90 %, 50 % and 10 % probability levels. These initial figures were provided for discussion, during which the participants explained and sometimes adjusted their estimates. The purpose of the discussion was to determine whether a consensus estimate could be reached. When a consensus was not reached, the averages of the estimates at each probability level were used as the final estimates at the 90 %, 50 % and 10 % probability levels. Published deposit density models for VMS deposits (Mosier et al. 2007) and porphyry copper deposits (Singer & Menzie 2010) were used as guidelines in the estimation.

Table 5. Permissive tracts for VMS, porphyry copper and Outokumpu-type deposits in Finland.

| Map number | Tract name | Tract type | Tract area (km²) | N of known deposits |
|---|---|---|---|---|
| 1 | Hyvinkää | VMS mafic | 1,172 | 0 |
| 2 | Jurva | VMS mafic | 758 | 0 |
| 3 | Leteensuo | VMS bimodal-mafic | 690 | 0 |
| 4 | Orijärvi | VMS felsic | 57 | 4 |
| 5 | Salo-Issakka | VMS mafic | 1,323 | 1 |
| 6 | Tampere | VMS bimodal-mafic | 2,818 | 0 |
| 7 | Tupala-Kiipu | VMS felsic | 843 | 0 |
| 8 | Uusimaa-E | VMS felsic | 3,061 | 1 |
| 9 | Uusimaa-N | VMS felsic | 1,436 | 0 |
| 10 | Uusimaa-W | VMS felsic | 3,163 | 1 |
| 11 | Ala-Luoma | VMS felsic | 257 | 0 |
| 12 | Hammaslahti | VMS mafic | 1,847 | 0 |
| 13 | Otravaara | VMS bimodal-mafic | 1,262 | 0 |
| 14 | Pyhäsalmi | VMS felsic | 1,981 | 6 |
| 15 | Rauhala | VMS bimodal-mafic | 3,477 | 1 |
| 16 | Taivaljärvi | VMS felsic | 678 | 0 |
| 17 | Upper Svecofennian | VMS bimodal-mafic | 2,224 | 0 |
| 18 | Vihanti | VMS felsic | 5,226 | 4 |
| 19 | Virtasalmi | VMS mafic | 1,483 | 1 |
| 20 | Haukipudas | VMS mafic | 2,262 | 0 |
| 21 | Jauratsi | VMS bimodal-mafic | 392 | 0 |
| 22 | Kiimavaara | VMS bimodal-mafic | 84 | 0 |
| 23 | Kiimavuoma | VMS mafic | 641 | 0 |
| 24 | Kilpisjärvi | VMS mafic | 105 | 0 |
| 25 | Mauru | VMS felsic | 84 | 0 |
| 26 | Misi | VMS mafic | 119 | 0 |
| 27 | Oijärvi | VMS mafic | 172 | 0 |
| 28 | Pahtavuoma | VMS mafic | 605 | 1 |
| 29 | Pulju | VMS mafic | 623 | 0 |
| 30 | Sattasvaara | VMS mafic | 1,176 | 0 |
| 31 | Vesmajärvi | VMS mafic | 1,575 | 0 |
| 32 | Southern Ostrobothnia | PorCu | 2,321 | 0 |
| 33 | Häme | PorCu | 4,720 | 0 |
| 34 | Central Finland | PorCu | 3,861 | 0 |
| 35 | Mäntsälä | PorCu | 1,737 | 0 |
| 36 | Ruokolahti | PorCu | 806 | 0 |
| 37 | Tampere | PorCu | 5,023 | 0 |
| 38 | Southern Savo | PorCu | 603 | 0 |
| 39 | Central Ostrobothnia | PorCu | 11,157 | 1 |
| 40 | Haaparanta | PorCu | 6,184 | 0 |
| 41 | Nilipää | PorCu | 2,035 | 0 |
| 42 | Outokumpu | Outokumpu | 9,824 | 10 |

Map number: Number of tract in Figure 15; N of known deposits: Number of known VMS-, porphyry copper- or Outokumpu-type deposits within the tract.

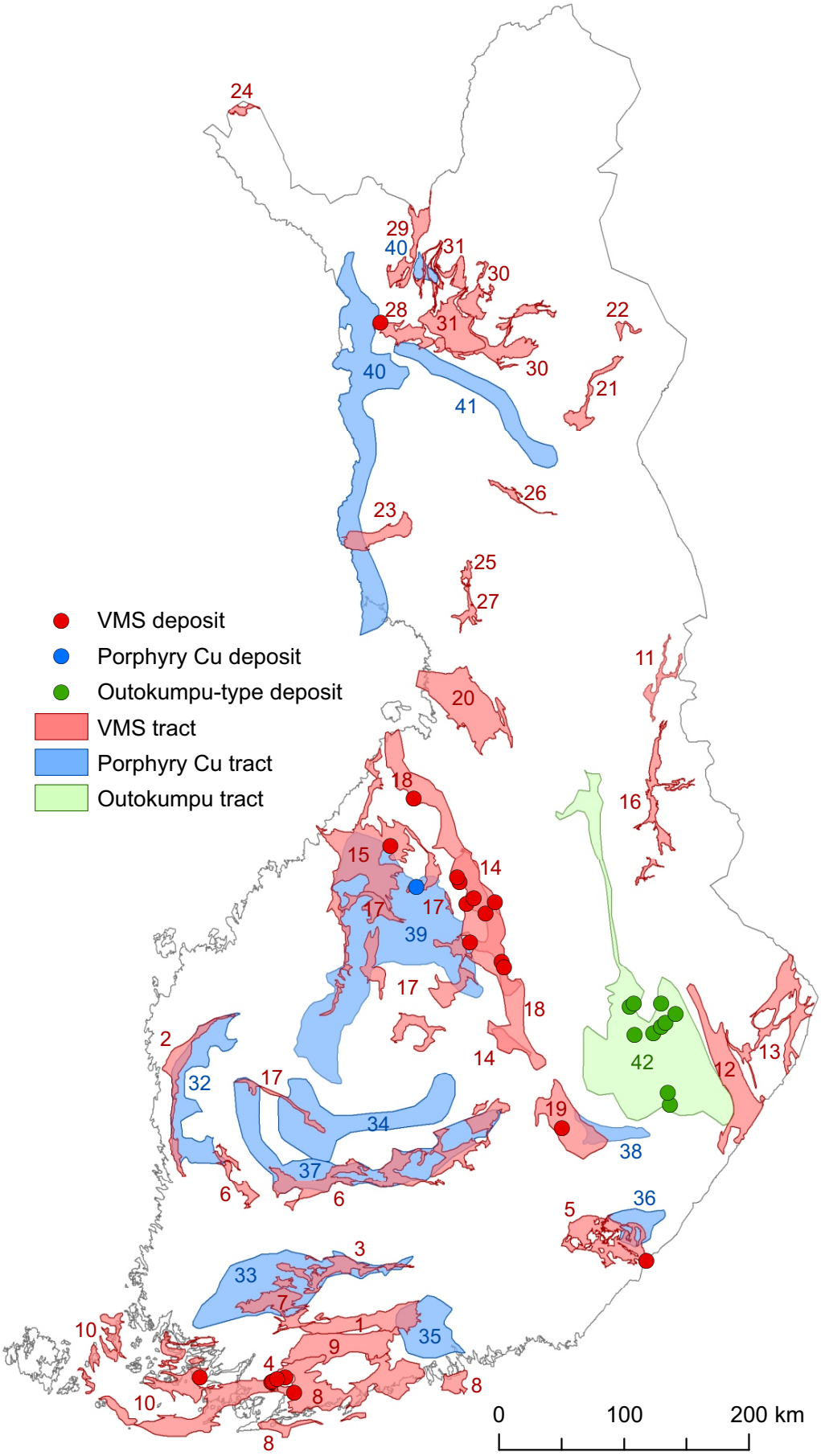


Fig. 15. Location of permissive tracts and known deposits for the VMS, porphyry copper and Outokumpu types in Finland. The numbers refer to Table 5.

According to the three-part method, incompletely known deposits and occurrences are considered as undiscovered. The estimators assess the probability that an incompletely known deposit might with further exploration become a deposit with a potential for economically viable mining. However, the well-known deposits that are included in the grade-tonnage model are by definition assumed to be totally delineated and without any remaining unknown resources. This means that the possibly existing hidden resources in the well-known deposits are not considered and remain outside of the assessment.

### 4.7 Assessment of metal tonnages

The assessment of metal tonnages in the undiscovered deposits was performed using Eminers software (Root et al. 1992, Duval 2012). The software uses as input the data from the grade-tonnage model and the estimated numbers of undiscovered deposits at the 90 %, 50 % and 10 % probability levels. The software estimates an average non-parametric frequency distribution for the number of undiscovered deposits within a tract. It also estimates empirical and log-normal frequency distributions for the ore tonnage and metal grades in the grade-tonnage model. It then uses these estimated frequency distributions in Monte Carlo simulation and calculates frequency distributions of ore and metal tonnages in the undiscovered deposits.

Since the ore tonnages and metal grades in the grade-tonnage models for the VMS-, porphyry copper- and Outokumpu-type deposits do not always follow a log-normal distribution, the estimated empirical distributions were used in the simulations for the Finnish Cu-Zn deposits. This also prohibits the very large estimated metal tonnages that sometimes result from using a log-normal model. The empirical distributions are restricted between 1.5 times the maximum value and 0.5 times the minimum value in the model data.

The assessment of metal tonnages in the undiscovered deposits was performed separately for each permissive tract. It is not statistically correct to add together the frequency distributions of ore and metal tonnages produced for the tracts. Hence, total metal endowments for all undiscovered VMS deposits, porphyry copper deposits and Outokumpu-type deposits were estimated in separate simulation runs.

## 5 RESULTS AND DISCUSSION

The results of the Cu-Zn assessment are summarised in Figures 15–19 and in Tables 5–8. The results for individual permissive tracts are provided in Appendix 7.

The results of the Monte Carlo runs are simulated frequency distributions of ore and metal tonnages in the undiscovered deposits. These distributions combine the amount of undiscovered metal and the probability that this amount exists (Fig. 16). Details of this information for each permissive tract are presented in Appendix 7, where cumulative frequency distributions of undiscovered metal and ore tonnages are plotted and tonnages corresponding to several probability values are tabulated. The arithmetic mean value of the frequency distribution for a metal can be considered as the expected amount of undiscovered metal. Since the frequency distributions of metal grades and ore tonnages in the grade-tonnage models are skewed and usually closer to a log-normal than a normal distribution, the probabilities associated with the expected (mean) amounts of undiscovered metals and ore are less than 50 %, generally 20–40 % for aggregated results and often even less for individual permissive tracts. On the other hand, there is a 50 % probability that at least the amount of metal given by the median of the simulated frequency distribution (the value associated with the 50 % quantile) exists. This is why we prefer to report the median estimate of undiscovered metal and ore in Tables 6 and 7, in which the results for individual permissive tracts are summarised. Table 8, which aggregates the total undiscovered metal endowment over a number of permissive tracts, gives several quantile values to better characterise the frequency distributions of undiscovered metal

tonnages. In the following, median estimates, i.e., values corresponding to the 50 % quantile of the cumulative frequency distribution, are used when discussing the amounts of undiscovered metals.

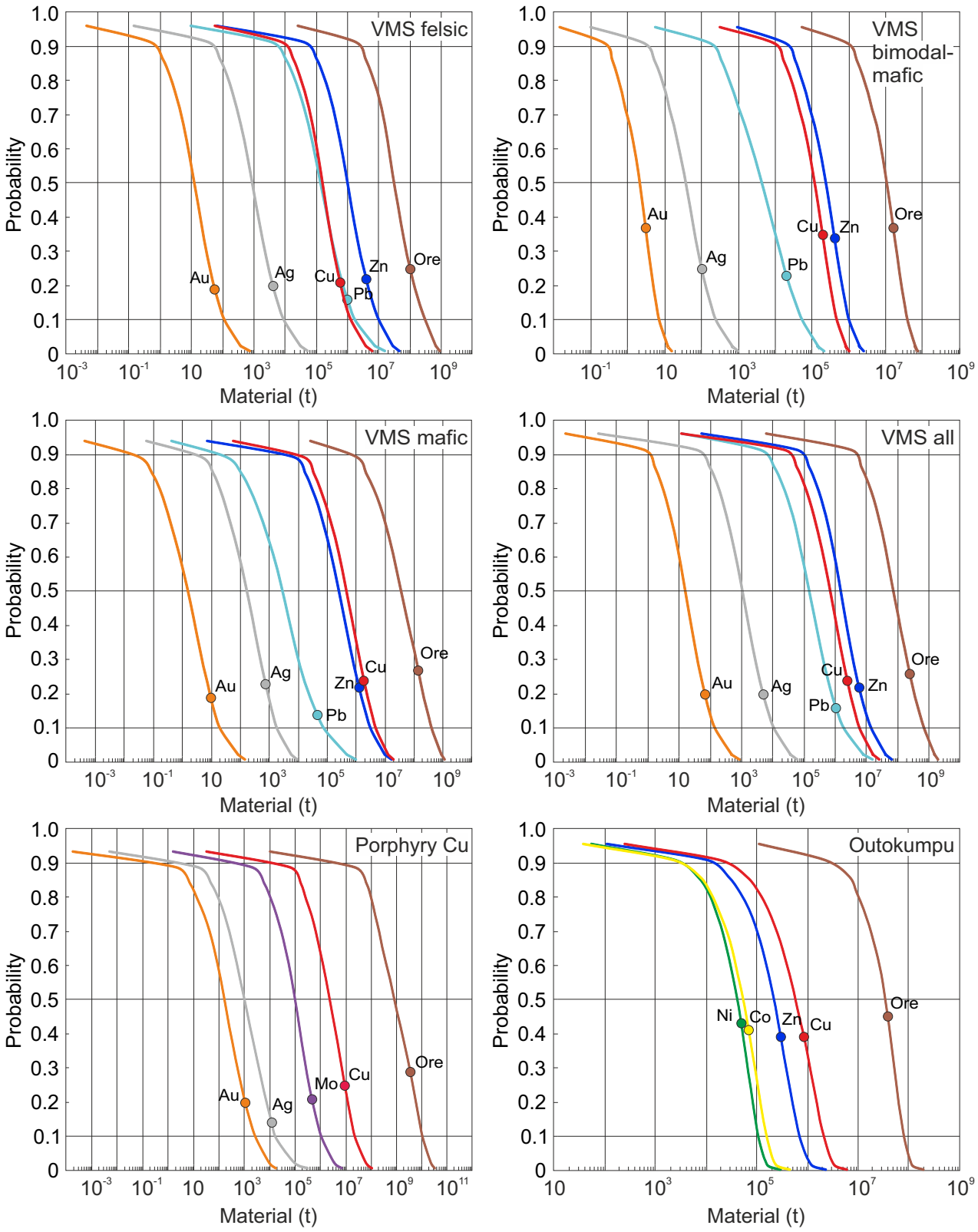


Fig. 16. Summary frequency distributions of simulated undiscovered resources in VMS, porphyry copper and Outokumpu-type deposits. Labelled dots indicate mean values.

### 5.1 Permissive tracts delineated

In total, 31 permissive tracts were delineated for VMS deposits, 10 tracts for porphyry copper deposits and one tract for Outokumpu-type deposits (Fig. 15, Tables 5–7, Appendix 7). These tracts contain all the known VMS, porphyry copper and Outokumpu-type deposits and significant occurrences in Finland. The VMS tracts cover approximately 41,600 km$^2$, the porphyry copper tracts approximately 38,400 km$^2$ and the Outokumpu-type tract approximately 9800 km$^2$. The total area of all the tracts is approximately 90,000 km$^2$, but due to substantial overlap of the VMS and porphyry copper tracts, the combined tracts cover 80,000 km$^2$, which is 24 % of the total land area of Finland.

### 5.2 Undiscovered resources in VMS deposits, Outokumpu-type deposits and porphyry copper deposits

There are 20 well-known VMS deposits, 10 well-known Outokumpu-type deposits and only one well-known porphyry copper deposit in Finland (Tables 6 and 7). According to our assessment, the mean estimate of the number of undiscovered VMS deposits within the topmost one kilometre of the bedrock in Finland is 45 deposits, of which 18 belong to the felsic type, 10 to the bimodal-mafic type and 17 to the mafic type (Table 6). For the Outokumpu type, the figure is 6 deposits and for the porphyry copper type, 11 deposits (Table 7).

The median estimated undiscovered resources in VMS deposits are 730,000 t Cu, 1.6 Mt Zn, 150,000 t Pb, 1100 t Ag and 16 t Au (Table 8). For copper, the largest part of the undiscovered resources resides in mafic-type deposits, whereas for zinc, lead, silver and gold, the majority are in felsic-type deposits. In comparison, the remaining resources in well-known VMS deposits at the end of 2012 were 341,000 t Cu, 745,000 t Zn, 122,000 t Pb, 1100 t Ag and 14 t Au (Table 9). The majority of these are in felsic-type deposits.

The median estimated undiscovered resources in porphyry copper deposits are 2.4 Mt Cu, 100,000 t Mo, 1000 t Ag and 170 t Au (Table 8). The metal resources of the only well-known porphyry copper deposit in Finland (Kopsa) are 45,000 t Cu, 100 t Ag and 14 t Au (Table 9). The deposit has not been mined.

The median undiscovered resources in Outokumpu-type deposits are 580,000 t Cu, 220,000 t Zn, 53,000 t Co and 41,000 t Ni (Table 8). In comparison, the well-known Outokumpu-type resources at the end of 2012 were 197,000 t Cu, 114,000 t Zn, 30,000 t Co and 37,000 t Ni (Table 9).

Comparison of the well-known and estimated undiscovered resources (at 50 % probability) of copper and zinc for VMS and Outokumpu-type deposits within the topmost one kilometre of the Finnish bedrock indicate that at least 71 % of the total copper resources and 68 % of the total zinc resources in these deposit types are in poorly explored and undiscovered deposits (Table 9). In the case of porphyry copper deposits, the assessment results indicate that more than 98 % of the total metal resources are in poorly explored and undiscovered deposits.

The area covered by the VMS permissive tracts varies from 57 km$^2$ of the Orijärvi felsic VMS tract to 5226 km$^2$ of the Vihanti felsic VMS tract (Table 6). The median size of a VMS tract varies from 965 km$^2$ for mafic tracts to 1262 km$^2$ for bimodal-mafic tracts, and the median deposit density varies from 1.4 deposits per 1000 km$^2$ for bimodal-mafic tracts to 2.0 deposits per 1000 km$^2$ for felsic tracts. In contrast to the VMS permissive tracts, the porphyry copper tracts range from 603 km$^2$ (Southern Savo tract) to 11,157 km$^2$ (Central Ostrobothnia tract) and have a median area of 3091 km$^2$ (Table 7). The median deposit density for porphyry copper tracts is 0.28 deposits per 1000 km$^2$. The only Outokumpu-type permissive tract delineated is rather large in comparison with the VMS and porphyry copper tracts. It covers an area of 9824 km$^2$ and has a deposit density of 1.6 deposits per 1000 km$^2$.

The larger area of the Outokumpu permissive tract as compared to the VMS tracts is due to the fact that the borders of the Outokumpu tract are largely based on the extent of the Outokumpu Allochthon, and the tract has not been divided into subareas. The VMS tracts are based on the extent of individual volcanic belts, which are usually more restricted in size. The larger size of the porphyry copper permissive tracts on average compared to the VMS tracts is also probably due to the

Table 6. Summary of principal results for VMS-type permissive tracts in Finland.

| Tract name | Type | Estimated number of undiscovered deposits | | | | | | Known resources (t) | | | | | | | Median undiscovered resources (t) | | | | | | Total de-posits | Tract area (km²) | Deposit density |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 90 | 50 | 10 | E | Std | Cv | N | Cu | Zn | Pb | Au | Ag | Ore | Cu | Zn | Pb | Au | Ag | Ore | | | |
| Ala-Luoma | Felsic VMS | 0 | 0 | 1 | 0.30 | 0.50 | 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.30 | 257 | 0.0012 |
| Mauru | Felsic VMS | 0 | 0 | 1 | 0.30 | 0.50 | 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.30 | 84 | 0.0036 |
| Orijärvi | Felsic VMS | 1 | 1 | 2 | 1.2 | 0.55 | 45 | 4 | 29,709 | 87,088 | 20,687 | 3.1 | 89 | 3,292,000 | 6,600 | 40,000 | 4,300 | 0.43 | 32 | 1,300,000 | 5.2 | 57 | 0.091 |
| Pyhäsalmi | Felsic VMS | 2 | 4 | 7 | 4.2 | 1.9 | 46 | 6 | 617,819 | 1,528,376 | 124 | 27.5 | 952 | 71,467,000 | 51,000 | 340,000 | 47,000 | 4.1 | 300 | 10,000,000 | 10.2 | 1,981 | 0.0051 |
| Taivaljärvi | Felsic VMS | 1 | 2 | 3 | 1.9 | 0.84 | 43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14,000 | 93,000 | 11,000 | 1.1 | 75 | 2,900,000 | 1.9 | 678 | 0.0029 |
| Tupala-Kiipu | Felsic VMS | 1 | 2 | 3 | 1.9 | 0.84 | 43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14,000 | 89,000 | 11,000 | 1.1 | 75 | 2,900,000 | 1.9 | 843 | 0.0023 |
| Uusimaa-E | Felsic VMS | 1 | 2 | 3 | 1.9 | 0.84 | 43 | 1 | 248 | 630 | 368 | 0 | 3 | 46,000 | 15,000 | 93,000 | 11,000 | 1.1 | 78 | 2,900,000 | 2.9 | 3,061 | 0.00096 |
| Uusimaa-N | Felsic VMS | 0 | 0 | 1 | 0.30 | 0.50 | 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.30 | 1,436 | 0.00021 |
| Uusimaa-W | Felsic VMS | 1 | 1 | 3 | 1.5 | 0.93 | 61 | 1 | 6,912 | 76,032 | 45,360 | 0 | 186 | 4,320,000 | 8,400 | 53,000 | 5,700 | 0.60 | 42 | 1,800,000 | 2.5 | 3,163 | 0.0008 |
| Vihanti | Felsic VMS | 2 | 4 | 7 | 4.2 | 1.9 | 46 | 4 | 217,504 | 1,642,655 | 155,150 | 20.2 | 1,079 | 44,476,000 | 52,000 | 340,000 | 48,000 | 4.2 | 300 | 10,000,000 | 8.2 | 5,226 | 0.0016 |
| Total felsic | | | | | 17.7 | | | 16 | 872,192 | 3,334,781 | 221,689 | 50.8 | 2,309 | 123,601,000 | 161,000 | 1,048,000 | 138,000 | 12.63 | 902 | 31,800,000 | 33.7 | 16,786 | |
| Jauratsi | Bimodal-Mafic VMS | 0 | 1 | 1 | 0.70 | 0.41 | 58 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4,100 | 9,000 | 86 | 0.11 | 1.3 | 400,000 | 0.70 | 392 | 0.0018 |
| Kiimavaara | Bimodal-Mafic VMS | 0 | 0 | 1 | 0.30 | 0.50 | 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.30 | 84 | 0.0036 |
| Leteensuo | Bimodal-Mafic VMS | 0 | 1 | 2 | 1.0 | 0.79 | 79 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7,900 | 15,000 | 160 | 0.17 | 2.6 | 710,000 | 1.0 | 690 | 0.0014 |
| Otravaara | Bimodal-Mafic VMS | 1 | 2 | 4 | 2.2 | 1.2 | 54 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30,000 | 59,000 | 1,200 | 0.54 | 10 | 2,700,000 | 2.2 | 1,262 | 0.0018 |
| Rauhala | Bimodal-Mafic VMS | 0 | 1 | 3 | 1.3 | 1.2 | 90 | 1 | 22,610 | 81,430 | 16,320 | 0.68 | 90 | 1,700,000 | 9,900 | 20,000 | 210 | 0.22 | 3.2 | 920,000 | 2.3 | 3,477 | 0.00066 |
| Tampere | Bimodal-Mafic VMS | 2 | 3 | 4 | 2.9 | 0.88 | 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 44,000 | 89,000 | 2,200 | 0.75 | 15 | 3,800,000 | 2.9 | 2,818 | 0.001 |
| Upper Svecofennian | Bimodal-Mafic VMS | 0 | 2 | 3 | 1.7 | 1.1 | 63 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21,000 | 41,000 | 560 | 0.39 | 6.4 | 1,900,000 | 1.7 | 2,224 | 0.00076 |
| Total bimodal-mafic | | | | | 10.1 | | | 1 | 22,610 | 81,430 | 16,320 | 0.68 | 90 | 1,700,000 | 116,900 | 233,000 | 4,416 | 2.18 | 38.5 | 10,430,000 | 11.1 | 10,947 | |
| Hammaslahti | Mafic VMS | 1 | 2 | 2 | 1.6 | 0.46 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 44,000 | 27,000 | 310 | 0.15 | 17 | 3,500,000 | 1.6 | 1,847 | 0.00088 |
| Haukipudas | Mafic VMS | 0 | 1 | 2 | 1.0 | 0.79 | 79 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12,000 | 5,900 | 45 | 0.034 | 4.0 | 840,000 | 1.0 | 2,262 | 0.00044 |
| Hyvinkää | Mafic VMS | 0 | 0 | 1 | 0.30 | 0.50 | 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.30 | 1,172 | 0.00026 |
| Jurva | Mafic VMS | 0 | 2 | 3 | 1.7 | 1.1 | 63 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39,000 | 23,000 | 240 | 0.13 | 14 | 3,000,000 | 1.7 | 758 | 0.0022 |
| Kiimavuoma | Mafic VMS | 0 | 1 | 2 | 1.0 | 0.79 | 79 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9,900 | 5,400 | 40 | 0.029 | 3.4 | 710,000 | 1.0 | 641 | 0.0016 |
| Kilpisjärvi | Mafic VMS | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 105 | 0 |
| Misi | Mafic VMS | 0 | 1 | 2 | 1.0 | 0.79 | 79 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10,000 | 6,000 | 39 | 0.032 | 3.6 | 740,000 | 1.0 | 119 | 0.0084 |
| Oijärvi | Mafic VMS | 0 | 0 | 1 | 0.30 | 0.50 | 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.30 | 172 | 0.0017 |
| Pahtavuoma | Mafic VMS | 1 | 3 | 4 | 2.6 | 1.1 | 43 | 1 | 64,200 | 143,380 | 17,120 | 0 | 214 | 21,400,000 | 100,000 | 60,000 | 710 | 0.37 | 40 | 8,500,000 | 3.6 | 605 | 0.006 |
| Pulju | Mafic VMS | 0 | 0 | 1 | 0.30 | 0.50 | 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.30 | 623 | 0.00048 |
| Salo-Issakka | Mafic VMS | 0 | 1 | 2 | 1.0 | 0.79 | 79 | 1 | 5,940 | 29,520 | 0 | 0 | 25 | 1,800,000 | 10,000 | 6,000 | 42 | 0.032 | 3.6 | 720,000 | 2.0 | 1,323 | 0.0015 |
| Sattasvaara | Mafic VMS | 1 | 2 | 4 | 2.2 | 1.2 | 54 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 77,000 | 45,000 | 510 | 0.28 | 30 | 5,900,000 | 2.2 | 1,176 | 0.0019 |
| Vesmajärvi | Mafic VMS | 1 | 2 | 4 | 2.2 | 1.2 | 54 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 74,000 | 41,000 | 490 | 0.27 | 29 | 5,600,000 | 2.2 | 1,575 | 0.0014 |
| Virtasalmi | Mafic VMS | 1 | 2 | 4 | 2.2 | 1.2 | 54 | 1 | 32,604 | 0 | 0 | 0.42 | 0 | 4,180,000 | 71,000 | 41,000 | 480 | 0.26 | 28 | 5,500,000 | 3.2 | 1,483 | 0.0022 |
| Total mafic | | | | | 17.4 | | | 3 | 102,744 | 172,900 | 17,120 | 0.42 | 239 | 27,380,000 | 446,900 | 260,300 | 2,906 | 1.587 | 172.6 | 35,010,000 | 20.4 | 13,861 | |
| Grand total | | | | | 45.2 | | | 20 | 997,546 | 3,589,111 | 255,129 | 51.9 | 2,638 | 152,681,000 | 724,800 | 1,541,300 | 145,322 | 16.397 | 1113.1 | 77,240,000 | 65.2 | 41,594 | |

90, 50, 10: Estimated number of undiscovered deposits associated with the 90 %, 50 % and 10 % quantiles; E: Expected number (mean estimate) of undiscovered deposits; Std: Standard deviation; Cv: Coefficient of variation (%); N: Number of known deposits within the permissive tract; Ore: Mineralized rock containing the metals; Median estimated undiscovered resources: The minimum amount of metals present within the permissive tract at the probability of 50 %, rounded to two significant digits; Total deposits: Sum of the number of known deposits and expected number of undiscovered deposits within the tract; Deposit density: Total number of deposits within the tract divided by tract area, rounded to two significant digits; Total felsic, bimodal-mafic, mafic: Sum across felsic, bimodal-mafic and mafic tracts, respectively; Grand total: Sum across all tracts. E and Std are calculated using a regression equation (Singer & Menzie 2005). Known resources consist of resources remaining at the end of 2012 and previously mined resources. Although it is not statistically strictly correct to sum the median estimates for individual tracts, the resulting totals are very close to the values obtained by including all the tracts in one simulation (Table 8).

Table 7. Summary of principal results for porphyry copper- and Outokumpu-type permissive tracts in Finland.

| Tract name | Type | Estimated number of undiscovered deposits | | | | | | Known resources (t) | | | | | | Median undiscovered resources (t) | | | | | Total deposits | Tract area (km²) | Deposit density |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 90 | 50 | 10 | E | Std | Cv | N | Cu | Mo | Au | Ag | Ore | Cu | Mo | Au | Ag | Ore | | | |
| Central Finland | Porphyry Cu | 0 | 1 | 2 | 1.0 | 0.79 | 79 | 0 | 0 | 0 | 0 | 0 | 0 | 93,000 | 3,800 | 5.0 | 33 | 34,000,000 | 1.0 | 3,861 | 0.00026 |
| Central Ostrobothnia | Porphyry Cu | 1 | 2 | 4 | 2.2 | 1.2 | 54 | 1 | 45,000 | 0 | 14 | 100 | 25,000,000 | 670,000 | 27,000 | 46 | 290 | 230,000,000 | 3.2 | 11,157 | 0.00029 |
| Haaparanta | Porphyry Cu | 0 | 2 | 3 | 1.7 | 1.1 | 63 | 0 | 0 | 0 | 0 | 0 | 0 | 340,000 | 16,000 | 27 | 150 | 110,000,000 | 1.7 | 6,184 | 0.00027 |
| Häme | Porphyry Cu | 1 | 2 | 4 | 2.2 | 1.2 | 54 | 0 | 0 | 0 | 0 | 0 | 0 | 630,000 | 27,000 | 43 | 280 | 220,000,000 | 2.2 | 4,720 | 0.00047 |
| Mäntsälä | Porphyry Cu | 0 | 0 | 1 | 0.30 | 0.50 | 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.30 | 1,737 | 0.00017 |
| Nilipää | Porphyry Cu | 0 | 0 | 1 | 0.30 | 0.50 | 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.30 | 2,035 | 0.00015 |
| Ruokolahti | Porphyry Cu | 0 | 0 | 1 | 0.30 | 0.50 | 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.30 | 806 | 0.00037 |
| Southern Ostrobothnia | Porphyry Cu | 0 | 0 | 1 | 0.30 | 0.50 | 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.30 | 2,321 | 0.00013 |
| Southern Savo | Porphyry Cu | 0 | 0 | 1 | 0.30 | 0.50 | 170 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.30 | 603 | 0.0005 |
| Tampere | Porphyry Cu | 1 | 2 | 4 | 2.2 | 1.2 | 54 | 0 | 0 | 0 | 0 | 0 | 0 | 660,000 | 29,000 | 47 | 280 | 240,000,000 | 2.2 | 5,023 | 0.00044 |
| Total porphyry Cu | | | | | 10.8 | | | 1 | 45,000 | 0 | 14 | 100 | 25,000,000 | 2,393,000 | 102,800 | 168 | 1,033 | 834,000,000 | 10.8 | 38,447 | |
| **Tract name** | **Type** | **Estimated number of undiscovered deposits** | | | | | | **Known resources (t)** | | | | | | **Median undiscovered resources (t)** | | | | | **Total deposits** | **Tract area (km²)** | **Deposit density** |
| | | 90 | 50 | 10 | E | Std | Cv | N | Cu | Zn | Co | Ni | Ore | Cu | Zn | Co | Ni | Ore | | | |
| Outokumpu | Outokumpu | 2 | 6 | 10 | 5.9 | 2.9 | 49 | 10 | 1,486,298 | 536,644 | 117,616 | 84,252 | 60,380,000 | 580,000 | 220,000 | 53,000 | 41,000 | 33,000,000 | 16 | 9824 | 0.0016 |

90, 50, 10: Estimated number of undiscovered deposits associated with the 90 %, 50 % and 10 % quantiles; E: Expected number (mean estimate) of undiscovered deposits; Std: Standard deviation; Cv: Coefficient of variation (%); N: Number of known deposits within the permissive tract; Ore: Mineralized rock containing the metals; Median estimated undiscovered resources: The minimum amount of metals present within the permissive tract at the probability of 50 %, rounded to two significant digits; Total deposits: Sum of the number of known deposits and expected number of undiscovered deposits within the tract; Deposit density: Total number of deposits within the tract divided by tract area, rounded to two significant digits; Total porphyry Cu: Sum across all porphyry Cu tracts. E and Std are calculated using a regression equation (Singer & Menzie 2005). Known resources consist of resources remaining at the end of 2012 and previously mined resources. Known resources are rounded to two significant digits for Au, full tonnes for the other metals and full thousands of tonnes for ore. Although it is not statistically strictly correct to sum the median estimates for individual tracts, the resulting totals are very close to the values obtained by including all the tracts in one simulation (Table 8).

Table 8. Summary of the estimated amounts of metal and ore in undiscovered VMS, porphyry copper and Outokumpu-type deposits in Finland.

| **VMS felsic** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of** | |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | Mean or greater | None |
| Cu (t) | 1,200 | 11,000 | 160,000 | 1,300,000 | 2,500,000 | 580,000 | 0.21 | 0.04 |
| Zn (t) | 7,000 | 59,000 | 1,100,000 | 11,000,000 | 19,000,000 | 4,100,000 | 0.22 | 0.04 |
| Pb (t) | 550 | 5,200 | 140,000 | 1,800,000 | 3,700,000 | 1,000,000 | 0.16 | 0.04 |
| Au (t) | 0.087 | 0.67 | 13 | 120 | 220 | 55 | 0.19 | 0.04 |
| Ag (t) | 4.5 | 47 | 900 | 9,400 | 18,000 | 4,100 | 0.20 | 0.04 |
| Ore (Mt) | 0.29 | 2.4 | 31 | 310 | 500 | 100 | 0.25 | 0.04 |

| **VMS bimodal-mafic** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of** | |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | Mean or greater | None |
| Cu (t) | 2,000 | 11,000 | 120,000 | 470,000 | 640,000 | 190,000 | 0.35 | 0.04 |
| Zn (t) | 4,300 | 22,000 | 230,000 | 990,000 | 1,400,000 | 400,000 | 0.34 | 0.04 |
| Pb (t) | 29 | 200 | 4,300 | 55,000 | 93,000 | 20,000 | 0.23 | 0.04 |
| Au (t) | 0.057 | 0.27 | 2.2 | 7.3 | 9.5 | 3.1 | 0.37 | 0.04 |
| Ag (t) | 0.63 | 3.3 | 38 | 250 | 430 | 100 | 0.25 | 0.04 |
| Ore (Mt) | 0.22 | 1.0 | 10 | 38 | 49 | 16 | 0.37 | 0.04 |

| **VMS mafic** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of** | |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | Mean or greater | None |
| Cu (t) | 0 | 13,000 | 450,000 | 4,700,000 | 7,900,000 | 1,800,000 | 0.24 | 0.06 |
| Zn (t) | 0 | 6,100 | 260,000 | 3,200,000 | 5,900,000 | 1,300,000 | 0.22 | 0.06 |
| Pb (t) | 0 | 29 | 2,900 | 77,000 | 200,000 | 47,000 | 0.14 | 0.06 |
| Au (t) | 0 | 0.028 | 1.6 | 20 | 42 | 9.4 | 0.19 | 0.06 |
| Ag (t) | 0 | 3.8 | 170 | 1,900 | 3,500 | 750 | 0.23 | 0.06 |
| Ore (Mt) | 0 | 0.90 | 35 | 400 | 640 | 130 | 0.27 | 0.06 |

| **VMS all** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of** | |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | Mean or greater | None |
| Cu (t) | 4,200 | 35,000 | 730,000 | 6,400,000 | 11,000,000 | 2,500,000 | 0.24 | 0.04 |
| Zn (t) | 14,000 | 88,000 | 1,600,000 | 15,000,000 | 27,000,000 | 5,800,000 | 0.22 | 0.04 |
| Pb (t) | 750 | 6,000 | 150,000 | 1,900,000 | 4,000,000 | 1,000,000 | 0.16 | 0.04 |
| Au (t) | 0.19 | 1.1 | 16 | 150 | 280 | 68 | 0.20 | 0.04 |
| Ag (t) | 8.0 | 56 | 1,100 | 12,000 | 23,000 | 5,000 | 0.20 | 0.04 |
| Ore (Mt) | 0.65 | 4.4 | 76 | 750 | 1,200 | 250 | 0.26 | 0.04 |

| **Porphyry Cu** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of** | |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | Mean or greater | None |
| Cu (t) | 0 | 35,000 | 2,400,000 | 24,000,000 | 39,000,000 | 9,300,000 | 0.25 | 0.07 |
| Mo (t) | 0 | 1,300 | 100,000 | 1,100,000 | 2,100,000 | 460,000 | 0.21 | 0.07 |
| Au (t) | 0 | 1.3 | 170 | 2,700 | 5,400 | 1,100 | 0.20 | 0.07 |
| Ag (t) | 0 | 9.9 | 1,000 | 17,000 | 37,000 | 12,000 | 0.14 | 0.07 |
| Ore (Mt) | 0 | 11 | 830 | 11,000 | 16,000 | 3,600 | 0.29 | 0.07 |

| **Outokumpu** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of** | |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | Mean or greater | None |
| Cu (t) | 1,200 | 24,000 | 580,000 | 2,100,000 | 2,600,000 | 860,000 | 0.39 | 0.05 |
| Zn (t) | 800 | 13,000 | 220,000 | 700,000 | 900,000 | 300,000 | 0.39 | 0.05 |
| Co (t) | 170 | 2,900 | 53,000 | 150,000 | 190,000 | 68,000 | 0.41 | 0.05 |
| Ni (t) | 230 | 3,000 | 41,000 | 100,000 | 130,000 | 49,000 | 0.43 | 0.05 |
| Ore (Mt) | 0.27 | 2.7 | 33 | 77 | 92 | 37 | 0.45 | 0.05 |

Ore: Mineralised rock containing the metals. The estimated amounts of metal and ore are rounded to two significant digits.

Table 9.Well-known resources, cumulative production and median estimated undiscovered resources of copper and zinc for selected deposit types in Finland.

| | **Well-known resources** | | **Cumulative production** | | **Median undiscovered resources** | | **Present endowment** | |
|---|---|---|---|---|---|---|---|---|
| Deposit type | Cu (t) | Zn (t) | Cu (t) | Zn (t) | Cu (t) | Zn (t) | Cu (t) | Zn (t) |
| VMS | 341,000 | 745,000 | 637,000 | 2,830,000 | 730,000 | 1,600,000 | 1,071,000 | 2,345,000 |
| Outokumpu | 197,000 | 114,000 | 1,161,000 | 334,000 | 580,000 | 220,000 | 777,000 | 334,000 |
| Porphyry Cu | 45,000 | - | 0 | - | 2,400,000 | - | 2,445,000 | 0 |
| Layered intrusions | 430,000 | - | 0 | - | 5,700,000 | - | 6,130,000 | 0 |
| Orogenic intrusive Ni-Cu | 68,000 | - | 121,000 | - | 200,000 | - | 268,000 | 0 |
| Komatiitic Ni-Cu | 8,000 | - | 23 | - | 59,000 | - | 67,000 | 0 |
| Talvivaara | 2,669,000 | 10,264,000 | 52 | 86,000 | - | - | 2,669,000 | 10,264,000 |
| Kevitsa | 1,099,000 | - | 8,000 | - | - | - | 1,099,000 | 0 |
| Total | 4,857,000 | 11,123,000 | 1,927,075 | 3,250,000 | 9,669,000 | 1,820,000 | 14,526,000 | 12,943,000 |

- : Not present in significant amounts, not assessed; Present endowment: Well-known resources + median undiscovered resources. Well-known resources and cumulative production as of the end of 2012. Data sources: Puustinen (2003) and those listed in Appendices 2, 4 and 6 and in and Rasilainen et al. (2010a, 2012). For mines operated after 2001, company reports and news releases were used. Well-known resources and cumulative production larger than 1000 are rounded to full thousands, and median undiscovered resources are rounded to two significant digits. Talvivaara and Kevitsa resources are indentified resources.

different delineation criteria. The porphyry copper tracts are defined largely based on the existence of early to synorogenic ~1.89–1.88 Ga granitoid rocks within orogenic belts, which is a less restrictive criterion than the extent of individual volcanic belts.

The known VMS-type deposits are concentrated in two areas: the Vihanti-Pyhäsalmi belt containing the Vihanti and Pyhäsalmi VMS permissive tracts in central Finland and the Orijärvi-Aijala-Attu belt containing the Orijärvi and Uusimaa West VMS tracts in southernmost Finland (Fig. 15). Twenty-one of the 30 permissive VMS tracts contain no well-known deposits. The majority (61 %) of the well-known VMS copper-zinc resources are located within the Pyhäsalmi and Vihanti tracts; the Pahtavuoma and Rauhala tracts contain 19 % and 10 % of the well-known resources, respectively (Table 6, Fig. 17). Most of the well-known lead resources in VMS deposits (73 %) are within the Vihanti and Uusimaa West VMS tracts. In addition, the Rauhala and Pahtavuoma tracts each contain 13 % of the well-known lead resources (Fig. 18). Of the well-known VMS-type copper-zinc resources, 68 % are in felsic deposits, 10 % in bimodal-mafic and 22 % in mafic deposits. Seventy-three per cent of the well-known lead resources are in felsic VMS deposits, 13 % in bimodal-mafic and 13 % in mafic deposits.

Compared with the well-known resources, the undiscovered VMS resources are estimated to be more evenly distributed between the permissive tracts. The Pyhäsalmi and Vihanti tracts have the highest median estimates of undiscovered resources, 0.39 Mt combined copper and zinc each, but eight other tracts also have median estimated resources of more than 100,000 t of combined copper and zinc (Table 6, Fig. 17). The undiscovered lead resources are strongly concentrated in felsic-type deposits in southern and central Finland (Fig. 18). The Vihanti and Pyhäsalmi tracts are estimated to contain 65 % of the undiscovered lead resources in VMS deposits. Fifty-three per cent of the undiscovered copper-zinc resources are estimated to be in felsic deposits, 15 % in bimodal-mafic and 31 % in mafic deposits. Felsic deposits are estimated to contain 95 % of the total undiscovered VMS-related lead resources.

Only one Outokumpu-type permissive tract was delineated in Finland, and all the known Outokumpu-type deposits are located in the southern part of the tract (Fig. 15). However, our estimate does not imply the location of the possible undiscovered resources within the tract.

The only well-known porphyry copper deposit in Finland is located in the Central Ostrobothnia permissive tract, and the undiscovered porphyry copper resources are estimated to be concentrated in the Central Ostrobothnia, Tampere, Häme and Haaparanta permissive tracts (Table 7, Figs. 15 and 19). According to the median estimate, 86 % of all the undiscovered porphyry copper resources are located in central and southern Finland.

There were three mines in Finland producing copper (Kevitsa, Kylylahti, Pyhäsalmi) and three producing zinc (Kylylahti, Pyhäsalmi, Talvivaara) in 2012, and total mine production was 25,000 t of copper and 52,000 t of zinc (Pokki et al. 2014). In comparison, total smelter and refinery production was 129,000 t of copper and 315,000 t of zinc (Pokki 2013). This suggests that the raw material was imported for 81 % of the copper and 83 % of the zinc produced by Finnish smelters and refineries in 2012.

Considering known resources, this state of affairs is likely to remain unchanged for both of these metals at least during the 2010s. Annual copper production from the presently operating Finnish mines in the next few years is likely to grow to about 40,000 t of copper due to increasing production mostly in Kevitsa and Kylylahti (First Quantum Minerals Ltd. 2014, Altona Mining Limited 2014). On the other hand, forward-looking statements of mining companies indicate that zinc production from Finnish mines in the next few years will diminish somewhat to about 40,000 t of zinc per annum (First Quantum Minerals Ltd. 2014, Talvivaara Mining Company Plc 2014). However, this is strongly dependent on the developments with Talvivaara. If the company manages to overcome its problems, annual zinc production from Finnish mines might return to the 2012 level of around 50,000 t, but in case of mine suspension, the production would probably decrease to less than half of the 2012 level.

There are presently at least three projects that might eventually lead to opening a new copper-producing mine in Finland: Hannukainen, Suhanko and Sakatti. The estimated copper production from Hannukainen and Suhanko is approximately 33,000 t of copper annually (Pöyry Finland Oy 2013, Risto et al. 2013). The Sakatti project is at too early a stage for production estimates. No promising significant zinc mine

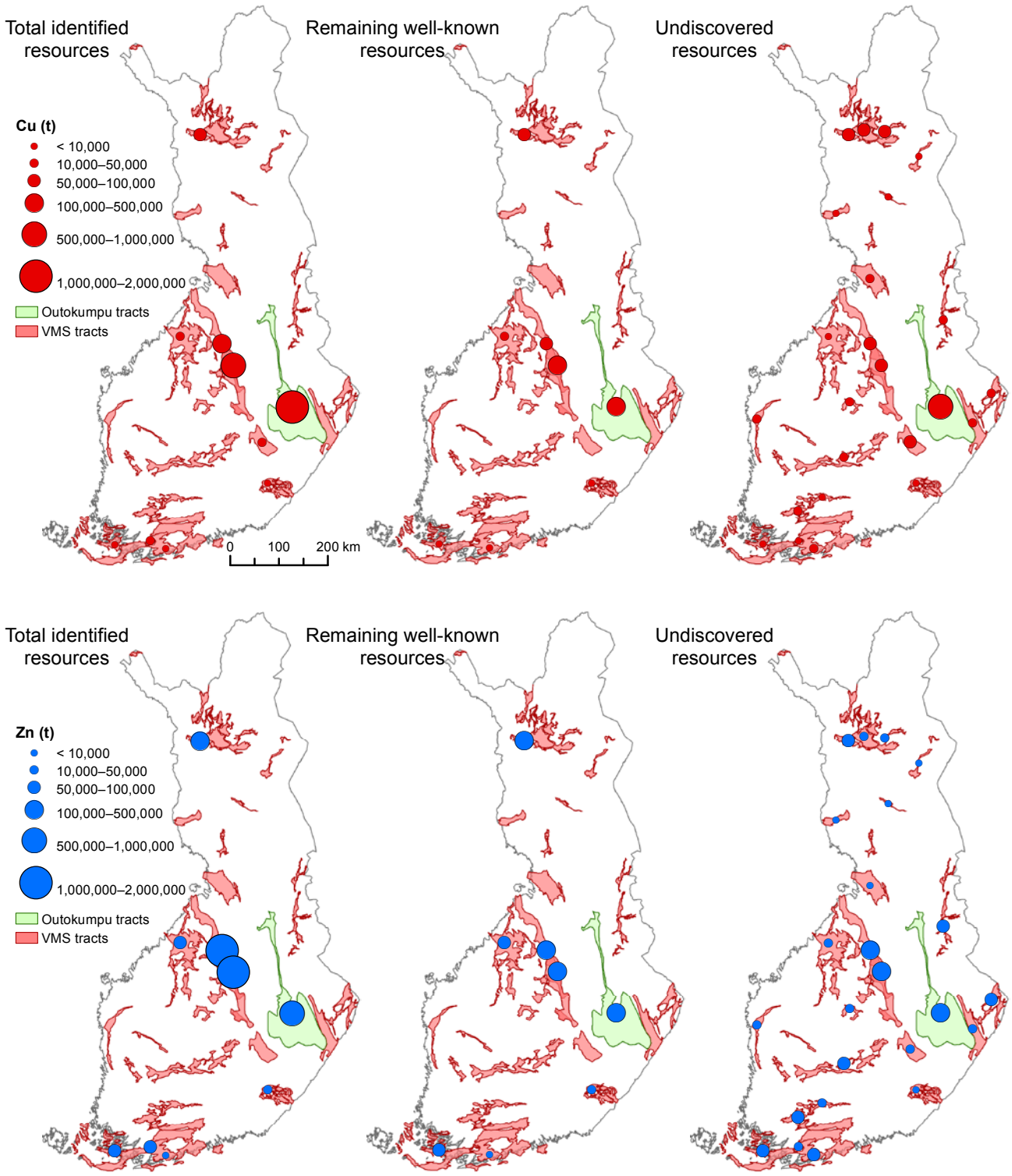


Fig. 17. Geographic distribution of total identified, well-known and estimated undiscovered copper and zinc resources of VMS and Outokumpu types in Finland. The total identified resources include well-known resources plus cumulative production. The undiscovered resources are estimated at 50 % probability.

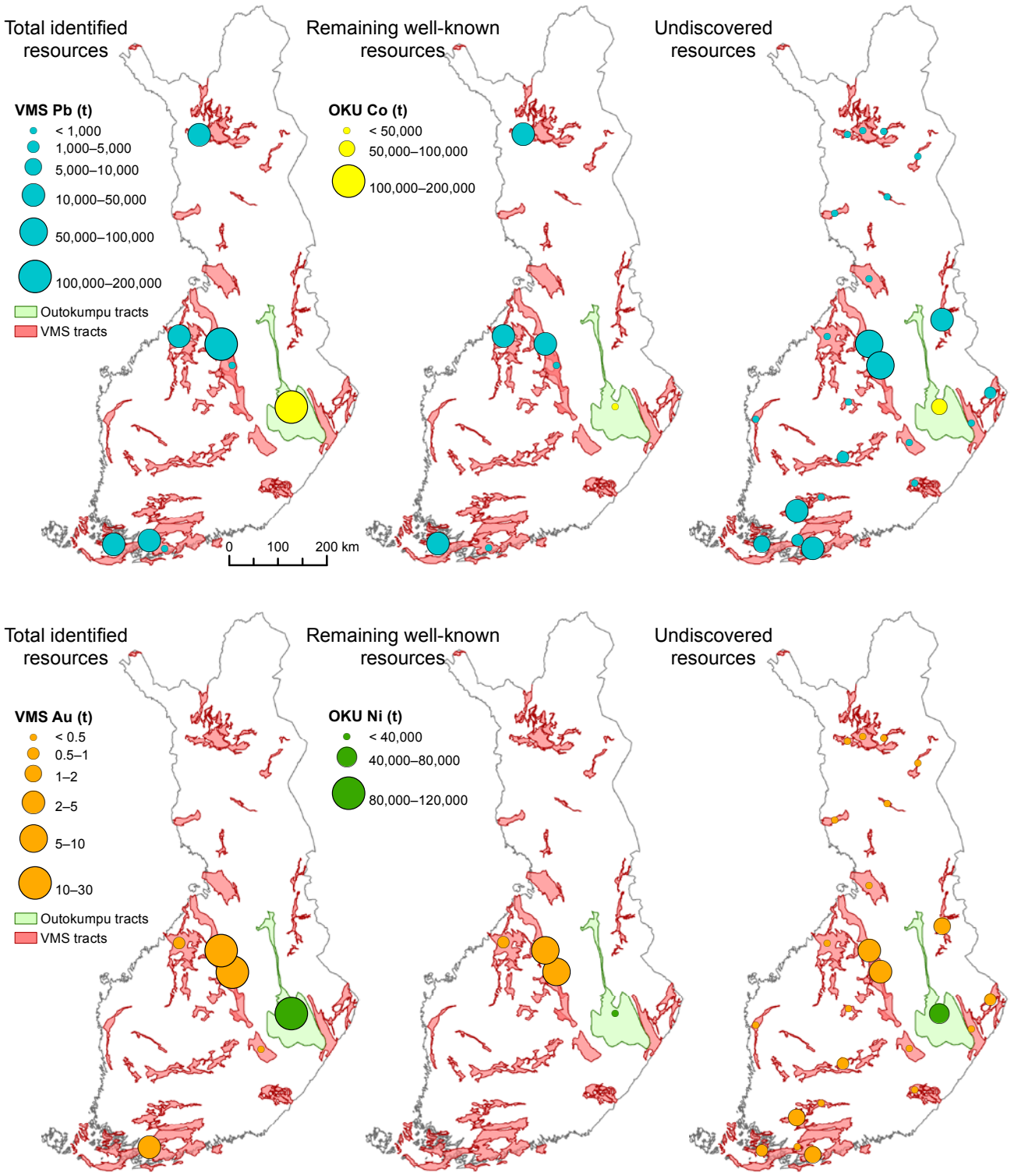


Fig. 18. Geographic distribution of total identified, well-known and estimated undiscovered lead, gold, cobalt and nickel resources of VMS and Outokumpu types in Finland. The total identified resources include well-known resources plus cumulative production. The undiscovered resources are estimated at 50 % probability.

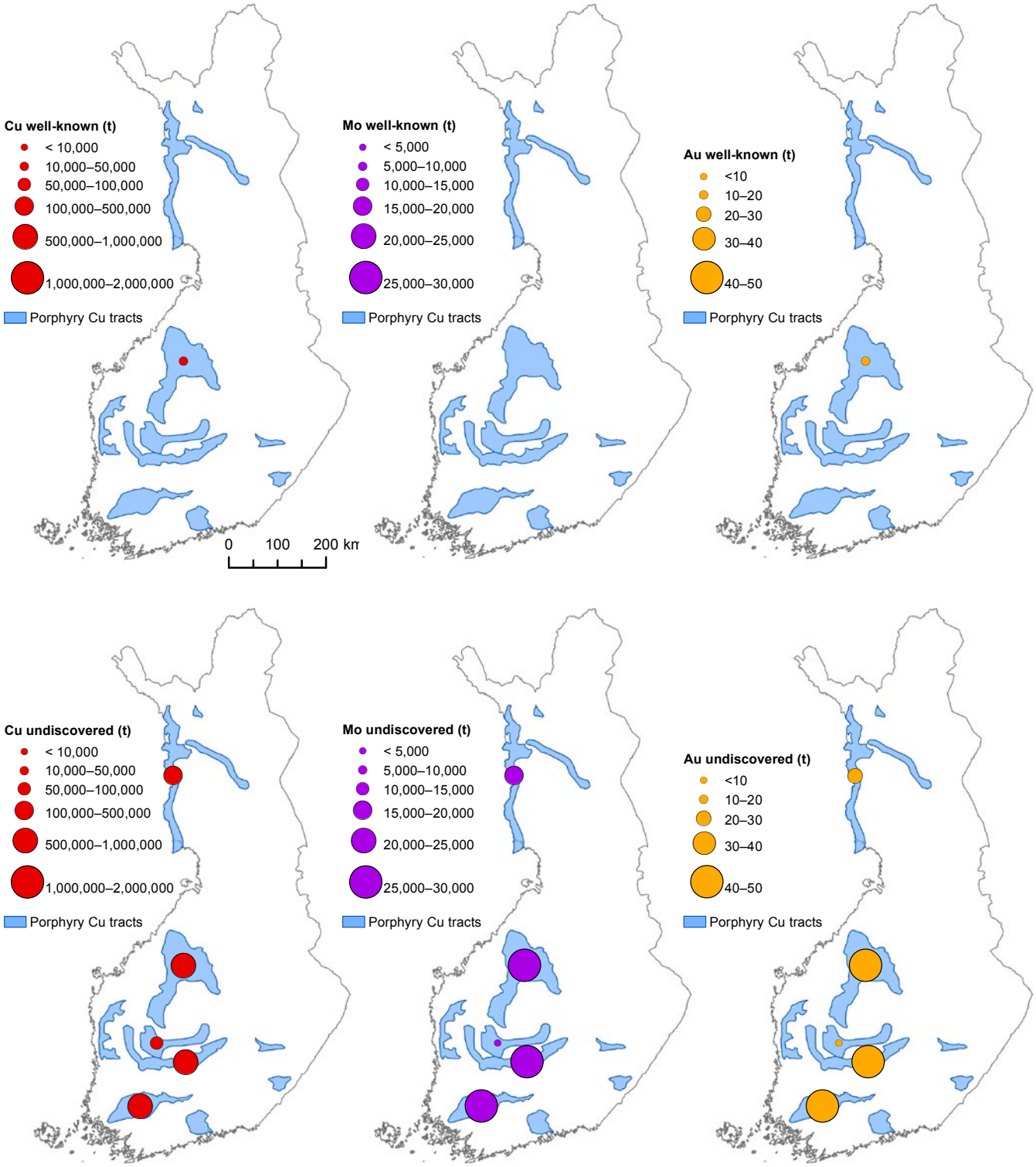


Fig. 19. Geographic distribution of well-known and estimated undiscovered copper, molybdenum and gold resources of the porphyry copper type in Finland. The undiscovered resources are estimated at 50 % probability.

projects are ongoing in Finland. If both Hannukainen and Suhanko were brought into production before the end of the 2010s, and if the existing mines operated according to expectations, then the annual mine production of copper in Finland could rise to 75,000 t, but the annual zinc production would remain around 50,000 t at the most. Assuming the throughput of Finnish smelters and refineries remained unchanged, they would even in this "best case" scenario need to import a considerable proportion of the copper (42 %) and zinc (84 %) concentrate they use annually.

Further additions to these production figures could come from individual, so far undiscovered, deposits. The median estimated resources of copper and zinc in undiscovered VMS, Outokumpu-type and porphyry copper deposits are 3.7 Mt Cu and 1.8 Mt Zn, respectively (Table 9). This could produce the present output of Finnish smelters and refineries for 29 years for copper and for six years for zinc. However, it would require four new average VMS deposits or two new average porphyry copper deposits to raise the mine production of copper in Finland to the level of the present smelter and refinery production. For zinc, that would require six new average VMS deposits. Discovering and bringing to operation so many new deposits simultaneously is very unlikely, and Finland will consequently remain dependent on exports for at least a large part of its copper and zinc metal production. However, new mines could be very significant for the economies of regions with few other industrial enterprises, and especially for small to medium-sized mining companies.

### 5.3 Finnish Cu-Zn endowment in the global context

On a global scale, porphyry copper and VMS deposits are important sources of copper and zinc, respectively. Total world mine production in 2012 was 17 Mt of copper and 13 Mt of zinc (Edelstein 2013, Tolcin 2013). Sixty-two per cent of the copper came from five countries: Chile (32 %), China (9 %), Peru (8 %), the United States (7 %) and Australia (6 %). For zinc, the following five countries were responsible for 67 % of the total production: China (35 %), Australia (11 %), Peru (10 %), the Unites States (6 %) and India (5 %). Over 60 % of the total world copper production comes from porphyry copper deposits, and about 20 % comes from VMS deposits (Polinares Consortium 2012).

Identified world copper reserves are estimated to be 680 Mt, of which 27 % is in Chile, 13 % in Australia, 11 % in Peru, 6 % in the United States and 6 % in Mexico (Edelstein 2013). World zinc reserves are estimated to be 250 Mt, of which 28 % is in Australia, 17 % in China, 7 % in Peru and 6 % in Mexico (Tolcin 2013).

According to Singer (1995), 57 % of the world's total known copper endowment (present resources and past production) is in porphyry copper deposits, whereas 6 % of the copper endowment, 23 % of the zinc endowment and 10 % of the lead endowment are in VMS deposits. According to a more recent compilation, identified land-based copper resources of the world in 2010 were at least 1781 Mt of Cu, of which porphyry copper deposits contained 74 % and VMS deposits 1.8 % (Mudd et al. 2013). Johnson et al. (2014) report 2100 Mt of identified global copper resources in porphyry deposits (1800 Mt) and in sediment-hosted stratabound deposits (300 Mt). Identified zinc resources of the world are estimated to be about 1900 Mt (Tolcin 2013).

Results of assessments by the U.S. Geological Survey indicate that undiscovered land-based copper resources of the world exceed 3 billion tons (Johnson et al. 2014). In addition to land-based resources, the present-day ocean floor contains copper and zinc resources in the form of deep-sea nodules and submarine massive sulphides. Median estimates of undiscovered copper and zinc contained in seafloor massive sulphide deposits are 4.6 Mt and 6.4 Mt, respectively (Singer 2014).

VMS and Outokumpu-type deposits have had a very important role in the production of copper and zinc in Finland. These two deposit types have produced 1.8 Mt copper and 3.2 Mt zinc, which is over 90 % the total cumulative production of these metals in Finland (Table 9). However, in the light of the presently well-known resources, these deposit types are only of minor importance for the total copper and zinc endowment in Finland. The total well-known resources of copper and zinc in significant deposit types in Finland are 4.9 Mt and 11 Mt, respectively. For these resources, 341,000 t (7 %) of the copper and 745,000 t (7 %) of the zinc

are in VMS deposits, 197,000 t (4 %) of the copper and 114,000 t (1 %) of the zinc are in Outokumpu-type deposits, and 45,000 t (1 %) of the copper is in porphyry copper deposits. Seventy-eight per cent of the well-known copper resources and 92 % of the well-known zinc resources in Finland are in two large deposits: Talvivaara and Kevitsa.

Compared to the identified global land-based resources of at least 2.1 Bt of copper and 1.9 Bt of zinc, the well-known copper and zinc resources of Finland are insignificant; they are only 0.2 % and 0.6 % of the global resources, respectively. Similarly, the median estimated undiscovered copper resources of 9.7 Mt in Finland (Table 9) are only 0.3 % of the median estimated undiscovered global resources of 3200 Mt of copper in land-based porphyry copper and sediment-hosted deposits (Johnson et al. 2014). Global estimates of undiscovered land-based zinc resources are not available, but even the estimated present endowment of 13 Mt of zinc in Finland (well-known + median estimated undiscovered resources in Table 9) is only 0.7 % of the global identified land-based zinc resources. In view of the above, the estimated present endowments of 15 Mt of copper and 13 Mt of zinc are insignificant in comparison to the total global copper and zinc endowments.

It is not statistically correct to sum the median estimates of undiscovered metals across deposit types, as has been done in Table 9. Instead, the median estimate of total undiscovered resources across different deposit types should be calculated in a single simulation run. This could not be done due to limitations in the software used. However, the comparison of the sums of simulation results for individual permissive tracts (Tables 6 and 7) with simulation results for all tracts (Table 8) indicates that the totals resulting from summing across deposit types are very close to the values that would be produced by including all the deposit types in one simulation.

### 5.4 Reliability and usability of the estimates

Sensitivity analysis indicated that changes in grade and tonnage estimates have a much larger influence on the expected metal content in an assessment than changes in the expected number of deposits (Singer & Kouda 1999). Consequently, the greatest sources of possible error in the present assessment are associated with the grade-tonnage models used for the deposit types.

As discussed in Section 4.4.1, the Fennoscandian felsic and bimodal-mafic VMS deposits in our dataset have significantly lower average tonnages compared to the corresponding global deposits outside of the Fennoscandian Shield. The Fennoscandian felsic VMS deposits also have lower average copper grades than their global counterparts, and the Fennoscandian mafic VMS deposits have higher average zinc, lead and silver grades than the global mafic VMS deposits (Table 2).

It is reasonable to assume that deposits with larger tonnages and/or higher metal grades are more likely to be developed into mines than smaller or poorer deposits. Hence, a clearly larger proportion of active or historic mines in the global dataset might cause higher average ore tonnage and metal grade values. In the Fennoscandian VMS dataset, 50–77 % of the felsic, bimodal-mafic and mafic deposits has been mined, whereas in the global dataset, the percentages vary from 63 % to 86 %. The fraction of deposits mined is 8–13 percentage units higher for the global deposit types. These differences are small and probably have no significant effect on the differences in tonnage and metal grades between the global and Fennoscandian deposits. Furthermore, average tonnages and metal grades calculated separately for mined deposits and deposits that have never been mined show roughly similar differences between the Fennoscandian and global datasets. This indicates that the differences between the global and Fennoscandian VMS deposits are real, and the development of Fennoscandian grade-tonnage models is justified.

Statistical tests indicate that the Precambrian porphyry copper deposits in our dataset differ from the younger Phanerozoic deposits, especially by having smaller average tonnage and copper grade (See Section 4.4.2). The percentages of deposits that have been mined at some stage of their history are 26 % for the Precambrian and 30 % for the Phanerozoic deposits. However, information on whether a deposit has been mined or not is only available for 79 % of the Phanerozoic dataset. The difference in the proportion of deposits mined between the Precambrian and Phanerozoic datasets is small and probably does not contribute significantly to the differences in tonnage and

metal grades between the datasets. As with the VMS deposits, average tonnages and metal grades calculated separately for mines and deposits that have never been mined show roughly similar differences between two datasets. The smaller average tonnage of the Precambrian deposits might be explained by the generally deeper level of erosion in the Precambrian terranes, but the lower average copper grade and the marginally higher average molybdenum and gold grades compared to Phanerozoic deposits remain unexplained. In spite of the small number of Precambrian deposits in our dataset (27), we consider the differences significant and the use of a Precambrian porphyry copper grade-tonnage model justified.

The Outokumpu-type grade-tonnage model is based on 10 well-known deposits within a restricted area (Fig. 15). Although the number of well-known deposits is small, the data appear to cover the spread of tonnage and grade values of this deposit type. The undiscovered Outokumpu-type deposits are estimated to be located within the same permissive tract that contains all the well-known deposits. This eliminates the variance that might be caused if the model was applied to a larger group of tracts covering more varied lithologies.

Compared to assessment results achieved using global grade-tonnage models for VMS and porphyry copper deposits, our estimates can be regarded conservative. Performing the assessment using global models for VMS deposits (Mosier et al. 2009) results in slightly more than two times higher median estimates for undiscovered copper and zinc tonnages. Similarly, using a global grade-tonnage model for porphyry copper deposits (Singer et al. 2005) results in a five times higher median estimate of undiscovered copper resources. The estimates carried out using local grade-tonnage models for the VMS and Outokumpu-type deposits and a Precambrian model for the porphyry copper deposits give a more accurate estimate of the remaining undiscovered resources in Finland than estimates using global grade-tonnage models.

The assessment results indicate that 98 % of the total metal endowment in porphyry copper deposits in Finland is in undiscovered or poorly known deposits. The high percentage is due to the fact that only one porphyry-type deposit (Kopsa) in Finland was considered to be known well enough for inclusion in the grade-tonnage model. Furthermore, the calculated copper content of the Kopsa deposit (45,000 t of copper) is only half of the copper content of a median porphyry copper deposit according to the grade-tonnage model used (92,000 t of copper). On the other hand, many porphyry-type occurrences are known in Finland, and these were regarded as promising indications for the existence of several undiscovered deposits.

Care must always be taken when applying the results of assessments such as these. Although the method predicts the existence of a number of undiscovered deposits, it gives no guarantee that these deposits will ever be discovered. The method does not address possible extensions of the well-known deposits in the grade-tonnage models. However, even well-known deposits might contain undiscovered resources, which in some cases could represent a notable part of the unknown resources.

Many of the undiscovered deposits estimated to exist by this work are probably under hundreds of metres of barren rock, whereas others may crop out at the surface. Some of the buried deposits are likely to be beyond the reach of present day exploration technology, or their discovery may require exploration expenditures so large they are unlikely to be discovered in the near future. Although technological advances act over time to lower mining costs and allow formerly uneconomic occurrences to become operating mines, some of the undiscovered deposits estimated here might never be mined for one or more reasons, including relatively low tonnages or grades, deep burial, their occurrence in or near environmentally sensitive areas, or occurrence in areas designated for other land uses than mining.

## 6 SUMMARY

Experts in copper±zinc deposits and in metallogeny and geostatistics at the Geological Survey of Finland produced this assessment of undiscovered copper and zinc resources within the uppermost one kilometre of Finnish bedrock. The resources were assessed using the three-part quantitative

method developed at the U.S. Geological Survey, and the assessment covered volcanogenic massive sulphide (VMS) deposits, porphyry copper deposits and Outokumpu-type copper-zinc-cobalt deposits.

This report provides numerical estimates of the undiscovered resources of copper and zinc in undiscovered, potentially exploitable deposits. Depending on the deposit type, estimates of undiscovered lead, silver, gold, molybdenum and cobalt resources are also given. The main results include the following:

1. The three-part quantitative assessment method developed by the USGS is suitable for assessing VMS, porphyry copper and Outokumpu-type deposits.
2. Well-known VMS, porphyry copper and Outokumpu-type deposits contain 0.58 Mt of copper and 0.86 Mt of zinc, which is only 12 % and 8 % of the known copper and zinc resources in Finland, respectively. In comparison, the Talvivaara deposit contains 55 % of the known copper and 92 % of the known zinc resources in Finland, and the Kevitsa deposit contains a further 23 % of the known copper resources in Finland.
3. The grades and tonnages of VMS deposits in the Fennoscandian Shield deviate significantly from global data. Precambrian porphyry copper deposits differ from Phanerozoic deposits in grade and tonnage. Due to these differences, grade-tonnage models were constructed for Fennoscandian felsic, bimodal-mafic and mafic VMS deposits and for Precambrian porphyry copper deposits.
4. Thirty-one permissive tracts were delineated for VMS deposits, ten for porphyry copper deposits and one for Outokumpu-type deposits. The VMS tracts cover 41,600 km$^2$, the porphyry copper tracts 38,400 km$^2$, and the Outokumpu tract 9800 km$^2$. The VMS and porphyry copper tracts overlap substantially, and the total area covered by one or more tracts is 80,000 km$^2$, which is 24 % of the total land area of Finland.
5. The expected numbers of undiscovered felsic, bimodal-mafic and mafic VMS deposits within the permissive tracts are 18, 10 and 17, respectively. The expected number of undiscovered porphyry copper deposits is 11, and that of undiscovered Outokumpu-type deposits 6.
6. The undiscovered VMS deposits are estimated to contain, at 50 % probability, at least 730,000 t Cu, 1.6 Mt Zn, 150,000 t Pb, 1100 t Ag and 16 t Au. Most of the copper is in mafic-type deposits, whereas most of the other metals are in felsic-type deposits. The median estimated undiscovered resources in porphyry copper deposits are at least 2.4 Mt Cu, 100,000 t Mo, 1000 t Ag and 170 t Au. The median undiscovered resources in Outokumpu-type deposits are estimated to be at least 580,000 t Cu, 220,000 t Zn, 53,000 t Co and 41,000 t Ni.
7. About 71 % of the copper and 68 % of the zinc endowment in VMS and Outokumpu-type deposits, and at least 98 % of the copper endowment in porphyry copper deposits in Finland occurs in poorly explored and undiscovered deposits.
8. Most of the well-known VMS resources are concentrated in the Vihanti, Pyhäsalmi, Orijärvi and Uusimaa West permissive tracts. The undiscovered resources are estimated to be more evenly distributed between the tracts, with the Vihanti and Pyhäsalmi tracts having the largest undiscovered resources. Felsic deposits are estimated to contain 53 % of the undiscovered VMS-type copper-zinc resources and 95 % of the undiscovered VMS-type lead resources in Finland.
9. The only well-known porphyry copper deposit in Finland is located in the Central Ostrobothnia permissive tract. The undiscovered porphyry copper resources are estimated to be concentrated in the Central Ostrobothnia, Tampere, Häme and Haaparanta tracts, with 86 % of the resources in central and southern Finland.
10. At the 50 % level of probability, the undiscovered copper-zinc resources in VMS, porphyry copper and Outokumpu-type deposits in Finland are at least 3.7 Mt of copper and 1.8 Mt of zinc. This is 38 % of the total estimated undiscovered copper resources and 100 % of the total estimated undiscovered zinc resources in Finland.

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**APPENDIX 1**

# DESCRIPTIVE MODEL OF VOLCANOGENIC MASSIVE SULPHIDE (VMS)

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**APPROXIMATE SYNONYMS** Exhalative massive sulphide, volcanic-exhalative massive sulphide, submarine-exhalative massive sulphide, seafloor massive sulphide, volcanic-hosted massive sulphide, volcanic-sediment-hosted massive sulphide, volcanic-associated massive sulphide

**DESCRIPTION** Stratabound concentrations of sulphide minerals precipitated from hydrothermal fluids in extensional seafloor environments and mostly associated with volcanic lithologies. Based on the associated lithology, the deposits can be classified into mafic-ultramafic, siliciclastic-mafic, bimodal-mafic, bimodal-felsic and siliciclastic felsic types.

**GENERAL REFERENCE** Barrie & Hannington (1999), Franklin et al. (2005), Galley et al. (2007), Shanks & Thurston (2012).

## EXAMPLES

Siliciclastic felsic: Rio Tinto (Williams et al. 1975, Solomon et al. 1980, Tornos 2006)
Bimodal-felsic: Pyhäsalmi (Helovuori 1979, Mäki & Puustjärvi 2003)
Bimodal-mafic: Horne (Gibson et al. 2000)
Siliciclastic-mafic: Windy Craggy (Peter & Scott 1999)
Mafic-ultramafic: Skouriotissa (Constantinou & Govett 1973)

## GEOLOGICAL ENVIRONMENT

**Rock Types** The composition of volcanic host rocks range from mafic to felsic; bimodal mixtures are quite common. The volcanic strata consist of massive and pillow lavas, sheet flows, hyaloclastites, lava breccias, pyroclastic deposits and volcaniclastic sediment. Siliciclastic rocks dominate the stratigraphic assemblage in some settings. Synvolcanic intrusions are common, especially in flow-dominated successions.

**Structures and textures** Submarine volcanic structures and textures are common; clastic sediments mixed with dykes and sills, peperites, lava flows, autoclastic breccias, pillows, sheet flows, flow domes and volcaniclastic rocks.

**Age Range** Early Archaean (3.55 Ga) to Holocene (presently forming in seafloor settings).

**Depositional Environment** Extensional seafloor and subseafloor environment.

**Tectonic Setting(s)** Mid-oceanic ridges, intraoceanic and continental margin volcanic arcs, back-arc basins, rifted continental margins, pull-apart basins.

**Associated Deposit Types** Epithermal Au-Ag, Co-Cu-As in ophiolitic ultramafic rocks.

## DEPOSIT DESCRIPTION

**Mineralogy** Abundant Fe sulphides (pyrite or pyrrhotite) and variable but generally subordinate amounts of chalcopyrite and sphalerite. Galena occurs as a major component in deposits associated with bimodal-felsic and siliciclastic-felsic lithologies. Minor minerals include marcasite, magnetite, cobaltite, arsenopyrite, tennantite and tetrahedrite. For example, bornite, stibnite, realgar, stannite and cassiterite usually occur as trace minerals, but are abundant in some deposits. Co- and Ni-bearing arsenides, sulpharsenides and sulphides, although rare in most VMS deposits, can be relatively abundant in deposits associated with serpentinised ultramafic rocks in ophiolitic terranes.

**Texture/Structure** Undeformed deposit forms include sheets, layers, lenses, mounds, pipes, and stockworks. Characteristic primary structures include fragmental and layered ores at the deposit scale, and blocky, fragmental and sandy zones form characteristic internal features of well-preserved deposits. Sulphide textures vary from massive (100 % sulphide minerals) through semimassive mixtures of sulphides, gangue minerals and host rock to sulphide disseminated in wall rocks. Sulphides also form veins, usually with quartz and other gangue minerals, cutting wall rock and earlier-formed massive sulphides. Many deposits are underlain by discordant sulphide-bearing vein systems. Massive sulphides are often laterally gradational to bedded or layered sulphide deposits. Many deposits display a zonation of metals within the massive sulphide body from Fe+Cu at the base to Zn+Fe±Pb±Ba at the top and margins.

**Alteration** Pervasive alteration zones characterized by secondary quartz and phyllosilicate minerals reflect hydrothermal circulation through footwall volcanic rocks. The mineralogy of the alteration zones depends on the composition of the ore-forming fluids and the footwall rocks, and on the grade of post-mineralization metamorphism. The most strongly altered rocks are generally in the stringer zone and immediately below the massive sulphides, and the intensity of alteration decreases outward away from the deposit. Alteration can extend to the hanging-wall rocks if hydrothermal activity continued after burial of the deposit. Semi-conformable alteration zones clearly discordant to regional metamorphic isograds occur in many VMS districts. These zones can be traced over several kilometres of strike length, and they are probably related to premetamorphic horizontal hydrothermal circulation driven by the heat of underlying intrusive bodies.

**Ore Control** Controlling features include calderas, craters, grabens, domes, (synvolcanic) faults and fault intersections, seafloor depressions and local basins.

**Weathering** Submarine weathering (halmyrolysis) on the seafloor by circulation of oxygenated water is associated with the formation of secondary copper sulphide minerals, but if continued long enough, it will eventually result in the destruction of VMS deposits. Subaerial weathering by descending acidic meteoric water causes mobilisation of metals from primary sulphide minerals and precipitation of copper±gold±silver at depth, forming a supergene enrichment zone overlain by a leached iron oxide-rich gossan. The resulting acid drainage production can cause severe environmental consequences.

**Geophysical signature** VMS deposits produce significant electric, electromagnetic, gravimetric and magnetic responses. Potassium enrichment or depletion in wall rocks can produce radiometric anomalies.

**Geochemical Signature** High concentrations of one or more of Cu, Zn, Pb. Possibly elevated concentrations of some of Ag, As, Au, Bi, Cd, Co, Ga, Ge, Hg, In, Mo, Ni, Sb, Se, Sn, Tl, W. Depleted Na, especially in footwall rocks. Possibly elevated K. Possibly widespread Fe±Mn±Si±S±Ba±B in exhalites precipitated from VMS-related hydrothermal vents and plumes. Fluid upflow zones often have lower $\delta^{18}O$ values than surrounding areas.

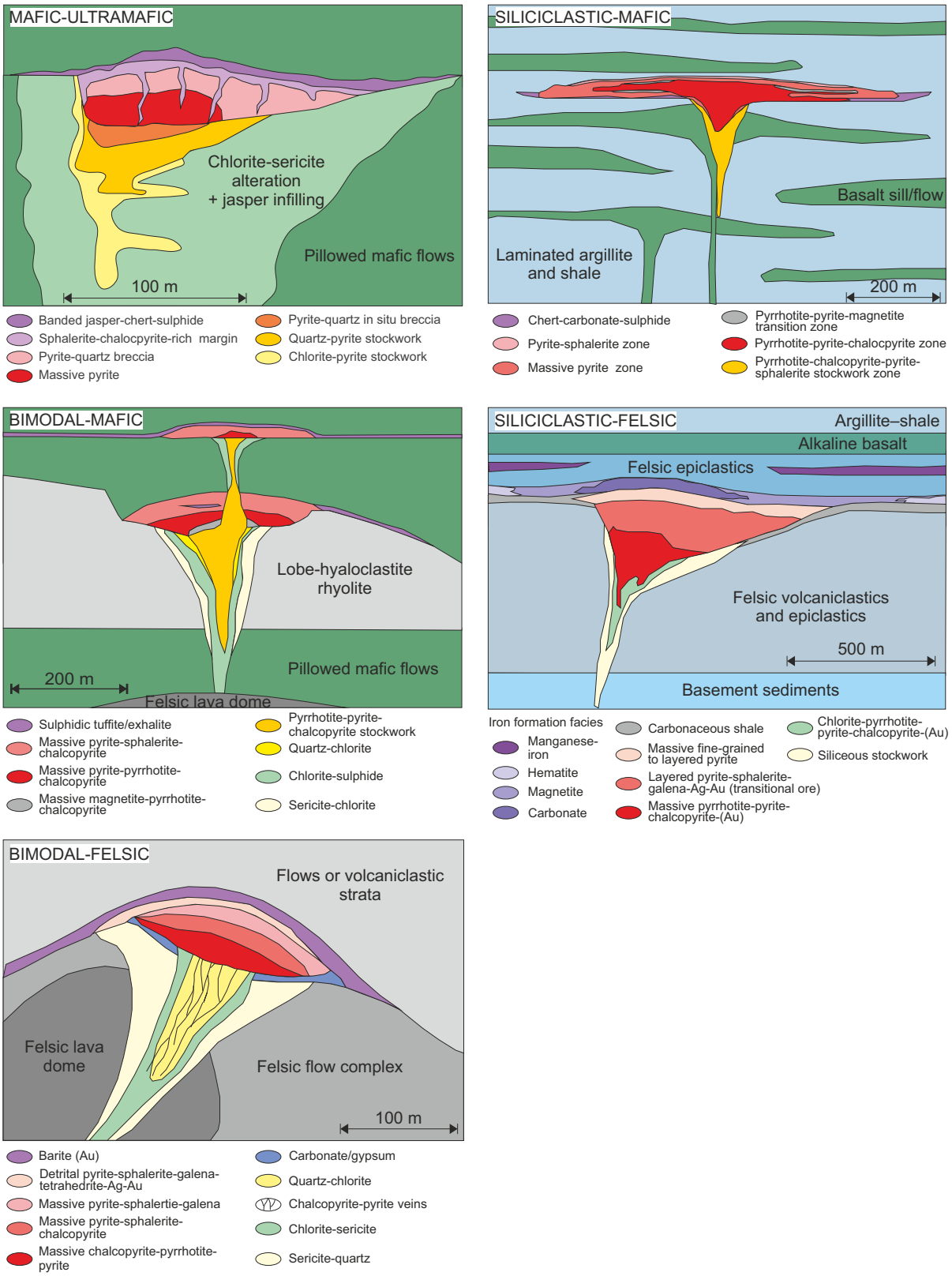


Fig. 1. Generalised features of the lithologically classified VMS deposit types. Modified from Morgan & Schulz (2012).

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**APPENDIX 2**

# GRADE-TONNAGE MODEL OF FENNOSCANDIAN VOLCANOGENIC MASSIVE SULPHIDE (VMS)

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## INTRODUCTION

This model contains data from 134 volcanogenic massive sulphide (VMS) deposits within the Fennoscandian shield (Table 1). A spatial rule has been applied, according to which deposits less than 500 m from each other have been combined.

In this model, we follow the threefold classification of VMS deposits (Mosier et al. 2009) into *mafic*, *bimodal-mafic* and *felsic* types. This classification is based on 1090 VMS deposits and was designed for U.S. Geological Survey mineral resource assessments. It simplifies the fivefold classification of the associated VMS occurrence model (Shanks & Thurston 2012) by combining deposit classes that cannot be distinguished from each other based on average ore tonnage and metal grades. The *mafic* type contains siliciclastic-mafic deposits in mature oceanic backarcs and mafic-ultramafic deposits in primitive oceanic backarc and mid-ocean ridge settings. The *bimodal-mafic* type includes deposits in both oceanic arc and epicontinental arc settings. The *felsic* group contains both siliciclastic-felsic deposits in mature epicontinental arcs and bimodal-felsic deposits in epicontinental and oceanic arc settings.

## DATA

All the 134 VMS deposits from the Fennoscandian shield area are listed in Table 1 with references to the grade-tonnage data. Table 2 summarises the type, location, status and age data of the deposits. There are 31 mafic, 18 bimodal-mafic and 85 felsic deposits from Finland, Norway and Sweden. Of the deposits, 78 are Palaeoproterozoic, 6 are Neoproterozoic and 50 are Phanerozoic in age. Altogether, 83 deposits are presently being mined or have previously been mined; 51 of the deposits have not been developed into mines.

Table 1. VMS deposits included in the grade-tonnage model.

| Name | Country | Deposit type | Age | Status | Tonnage (Mt) | Cu (%) | Zn (%) | Pb (%) | Au (g/t) | Ag (g/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Aijala | Finland | Felsic | Paleoproterozoic | Mine | 0.835 | 1.59 | 0.70 | - | 0.70 | 14.00 | Warma (1975) |
| Attu | Finland | Felsic | Paleoproterozoic | Mine | 4.320 | 0.16 | 1.76 | 1.05 | - | 43.00 | Anttonen (1992) |
| Backgränd | Finland | Felsic | Paleoproterozoic | Deposit | 0.046 | 0.54 | 1.37 | 0.80 | - | 65.00 | Isomäki (1984) |
| Hallaperä | Finland | Felsic | Paleoproterozoic | Deposit | 2.050 | 0.57 | 1.10 | - | - | - | Helovuori (1980) |
| Hällinmäki | Finland | Mafic | Paleoproterozoic | Mine | 4.180 | 0.78 | - | - | 0.10 | - | Pulkkinen (1985) |
| Kangasjärvi | Finland | Felsic | Paleoproterozoic | Mine | 0.300 | 0.06 | 5.40 | 0.02 | 0.30 | 5.00 | Puustjärvi (1992), Mäki (1997) |
| Kaskela | Finland | Felsic | Paleoproterozoic | Deposit | 0.124 | 0.40 | 3.90 | 0.10 | - | 12.00 | Puustjärvi (1992, 1994) |
| Kurpas | Finland | Felsic | Paleoproterozoic | Deposit | 0.400 | 0.63 | 0.55 | - | - | - | Puustjärvi (1992) |
| Liipola S | Finland | Felsic | Paleoproterozoic | Deposit | 0.024 | - | 0.69 | - | - | 112.00 | Isomäki (1989) |
| Metsämonttu | Finland | Felsic | Paleoproterozoic | Mine | 1.508 | 0.28 | 3.34 | 0.74 | 1.43 | 24.79 | Puustinen (2003) |
| Mullikkoräme | Finland | Felsic | Paleoproterozoic | Mine | 2.100 | 0.27 | 7.13 | 1.00 | 0.47 | 51.00 | Puustjärvi (1992, pers. comm. 2001) |
| Orijärvi | Finland | Felsic | Paleoproterozoic | Mine | 0.925 | 1.32 | 3.32 | 1.03 | 0.40 | 40.00 | Puustinen (2003) |
| Pahtavuoma Zn | Finland | Mafic | Paleoproterozoic | Mine | 21.400 | 0.30 | 0.67 | 0.08 | - | 10.00 | Korkalo (2006) |
| Paloniemi | Finland | Felsic | Paleoproterozoic | Deposit | 0.112 | 0.13 | 0.89 | - | - | 4.10 | Tontti et al. (1981) |
| Pyhäsalmi | Finland | Felsic | Paleoproterozoic | Mine | 65.824 | 0.90 | 2.18 | - | 0.40 | 14.00 | Inmet Mining Corporation (2009, 2013), Mäki pers. comm. (2010) |
| Rauhala | Finland | Bimodal-Mafic | Paleoproterozoic | Deposit | 1.700 | 1.33 | 4.79 | 0.96 | 0.40 | 53.00 | Västi (1989) |
| Ruostesuo | Finland | Felsic | Paleoproterozoic | Mine | 2.769 | 0.38 | 1.72 | - | 0.38 | 9.90 | Reino (1985), Mäki (1997) |
| Salo-Issakka | Finland | Mafic | Paleoproterozoic | Deposit | 1.800 | 0.33 | 1.64 | - | - | 14.00 | Kurki (1976) |
| Säviä | Finland | Felsic | Paleoproterozoic | Deposit | 5.000 | 0.88 | 0.40 | - | 0.20 | 8.00 | Laitakari (1968) |
| Vihanti Zn | Finland | Felsic | Paleoproterozoic | Mine | 37.264 | 0.45 | 3.95 | 0.36 | 0.49 | 25.00 | Mäki (1997, pers. comm. 2006) |
| Åsoren | Norway | Mafic | Phanerozoic | Mine | 0.730 | 1.43 | 1.32 | - | - | - | FODD (2012) |
| Båsmo | Norway | Felsic | Neoproterozoic | Mine | 1.850 | 0.13 | 0.14 | - | - | - | Bjerkgård & Hallberg (2012a) |
| Bjørkåsen | Norway | Mafic | Phanerozoic | Mine | 6.000 | 0.45 | 1.00 | - | - | - | FODD (2012) |
| Bleikvassli | Norway | Felsic | Neoproterozoic | Mine | 6.000 | 0.15 | 4.00 | 2.00 | - | 25.00 | FODD (2012) |
| Bursi | Norway | Mafic | Phanerozoic | Mine | 1.845 | 1.50 | 0.31 | - | - | - | Bjerkgård & Hallberg (2012b) |
| Christianus Sextus | Norway | Mafic | Phanerozoic | Mine | 0.250 | 2.70 | 7.90 | 0.30 | 0.14 | 14.00 | Bjerkgård (2012c), FODD (2012) |
| Fløttum | Norway | Mafic | Phanerozoic | Mine | 0.350 | 0.96 | 4.76 | - | - | 29.00 | Bjerkgård & Often (2012) |
| Folldal | Norway | Bimodal-Mafic | Phanerozoic | Mine | 2.000 | 1.90 | 1.10 | - | - | - | Bjerkgård (2012b) |
| Gjersvik | Norway | Bimodal-Mafic | Phanerozoic | Mine | 1.620 | 1.70 | 1.00 | - | - | - | Sandstad & Hallberg (2012) |
| Godejord | Norway | Bimodal-Mafic | Phanerozoic | Deposit | 0.100 | 0.80 | 6.90 | 0.20 | 0.80 | 20.00 | Sandstad & Hallberg (2012) |
| Jakobsbakken | Norway | Mafic | Phanerozoic | Mine | 4.500 | 1.55 | 2.42 | - | - | - | Bjerkgård & Hallberg (2012b) |
| Joma | Norway | Mafic | Phanerozoic | Mine | 22.453 | 1.49 | 1.45 | - | - | - | Sandstad & Hallberg (2012) |
| Killingdal | Norway | Bimodal-Mafic | Phanerozoic | Mine | 3.000 | 1.70 | 5.50 | 0.40 | - | - | Bjerkgård (2012b) |
| Kjøli | Norway | Mafic | Phanerozoic | Mine | 0.250 | 2.90 | 0.02 | - | - | - | Bjerkgård (2012c) |
| Kongens gruve | Norway | Mafic | Phanerozoic | Mine | 3.000 | 2.80 | 5.70 | 0.40 | 0.17 | 23.00 | Bjerkgård (2012c), FODD (2012) |
| Kviknegruvene | Norway | Mafic | Neoproterozoic | Mine | 0.250 | 2.36 | 1.81 | - | - | 11.00 | FODD (2012) |

Table 1. Cont.

| Name | Country | Deposit type | Age | Status | Tonnage (Mt) | Cu (%) | Zn (%) | Pb (%) | Au (g/t) | Ag (g/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lergruvbakken | Norway | Mafic | Phanerozoic | Mine | 0.940 | 1.00 | 9.40 | 0.40 | - | 20.00 | FODD (2012) |
| Lillefjell | Norway | Mafic | Phanerozoic | Mine | 0.107 | 5.00 | 4.50 | - | - | - | Bjerkgård (2012c) |
| Løkken | Norway | Mafic | Phanerozoic | Mine | 30.000 | 2.30 | 1.80 | 0.02 | 0.20 | 16.00 | Bjerkgård (2012a) |
| Mannfjell | Norway | Felsic | Phanerozoic | Mine | 0.100 | 1.80 | 5.30 | - | 1.00 | - | Bjerkgård (2012b), FODD (2012) |
| Mofjellet | Norway | Felsic | Neoproterozoic | Mine | 5.350 | 0.31 | 3.61 | 0.71 | 0.30 | 10.00 | FODD (2012) |
| Muggruva | Norway | Mafic | Phanerozoic | Mine | 0.650 | 4.10 | 0.90 | - | 0.34 | 12.00 | FODD (2012) |
| Nordre Geitryggen | Norway | Felsic | Phanerozoic | Mine | 3.000 | 1.30 | 3.20 | 0.20 | 0.20 | 31.00 | Bjerkgård (2012b), FODD (2012) |
| Nygruva | Norway | Bimodal-Mafic | Phanerozoic | Mine | 0.200 | 0.70 | 3.40 | 0.05 | 0.80 | - | FODD (2012) |
| Rieppe | Norway | Mafic | Phanerozoic | Mine | 3.000 | 0.50 | 2.00 | - | - | - | Bjerkgård (2012d) |
| Rødkleiv | Norway | Bimodal-Mafic | Phanerozoic | Mine | 2.646 | 0.78 | 1.71 | - | - | - | Sandstad (2012a) |
| Røstvangen | Norway | Mafic | Neoproterozoic | Mine | 0.488 | 2.70 | 0.73 | - | 0.28 | 12.00 | FODD (2012) |
| Sagmo | Norway | Mafic | Phanerozoic | Mine | 1.900 | 1.60 | 0.23 | - | 0.07 | - | Bjerkgård & Hallberg (2012b), FODD (2012) |
| Sivilvangen | Norway | Bimodal-Mafic | Phanerozoic | Mine | 0.400 | 0.69 | 4.31 | - | - | - | Bjerkgård (2012b) |
| Skiftesmyr | Norway | Bimodal-Mafic | Phanerozoic | Deposit | 2.750 | 1.23 | 1.86 | - | 0.40 | 11.00 | Sandstad & Hallberg (2012) |
| Skorovas | Norway | Bimodal-Mafic | Phanerozoic | Mine | 6.900 | 1.14 | 2.71 | - | - | - | Sandstad & Hallberg (2012) |
| Stordø | Norway | Mafic | Phanerozoic | Mine | 9.000 | - | 0.28 | - | - | - | Sandstad (2012b) |
| Tverrfjellet | Norway | Mafic | Phanerozoic | Mine | 19.000 | 1.00 | 1.20 | 0.20 | 0.08 | 10.00 | Bjerkgård (2012a), FODD (2012) |
| Undal | Norway | Mafic | Phanerozoic | Mine | 1.000 | 1.15 | 1.86 | - | - | - | Bjerkgård & Often (2012) |
| Vaddas | Norway | Mafic | Phanerozoic | Mine | 1.415 | 1.37 | 0.01 | - | - | - | FODD (2012) |
| Vigsnes | Norway | Bimodal-Mafic | Phanerozoic | Mine | 1.440 | 1.66 | 1.40 | - | - | - | Sandstad (2012a) |
| Visletten | Norway | Bimodal-Mafic | Phanerozoic | Deposit | 0.780 | 0.92 | 3.86 | - | 0.50 | - | Sandstad & Hallberg (2012), FODD (2012) |
| Ytterøya | Norway | Bimodal-Mafic | Phanerozoic | Mine | 0.500 | 1.90 | 2.40 | 0.30 | - | - | Bjerkgård (2012a) |
| Abelvattnet | Sweden | Mafic | Phanerozoic | Deposit | 0.070 | 0.90 | 0.07 | - | - | - | Sandstad & Hallberg (2012) |
| Åkulla-Bastuheden[1] | Sweden | Felsic | Paleoproterozoic | Mine | 1.362 | 1.02 | 0.02 | - | 0.67 | 10.92 | FODD (2012) |
| Ankarvattnet | Sweden | Felsic | Phanerozoic | Deposit | 0.800 | 0.50 | 5.50 | 0.37 | 0.20 | 17.00 | Sandstad & Hallberg (2012), FODD (2012) |
| Åsen | Sweden | Felsic | Paleoproterozoic | Mine | 0.289 | 1.70 | 1.90 | 0.50 | 1.00 | 64.00 | FODD (2012) |
| Askelluokta | Sweden | Felsic | Paleoproterozoic | Deposit | 0.100 | - | 3.33 | 4.15 | - | - | FODD (2012) |
| Bastuheden Norra | Sweden | Felsic | Paleoproterozoic | Deposit | 0.070 | 0.07 | 4.60 | 1.06 | 1.70 | 86.00 | FODD (2012) |
| Beitsetjenjunje | Sweden | Bimodal-Mafic | Phanerozoic | Deposit | 0.200 | 0.97 | 1.00 | 0.16 | 0.20 | 13.00 | Sandstad & Hallberg (2012), FODD (2012) |
| Björkvattnet | Sweden | Mafic | Phanerozoic | Deposit | 0.130 | 0.73 | 0.40 | 0.05 | 0.20 | 4.00 | Sandstad & Hallberg (2012), FODD (2012) |
| Bjurfors[2] | Sweden | Felsic | Paleoproterozoic | Deposit | 0.801 | 0.65 | 2.62 | 0.15 | 0.50 | - | FODD (2012) |
| Bjurliden | Sweden | Felsic | Paleoproterozoic | Deposit | 0.730 | 0.11 | 3.45 | 0.36 | 0.30 | 46.30 | FODD (2012) |
| Bjurträsk[3] | Sweden | Felsic | Paleoproterozoic | Deposit | 0.410 | 0.55 | 2.26 | 0.02 | 0.28 | 6.12 | FODD (2012) |
| Bunsås koppargruva | Sweden | Felsic | Paleoproterozoic | Mine | 0.965 | 0.50 | 1.91 | - | 0.36 | 17.70 | FODD (2012) |
| Daningen | Sweden | Mafic | Phanerozoic | Deposit | 0.050 | 9.85 | 0.60 | - | 0.60 | 12.00 | Sandstad & Hallberg (2012), FODD (2012) |

Table 1. Cont.

| Name | Country | Deposit type | Age | Status | Tonnage (Mt) | Cu (%) | Zn (%) | Pb (%) | Au (g/t) | Ag (g/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Elvaberget | Sweden | Felsic | Paleoproterozoic | Deposit | 0.930 | 0.60 | 1.80 | 0.20 | 0.50 | 22.00 | FODD (2012) |
| Fjällboheden | Sweden | Felsic | Paleoproterozoic | Deposit | 0.200 | 0.50 | 0.21 | - | - | 3.00 | FODD (2012) |
| Garpenberg | Sweden | Felsic | Paleoproterozoic | Mine | 85.000 | 0.06 | 5.01 | 1.83 | 0.10 | 51.00 | FODD (2012) |
| Gräskevardo | Sweden | Felsic | Neoproterozoic | Deposit | 0.100 | 0.40 | 3.50 | 1.23 | 0.10 | 34.00 | FODD (2012) |
| Gruvberget | Sweden | Felsic | Paleoproterozoic | Mine | 0.046 | - | 10.00 | 4.50 | - | 200.00 | Hallberg & Ripa (2012) |
| Högkulla östra | Sweden | Felsic | Paleoproterozoic | Mine | 0.113 | 0.18 | 12.60 | 0.65 | 0.60 | 110.00 | FODD (2012) |
| Holmtjärn nya | Sweden | Felsic | Paleoproterozoic | Mine | 0.460 | 0.40 | 4.00 | 0.40 | 7.40 | 92.00 | FODD (2012) |
| Hornträskviken[4] | Sweden | Felsic | Paleoproterozoic | Deposit | 1.140 | 1.04 | 2.64 | 0.46 | 0.53 | 55.70 | FODD (2012) |
| Jervas | Sweden | Mafic | Phanerozoic | Deposit | 10.000 | 4.10 | 0.07 | 0.04 | - | - | FODD (2012) |
| Kallmorbergsfältet | Sweden | Felsic | Paleoproterozoic | Mine | 0.069 | 9.70 | 16.00 | 25.00 | - | 300.00 | Hallberg & Ripa (2012) |
| Kalvbäcksfältet | Sweden | Felsic | Paleoproterozoic | Mine | 0.556 | 0.10 | 8.30 | 3.60 | 0.30 | 100.00 | Hallberg & Ripa (2012) |
| Kankberg | Sweden | Felsic | Paleoproterozoic | Mine | 1.160 | 1.40 | 1.80 | 0.30 | 2.60 | 52.00 | FODD (2012) |
| Kaveltorps gruvor | Sweden | Felsic | Paleoproterozoic | Mine | 1.205 | 0.50 | 7.20 | 3.70 | - | - | Hallberg & Ripa (2012) |
| Kedträsk | Sweden | Felsic | Paleoproterozoic | Mine | 0.690 | 0.40 | 2.90 | 0.20 | 0.50 | 24.00 | FODD (2012) |
| Kimheden | Sweden | Felsic | Paleoproterozoic | Mine | 0.132 | 0.95 | 0.27 | - | 0.44 | 7.00 | FODD (2012) |
| Kristineberg | Sweden | Felsic | Paleoproterozoic | Mine | 34.513 | 1.10 | 6.09 | 0.26 | 1.20 | 47.80 | FODD (2012) |
| Långdal | Sweden | Felsic | Paleoproterozoic | Mine | 4.482 | 0.14 | 5.70 | 1.70 | 1.90 | 160.00 | FODD (2012) |
| Långsele | Sweden | Felsic | Paleoproterozoic | Mine | 11.205 | 0.60 | 3.90 | 0.30 | 0.90 | 25.00 | Hallberg (2012) |
| Långviken | Sweden | Felsic | Paleoproterozoic | Deposit | 0.100 | 1.50 | 0.68 | 0.11 | 0.50 | 19.00 | FODD (2012) |
| Levimalmen | Sweden | Felsic | Phanerozoic | Deposit | 5.000 | 1.40 | 1.60 | 0.10 | 0.20 | 24.00 | Sandstad & Hallberg (2012), FODD (2012) |
| Ljusnarsbergsfältet | Sweden | Felsic | Paleoproterozoic | Mine | 0.762 | - | 3.50 | 2.50 | - | - | Hallberg & Ripa (2012) |
| Lövåsfältet | Sweden | Felsic | Paleoproterozoic | Mine | 0.309 | - | 2.00 | 4.00 | - | - | Hallberg & Ripa (2012) |
| Lovisagruvan | Sweden | Felsic | Paleoproterozoic | Mine | 0.553 | - | 11.00 | 7.00 | - | - | FODD (2012) |
| Maurliden[5] | Sweden | Felsic | Paleoproterozoic | Deposit | 2.470 | 0.89 | 1.09 | 0.06 | 0.89 | 24.19 | FODD (2012) |
| Maurliden Västra | Sweden | Felsic | Paleoproterozoic | Mine | 5.058 | 0.20 | 3.40 | 0.40 | 0.90 | 49.00 | Hallberg (2012) |
| Mörkliden 1-2[6] | Sweden | Felsic | Paleoproterozoic | Deposit | 0.250 | 0.17 | 3.59 | 0.34 | 0.30 | 69.40 | FODD (2012) |
| Mörkliden-4[7] | Sweden | Felsic | Paleoproterozoic | Deposit | 1.090 | 0.85 | 0.73 | 0.05 | 0.58 | 7.75 | FODD (2012) |
| Näsliden[8] | Sweden | Felsic | Paleoproterozoic | Deposit | 4.930 | 1.09 | 2.70 | 0.28 | 1.31 | 35.36 | FODD (2012) |
| Norrliden Norra | Sweden | Felsic | Paleoproterozoic | Deposit | 2.343 | 0.80 | 7.80 | 0.70 | 1.20 | 100.00 | FODD (2012) |
| Nyborg | Sweden | Felsic | Paleoproterozoic | Deposit | 0.290 | 0.53 | 4.80 | 0.50 | 0.20 | 41.00 | FODD (2012) |
| Petiknäs norra | Sweden | Felsic | Paleoproterozoic | Deposit | 2.230 | 0.73 | 2.48 | 0.27 | 3.60 | 48.80 | FODD (2012) |
| Petiknäs södra | Sweden | Felsic | Paleoproterozoic | Mine | 5.399 | 0.90 | 4.90 | 0.90 | 2.40 | 102.00 | Hallberg (2012) |
| Rakkejaur | Sweden | Felsic | Paleoproterozoic | Mine | 20.720 | 0.30 | 2.30 | 0.20 | 1.00 | 45.00 | FODD (2012) |
| Rävliden | Sweden | Felsic | Paleoproterozoic | Mine | 7.543 | 1.00 | 4.23 | 0.79 | 0.50 | 90.00 | FODD (2012) |
| Rävlidmyran | Sweden | Felsic | Paleoproterozoic | Mine | 1.900 | 0.95 | 3.96 | 0.54 | 0.80 | 51.00 | FODD (2012) |
| Remdalen | Sweden | Bimodal-Mafic | Phanerozoic | Deposit | 0.700 | 1.43 | 2.74 | 0.04 | - | - | Sandstad & Hallberg (2012) |

Table 1. Cont.

| Name | Country | Deposit type | Age | Status | Tonnage (Mt) | Cu (%) | Zn (%) | Pb (%) | Au (g/t) | Ag (g/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Renström | Sweden | Felsic | Paleoproterozoic | Mine | 15.296 | 0.81 | 7.26 | 1.44 | 2.80 | 151.00 | FODD (2012) |
| Riddarhytte odalutmål | Sweden | Felsic | Paleoproterozoic | Mine | 0.028 | 7.70 | 12.00 | - | - | - | Hallberg & Ripa (2012) |
| Rikarbäcken | Sweden | Felsic | Phanerozoic | Deposit | 0.150 | 0.80 | 4.30 | 1.10 | 0.20 | 43.00 | Sandstad & Hallberg (2012), FODD (2012) |
| Rockliden | Sweden | Felsic | Paleoproterozoic | Deposit | 2.200 | 1.98 | 5.56 | 0.97 | - | 94.00 | FODD (2012) |
| Rudtjebäcken | Sweden | Felsic | Paleoproterozoic | Mine | 5.749 | 0.92 | 2.96 | 0.10 | 0.30 | 10.00 | FODD (2012) |
| Ryllshyttegruvan | Sweden | Felsic | Paleoproterozoic | Mine | 0.827 | - | 2.00 | - | - | - | Hallberg & Ripa (2012) |
| Saxberget | Sweden | Felsic | Paleoproterozoic | Mine | 6.433 | 0.90 | 7.10 | 2.20 | 0.40 | 42.00 | Hallberg & Ripa (2012) |
| Silvbergsgruvor | Sweden | Felsic | Paleoproterozoic | Mine | 0.011 | - | 5.60 | 1.20 | 4.50 | 45.00 | FODD (2012) |
| Skidträskbäcken | Sweden | Mafic | Phanerozoic | Deposit | 0.230 | 0.71 | 1.53 | 0.04 | - | 7.00 | Sandstad & Hallberg (2012), FODD (2012) |
| Skidträsk-bäcken Norra | Sweden | Mafic | Phanerozoic | Deposit | 0.140 | 0.46 | 0.10 | 0.07 | - | 3.00 | Sandstad & Hallberg (2012), FODD (2012) |
| Snåttermyran | Sweden | Felsic | Paleoproterozoic | Deposit | 0.100 | 0.30 | 6.60 | - | - | - | FODD (2012) |
| Stekenjokk | Sweden | Felsic | Phanerozoic | Mine | 17.098 | 1.35 | 3.22 | 0.36 | 0.30 | 54.00 | Sandstad & Hallberg (2012), FODD (2012) |
| Stollbergsmalmen | Sweden | Felsic | Paleoproterozoic | Mine | 3.481 | - | 3.00 | 5.00 | - | 20.00 | Hallberg & Ripa (2012) |
| Storbäcks-dalen Västra | Sweden | Felsic | Phanerozoic | Deposit | 0.150 | 1.20 | 6.30 | 2.40 | 0.50 | 49.00 | Sandstad & Hallberg (2012), FODD (2012) |
| Storliden | Sweden | Felsic | Paleoproterozoic | Mine | 1.659 | 4.00 | 10.00 | - | 0.30 | 30.00 | FODD (2012) |
| Svansele | Sweden | Felsic | Paleoproterozoic | Deposit | 0.650 | 0.30 | 5.20 | 0.30 | 0.50 | 27.00 | FODD (2012) |
| Svansele Väggruva | Sweden | Felsic | Paleoproterozoic | Deposit | 0.360 | 0.20 | 3.10 | 0.04 | 0.30 | 7.00 | FODD (2012) |
| Svärdsjö gruva | Sweden | Felsic | Paleoproterozoic | Mine | 1.044 | 0.60 | 4.50 | 1.50 | 0.40 | 66.00 | Hallberg & Ripa (2012) |
| Svartliden | Sweden | Felsic | Paleoproterozoic | Deposit | 0.465 | 1.65 | 0.20 | - | 0.10 | 17.20 | FODD (2012) |
| Tjärnberget | Sweden | Bimodal-Mafic | Paleoproterozoic | Deposit | 0.400 | 0.50 | 5.20 | 0.90 | - | - | FODD (2012) |
| Tjåter | Sweden | Felsic | Phanerozoic | Deposit | 0.150 | 1.00 | 4.80 | 1.90 | 0.50 | 49.00 | Sandstad & Hallberg (2012), FODD (2012) |
| Tjokkola | Sweden | Felsic | Phanerozoic | Deposit | 0.170 | 0.89 | 2.20 | 0.10 | 0.10 | 22.00 | Sandstad & Hallberg (2012), FODD (2012) |
| Udden | Sweden | Felsic | Paleoproterozoic | Mine | 5.950 | 0.50 | 4.80 | 0.30 | 0.80 | 39.00 | Hallberg (2012) |
| Unna Gaisartjåkko | Sweden | Bimodal-Mafic | Phanerozoic | Deposit | 1.000 | 0.80 | 0.50 | - | 0.50 | 20.00 | Sandstad & Hallberg (2012), FODD (2012) |
| Usmeten | Sweden | Bimodal-Mafic | Phanerozoic | Deposit | 0.250 | 1.28 | 0.31 | - | - | - | Sandstad & Hallberg (2012) |
| Viscaria[9] | Sweden | Mafic | Paleoproterozoic | Mine | 78.723 | 1.33 | 0.62 | 0.01 | 0.09 | 3.54 | FODD (2012) |
| Zincgruvan[10] | Sweden | Felsic | Paleoproterozoic | Mine | 58.881 | 0.52 | 7.63 | 3.50 | - | 75.75 | FODD (2012) |

Status: Mine – Deposit has been mined or is being mined, Deposit – Deposit has not been mined; -: Concentration not reported. Tonnes are rounded to full thousands.

[1]: Includes Åkulla Västra, Bastuheden Mellersta, Bastuheden Södra.
[2]: Includes Bjurfors Gruvfält, Bjurfors Mellersta.
[3]: Includes Bjurträsk Norra, Bjurträsk Södra.
[4]: Includes Hornträskviken, Hornträskviken Västra.
[5]: Includes Maurliden Norra, Maurliden Östra.
[6]: Includes Mörkliden 1, Mörkliden 2.
[7]: Includes Mörkliden, Mörkliden 4.
[8]: Includes Näsliden, Näsliden Norra.
[9]: Includes Viscaria, Viscaria D-Zone.
[10]: Includes Zinkgruvan, Zinkgruvan Cu.

Table 2. Summary of deposit types, ages, locations and status for the VMS deposits in the Fennoscandian grade-tonnage model.

| Felsic VMS | Palaeoproterozoic | Neoproterozoic | Phanerozoic | Total |
|---|---|---|---|---|
| Finland | 16 | | | 16 |
| Deposit | 7 | | | 7 |
| Mine | 9 | | | 9 |
| Norway | | 3 | 2 | 5 |
| Mine | | 3 | 2 | 5 |
| Sweden | 56 | 1 | 7 | 64 |
| Deposit | 21 | 1 | 6 | 28 |
| Mine | 35 | | 1 | 36 |
| Total | 72 | 4 | 9 | 85 |

| Bimodal-mafic VMS | Palaeoproterozoic | Neoproterozoic | Phanerozoic | Total |
|---|---|---|---|---|
| Finland | 1 | | | 1 |
| Deposit | 1 | | | 1 |
| Norway | | | 12 | 12 |
| Deposit | | | 3 | 3 |
| Mine | | | 9 | 9 |
| Sweden | 1 | | 4 | 5 |
| Deposit | 1 | | 4 | 5 |
| Total | 2 | | 16 | 18 |

| Mafic VMS | Palaeoproterozoic | Neoproterozoic | Phanerozoic | Total |
|---|---|---|---|---|
| Finland | 3 | | | 3 |
| Deposit | 1 | | | 1 |
| Mine | 2 | | | 2 |
| Norway | | 2 | 19 | 21 |
| Mine | | 2 | 19 | 21 |
| Sweden | 1 | | 6 | 7 |
| Deposit | | | 6 | 6 |
| Mine | 1 | | | 1 |
| Total | 4 | 2 | 25 | 31 |

## STATISTICS

Summary statistics for the mafic, bimodal-mafic and felsic VMS deposits are given in Table 3. Before calculating summary statistics, missing values for metal grades (reported as '-' in Table 1) were estimated using the robust ROS method (Helsel 2005) assuming a log-normal distribution. The missing grade values for each metal were then replaced by the median of the estimated missing values for that metal. Statistical tests indicate that, excluding zinc in the felsic group, metal grades and ore tonnage do not significantly differ from a log-normal distribution for the felsic, bimodal-mafic and mafic deposit types (Table 3, Figs. 1 and 2). Analysis of variance tests on the means of ore tonnages and metal grades show that there are significant differences between the deposit types. The following differences are significant at the one per cent level (Table 3, Fig. 3):

1. The felsic type has lower copper grades than both the bimodal-mafic and mafic types;
2. The mafic type has lower zinc grades than both the bimodal-mafic and felsic types;
3. The felsic type has higher lead grades than both

the bimodal-mafic and mafic types;

4. The felsic type has higher gold grades than both the bimodal-mafic and mafic types;
5. The felsic type has higher silver grades than both the bimodal-mafic and mafic types.

Some differences also exist between deposits of different ages. Felsic Palaeoproterozoic deposits have significantly lower copper than felsic Phanerozoic deposits, and bimodal-mafic Palaeoproterozoic deposits have significantly higher lead than bimodal-mafic Phanerozoic deposits. However, the small number of Precambrian mafic and bimodal-mafic deposits makes these comparisons uncertain.

The results above form the basis for creating separate grade-tonnage models for the felsic, bimodal-mafic and mafic deposit types. The models are summarised in Table 3.

Table 3. Summary statistics for VMS deposits.

| **Felsic subclass** | | | | | | |
|---|---|---|---|---|---|---|
| | **Tonnage (Mt)** | **Cu (%)** | **Zn (%)** | **Pb (%)** | **Au (g/t)** | **Ag (g/t)** |
| N of cases | 85 | 76 | 85 | 65 | 62 | 72 |
| Minimum | 0.011 | 0.030 | 0.024 | 0.0040 | 0.015 | 1.5 |
| Maximum | 85.000 | 9.7 | 16 | 25 | 7.4 | 300 |
| Mean | 5.520 | 0.86 | 4.0 | 1.2 | 0.66 | 43 |
| St dev | 14.051 | 1.4 | 3.0 | 2.9 | 1.1 | 48 |
| 90% | 0.100 | 0.075 | 0.69 | 0.023 | 0.056 | 4.3 |
| 50% | 0.930 | 0.54 | 3.5 | 0.36 | 0.30 | 27 |
| 10% | 11.205 | 1.5 | 7.6 | 3.5 | 1.4 | 100 |
| S-W p | 0.733 | 0.058 | 0.000 | 0.980 | 0.068 | 0.498 |
| T p F-B | 0.957 | 0.009 | 0.640 | 0.001 | 0.008 | 0.000 |
| T p F-M | 0.615 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Bimodal-Mafic subclass** | | | | | | |
| | **Tonnage (Mt)** | **Cu (%)** | **Zn (%)** | **Pb (%)** | **Au (g/t)** | **Ag (g/t)** |
| N of cases | 18 | 18 | 18 | 8 | 7 | 5 |
| Minimum | 0.100 | 0.50 | 0.31 | 0.00059 | 0.038 | 0.25 |
| Maximum | 6.900 | 1.9 | 6.9 | 0.96 | 0.80 | 53 |
| Mean | 1.477 | 1.2 | 2.8 | 0.17 | 0.27 | 8.2 |
| St dev | 1.651 | 0.49 | 2.0 | 0.30 | 0.24 | 13 |
| 90% | 0.200 | 0.69 | 0.65 | 0.0018 | 0.059 | 0.51 |
| 50% | 0.890 | 1.2 | 2.6 | 0.027 | 0.18 | 3.1 |
| 10% | 2.925 | 1.8 | 5.4 | 0.75 | 0.71 | 20 |
| S-W p | 0.885 | 0.359 | 0.382 | 0.511 | 0.339 | 0.332 |
| T p B-M | 0.632 | 0.998 | 0.007 | 0.492 | 0.688 | 0.254 |
| **Mafic subclass** | | | | | | |
| | **Tonnage (Mt)** | **Cu (%)** | **Zn (%)** | **Pb (%)** | **Au (g/t)** | **Ag (g/t)** |
| N of cases | 31 | 30 | 30 | 11 | 11 | 16 |
| Minimum | 0.050 | 0.17 | 0.010 | 0.000040 | 0.0024 | 0.59 |
| Maximum | 78.723 | 9.9 | 9.4 | 0.40 | 0.60 | 29 |
| Mean | 7.221 | 1.9 | 1.8 | 0.054 | 0.088 | 7.5 |
| St dev | 15.376 | 1.9 | 2.3 | 0.11 | 0.13 | 7.3 |
| 90% | 0.121 | 0.40 | 0.050 | 0.00022 | 0.0063 | 1.2 |
| 50% | 1.415 | 1.4 | 1.0 | 0.0052 | 0.037 | 3.8 |
| 10% | 21.821 | 4.1 | 5.1 | 0.24 | 0.23 | 18 |
| S-W p | 0.631 | 0.925 | 0.073 | 0.522 | 0.728 | 0.203 |

N of cases: Number of available data values; Mean: Arithmetic mean; St dev: Standard deviation; 90 %, 50 %, 10 %: Percentile values; S-W p: Shapiro-Wilk normality test p-value; T p F-B, T p F-M, T p B-M: Tukey's Honestly-Significant-Difference Test p-values for comparisons of means between the felsic and bimodal-mafic (F-B), felsic and mafic (F-M) and bimodal-mafic and mafic (B-M) types. The statistical tests are conducted using logatithmic values of tonnage and metal grades. The minimum, mean, standard deviation and percentiles are estimated for Cu in the felsic subclass and for Pb, Au and Ag in all the subclasses, using the robust ROS method (Helsel 2005) assuming a log-normal distribution. Tonnages are rounded to full thousands and grades to two significant digits.

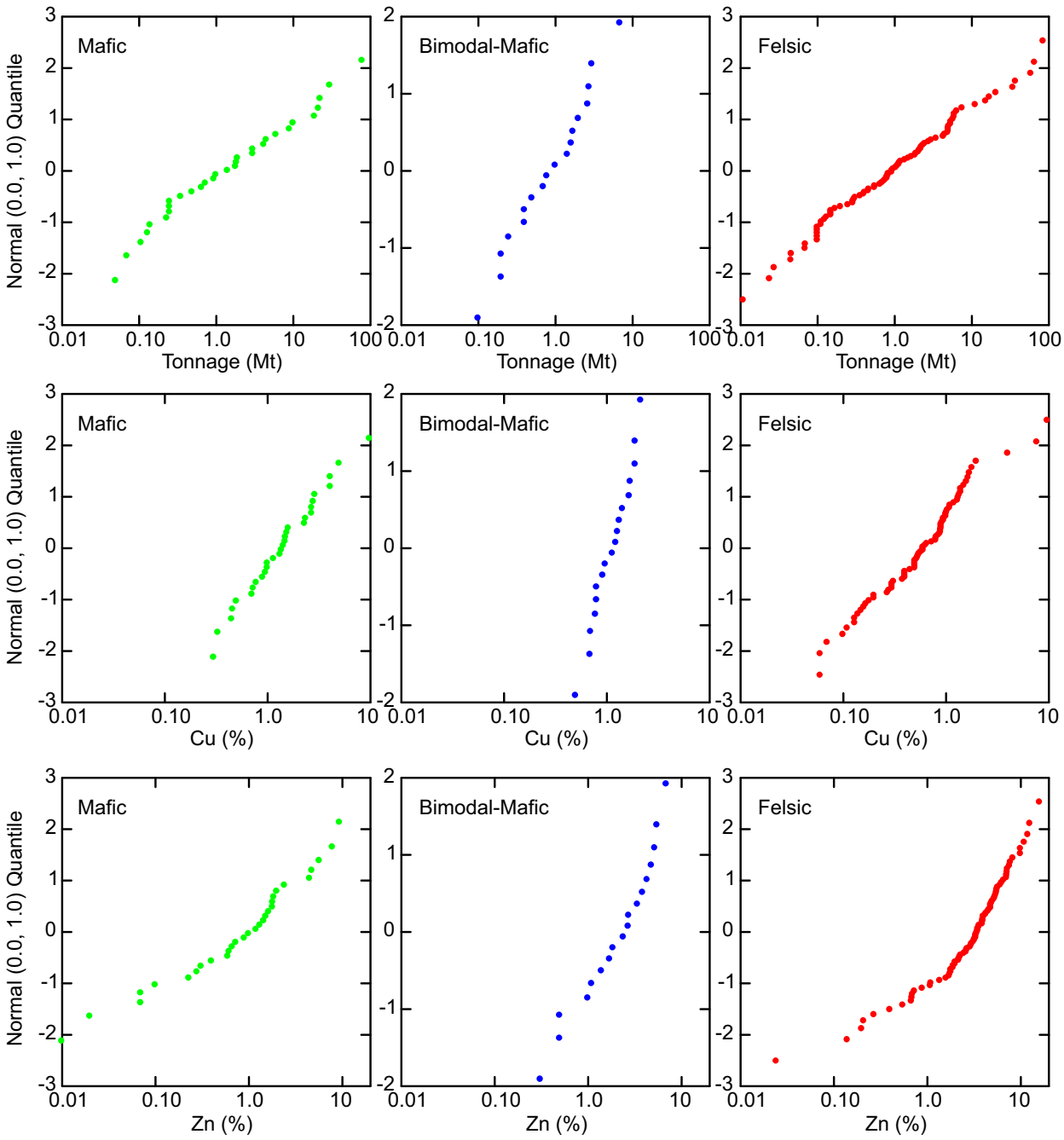


Fig. 1. Normal probability plots of ore tonnage and copper and zinc grades for mafic, bimodal-mafic and felsic VMS deposits in Table 1.

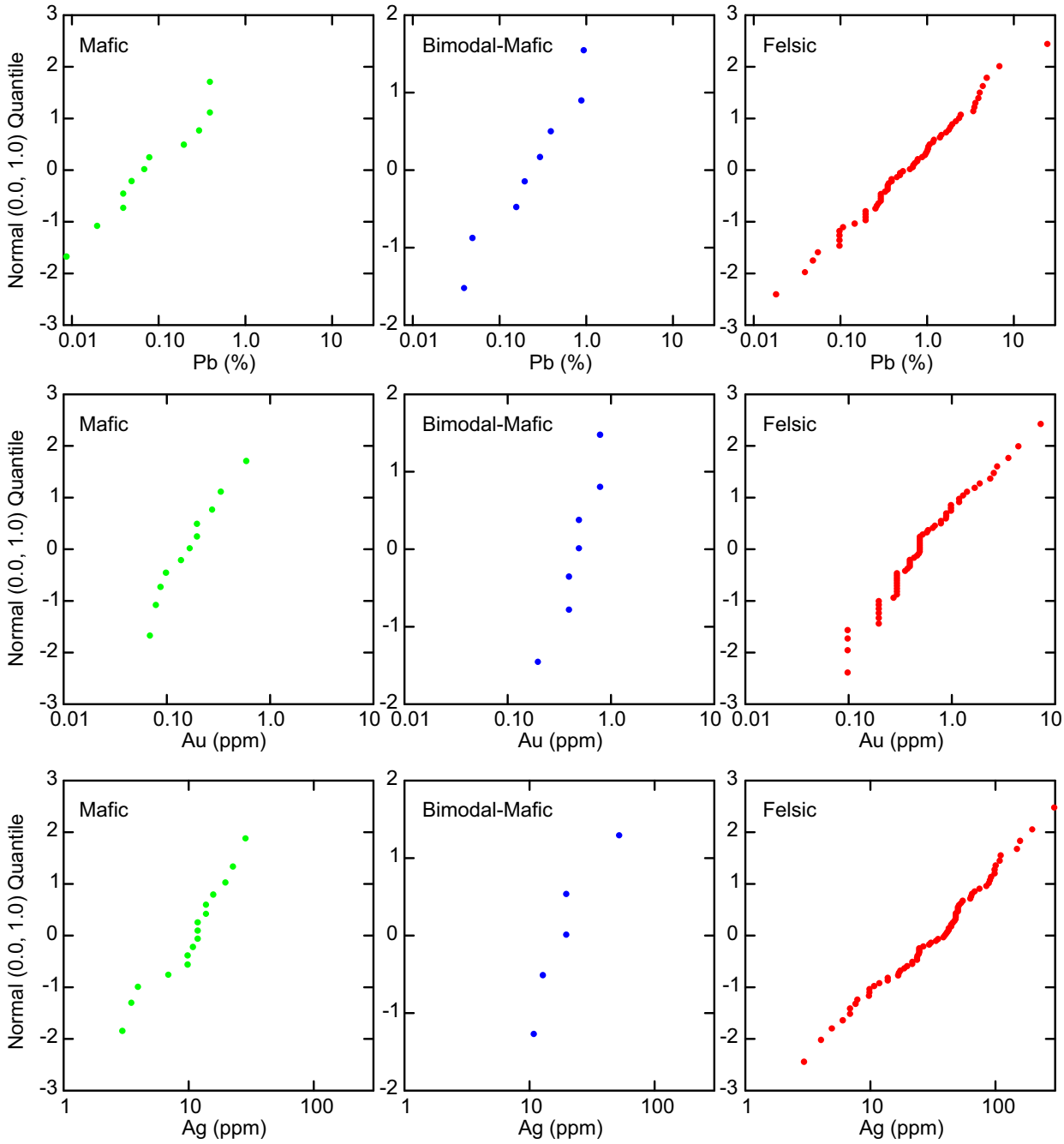


Fig. 2. Normal probability plots of lead, gold and silver grades for mafic, bimodal-mafic and felsic VMS deposits in Table 1.

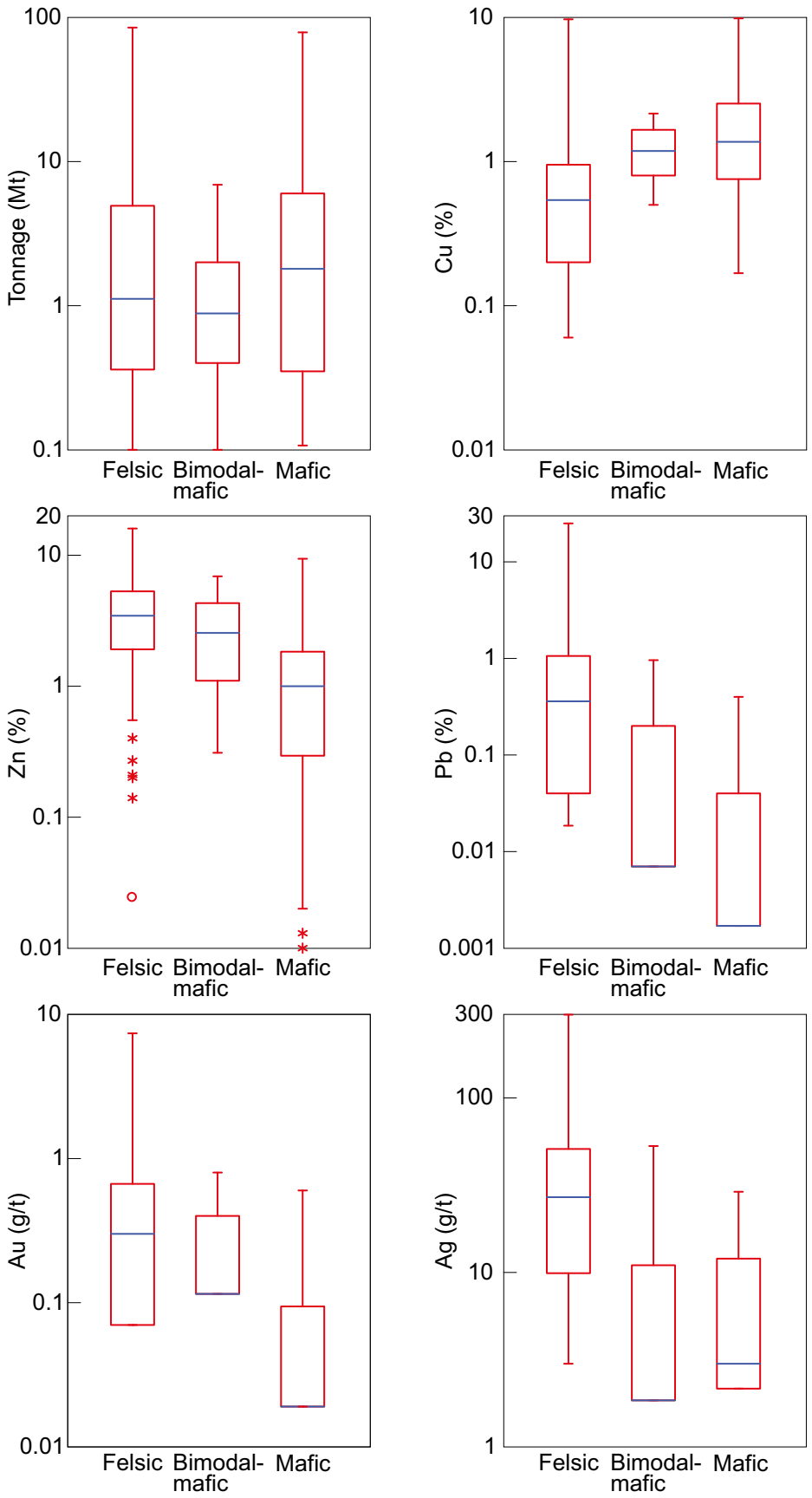


Fig. 3. Box plots of ore tonnage and metal grades for mafic, bimodal-mafic and felsic VMS deposits in Table 1.

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**APPENDIX 3**

# DESCRIPTIVE MODEL OF PORPHYRY COPPER (GOLD, MOLYBDENUM)

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**DESCRIPTION** This is a generalised model that includes various subtypes, all of which contain chalcopyrite (+ molybdenite in Mo-rich cases) in stockwork veinlets in a hydrothermally altered porphyry intrusion and adjacent country rocks. In Cu-Au porphyries, Au ppm/Mo % ≥ 30; in Cu-Mo porphyries, Au ppm/Mo % ≤ 3.

**GENERAL REFERENCE** John et al. (2010), Sillitoe (2010). Other useful references include Cox (1986a, 1986b, 1986c), Kirkham & Sinclair (1996), Richards (2003).

## EXAMPLES

Ann-Mason, USA (Dilles & Einaudi 1992, Seedorf et al. 2008)
Bingham Canyon, USA (Redmond & Einaudi 2010)
El Teniente, Chile (Vry et al. 2010)
Aitik, Sweden (Wanhainen et al. 2005)

## GEOLOGICAL ENVIRONMENT

**Rock Types** A composite, I-type, magnetite-series (i.e. oxidised), calc-alkaline or alkaline diorite to granodiorite and tonalite, monzodiorite to monzonite (shoshonitic) stock and its immediate country rocks. Gold-rich porphyries are more commonly alkaline than the Au-poor and Mo-rich types.

**Textures** The porphyry has closely-spaced phenocrysts and aplitic groundmass. However, the porphyritic texture is not distinct in all cases.

**Age Range** Perhaps >90 % of known deposits are Mesozoic to Cainozoic, but deposits of all ages since ca. 3.3 Ga are known.

**Depositional Environment** High-level (<10–5 km palaeodepth) intrusions contemporaneous with abundant dykes, magmatic breccia pipes and faults. Also cupolas of batholiths.

**Tectonic Setting(s)** The deposit is in an igneous arc (greenstone belt, continental arc, island arc) in a broadly contractional setting, in convergent plate margins. Isolated deposits in post-subduction continental margin rifts. Commonly in sites of local extension, e.g., the junction of arc-parallel and cross-cutting lineaments.

**Associated Deposit Types** Au, Cu, Fe, Zn skarns, high- and intermediate-sulphidation epithermal Au (±Ag ± Cu), polymetallic veins (Au, Ag, Cu, Pb, Zn, Mn, As), polymetallic replacement (Ag, Pb, Zn, Cu), sediment-hosted distal-disseminated Au-Ag ± Sb ± Hg. Replacement and skarn mineralisation are common if calcareous country rocks are present, but otherwise uncommon.

## DEPOSIT DESCRIPTION

**Mineralogy** Chalcopyrite + pyrite ± molybdenite, Chalcopyrite + pyrite ± bornite ± native gold, Chalcopyrite + magnetite ± bornite ± native gold, electrum, hessite, sylvanite. Quartz + K feldspar + biotite ± anhydrite, quartz + sericite + clay minerals. Late or peripheral veins of enargite, tetrahedrite, galena, sphalerite, baryte, calcite, chalcopyrite + sphalerite + galena + gold, and Cu-Ag-Sb sulphides + baryte + gold may occur.

**Texture/Structure** Multiple sets of stockwork veins, veinlets, dissemination and breccia matrices. Multi-stage quartz ± sulphides ± mica veining. Poorly developed vein networks in alkaline intrusions. Massive replacement in favourable country rocks (calcareous sediments and ferrous iron-rich igneous rocks). *Root zones* (> 5 km?) are characterised by sheeted quartz veins + potassic alteration, sodic-calcic, sodic and calcic alteration, and relatively coarse-grained muscovite-quartz greisen domains (Seedorf et al. 2008). Quartz veins + potassic alteration occur in the central and sodic to calcic alteration in the flanks of the root zones.

**Alteration** From the bottom (>5 km palaeodepth), innermost zones upward: Albite-actinolite-magnetite, Actinolite, Albite, Potassic (K feldspar + biotite), K (transitional to Ca), Albitic transitional to potassic and sericitic, Sericitic, Advanced argillic. Distal propylitic, and/or sericitic to advanced argillic commonly show partial overprint, and may cause remobilisation of Cu (±Au), due to telescoping of the hydrothermal system. Greisen alteration may occur in the deep root zones of the system and skarnification in calcareous country rocks. The potassic and sericitic alteration types are invariably associated with sulphide mineralisation.

**Ore Controls** Stockwork veins, closely-spaced veinlets and fractures – filled by quartz, sulphides, K feldspar, magnetite, biotite, or chlorite – in the porphyry intrusion and in the immediate country rocks. Country rocks host ore especially if they have a favourable chemical composition, such as a calcareous or a high ferrous iron content. A bell-, shell-, ring- or torus-like original ore zone around the core of the intrusion is very common; the core may be silicified or pyritised, but typically carries lower Cu, Au or Mo grades than the main ore shell. The form of the deposit is commonly affected by postmineralisation erosion, faulting and deformation, however.

**Weathering** Copper silicates and carbonates, iron oxide stain, haematite, limonite. May leach all Cu from the upper parts of the weathered profiles, whereas Au may be enriched. Residual soils may contain anomalous amounts of rutile. On the

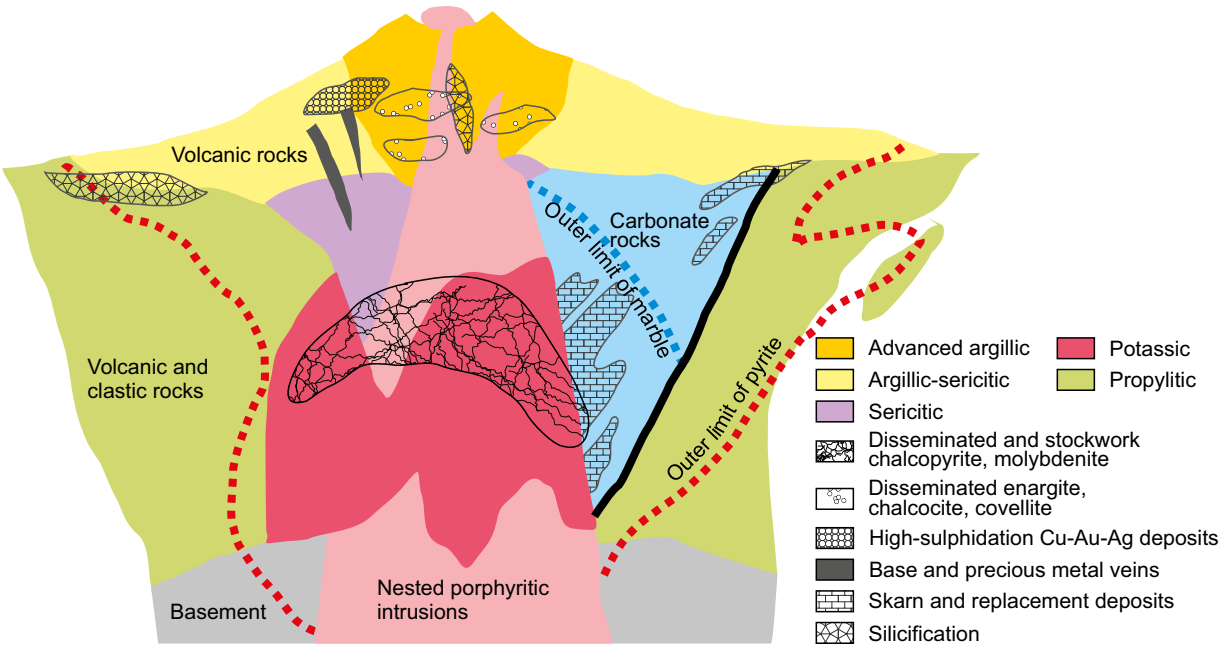


Fig. 1. A schematic model of a porphyry copper system showing distribution and types of mineral deposits, rocks and alteration zones. Modifier from Graybeal & Vikre (2010).

other hand, the supergene Cu sulphide mineralisation typically has a higher grade than the hypogene part of the deposit, whereas supergene oxide parts (formed above the sulphide mineralisation) may have higher or lower Cu concentrations. Molybdenum is not significantly enriched in the supergene parts.

**Geochemical Signature** Cu + Mo + Au ± Ag, W, B, Sr for central parts, Pb, Zn, Cu, As, Sb, Se, Te, Mn, Co, Ba, Rb for outer parts. In some cases, $\delta^{18}O$ depletion, As, Bi, Sn and/or Hg form the most distal anomalies which may extend for 10 km or more beyond the ore. High S in all zones.

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**APPENDIX 4**

# GRADE-TONNAGE MODEL OF PRECAMBRIAN PORPHYRY COPPER

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## INTRODUCTION

This model contains data from 27 Precambrian porphyry copper deposits (Table 1). A spatial rule has been applied, according to which deposits less than 2000 m from each other have been combined.

## DATA

The model includes data from the following databases: Singer et al. (2005), Sinclair (2007) and FODD (2011). The individual deposits in the model are listed in Table 1. Only Precambrian deposits with no missing data for tonnage and Cu grade were accepted for the model. The Singer et al. (2005) data include eight Precambrian deposits, the Sinclair (2007) data include 15, and the FODD data four. Tonnage and grade values for the Boddington deposit were updated based on the Australian Mines Atlas database (Geoscience Australia 2011).

Altogether, the model contains 27 Precambrian deposits. Based on Au and Cu grades, the deposits can be classified into three categories: Cu-Au (Au/Mo ≥ 30), Cu-Mo (Au/Mo ≤ 3) and Cu (3 < Au/Mo < 30), where Au is the gold grade in g/t and Mo is molybdenum grade in weight % (Cox & Singer 1992). The data include 12 Cu-Au deposits, 8 Cu-Mo deposits and 7 Cu deposits.

## STATISTICS

Summary statistics of the Precambrian porphyry copper deposit model are provided in Table 2. Statistical tests indicate that metal grades and ore tonnages do not significantly differ from the log-normal distribution for the whole group of Precambrian deposits. (Table 2, Figure 1). Analysis of variance tests on the means of ore tonnages and metal grades indicate that the three deposit types (Cu, Cu-Au, Cu-Mo) do not differ significantly in tonnage or copper grade. They are expected to differ in Mo and Au, and possibly also in Ag, but insufficient Mo, Au and Ag values are available to quantify the differences. Hence, no Precambrian porphyry copper grade-tonnage submodels were constructed.

Table 1. Precambrian porphyry copper deposits included in the grade-tonnage model.

| Name | Country | Deposit type | Age | Status | Tonnage (Mt) | Cu (%) | Mo (%) | Ag (g/t) | Au (g/t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| Boddington | Australia | Cu-Au | Archaean | Mine | 1474.258 | 0.10 | - | - | 0.58 | Sinclair (2007) |
| Coppin Gap | Australia | Cu-Mo | Archaean | Deposit | 102 | 0.15 | 0.105 | - | - | Singer et al. (2005) |
| Mount Angelo | Australia | Cu | Palaeoproterozoic | Deposit | 21 | 0.44 | - | - | - | Sinclair (2007) |
| Gaoua | Burkina Faso | Cu-Au | Palaeoproterozoic | Deposit | 24 | 0.80 | - | - | 0.5 | Sinclair (2007) |
| Goren | Burkina Faso | Cu | Palaeoproterozoic | Deposit | 40 | 0.35 | - | - | - | Sinclair (2007) |
| Beidelman Bay | Canada | Cu | Archaean | Deposit | 0.01 | 0.20 | 0.03 | - | 0.4 | Sinclair (2007) |
| Coxheath | Canada | Cu-Au | Neoproterozoic | Mine | 0.405 | 3.15 | - | 85 | 1.2 | Sinclair (2007) |
| Don Rouyn | Canada | Cu | Archaean | Mine | 36 | 0.15 | - | - | - | Singer et al. (2005) |
| East Sullivan porphyry | Canada | Cu-Mo | Archaean | Deposit | 5 | 0.20 | 0.02 | - | - | Sinclair (2007) |
| Grandroy | Canada | Cu-Au | Archaean | Mine | 0.450 | 1.33 | - | - | 0.37 | Sinclair (2007) |
| Jogran | Canada | Cu-Mo | Mesoproterozoic | Deposit | 20 | 0.19 | 0.05 | - | - | Singer et al. (2005) |
| Macleod Lake | Canada | Cu-Mo | Archaean | Deposit | 37 | 0.44 | 0.05 | 3.7 | 0.04 | Sinclair (2007) |
| McIntyre | Canada | Cu-Au | Archaean | Mine | 12.86 | 0.50 | - | - | 1.3 | Sinclair (2007) |
| R-2 | Canada | Cu-Mo | Archaean | Deposit | 10.886 | 0.36 | 0.015 | - | - | Sinclair (2007) |
| Tribag | Canada | Cu-Mo | Mesoproterozoic | Deposit | 165 | 0.15 | 0.03 | - | - | Singer et al. (2005) |
| Troilus ( Lac Frotet) | Canada | Cu-Au | Archaean | Mine | 71.195 | 0.10 | - | - | 0.93 | Sinclair (2007) |
| Tongkuangyu | China | Cu-Mo | Palaeoproterozoic | Deposit | 440 | 0.69 | 0.003 | 0.22 | - | Singer et al. (2005) |
| Kopsa | Finland | Cu-Au | Palaeoproterozoic | Deposit | 25 | 0.18 | - | 4 | 0.57 | FODD (2011) |
| Malanjkhand | India | Cu-Au | Mesoproterozoic | Deposit | 797 | 0.83 | 0.003 | 6 | 0.2 | Singer et al. (2005) |
| Haib | Namibia | Cu | Palaeoproterozoic | Deposit | 1350 | 0.23 | - | - | - | Sinclair (2007) |
| Lobash | Russia | Cu-Mo | Archaean | Deposit | 173 | 0.03 | 0.075 | - | - | Sinclair (2007) |
| Pellapahk | Russia | Cu | Archaean | Deposit | 667.741 | 0.25 | 0.062 | 2.12 | 1.09 | FODD (2011) |
| Aitik | Sweden | Cu-Au | Palaeoproterozoic | Mine | 2750.238 | 0.21 | 0.003 | 1.3 | 0.17 | FODD (2011) |
| Tallberg | Sweden | Cu-Au | Palaeoproterozoic | Deposit | 44 | 0.27 | - | 1 | 0.2 | FODD (2011) |
| Copper King | United States | Cu-Au | Mesoproterozoic | Deposit | 35 | 0.21 | - | - | 0.75 | Singer et al. (2005) |
| Las Cristinas | Venezuela | Cu-Au | Palaeoproterozoic | Deposit | 255.4 | 0.12 | - | - | 1.16 | Sinclair (2007) |
| Samba | Zambia | Cu | Mesoproterozoic | Deposit | 50 | 0.50 | - | - | - | Singer et al. (2005) |

Status: Mine – Deposit has been mined or is being mined, Deposit – Deposit has not been mined; -: Concentration not reported. Tonnes are rounded to full thousands.

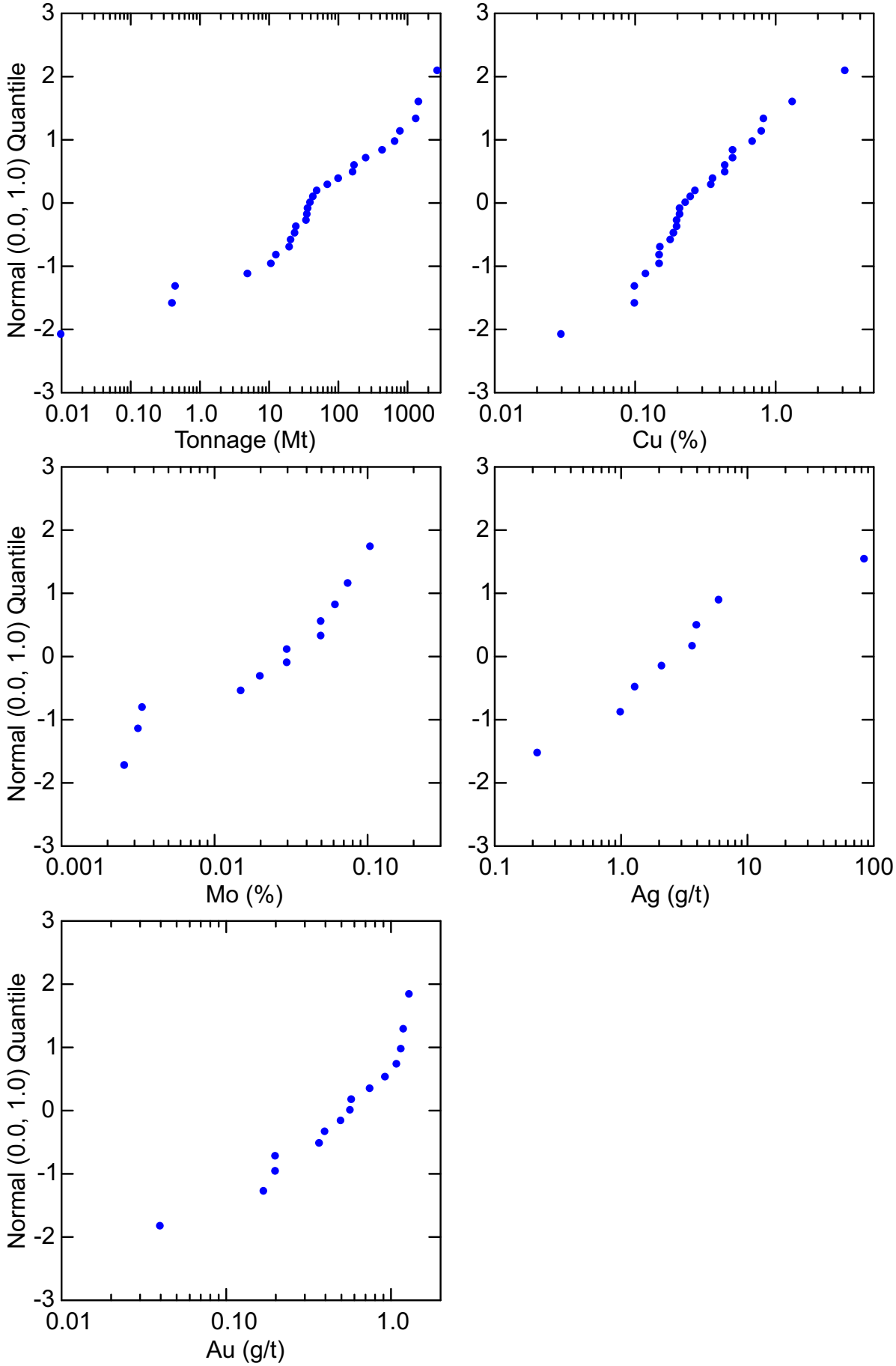


Fig. 1. Normal probability plots of tonnage and metal grades for the Precambrian porphyry deposits in Table 1.

Table 2. Summary statistics for Precambrian porphyry copper deposits.

| | Tonnage (Mt) | Cu (%) | Mo (%) | Ag (g/t) | Au (g/t) |
|---|---|---|---|---|---|
| N of cases | 27 | 27 | 12 | 8 | 15 |
| Minimum | 0.01 | 0.03 | 0.001 | 0.079 | 0.014 |
| Maximum | 2750.24 | 3.15 | 0.105 | 85 | 1.3 |
| Mean | 320 | 0.45 | 0.021 | 4.7 | 0.38 |
| St Dev | 630 | 0.61 | 0.026 | 16 | 0.42 |
| 90% | 1.4 | 0.10 | 0.0024 | 0.20 | 0.034 |
| 50% | 40 | 0.23 | 0.011 | 1.1 | 0.17 |
| 10% | 1200 | 0.82 | 0.060 | 4.1 | 1.1 |
| S-W p | 0.025 | 0.498 | 0.765 | 0.261 | 0.068 |

N of cases: Number of available data values; Mean: Arithmetic mean; St dev: Standard deviation; 90 %, 50 %, 10 %: Percentile values; S-W p: Shapiro-Wilk normality test p-value (calculated for logarithmic values). The minimum, mean, standard deviation and percentiles for Mo, Ag and Au are estimated using the robust ROS method (Helsel 2005) assuming a log-normal distribution. Statistics other than minimum and maximum are rounded to two significant digits.

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**APPENDIX 5**

# DESCRIPTIVE MODEL OF OUTOKUMPU-TYPE CU-ZN-CO

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**DESCRIPTION** Lenses to sheets of massive–semi-massive Cu-Zn-Co sulphides with parallel zones of dissemination in association with usually metamorphosed carbonate-silica altered ultramafic rocks, which are typically residual mantle peridotites in ultramafic-dominated ophiolite bodies.

## EXAMPLES

Outokumpu, Finland (Gaal & Parkkinen 1993, Kontinen et al. 2006, Peltonen et al. 2008)
Eastern Metals, Quebec, Canada (Auclair et al. 1993)
Dur'ngoi (Derni), Kunlun Mountains, China (Yang et al. 1997)

## GEOLOGICAL ENVIRONMENT

**Rock Types** Serpentinised ultramafic and metaultramafic rock bodies with pre-peak metamorphic, low-T carbonate-silica alteration in their margins. Typically enclosed by dominantly sedimentary sequences that in the ore environments contain graphite-sulphide-rich black shale units with interlayers of bedded-laminated pyritic mud. The massive to semi-massive ore bodies frequently occur as lenses or sheets between the carbonate-silica altered ultramafic rocks and black shale.

**Structures and textures** Host rock magmatic and sedimentary structures and textures appear unimportant for primary mineralisation. However, where unmetamorphosed to weakly metamorphosed, the host ultramafic rocks generally have textural features suggesting a mantle residual peridotite origin; such features are occasionally also preserved in the carbonate-silica alteration products. The enclosing sediments are typically of a deepwater turbidite character. Final localization of the sulphides is in many cases by remobilization into faults/shear zones relatively late in sequences of regional structural events. Related to this, the host rock and ore bodies commonly show distinct mylonitic mineral segregation banding, which is easily mistaken for sedimentary bedding-lamination.

**Age Range** Early Proterozoic (ca. 1.95 Ga) in the Outokumpu area in Finland, Cambrian–Ordovician in Quebec Appalachians, and Permian–Triassic in Kunlun Mountains in China. The emergence of the Outokumpu-type deposits in the global rock record is possibly defined by the onset of the modern-style plate tectonics and/or ophiolite incorporation and preservation in the record (at ca. 2.0 Ga?).

**Environment of Formation** The Outokumpu-type deposits are inferred to be polygenetic with mineralisation in two main stages and formational environments: 1) Formation of a Cu proto-ore by submarine hydrothermal processes within domi-

nantly ultramafic oceanic crust, and 2) syntectonic interaction/mixing of the Cu protosulphides with Ni-rich sulphides developed subsequent to the Cu-mineralised rock in the adjoining carbonate-silica altered peridotites.

**Tectonic Setting(s)** The Cu-Zn-Co proto-ore sulphides are interpreted to have formed within slow-spreading oceanic ridges or leaky oceanic transform faults, which expose mantle residual peridotites by mechanisms such as listric faulting, and which rapidly became buried below a continent-derived blanket of turbidite fans. The carbonate-silica alteration of peridotites and the associated sulphidation of their silicate Ni occurred during obduction and accretion of the host ultramafic bodies and the enclosing (initially covering) turbidites into the continental rock record. The interaction and mixing of the Cu-Zn-Co and Ni sulphides, responsible for the high Ni characteristic of Outokumpu-type sulphides (compared to conventional VMS and SEDEX sulphides), took place after the host ophiolite obduction, during the regional deformation and metamorphism.

**Associated Deposit Types** In the Outokumpu type area, low-grade (Kokka-type) Ni sulphide occurrences (Huhma, 1975; Kontinen et al. 2006) in carbonate-silica rocks and their metamorphic derivatives (diopside-tremolite calc-silicate and quartz rocks). However, it is noteworthy that these Ni occurrences are generally without any indications of related Cu-Zn-Co sulphides.

## DEPOSIT DESCRIPTION

**Mineralogy** The usual main sulphides both in the massive–semi-massive and parallel dissemination types, in various proportions and in part depending on metamorphic grade, are pyrrhotite, pyrite, chalcopyrite, cubanite, sphalerite, Co-pentlandite, and cobaltite. In addition, a wide variety of minor to trace sulphides, arsenides and oxides may occur, including cassiterite, linneite, mackinawite, magnetite, maucherite, siegenite, and stannite. Gangue minerals are typically restricted to quartz, carbonate and calc-silicate minerals. In amphibolite grade environments, many metamorpohogenic mineral rarities such as gem-quality Cr-diopside, Cr-epidote, Cr-tourmaline, eskolaite, gahnite, karelianite and uvaroite have been detected within the marginal parts of the massive–semi-massive ore bodies and in the parallel disseminated parts.

**Structures and Textures** The massive–semi-massive ores are variably massive and granoblastic, sulphide blebby or distinctly sulphide-quartz ±calc-silicate banded, reflecting the varying effects of deformation (usually in multiple events), peak metamorphism and related recrystallisation. Sulphide blebs, veinlets and dissemination typify the parallel low-grade Co-Ni-enriched zones. In the Outokumpu type area, peak metamorphism post-dated the initial Cu-Zn-Co stage and the main events of deformation, possibly by ca. 100 Ma and ca. 50 Ma, respectively. The late peaking of metamorphism caused grade-intensifying recrystallization and annealing of sulphides and quartz.

**Alteration** Listwaenite–birbirite-type carbonate-silica alteration of host ultramafic rocks is an always occurring characteristic of the ore environments, but seems a nonessential requirement for the existence of the Cu sulphides. However, the carbonate-silica alteration and associated silicate Ni sulphidation was an essential prerequisite for the syntectonic Ni enrichment of the Cu-Zn-Co protosulphides.

**Ore Controls** The initial Cu-Zn-Co mineralisation is inferred to have been produced by thermally driven hydrothermal circulation within dominantly ultramafic seafloor/oceanic crust, where fluid upflow zones, venting and related sulphide precipitation were controlled by prominent listric or strike-slip faults and related fractures. Sulphidation of silicate nickel in the protoliths of the carbonate-silica alteration fringes was caused by early metamorphic (>250 °C), C-S-bearing fluids partly derived from the adjacent C-S-rich black shales. During the subsequent higher temperature syntectonic interaction of the Cu and Ni sulphides, the main control was probably fluid-assisted diffusion over the ore–host rock contacts. The final location and shape of the ore bodies are typically controlled by faults post-dating the major deformation

events. The sulphides have been remobilised into these faults to form from small lenses up to tens of metres thick and kilometres long tapeworm-shaped bodies. Considering exploration, the most promising targets appear to be areas where wide zones of carbonate-silica altered ultramafic rocks are in faulted/sheared contact with thick layers of graphite- and sulphide-rich black shales. The economically decisive massive–semi-massive bodies tend to occur just along such contacts or only slightly (up to a few hundred metres at maximum) displaced/remobilized into the adjacent peridotites/altered peridotites (Fig. 1A) or enveloping sedimentary rocks (Fig. 1B).

**Weathering** Negligible to weakly oxidised surficial weathering in the Outokumpu type area, Finland.

**Geochemical Signature** Ni, Cu, Zn.

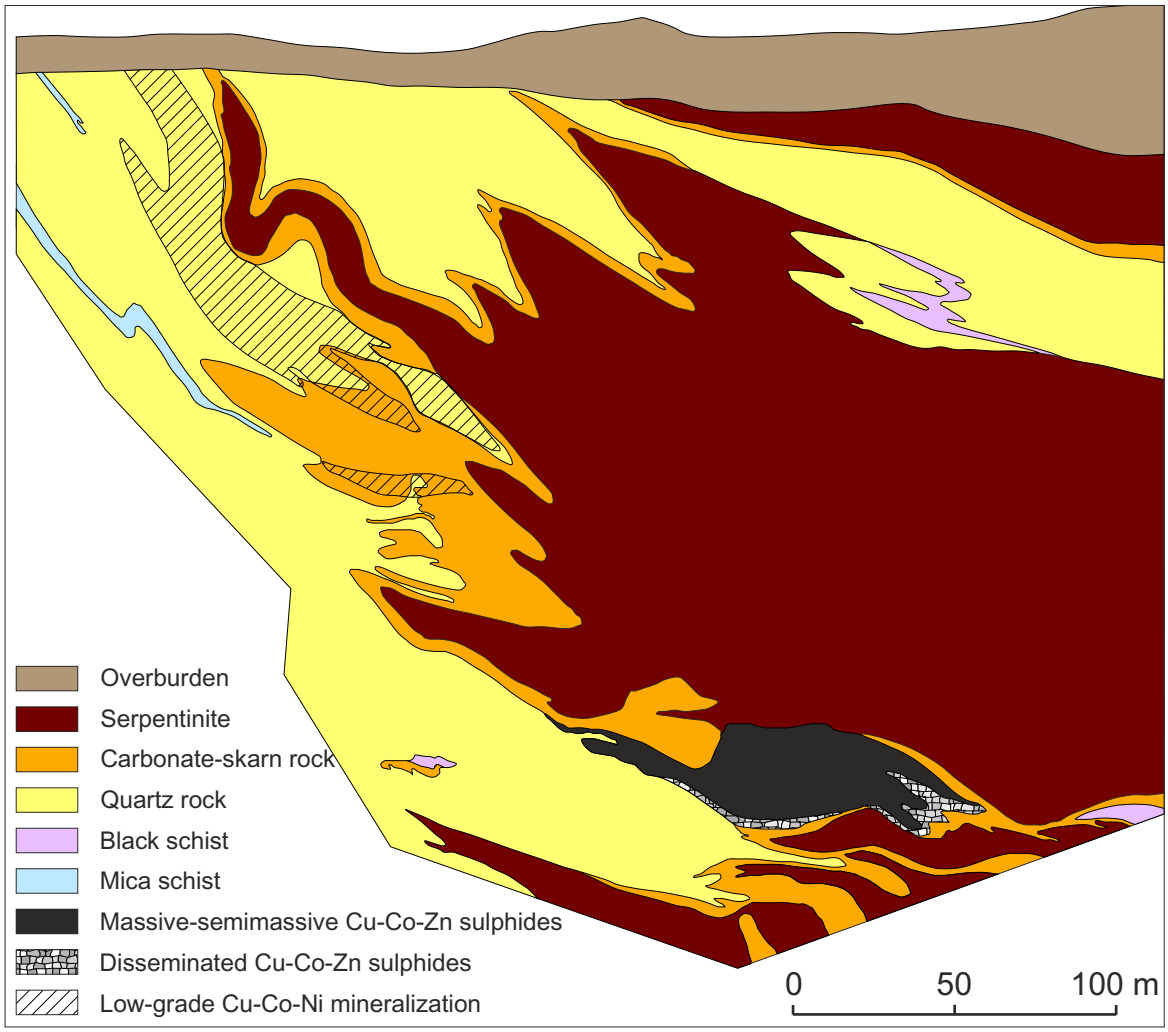


Fig. 1. (A) Profile view across the Outokumpu deposit. Modified from Kontinen et al. (2006).

Fig. 1. (B) Profile view across the Kylylahti deposit. The 1000 ppm Cu isopleths approximates the parallel low-grade Cu-Co-Ni dissemination related to the massive–semi-massive sulphide lens; in (A) the same feature is indicated by diagonal hatching. Modified from Kontinen et al. (2006).

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**APPENDIX 6**

# GRADE-TONNAGE MODEL OF OUTOKUMPU-TYPE CU-ZN-CO

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## INTRODUCTION

This model contains data from 10 Outokumpu-type 1.95–1.91 Ga Cu-Zn-Co deposits in Finland. A spatial rule has been applied, according to which deposits less than 500 m from each other have been combined. We have adopted the recent model by Peltonen et al. (2008), according to which the Outokumpu deposits are polygenetic with mineralisation in two main stages and formational environments. In the first stage, a Cu proto-ore is formed by submarine hydrothermal processes in dominantly ultramafic oceanic crust. The second stage consists of syntectonic interaction of the Cu sulphides with Ni-rich sulphides developed subsequent to the Cu mineralisation in the adjoining carbonate-silica altered peridotites. According to Peltonen et al. (2008), close analogies for the Outokumpu-type deposits are very uncommon. Hence, this grade-tonnage model only contains deposits from the Outokumpu area in Finland.

## DATA

All the 10 Outokumpu-type deposits in the model are listed in Table 1 with references to the grade-tonnage data. Four of the deposits have been mined in the past; at present, only the Kylylahti mine is in operation. The remaining six deposits in the model have not been developed into mines.

Table 1. Outokumpu-type deposits included in the grade-tonnage model.

| Name | Status | Tonnage (Mt) | Cu (%) | Zn (%) | Co (%) | Ni (%) | Reference |
|---|---|---|---|---|---|---|---|
| Hoikka | Deposit | 0.2 | 0.50 | 0.10 | 0.04 | 0.15 | Parkkinen (1997) |
| Hietajärvi | Deposit | 0.341 | 0.67 | 1.13 | 0.14 | 0.18 | Isomäki (1994) |
| Kettukumpu | Deposit | 0.4 | 0.44 | 0.10 | 0.07 | 0.18 | Parkkinen (1997) |
| Riihilahti | Deposit | 0.7 | 0.72 | 0.09 | 0.09 | 0.03 | Parkkinen (1997) |
| Perttilahti | Deposit | 1.324 | 2.15 | 1.89 | 0.16 | 0.15 | Hakanen (1985) |
| Saramäki | Deposit | 3.4 | 0.71 | 0.63 | 0.09 | 0.05 | Parkkinen (1997) |
| Vuonos Cu | Mine | 6.26 | 2.09 | 1.32 | 0.14 | 0.12 | Kontinen et al. (2006), Vulcan Resources (2009) |
| Luikonlahti | Mine | 7.7 | 1.20 | 0.65 | 0.12 | 0.09 | Eskelinen et al. (1983) |
| Kylylahti | Mine | 8.395 | 1.25 | 0.54 | 0.24 | 0.20 | Universal Resources (2010), Altona Mining Ltd (2013) |
| Outokumpu | Mine | 31.66 | 3.46 | 0.97 | 0.23 | 0.15 | Parkkinen (1997), Altona Mining Ltd (2012) |

Status: Mine – Deposit has been mined or is being mined, Deposit – Deposit has not been mined. Tonnes are rounded to full thousands.

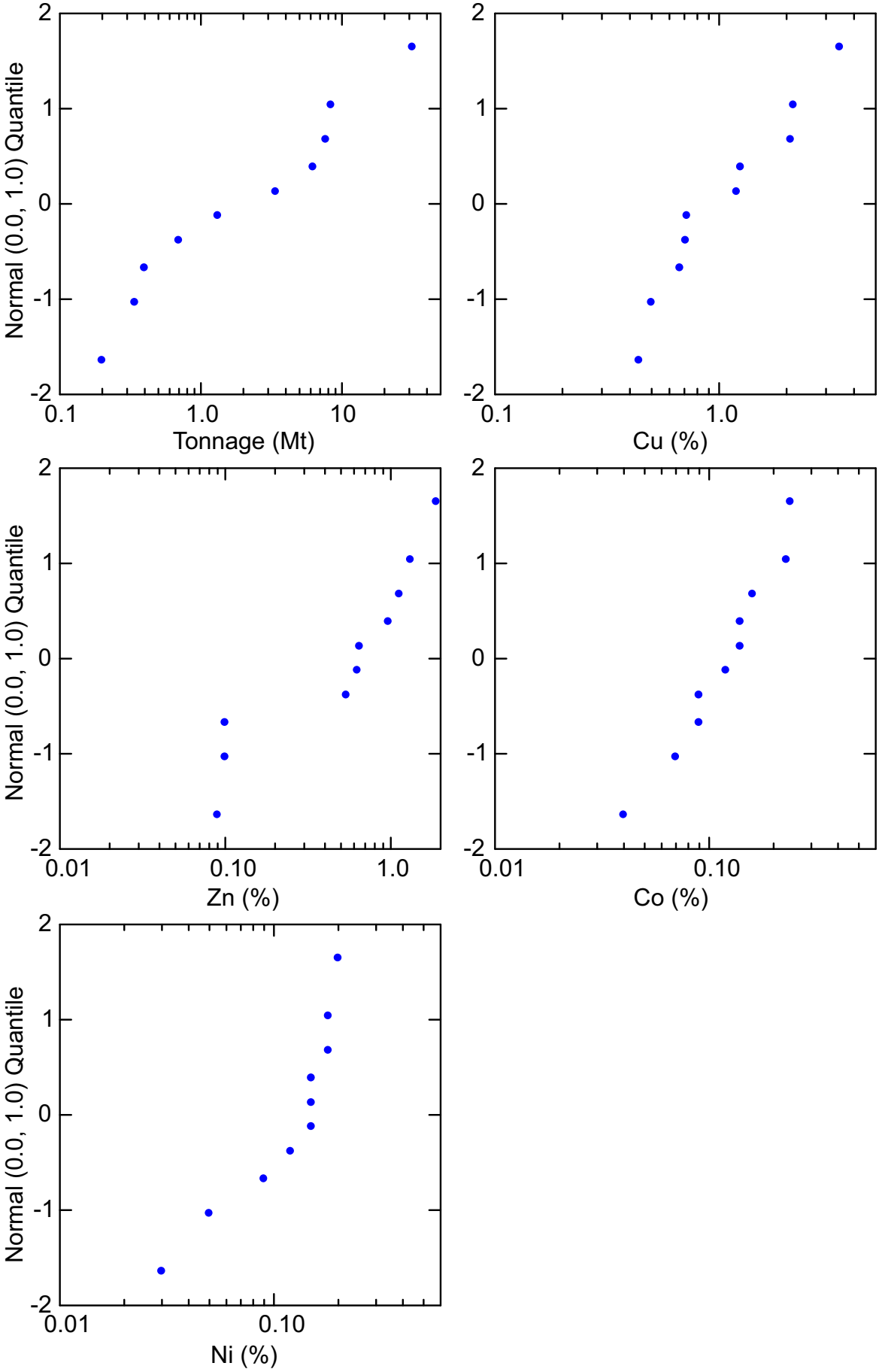


Fig. 1. Normal probability plots of tonnage and metal grades for the Outokumpu-type deposits in Table 1.

## STATISTICS

Summary statistics for the Outokumpu-type grade-tonnage model are given in Table 2. Statistical tests indicate that metal grades and ore tonnage do not differ from a log-normal distribution at the one per cent significance level (Table 2, Figure 1). Nickel, however, deviates from log-normal at the marginally significant five per cent level.

Table 2. Summary statistics for Outokumpu-type deposits.

| | Tonnage (Mt) | Cu (%) | Zn (%) | Co (%) | Ni (%) |
|---|---|---|---|---|---|
| N of cases | 10 | 10 | 10 | 10 | 10 |
| Minimum | 0.2 | 0.44 | 0.09 | 0.04 | 0.03 |
| Maximum | 31.66 | 3.46 | 1.89 | 0.24 | 0.2 |
| Mean | 6.0 | 1.3 | 0.74 | 0.13 | 0.13 |
| St Dev | 9.6 | 0.97 | 0.59 | 0.065 | 0.057 |
| 10% | 0.27 | 0.47 | 0.095 | 0.055 | 0.04 |
| 50% | 2.4 | 0.96 | 0.64 | 0.13 | 0.15 |
| 90% | 20 | 2.8 | 1.6 | 0.24 | 0.19 |
| S-W p | 0.623 | 0.505 | 0.051 | 0.733 | 0.023 |

N of cases: Number of available data values; Mean: Arithmetic mean; St dev: Standard deviation; 90 %, 50 %, 10 %: Percentile values; S-W p: Shapiro-Wilk normality test p-value (calculated for logatithmic values). The mean, standard deviation and percentiles are rounded to two significant digits.

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# APPENDIX 7

## ASSESSMENT RESULTS FOR VMS, PORPHYRY COPPER AND OUTOKUMPU-TYPE Cu-Zn-Co PERMISSIVE TRACTS IN FINLAND

Ala-Luoma VMS ....92
Central Finland PorCu ....100
Central Ostrobothnia PorCu ....107
Haaparanta PorCu ....115
Hammaslahti VMS ....121
Haukipudas VMS ....128
Hyvinkää VMS....135
Häme PorCu ....142
Jauratsi VMS ....150
Jurva VMS ....158
Kiimavaara VMS ....164
Kiimavuoma VMS ....172
Kilpisjärvi VMS ....179
Leteensuo VMS ....184
Mäntsälä PorCu ....192
Mauru VMS ....198
Misi VMS ....204
Nilipää PorCu ....210
Oijärvi VMS ....216
Orijärvi VMS ....222
Otravaara VMS ....230
Outokumpu Cu-Zn-Co ....237
Pahtavuoma VMS ....245
Pulju VMS ....253
Pyhäsalmi VMS ....260
Rauhala VMS ....270
Ruokolahti PorCu ....277
Salo-Issakka VMS ....283
Sattasvaara VMS ....289
Southern Ostrobothnia PorCu ....297
Southern Savo PorCu ....303
Taivaljärvi VMS ....309
Tampere PorCu....317
Tampere VMS....325
Tupala-Kiipu VMS ....333
Upper Svecofennian VMS ....339
Uusimaa East VMS ....347
Uusimaa North VMS ....355
Uusimaa West VMS ....361
Vihanti VMS ....377
Virtasalmi VMS ....387

# VMS Cu-Zn ASSESSMENT FOR THE TRACT ALA-LUOMA VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS felsic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Ala-Luoma VMS permissive tract is a 5–10-km-wide and 72-km-long NE-trending zone in eastern Finland, within the municipality of Suomussalmi (Fig. 1). The 1:100,000 KKJ map sheets are 4422, 4424, 4511, 4513 and 4514. The UTM map sheets containing the tract are R524, R541, R542, S5311 and S532. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Ala-Luoma VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 257 | Cu | 0 | Cu | 9,500 | Cu | 0 |
| | | | Zn | 0 | Zn | 72,000 | Zn | 0 |
| | | | Pb | 0 | Pb | 18,000 | Pb | 0 |
| | | | Ag | 0 | Ag | 60 | Ag | 0 |
| | | | Au | 0 | Au | 0.87 | Au | 0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by Meso- or Neoarchaean supracrustal rocks of the Suomussalmi greenstone belt. The greenstone belt contains felsic, intermediate, tholeiitic and komatiitic volcanic rocks, metasedimentary rocks, Cr-rich basalts, komatiitic serpentinite lenses and banded iron formations; these are bounded by Archaean ortho- and paragneisses of the granite gneiss complex and granitic rocks (Luukkonen et al. 2002, Mikkola 2008, Papunen et al. 2009). The delineation is based on the extent of the Suomussalmi belt rocks in the GTK digital bedrock database. The tract extends down to 1000 m depth. The depth extension is based on stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There are no well-explored VMS deposits within the Ala-Luoma VMS permissive tract (Table 2).

Table 2. Known VMS deposits in the Ala-Luoma VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences and related deposit types

One partially explored VMS occurrence is known within the Ala-Luoma VMS permissive tract (Table 3). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 3. Significant VMS-type occurrences in the Ala-Luoma VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Ala-Luoma | 7244341 | 3606207 | ~2800 | 3 m @ 1.21% Zn; 1 m @ 3.29% Zn | Pietikäinen & Niskanen (2001), Luukkonen et al. (2002) |

Ma – million years

## EXPLORATION HISTORY

Several types of exploration have been performed in the Ala-Luoma VMS tract, mostly targeting nickel, copper and gold. Geological Survey of Finland has explored the area since the 1980s (Talvitie 1980, Halkoaho et al. 2000, Koistinen & Halkoaho 2000, Luukkonen et al. 2002), Outokumpu Mining Oy from the 1960s to 2005 (Kurki & Papunen 1985, Kojonen 1981, Papunen 1989), Kajaani Oy during the 1970s (Kopperoinen 1987, Kopperoinen & Tuokko 1988) and Kuhmo Metals Oy since 2005. In addition, a few economic geology research projects have targeted the region. These include the projects 'Ore Deposits in Kuhmo' (Kuhmon malmiprojekti) and 'Ore Deposits in Archaean Areas' (Arkeeisten alueiden malmiprojekti) by the University of Oulu in 1977–1984 (Piirainen 1985), and the Komatiite Project and the GeoNickel Project of the University of Turku in 1993–1998

(Halkoaho & Papunen 1998). Outokumpu Mining Oy and Kajaani Oy carried out zinc exploration during the 1970s and Geological Survey of Finland during the 1990s. Exploration activities for VMS-type deposits within the Ala-Luoma VMS tract are listed in Table 4.

Table 4. Exploration history for the Ala-Luoma VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Bedrock mapping 1:400 000 | No | Geological Survey of Finland | 1907–1910, 1931–1933, 1949–1953 |
| | Bedrock mapping | Yes | University of Oulu | 1979–1980s |
| | Bedrock mapping, glacial erratic boulder survey | Yes | Geological Survey of Finland | 1990s–2000s |
| | Bedrock mapping | Yes | University of Turku | 1994–1996 |
| | Bedrock mapping 1:200 000 | Yes | Geological Survey of Finland | 2003–2008 |
| | Bedrock mapping, glacial erratic boulder survey (mainly nickel exploration) | Yes | Outokumpu Oy | 1960s–2000s |
| | Bedrock mapping, glacial erratic boulder survey | Yes | Kajaani Oy | 1970s |
| Geochemical surveys | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| | Targeted till and peat geochemical surveys | Yes | Geological Survey of Finland | 1990s |
| | Till geochemical survey (mainly nickel exploration) | Yes | Outokumpu Oy | 1960s–2000s |
| | Till geochemical survey (Cobra, 2191 points, analysed metals Fe, Cu, Ni, Co, Zn, Pb and Mn | Yes | Kajaani Oy | 1970s–1980s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric | | GeologicalSurvey of Finland | 1977, 1992, 1996 |
| Ground geophysical surveys | Electromagnetic and magnetic surveys (mainly nickel exploration) | | Geological Survey of Finland | 1990s–2000s |
| | Electromagnetic (Slingram) and magnetic surveys, Turam method | | Kajaani Oy | 1970s |
| | Electromagnetic and magnetic surveys (mainly nickel exploration) | | Outokumpu Oy | 1960s–2000s |
| Drilling | Four diamond-drill holes, total 275 m, at Ala-Luoma | Yes | Geological Survey of Finland | 1997 |
| | 24 diamond-drill holes, total 1769 m, in the area of Ala-Luoma-Kaleton | Yes | Kajaani Oy | 1970s |

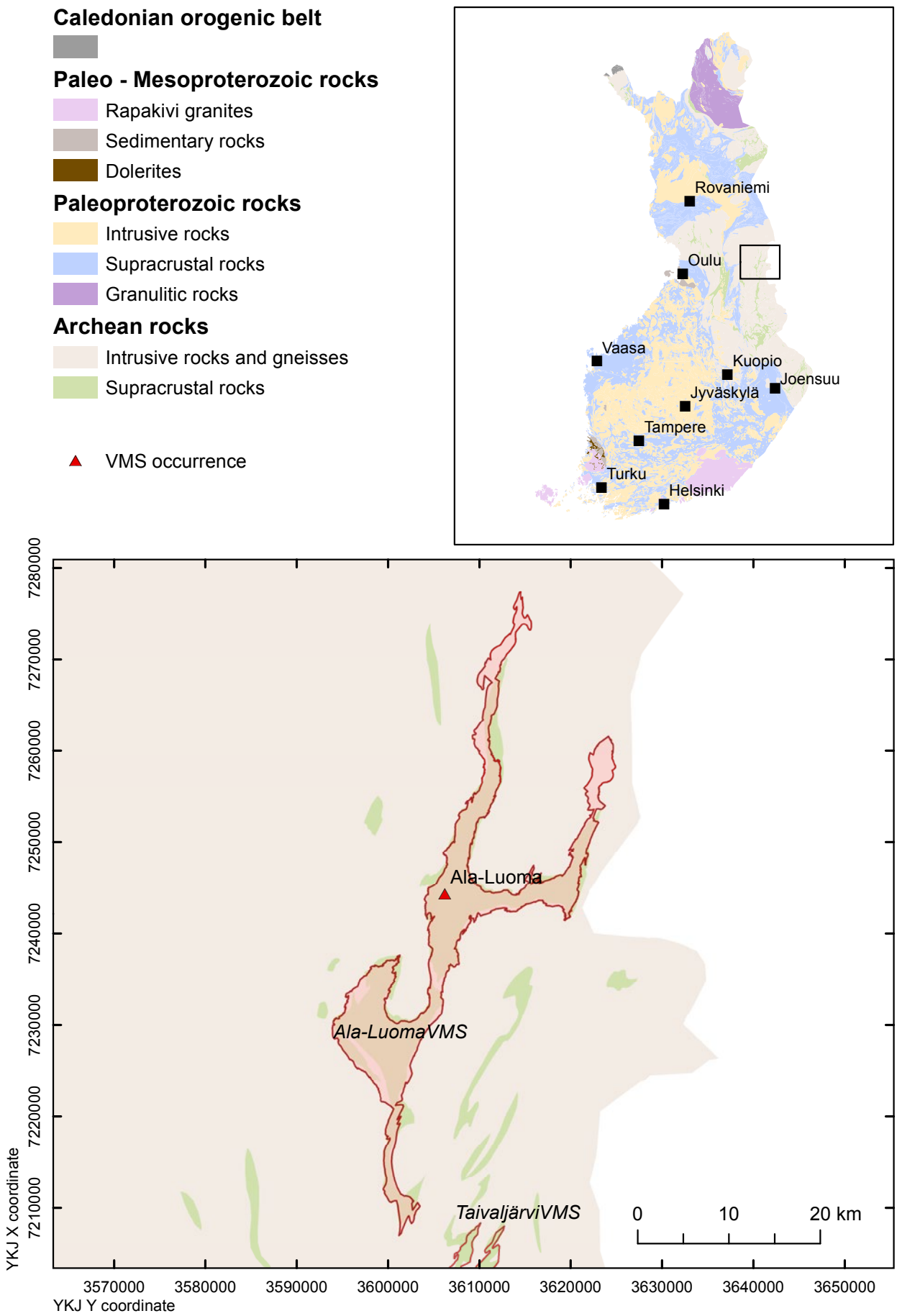


Fig. 1. Location of the Ala-Luoma VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Ala-Luoma VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Ala-Luoma VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Geological maps | 1:400,000 | Matisto (1954, 1958) |
| | Regional bedrock map | 1:200,000 | Mikkola (2008) |
| | Reports, publications | | Piirainen (1985), Halkoaho & Papunen (1998), Papunen et al. (2009) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Reports | | Kopperoinen & Tuokko (1988), Papunen (1990), Pietikäinen & Niskanen (2001), Luukkonen et al. (2002) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Kopperoinen (1987), Luukkonen et al. (2002) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Luukkonen et al. (2002) |
| Exploration | Exploration reports | | Pietikäinen & Niskanen (2001), Luukkonen et al. (2002) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

One partially explored VMS occurrence is known within the tract (Table 3). However, this occurrence is so small that it was considered unlikely to become an economic deposit, even under the most favourable circumstances. Very little exploration has been carried out for VMS deposits within the tract, as most of the exploration efforts within the region have focused on gold and nickel. Favourable factors for VMS deposits within the Ala-Luoma VMS tract include the Ala-Luoma occurrence and the presence of felsic to intermediate metavolcanic rocks. No consensus was reached in the discussion and the mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Ala-Luoma VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km2)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 0 | 1 | | | 0.30 | 0.50 | 170 | 0 | 0.30 | 257 | 0.0012 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 1 | | |
| Individual 2 | 0 | 0 | 1 | | |
| Individual 3 | 0 | 0 | 0 | | |
| Individual 4 | 1 | 1 | 2 | | |
| Individual 5 | 0 | 0 | 1 | | |
| Individual 6 | 0 | 0 | 1 | | |
| Individual 7 | 0 | 1 | 1 | | |
| Mean | 0 | 0 | 1 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen J. Luukas, J. Nikander, K. Rasilainen, P. Sorjonen-Ward, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS felsic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Ala-Luoma VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 0 | 11,000 | 34,000 | 9,500 | 0.11 | 0.70 |
| Zn (t) | 0 | 0 | 0 | 69,000 | 240,000 | 72,000 | 0.10 | 0.70 |
| Pb (t) | 0 | 0 | 0 | 8,000 | 33,000 | 18,000 | 0.070 | 0.70 |
| Ag (t) | 0 | 0 | 0 | 55 | 190 | 60 | 0.10 | 0.70 |
| Au (t) | 0 | 0 | 0 | 0.71 | 2.5 | 0.87 | 0.090 | 0.70 |
| Rock (Mt) | 0 | 0 | 0 | 2.2 | 5.8 | 1.8 | 0.11 | 0.70 |

t – metric tons; Mt – million metric tons.

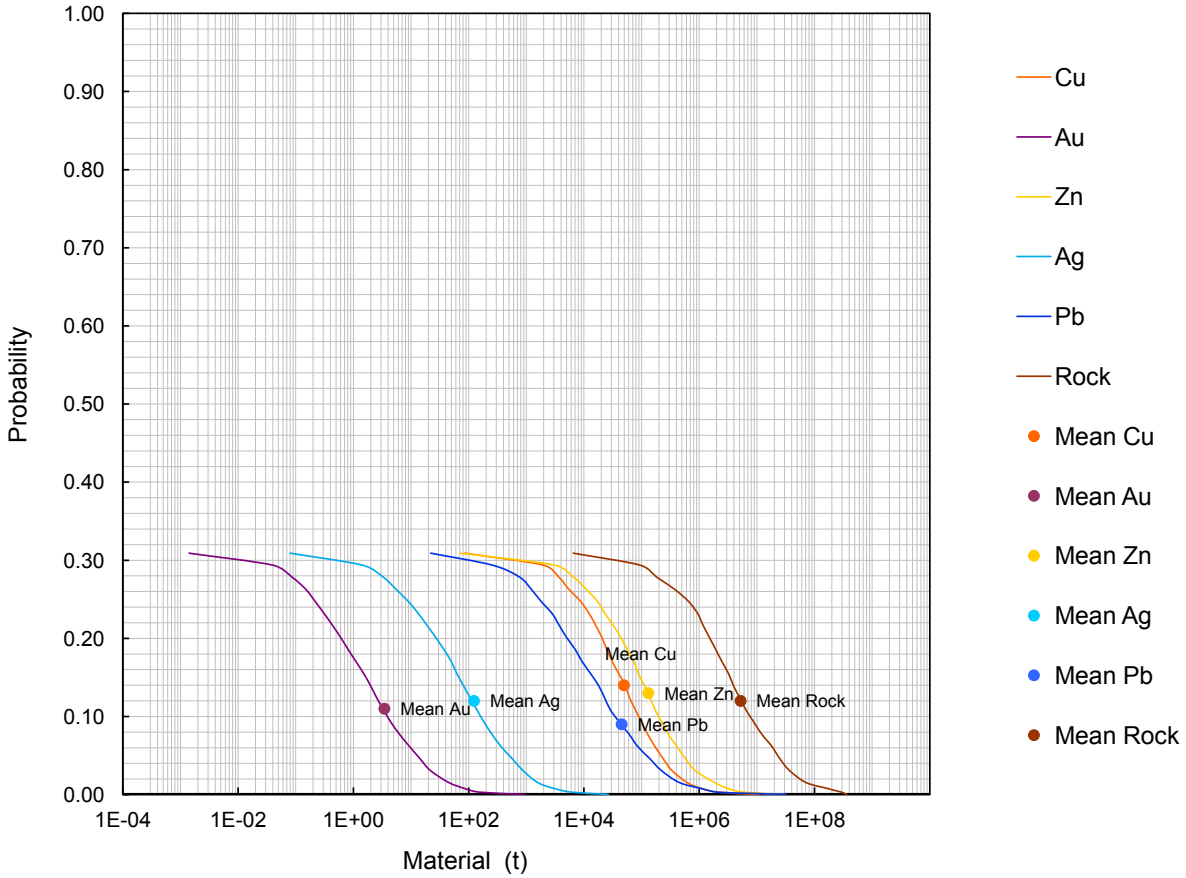


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Ala-Luoma VMS permissive tract.

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# PORPHYRY Cu ASSESSMENT FOR THE TRACT CENTRAL FINLAND PORCU, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: Porphyry Cu
**Descriptive model**: Porphyry Cu (Appendix 3)
**Grade-tonnage model**: Porphyry Cu (Appendix 4)

## LOCATION AND RESOURCE SUMMARY

The central Finland PorCu permissive tract is located in southern Finland in the municipalities of Jyväskylä, Keuruu, Mänttä-Vilppula, Muurame, Petäjävesi, Ruovesi, Virrat and Ylöjärvi, to the north of the city of Tampere and west of Jyväskylä (Fig. 1). The 1:100,000 KKJ map sheets are 2124, 2142, 2144, 2213, 2214, 2231, 2142, 2231, 2233, 2234, 3212 and 3221. The UTM map sheets containing the tract are N411, N412, N413, N414, N424, N431, N432 and N441. The resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Central Finland PorCu permissive tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 9/11/2012 | 1 | 3861 | Cu | 0 | Cu | 760,000 | Cu | 93,000 |
| | | | Mo | 0 | Mo | 43,000 | Mo | 3,800 |
| | | | Ag | 0 | Ag | 960 | Ag | 33 |
| | | | Au | 0 | Au | 94 | Au | 5 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The 170-km-long and 15–50-km-wide Central Finland PorCu permissive tract is defined by probably ca. 1.89–1.88 Ga early to synorogenic granitoids along the southern part of the Central Finland granitoid complex and to the north of the Tampere PorCu tract. The tract delineation is based on the extent of these intrusions. The tract extends down to 1000 m depth. The depth extension is based on interpretation of the geology of the region. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored porphyry Cu deposits within the Central Finland PorCu permissive tract (Table 2). According to the spatial rule used, deposits located less than 2 km from each other were combined in this assessment. An exception was allowed if two occurrences <2 km apart could be shown to be products of separate mineralising systems.

Table 2. Known porphyry Cu deposits in the Central Finland PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade (%) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|
| None | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric tons. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

There are no partially explored Cu occurrences clearly of the porphyry type within the Central Finland PorCu permissive tract. However, there are a few occurrences that may be genetically related to synorogenic granitoid magmatism (Table 3). No other types of mineral occurrences of any significant size are known from the tract area.

Table 3. Possible porphyry Cu-related occurrences in the Central Finland PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Äijänneva | 6917011 | 3324991 | | 1 m @ 1.5 % Cu, up to 0.7 % As, in sheared volcanic rocks; also Cu-mineralised granitoid boulders occur in the area. | Kärkkäinen & Alanen (1993) |
| Majaniemi, Lylyniemi and surroundings | 6884844 | 3360051 | | Several indications of arseniferous Cu±Ag±Mo±Au occurrences in granodiorite (outcrop and boulder indications). | Oivanen (1981a), Kärkkäinen (1990) |
| Riuttamäki | 6915200 | 3438550 | | Extensive chalcopyrite-arsenopyrite mineralisation, with anomalous Zn, Mo, W and Ag, in granitoids. | Laitakari (1985) |
| Riuttaskorpi | 6886937 | 3325253 | | Channel sample of 8 m @ 116 g/t Ag, 0.23 % Cu, 0.59 % Pb, 0.30 % Zn; possibly epithermal style of mineralisation. | Oivanen (1981a), Kärkkäinen (1991) |

Ma – million years

## Exploration history

Exploration activities targeting porphyry and potentially related styles of mineralisation are listed in Table 4.

Table 4. Exploration history for the Central Finland PorCu permissive tract.

| Theme | Type of work | Cu analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder surveys | Yes | Geological Survey of Finland | 1880s–1990s |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Geochemical survey of basal till, and lithogeochemical survey | Yes | Geological Survey of Finland | 1970s–1990s |
| Airborne geophysical surveys | Regional low-altitude airborne magnetic, electromagnetic and radiometric survey | | Geological Survey of Finland | 1977–2007 |
| Ground geophysical surveys | Magnetic, IP, VLF, slingram surveys | | Geological Survey of Finland | 1950s–1990s |
| Drilling | Diamond drilling at exploration targets | Yes | Geological Survey of Finland | 1970s–1980s |

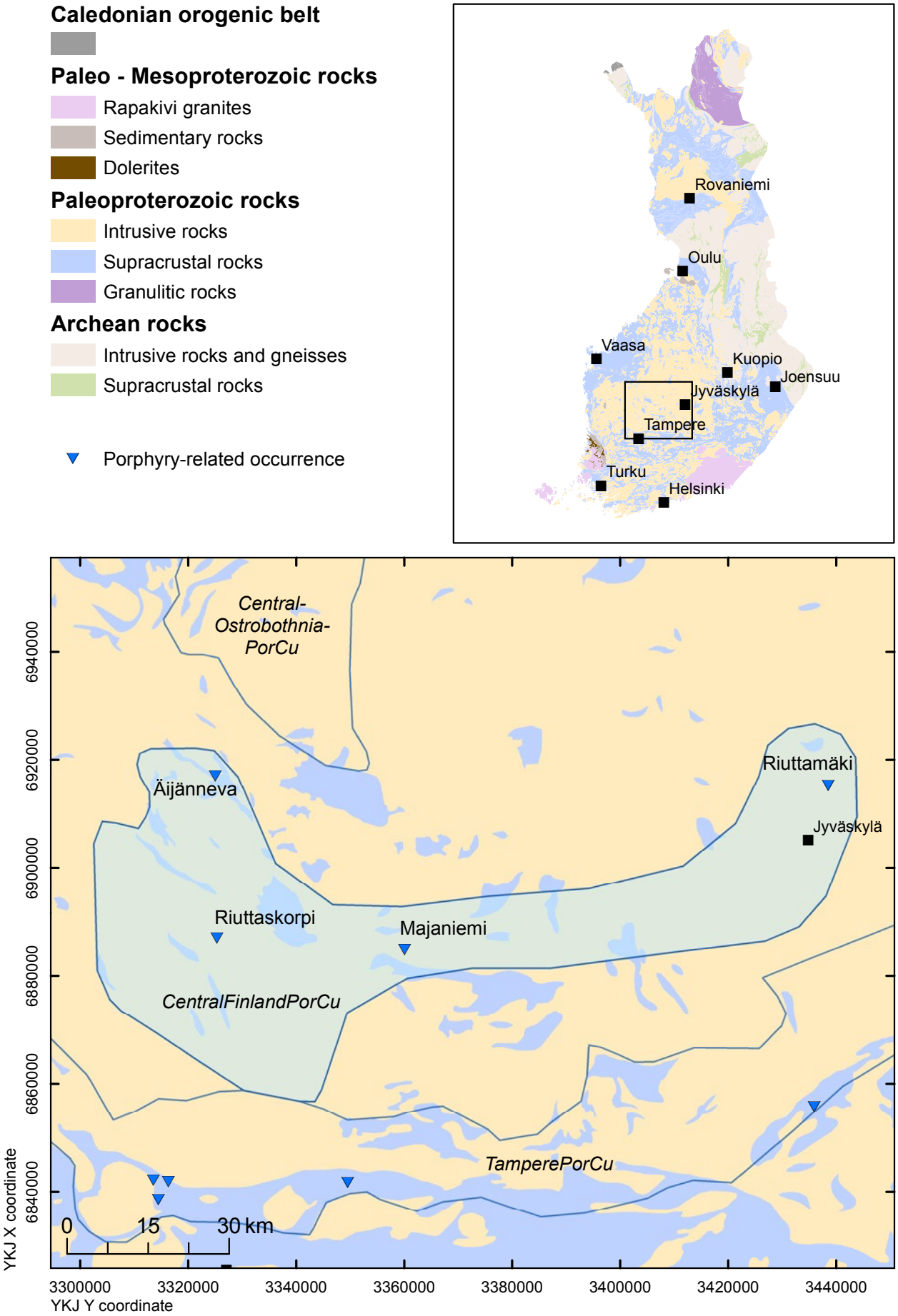


Fig. 1. Location of the Central Finland PorCu permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Central Finland PorCu tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Central Finland PorCu permissive tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:500–1:4000 | Oivanen (1981a), Laitakari (1985) |
| Mineral occurrences | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Geological Survey of Finland gold deposit database | | Eilu & Pankka (2009) |
| | Metallogenic assessment | 1:4000–1:10,000 | Lampio (1983), Nurmi (1984, 1985), Nurmi et al. (1984), Laitakari (1985), Kärkkäinen (1991) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Oivanen (1981a, 1981b), Laitakari (1985), Kärkkäinen (1991), Kärkkäinen & Alanen (1993) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Oivanen (1981a, 1981b), Laitakari (1985), Kärkkäinen & Alanen (1993) |
| Exploration | Reports | 1:4000–1:10,000 | Oivanen (1981a, 1981b), Laitakari (1985), Kärkkäinen (1990, 1991), Kärkkäinen & Alanen (1993) |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

No obvious porphyry Cu occurrences are known within the Central Finland PorCu permissive tract. The existence of several occurrences possibly genetically related to porphyry-style mineralisation, synorogenic subvolcanic granitoid intrusions as well as numerous Cu- and a few Mo-mineralised boulders were considered as favourable indications for porphyry copper mineralisation in the tract area. Little exploration has taken place within the tract, which weakens the quality of assessment to some extent. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Central Finland PorCu permissive tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 1 | 2 | | | 1.0 | 0.79 | 79 | 0 | 1.0 | 3861 | 0.00026 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 1 | 2 | | |
| Individual 2 | 0 | 0 | 2 | | |
| Individual 3 | 0 | 1 | 3 | | |
| Individual 4 | 0 | 0 | 1 | | |
| Individual 5 | 0 | 1 | 2 | | |
| Individual 6 | 0 | 0 | 2 | | |
| Individual 7 | 0 | 1 | 2 | | |
| Mean | 0 | 1 | 2 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variation; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, L. Lauri, J. Luukas, M. Tiainen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the porphyry Cu grade-tonnage model (Appendix 4) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Central Finland PorCu permissive tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 93,000 | 2,400,000 | 4,000,000 | 760,000 | 0.22 | 0.31 |
| Mo (t) | 0 | 0 | 3,800 | 96,000 | 210,000 | 43,000 | 0.18 | 0.31 |
| Ag (t) | 0 | 0 | 33 | 1,600 | 3,100 | 960 | 0.14 | 0.31 |
| Au (t) | 0 | 0 | 5.0 | 210 | 510 | 94 | 0.17 | 0.31 |
| Rock (Mt) | 0 | 0 | 34 | 1,200 | 1,900 | 310 | 0.22 | 0.31 |

t – metric tons; Mt – million metric tons.

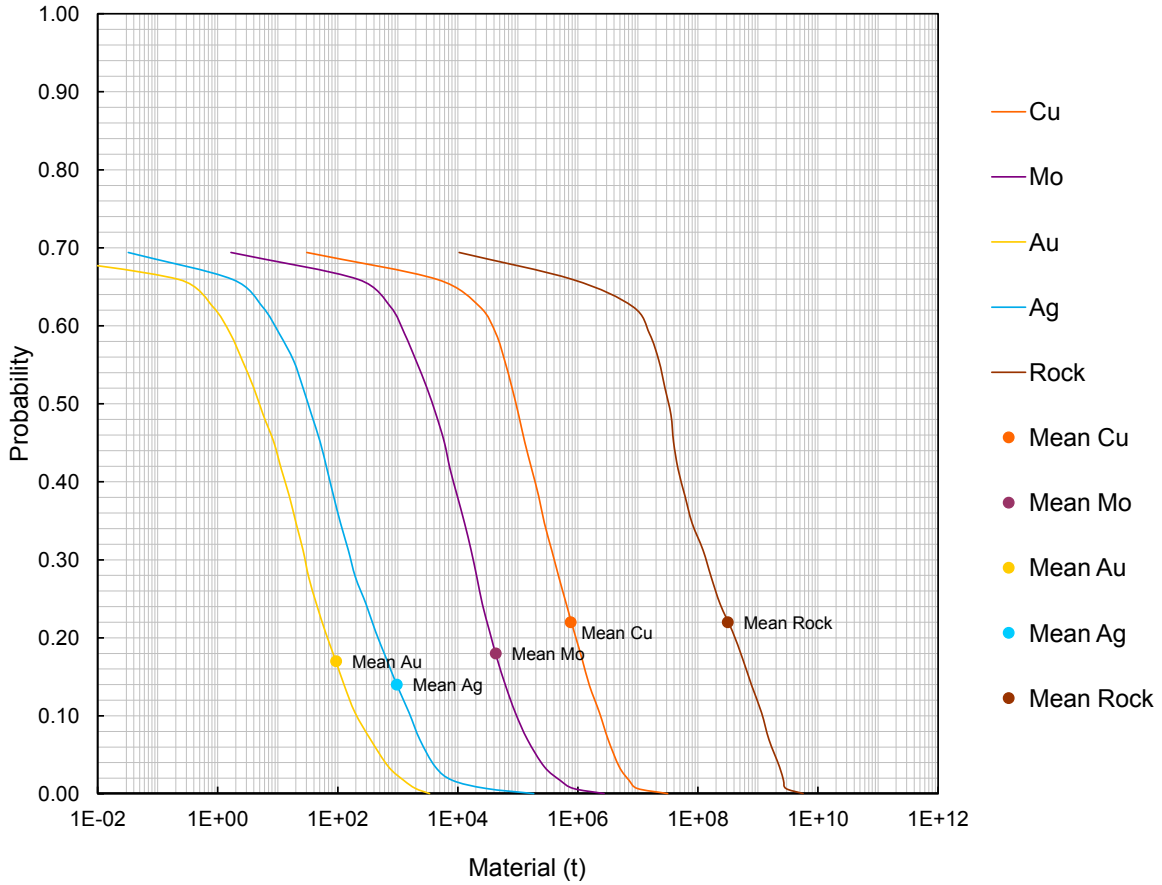


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Central Finland PorCu permissive tract.

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# PORPHYRY Cu ASSESSMENT FOR THE TRACT CENTRAL OSTROBOTHNIA PORCU, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: Porphyry Cu
**Descriptive model**: Porphyry Cu (Appendix 3)
**Grade-tonnage model**: Porphyry Cu (Appendix 4)

## LOCATION AND RESOURCE SUMMARY

The Central Ostrobothnia PorCu permissive tract is located in central-western Finland in the municipalities of Alavus, Töysä, Kuortane, Alajärvi, Soini, Kyyjärvi, Kivijärvi, Karstula, Vimpeli, Perho, Halsua, Kokkola, Toholampi, Kannus, Kalajoki, Alavieska, Ylivieska, Sievi, Nivala, Haapajärvi, Pyhäjärvi, Reisjärvi, Lestijärvi, Kinnula, Pihtipudas, Viitasaari, Keitele and Vesanto, 100–200 km north-northwest of the city of Jyväskylä (Fig. 1). The 1:100,000 KKJ map sheets are 2223, 2224, 2313, 2323, 2324, 2242, 2331, 2332, 2334, 2341, 2342, 2343, 2344, 2431, 3311, 3312, 3313, 3321 and 3322. The UTM map sheets containing the tract are N422, P411, P412, P413, P414, P421, P422, P423, P424, Q411, Q412, Q413, Q414, Q421Q423, P432, P434, P441, P442, P443, Q431 and Q432. The resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Central Ostrobothnia PorCu permissive tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t)* | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 9/11/2012 | 1 | 11,157 | Cu | 45,000 | Cu | 1,900,000 | Cu | 670,000 |
| | | | Mo | 0 | Mo | 95,000 | Mo | 27,000 |
| | | | Ag | 100 | Ag | 2,500 | Ag | 290 |
| | | | Au | 14 | Au | 230 | Au | 46 |

t – metric tons.
* Gaal & Isohanni (1979) data used

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The Central Ostrobothnia PorCu permissive tract is defined by felsic intrusive rocks of the northern part of the Central Finland Granitoid Complex. The delineation is based on the extent of the intrusions with an age of about 1.88 Ga. These intrusions contain a few bedrock and boulder indications of copper and molybdenum. The tract extends down to 1000 m depth. The depth extension is based on interpretation of the geology of the region. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There is one well-explored porphyry Cu deposit within the Central Ostrobothnia PorCu permissive tract (Table 2). According to the spatial rule used, deposits located less than 2 km apart other were combined in this assessment. An exception was allowed if two occurrences <2 km apart could be shown to be products of separate mineralising systems.

Table 2. Known porphyry Cu deposits in the Central Ostrobothnia PorCu permissive tract. Note that we give here two resource estimates for the same Kopsa deposit.

| Name | X coordinate | Y coordinate | Age (Ga) | Tonnage (Mt) | Grade Cu (%) | Grade Mo (%) | Grade Ag (g/t) | Grade Au (g/t) | Contained metal (t) | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kopsa | 7075648 | 3413064 | 1.89– 1.88 | 25 | 0.18 | n/a | 4 | 0.57 | Cu | 45,000 | Gaal & Isohanni (1979) |
| | | | | | | | | | Mo | - | |
| | | | | | | | | | Ag | 100 | |
| | | | | | | | | | Au | 14 | |
| Kopsa | 7075648 | 3413064 | 1.89– 1.88 | 16.3 | 0.16 | n/a | 2.22 | 0.81 | Cu | 26,080 | Belvedere Resources (2013) |
| | | | | | | | | | Mo | - | |
| | | | | | | | | | Ag | 36 | |
| | | | | | | | | | Au | 13.2 | |

Ga – billion years; Mt – million metric tons; t – metric tons; n/a – data not included in the resource estimate. The contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences and related deposit types

One partially explored porphyry Cu occurrence (Susineva), one probably porphyry-related, partially explored deposit (Jouhineva), and six poorly explored occurrences of possibly porphyry type (Sorola, Tienpää, Taipale, Hallapuro, Vinnolinneva and Lahnanen) are known from the Central Ostrobothnia PorCu permissive tract (Table 3). Other types of occurrences that exist within the tract area are: 1) Hitura and Makola ultramafic intrusion-hosted Ni-Cu deposits, 2) Koivusaarenneva gabbro-hosted ilmenite deposit and 3) numerous orogenic gold occurrences of the Sievi, Ylivieska and Reisjärvi regions.

Table 3. Significant porphyry Cu occurrences in the Central Ostrobothnia PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ga) | Comments | Reference |
|---|---|---|---|---|---|
| Hallapuro | 7013774 | 3357689 | 1.89–1.88 | Up to 0.14 % Cu, 0.004 % Mo. Similar to the Tienpää occurrence | Västi (1988) |
| Jouhineva (Pöllä) | 7110107 | 3365066 | 1.89–1.88 | 0.45 Mt @ 0.81 % Cu, 0.18 % Co, 7.9 g/t Ag, 0.88 g/t Au | Isohanni (1984) |
| Lahnanen | 6996000 | 3457600 | 1.89–1.88 | 0.01 Mt @ 0.14 % Mo; several ore bodies know, resource only given for one of them | Nironen (1981), Nurmi et al. (1984) |
| Sorola | 7076054 | 3414226 | 1.89–1.88 | 21.1 m @ 0.4% Cu, 18 g/t Ag, 0.3 g/t Au | Nikander (1986) |
| Susineva | 7103233 | 3361138 | 1.883 | 0.3 Mt @ 0.04 % Mo | Gaal & Isohanni (1979) |
| Taipale | 7102599 | 3363608 | 1.89–1.88 | 1.7 m @ 0.15 % Mo, 0.22 % W | Hyvärinen & Vorma (1953), Mattila (1978) |
| Tienpää | 7034120 | 3362417 | 1.89–1.88 | 15 m @ 0.125 % Cu, 1.5 m @ 1.96 % Cu | Västi (1984) |
| Vinnolinneva | 7019519 | 3360111 | 1.89–1.88 | Up to 0.95 % Mo, 0.72 % Cu, 6 g/t Ag, 1.1 % W per 1 m. Scattered mineralisation. | Isohanni (1981) |

Ga – billion years

## Exploration history

Exploration activities for porphyry Cu deposits within the Central Ostrobothnia PorCu tract are listed in Table 4. Porphyry deposits have not been explored within the tract area.

Table 4. Exploration history for the Central Ostrobothnia PorCu permissive tract.

| Theme | Type of work | Cu analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder surveys | Yes | Geological Survey of Finland | 1930s–2000s |
| | Outcrop observations and boulder surveys | Yes | Geological Survey of Finland | 1970s–1980s |
| | Outcrop observations and boulder surveys | Yes | Outokumpu Oy | 1940–1980s |
| | Outcrop observations and boulder surveys | Yes | Baltic Minerals JV | 1995–1999 |
| | Outcrop observations and boulder surveys | Yes | Belvedere Resources | 2002– |
| | Outcrop observations and boulder surveys | Yes | Rautaruukki Oy | 1970s |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Geochemical till and stream-sediment surveys | Yes | Geological Survey of Finland | 1980s–1990s |
| | Geochemical till survey | Yes | Outokumpu Oy | 1940–1980s |
| | Geochemical till survey | Yes | Baltic Minerals JV | 1995–1999 |
| | Geochemical till survey | Yes | Rautaruukki Oy | 1970s |
| Airborne geophysical surveys | Regional low-altitude airborne magnetic, electromagnetic and radiometric survey | | Geological Survey of Finland | 1976–2006 |
| Ground geophysical surveys | Magnetic, slingram, Turam, VLF and IP surveys | | Outokumpu Oy | 1940–1980s |
| | Magnetic, IP and slingram surveys | | Geological Survey of Finland | 1950s |
| | Magnetic, slingram, IP and self potential surveys | | Baltic Minerals JV | 1995–1999 |
| | Resistivity, magnetic and IP survey | | Belvedere Resources | 2002– |
| | IP and magnetic surveys | | Rautaruukki Oy | 1970s |
| Drilling | Tens of diamond-drill holes | Yes | Geological Survey of Finland | 1939–2000s |
| | Tens of diamond-drill holes; 200 percussion-drill holes at Kopsa | Yes | Outokumpu Oy | 1940–1980s |
| | Diamond and percussion drilling | Yes | Rautaruukki Oy | 1970s |
| | Diamond, percussion and RC drilling | Yes | Baltic Minerals JV | 1995–1999 |
| | Percussion and diamond drilling | Yes | Belvedere Resources | 2002– |

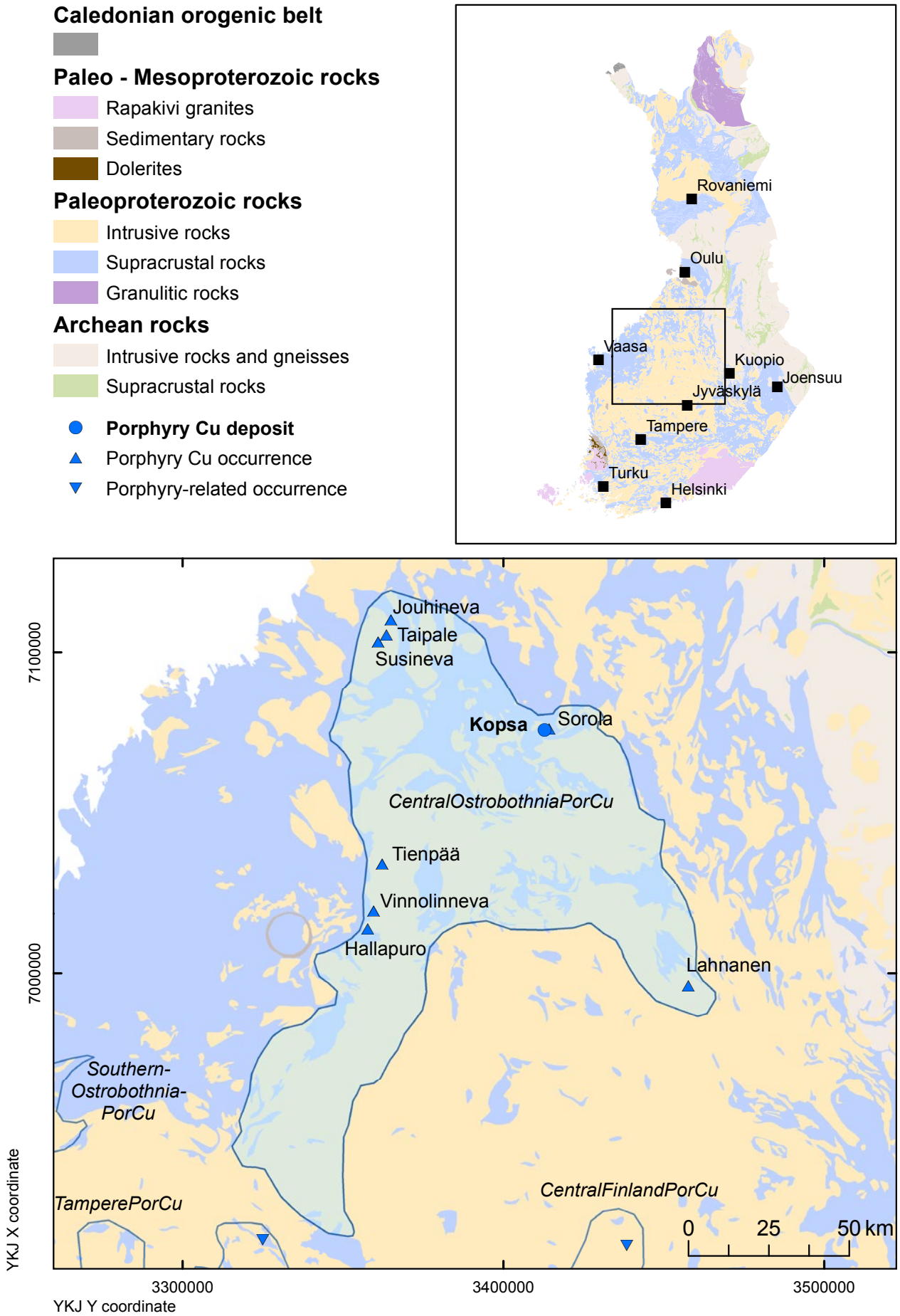


Fig. 1. Location of the Central Ostrobothnia PorCu permissive tract.

## Sources of information

The principal sources of information used by the assessment team for the delineation of the Central Ostrobothnia PorCu tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Central Ostrobothnia PorCu permissive tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:500–1:4000 | Lindmark (1966), Nironen (1981), Isokoski (1982) |
| Mineral occurrences | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Geological Survey of Finland gold deposit database | | Eilu & Pankka (2009) |
| | Metallogenic assessment | | Isokoski (1982), Nurmi et al. (1984) |
| | Deposit descriptions | | Lindmark (1966), Jalander (1978), Mattila (1978), Gaal & Isohanni (1979), Nironen (1981), Isokoski (1982), Isohanni (1984), Nurmi et al. (1984), Nikander (1986), Västi (1988), Belvedere Resources (2012, 2013) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Gaal (1978), Västi (1984), Nurmi & Isohanni (1984), Nikander (1986), Tenhola (1990), Strauss (1999), Belvedere Resources (2005) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Jalander & Makkonen (1954), Laitakari (1964), Gaal (1978), Mattila (1978), Västi (1984, 1988), Nikander (1986), Strauss (1999) |
| Exploration | Reports | | Hyvärinen & Vorma (1953), Jalander & Makkonen (1954), Laitakari (1964), Lindmark (1966), Pehkonen (1976), Gaal (1978), Isohanni (1981, 1982, 1984), Mattila (1978), Västi (1984, 1988), Nikander (1986), Strauss (1999), Belvedere Resources (2012, 2013) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Eight porphyry Cu occurrences are known within the Central Ostrobothnia PorCu permissive tract (Table 3). Many of these occurrences may be so modest that it was only considered possible for a few of them to become economic deposits, even under the most favourable circumstances. In addition to the known occurrences, the existence of numerous synkinematic, syn-subduction(?) Central Finland Granitoid Complex (1.89–1.86 Ga) granitoids, the presence of the Kopsa deposit, several bedrock indications of Mo mineralisation, and Cu- and Mo-enriched boulders were considered to indicate the potential for undiscovered porphyry Cu deposits. Furthermore, there are porphyry Cu-Au occurrences within the Skellefte belt in Sweden, in the NW continuation of the Central Ostrobothnia PorCu tract. Another potentially positive sign was seen in the Au deposits within the tract area; in north-central Chile, IOCG and porphyry copper deposits occur in partially overlapping areas. The rather large size of the tract (Table 6) enables the presence of several deposits within the tract. On the other hand, direct evidence of porphyry copper is scarce and little exploration of any kind has been carried out within the southern, central and eastern parts of the tract. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Central Ostrobothnia PorCu permissive tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 2 | 4 | | | 2.2 | 1.2 | 54 | 1 | 3.2 | 11,157 | 0.00029 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 2 | 4 | 6 | | |
| Individual 2 | 2 | 3 | 4 | | |
| Individual 3 | 1 | 2 | 3 | | |
| Individual 4 | 1 | 2 | 4 | | |
| Individual 5 | 1 | 2 | 4 | | |
| Individual 6 | 1 | 2 | 4 | | |
| Individual 7 | 0 | 2 | 4 | | |
| Individual 8 | 1 | 2 | 3 | | |
| Mean | 1 | 2 | 4 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variation; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. Nund, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, L. Lauri, J. Luukas, T. Niiranen, M. Tiainen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the porphyry Cu grade-tonnage model (Appendix 4) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Central Ostrobothnia PorCu permissive tract.

| Material | At least the indicated amount at the probability of | | | | | Mean | Probability of mean or greater | Probability of zero |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 16,000 | 670,000 | 5,100,000 | 7,500,000 | 1,900,000 | 0.29 | 0.070 |
| Mo (t) | 0 | 510 | 27,000 | 240,000 | 420,000 | 95,000 | 0.24 | 0.070 |
| Ag (t) | 0 | 3.9 | 290 | 4,100 | 8,600 | 2,500 | 0.16 | 0.070 |
| Au (t) | 0 | 0.52 | 46 | 650 | 1,200 | 230 | 0.23 | 0.070 |
| Rock (Mt) | 0 | 4.8 | 230 | 2,300 | 2,900 | 730 | 0.33 | 0.070 |

t – metric tons; Mt – million metric tons.

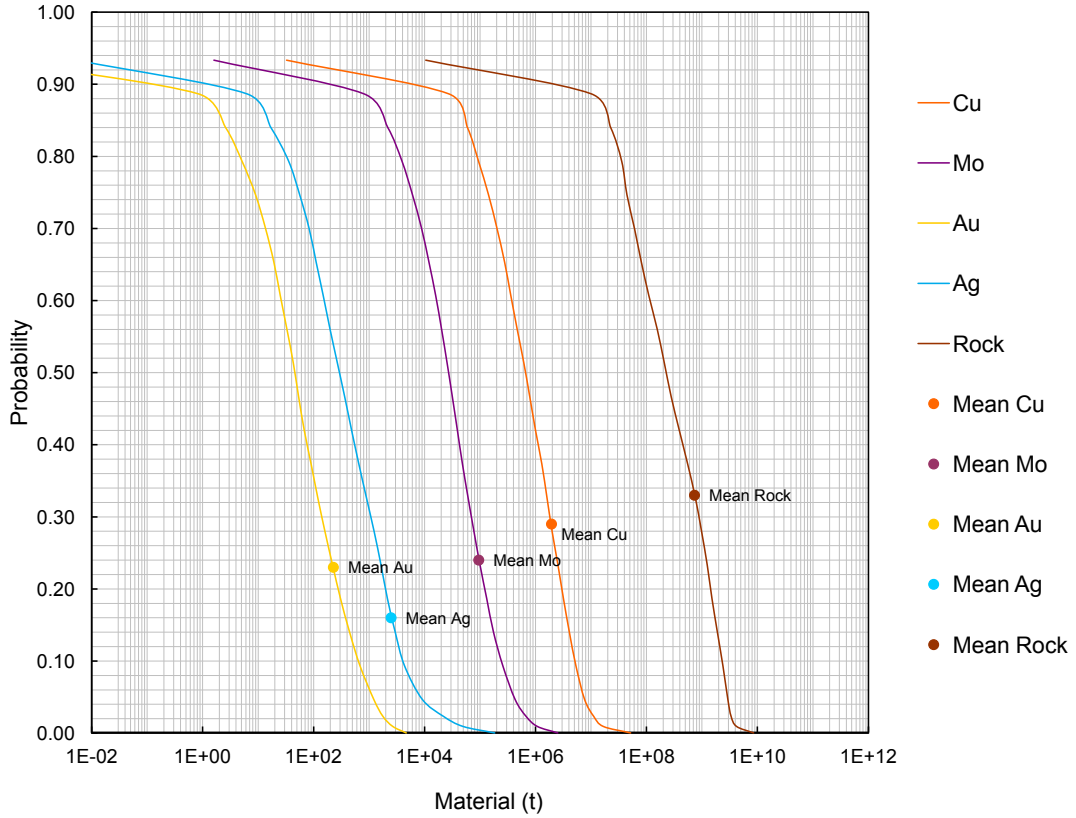


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Central Ostrobothnia PorCu permissive tract.

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# PORPHYRY Cu ASSESSMENT FOR THE TRACT HAAPARANTA PORCU, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: Porphyry Cu
**Descriptive model**: Porphyry Cu (Appendix 3)
**Grade-tonnage model**: Porphyry Cu (Appendix 4)

## LOCATION AND RESOURCE SUMMARY

The Haaparanta PorCu permissive tract is located in northwestern Finland in the municipalities of Kemi, Tornio, Ylitornio, Kittilä, Kolari, and Muonio, 100 km west of the city of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 2532, 2541, 2542, 2613, 2624, 2713, 2714, 2723, 2724, 2731, 2732, 2741, 2742, 2744 and 2831. The UTM map sheets containing the tract are S41, T41, U41, U42, U43, U44, V41, V43 and V44. The resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Haaparanta PorCu permissive tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 9/11/2012 | 1 | 6184 | Cu | 0 | Cu | 1,500,000 | Cu | 340,000 |
| | | | Mo | 0 | Mo | 68,000 | Mo | 16,000 |
| | | | Ag | 0 | Ag | 1,800 | Ag | 150 |
| | | | Au | 0 | Au | 170 | Au | 27 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The Haaparanta PorCu permissive tract is defined by Haaparanta suite rocks. The delineation is based on the extent of the known intrusions of the 1.88 Ga Haaparanta suite. The reason for selecting the Haaparanta suite as a permissive tract is based on the presence of the giant Aitik porphyry Cu de-

posit in Sweden in an intrusion of similar age. The tract extends down to 1000 m depth. The depth extension is based on the interpretation of the geology of the region. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored porphyry Cu deposits within the Haaparanta PorCu permissive tract (Table 2). According to the spatial rule used, deposits located less than 2 km from each other were combined in this assessment. An exception was allowed if two occurrences <2 km apart could be shown to be products of separate mineralising systems.

Table 2. Known porphyry Cu deposits in the Haaparanta PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade (%) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|
| None | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric tons. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

No partially explored porphyry Cu occurrences are known within the Haaparanta PorCu permissive tract (Table 3). Other types of occurrences that exist within the tract include the Kourilehto and Kaitamaa ultramafic intrusion-related Ni-Cu deposits and the numerous IOCG deposits of the Kolari region.

Table 3. Significant porphyry Cu occurrences in the Haaparanta PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| None | | | | | |

Ma – million years

## Exploration history

Exploration activities within the Haaparanta PorCu tract are listed in Table 4. Porphyry deposits have not been explored within the tract area.

Table 4. Exploration history for the Haaparanta PorCu permissive tract.

| Theme | Type of work | Cu analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder surveys | Yes | Geological Survey of Finland | 1930s–2000s |
| | Outcrop observations and boulder surveys | Yes | Outokumpu Oy | 1970s–1980s |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| Airborne geophysical surveys | Regional low-altitude airborne magnetic, electromagnetic and radiometric survey | | Geological Survey of Finland | 1979–2006 |
| Ground geophysical surveys | Magnetic and IP surveys | | Outokumpu Oy | 1970s–1980s |
| | Magnetic and slingram surveys | | Geological Survey of Finland | 1950s |
| Drilling | A few diamond-drill holes at Kallijärvi | Yes | Geological Survey of Finland | 1950s |
| | A few diamond-drill holes at Kallijärvi | Yes | Outokumpu Oy | 1970s–1980s |

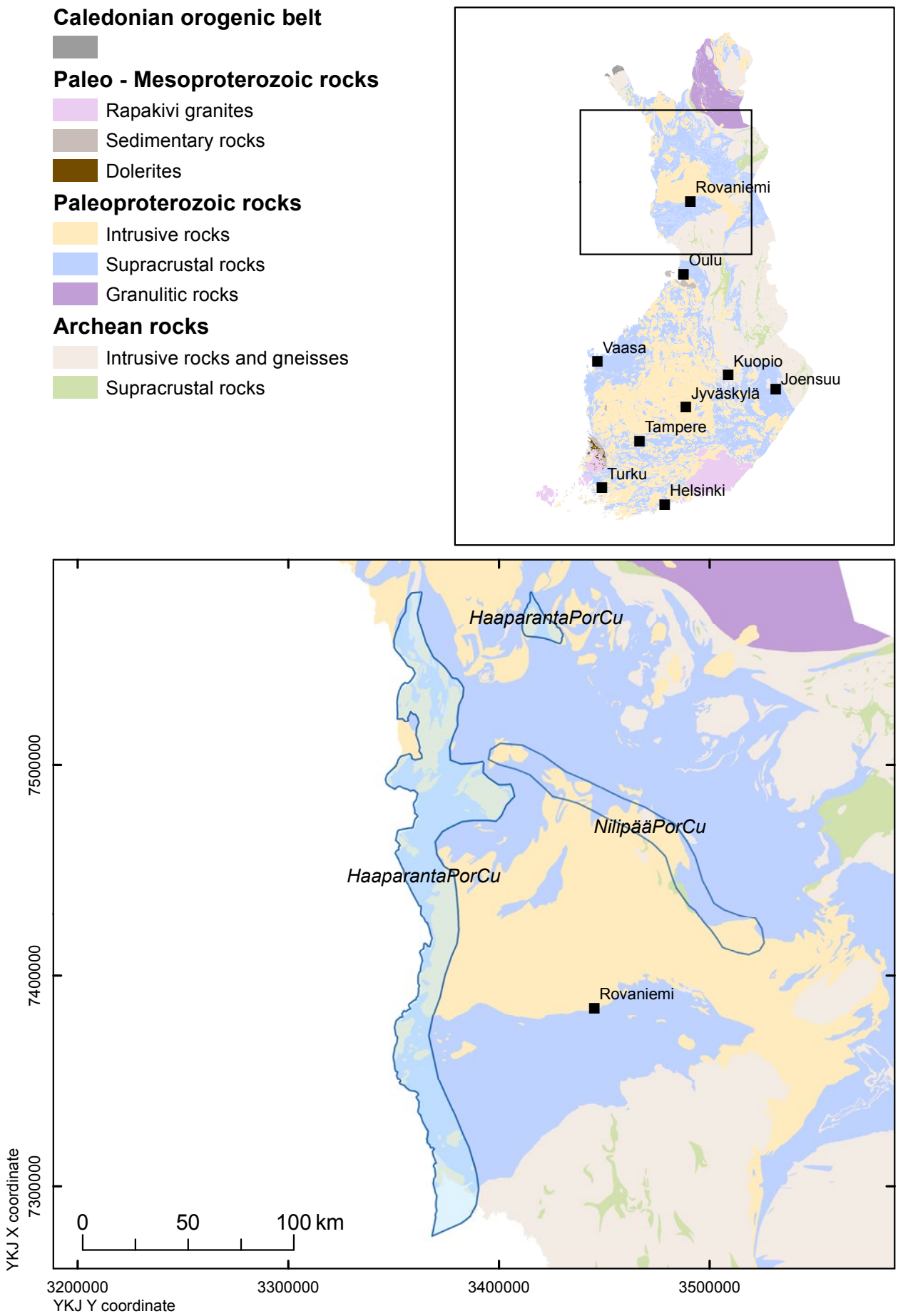


Fig. 1. Location of the Haaparanta PorCu permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Haaparanta PorCu tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Haaparanta PorCu permissive tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:500–1:4000 | Kahma (1956) |
| Mineral occurrences | Geological Survey of Finland copper deposit database | | Västi (2009) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Kahma (1956) |
| Exploration | Reports | 1:4000–1:10,000 | Kahma (1956), Ilvonen (1980), Inkinen (1984) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

No obvious porphyry Cu occurrences are known within the Haaparanta PorCu permissive tract (Table 3). The existence of numerous synkinematic, syn-subduction(?) Haaparanta suite (1.89–1.86 Ga) granitoids, the presence of the huge Aitik deposit in Sweden in the same suite of rocks, and minor indications of Mo mineralisation bedrock and Cu- and Mo-enriched boulders were considered to indicate the potential for undiscovered porphyry Cu deposits. Another potentially positive sign was seen in the IOCG deposits within the tract area; in north-central Chile, IOCG and porphyry copper deposits occur in partially overlapping areas. The rather large size of the tract (Table 6) enables the presence of several deposits within the tract. On the other hand, direct evidence of porphyry copper is lacking. Very little exploration of any kind has been carried out within those parts of the tract that are beyond the Kolari IOCG domain. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Haaparanta PorCu permissive tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area ($km^2$)** | **Deposit density ($N/km^2$)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 2 | 3 | | | 1.7 | 1.1 | 63 | 0 | 1.7 | 6184 | 0.00027 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 2 | 3 | | |
| Individual 2 | 1 | 2 | 4 | | |
| Individual 3 | 0 | 1 | 2 | | |
| Individual 4 | 0 | 1 | 2 | | |
| Individual 5 | 1 | 2 | 3 | | |
| Individual 6 | 0 | 1 | 2 | | |
| Individual 7 | 0 | 1 | 2 | | |
| Individual 8 | 1 | 2 | 3 | | |
| Mean | 0 | 2 | 3 | | |

$N_{xx}$ – Estimated number of deposits associated with the $xx^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variation; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per $km^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied. in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, L. Lauri, J. Luukas, T. Niiranen, M. Tiainen, K. Västi

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the porphyry Cu grade-tonnage model (Appendix 4) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Haaparanta PorCu permissive tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 340,000 | 4,100,000 | 6,000,000 | 1,500,000 | 0.28 | 0.20 |
| Mo (t) | 0 | 0 | 16,000 | 180,000 | 320,000 | 68,000 | 0.23 | 0.20 |
| Ag (t) | 0 | 0 | 150 | 2,900 | 5,500 | 1,800 | 0.16 | 0.20 |
| Au (t) | 0 | 0 | 27 | 450 | 910 | 170 | 0.21 | 0.20 |
| Rock (Mt) | 0 | 0 | 110 | 2,000 | 2,600 | 570 | 0.29 | 0.20 |

t – metric tons; Mt – million metric tons.

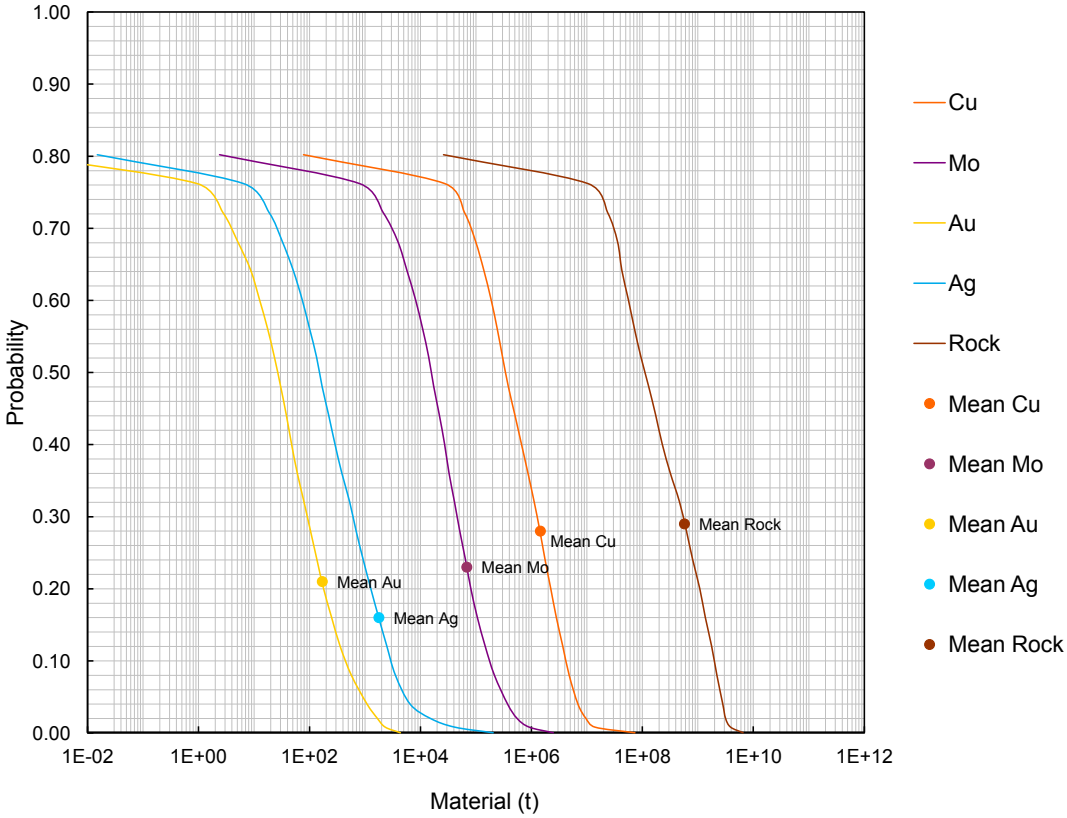


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Haaparanta PorCu permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT HAMMASLAHTI VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Hammaslahti VMS permissive tract is an approximately 15-km-wide and 120-km-long NNW-trending zone in eastern Finland extending from Juuka in the NW to Kitee in the SE (Fig. 1). The 1:100,000 KKJ map sheets are 4214, 4223, 4224, 4232, 4241, 4242, 4311 and 4313. The UTM map sheets containing the tract are N534, N541, N542, N543, N544, P531, P532, P533 and P541. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Hammaslahti VMS tract.

| Date of assessment | Assessment depth (km) | Tract area ($km^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 1847 | Cu | 0 | Cu | 170,000 | Cu | 44,000 |
| | | | Zn | 0 | Zn | 120,000 | Zn | 27,000 |
| | | | Pb | 0 | Pb | 4,200 | Pb | 310 |
| | | | Ag | 0 | Ag | 72 | Ag | 17 |
| | | | Au | 0 | Au | 0.89 | Au | 0.15 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by 2.1–2.0 Ga Marine Jatuli and Lower Kaleva supracrustal rocks. The delineation is based on the extent of mafic volcanic and turbiditic sedimentary rocks of the Tohmajärvi Group. The tract extends down to 1000 m depth. The depth extension is based on data from the Hammaslahti mine and the local stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There are no well-explored VMS deposits within the permissive tract (Table 2). The Hammaslahti deposit, which is located within the tract, is not considered a typical and well-explored VMS deposit. According to the spatial rule used, deposits less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Hammaslahti VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences and related deposit types

The closed Hammaslahti mine is listed in Table 3, since Hammaslahti is not considered as a typical VMS deposit. There are several outcrops with indications of copper and zinc mineralisation in the central to southern part of the tract.

Table 3. Significant VMS occurrences in the Hammaslahti VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Hammaslahti | 6932244 | 3656496 | 1950? | 7.36 Mt @ 1.16 % Cu, 1.26 % Zn | Hämäläinen (1987), Peltola (1971), Loukola-Ruskeeniemi et al. (1992) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Hammaslahti VMS tract are listed in Table 4.

Table 4. Exploration history for the Hammaslahti VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Bedrock mapping and glacial erratic boulder survey | Yes | Geological Survey of Finland | 1966–1979, 2007–2010 |
| | Bedrock mapping and glacial erratic boulder survey | Yes | Outokumpu Oy | 1960s–1990s |
| Geochemical surveys | Till and stream sediment survey, lithogeochemistry | Yes | Geological Survey of Finland | 1966–1979, 2007–2010 |
| | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| | Till geochemical survey | Yes | Outokumpu Oy | 1970s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1975–1998 |
| | Gravimetric | | Geological Survey of Finland | 1966–1979, 2008 |
| Ground geophysical surveys | Slingram, magnetic, gravimetric and radiation surveys | | Geological Survey of Finland | 1966–1979, 2007–2010 |
| | Electromagnetic, magnetic and gravimetric surveys | | Outokumpu Oy | 1960s–1990s |
| Drilling | 140 diamond-drill holes | Yes | Outokumpu Oy | 1971–1979 |
| | 100 diamond-drill holes, total 18785 m | Yes | Geological Survey of Finland | 1967–1970 |
| | Diamond drilling | Yes | Geological Survey of Finland | 2008–2010 |
| | Diamond drilling | Yes | FinnAust Mining plc | 2010s– |
| Other | Pilot-plant tests, feasibility study | Yes | Outokumpu Oy | 1970s |

## Sources of information

The principal sources of information used by the assessment team for the delineation of the Hammaslahti VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Hammaslahti VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Reports | | Pelkonen et al. (1973), Karppanen (1986), Hämäläinen (1987), Loukola-Ruskeeniemi et al. (1992), Karell (2001) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Lestinen (1979), Loukola-Ruskeeniemi et al. (1992), Kokkola & Penninkilampi (1984), Iisalo (2009) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Siikarla (1970), Airo & Karell (2001), Karell (2001) |
| Exploration | Reports | | Hyvärinen (1970), Pekkarinen (1979), Damsten (2010a, 2010 b), Western Areas (2012) |
| | Geological Survey of Finland in-house drill-core database | | |

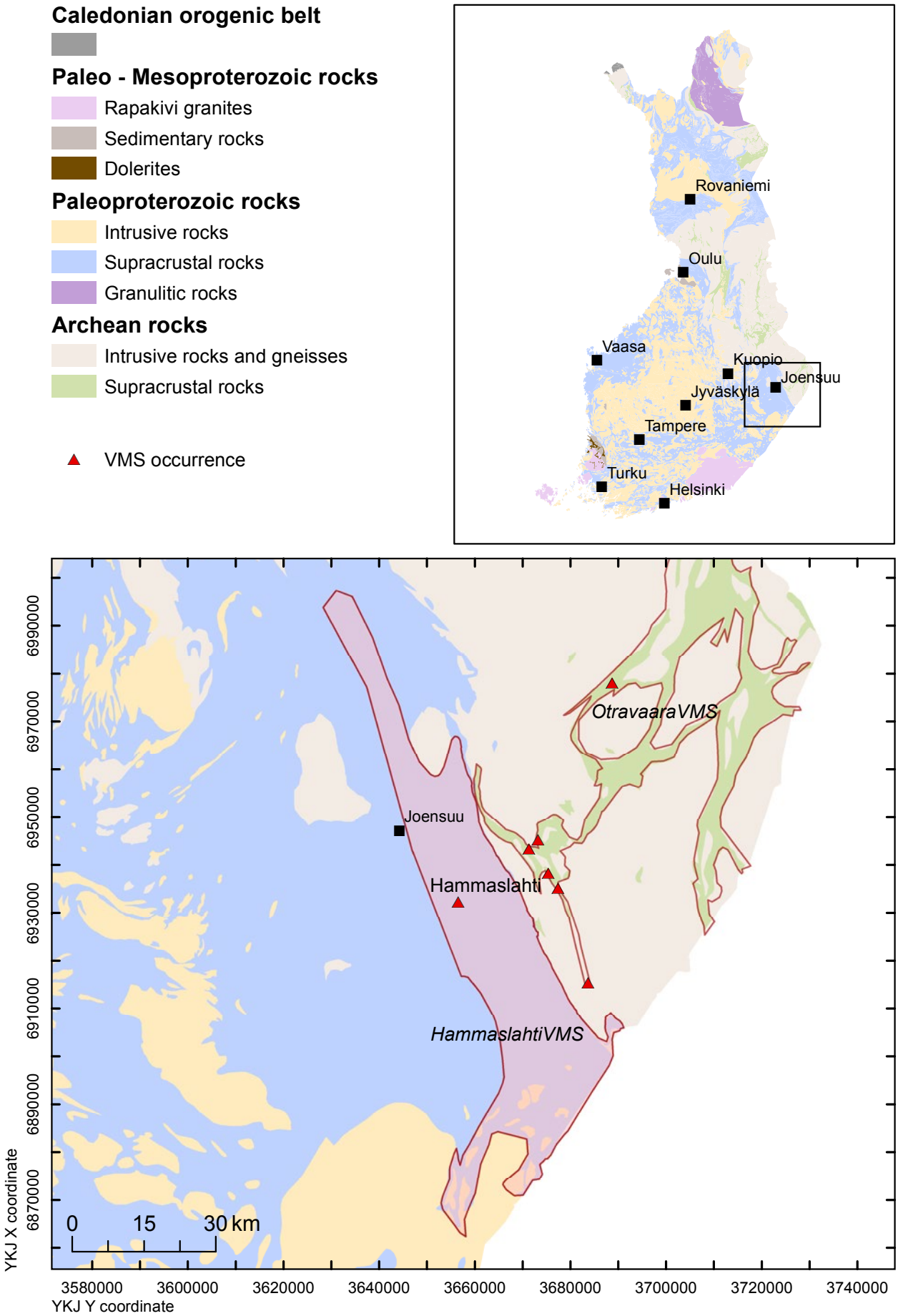


Fig. 1. Location of the Hammaslahti VMS permissive tract.

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

No partially explored VMS occurrences are known within the Hammaslahti VMS permissive tract (Table 3). The existence of the mined Hammaslahti deposit and metal-rich glacial erratic boulders that seemed not to have originated from the Hammaslahti deposit were considered to indicate the potential for undiscovered VMS deposits. Drilling within the tract has only been extensive in a few localities, including the Hammaslahti mine. The results of drilling decrease the favourability for the existence of undiscovered VMS deposits. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Hammaslahti VMS tract.

| Mean undiscovered deposit estimate | | | | | Summary statistics | | | | | Area (km²) | Deposit density (N/km²) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 2 | 2 | | | 1.6 | 0.46 | 28 | 0 | 1.6 | 1847 | 0.00088 |

| | Estimated number of undiscovered deposits | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 2 | 3 | 4 | | |
| Individual 2 | 0 | 1 | 2 | | |
| Individual 3 | 0 | 1 | 2 | | |
| Individual 4 | 0 | 1 | 2 | | |
| Individual 5 | 0 | 1 | 2 | | |
| Individual 6 | 0 | 1 | 2 | | |
| Individual 7 | 2 | 3 | 3 | | |
| Mean | 1 | 2 | 2 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen J. Luukas, J. Nikander, K. Rasilainen, P. Sorjonen-Ward, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Hammaslahti VMS tract.

| Material | At least the indicated amount at the probability of | | | | | Mean | Probability of mean or greater | Probability of zero |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 2,300 | 44,000 | 450,000 | 700,000 | 170,000 | 0.25 | 0.060 |
| Zn (t) | 0 | 1,000 | 27,000 | 320,000 | 560,000 | 120,000 | 0.22 | 0.060 |
| Pb (t) | 0 | 4.5 | 310 | 7,800 | 20,000 | 4,200 | 0.14 | 0.060 |
| Ag (t) | 0 | 0.62 | 17 | 180 | 330 | 72 | 0.23 | 0.060 |
| Au (t) | 0 | 0.0048 | 0.15 | 1.8 | 4.2 | 0.89 | 0.19 | 0.060 |
| Rock (Mt) | 0 | 0.15 | 3.5 | 38 | 59 | 12 | 0.28 | 0.060 |

t – metric tons; Mt – million metric tons.

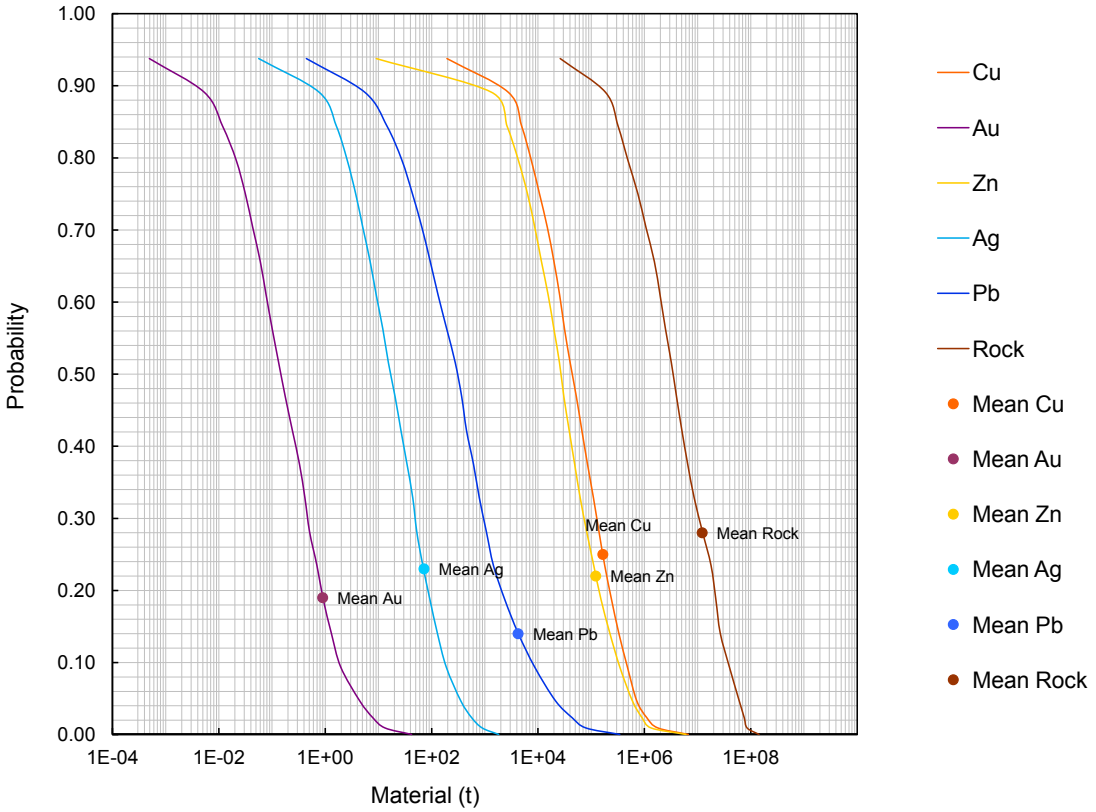


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Hammaslahti VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT HAUKIPUDAS VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Haukipudas VMS permissive tract is located in northern Finland in the municipalities of Oulu, Haukipudas, Ii, Yli-Ii, Kiiminki, Muhos and Utajärvi 10–40 km northeast of Oulu (Fig. 1). The 1:100,000 KKJ map sheets are 2533, 3422, 3423, 3424, 3511 and 3513. The UTM map sheets containing the tract are R441, R442, S431, R434, R443, R444 and S433. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Haukipudas VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 2262 | Cu | 0 | Cu | 110,000 | Cu | 12,000 |
| | | | Zn | 0 | Zn | 73,000 | Zn | 5,900 |
| | | | Pb | 0 | Pb | 2,600 | Pb | 45 |
| | | | Ag | 0 | Ag | 45 | Ag | 4.0 |
| | | | Au | 0 | Au | 0.56 | Au | 0.034 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by 1950–2060 Ma Lower Kaleva metasedimentary rocks of the Utajärvi Group. The delineation is based on the extent of mica schists and graywackes together with subordinate mafic volcanic rocks and black schists. The tract also includes some older quartzites and mafic volcanic rocks belonging to the Kiiminki Group (Jatuli and Merijatuli, 2060–2300 Ma). Information from diamond drill cores and outcrops, together with geophysical data, were used to define the margins of the tract. The tract is bordered by Archaean gneisses to the north and NE, Proterozoic granites to the south, and quartzites and conglomerates of the Lower Kaleva Utajärvi Formation to the SE. The latter are not included in the tract, as they represent fluvial and shallow marine sediments. The tract extends down to 1000 m depth. The depth extension is based on the assumption that the schist belt rocks continue downwards. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There are no well-explored VMS deposits within the Haukipudas VMS tract (Table 2). According to the spatial rule used, deposits nearer than 500 m of each other are counted as one in this assessment.

Table 2. Known VMS deposits in the Haukipudas VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences, and related deposit types

Four partially explored Cu or Zn occurrences, which are possibly of VMS type, are known within the Haukipudas VMS tract (Table 3). Some Zn-Pb-Ag and Cu-rich glacial erratic boulders are also known from the tract. There are indications of skarn-type W mineralisation in the SW part of the tract area.

Table 3. Significant VMS occurrences in the Haukipudas VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Kalliosuo | 7237294 | 3423654 | | Modest target with several outcrops in the surrounding area with elevated Zn concentrations. | Rossi (1997) |
| Laivakangas | 7220570 | 3441750 | 1950–2060 | Best section 1 m @ 1.1 % Zn | Korkiakoski (2002), GTK drill assay database |
| Rytikangas | 7233250 | 3424463 | | 0.5–2.5 % Zn in grab samples. | Vanhanen (1995) |
| Vepsä | 7206000 | 3463500 | | Modest target, several drill holes with elevated concentrations of Zn or Cu (<0.4 %) | Vanhanen (1995), GTK drill assay database |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Haukipudas VMS tract are listed in Table 4.

Table 4. Exploration history for the Haukipudas VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop and boulder observations | (Yes) | Geological Survey of Finland | 1970s to 2002 |
| Geochemical surveys | Targeted till and heavy mineral survey, 6741 samples | Yes | Rautaruukki Oy | 1970s and 1980s |
| | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| | Targeted till survey: 2706 samples from 167 km2 | Yes | Geological Survey of Finland | Mostly 1990s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1976–2006 |
| Ground geophysical surveys | Systematic slingram and magnetic, 28.35 $km^2$ | | Rautaruukki Oy | 1970s –1980s |
| | Extensive systematic magnetic, VLF-R and gravity surveys, minor IP and SP surveys | | Geological Survey of Finland | 1990s |
| Drilling | 43 DDH, 2702 m | Yes | Malminetsijä Oy | 1940–1965 |
| | 53 DDH, 7085 m | Yes | Rautaruukki Oy | 1973–1983 |
| | 214 DDH, 16194 m | Yes | Geological Survey of Finland | 1992–2004 |
| | 1 DDH, 37.8 m | Yes? | RTZ Mining and Exploration Ltd. | 1996 |

DDH – diamond-drill hole

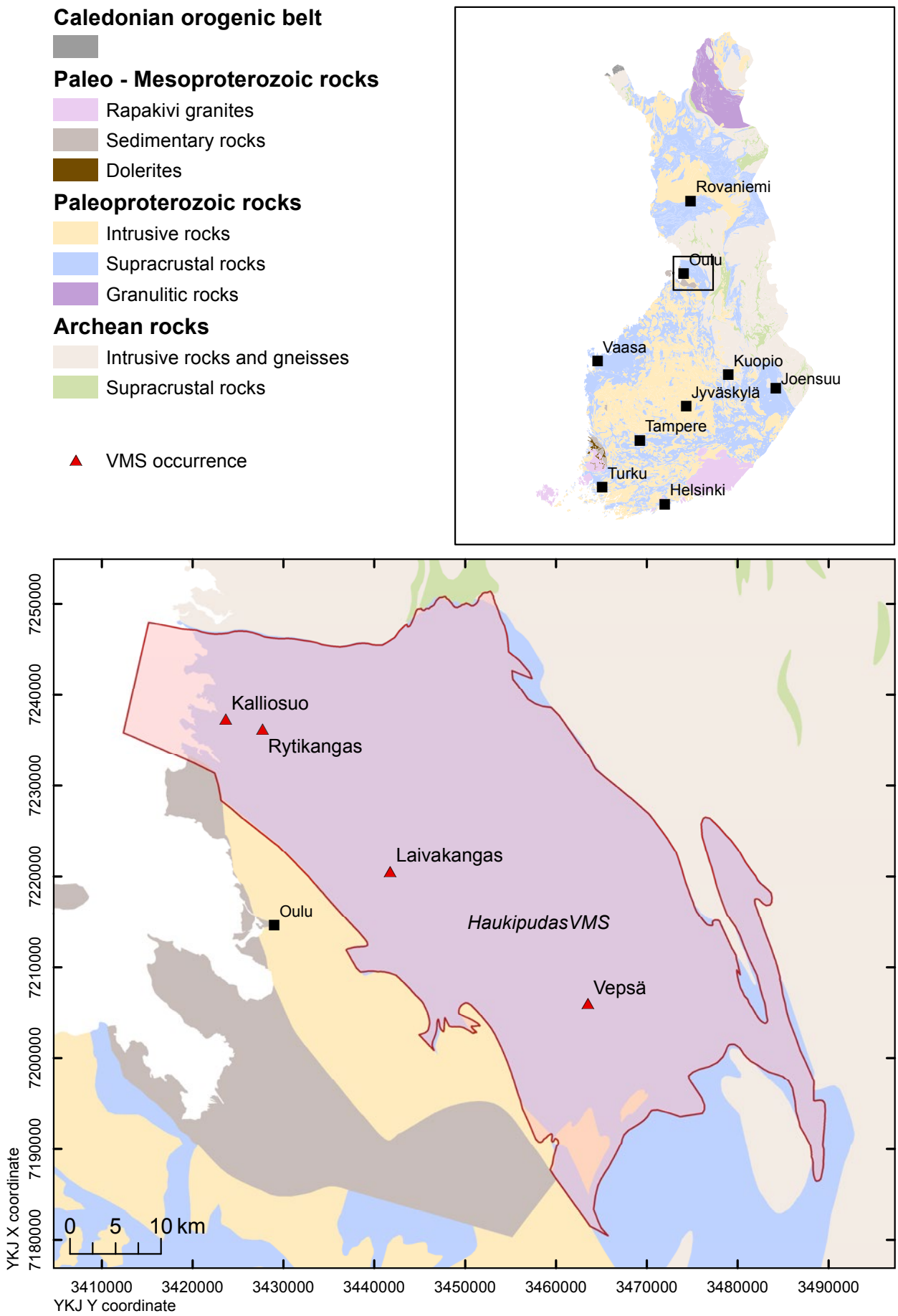


Fig. 1. Location of the Haukipudas VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Haukipudas VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Haukipudas VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Bedrock maps and their explanations | 1:100,000 | Kesola (1985), Honkamo (1988), Ahtonen (1996) |
| | Regional stratigraphic assessment | | Korkiakoski (2002) |
| Mineral occurrences | Report | | Korkiakoski (2002) |
| | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Alapieti et al. (2000), Korkiakoski (2002) |
| Geophysics | Geological Survey of Finland in-house database | | |
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| Exploration | Reports | | Makkonen (1980), Vanhanen (1995), Rossi (1997), Korkiakoski (2002) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Four poorly explored Zn occurrences of possibly VMS type are known within the tract (Table 3). In addition to these, the existence of Zn-Pb-Ag- and Cu-rich glacial erratic boulders, the distinct Cu-Zn-Pb anomalies in till, and the large area of potential host rocks were considered as favourable indications for the presence of VMS deposits in the tract. The tract is poorly exposed and little exploration has been carried out in the area, which adds to the uncertainty of the assessment. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Haukipudas VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 1 | 2 | | | 1.0 | 0.79 | 79 | 0 | 1.0 | 2262 | 0.00044 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 1 | 2 | 2 | | |
| Individual 2 | 0 | 0 | 2 | | |
| Individual 3 | 0 | 1 | 2 | | |
| Individual 4 | 1 | 1 | 2 | | |
| Individual 5 | 1 | 2 | 3 | | |
| Individual 6 | 0 | 2 | 4 | | |
| Individual 7 | 0 | 1 | 1 | | |
| Individual 8 | 0 | 0 | 1 | | |
| Individual 9 | 0 | 0 | 1 | | |
| Individual 10 | 0 | 0 | 1 | | |
| Mean | 0 | 1 | 2 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer and Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen, H. Kujala, J. Luukas, J. Nikander, K. Rasilainen, P. Sipilä, P. Sorjonen-Ward, M. Tiainen, T. Törmänen, K. Västi

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Haukipudas VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 12,000 | 290,000 | 570,000 | 110,000 | 0.20 | 0.30 |
| Zn (t) | 0 | 0 | 5,900 | 190,000 | 380,000 | 73,000 | 0.19 | 0.30 |
| Pb (t) | 0 | 0 | 45 | 3,000 | 10,000 | 2,600 | 0.11 | 0.30 |
| Ag (t) | 0 | 0 | 4.0 | 120 | 220 | 45 | 0.20 | 0.30 |
| Au (t) | 0 | 0 | 0.034 | 1.1 | 2.6 | 0.56 | 0.17 | 0.30 |
| Rock (Mt) | 0 | 0 | 0.84 | 24 | 45 | 7.7 | 0.22 | 0.30 |

t – metric tons; Mt – million metric tons.

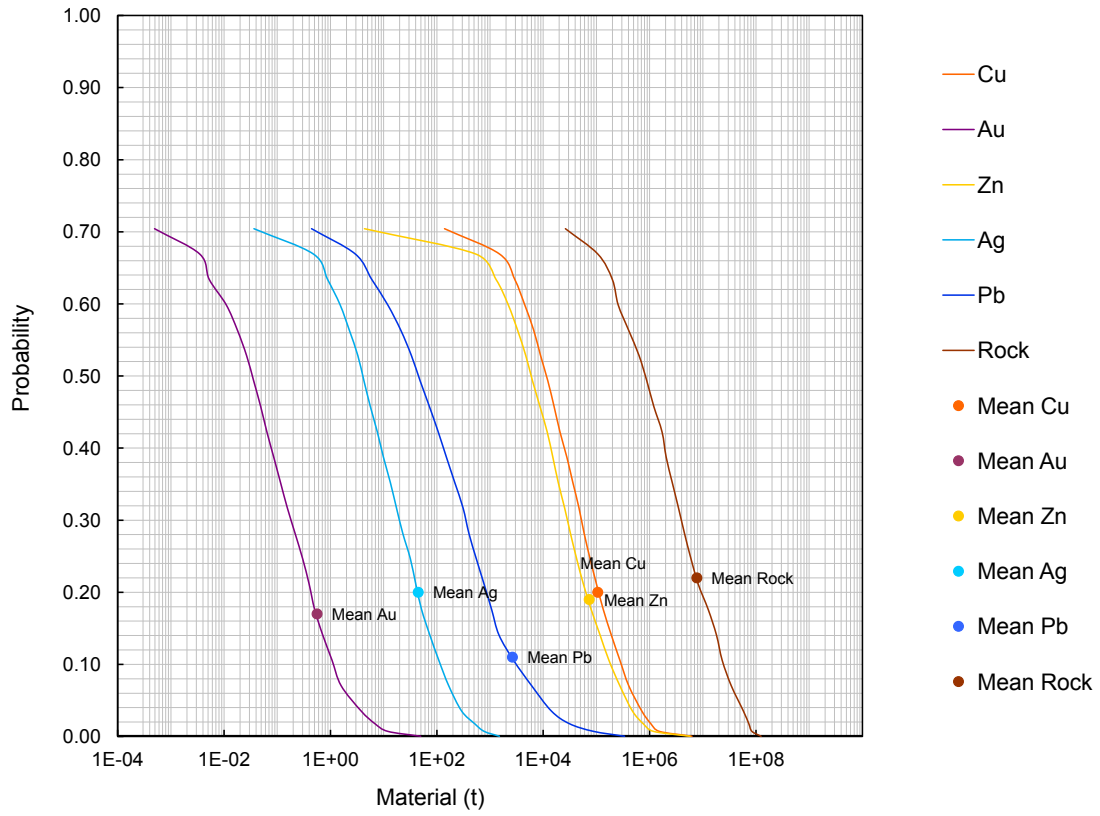


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Haukipudas VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT HYVINKÄÄ VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Hyvinkää VMS permissive tract is located in southern Finland. It is a 10–20-km-wide area striking E-W for approximately 80 km, north and NW of Hyvinkää town (Fig. 1). The 1:100,000 KKJ map sheets are 2024, 2042, 2044 and 2133. The UTM map sheets containing the tract are L421, L423, L424, L441 and L442. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Hyvinkää VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 1172 | Cu | 0 | Cu | 27,000 | Cu | 0 |
| | | | Zn | 0 | Zn | 21,000 | Zn | 0 |
| | | | Pb | 0 | Pb | 740 | Pb | 0 |
| | | | Ag | 0 | Ag | 11 | Ag | 0 |
| | | | Au | 0 | Au | 0.14 | Au | 0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geologic criteria

The Hyvinkää VMS permissive tract is defined by 1.90–1.88 Ga Svecofennian volcanic rocks. The delineation is based on the extent of mafic and minor intermediate volcanic rocks around synvolcanic layered intrusions. The tract is based on the existence of tholeiitic to calc-alkaline volcanic rocks and Cu±Zn occurrences possibly of the VMS type in that area. The tract extends down to 1000 m depth. The depth extension is based on stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There are no well-explored VMS deposits within the Hyvinkää VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Hyvinkää VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences and related deposit types

At least three partially explored Cu-Zn occurrences of possibly VMS type are known within the Hyvinkää VMS tract (Table 3). In addition, several outcrops with uncertain type of Cu and Zn mineralization have been discovered in the south easternmost part of the tract.

Table 3. VMS occurrences in the Hyvinkää VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Mustasuo | 6730200 | 3391300 | | 9 m @ 0.93 % Cu. Genetic type unknown. | Mustala (1975a, 1975b) |
| Kytäjä | 6725036 | 3377634 | | 120 t @ about 0.5 % Cu mined between 1556 and 1629. Genetic type unknown. | Puustinen (2003) |
| Kotkakorpi (Hirvihaara) | 6728650 | 3411630 | | 150 m long, 60 m wide mineralised zone; 2 m @ 0.47 % Cu in mafic volcanic rock; Zn not enriched | Lindmark (1982a, 1982b) |

Ma – million years; Mt – million metric tons; t – metric ton. Contained metal is given in metric tons and computed as tonnage * grade.

## Exploration history

Exploration activities for VMS deposits within the Hyvinkää VMS tract are listed in Table 4.

Table 4. Exploration history for the Hyvinkää VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1970s–1980s |
| | Outcrop and boulder observations | Yes | Rautaruukki | 1970s |
| | Outcrop and boulder observations | Yes | Outokumpu | 1970s–1980s |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Detailed till-geochemical survey | Yes | Geological Survey of Finland | 1970s |
| | Biogeochemical survey | Yes | Outokumpu | 1977 |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1978–1999 |
| Ground geophysical surveys | Magnetic, slingram, minmax, IP surveys | | Geological Survey of Finland | 1960s–1990s |
| | Magnetic surveys | | Rautaruukki | 1972 |
| | Magnetic, slingram and IP surveys | | Outokumpu | 1970s |
| Drilling | Seven diamond-drill holes at Mustasuo, three holes at Mäntymäki | Yes | Outokumpu | 1975–1979 |
| | Two diamond-drill holes at Kotkakorpi | Yes | Geological Survey of Finland | 1981 |

## Sources of information

The principal sources of information used by the assessment team for the delineation of the Hyvinkää VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Hyvinkää VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Exploration reports | | Mustala (1975a, 1975b) |
| | Metallogenic assessments | | Tiainen & Viita (1994) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Kokkola (1978), Lindmark (1982a, 1982b) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Penninkilampi (1972), Puranen (1972), Mustala (1975a, 1975b), Pehkonen (1981), Lindmark (1982a, 1982b), Valli (2000) |
| Exploration | Reports | | Penninkilampi (1972), Mustala (1975a, 1975b), Puustjärvi (1980), Pehkonen (1981), Lindmark (1982a, 1982b) |
| | Geological Survey of Finland in-house drill-core database | | |

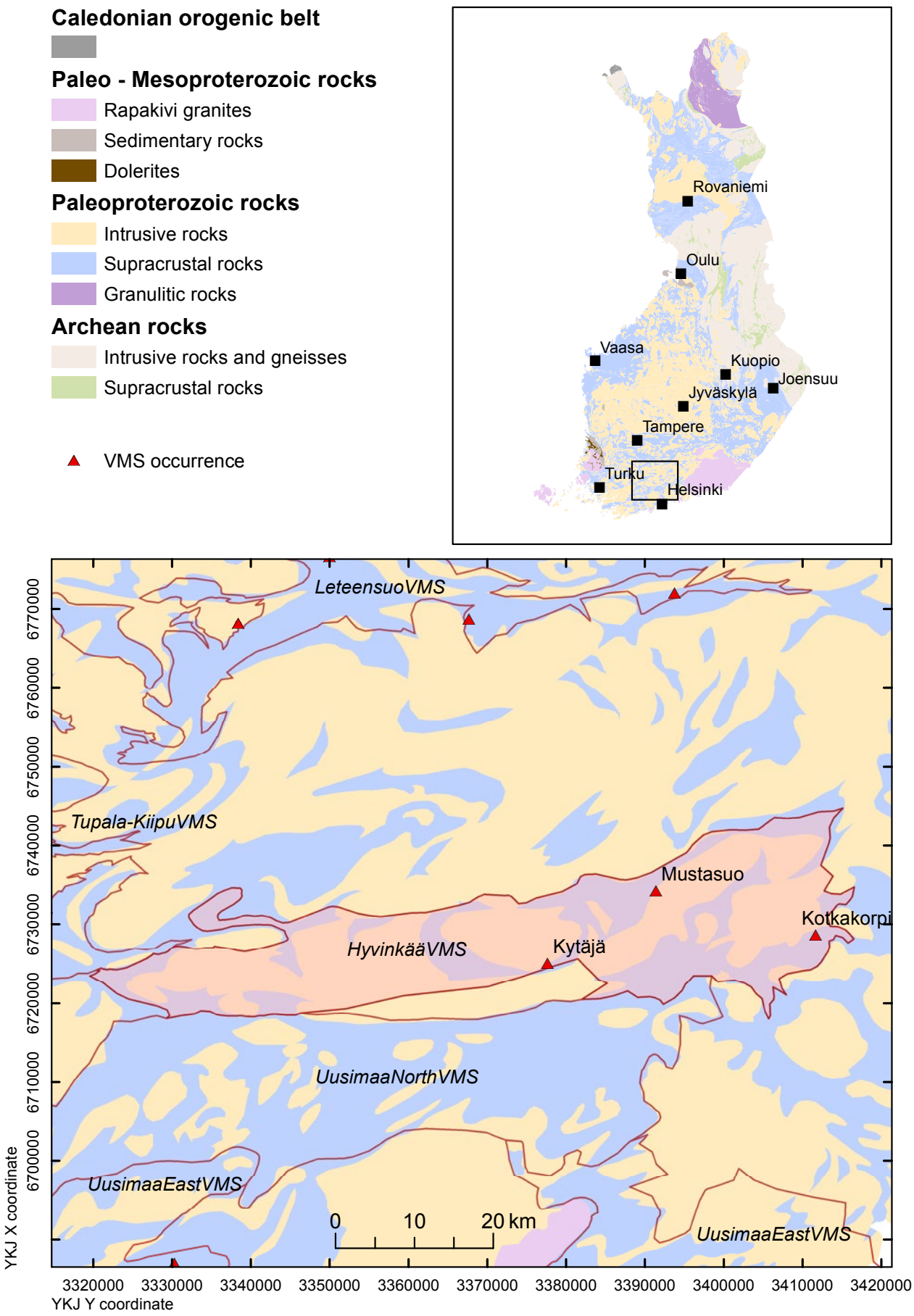


Fig. 1. Location of the Hyvinkää VMS permissive tract.

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Three partially explored Cu-Zn occurrences of possibly VMS type are known within the tract (Table 3). However, these occurrences were considered so small that most of the estimators believed that none of them will become economic, even under the most favourable circumstances. The known indications for VMS deposits are few. The existence of the few occurrences and mineralised glacial boulders was considered to indicate the potential for VMS mineralisation. Outcrops are scarce and very little drilling or other types of exploration have targeted VMS occurrences in the tract. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Hyvinkää VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area ($km^2$)** | **Deposit density ($N/km^2$)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 0 | 1 | | | 0.30 | 0.50 | 170 | 0 | 0.30 | 1172 | 0.00026 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 0 | | |
| Individual 2 | 0 | 0 | 0 | | |
| Individual 3 | 0 | 0 | 0 | | |
| Individual 4 | 0 | 0 | 2 | | |
| Individual 5 | 0 | 0 | 1 | | |
| Individual 6 | 0 | 0 | 1 | | |
| Individual 7 | 0 | 0 | 0 | | |
| Individual 8 | 0 | 0 | 1 | | |
| Individual 9 | 0 | 0 | 1 | | |
| Individual 10 | 0 | 0 | 1 | | |
| Individual 11 | 0 | 0 | 1 | | |
| Consensus | 0 | 0 | 1 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per $km^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen, H. Kujala, J. Luukas, J. Nikander, M. Nironen, K. Rasilainen, P. Sipilä, P. Sorjonen-Ward, M. Tiainen, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Hyvinkää VMS tract.

| Material | At least the indicated amount at the probability of | | | | | Mean | Probability of mean or greater | Probability of zero |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 0 | 39,000 | 130,000 | 27,000 | 0.12 | 0.70 |
| Zn (t) | 0 | 0 | 0 | 25,000 | 79,000 | 21,000 | 0.11 | 0.70 |
| Pb (t) | 0 | 0 | 0 | 340 | 1,200 | 740 | 0.070 | 0.70 |
| Ag (t) | 0 | 0 | 0 | 16 | 49 | 11 | 0.12 | 0.70 |
| Au (t) | 0 | 0 | 0 | 0.13 | 0.48 | 0.14 | 0.10 | 0.70 |
| Rock (Mt) | 0 | 0 | 0 | 2.9 | 12 | 2.1 | 0.11 | 0.70 |

t – metric tons; Mt – million metric tons.

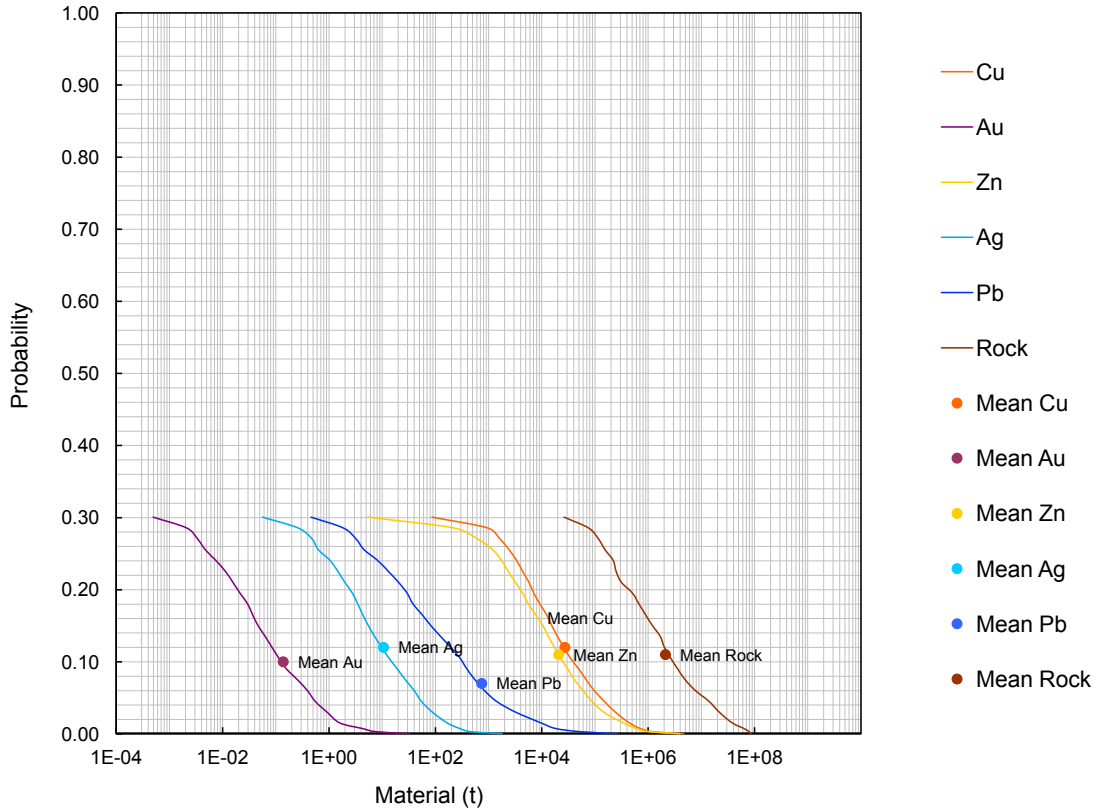


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Hyvinkää VMS permissive tract.

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# PORPHYRY Cu ASSESSMENT FOR THE TRACT HÄME PORCU, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: Porphyry Cu
**Descriptive model**: Porphyry Cu (Appendix 3)
**Grade-tonnage model**: Porphyry Cu (Appendix 4)

## LOCATION AND RESOURCE SUMMARY

The Häme PorCu permissive tract is located in southern Finland in the municipalities of Hämeenlinna, Asikkala, Hämeenkoski, Janakkala, Hattula, Tammela, Forssa, Urjala, Humppila, Jokionen, Ypäjä, Somero, Loimaa, Huittinen, Koski Tl., Marttila, Oripää, Pöytyä, Tarvasjoki, Aura, Lieto, Rusko, Nousiainen, Masku and Turku, extending from 45 km to the NE of the city of Hämeenlinna to 20 km to the NE of the city of Turku (Fig. 1). The 1:100,000 KKJ map sheets are 2134, 2133, 2132, 2131, 2114, 2113, 2024, 2111, 2022, 1133 and 1044. The UTM map sheets containing the tract are M431, M413, M411, L422, L421, M333, L344, L343, L342 and L341. The resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Häme PorCu permissive tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 8/11/2012 | 1 | 4720 | Cu | 0 | Cu | 1,900,000 | Cu | 630,000 |
| | | | Mo | 0 | Mo | 96,000 | Mo | 27,000 |
| | | | Ag | 0 | Ag | 2,600 | Ag | 280 |
| | | | Au | 0 | Au | 220 | Au | 43 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The Häme PorCu permissive tract is defined by early to synorogenic 1.89–1.88 Ga granitoid rocks within the Häme volcanic belt. The delineation is based on the extent of these intrusions. The tract extends down to 1000 m depth. The depth extension is based on interpretation of the geology of the region. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There are no well-explored porphyry Cu deposits within the Häme PorCu permissive tract (Table 2). According to the spatial rule used, deposits located less than 2 km apart were combined in this assessment. An exception was allowed if two occurrences <2 km apart could be shown to be products of separate mineralising systems.

Table 2. Known porphyry Cu deposits in the Häme PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade (%) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|
| None | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric tons. The contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences and related deposit types

There are three partially explored Cu occurrences that could go into the porphyry category within the Häme PorCu permissive tract (Table 3). Kedonojankulma is the most investigated one and is most probably of the porphyry type. In addition to these, the Kotka occurrence (Kinnunen 1987, 1990), which is classified as belonging to the VMS type (see the LeteensuoVMS tract report), could be related to a porphyry Cu system. Other types of occurrences that exist within the tract include VMS Cu-Zn occurrences in mafic volcanic rocks, W occurrences in skarns and orogenic gold occurrences.

Table 3. Possible porphyry Cu occurrences in the Häme PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ga) | Comments | Reference |
|---|---|---|---|---|---|
| Arolanmäki | 6760110 | 3315650 | 1.89 Ga? | 2 m @ 0.8–1.6 g/t Au. The hosting intrusion is similar to that at Kedonojankulma. Drilled Au mineralization is in a mafic dyke. | Eilu (2012), Tiainen et al. (2012) |
| Kedon-ojankulma | 6761645 | 3311718 | 1.88 Ga | 68 m @ 0.57 % Cu; 1 m @ 8 g/t Au; 1 m @ 120 g/t Ag; 1 m @ 1.3 % Zn; 1 m @ 0.13 % Mo. The drilled part about 2 Mt @ 0.46 % Cu eq. The mineralised body (ore) may extend across the entire intrusion, which is 1.5 km across. | Tiainen et al. (2011, 2012) |
| Liesjärvi | 6761240 | 3326120 | 1.89 Ga? | 6 m @ 2 g/t Au; chalcopyrite locally common. May be related to porphyry copper or to orogenic gold mineralisation; very little work done. | Kokkola (1986) |

Ga – billion years

## Exploration history

Exploration targeting mainly, or at least partly, the porphyry-style mineralisation in the Häme PorCu tract area is listed in Table 4. Other metal exploration in the region has targeted VMS Cu-Zn, skarn W, orogenic gold and rare-metal pegmatite.

Table 4. Exploration history for the Häme PorCu permissive tract.

| Theme | Type of work | Cu analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1970s–2010s |
| | Detailed outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1970s–1980s |
| | Detailed outcrop observations and boulder survey | Yes | Outokumpu | 1970s–1980s |
| | Detailed outcrop observations and boulder survey | Yes | University of Helsinki | 1981 |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Till geochemical surveys | Yes | Outokumpu | 1970s–1980s |
| | Detailed till geochemical surveys | Yes | Geological Survey of Finland | 2003–2010s |
| Airborne geophysical surveys | Regional low-altitude airborne magnetic, electromagnetic and radiometric survey | | Geological Survey of Finland | 2007 |
| Ground geophysical surveys | Magnetic, slingram and IP survey | | Outokumpu | 1970s–1980s |
| | Magnetic, gravimetric and slingram survey | | Geological Survey of Finland | 1970s–2010s |
| Drilling | Diamond and percussion drilling | Yes | Geological Survey of Finland | 1970s–2010s |
| | Diamond and percussion drilling | Yes | Outokumpu | 1970s–1980s |

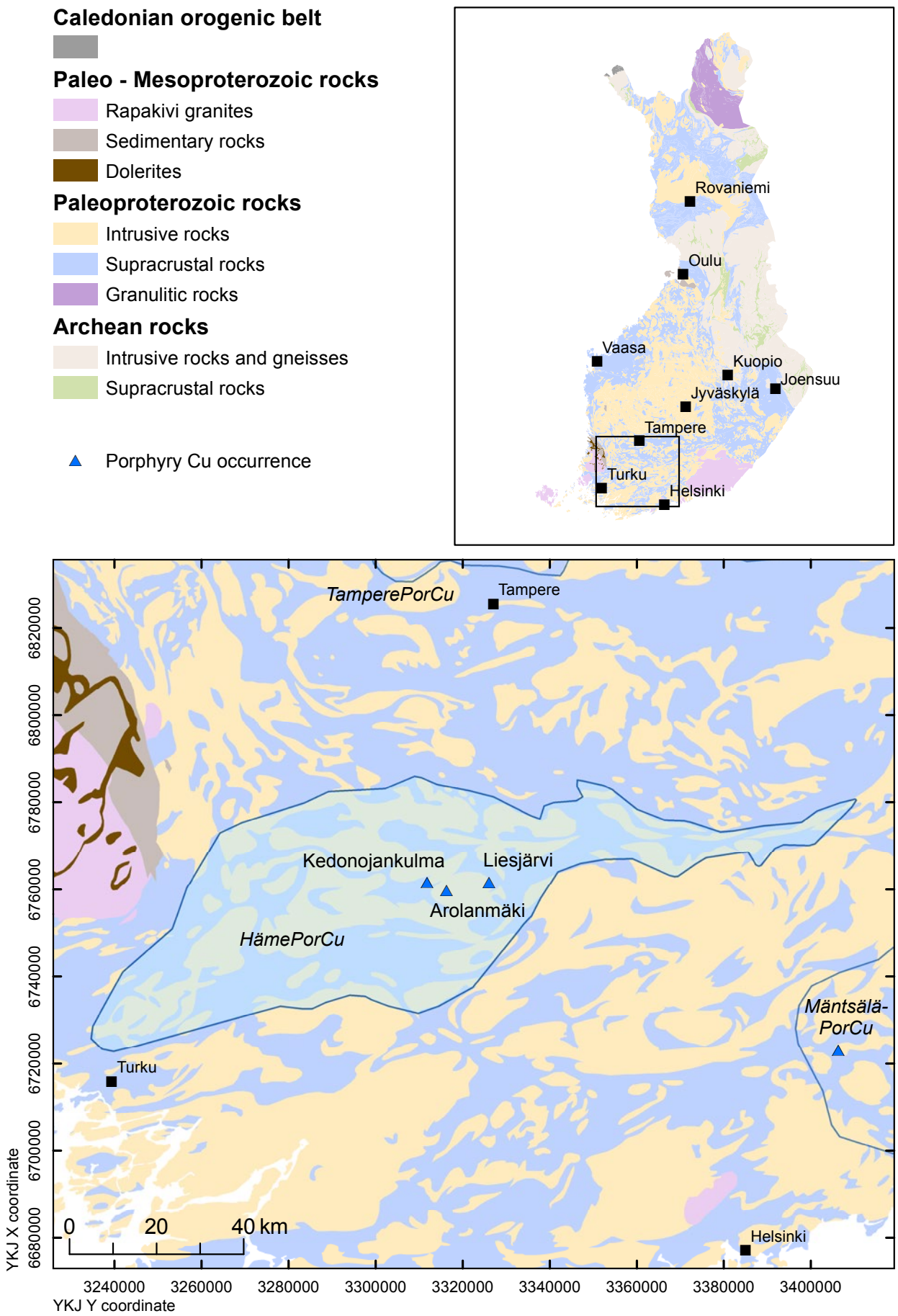


Fig. 1. Location of the Häme PorCu permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Häme PorCu tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Häme PorCu permissive tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:1000–1:10,000 | |
| Mineral occurrences | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Geological Survey of Finland gold deposit database | | Eilu & Pankka (2009) |
| | Deposit descriptions | | Kokkola (1986), Kinnunen (1987), Kärkkäinen et al. (2003), Kärkkäinen & Lehto (2004), Tiainen et al. (2011, 2012, 2013) |
| | Regional metallogenic assessments | | Kärkkäinen et al. (2003, 2012), Saalmann et al. (2010), Eilu (2012) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Kinnunen (1987, 1990), Kärkkäinen et al. (2003, 2012), Huhta et al. (2012), Tiainen et al. (2012) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Kinnunen (1987, 1990), Kärkkäinen et al. (2003), Airo & Leväniemi (2012), Lohva & Jokinen (2012), Mertanen & Karell (2012), Tiainen et al. (2012) |
| Exploration | Reports | | Nurmi (1981), Kinnunen (1987, 1990), Kokkola (1986), Kärkkäinen et al. (2003, 2012), Kärkkäinen & Lehto (2004), Tiainen et al. (2012) |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

At least three possible porphyry Cu occurrences are known within the Häme PorCu permissive tract. However, not all estimators considered these large enough to ever become economic deposits. The existence of the few porphyry copper-like occurrences, several granitoid rock outcrops with Cu, other intrusions similar to those at Kedonojankulma and Arolanmäki, indications of possible epithermal mineralisation, and Cu-mineralised boulders with no bedrock source yet discovered were considered to indicate the potential for an undiscovered porphyry Cu deposit within the Häme PorCu tract. The fact that porphyry deposits commonly occur in clusters increases the mineral potential of the tract area. Most exploration in the tract area has focused on other types of mineralisation, and porphyry-type deposits have only been targeted for a small part of the tract. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Häme PorCu permissive tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 2 | 4 | | | 2.2 | 1.2 | 54 | 0 | 2.2 | 4720 | 0.00047 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 2 | 3 | 7 | | |
| Individual 2 | 2 | 4 | 7 | | |
| Individual 3 | 1 | 2 | 3 | | |
| Individual 4 | 1 | 1 | 3 | | |
| Individual 5 | 1 | 2 | 3 | | |
| Individual 6 | 1 | 2 | 4 | | |
| Individual 7 | 1 | 2 | 4 | | |
| Individual 8 | 1 | 2 | 3 | | |
| Individual 9 | 1 | 2 | 4 | | |
| Individual 10 | 0 | 0 | 2 | | |
| Individual 11 | 0 | 1 | 3 | | |
| Individual 12 | 1 | 1 | 2 | | |
| Mean | 1 | 2 | 4 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variation; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, S.Grönholm, N. Kärkkäinen, J. Kousa, L. Lauri, J. Luukas, F. Molnar, T. Niiranen, M. Nironen, P. Sorjonen-Ward, M. Tiainen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the porphyry Cu grade-tonnage model (Appendix 4) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Häme PorCu permissive tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 9,000 | 630,000 | 5,000,000 | 7,500,000 | 1,900,000 | 0.29 | 0.07 |
| Mo (t) | 0 | 410 | 27,000 | 260,000 | 420,000 | 96,000 | 0.23 | 0.07 |
| Ag (t) | 0 | 2.6 | 280 | 3,900 | 8,400 | 2,600 | 0.15 | 0.07 |
| Au (t) | 0 | 0.37 | 43 | 620 | 1,100 | 220 | 0.22 | 0.07 |
| Rock (Mt) | 0 | 2.9 | 220 | 2,200 | 2,800 | 710 | 0.33 | 0.07 |

t – metric tons; Mt – million metric tons.

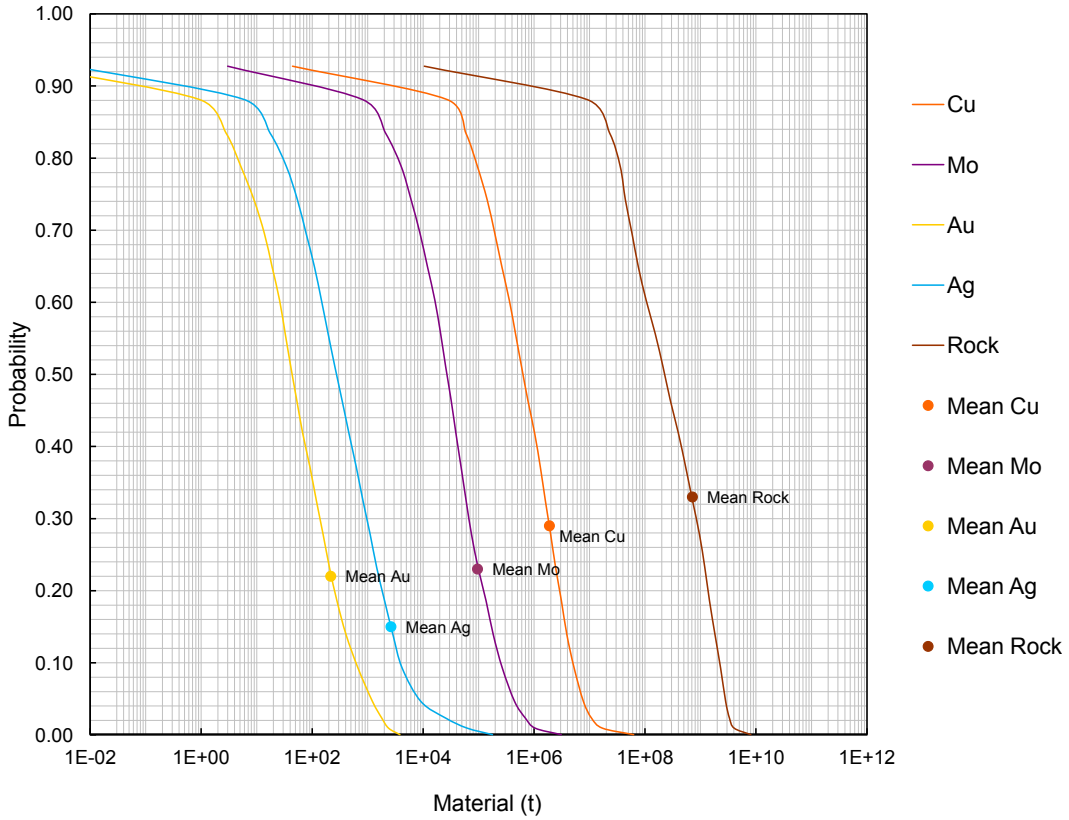


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Häme PorCu permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT JAURATSI VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix1)
**Grade-tonnage model**: VMS bimodal-mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Jauratsi VMS permissive tract is located in northern Finland in the municipalities of Pelkosenniemi and Savukoski, 130 km NE of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 3642, 3644, 3733, 4711 and 4712. The UTM map sheets containing the intrusion are U511, U512, U513, U514 and U523. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Jauratsi VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 392 | Cu | 0 | Cu | 13,000 | Cu | 4,100 |
| | | | Zn | 0 | Zn | 28,000 | Zn | 9,000 |
| | | | Pb | 0 | Pb | 1,400 | Pb | 86 |
| | | | Ag | 0 | Ag | 7.3 | Ag | 1.3 |
| | | | Au | 0 | Au | 0.21 | Au | 0.11 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by the occurrence of Proterozoic 2000–2200 Ma graphitic metasedimentary rocks. The delineation is based on the extent of the graphite- and sulphide-bearing schists of the Siulionpalo Formation, and associated ultramafic–mafic volcanic rocks of the Kummitsoiva and Ihanoja formations, which belong to the 2.15–2.05 Ga Savukoski Group of the Central Lapland Greenstone Belt. The tract is bordered by quartzites belonging to the Sodankylä Group in the west

and south, and mostly by Archaean gneisses in the east and north. Most of the komatiitic rocks are visible on the low-altitude airborne magnetic map, whereas the graphite- and sulphide-rich schists are visible on the electromagnetic map. Geophysical methods, drilling and outcrop observations were used to define the margins of the tract. The tract extends down to 1000 m depth. The depth extension is based on the assumption that the volcano-sedimentary belt continues downwards to such a depth. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored VMS deposits within the Jauratsi VMS permissive tract (Table 2).

Table 2. Known VMS deposits in the Jauratsi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

Six partially explored VMS occurrences are known within the Jauratsi VMS permissive tract (Table 3). Other types of mineral occurrences that exist within the tract include BIFs, which dominantly are of the sulphide-facies subtype (Roos 1982).

Table 3. Significant VMS occurrences in the Jauratsi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Jauratsinlampi | 7445370 | 3545750 | 2050–2150 | R115 best sections: 2.2 m @ 0.15 % Cu, 0.004 % Zn, 3.5 m @ 0.09 % Cu, 0.44 % Zn | Kerkkonen (1982) |
| Jauratsiselkä | 7447110 | 3540510 | 2050–2150 | R109 18 m @ 0.22 % Zn, 0.06 % Ni, 0.02 % Cu, 0.014 % Co, including 1 m @ 0.82 % Zn, 0.07 % Ni, 0.04 % Cu, 0.01 % Co | GTK drill assay database |
| Kummitsoivankuusikko | 7447290 | 3545150 | 2050–2150 | R724 4 m @ 0.45 % Zn, 0.046 % Ni, 0.027 % Cu, including 1 m @ 1.04 % Zn, 0.05 % Ni, 0.018 % Cu | GTK drill assay database |
| Siulionpalo | 7445370 | 3547040 | 2050–2150 | ~3-km-long E–W zone that has been drilled in several locations, generally <500 m from each other. R723 5 m @ 0.52 % Zn, 0.05 % Ni, 0.018 % Cu and 0.01 % Co. R721 1 m @ 0.4 % Zn, 0.05 % Ni, 0.03 % Cu, 0.01 % Co R682 6 m @ 0.28 %Zn, 0.07 % Ni, 0.038 % Cu, including 1 m @ 0.55 % Zn, 0.068 % Ni, 0.038 % Cu | GTK drill assay database |
| Siuliovaara | 7444350 | 3546190 | 2050–2150 | R642 26.1 m @ 0.43 % Zn, 0.16 % Ni, 0.09 % Cu, 0.01 % Co, including 2 m @ 0.87 % Zn, 0.22 % Ni, 0.14 % Cu, 0.014 % Co | GTK drill assay database |
| Vesilaskujänkä | 7443000 | 3541675 | 2050–2150 | R104 11.45 m @ 0.57 % Cu, 0.014 % Co, 0.1 ppm Au R110 5.3 m @ 0.44 % Cu, 0.012 % Co | Kerkkonen (1982) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Jauratsi VMS tract are listed in Table 4.

Table 4. Exploration history for the Jauratsi VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop and boulder observations | (Yes) | Geological Survey of Finland | 1970s–2008 |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Line till sampling covers the southern part; in addition 456 grid samples | Yes | Geological Survey of Finland | 1970s–2000s |
| | 126 grid till samples | Yes | Anglo American Exploration B.V. | 2004–2008 |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1977–1992 |
| Ground geophysical surveys | 25 $km^2$ magnetic, 19 $km^2$ slingram and 11.7 $km^2$ gravity survey | | Rautaruukki Oy | Mostly 1960s |
| | 5.4 line-km of magnetic survey | | RTZ Mining and Exploration Ltd. | 1995 |
| | 0.4 $km^2$ of slingram and 0.6 $km^2$ gravity survey | | Outokumpu oy | 1980s |
| | 7.3 line-km of magnetic and slingram survey | | Anglo American Exploration B.V. | 2004–2008 |
| | 52 $km^2$ systematic magnetic and VLF-R survey, 43 line-km of slingram, 13 line-km gravity, and 2.9 line-km IP survey | | Geological Survey of Finland | Mostly 1999–2006 |
| Drilling | 30 DDH, 1787 m | Yes? | Rautaruukki Oy | 1969–1975 |
| | 26 DDH, 4700 m | Yes | Outokumpu Oy | 1969–1989 |
| | 111 DDH, 7548 m | Yes | Geological Survey of Finland | 1986–2009 |
| | 1 DDH, 21.8 m | No? | RTZ Mining and Exploration Ltd. | 1995 |
| | 5 DDH, 329 m | Yes? | Anglo American Exploration B.V. | 2004–2005 |

DDH – diamond-drill hole

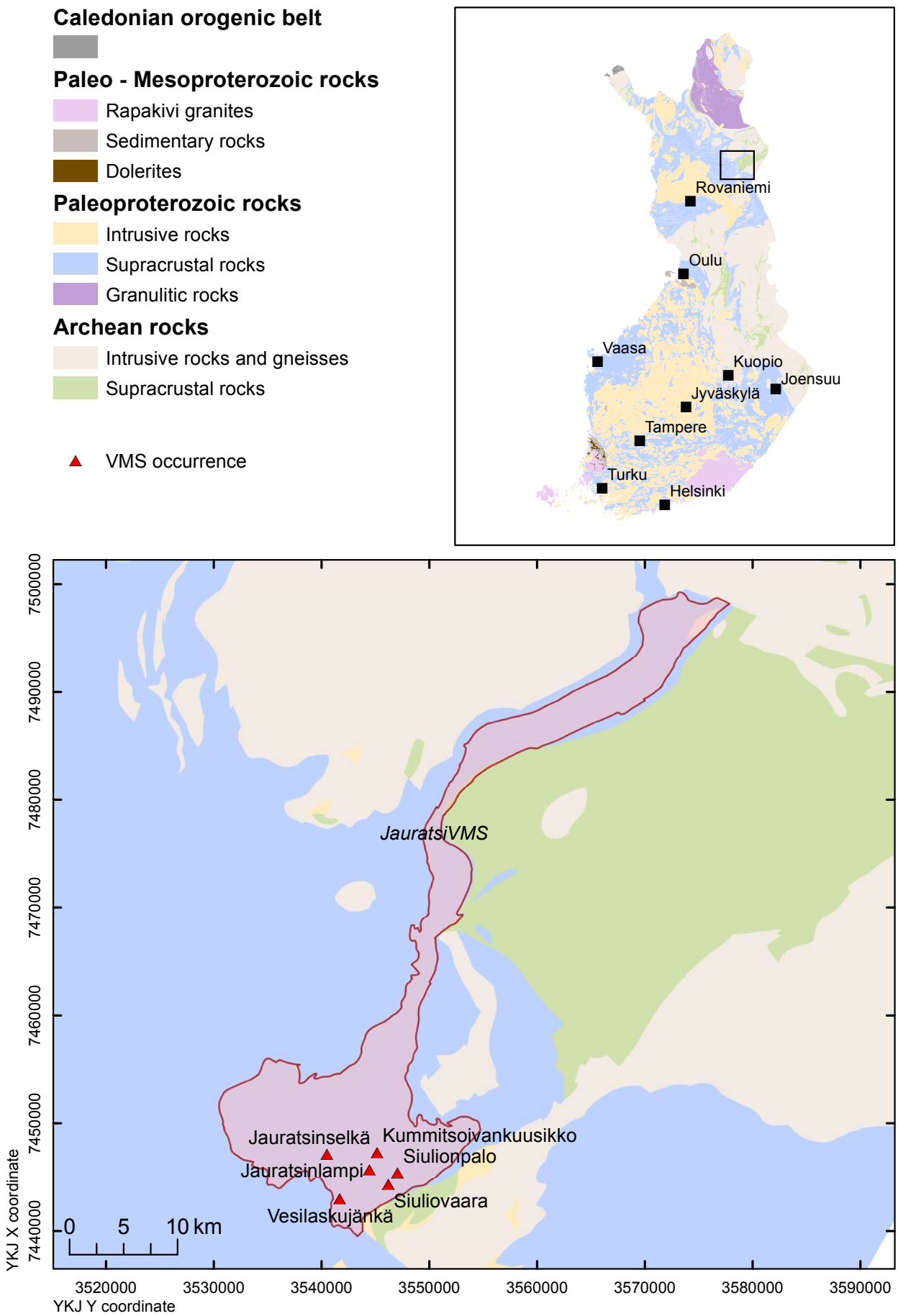


Fig. 1. Location of the Jauratsi VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Jauratsi VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Jauratsi VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Bedrock map | 1:100,000 | Räsänen (1983) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Vuotovesi (1985), Sarapää et al. (2008), Karvinen & Sandgren (2010) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Hiltunen (1970), Lanne (2006), Karvinen & Sandgren (2010) |
| Exploration | Reports | | Hiltunen (1970), Kerkkonen (1982), Roos (1982), Vuotovesi (1985), Inkinen (1990), RTZ Mining and Exploration Ltd. (1995), Austen & Långbacka (2008), Långbacka (2008), Sarapää et al. (2008), Karvinen & Sandgren (2010), Lintinen (2010) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Six partially explored, possibly VMS-type Cu-Zn occurrences are known within the tract (Table 3). These occurrences were considered so modest that most of the estimators believed it possible that none of them will ever become economic deposits, even under the most favourable circumstances. Indicators favourable for VMS mineralisation within the tract include the known VMS occurrences, the extensive felsic volcanic rocks and the sulphide-facies BIFs. On the other hand, extensive drilling has only taken place in a few localities, whereas detailed exploration is lacking for large parts of the tract. Major hindrances to exploration and assessment in the area are the extensive wetlands and other cover over the bedrock. No consensus was reached in the discussion and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Jauratsi VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 1 | 1 | | | 0.70 | 0.41 | 58 | 0 | 0.70 | 392 | 0.0018 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 0 | | |
| Individual 2 | 0 | 0 | 1 | | |
| Individual 3 | 0 | 0 | 1 | | |
| Individual 4 | 1 | 2 | 2 | | |
| Individual 5 | 0 | 0 | 1 | | |
| Individual 6 | 0 | 0 | 1 | | |
| Individual 7 | 1 | 2 | 2 | | |
| Individual 8 | 0 | 1 | 1 | | |
| Individual 9 | 0 | 1 | 1 | | |
| Individual 10 | 0 | 1 | 2 | | |
| Mean | 0 | 1 | 1 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen, H. Kujala, J. Luukas, J. Nikander, K. Rasilainen, P. Sipilä, P. Sorjonen-Ward, M. Tiainen, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS bimodal-mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Jauratsi VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 4,100 | 36,000 | 53,000 | 13,000 | 0.30 | 0.30 |
| Zn (t) | 0 | 0 | 9,000 | 80,000 | 120,000 | 28,000 | 0.28 | 0.30 |
| Pb (t) | 0 | 0 | 86 | 3,600 | 7,600 | 1,400 | 0.17 | 0.30 |
| Ag (t) | 0 | 0 | 1.3 | 14 | 33 | 7.3 | 0.19 | 0.30 |
| Au (t) | 0 | 0 | 0.11 | 0.59 | 0.82 | 0.21 | 0.31 | 0.30 |
| Rock (Mt) | 0 | 0 | 0.40 | 2.8 | 4.3 | 1.1 | 0.33 | 0.30 |

t – metric tons; Mt – million metric tons.

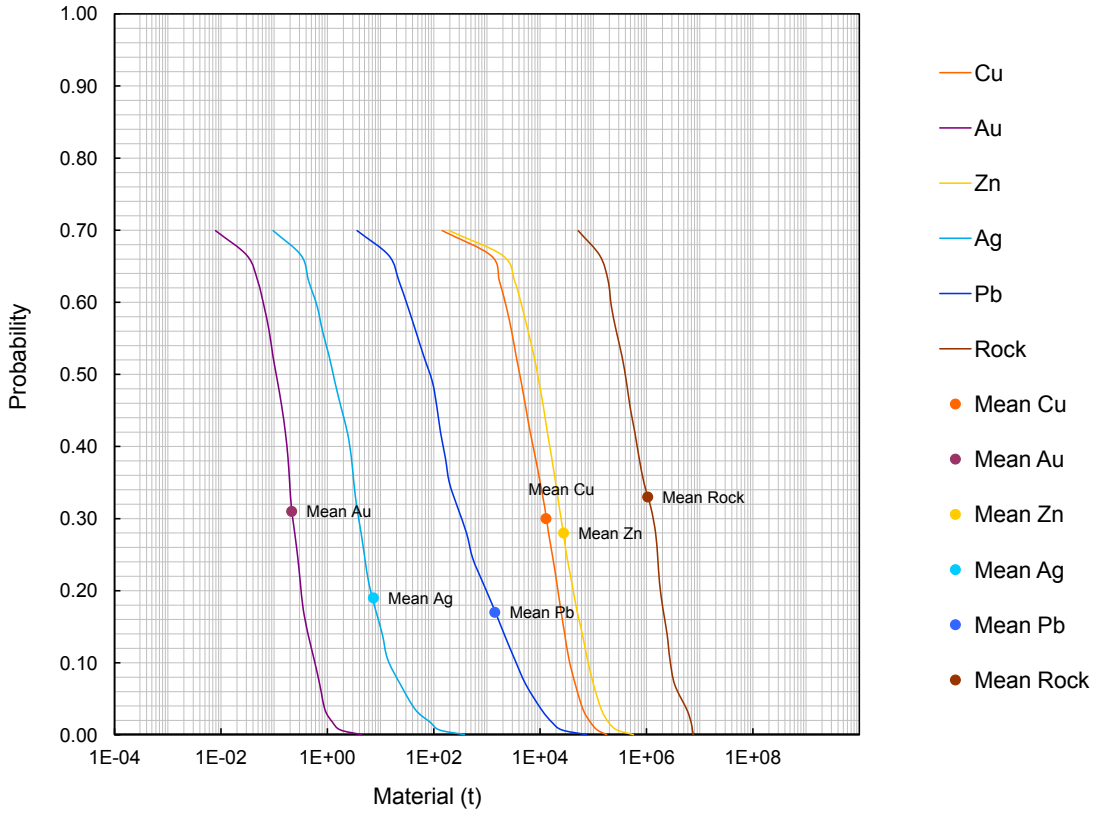


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Jauratsi VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT JURVA VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Jurva VMS permissive tract is located in western Finland. It is a 120-km-long and 5–15-km-wide, N-striking domain, between the cities of Pori in the south and Vaasa in the north, close to the western coast of Finland (Fig. 1). The 1:100,000 KKJ map sheets are 1142, 1144, 1231, 1232, 1241, 1243 and 1244. The UTM map sheets containing the tract are M324, N313, N314, N323, N324, N342 and P331. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Jurva VMS tract.z

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 10/12/2012 | 1 | 758 | Cu | 0 | Cu | 170,000 | Cu | 39,000 |
| | | | Zn | 0 | Zn | 130,000 | Zn | 23,000 |
| | | | Pb | 0 | Pb | 4,800 | Pb | 240 |
| | | | Ag | 0 | Ag | 75 | Ag | 14 |
| | | | Au | 0 | Au | 0.90 | Au | 0.13 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by ca. 1900 Ma Svecofennian mostly intermediate volcanic rocks of the Jurva suite, which belong to the Western Finland supersuite. The tract is based on the existence of island arc type calc-alkaline volcanic rocks. The tract extends down to 1000 m depth. The depth extension is based on stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored VMS deposits within the Jurva VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Jurva VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

There are no partially explored VMS occurrences within the Jurva VMS permissive tract (Table 3).

Table 3. VMS occurrences in the Jurva VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| None | | | | | |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Jurva VMS tract are listed in Table 4.

Table 4. Exploration history for the JurvaVMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1900s– |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1975–1995 |
| Ground geophysical surveys | Gravimetry: occasional E–W profiles; magnetic survey in small parts of the northern section of the tract | | Geological Survey of Finland | 1990s |
| Drilling | None | No | | |

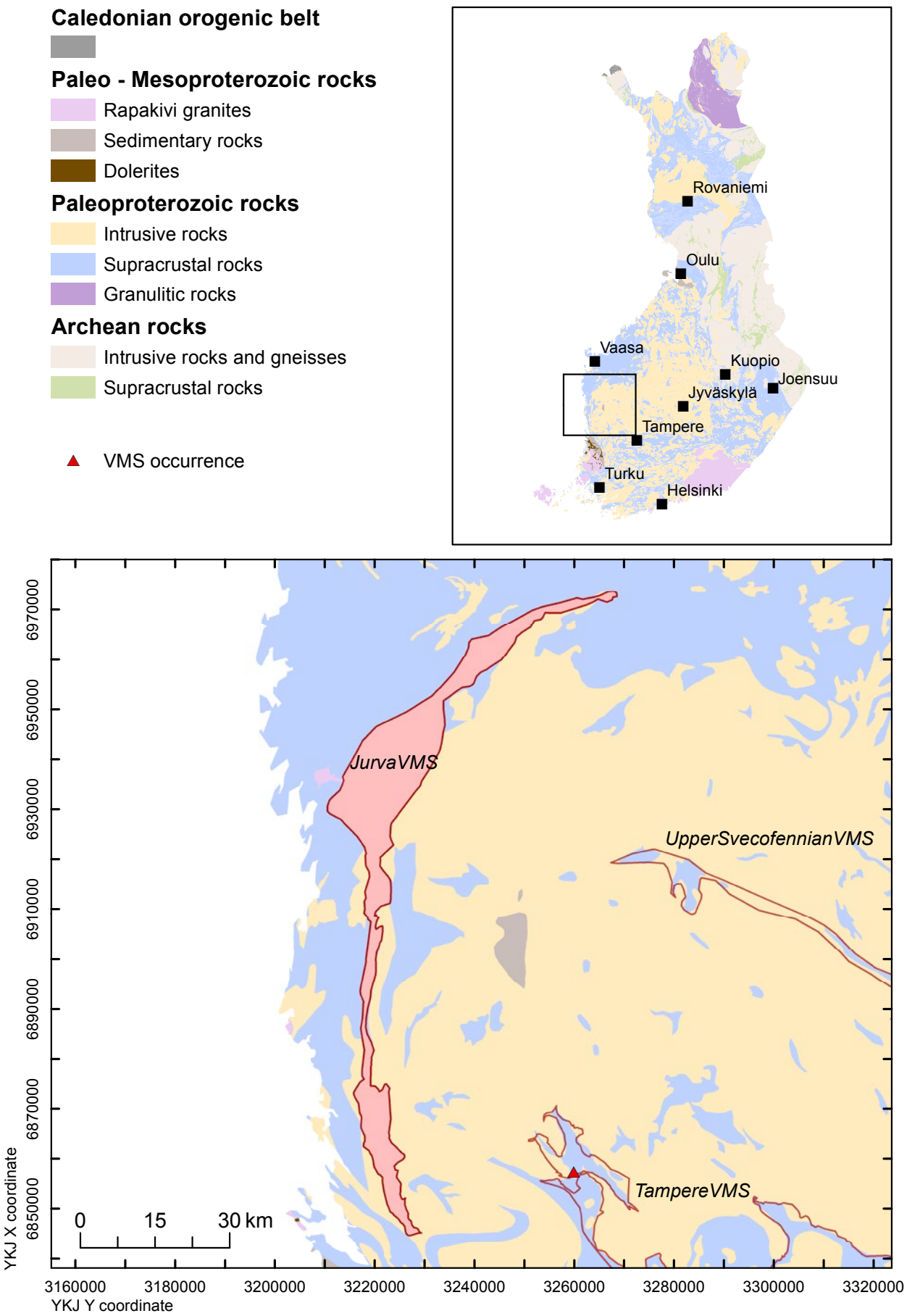


Fig. 1. Location of the Jurva VMS permissive tract.

### Sources of information

Principal sources of information used by the assessment team for the delineation of the Jurva VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Jurva VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | 1:200 000 | |
| | Regional mapping | 1:100,000 | Lehtonen et al. (2005) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Lehtonen et al. (2005) |
| Exploration | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

No partially explored VMS occurrences are known within the tract (Table 3). A few variably Zn- or Cu-mineralised boulders without a known source exist within the tract. Very little exploration of any kind has been carried out in the tract. The presence of calc-alkaline volcanic rocks in an extensive area was seen as the main positive factor for VMS mineralisation within the Jurva tract. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Jurva VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area ($km^2$)** | **Deposit density ($N/km^2$)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 2 | 3 | | | 1.7 | 1.1 | 63 | 0 | 1.7 | 758 | 0.0022 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 1 | 2 | | |
| Individual 2 | 0 | 1 | 2 | | |
| Individual 3 | 2 | 4 | 6 | | |
| Individual 4 | 0 | 2 | 3 | | |
| Individual 5 | 0 | 1 | 2 | | |
| Individual 6 | 0 | 2 | 5 | | |
| Individual 7 | 0 | 0 | 1 | | |
| Individual 8 | 0 | 1 | 2 | | |
| Consensus | 0 | 2 | 3 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per $km^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, O. Kontoniemi, J. Kousa, K. Rasilainen, P. Sipilä, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Jurva VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 39,000 | 480,000 | 770,000 | 170,000 | 0.25 | 0.20 |
| Zn (t) | 0 | 0 | 23,000 | 350,000 | 610,000 | 130,000 | 0.22 | 0.20 |
| Pb (t) | 0 | 0 | 240 | 8,800 | 22,000 | 4,800 | 0.14 | 0.20 |
| Ag (t) | 0 | 0 | 14 | 200 | 360 | 75 | 0.23 | 0.20 |
| Au (t) | 0 | 0 | 0.13 | 1.9 | 4.3 | 0.90 | 0.20 | 0.20 |
| Rock (Mt) | 0 | 0 | 3.0 | 41 | 66 | 13 | 0.28 | 0.20 |

t – metric tons; Mt – million metric tons.

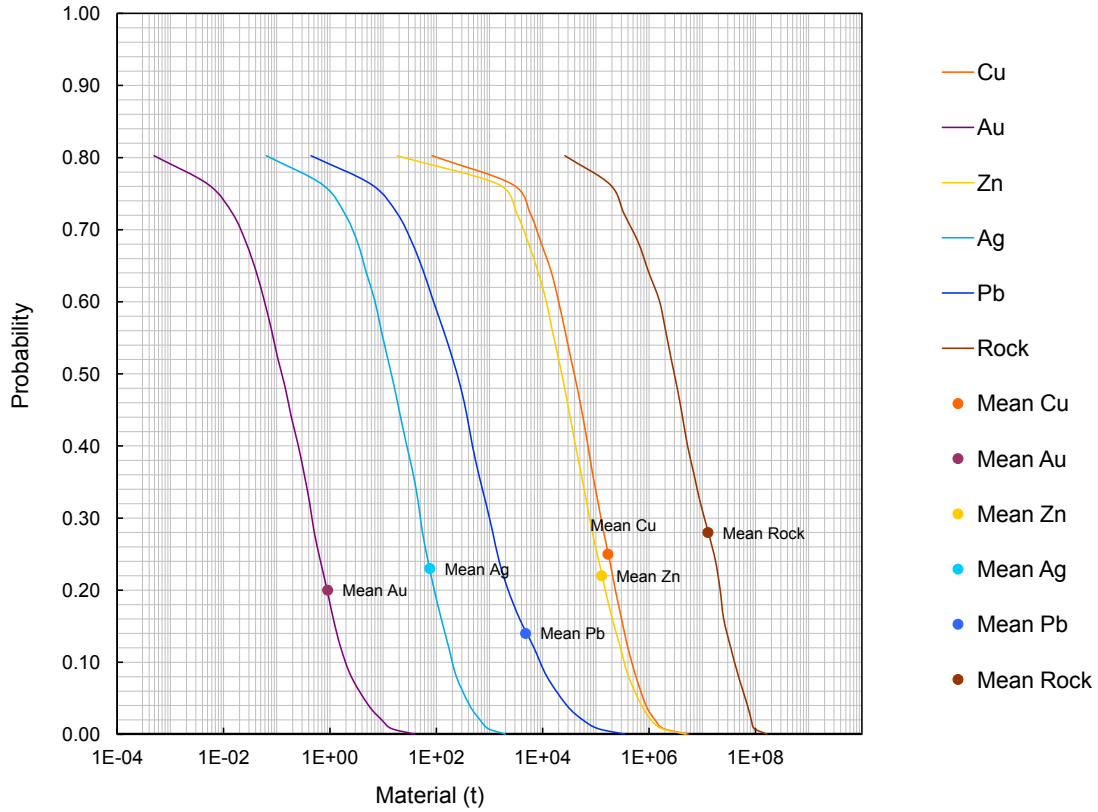


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Jurva VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT KIIMAVAARA VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS bimodal-mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The the Kiimavaara VMS permissive tract is located in northern Finland in the municipality of Savukoski, 200 km NE of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 4712, 4714 and 4721. The UTM map sheet containing the tract is U524. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Kiimavaara VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 10/12/2012 | 1 | 84 | Cu | 0 | Cu | 5,800 | Cu | 0 |
| | | | Zn | 0 | Zn | 12,000 | Zn | 0 |
| | | | Pb | 0 | Pb | 580 | Pb | 0 |
| | | | Ag | 0 | Ag | 2.9 | Ag | 0 |
| | | | Au | 0 | Au | 0.092 | Au | 0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by the occurrence of Archaean Tulppio suite amphibolites (mafic volcanic rocks) and mica gneisses together with electromagnetic anomalies on the low-altitude aerogeophysical maps. The anomalies are related to the occurrence of massive iron sulphide deposits and iron oxide gossans associated with the amphibolites and felsic schists. Several studies suggest

that the quartz-feldspar schists (mica gneisses on the bedrock map) represent felsic volcanic rocks, forming a bimodal volcanic series together with the amphibolites. The tract was drawn so that it encompasses most of the mica schists and associated aerogeophysical anomalies in the area. The tract extends down to 1000 m depth. The depth extension is based on the assumption that the schist belt rocks continue downwards. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored VMS deposits within the Kiimavaara VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS-type Cu-Zn deposits in the Kiimavaara VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

One partially explored VMS occurrence is known within the Kiimavaara VMS permissive tract (Table 3). There is also one Au occurrence at Rovaukonselkä with 2.05 m @ 2.25 ppm Au.

Table 3. Significant VMS occurrences in the KiimavaaraVMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Kiimavaara | 7519000 | 3590294 | Archaean | 3.2 m @ 0.74 % Zn, 0.6 % Pb | Vuotovesi (1985) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Kiimavaara VMS tract are listed in Table 4.

Table 4. Exploration history for the Kiimavaara VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop and boulder observations | No | Geological Survey of Finland | 1980–2008 |
| | Outcrop and boulder observations | Yes | Outokumpu Oy | 1970s |
| | Outcrop and boulder observations | Yes | University of Oulu | 1981–1983 |
| | Outcrop and boulder observations | Yes | Outokumpu Oy and University of Turku | 1996–1997 |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Humus sampling, 634 samples | Yes | Geological Survey of Finland | 1970 |
| | Basal-till sampling, 1100 samples | Yes | Outokumpu | 1979–1982 |
| | Heavy mineral sampling 600 $km^2$ | Yes | Rautaruukki Oy | 1978 |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1970s, 2000 |
| Ground geophysical surveys | 23 line km magnetic and VLF-R surveys, 2.4 line km gravimetric surveys | | Geological Survey of Finland | 1987–1996 |
| | Regional gravity survey, whole tract area | | Geological Survey of Finland | 2005–2007 |
| | Systematic magnetic and slingram surveys 20 $km^2$, 15 line km gravity surveys | | Outokumpu Oy | 1979–1982 |
| | 15 $km^2$ systematic magnetic and slingram | Yes | Rautaruukki Oy | 1979–1980 |
| Drilling | 9 diamond-drill holes, in total 495 m | Yes | Geological Survey of Finland | 1987–2009 |
| | 2 diamond-drill holes, in total 299 m | Yes | Rautaruukki Oy | 1979 |
| | 6 diamond-drill holes, in total 1147 m | Yes | Outokumpu Oy | 1980–1986 |

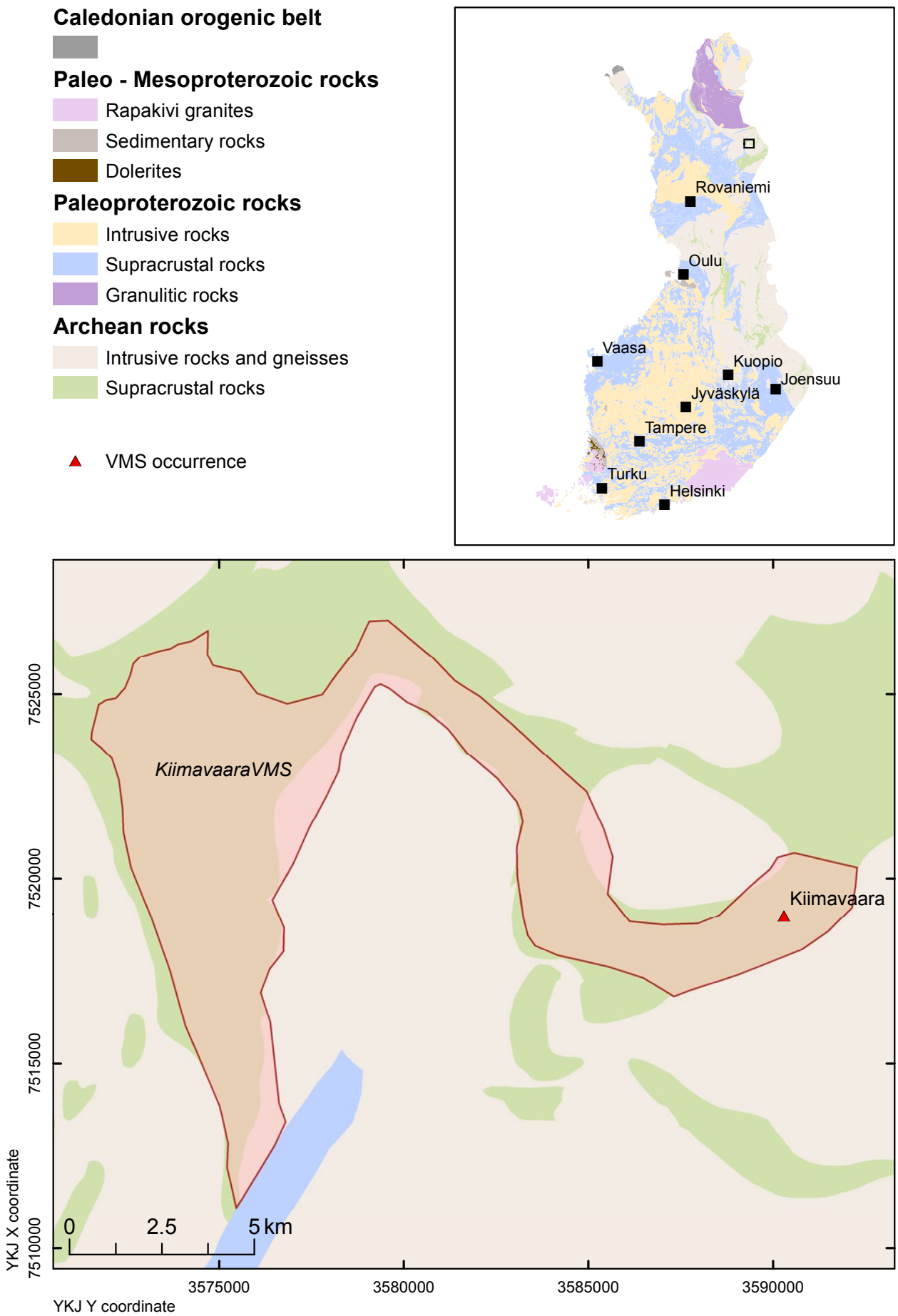


Fig. 1. Location of the Kiimavaara VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Kiimavaara VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Kiimavaara VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:100–1:20,000 | Tukiainen & Mattila (1979), Peltoniemi (1984), Kauniskangas (1987), Juopperi (1994), Halkoaho et al. (1999) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Reports | | Vuotovesi (1985), Inkinen (1990) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Mattila & Korvuo (1979), Kontas & Lehmuspelto (1980), Lehmuspelto et al. (2009) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Mattila (1979, 1980) |
| Exploration | Reports | | Mattila (1980), Vuotovesi (1984, 1985), Inkinen (1990), Heikura et al. (2009) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

One partially explored VMS occurrence is known within the tract (Table 3). However, this occurrence was considered so modest that most of the estimators believed it will never become economic, even under the most favourable circumstances. Favourable indicators for the tract include the probably subaqueous bimodal volcanic rocks (mafic and felsic), iron sulphide-rich units in the local supracrustal sequence, an iron gossan, signs of submarine alteration (e.g., epidosites) and a zinc anomaly in till. Very little exploration for base metals has been carried out in the tract area. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Kiimavaara VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area ($km^2$)** | **Deposit density ($N/km^2$)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 0 | 1 | | | 0.30 | 0.50 | 170 | 0 | 0.30 | 84 | 0.0036 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 1 | | |
| Individual 2 | 0 | 1 | 1 | | |
| Individual 3 | 0 | 0 | 2 | | |
| Individual 4 | 0 | 0 | 1 | | |
| Individual 5 | 0 | 0 | 1 | | |
| Individual 6 | 0 | 0 | 1 | | |
| Consensus | 0 | 0 | 1 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per $km^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed.Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, K. Rasilainen, P. Sipilä, T. Törmänen.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS bimodal-mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Kiimavaara VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 0 | 19,000 | 34,000 | 5,800 | 0.19 | 0.70 |
| Zn (t) | 0 | 0 | 0 | 35,000 | 71,000 | 12,000 | 0.19 | 0.70 |
| Pb (t) | 0 | 0 | 0 | 680 | 2,500 | 580 | 0.10 | 0.70 |
| Ag (t) | 0 | 0 | 0 | 5.2 | 13 | 2.9 | 0.16 | 0.70 |
| Au (t) | 0 | 0 | 0 | 0.30 | 0.52 | 0.092 | 0.23 | 0.70 |
| Rock (Mt) | 0 | 0 | 0 | 1.7 | 2.7 | 0.46 | 0.20 | 0.70 |

t – metric tons; Mt – million metric tons.

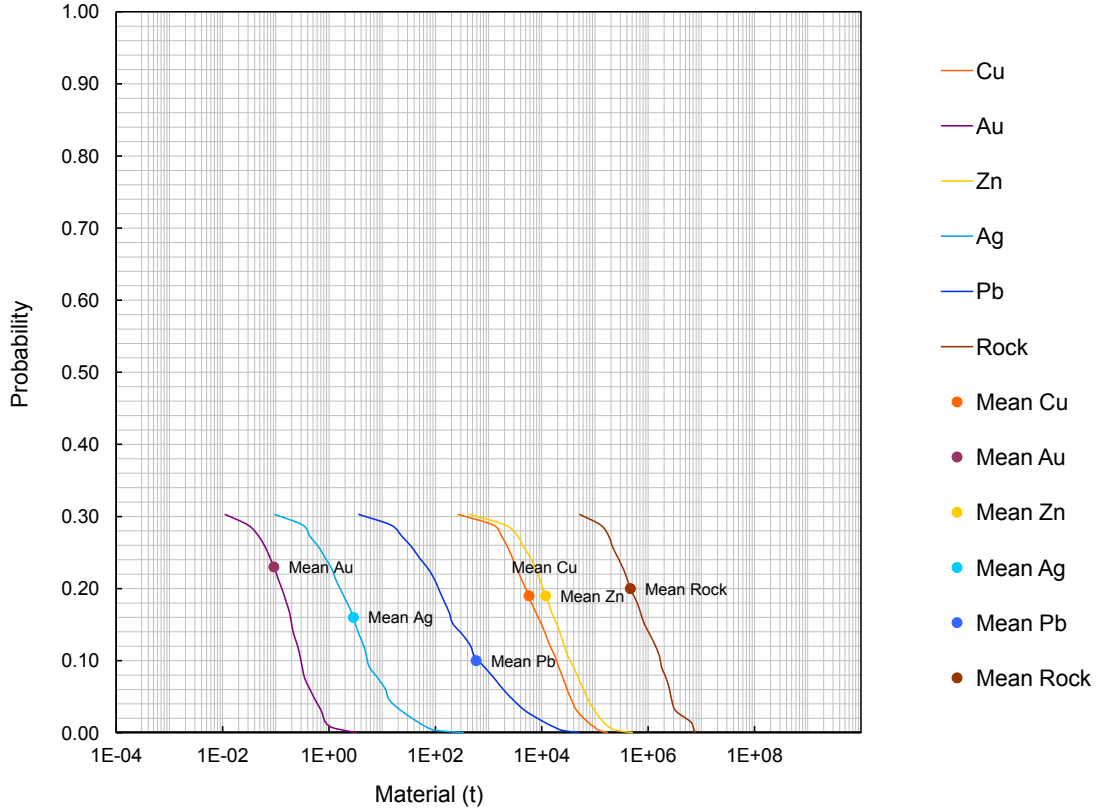


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Kiimavaara VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT KIIMAVUOMA VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Kiimavuoma VMS permissive tract is located in northern Finland in the municipalities of Rovaniemi, Tervola, Ylitornio and Tornio, 40–80 km WSW of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 2613, 2631, 2632 and 2633. The UTM map sheets containing the tract are T411, T413, T414, T431 and T432. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Kiimavuoma VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 10/12/2012 | 1 | 641 | Cu | 0 | Cu | 97,000 | Cu | 9,900 |
| | | | Zn | 0 | Zn | 79,000 | Zn | 5,400 |
| | | | Pb | 0 | Pb | 3,000 | Pb | 40 |
| | | | Ag | 0 | Ag | 42 | Ag | 3.4 |
| | | | Au | 0 | Au | 0.49 | Au | 0.029 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by the presence of the 1950–2060 Ma Lower Kaleva metasedimentary rocks of the Paakkola Group. The delineation is based on the extent of mica schists, phyllites and black schists of the Martimo Formation, together with subordinate mafic volcanic rocks of Väystäjä

Formation. The Väystäjä Formation mafic volcanic rocks were included in the tract as they are commonly pillowed, suggesting a submarine deposition environment, whereas other mafic volcanic units within the Peräpohja schist belt are either tuffites, tuffs or vesicular lavas. The tract is bordered by the older Jatuli quartzites of the Kivalo Group (2300–2100 Ma) to the south and east, by the younger Haaparanta Suite granodiorites and the Swedish border to the west, and by various gneisses and schists of the Kemijärvi complex to the north. Diamond drill core and outcrop observations, as well as geophysical information were used to define the extent of the tract. The tract extends down to 1000 m depth. The depth extension is based on the assumption that the schist belt rocks continue downwards. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored VMS deposits within the Kiimavuoma VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Kiimavuoma VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

One partially explored VMS occurrence is known within the Kiimavuoma VMS permissive tract (Table 3). There are also epigenetic U-Au and possibly syngenetic U-P occurrences near the tract margins.

Table 3. Significant VMS occurrences in the Kiimavuoma VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Kiimavuoma | 7373560 | 3405159 | 2060–1950 | 15.9 m @ 0.28 % Zn, 0.09 % Cu, 0.04 % Ni including 2 m @ 0.6 % Zn, 0.09 % Cu, 0.04 % Ni, several 1–2 m intervals @ 0.3–0.4 % Zn | Pulkkinen (2000) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Kiimavuoma VMS tract are listed in Table 4.

Table 4. Exploration history for the KiimavuomaVMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop and boulder observations | No | Geological Survey of Finland | Mostly 1970s |
| | Outcrop and boulder observations | Yes | Lapin Malmi Oy | 1980s? |
| | Outcrop and boulder observations, not yet reported | Yes | First Quantum Minerals Ltd | 2011– |
| | Outcrop and boulder observations | Yes | Inmet Mining Co | 2006–2007 |
| Geochemical surveys | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| | Targeted grid sampling of till, 572 samples | Yes | Geological Survey of Finland | 1997 |
| | Till geochemical survey, MMI-survey | Yes | Inmet Mining Co | 2009, 2012 |
| | Local-scale till sampling, 851 samples | Yes | Lapin Malmi Oy | 1980s? |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electro-magnetic and radiometric surveys | | Geological Survey of Finland | 1994–2002 |
| Ground geophysical surveys | 1.41 $km^2$ of systematic magnetic and VLF-R survey; 23.38 line-km of magnetic, 9.4 line-km slingram, 8.6 line-km gravimetric and 5 line-km VLF-R survey | | Geological Survey of Finland | 1976–1999 |
| | Electromagnetic, magnetic and IP surveys | | Inmet Mining Co | 2006–2007 |
| | 9 $km^2$ magnetic and slingram, 2.2 $km^2$ VLF-R survey | | Rautaruukki Oy | 1978–1979 |
| Drilling | 26 DDH, 1025 m | Yes | Geological Survey of Finland | 1995–1999 |
| | 10 DDH, 2051.05 m | Yes | Inmet Mining Co | 2007–2008 |
| | 10 DDH, 1616 m | Yes? | Rautaruukki Oy | 1979 |
| | 2 DDH, 277 m | Yes? | Outokumpu Oy | 1967 and 1980 |

DDH – diamond-drill hole

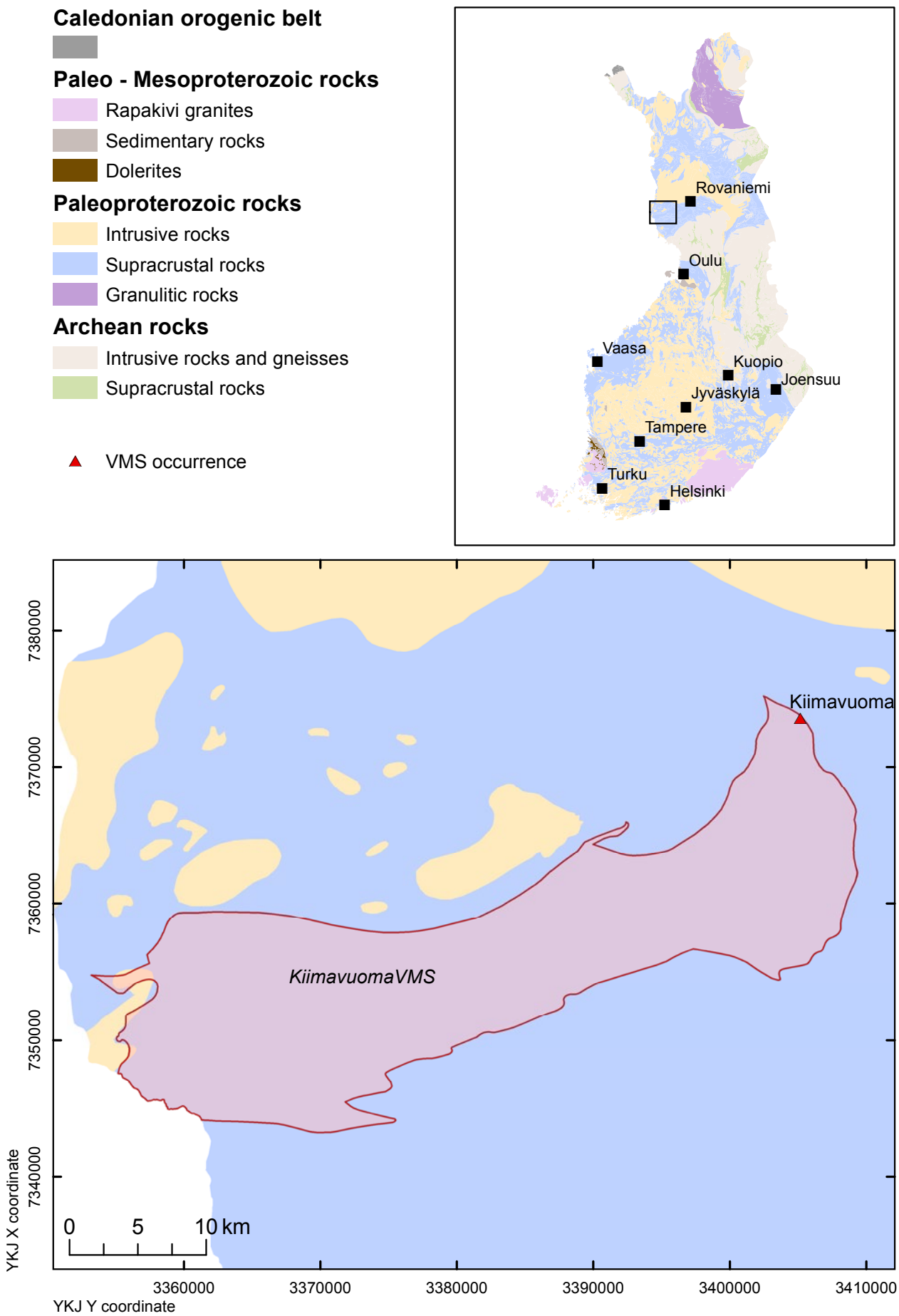


Fig. 1. Location of the Kiimavuoma VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Kiimavuoma VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Kiimavuoma VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Report | | Perttunen (1983) |
| | Bedrock maps | 1:100,000 | Perttunen & Hanski (2003), Perttunen (2006) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Report | | Korvuo (1982), Pulkkinen (2000) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Korvuo (1982), Pulkkinen (2000), Lehmuspelto & Pohjola (2010) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Korvuo (1982), Pulkkinen (2000) |
| Exploration | Reports | | Korvuo (1982), Pulkkinen (2000) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

One partially explored VMS occurrence is known within the tract (Table 3). This occurrence was considered so modest that most of the estimators believed that it will never become an economic deposit, even under the most favourable circumstances. Favourable indicators for the tract include the extensive subaqueous mafic volcanic and fine-grained sedimentary rocks, and abundant undrilled conductors. Very little exploration for base metals has been performed within the tract. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Kiimavuoma VMS tract.

| Mean undiscovered deposit estimate | | | | | Summary statistics | | | | | Area (km²) | Deposit density (N/km²) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 1 | 2 | | | 1.0 | 0.79 | 79 | 0 | 1.0 | 641 | 0.0016 |

| | Estimated number of undiscovered deposits | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 2 | | |
| Individual 2 | 0 | 1 | 1 | | |
| Individual 3 | 0 | 0 | 2 | | |
| Individual 4 | 0 | 1 | 2 | | |
| Individual 5 | 0 | 0 | 1 | | |
| Individual 6 | 0 | 1 | 2 | | |
| Consensus | 0 | 1 | 2 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, K. Rasilainen, P. Sipilä, T. Törmänen.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS mafic grade-tonnage model (Appendix 2) using the Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Kiimavuoma VMS tract.

| Material | At least the indicated amount at the probability of | | | | | Mean | Probability of mean or greater | Probability of zero |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 9,900 | 270,000 | 490,000 | 97,000 | 0.21 | 0.30 |
| Zn (t) | 0 | 0 | 5,400 | 190,000 | 390,000 | 79,000 | 0.18 | 0.30 |
| Pb (t) | 0 | 0 | 40 | 3,000 | 11,000 | 3,000 | 0.10 | 0.30 |
| Ag (t) | 0 | 0 | 3.4 | 110 | 200 | 42 | 0.20 | 0.30 |
| Au (t) | 0 | 0 | 0.029 | 1.1 | 2.0 | 0.49 | 0.17 | 0.30 |
| Rock (Mt) | 0 | 0 | 0.71 | 23 | 43 | 7.3 | 0.22 | 0.30 |

t – metric tons; Mt – million metric tons.

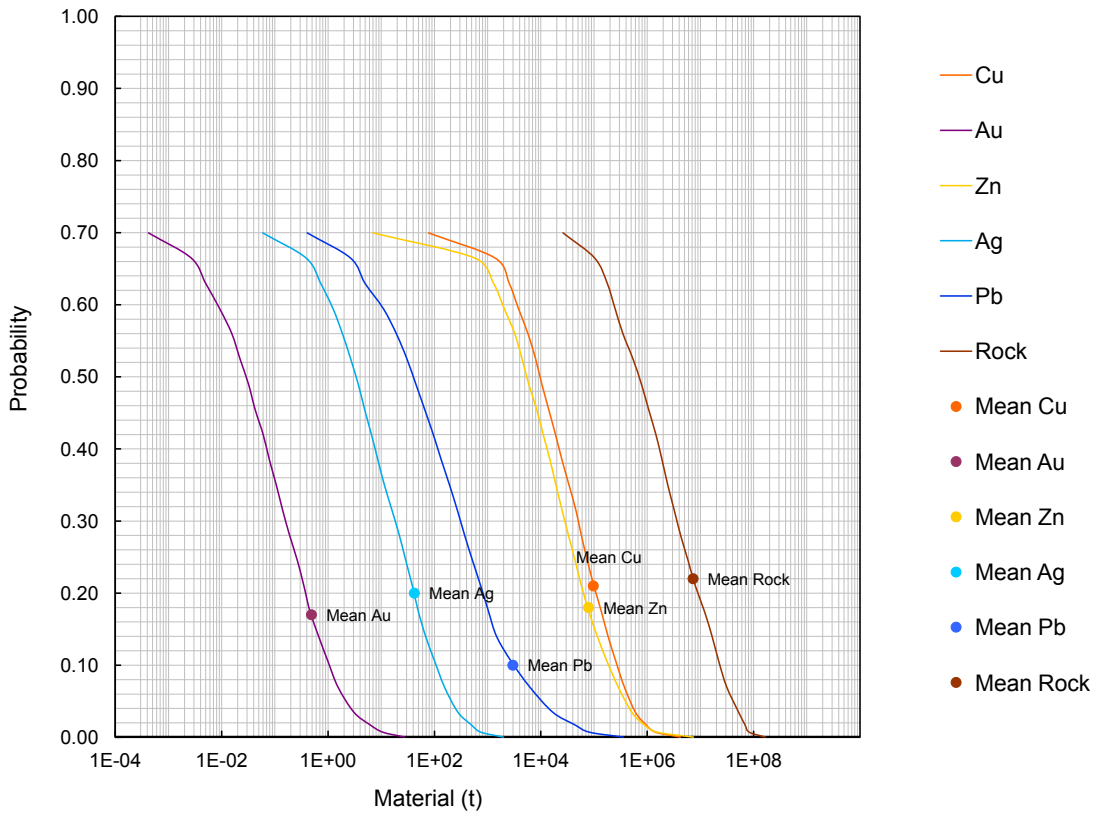


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Kiimavuoma VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT KILPISJÄRVI VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Kilpisjärvi VMS permissive tract is located in northern Finland in the municipality of Enontekiö, 360 km northwest of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheet is 1842. The UTM map sheets containing the tract are W3432 and W3434. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Kilpisjärvi VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 10/12/2012 | 1 | 105 | Cu | 0 | Cu | 0 | Cu | 0 |
| | | | Zn | 0 | Zn | 0 | Zn | 0 |
| | | | Pb | 0 | Pb | 0 | Pb | 0 |
| | | | Ag | 0 | Ag | 0 | Ag | 0 |
| | | | Au | 0 | Au | 0 | Au | 0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by Archaean–Proterozoic, and possibly also Palaeozoic, metasedimentary and metavolcanic rocks, which were transported towards the southeast during the Palaeozoic Caledonian orogeny. The delineation is based on the extent of mica gneisses and amphibolites belonging to the Nabar Nappe. Outcrop observations and bedrock maps were used to define the margins of the tract. The tract is delineated by the Saana arkose quartzite (also called the

Nalganas Nappe arkose quartzite) to the south and southeast and by the Norwegian border to the north. The tract extends down to 1000 m depth. The depth extension is based on the assumption that the nappe complex continues downwards. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored VMS deposits within the Kilpisjärvi VMS tract (Table 2). According to the spatial rule used, deposits located nearer than 500 m of each other are counted as one in this assessment.

Table 2. Known VMS deposits in the Kilpisjärvi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

One partially explored VMS-type Cu-Zn occurrence is known within the Kilpisjärvi VMS permissive tract (Table 3).

Table 3. Significant VMS occurrences in the Kilpisjärvi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Kovddoskaisi | 7696055 | 3269913 | | More than eight individual, 5–25-cm-thick, 0.5–1-km-long mineralised beds. Not drilled. Up to 1.53 % Zn, 1.03 % Pb, and 0.7 % Cu in grab samples. | Isomaa (1988) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Kilpisjärvi VMS tract are listed in Table 4.

Table 4. Exploration history for the Kilpisjärvi VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop and boulder observations | No | Geological Survey of Finland | 1980s |
| Geochemical surveys | Nationwide till survey | Yes | Geological Survey of Finland | 1970s–1980s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 2002 |
| Ground geophysical surveys | None | | | |
| Drilling | None | | | |

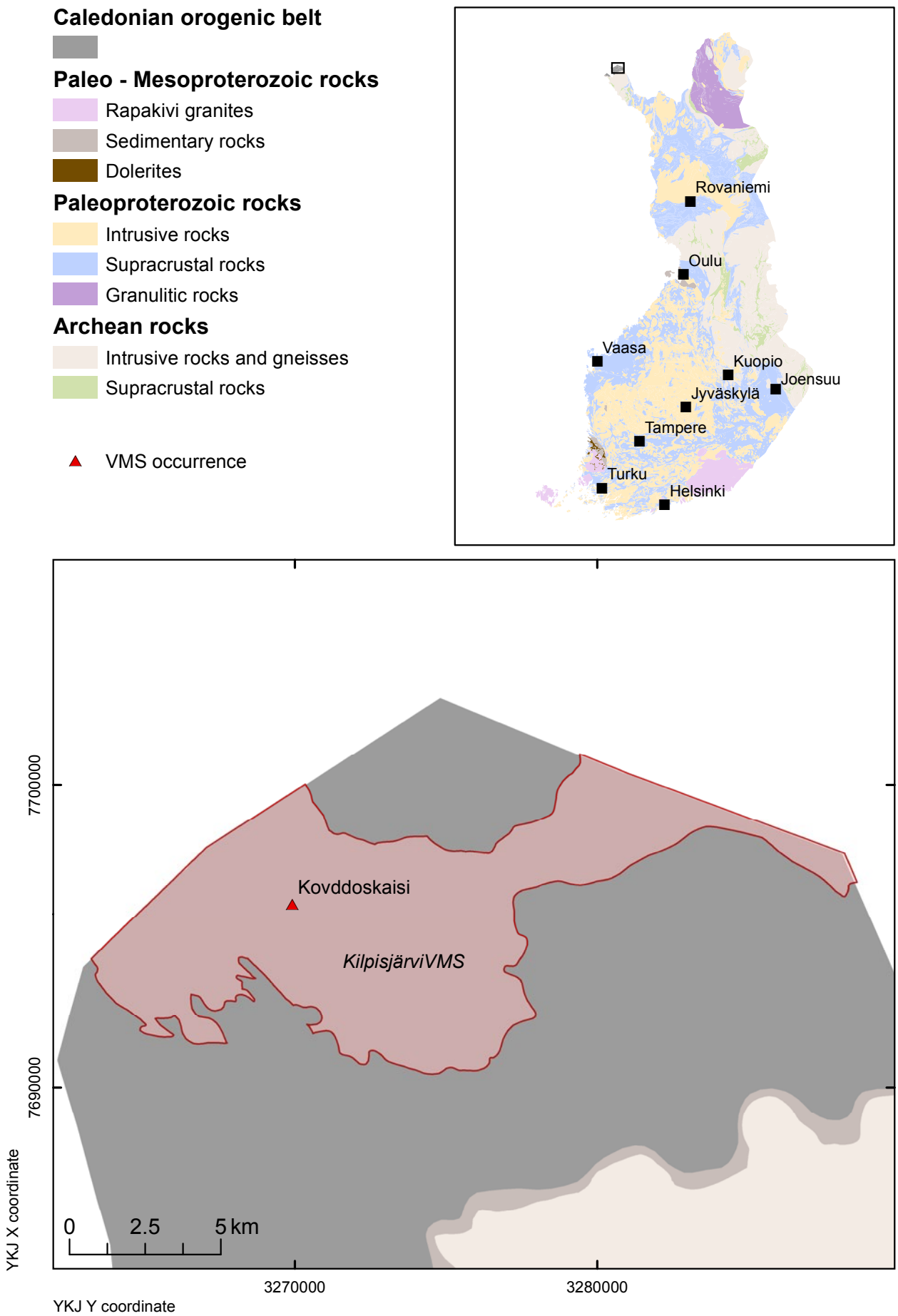


Fig. 1. Location of the Kilpisjärvi VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Kilpisjärvi VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Kilpisjärvi VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Reports | | Lehtovaara (1984, 1989), Sipilä (1992) |
| | Bedrock mapping | 1:100,000 | Lehtovaara (1995) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| Geophysics | Geological Survey of Finland in-house database | | |
| Geochemistry | Geological Survey of Finland in-house database | | |
| Exploration | Report | | Isomaa (1988) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

One partially explored possibly VMS-type Zn-Pb±Cu occurrence is known within the tract (Table 3). However, this occurrence was considered so difficult to exploit that all the estimators believed that it will never become an economic deposit, even under the most favourable circumstances. It is also unclear whether the Kovddoskaisi occurrence really is of the VMS type. Very little exploration of any kind (e.g., no drilling) has been performed in the tract area, and due to the difficult terrain, a mineral deposit of any kind would be difficult to exploit there. A consensus was reached in the discussion that there are no VMS deposits, even at the 10 % probability, within the tract area. Hence, no simulation of undiscovered metal tonnages was performed for the Kilpisjärvi VMS permissive tract.

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Kilpisjärvi VMS tract.

| Mean undiscovered deposit estimate | | | | | Summary statistics | | | | | Area (km²) | Deposit density (N/km²) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 0 | 0 | | | 0 | 0 | | 0 | 0 | 105 | 0 |

| | Estimated number of undiscovered deposits | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 0 | | |
| Individual 2 | 0 | 0 | 0 | | |
| Individual 3 | 0 | 0 | 0 | | |
| Individual 4 | 0 | 0 | 0 | | |
| Individual 5 | 0 | 0 | 0 | | |
| Individual 6 | 0 | 0 | 0 | | |
| Consensus | 0 | 0 | 0 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, K. Rasilainen, P. Sipilä, T. Törmänen.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT LETEENSUO VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS bimodal-mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Leteensuo VMS permissive tract is located in southern Finland. It is a 5–30-km-wide, irregular domain striking E–W for approximately 100 km, from NE to NW of the city of Hämeenlinna (Fig. 1). The 1:100,000 KKJ map sheets are 2113, 2114, 2131, 2132, 2133 and 2134. The UTM map sheets containing the tract are L422, L424, M411 and M413. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Leteensuo VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 690 | Cu | 0 | Cu | 18,000 | Cu | 7,900 |
| | | | Zn | 0 | Zn | 39,000 | Zn | 15,000 |
| | | | Pb | 0 | Pb | 1,900 | Pb | 160 |
| | | | Ag | 0 | Ag | 10 | Ag | 2.6 |
| | | | Au | 0 | Au | 0.30 | Au | 0.17 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by 1.90–1.88 Ga Svecofennian volcanic rocks. The delineation is based on the extent of the Häme volcanic suite in the upper part of the Häme belt and the existence of tholeiitic to calc-alkaline dominated distal Kuroko type Cu-Zn occurrences in the area. The tract extends down to 1000 m depth. The depth extension is based on stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored VMS deposits within the Leteensuo VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Leteensuo VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

Five partially explored VMS occurrences are known within the Leteensuo permissive tract (Table 3). In addition, there are a few indications, for example Saajanmäki (Kinnunen 1985), where low Zn grades occur in mineralised systems whose genetic types are unclear.

Table 3. VMS-type Cu-Zn occurrences in the Leteensuo VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Katumajärvi | 6768744 | 3367658 | 1900–1880 | 1.0 m @ 0.1 % Cu; 0.15 m @ 0.65 % Cu; 1.2 m @ 0.06 g/t Au, 1.9 g/t Ag | Kinnunen (1987a) |
| Kotka (Kotkanpoika) | 6767975 | 3338586 | 1900–1880 | 20.9 m @ 0.54 % Cu. Also a high Co grade, whereas Zn, Au and Ag contents are low: 0.55 m @ 0.34 % Cu, 0.14 % Co, 0.17 g/t Au, 4.6 g/t Ag. Uncertain type: could be related to a porphyry Cu system. | Kinnunen (1987b, 1990) |
| Leteensuo Zn | 6776696 | 3349962 | 1900–1880 | 0.4 m @ 4.1 % Zn; 0.6 m @ 2.7 % Zn, 0.1 % Cu; 0.5 m @ 0.1 % Cu, 4.1 % Zn | Mäkelä (1980a), Pekkarinen (1995) |
| Leteensuo Cu | 6777756 | 3350671 | 1900–1880 | 0.4 m @ 3.8 % Cu, 0.02 % Zn | Mäkelä (1980a) |
| Pääjärvi | 6772062 | 3393756 | 1900–1880 | 0.35 m @ 2 % Zn, 0.3 % Pb, 11 g/t Au; 10 m @ 0.2 % Zn, 2.9-0.1 g/t Au | Mäkelä (1980b, 1981) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Leteensuo VMS tract are listed in Table 4.

Table 4. Exploration history for the Leteensuo VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1900s–2010s |
| | Outcrop and boulder observations | Yes | Rautaruukki | 1970s–1980s |
| | Outcrop and boulder observations | Yes | Outokumpu | 1960s–1980s |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Detailed till geochemical survey | Yes | Geological Survey of Finland | 1970s–2000s |
| | Detailed till geochemical survey | Yes | Rautaruukki | 1980s |
| | Detailed till geochemical survey | Yes | Outokumpu | 1970s–1980s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1978–1988 and 2007 |
| | Low-altitude airborne magnetic and electromagnetic surveys | | Outokumpu | 1975 |
| Ground geophysical surveys | Magnetic and slingram surveys | | Geological Survey of Finland | 1960s–1990s |
| | Magnetic, slingram, gravimetric surveys | | Rautaruukki | 1970s–1980s |
| | Magnetic, slingram surveys | | Outokumpu | 1970s–1980s |
| Drilling | A few diamond-drill holes | Yes | Rautaruukki | 1970s |
| | A few tens of diamond-drill holes | Yes | Outokumpu | 1970s–1980s |
| Other | Regional mineral potential assessment and deposit modelling | | Geological Survey of Finland | 1990s |

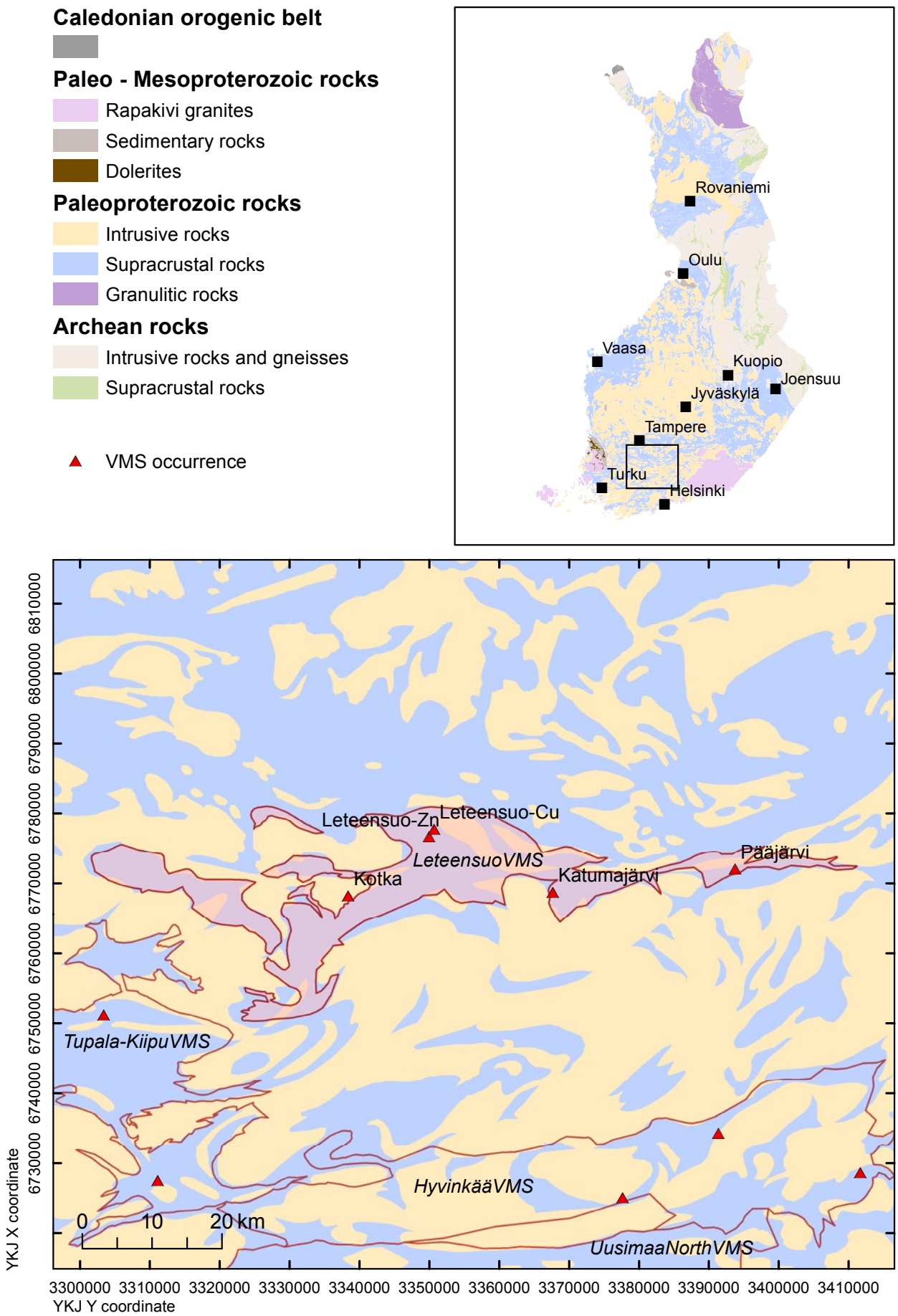


Fig. 1. Location of the Leteensuo VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Leteensuo VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Leteensuo VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:100–1:10,000 | Aumo (1982), Kinnunen (1987a, 1987b, 1990), Mäkelä (1980b, 1981) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Deposit descriptions | | Papunen (1990) |
| | Reports | | Mäkelä (1980a, 1980b, 1981) Aumo (1982), Kinnunen (1987a) |
| | Metallogenic assessments | | Tiainen & Viita (1994) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Isomäki (1983), Kinnunen (1987a, 1987b, 1990) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Isomäki (1983), Kinnunen (1987a, 1987b, 1990), Kärkkäinen et al. (1998) |
| Exploration | Reports | | Mäkelä (1980a, 1980b, 1981), Isomäki (1983), Kinnunen (1985, 1987a, 1987b, 1990), Pekkarinen (1995), Kärkkäinen et al. (1998) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Five partially explored Cu±Zn occurrences possibly of the VMS type are known within the tract (Table 3). These occurrences were considered so modest that most of the estimators believed it possible that none of them will ever become economic, even under the most favourable circumstances. The existence of the partially explored Zn, Cu-Zn and Cu occurrences, VMS-style alteration, uninvestigated Zn anomalies in till in the western part of the tract, the fact that not all mineralisation found in boulders has been detected in bedrock, and the extensive volcanism related to a rifting arc environment were considered to indicate the potential for VMS-type deposits. Most of the diamond drilling in the area is around the known occurrences. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Leteensuo VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 1 | 2 | | | 1.0 | 0.79 | 79 | 0 | 1.0 | 690 | 0.0014 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 1 | | |
| Individual 2 | 0 | 1 | 1 | | |
| Individual 3 | 0 | 1 | 2 | | |
| Individual 4 | 0 | 1 | 2 | | |
| Individual 5 | 0 | 1 | 2 | | |
| Individual 6 | 0 | 1 | 2 | | |
| Individual 7 | 0 | 1 | 2 | | |
| Individual 8 | 1 | 1 | 2 | | |
| Individual 9 | 1 | 2 | 2 | | |
| Individual 10 | 0 | 1 | 2 | | |
| Individual 11 | 1 | 2 | 3 | | |
| Consensus | 0 | 1 | 2 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen, H. Kujala, J. Luukas, J. Nikander, M. Nironen, K. Rasilainen, P. Sipilä, P. Sorjonen-Ward, M. Tiainen, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS bimodal-mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Leteensuo VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 7,900 | 51,000 | 72,000 | 18,000 | 0.34 | 0.30 |
| Zn (t) | 0 | 0 | 15,000 | 110,000 | 160,000 | 39,000 | 0.31 | 0.30 |
| Pb (t) | 0 | 0 | 160 | 5,300 | 11,000 | 1,900 | 0.20 | 0.30 |
| Ag (t) | 0 | 0 | 2.6 | 24 | 43 | 9.6 | 0.23 | 0.30 |
| Au (t) | 0 | 0 | 0.17 | 0.81 | 1.1 | 0.30 | 0.35 | 0.30 |
| Rock (Mt) | 0 | 0 | 0.71 | 4.0 | 6.2 | 1.5 | 0.38 | 0.30 |

t – metric tons; Mt – million metric tons.

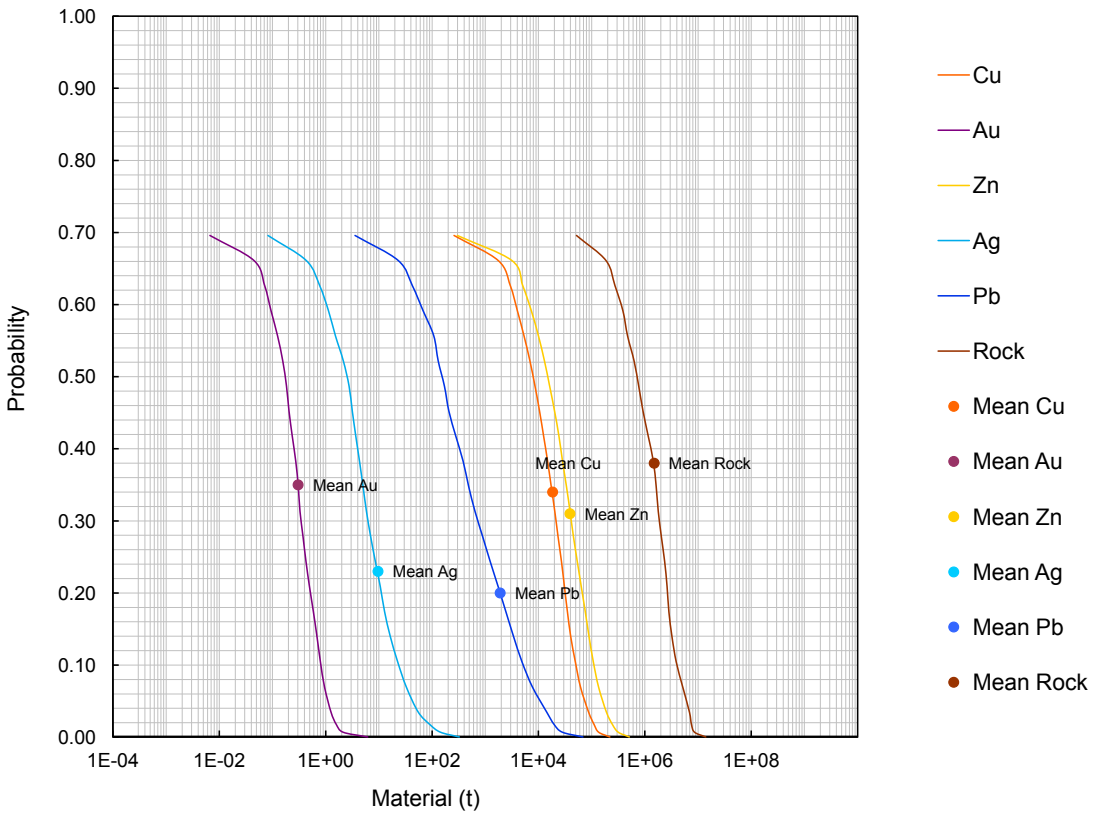


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Leteensuo VMS permissive tract.

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# PORPHYRY Cu ASSESSMENT FOR THE TRACT MÄNTSÄLÄ PORCU, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: Porphyry Cu
**Descriptive model**: Porphyry Cu (Appendix 3)
**Grade-tonnage model**: Porphyry Cu (Appendix 4)

## LOCATION AND RESOURCE SUMMARY

The Mäntsälä PorCu permissive tract is located in southern Finland in the municipalities of Mäntsälä, Pukkila, Askola, Pornainen, Loviisa, Orimattila and Porvoo, 35–85 km NE of the city of Helsinki (Fig. 1). The 1:100,000 KKJ map sheets are 2043, 2044, 3021 and 3022. The UTM map sheets containing the tract are L414, L423, L432 and L441. The resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Mäntsälä PorCu permissive tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 8/11/2012 | 1 | 1737 | Cu | 0 | Cu | 270,000 | Cu | 0 |
| | | | Mo | 0 | Mo | 14,000 | Mo | 0 |
| | | | Ag | 0 | Ag | 420 | Ag | 0 |
| | | | Au | 0 | Au | 33 | Au | 0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The Mäntsälä PorCu permissive tract is defined by early to synorogenic 1.89–1.88 Ga granitoid rocks. The delineation is based on the extent of these intrusions on the bedrock map. The tract extends down to 1000 m depth. The depth extension is based on interpretation of the geology of the region. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored porphyry Cu deposits within the Mäntsälä PorCu permissive tract (Table 2). According to the spatial rule used, deposits located less than 2 km apart were combined in this assessment. An exception was allowed if two occurrences <2 km apart could be shown to be products of separate mineralising systems.

Table 2. Known porphyry Cu deposits in the Mäntsälä PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade (%) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|
| None | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric tons. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

There are no partially explored Cu occurrences that would clearly go into the porphyry category within the Mäntsälä PorCu permissive tract (Table 3). Only the scantily investigated Mäntymäki occurrence could perhaps be related to felsic–intermediate intrusions. Other types of occurrences that exist within the tract include minor Cu occurrences possibly of the VMS type in mafic volcanic rocks, uranium occurrences in granitoids and small BIFs in the supracrustal sequences.

Table 3. Possible porphyry Cu occurrences in the Mäntsälä PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ga) | Comments | Reference |
|---|---|---|---|---|---|
| Mäntymäki | 6722970 | 3406235 | 1.89 Ga? | 2.35 m @ 0.59 % Cu, 20 ppm Ag, 22 m @ 0.13 % Cu, 6 ppm Ag | Pehkonen (1981) |

Ga – billion years

## Exploration history

No exploration targeting porphyry-style mineralisation has been carried out in the Mäntsälä PorCu tract area. Hence, mostly general and regional work is listed in Table 4.

Table 4. Exploration history for the Mäntsälä PorCu permissive tract.

| Theme | Type of work | Cu analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1950s–1990s |
| | Detailed outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1970s–1980s |
| | Detailed outcrop observations and boulder survey | Yes | Outokumpu | 1970s |
| | Detailed outcrop observations and boulder survey | Yes | University of Helsinki | 1982 |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| Airborne geophysical surveys | Regional low-altitude airborne magnetic, electromagnetic and radiometric survey | | Geological Survey of Finland | 1985–2001 |
| Ground geophysical surveys | Magnetic and IP survey | | Outokumpu | 1976–1978 |
| | Magnetic, gravimetric and slingram survey | | Geological Survey of Finland | 1975 |
| Drilling | Two diamond-drill holes, total 260 m | Yes | Geological Survey of Finland | 1975 |
| | Three diamond-drill holes, total 356 m | Yes | Outokumpu | 1977–1979 |

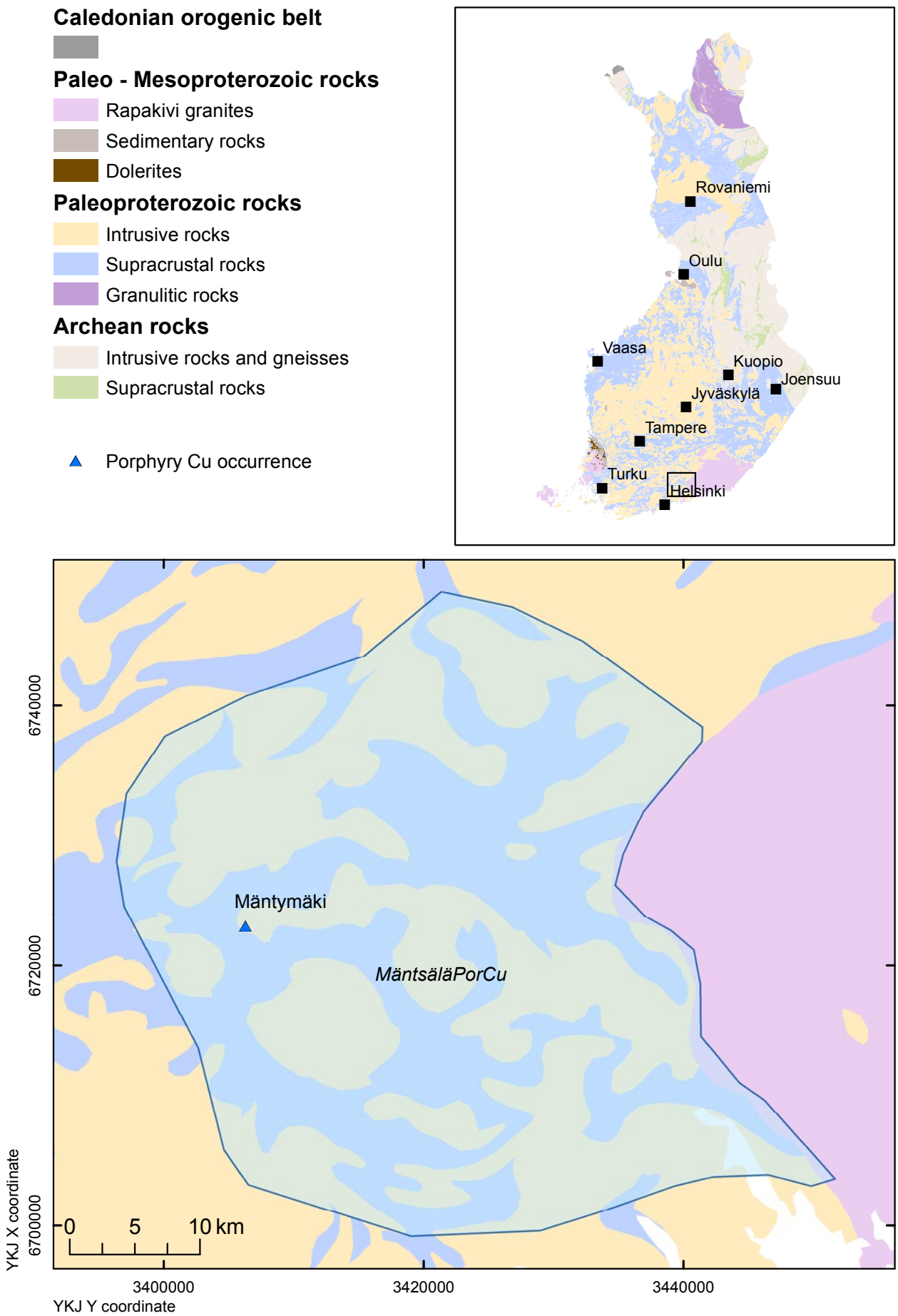


Fig. 1. Location of the Mäntsälä PorCu permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Mäntsälä PorCu tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Mäntsälä PorCu permissive tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:1000–1:10,000 | Oivanen (1976), Pehkonen (1981), Lindmark (1982a, 1982b), Nironen (1982) |
| Mineral occurrences | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Geological Survey of Finland gold deposit database | | Eilu & Pankka (2009) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Oivanen (1976), Pehkonen (1981), Valli (2000) |
| Exploration | Reports | | Oivanen (1976), Pehkonen (1981), Lindmark (1982a, 1982b) |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

No obvious porphyry Cu occurrences are known within the Mäntsälä PorCu permissive tract. The existence of the Mäntymäki occurrence in a granitoid rock, two granitoid rock outcrops with Cu, one with Cu and Mo, and two Mo-only mineralised outcrops, and a quartz-tourmaline breccia boulder (2.5 $m^3$ in size) with an obviously short transport distance were considered to indicate the potential for undiscovered porphyry Cu deposits. The presence of synorogenic granitoids and indications of bimodal intrusions with mafic and felsic magma mingling were also seen as a positive indication. On the other hand, the lack of clear porphyry-type occurrences and scarcity of known indirect indications lower the potential for undiscovered deposits within the tract. Most exploration in the tract area has been for uranium; some base metal and rare metal exploration has also been performed, but not recently. No systematic gold and copper exploration has been carried out for the region. Drilling within the tract has been rather scarce, and the results do not enhance or decrease the favourability for the existence of undiscovered porphyry Cu deposits. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Mäntsälä PorCu permissive tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 0 | 1 | | | 0.30 | 0.50 | 170 | 0 | 0.30 | 1737 | 0.00017 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 1 | | |
| Individual 2 | 0 | 0 | 1 | | |
| Individual 3 | 0 | 0 | 1 | | |
| Individual 4 | 0 | 0 | 1 | | |
| Individual 5 | 0 | 0 | 1 | | |
| Individual 6 | 0 | 0 | 1 | | |
| Individual 7 | 0 | 0 | 0 | | |
| Individual 8 | 0 | 0 | 0 | | |
| Individual 9 | 0 | 0 | 1 | | |
| Individual 10 | 0 | 0 | 0 | | |
| Individual 11 | 0 | 0 | 2 | | |
| Individual 12 | 0 | 1 | 1 | | |
| Mean | 0 | 0 | 1 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variation; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, S.Grönholm, N. Kärkkäinen, J. Kousa, L. Lauri, J. Luukas, F. Molnar, T. Niiranen, M. Nironen, P. Sorjonen-Ward, M. Tiainen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the porphyry Cu grade-tonnage model (Appendix 4) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Mäntsälä PorCu permissive tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 0 | 440,000 | 1,600,000 | 270,000 | 0.12 | 0.70 |
| Mo (t) | 0 | 0 | 0 | 17,000 | 49,000 | 14,000 | 0.11 | 0.70 |
| Ag (t) | 0 | 0 | 0 | 190 | 800 | 420 | 0.070 | 0.70 |
| Au (t) | 0 | 0 | 0 | 33 | 140 | 33 | 0.10 | 0.70 |
| Rock (Mt) | 0 | 0 | 0 | 160 | 700 | 100 | 0.11 | 0.70 |

t – metric tons; Mt – million metric tons.

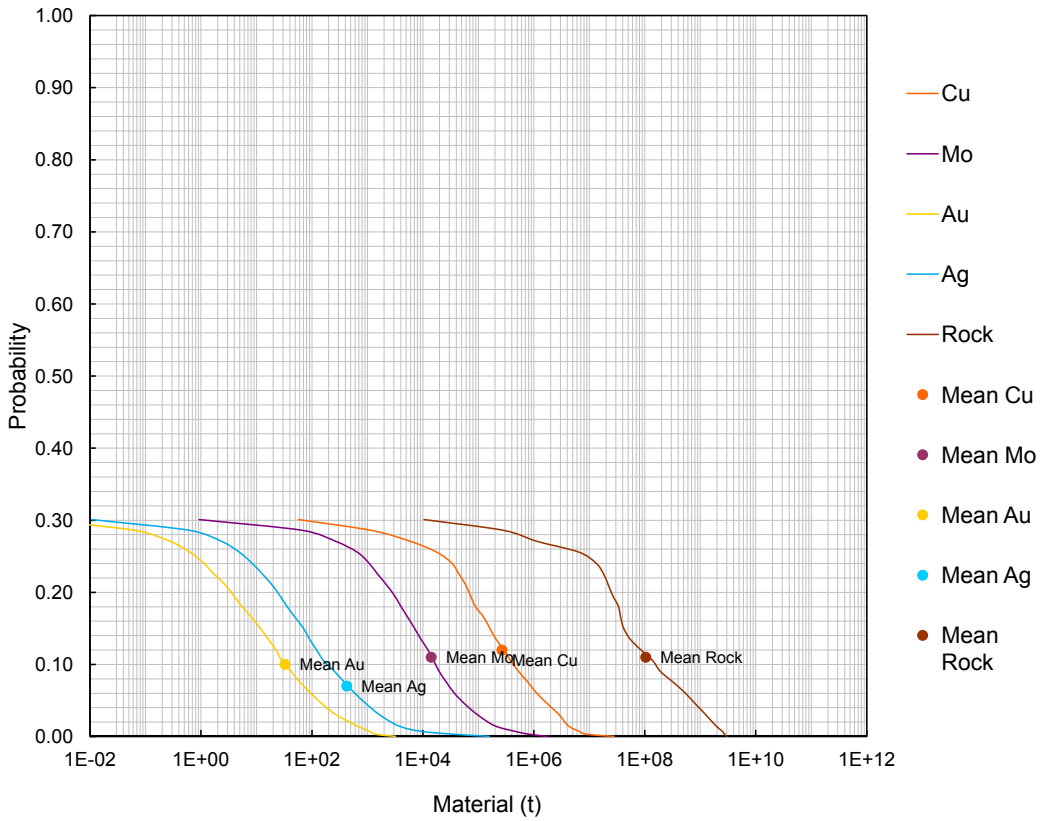


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Mäntsälä PorCu permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT MAURU VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS felsic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Mauru VMS permissive tract is located in northern Finland in the municipality of Ranua, 55 km south of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheet is 3522. The UTM map sheets containing the tract are S441, S442, S443 and S443. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Mauru VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 10/12/2012 | 1 | 84 | Cu | 0 | Cu | 10,000 | Cu | 0 |
| | | | Zn | 0 | Zn | 73,000 | Zn | 0 |
| | | | Pb | 0 | Pb | 15,000 | Pb | 0 |
| | | | Ag | 0 | Ag | 74 | Ag | 0 |
| | | | Au | 0 | Au | 1.1 | Au | 0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by the extent of Neoarchaean felsic volcanic rocks of the Mauru Formation. The bedrock in the tract area is composed of amphibolites, ultramafic rocks, mica gneisses and mica schists and quartz-feldspar gneisses and schists. The tract is bordered by Neoarchaean intrusive and gneisses. In addition to bedrock maps, diamond drill core and outcrop observations and low-altitude electromagnetic maps were used in the delineation of the tract. The tract extends down to 1000 m depth. The depth extension is based on the assumption that the occurrence of the schist belt rocks continues downwards. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored VMS deposits within the Mauru VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Mauru VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

Two partially explored VMS occurrences are known within the Mauru VMS permissive tract (Table 3).

Table 3. Significant VMS occurrences in the Mauru VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Mauru | 7323130 | 3455545 | 2600–2700 | 1 m @ 0.45 % Zn and 5.6 m @ 0.3 % Zn; R511 1 m @ 0.44% Zn | Karvinen & Juopperi (2000), Eilu & Västi (2009) |
| Kultalehto | 7331460 | 3454580 | 2600–2700 | 1 m @ 0.89 % Zn | GTK drill core database |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Mauru VMS tract are listed in Table 4.

Table 4. Exploration history for the Mauru VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop and boulder observations | Yes | Geological Survey of Finland | 1990s |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Targeted till sampling, about 1000 line samples | Yes | Outokumpu Oy | Mostly 1980s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1986 |
| Ground geophysical surveys | Systematic magnetic 19 km$^2$ and slingram 7.5 km$^2$ | | Outokumpu Oy | Mostly 1980s |
| | VLF-R 27.5 line-km, magnetic 21.5 line-km, gravity 1.5 line-km | | Geological Survey of Finland | 1990s |
| Drilling | 9 DDH, 1117 m | Yes | Outokumpu Oy | 1966, 1986–1990 |
| | 30 DDH, 3231 m | Yes | Geological Survey of Finland | 1987, 1997–1998, 2006 |

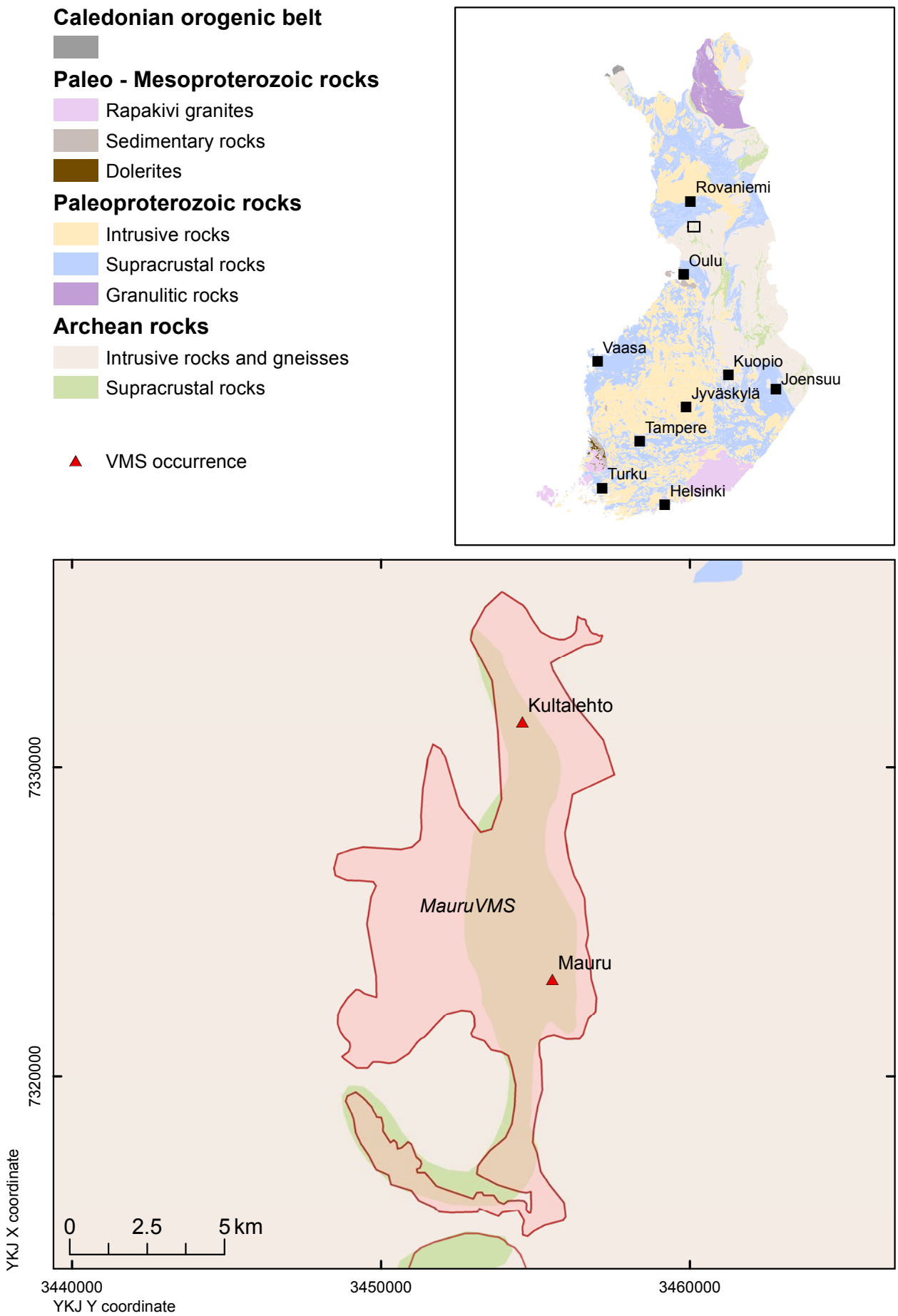


Fig. 1. Location of the Mauru VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Mauru VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Mauru VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:100–1:10,000 | Karvinen & Juopperi (2000) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Reports | | Karvinen & Juopperi (2000) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Karvinen & Juopperi (2000), Inkinen (1991a), Lahtinen (1991) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Karvinen & Juopperi (2000), Inkinen (1991a), Lahtinen (1991) |
| Exploration | Reports | | Karvinen & Juopperi (2000), Inkinen (1991a, 1991b, 1991c), Lahtinen (1991), Juopperi (2002, 2005, 2008) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Two partially explored VMS occurrences are known within the tract (Table 3). However, these were seen as being so modest that all estimators considered it possible that they will never become economic deposits, even under the most favourable circumstances. Favourable indicators for the tract include the detected VMS-type and strata-bound pyrite-pyrrhotite occurrences, the detected undrilled conductors, and mineralised boulders and till geochemical anomalies. The tract is very poorly exposed and very little exploration has been carried out. Notwithstanding the difficulty in assessing the tract, a consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Mauru VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 0 | 1 | | | 0.30 | 0.50 | 170 | 0 | 0.30 | 84 | 0.0036 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 1 | | |
| Individual 2 | 0 | 1 | 2 | | |
| Individual 3 | 0 | 0 | 2 | | |
| Individual 4 | 0 | 1 | 2 | | |
| Individual 5 | 0 | 0 | 1 | | |
| Individual 6 | 0 | 0 | 0 | | |
| Consensus | 0 | 0 | 1 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, K. Rasilainen, P. Sipilä, T. Törmänen.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS felsic grade-tonnage model (Appendix 2) using EMINERS software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Mauru VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 0 | 12,000 | 37,000 | 10,000 | 0.11 | 0.69 |
| Zn (t) | 0 | 0 | 0 | 86,000 | 250,000 | 73,000 | 0.11 | 0.69 |
| Pb (t) | 0 | 0 | 0 | 10,000 | 36,000 | 15,000 | 0.080 | 0.69 |
| Ag (t) | 0 | 0 | 0 | 73 | 240 | 74 | 0.10 | 0.69 |
| Au (t) | 0 | 0 | 0 | 1.0 | 2.9 | 1.1 | 0.10 | 0.69 |
| Rock (Mt) | 0 | 0 | 0 | 2.5 | 5.9 | 2.0 | 0.12 | 0.69 |

t – metric tons; Mt – million metric tons.

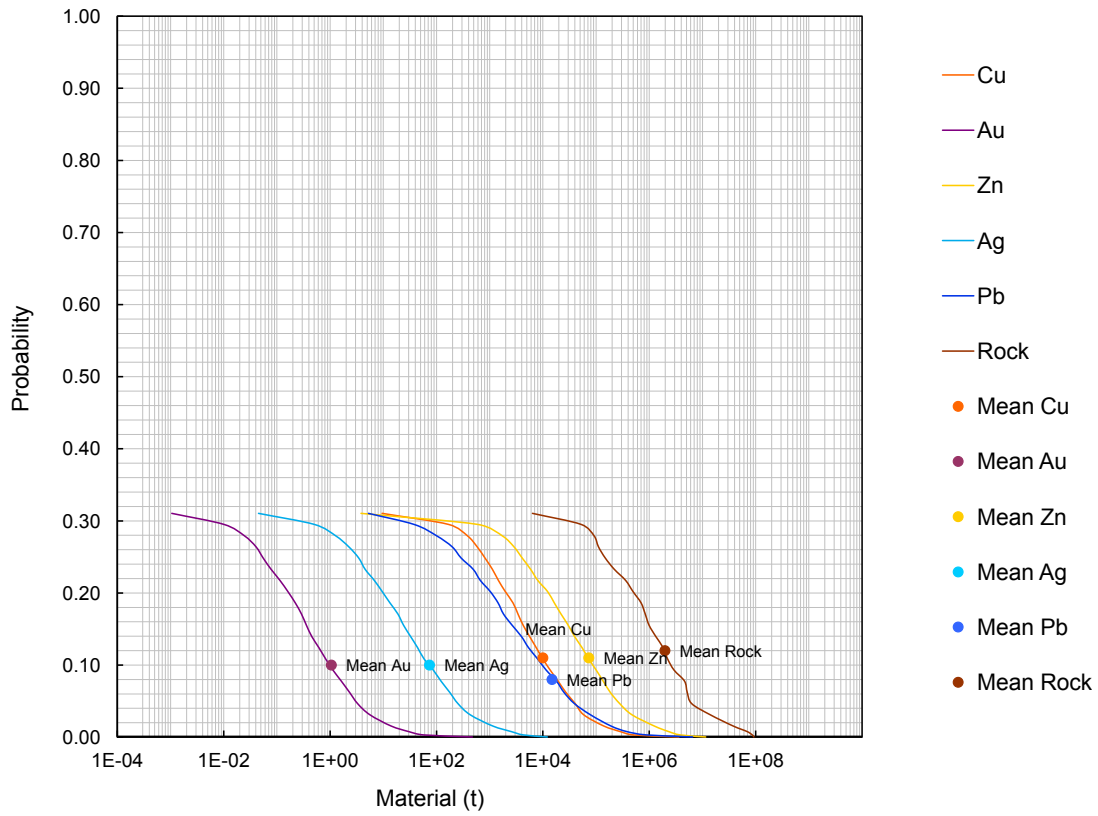


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Mauru VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT MISI VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Misi VMS permissive tract is located in northern Finland in the municipalities of Rovaniemi and Kemijärvi, 45 km E-ENE of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 3614, 3623 and 3632. The UTM map sheets containing the tract are T443, T434 and T512. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Misi VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 10/12/2012 | 1.0 | 119 | Cu | 0 | Cu | 100,000 | Cu | 10,000 |
| | | | Zn | 0 | Zn | 77,000 | Zn | 6,000 |
| | | | Pb | 0 | Pb | 2,800 | Pb | 39 |
| | | | Ag | 0 | Ag | 44 | Ag | 3.6 |
| | | | Au | 0 | Au | 0.56 | Au | 0.032 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by 2300–2100 Ma volcano-sedimentary rocks. The delineation is based on the extent of mafic volcanic rocks of the Misi Formation and mafic tuffs as well as associated mica schists and black schists of the Tuorevaara Formation of the Peräpohja schist belt. Diamond drill core and outcrop observations, as well as geophysical survey data were used to define the extent of the tract. The tract is bordered by granites belonging to the Central Lapland granite complex

and gabbroic intrusions of the Köyry Complex in the north and NE, and by arkositic metasedimentary rocks of the Köyry Complex in the south and SW. The tract extends down to 1000 m depth. The depth extension is based on the assumption that the schist belt rocks continue downwards beyond that depth. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored VMS deposits within the Misi VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Misi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

Three partially explored VMS-type Cu-Zn occurrences are known within the Misi VMS permissive tract (Table 3).

Table 3. Significant VMS occurrences in the Misi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Tuorevaara | 7390250 | 3485940 | | R391: 16 m @ 0.31 % Zn, 0.046 % Cu, including 3 m @ 0.6 % Zn, 0.057 % Cu; R352 1.12 m @ 1.24 % Cu | Isomaa et al. (2007) |
| Särkipalo | 7390700 | 3490500 | | R361: 4 m @ 0.74 % Cu, including 1 m @ 1.77 % Cu, 0.419 g/t Au+Pd+Pt | Isomaa et al. (2007) |
| Välijoki | 7391640 | 3483341 | | R331: 1.2 m @ 1.55 % Zn, 0.9 % Pb, 0.03 % Cu | Isomaa et al. (2007) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Misi VMS tract are listed in Table 4.

Table 4. Exploration history for the Misi VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop and boulder observations | (Yes) | Geological Survey of Finland | 1980s, 2000s |
| Geochemical surveys | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| | Till pit sampling | Yes | Geological Survey of Finland | 2001–2005 |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1982–1996 |
| Ground geophysical surveys | Systematic magnetic 19.3 km$^2$, VLF-R 25.3 km$^2$, and IP 1.6 km$^2$ survey | | Geological Survey of Finland | 2001–2005 |
| | Magnetic and slingram 10.44 line-km, VLF-R 6.28 line-km | | Outokumpu Oy | 1980s |
| Drilling | 11 DDH, 1548 m | ? | Rautaruukki Oy | 1960s–1970s |
| | 68 DDH, 7221 m | Yes | Geological Survey of Finland | Mostly 2001–2006 |

DDH – diamond-drill hole

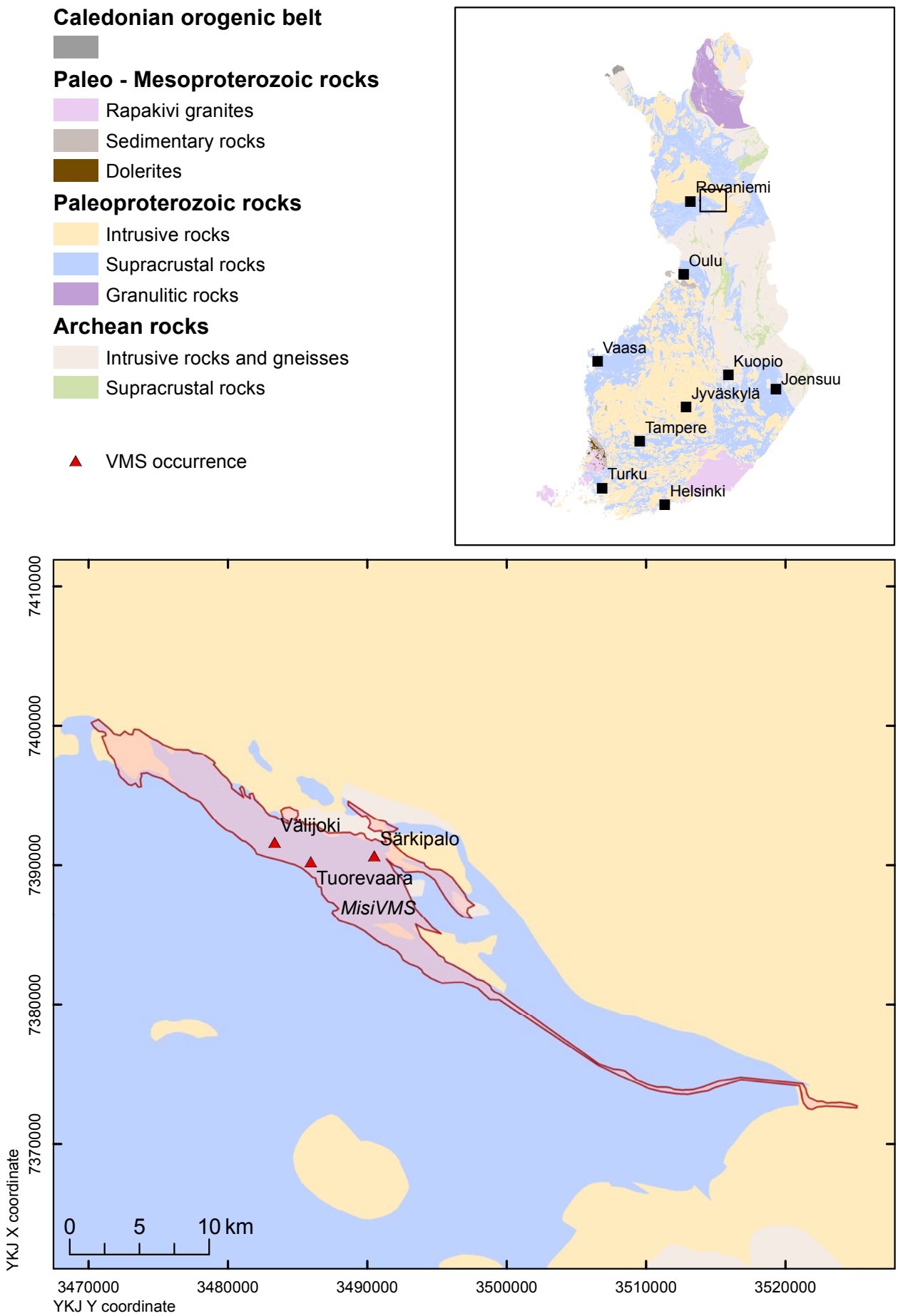


Fig. 1. Location of the Misi VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Misi VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Misi VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Reports | | Niiranen (2004), Isomaa et al. (2007) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Reports | | Nenonen (2005), Sarala & Nenonen (2005), Sarala & Peuraniemi (2007) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Kukkonen (1984), Isomaa & Sandgren (2006), Isomaa et al. (2007, 2008) |
| Exploration | Reports | | Hiltunen (1971), Vuotovesi (1984), Isomaa et al. (2007) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Three partially explored VMS occurrences are known within the tract (Table 3). These occurrences were considered so modest that most of the estimators believed that none would become economic deposits, even under the most favourable circumstances. The existence of the mafic volcanic rocks, the three known Zn-Cu occurrences, a few other locations with elevated Cu and Zn values in drill core, and the anomalous Cu, Au and Zn contents detected in till and in boulders were considered to indicate the potential for undiscovered VMS deposits. On the other hand, the entire supracrustal belt is very poorly explored. No consensus was reached in the discussion and the mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Misi VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 1 | 2 | | | 1.0 | 0.79 | 79 | 0 | 1.0 | 119 | 0.0084 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 2 | | |
| Individual 2 | 1 | 1 | 2 | | |
| Individual 3 | 0 | 1 | 3 | | |
| Individual 4 | 0 | 1 | 2 | | |
| Individual 5 | 0 | 1 | 1 | | |
| Individual 6 | 1 | 1 | 2 | | |
| Mean | 0 | 1 | 2 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, K. Rasilainen, P. Sipilä, T. Törmänen

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Misi VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 10,000 | 290,000 | 540,000 | 100,000 | 0.22 | 0.30 |
| Zn (t) | 0 | 0 | 6,000 | 190,000 | 390,000 | 77,000 | 0.18 | 0.30 |
| Pb (t) | 0 | 0 | 39 | 2,900 | 10,000 | 2,800 | 0.10 | 0.30 |
| Ag (t) | 0 | 0 | 3.6 | 120 | 210 | 44 | 0.21 | 0.30 |
| Au (t) | 0 | 0 | 0.032 | 1.2 | 2.3 | 0.56 | 0.17 | 0.30 |
| Rock (Mt) | 0 | 0 | 0.74 | 24 | 47 | 7.9 | 0.23 | 0.30 |

t – metric tons; Mt – million metric tons.

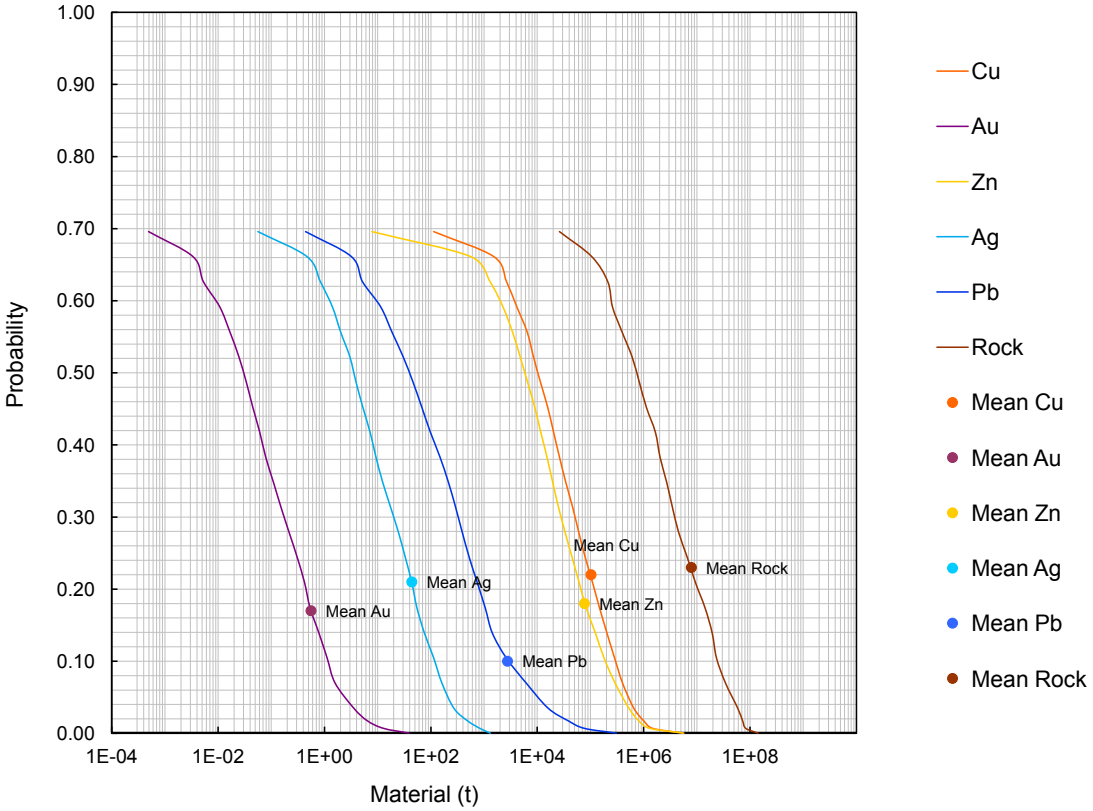


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Misi VMS permissive tract.

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# PORPHYRY Cu ASSESSMENT FOR THE TRACT NILIPÄÄ PORCU, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: Porphyry Cu
**Descriptive model**: Porphyry Cu (Appendix 3)
**Grade-tonnage model**: Porphyry Cu (Appendix 4)

## LOCATION AND RESOURCE SUMMARY

The Nilipää PorCu permissive tract is located in northern Finland in the municipality of Kemijärvi, Pelkosenniemi, Sodankylä and Kittilä, 100 km northeast of the city of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 2732, 2733, 2734, 3623, 3624, 3641, 3642, 3722, 3712 and 3713. The UTM map sheets containing the tract are T44, T52, U42, U43 and U44. The resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Nilipää PorCu permissive tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 9/11/2012 | 1 | 2035 | Cu | 0 | Cu | 210,000 | Cu | 0 |
| | | | Mo | 0 | Mo | 12,000 | Mo | 0 |
| | | | Ag | 0 | Ag | 190 | Ag | 0 |
| | | | Au | 0 | Au | 26 | Au | 0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The NilipääPorCu permissive tract is defined by the presence of ca. 2100 Ma granitoid intrusions. The delineation is based on the extent of the dated and inferred intrusions of this age. The tract was delineated by enclosing the known intrusions of this age and their immediate country rocks on the geological map. All the 2100 Ma intrusions are situated in the contact zone of the Central Lap-

land granitoid complex and the central Lapland greenstone belt. They are considered a potential analogue to the present Andean margin plutonic belt, which hosts important porphyry copper deposits. The granitoid intrusions also are situated along the crustal-scale Venejoki fault. The tract extends down to 1000 m depth. The depth extension is based on interpretation of the geology of the region. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored porphyry Cu deposits within the Nilipää PorCu permissive tract (Table 2). According to the spatial rule used, deposits located less than 2 km from each other were combined in this assessment. An exception was allowed if two occurrences <2 km apart could be shown to be products of separate mineralising systems.

Table 2. Known porphyry Cu deposits in the Nilipää PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade (%) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|
| None | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric tons. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

No partially explored porphyry Cu occurrences are known within the Nilipää PorCu permissive tract (Table 3). Other types of occurrences that exist within the tract include the IOCG-type Latvajärvi and Latvarova deposits at Kittilä and the Luosto Fe-occurrences and Ylipoki U indications at Sodankylä.

Table 3. Significant porphyry Cu occurrences in the Nilipää PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| None | | | | | |

Ma – million years

## Exploration history

No exploration targeting porphyry-style mineralisation has been carried out in the Nilipää PorCu tract area. Hence, mostly general and regional work is listed in Table 4.

Table 4. Exploration history for the Nilipää PorCu permissive tract.

| Theme | Type of work | Cu analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder surveys | Yes | Geological Survey of Finland | 1970s–2000s |
| | Outcrop observations and boulder surveys | Yes | Outokumpu Oy | 1970s–1990s |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Geochemical survey of basal till | Yes | Outokumpu Oy | 1990s |
| Airborne geophysical surveys | Regional low-altitude airborne magnetic, electromagnetic and radiometric survey | | Geological Survey of Finland | 1976–1999 |
| Ground geophysical surveys | Magnetic surveys | | Outokumpu Oy | 1990s |

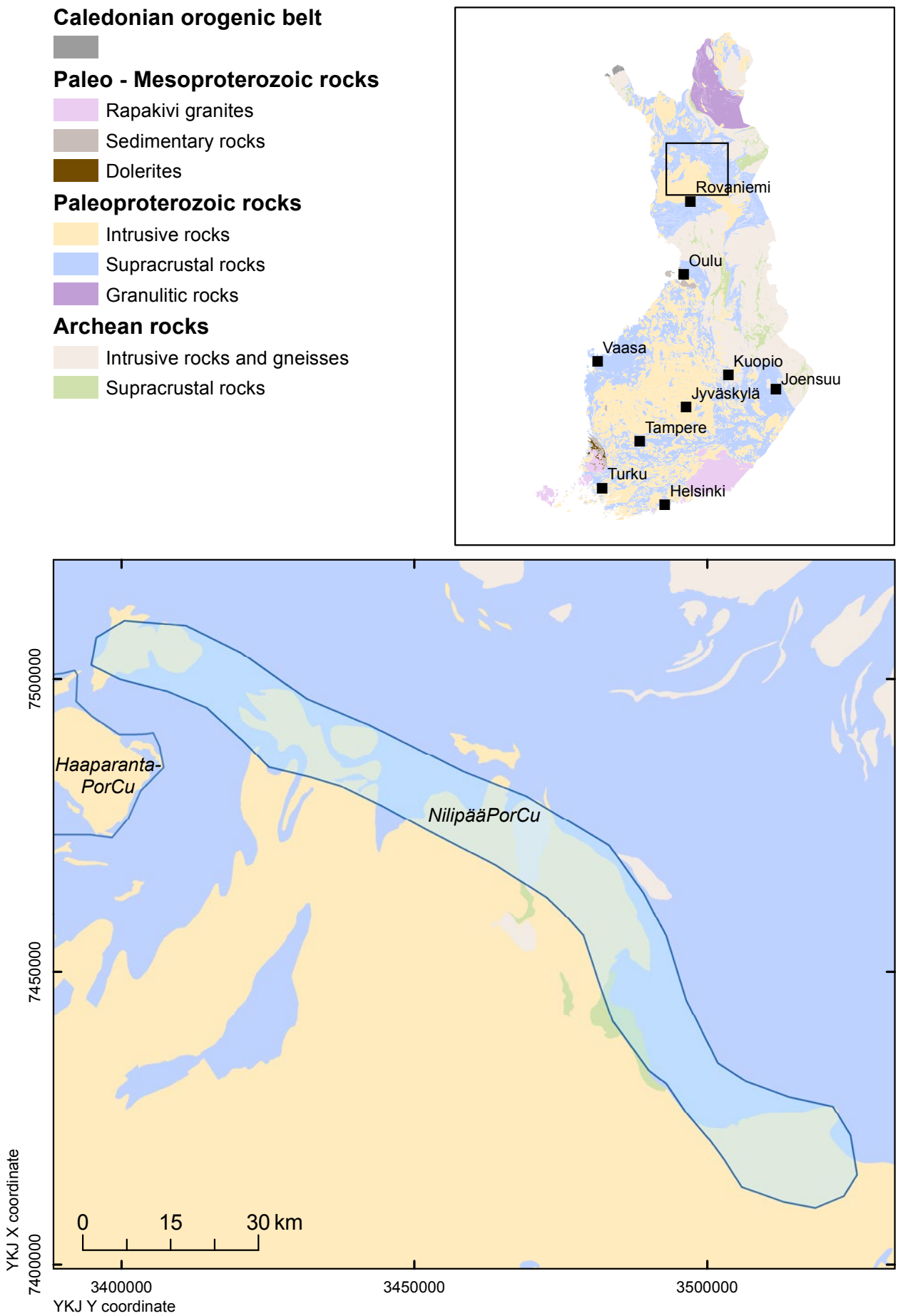


Fig. 1. Location of the Nilipää PorCu permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the NilipääPor-Cu tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Nilipää PorCu permissive tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:500–1:4000 | Ilvonen (1994) |
| Mineral occurrences | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Metallogenic assessment | 1:4000–1:10,000 | |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Ilvonen (1994) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Ilvonen (1994) |
| Exploration | Reports | 1:4000–1:10,000 | Ilvonen (1994) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

No obvious porphyry Cu occurrences are known within the Nilipää PorCu permissive tract. The existence of apparently I-type granitoids, one or two of which are possibly adakitic, intruded along a continental margin was considered to indicate the potential for undiscovered porphyry Cu deposits. Other possible indications of porphyry-style mineralisation include one Mo-enriched outcrop in the southernmost corner of the tract. On the other hand, the absence of both Cu anomalies in till and Cu-mineralised granitoid outcrops and boulders, and the absence of clear indications of 2.1 Ga subduction within the entire shield decrease the potential for undiscovered deposits within the tract. Very little exploration of any kind has been carried out within the tract, which includes large areas without any outcrops. These features make it difficult to reliably assess the mineralisation potential of the tract. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Nilipää PorCu permissive tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 0 | 1 | | | 0.30 | 0.50 | 170 | 0 | 0.30 | 2035 | 0.00015 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 2 | | |
| Individual 2 | 0 | 0 | 1 | | |
| Individual 3 | 0 | 0 | 2 | | |
| Individual 4 | 0 | 0 | 0 | | |
| Individual 5 | 0 | 0 | 1 | | |
| Individual 6 | 0 | 0 | 1 | | |
| Individual 7 | 0 | 0 | 1 | | |
| Individual 8 | 0 | 0 | 1 | | |
| Mean | 0 | 0 | 1 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variation; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits ; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, L. Lauri, J. Luukas, T. Niiranen, M. Tiainen, J. Västi

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the porphyry Cu grade-tonnage model (Appendix 4) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Nilipää PorCu permissive tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 0 | 300,000 | 1,200,000 | 210,000 | 0.12 | 0.70 |
| Mo (t) | 0 | 0 | 0 | 15,000 | 45,000 | 12,000 | 0.11 | 0.70 |
| Ag (t) | 0 | 0 | 0 | 140 | 600 | 190 | 0.090 | 0.70 |
| Au (t) | 0 | 0 | 0 | 26 | 79 | 26 | 0.10 | 0.70 |
| Rock (Mt) | 0 | 0 | 0 | 98 | 630 | 91 | 0.10 | 0.70 |

t – metric tons; Mt – million metric tons.

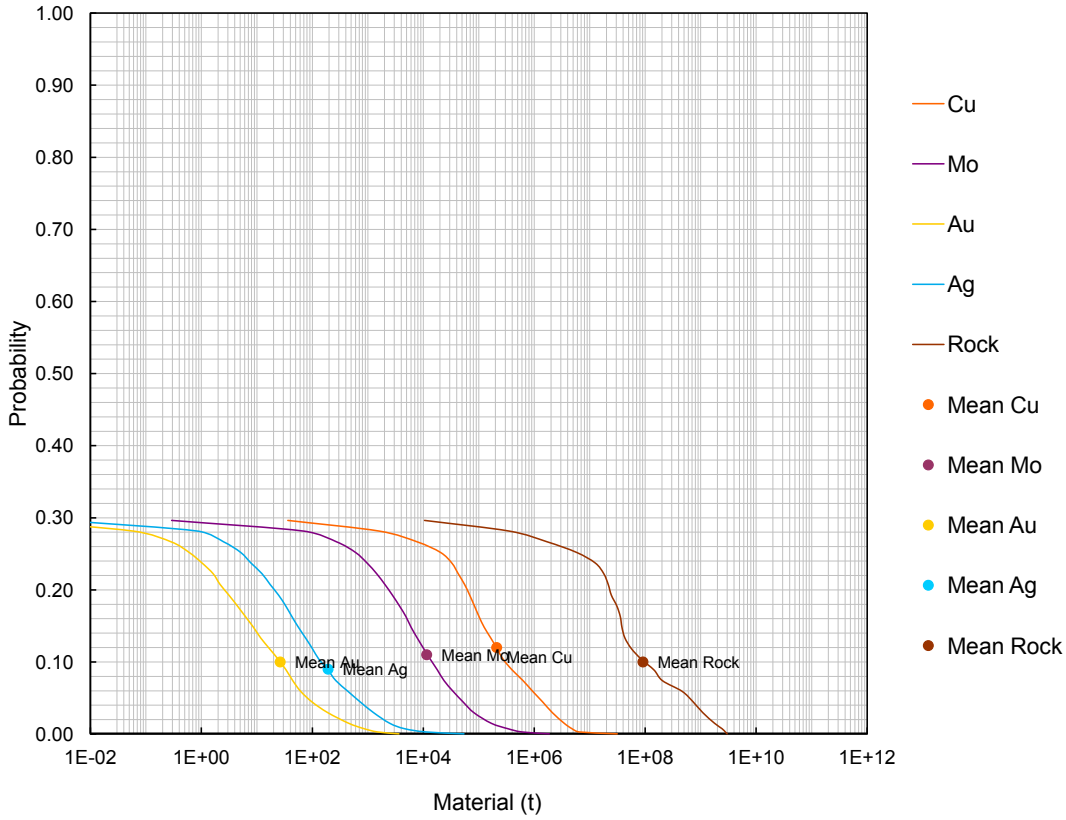


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Nilipää PorCu permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT OIJÄRVI VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Oijärvi VMS permissive tract is located in northern Finland in the municipalities of Ii, Pudasjärvi and Ranua, 85 km northeast of Oulu (Fig. 1). The 1:100,000 KKJ map sheets are 3512, 3521, 3522, and 3523. The UTM map sheets containing the intrusion are S432, S434, S441 and S443. The Cu-Zn resource assessment carried out for this report is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Oijärvi VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 10/12/2012 | 1 | 172 | Cu | 0 | Cu | 30,000 | Cu | 0 |
| | | | Zn | 0 | Zn | 22,000 | Zn | 0 |
| | | | Pb | 0 | Pb | 720 | Pb | 0 |
| | | | Ag | 0 | Ag | 13 | Ag | 0 |
| | | | Au | 0 | Au | 0.15 | Au | 0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by the Archaean Oijärvi greenstone belt. The belt mostly consists of mafic and ultramafic volcanic rocks (Fe and Mg tholeiites and komatiites) and associated subordinate mica schists as well as black schists and quartz-plagioclase schists interpreted to represent felsic to intermediate volcanic rocks. Bedrock maps, geophysical data, drilling data and outcrop observations were used to define the margins of the tract. The tract is bordered by Archaean tonalitic to granodioritic gneisses. The tract extends down to 1000 m depth. The depth extension is based on the assumption that the schist belt rocks continue downwards. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There are no well-explored VMS deposits within the Oijärvi VMS permissive tract (Table 2). According to the spatial rule used, deposits located nearer than 500 m of each other are counted as one in this assessment.

Table 2. Known VMS deposits in the Oijärvi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences, and related deposit types

No partially explored Cu-Zn occurrences of clearly VMS type are known within the Oijärvi VMS permissive tract. However, a low grade Zn occurrence in black schist has been detected at Karahkalehto, and Cu-anomalous massive Fe sulphides occur with intermediate volcanic rocks at Poromännikkö (Table 3). There are three known Au occurrences within the tract area: Kopsa, Kylmäkangas and Karahkalehto. Elevated Cu-Zn-Pb concentrations occur with the epithermal Au occurrence at Kylmäkangas.

Table 3. Cu-Zn occurrences possibly of the VMS type in the Oijärvi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Karahkalehto | 7292120 | 3453751 | Archaean | 6 m @ 0.3 % Zn, 0.06 % Cu | Juopperi & Karvinen (1999) |
| Poromännikkö | 7303980 | 3455101 | Archaean | 2.2 m @ 0.22 % Cu | Karvinen (1999) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Oijärvi VMS tract are listed in Table 4.

Table 4. Exploration history for the Oijärvi VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop and boulder observations | (Yes) | Geological Survey of Finland | 1995–2000 |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1990´s |
| | 49 km$^2$ regional till sampling at 16 samples/km$^2$ | Yes | Geological Survey of Finland | 1995 |
| | Targeted till sampling 4.4 km$^2$, 955 samples | Yes | Geological Survey of Finland | 1997 |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1994–1995 |
| Ground geophysical surveys | 25 km$^2$ systematic magnetic and VLF-R surveys, 20 km$^2$ systematic gravimetric survey and 11 line km IP measurements, bore hole geophysics | | Geological Survey of Finland | 1995–2007 |
| Drilling | 159 DDH, 22723 m | Yes | Geological Survey of Finland | 1995–2006 |
| | 9 DDH, >790 m | Yes(?) | Riddarhyttan AB, Troy Resources | 2001 |
| | 8 DDH, 3140 m | | Agnico Eagle, Troy Resources | 2006 |

DDH – diamond-drill hole.

## Sources of information

The principal sources of information used by the assessment team for delineation of the Oijärvi VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Oijärvi VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:100–1:20,000 | Juopperi & Karvinen (1999), Tolppi (1999) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Reports | | Juopperi & Karvinen (1999), Rossi (2000) |
| | Metallogenic assessment | | Eilu (1996) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Juopperi (2008) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Rossi (2000), Juopperi (2002, 2008) |
| Exploration | Reports | | Juopperi & Karvinen (1999), Karvinen (1999), Troy Resources (2002), Agnico-Eagle (2006), Juopperi et al. (2006) |
| | Geological Survey of Finland in-house drill-core database | | |

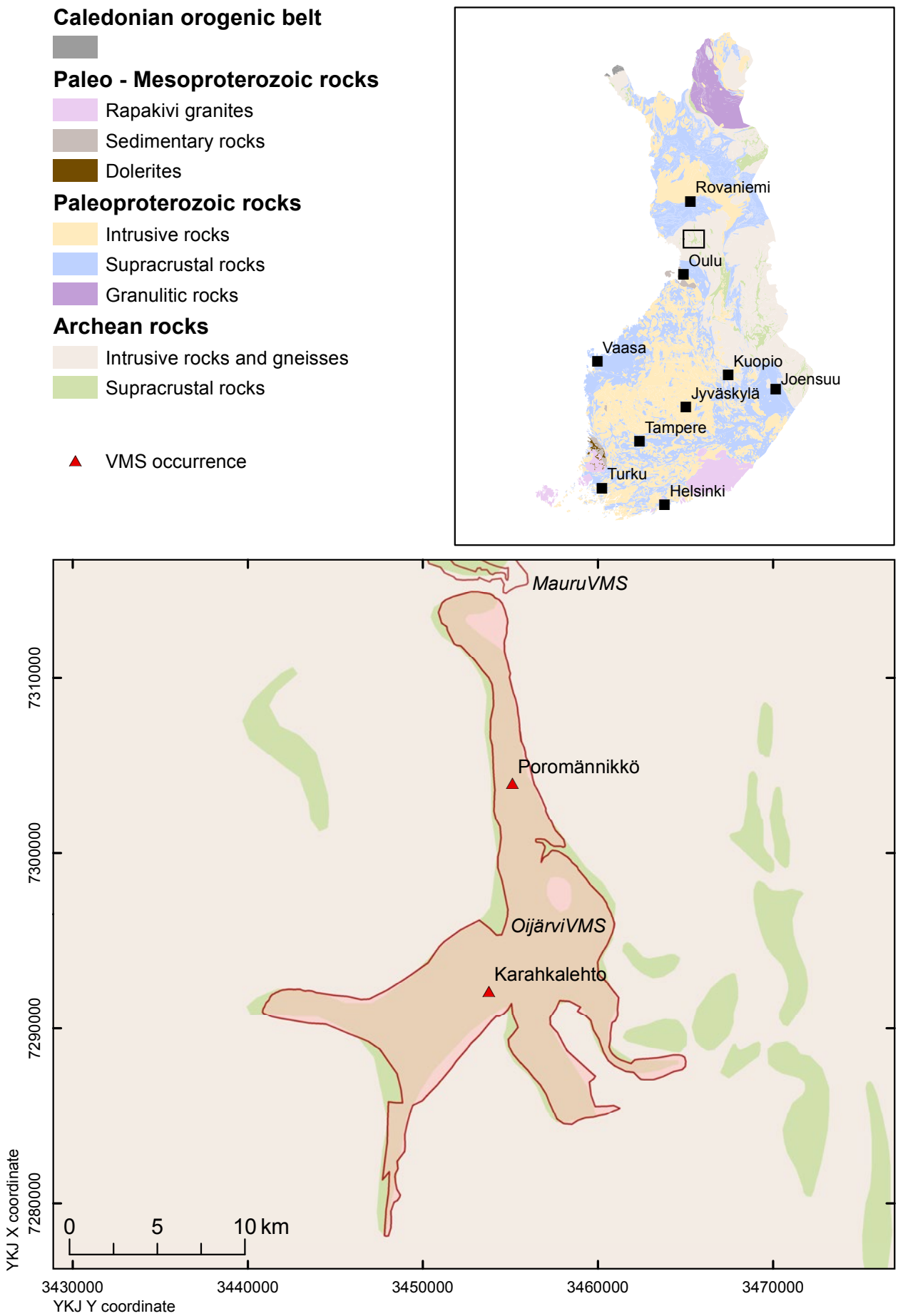


Fig. 1. Location of the Oijärvi VMS permissive tract.

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Two partially explored VMS occurrences are known within the tract (Table 3). These occurrences are so modest that it was considered possible that none of them will ever become an economic deposit, even under the most favourable circumstances. The existence of the mafic to felsic volcanic rocks, and the two known Zn-Cu occurrences were considered to indicate the potential for undiscovered VMS-type deposits. However, the entire supracrustal belt is very poorly exposed and has only been drilled at a few localities. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Oijärvi VMS tract.

| Mean undiscovered deposit estimate | | | | | Summary statistics | | | | | Area (km²) | Deposit density (N/km²) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 0 | 1 | | | 0.30 | 0.50 | 170 | 0 | 0.30 | 172 | 0.0017 |

| | Estimated number of undiscovered deposits | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 1 | | |
| Individual 2 | 0 | 0 | 1 | | |
| Individual 3 | 0 | 0 | 1 | | |
| Individual 4 | 0 | 0 | 1 | | |
| Individual 5 | 0 | 0 | 1 | | |
| Individual 6 | 0 | 0 | 1 | | |
| Consensus | 0 | 0 | 1 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie, 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, K. Rasilainen, P. Sipilä, T. Törmänen

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS mafic grade-tonnage model (Appendix 2) using EMINERS software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Oijärvi VMS tract.

| Material | At least the indicated amount at the probability of | | | | | Mean | Probability of mean or greater | Probability of zero |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 0 | 46,000 | 140,000 | 30,000 | 0.12 | 0.70 |
| Zn (t) | 0 | 0 | 0 | 25,000 | 95,000 | 22,000 | 0.11 | 0.70 |
| Pb (t) | 0 | 0 | 0 | 290 | 1,100 | 720 | 0.060 | 0.70 |
| Ag (t) | 0 | 0 | 0 | 17 | 51 | 13 | 0.11 | 0.70 |
| Au (t) | 0 | 0 | 0 | 0.15 | 0.49 | 0.15 | 0.10 | 0.70 |
| Rock (Mt) | 0 | 0 | 0 | 3.4 | 13 | 2.1 | 0.12 | 0.70 |

t – metric tons; Mt – million metric tons.

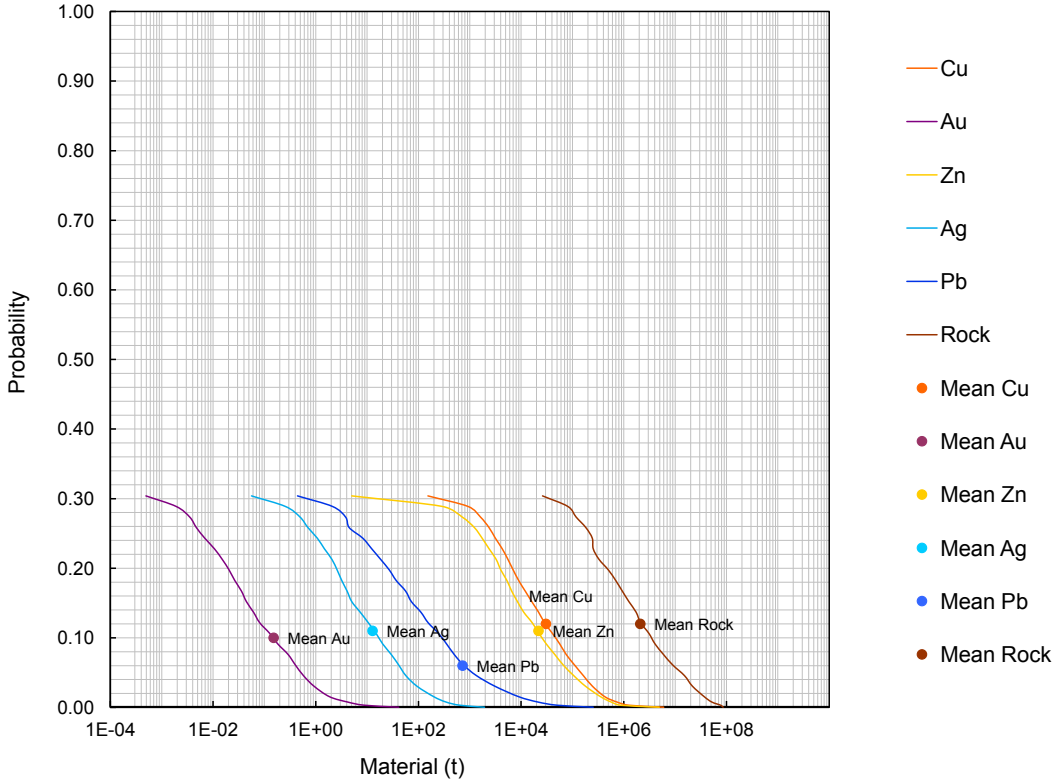


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Oijärvi VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT ORIJÄRVI VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS felsic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The small Orijärvi VMS permissive tract is located in southwestern Finland. It is a 20-km-long and 15-km-wide zone, 70 km to the west of the city of Helsinki (Fig. 1). The 1:100,000 KKJ map sheets are 2014 and 2023. The UTM map sheets containing the tract are L3333, L3334 and L4112. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Orijärvi VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 57 | Cu | 29,709 | Cu | 40,000 | Cu | 6,600 |
| | | | Zn | 87,088 | Zn | 290,000 | Zn | 40,000 |
| | | | Pb | 20,687 | Pb | 62,000 | Pb | 4,300 |
| | | | Ag | 89 | Ag | 280 | Ag | 32 |
| | | | Au | 3.1 | Au | 4.0 | Au | 0.43 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by ca. 1900 Ma Svecofennian volcanic rocks of the Uusimaa supracrustal belt. The delineation is based on the extent of the Orijärvi Group rocks. The tract is bounded to the north by stratigraphy, to the east and west by faults, and to the south by intrusions. The extent of the tract is based on the existence of abundant VMS deposits and calc-alkaline volcanic rocks and subvolcanic intrusions in a small area. The tract extends down to 1000 m depth. The depth extension is based on stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are four well-explored (and mined) VMS deposits within the Orijärvi VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Orijärvi VMS tract. Note that only the mined tonnages and grades are known for these deposits.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aijala | 6681288 | 3298496 | 1900 | 0.835 | 1.59 | 0.70 | | 14 | 0.7 | Cu<br>Zn<br>Pb<br>Ag<br>Au | 13,277<br>5,845<br><br>12<br>0.58 | Warma (1975), Latvalahti (1979), Mäkelä (1989) |
| Liipola S | 6683595 | 3301946 | 1900 | 0.024 | | 0.69 | | 112 | 0 | Cu<br>Zn<br>Pb<br>Ag<br>Au | <br>166<br><br>2.7<br> | Isomäki (1989), Mäkelä (1989) |
| Metsä-monttu | 6680970 | 3297340 | 1900 | 1.508 | 0.28 | 3.34 | 0.74 | 25 | 1.43 | Cu<br>Zn<br>Pb<br>Ag<br>Au | 4,222<br>50,367<br>11,159<br>37<br>2.2 | Latvalahti (1979), Mäkelä (1989), Puustinen (2003) |
| Orijärvi | 6684772 | 3308429 | 1900 | 0.925 | 1.3 | 3.32 | 1.03 | 40 | 0.4 | Cu<br>Zn<br>Pb<br>Ag<br>Au | 12,210<br>30,710<br>9,528<br>37<br>0.37 | Latvalahti (1979), Mäkelä (1989), Puustinen (2003) |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences, and related deposit types

Four partially explored VMS-type occurrences are known within the Orijärvi VMS tract (Table 3).

Table 3. Significant VMS occurrences in the Orijärvi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Aurums-Aijala | 6680953 | 3297720 | 1900 | Historic small-scale mining. Less than 500 m from Metsämonttu. | Puustinen (2003) |
| Iilijärvi | 6685506 | 3307491 | 1900 | 45,000 t @ 1.3 % Zn, 0.6 % Zn, 0.6 % Cu, 40 g/t Ag, 4 g/t Au. Several ore bodies; the resource reported only includes one or two. Total resource possibly >1 Mt. | Isomäki (1987, 1988), Mäkelä (1989), Pekkarinen (1996) |
| Liipola N | 6685056 | 3303515 | 1900 | 0.45 m @ 1.95 % Zn, 0.48 % Pb, 7 g/t Ag | Isomäki (1989) |
| Paavonholma | 6683560 | 3310375 | 1900 | 10 t at about 1 % Cu mined | Puustinen (2003) |

Ma – million years; Mt – million metric tons; t – metric ton.

## Exploration history

Exploration activities for VMS deposits within the Orijärvi VMS tract are listed in Table 4.

Table 4. Exploration history for the Orijärvi VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1880s– |
| | Outcrop and boulder observations | Yes | Orijärvi Gruvaktiebolag | 1918–1945 |
| | Outcrop and boulder observations | Yes | Suomen Malmi | 1945–1952 |
| | Outcrop and boulder observations | Yes | Outokumpu | 1948–2000 |
| | Outcrop and boulder observations | Yes | Finnish American Mining Co | 1907–1912 |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Detailed till and humus geochemical surveys | Yes | Outokumpu | 1950s–1990s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1982 |
| Ground geophysical surveys | Magnetic surveys | | Geological Survey of Finland | 1920s–2000s |
| | Magnetic and electro-magnetic surveys | | Suomen Malmi | 1945–1952 |
| | Magnetic, slingram, VLF, EM-37, turam, charged potential, gravimetric and IP surveys | | Outokumpu | 1948–1990s |
| | Electromagnetic survey | | BHP | 1996 |
| Drilling | Hundreds of diamond-drill holes | Yes | Outokumpu | 1948–1990s |
| | Unknown number of diamond-drill holes | Yes | Orijärvi Gruvaktiebolag | 1918–1945 |
| | Aijala: 32 diamond-drill holes, total 3373 m; other targets: tens of diamond-drill holes | Yes | Suomen Malmi | 1945–1952 |
| | Unknown number of diamond-drill holes | Yes | Finnish American Mining Co | 1907–1912 |
| | Three diamond-drill holes | Yes | SES Finland | 1996 |
| | A few diamond-drill holes | Yes | Geological Survey of Finland | 1900s–1990s |
| Other | Stratigraphic, structural, mineralogical, metallogenic and Pb-isotopic investigations | Yes | Geological Survey of Finland, University of Helsinki, Åbo Akademi University, University of Turku, Suomen Malmi, Outokumpu | 1900s–2010s |

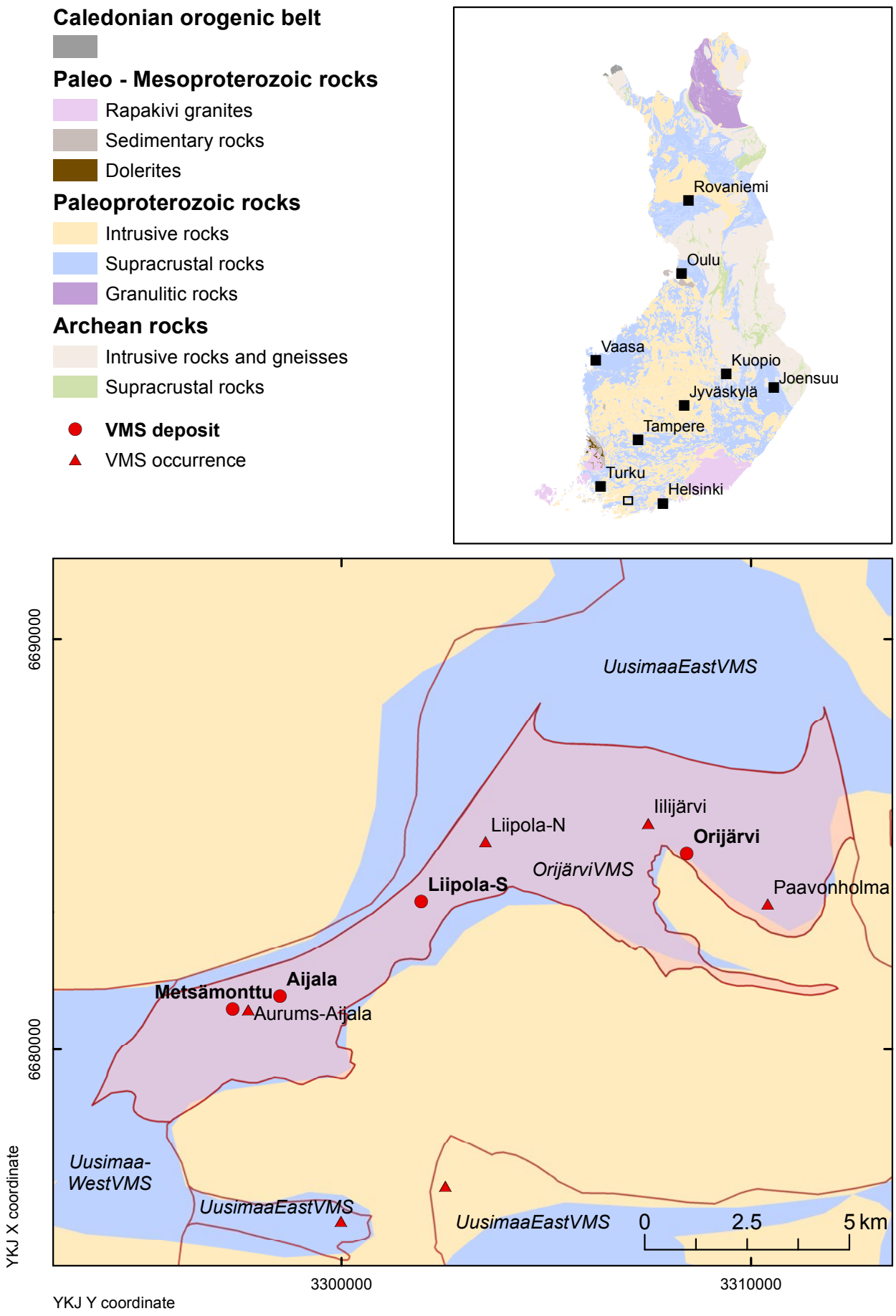


Fig. 1. Location of the Orijärvi VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Orijärvi VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Orijärvi VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:100–1:10,000 | Eskola (1914), Colley & Westra (1987), Mäkelä (1989), Ploegsma & Westra (1990), Väisänen et al. (2002), Skyttä et al. (2005) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Deposit descriptions | | Warma (1974), Latvalahti (1979,1980), Isomäki (1988, 1989), Mäkelä (1989), Papunen (1990) |
| | Metallogenic assessments | | Eskola (1914), Latvalahti (1979), Outokumpu Oy malminetsintä (1986), Mäkelä (1989), Papunen (1990) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Wennervirta & Papunen (1974), Isomäki (1987), Mäkelä (1989), Papunen (1990) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Latvalahti (1978), Isomäki (1985, 1987, 1988, 1989), Mäkelä (1983, 1989), Pekkarinen (1996), Björklund (2000) |
| Exploration | Reports | | Warma (1954, 1974), Huhma & Latvalahti (1975), Latvalahti (1978, 1980), Isomäki (1985, 1987, 1988, 1989), Outokumpu Oy malminetsintä (1986), Pekkarinen (1996), Björklund (2000) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Four partially explored VMS occurrences are known within the tract (Table 3). However, these occurrences were seen as being so modest that most of the estimators considered it possible that only some of them, if any, will ever become economic deposits, even under the most favourable circumstances. The tract has been rather intensely explored, especially in the surroundings of the known deposits. However, a large part of the exploration effort was targeted towards gold from 1990 onwards. Favourable indicators for VMS-type mineralisation within the tract include the four known VMS deposits and the four partially explored occurrences, extensive bimodal volcanism and several Zn- and Cu-rich glacial boulders with no identified source. On the other hand, the number of four known deposits is already near the upper 10 % confidence limit of a deposit den-

sity model based on well-known VMS belts in the world (Mosier et al. 2007). No consensus was reached in the discussion and the mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Orijärvi VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 1 | 2 | | | 1.2 | 0.55 | 45 | 4 | 5.2 | 57 | 0.091 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 1 | 2 | 3 | | |
| Individual 2 | 0 | 1 | 1 | | |
| Individual 3 | 1 | 2 | 4 | | |
| Individual 4 | 0 | 0 | 0 | | |
| Individual 5 | 1 | 1 | 1 | | |
| Individual 6 | 0 | 1 | 2 | | |
| Individual 7 | 1 | 1 | 1 | | |
| Individual 8 | 1 | 2 | 2 | | |
| Individual 9 | 2 | 3 | 3 | | |
| Individual 10 | 0 | 1 | 1 | | |
| Individual 11 | 1 | 2 | 1 | | |
| Mean | 1 | 1 | 2 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen, H. Kujala, J. Luukas, J. Nikander, M. Nironen, K. Rasilainen, P. Sipilä, P. Sorjonen-Ward, M.Tiainen, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS felsic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Orijärvi VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 240 | 6,600 | 75,000 | 170,000 | 40,000 | 0.18 | 0.060 |
| Zn (t) | 0 | 910 | 40,000 | 640,000 | 1,600,000 | 290,000 | 0.17 | 0.060 |
| Pb (t) | 0 | 62 | 4,300 | 99,000 | 230,000 | 62,000 | 0.14 | 0.060 |
| Ag (t) | 0 | 0.64 | 32 | 550 | 1,300 | 280 | 0.17 | 0.060 |
| Au (t) | 0 | 0.012 | 0.43 | 7.1 | 17 | 4.0 | 0.16 | 0.060 |
| Rock (Mt) | 0 | 0.067 | 1.3 | 18 | 47 | 7.2 | 0.16 | 0.060 |

t – metric tons; Mt – million metric tons.

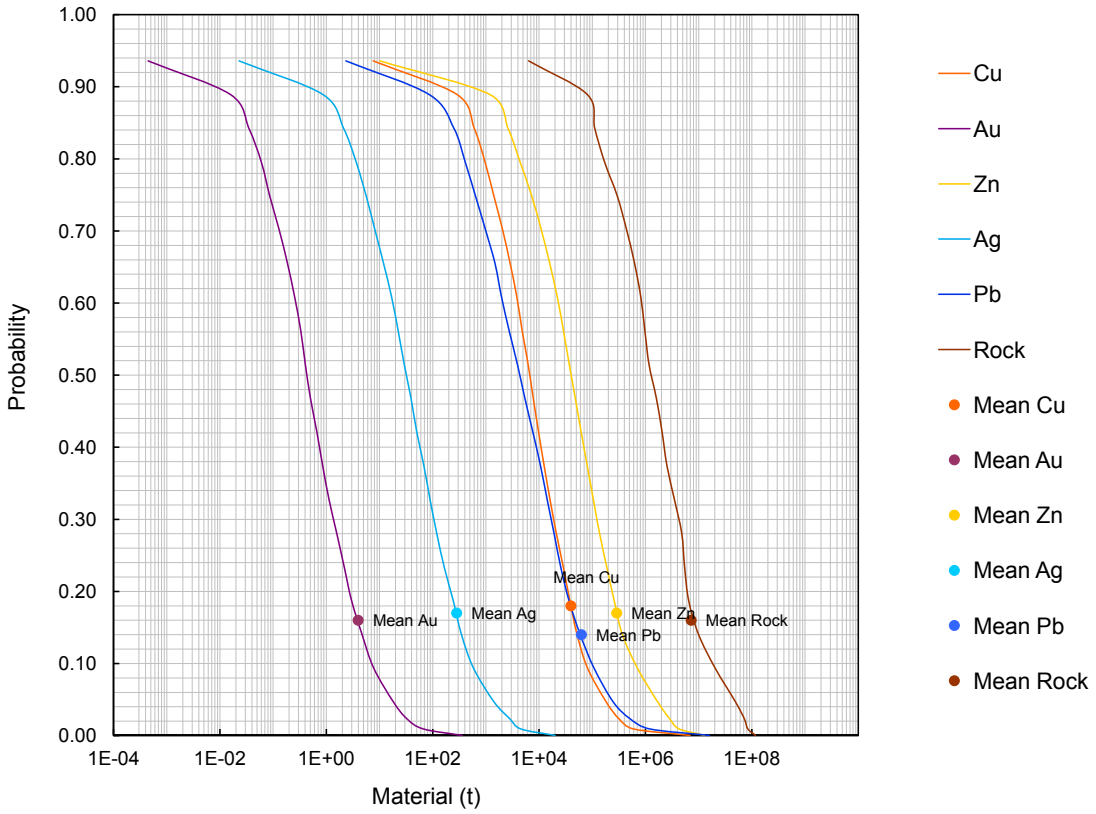


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Orijärvi VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT OTRAVAARA VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix1)
**Grade-tonnage model**: VMS bimodal-mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Otravaara VMS permissive tract is an approximately 5-km-wide and 200-km-long NE–SW trending zone in eastern Finland, mainly within the municipality of Ilomantsi (Fig. 1). The 1:100,000 KKJ map sheets are 4232, 4241, 4242, 4243, 4244 and 4333. The UTM map sheets containing the tract are N543, N544, N621, N622, P533, P534, P611, P612 and P621. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Otravaara VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 1262 | Cu | 0 | Cu | 42,000 | Cu | 30,000 |
| | | | Zn | 0 | Zn | 90,000 | Zn | 59,000 |
| | | | Pb | 0 | Pb | 4,300 | Pb | 1,200 |
| | | | Ag | 0 | Ag | 22 | Ag | 10 |
| | | | Au | 0 | Au | 0.70 | Au | 0.54 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by Meso- or Neoarchaean supracrustal rocks. The delineation is based on the extent of supracrustal rocks of the Hattu and Kovero groups and the Harkkojärvi Suite rocks. The tract extends down to 1000 m depth. The depth extension is based on stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored VMS deposits within the Otravaara VMS permissive tract (Table 2). According to the spatial rule used, deposits less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Otravaara VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

At least six partially explored occurrences of possibly VMS type are known within the Otravaara VMS permissive tract (Table 3).

Table 3. Significant VMS occurrences in the Otravaara VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Otravaara | 6945268 | 3673195 | | 0.022 Mt pyrite ore | Männikkö et al. (1987) |
| Huhus | 6978037 | 3688694 | | 10 m @ 4 % Zn, 4 % Pb; 15 m @ 0.5 % Zn and 3–4% Pb | Boström (1961) |
| Melasuo | 6935147 | 3677371 | | 2 m @ 1.2 % Zn, 0.27 % Pb, 4 g/t Ag | Parkkinen (1984) |
| Pekkula | 6915300 | 3683600 | | 7.5 m @ 0.35 % Zn, 0.1 % Pb | Nikander (2008) |
| Rahalampi | 6938356 | 3675319 | | 4 m @ 1.8 % Zn | Parkkinen (1982) |
| Saahkovaara | 6943376 | 3671280 | | 0.7 m @ 4.33 % Zn, 0.52 % Pb, 7 g/t Ag | Parkkinen & Pietilä (1984) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Otravaara VMS tract are listed in Table 4.

Table 4. Exploration history for the Otravaara VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Bedrock mapping, glacial erratic boulder survey | Yes | Geological Survey of Finland | 1960s–2000s |
| | Bedrock mapping, glacial erratic boulder survey | Yes | Outokumpu Oy | 1960s–1990s |
| | Bedrock mapping, glacial erratic boulder survey | Yes | Malminetsijä Oy | 1956–1973 |
| Geochemical surveys | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| | Targeted till and peat geochemical surveys | Yes | Geological Survey of Finland | 1960s–2000s |
| | Till geochemical survey | Yes | Outokumpu Oy | 1960s–1990s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric | | Geological Survey of Finland | 1975–1998 |
| Ground geophysical surveys | EM and magnetic surveys | | Geological Survey of Finland | 1960s–2000s |
| | EM, gravimetric and magnetic surveys | | Malminetsijä Oy | 1956–1973 |
| | EM and magnetic surveys | | Outokumpu Oy | 1960s–1990s |
| Drilling | Diamond drilling | Yes | Geological Survey of Finland | 1960s–2000s |
| | 30 diamond-drill holes, total 4782 m | Yes | Malminetsijä Oy | 1960s |
| | >35 diamond-drill holes | Yes | Outokumpu Oy | 1960s–1990s |

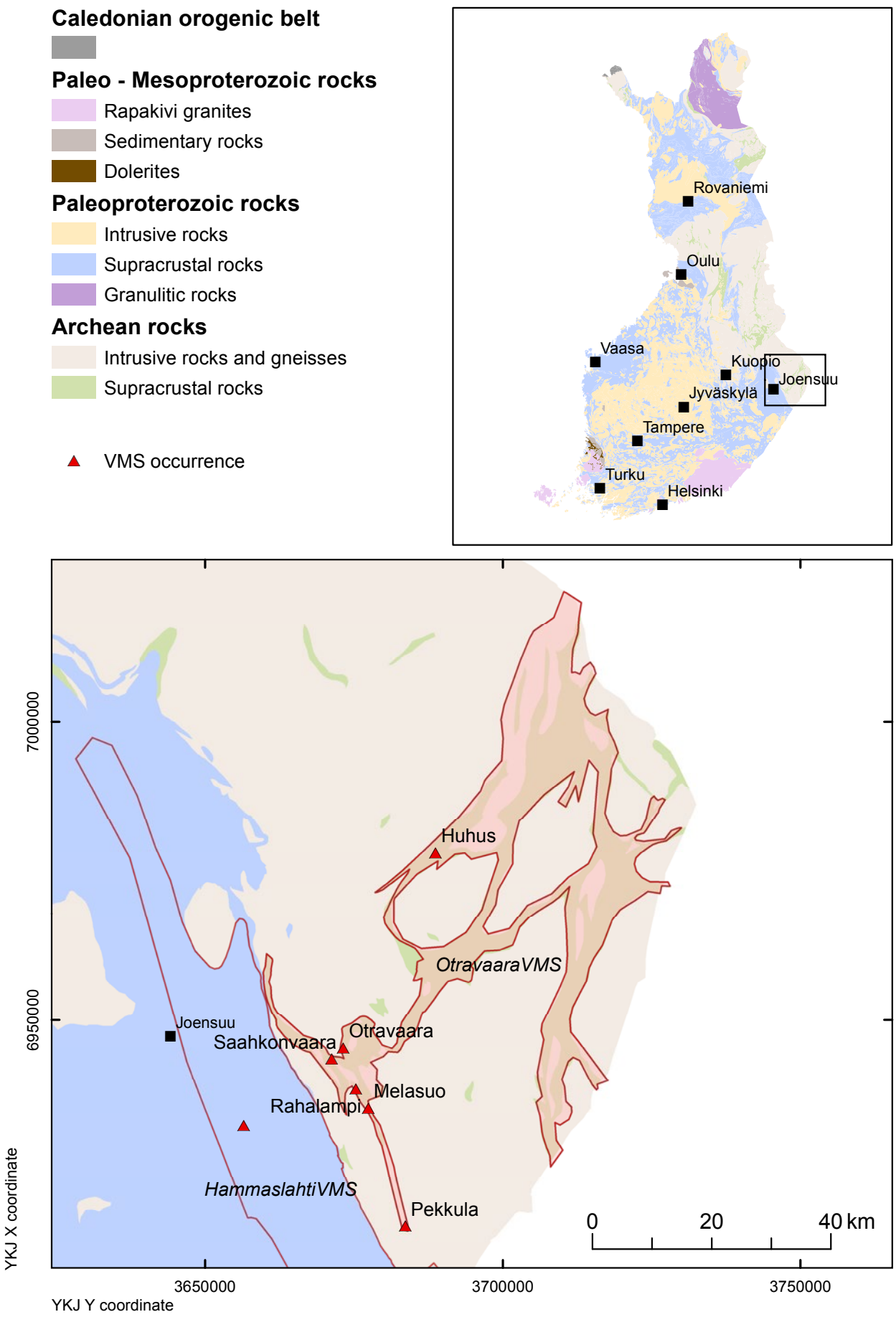


Fig. 1. Location of the Otravaara VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Otravaara VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Otravaara VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Reports | | Boström (1961, 1962), Kurki (1978, 1984), Parkkinen (1982, 1985), Männikkö et al. (1987), Papunen (1990), Lahtinen (2001) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Lestinen (1979, 1980), Mäkinen & Lestinen (1990) |
| Geophysics | Geological Survey of Finland in-house database | | |
| Exploration | Exploration reports | | Boström (1961, 1962), Parkkinen (1982, 1984, 1985), Yrjölä (1982), Kurki (1978, 1984), Parkkinen & Pietilä (1984), Männikkö et al. (1987), Lahtinen (2001), Nikander (2008) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Six partially explored VMS occurrences are known within the tract (Table 3). These occurrences are modest and it was considered probable that even under the most favourable circumstances, most of them will never become economic deposits. However, the relatively large number of VMS occurrences, all open along strike, was seen as a favourable indicator for economic deposits. The following features that exist throughout the tract were also considered favourable for VMS-type mineralisation: 1) strong magnetic anomalies due to Fe sulphide-rich lithological units and serpentinite bodies (possibly metamorphosed komatiitic units), 2) strong electric anomalies due to graphite-rich black shales, 3) the Zn-Pb and Zn anomalies in peat and till, 4) very extensive sericitic and epidote alteration zones, and 5) abundant mafic volcanic rocks plus minor felsic volcanic rocks (the latter often called leptites in old reports). No consensus was reached in the discussion and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Otravaara VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 2 | 4 | | | 2.2 | 1.2 | 54 | 0 | 2.2 | 1262 | 0.0018 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 1 | 1 | 3 | | |
| Individual 2 | 0 | 1 | 1 | | |
| Individual 3 | 1 | 2 | 4 | | |
| Individual 4 | 1 | 2 | 4 | | |
| Individual 5 | 1 | 2 | 4 | | |
| Individual 6 | 1 | 3 | 5 | | |
| Individual 7 | 2 | 3 | 5 | | |
| Mean | 1 | 2 | 4 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer and Menzie, 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen J. Luukas, J. Nikander, K. Rasilainen, P. Sorjonen-Ward, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS bimodal-mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Otravaara VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 2,300 | 30,000 | 97,000 | 130,000 | 42,000 | 0.39 | 0.070 |
| Zn (t) | 0 | 4,800 | 59,000 | 210,000 | 290,000 | 90,000 | 0.36 | 0.070 |
| Pb (t) | 0 | 35 | 1,200 | 13,000 | 19,000 | 4,300 | 0.26 | 0.070 |
| Ag (t) | 0 | 0.63 | 9.5 | 58 | 91 | 22 | 0.27 | 0.070 |
| Au (t) | 0 | 0.066 | 0.54 | 1.5 | 1.9 | 0.70 | 0.40 | 0.070 |
| Rock (Mt) | 0 | 0.21 | 2.7 | 7.9 | 9.7 | 3.4 | 0.39 | 0.070 |

t – metric tons; Mt – million metric tons.

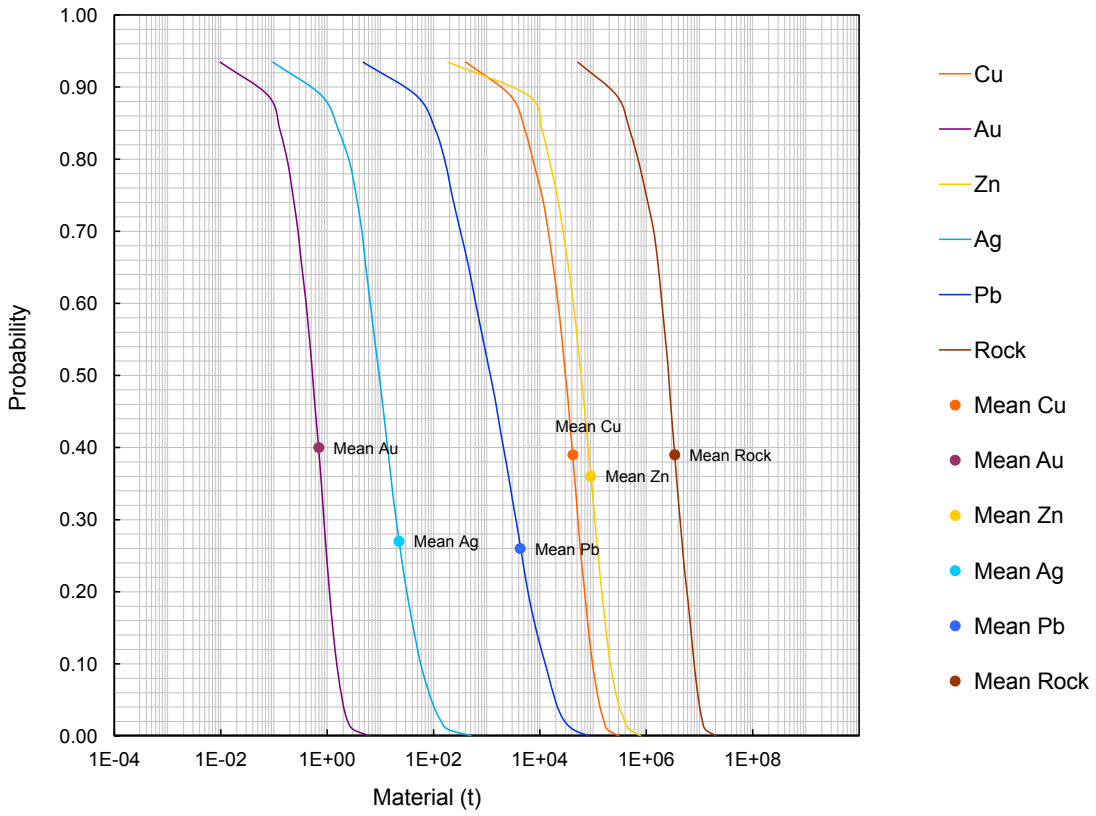


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Otravaara VMS permissive tract.

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# OUTOKUMPU Cu-Zn-Co ASSESSMENT FOR THE TRACT OUTOKUMPU Cu-Zn-Co, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: Outokumpu Cu-Zn-Co
**Descriptive model**: Outokumpu Cu-Zn-Co (Appendix 5)
**Grade-tonnage model**: Outokumpu Cu-Zn-Co (Appendix 6)

## LOCATION AND RESOURCE SUMMARY

The Outokumpu Cu-Zn-Co permissive tract in eastern Finland consists of two separate areas with a narrow corridor between them. The southern area is about 100 km wide and 100 km long and extends from Kaavi in the NW to Kitee in the SE. The northern part is a 5–15-km-wide and 90-km-long area extending from Ristijärvi in the south to Sotkamo in the north (Fig. 1). The 1:100,000 KKJ map sheets are 3234, 3243, 3244, 3333, 3334, 3343, 3344, 3432, 3433, 3434, 3443, 4212, 4213, 4214, 4221, 4222, 4223, 4231, 4232, 4241, 4311, 4312 and 4313. The UTM map sheets containing the tract are N514, N521, N522, N523, N524, N532, N534, N541, N542, N543, N544, P513, P514, P523, P524, P531, P532, Q513, Q514, Q522, Q523, Q524, R511 and R513. The Cu-Zn-Co resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for Outokumpu Cu-Zn-Co tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 9824 | Cu | 196,518 | Cu | 860,000 | Cu | 580,000 |
| | | | Zn | 113,668 | Zn | 300,000 | Zn | 220,000 |
| | | | Co | 30,247 | Co | 68,000 | Co | 53,000 |
| | | | Ni | 36,767 | Ni | 49,000 | Ni | 41,000 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is within the 1.96 Ga Upper Kaleva supracrustal rocks. It is delineated by the extent of the supracrustal rocks of the Nuasjärvi Group and Viinijärvi Suite. The tract area is included into the Outokumpu Allochthon, also called the 'Outokumpu Nappe Complex' or 'Outo-

kumpu Nappe', in various publications listed in Table 5. Bedrock observation, drill core and geophysical survey data and the presence of Cu-Zn-Co(-Ni)-occurrences have been used to define the tract area. The tract extends down to 1000 m depth. The depth extension is based on data from the Outokumpu mine and regional stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are 10 well-explored Outokumpu-type Cu-Zn-Co deposits within the permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known Outokumpu-type deposits in the Outokumpu Cu-Zn-Co tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | | Contained metal (t) | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Ni (%) | Co (%) | Ag (g/t) | Au (g/t) | | | |
| Hoikka | 6980721 | 3583310 | | 0.2 | 0.50 | 0.10 | 0.15 | 0.04 | | | Cu | 1,000 | Parkkinen (1997), Kontinen et al. (2006) |
| | | | | | | | | | | | Zn | 200 | |
| | | | | | | | | | | | Co | 80 | |
| | | | | | | | | | | | Ni | 300 | |
| Hieta-järvi | 6911504 | 3613542 | | 0.341 | 0.67 | 1.13 | 0.18 | 0.14 | | | Cu | 2,285 | Huhma & Huhma (1970), Isomäki (1994) |
| | | | | | | | | | | | Zn | 3,835 | |
| | | | | | | | | | | | Co | 477 | |
| | | | | | | | | | | | Ni | 614 | |
| Kettu-kumpu | 6901907 | 3615329 | | 0.4 | 0.44 | 0.10 | 0.18 | 0.07 | | | Cu | 1,760 | Parkkinen (1997) |
| | | | | | | | | | | | Zn | 400 | |
| | | | | | | | | | | | Co | 280 | |
| | | | | | | | | | | | Ni | 720 | |
| Kyly-lahti | 6974614 | 3619578 | 1950 | 8.4 | 1.25 | 0.54 | 0.20 | 0.24 | | 0.68 | Cu | 104,938 | Kontinen et al. (2006), Universal Resources (2010) |
| | | | | | | | | | | | Zn | 45,333 | |
| | | | | | | | | | | | Co | 20,148 | |
| | | | | | | | | | | | Ni | 16,790 | |
| | | | | | | | | | | | Au | 5.7 | |
| Luikon-lahti | 6983156 | 3586571 | | 7.7 | 1.2 | 0.65 | 0.09 | 0.12 | | | Cu | 92,400 | Eskelinen et al. (1983), Parkkinen (1997) |
| | | | | | | | | | | | Zn | 50,050 | |
| | | | | | | | | | | | Co | 9,240 | |
| | | | | | | | | | | | Ni | 6,930 | |
| Outo-kumpu[1] | 6959379 | 3602046 | 1950 | 31.7 | 3.46 | 0.97 | 0.15 | 0.23 | 8.9 | 0.8 | Cu | 1,095,436 | Papunen (1987), Parkkinen (1997), Altona Mining Ltd (2012) |
| | | | | | | | | | | | Zn | 307,102 | |
| | | | | | | | | | | | Co | 72,818 | |
| | | | | | | | | | | | Ni | 47,490 | |
| | | | | | | | | | | | Ag | 254 | |
| | | | | | | | | | | | Au | 22.8 | |
| Pert-tilahti | 6967387 | 3611685 | 1950 | 1.32 | 2.15 | 1.89 | 0.15 | 0.16 | 14 | | Cu | 28,466 | Hakanen (1985), Parkkinen (1997) |
| | | | | | | | | | | | Zn | 25,024 | |
| | | | | | | | | | | | Co | 2,118 | |
| | | | | | | | | | | | Ni | 1,986 | |
| | | | | | | | | | | | Ag | 19 | |
| Riihi-lahti | 6957880 | 3587048 | | 0.7 | 0.72 | 0.09 | 0.03 | 0.09 | 6 | 0.3 | Cu | 5,040 | Parkkinen (1997), Kontinen et al. (2006) |
| | | | | | | | | | | | Zn | 630 | |
| | | | | | | | | | | | Co | 630 | |
| | | | | | | | | | | | Ni | 210 | |
| | | | | | | | | | | | Ag | 4 | |
| | | | | | | | | | | | Au | 0.21 | |
| Sara-mäki | 6983301 | 3608340 | 1950 | 3.4 | 0.71 | 0.63 | 0.05 | 0.09 | | | Cu | 24,140 | Lappalainen (1980), Parkkinen (1997) |
| | | | | | | | | | | | Zn | 21,420 | |
| | | | | | | | | | | | Co | 3,060 | |
| | | | | | | | | | | | Ni | 1,700 | |
| Vuonos Cu | 6964298 | 3608185 | 1950 | 6.26 | 2.09 | 1.32 | 0.12 | 0.14 | 11 | 0.1 | Cu | 157,605 | Parkkinen (1997), Kontinen et al. (2006), Vulcan Resources (2009) |
| | | | | | | | | | | | Zn | 106,400 | |
| | | | | | | | | | | | Co | 9,975 | |
| | | | | | | | | | | | Ni | 8,645 | |
| | | | | | | | | | | | Ag | 69 | |
| | | | | | | | | | | | Au | 0.63 | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

[1]Outokumpu contains Hautalampi (Keretti low-grade halo)

## Prospects, mineral occurrences and related deposit types

At least one partially explored Outokumpu-type Cu-Zn-Co occurrence is known within the tract (Table 3). In addition, there are a number of serpentinite-hosted, low-grade Ni-Co occurrences within the tract, in rocks altered in a similar way to the Outokumpu-type deposits, but devoid of Zn and typically with very little Cu. The largest of the latter type include the mined Vuonos Ni deposit with 5.5 Mt @ 0.2 % Ni, 0.03 % Co, 0.04 % Cu, and the Hautalampi (Keretti Ni) prospect with 3.16 Mt @ 0.43 % Ni, 0.11 % Co and 0.36 % Cu (Papunen & Vorma 1985, Vulcan Resources 2009).

Table 3. Significant Outokumpu-type occurrences in Outokumpu Cu-Zn-Co tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Sola | 6967498 | 3619439 | | 0.1 Mt @ 0.1 % Co, 1 % Cu, 0.15 % Ni, 1 % Zn | Huhma & Huhma (1970) |

Ma – million years

## Exploration history

Exploration activities for Outokumpu-type deposit within the Outokumpu Cu-Zn-Co tract are listed in Table 4.

Table 4. Exploration history for Outokumpu Cu-Zn-Co tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Bedrock mapping and glacial erratic boulder surveys | Yes | Geological Survey of Finland | 1910s–2000s |
| | Bedrock mapping and glacial erratic boulder surveys | Yes | Outokumpu Oy | 1910s–1990s |
| | Bedrock mapping and glacial erratic boulder surveys | Yes | Malmikaivos Oy | 1960s–1980s |
| Geochemical surveys | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| | Targeted till geochemical surveys, lithogeochemistry | Yes | Geological Survey of Finland | 1960s–2000s |
| | Targeted till geochemical surveys | Yes | Outokumpu Oy | 1960s–1990s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1979–1991 |
| | ZTEM in FinAust Mining claim areas around known deposits | | FinAust Mining Plc | 2012 |
| Ground geophysical surveys | Electromagnetic, magnetic and gravimetric surveys, down-hole surveys | | Outokumpu Oy | 1920s–1990s |
| | Electromagnetic, magnetic and gravimetric surveys | | Malmikaivos Oy | 1960s–1980s |
| | Electromagnetic, magnetic and gravimetric surveys | | Geological Survey of Finland | 1920s–2000s |
| | Regional and targeted seismic reflection surveys | | Geological Survey of Finland | 2000s |
| Drilling | Thousands of diamond-drill holes, mostly in mines and known deposits and occurrences | Yes | Outokumpu Oy | 1910s–1990s |
| | Hundreds of diamond-drill holes | Yes | Malmikaivos Oy | 1960s–1980s |
| | Hundreds of diamond-drill holes | Yes | Geological Survey of Finland | 1910s–2000s |
| | Hundreds of diamond-drill holes | Yes | Vulcan Resources, Altona Mining | 2000s– |
| | Diamond drilling | Yes | FinnAust Mining Plc | 2010s– |
| Other | Feasibility studies and pilot-plant tests | Yes | Outokumpu Oy | 1910s–1990s |
| | Feasibility studies and pilot-plant tests | Yes | Vulcan Resources, Altona Mining | 2000s– |

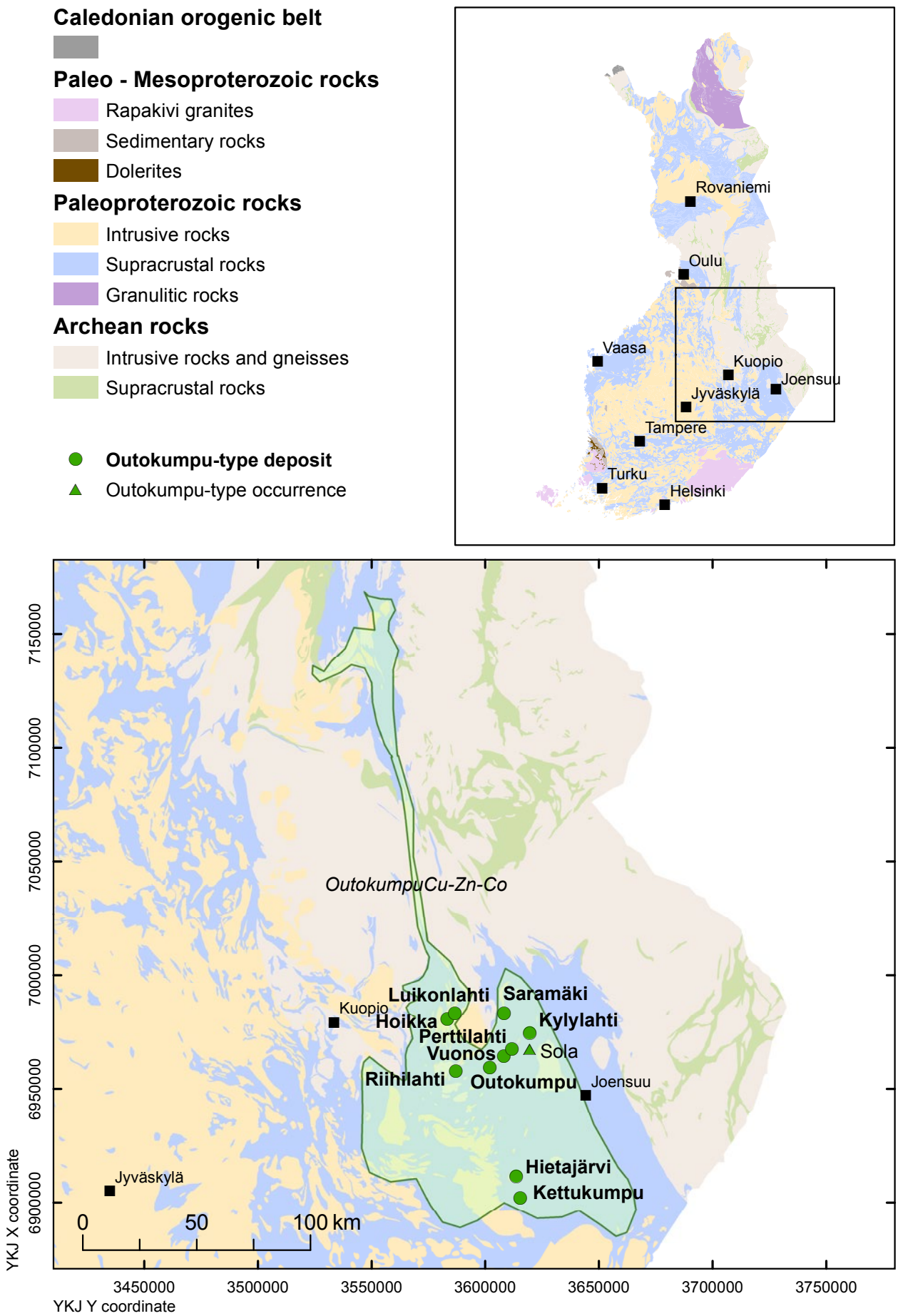


Fig. 1. Location of the Outokumpu Cu-Zn-Co permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Outokumpu Cu-Zn-Co tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment 2eam for Outokumpu Cu-Zn-Co tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Reports | | Huhma & Huhma (1975), Koistinen (1981), Park & Bowes (1983), Park (1988), Gaal & Parkkinen (1993), Pekkarinen et al. (1998), Loukola-Ruskeeniemi (1999), Kontinen et al. (2006), Kukkonen & Lahtinen (2006), Kukkonen (2011) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Reports | | Koistinen (1980), Lappalainen (1980), Hakanen (1985), Parkkinen & Reino (1985), Papunen (1987), Huhtelin & Sotka (1994), Isomäki (1994), Kontinen et al. (2006), Peltonen et al. (2008), Vulcan Resources (2009), Kukkonen (2011) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Kukkonen & Lahtinen (2006), Kukkonen et al. (2009), Kukkonen (2011) |
| Exploration | Reports | | Isokangas (1974), Koistinen (1980), Hakanen (1985), Parkkinen (1997), Västi & Tervo (2002, 2003), Vulcan Resources (2009), Western Areas (2012) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

One partially explored Outokumpu-type occurrence is known within the tract (Table 3). In addition to this, the large number of well-explored Outokumpu-type deposits and the serpentinite-hosted low-grade Ni-Co occurrences within the tract were seen as a favourable indicator for undiscovered economic deposits. On the other hand, all geophysical anomalies similar to those at the known deposits have been drilled without discovering new deposits. No consensus was reached in the discussion and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for Outokumpu Cu-Zn-Co tract.

| **[Consensus / Mean] undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 2 | 6 | 10 | | | 5.9 | 2.9 | 49 | 10 | 15.9 | 9824 | 0.00060 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 5 | 10 | 15 | | |
| Individual 2 | 2 | 4 | 6 | | |
| Individual 3 | 2 | 7 | 18 | | |
| Individual 4 | 2 | 4 | 8 | | |
| Individual 5 | 1 | 3 | 4 | | |
| Mean | 2 | 6 | 10 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Kontinen J. Kousa, K. Rasilainen, P. Sorjonen-Ward, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the Outokumpu Cu-Zn-Co grade-tonnage model (Appendix 6) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in Outokumpu Cu-Zn-Co tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 1,200 | 24,000 | 580,000 | 2,100,000 | 2,600,000 | 860,000 | 0.39 | 0.05 |
| Zn (t) | 800 | 13,000 | 220,000 | 700,000 | 900,000 | 300,000 | 0.39 | 0.05 |
| Ni (t) | 230 | 3,000 | 41,000 | 100,000 | 130,000 | 49,000 | 0.43 | 0.05 |
| Co (t) | 170 | 2,900 | 53,000 | 150,000 | 190,000 | 68,000 | 0.41 | 0.05 |
| Rock (Mt) | 0.27 | 2.7 | 33 | 77 | 92 | 37 | 0.45 | 0.05 |

t – metric tons; Mt – one million tons.

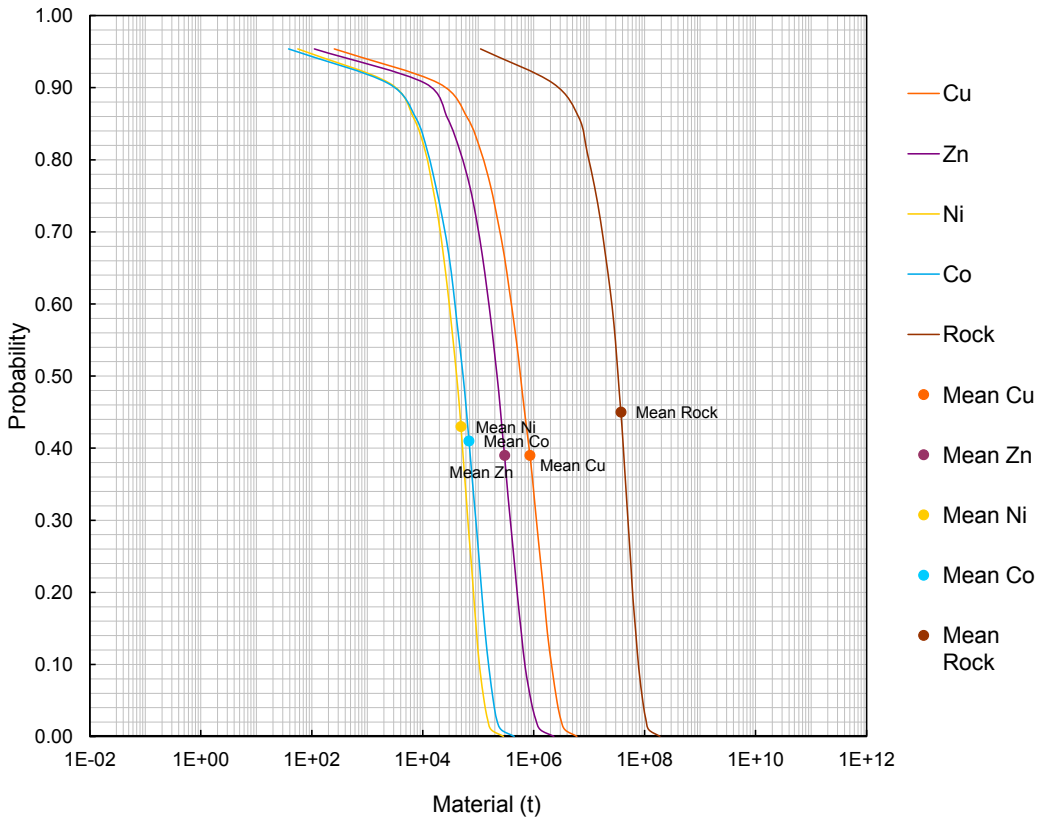


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Outokumpu Cu-Zn-Co permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT PAHTAVUOMA VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Pahtavuoma VMS permissive tract is located in northern Finland in the municipalities of Kittilä, Muonio and Sodankylä, 145 km NNW of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 2732, 2741, 2734, 2743 and 3712. The UTM map sheets containing the tract are U423, U424, U441, U442 and U443. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Pahtavuoma VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 605 | Cu | 64,200 | Cu | 260,000 | Cu | 100,000 |
| | | | Zn | 143,380 | Zn | 190,000 | Zn | 60,000 |
| | | | Pb | 17,120 | Pb | 6,900 | Pb | 710 |
| | | | Ag | 214 | Ag | 110 | Ag | 40 |
| | | | Au | 0 | Au | 1.4 | Au | 0.37 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The Pahtavuoma VMS permissive tract is defined by 2000–2200 Ma volcano-sedimentary rocks in the western part of the Central Lapland Greenstone Belt. The delineation is based on the extent of mafic volcanic rocks and various metasedimentary units of the Savukoski Group. A few local komatiitic volcanic units of the Savukoski Group are included in the tract. Diamond drill core and outcrop observations as well as low-altitude aeromagnetic survey data were used to define the margins of the tract. The tract is mostly bordered by younger formations belonging to the Kittilä and

Kumpu groups, and locally by granitic intrusive rocks and older Vuojärvi Goup formations (mainly on the south). To the west, the tract is bounded by the Baltic-Bothnia Megashear. The tract extends down to 1000 m depth. The depth extension is based on the assumption that the Savukoski Group rocks continue downwards to such a depth. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There is one well-explored VMS deposit within the tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Pahtavuoma VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pahta-vuoma | 7526200 | 3384200 | 2000–2200 | 21.1 | 0.3 | 0.67 | 0.08 | 10 | | Cu<br>Zn<br>Pb<br>Ag<br>Au | 64,200<br>143,380<br>17,120<br>214 | Inkinen (1979), Korkalo (2006) |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences, and related deposit types

There are three partially explored VMS occurrences within the Pahtavuoma VMS tract, and several occurrences that could be of stringer-type VMS overprinted by orogenic gold (Table 3). There are also several gold deposits within the tract area (Eilu & Pankka 2009).

Table 3. Significant VMS occurrences in the Pahtavuoma VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| VMS occurrences | | | | | |
| Poroaita | 7497250 | 3451000 | 2000–2200 | 7.9 m @ 1.44 % Zn, 0.92 % Pb, 0.14 % Cu; 8.9 m @ 0.57 % Zn, 0.60 % Pb, 0.016 % Cu | Karvinen (1988, 1992) |
| Pälkättivuoma | 7527215 | 3421550 | 2000–2200 | 10 m @ 0.32 % Zn, 0.51 % Pb, 0.024 % Cu; 6 m @ 0.47 % Zn, 0.03 % Cu; 1 m @ 0.74 % Zn, 0.46 % Pb, 0.22 % Ni | Auranen (1977) |
| Kortelehto | 7528230 | 3384570 | 2000–2200 | 3 m @ 0.8 % Zn, 0.35 % Pb, 0.15 % Cu; 2.2 m @ 0.6 % Cu, 0.8 % Zn, 1.7 % Pb | Korkalo (1979) |
| Remobilised/overprinted VMS occurrences | | | | | |
| Naakenavaara | 7513291 | 3421145 | | 2.3 m @ 1.77 % Cu, 15 m @ 0.3 % Cu, 5 m @ 0.57 % Cu; 1 m @ 10.3 g/t Au, 1 m @ 6.9 g/t Au | Keinänen (2002) |
| Riikonkoski | 7518990 | 3414270 | | Four major ore bodies totalling 9.45 Mt @ 0.45 % Cu, 0.1–12 g/t Au (erratic analyses for gold), cut-off at 0.3 % Cu; 2.13 m @ 10.97 g/t Au; Co is also enriched locally up to 0.2 % | Yletyinen & Nenonen (1972), Northern Lion Gold (2006) |
| Saattopora Cu | 7525700 | 3390500 | | 11.6 Mt @ 0.62 % Cu, 0.1 % Ni, 0.01 % Co, 0.25 g/t Au | Lehtinen (1987), Korkalo (2006) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Pahtavuoma VMS tract are listed in Table 4.

Table 4. Exploration history for the Pahtavuoma VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop mapping and boulder surveys | Yes | Atri Oy | 1939–1953 |
| | Outcrop mapping and boulder surveys, detailed mapping, structural geology | Yes | Outokumpu Oy | 1961–1990s |
| | Outcrop mapping and boulder surveys, relogging and reanalysing of drill core | Yes | Geological Survey of Finland | 1950s– |
| | Detailed prospect-scale mapping, relogging and reanalysing of drill core | Yes | University of Turku | 1984–1986 |
| | Relogging and reanalysing of drill core | Yes | Northern Lion Gold | 2006–2008 |
| Geochemical surveys | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| | Regional and targeted till surveys | Yes | Geological Survey of Finland | 1970s |
| | Targeted till survey, about 2000 points; targeted till line survey | Yes | Geological Survey of Finland | 1970s–1990s |
| | Targeted till, stream sediment, stream water surveys, including 8600 till samples | Yes | Outokumpu Oy | 1970s–1990s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1976–2004 |
| | Low-altitude airborne magnetic and electromagnetic survey 184.27 line-km | | Taranis Resources Inc. | 2011 |
| Ground geophysical surveys | Magnetic and electromagnetic survey | | Atri Oy | 1939–1953 |
| | Extensive systematic and line magnetic, slingram and gravity surveys. Some systematic VLF-R and IP surveys | | Geological Survey of Finland | 1970s–1990s |
| | The whole tract is covered by a regional gravity survey (APV) | | Geological Survey of Finland | 1970s–2000s |
| | Extensive magnetic and slingram surveys in the eastern part, and also some gravity and VLF surveys | | Outokumpu Oy | 1970s–1990s |
| | 68.3 line km magnetic and EM survey | | Taranis Resources Inc. | 2009–2010 |
| Drilling | A few short DDHs | Yes | Atri Oy | 1939–1953 |
| | 447 DDH, 52319 m | Yes | Geological Survey of Finland | 1970s to 2009 |
| | 871 DDH, 101436 m | Yes | Outokumpu Oy | 1960s to 1995 |
| | 4 DDH, 752.9 m, 5 DDH, ca 290 m | Yes | Taranis Resources | 2010 |

DDH – diamond-drill hole

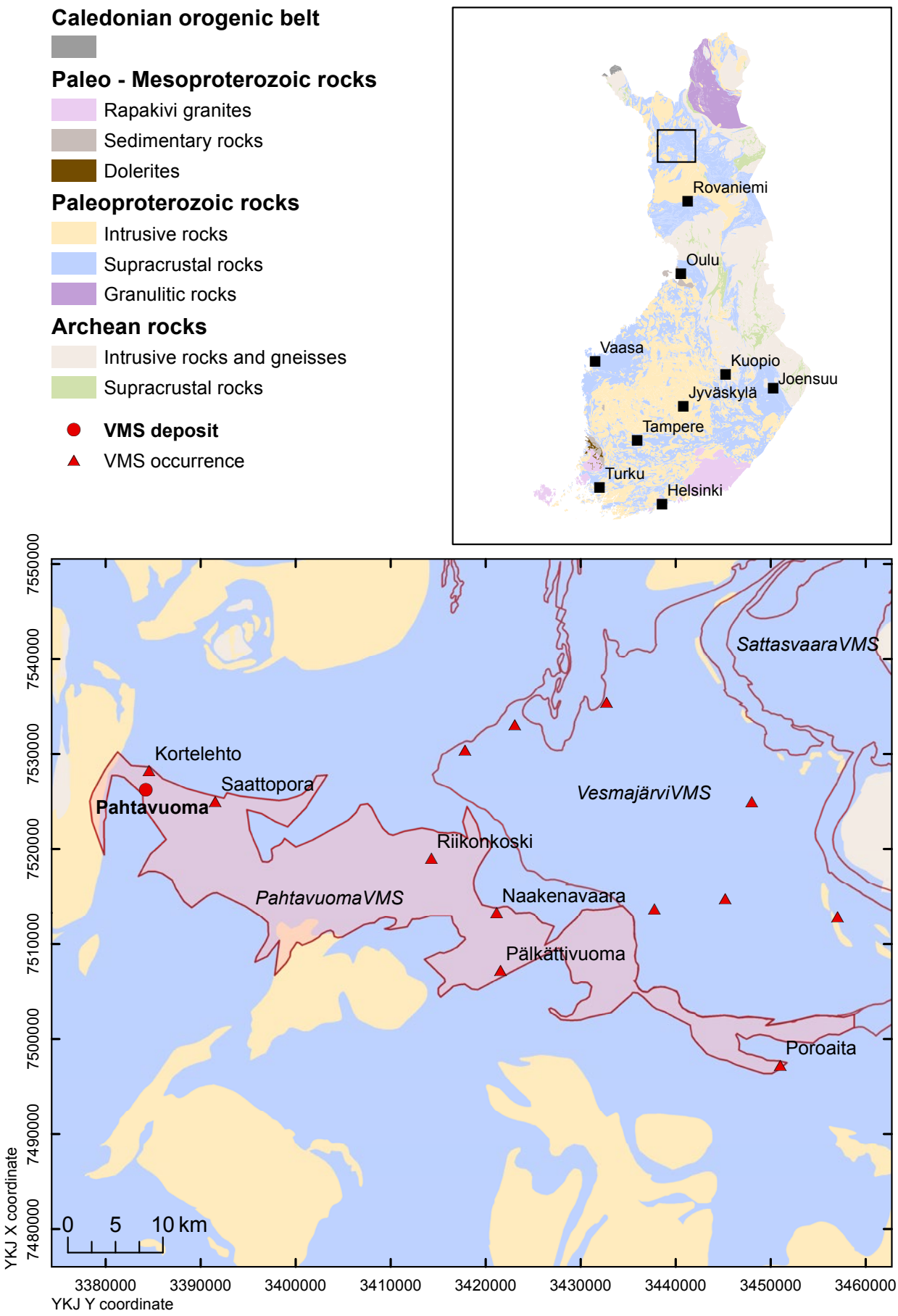


Fig. 1. Location of the Pahtavuoma VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Pahtavuoma VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Pahtavuoma VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Reports | | Latvalahti (1974), Lehtinen (1987), Lehtonen et al. (1998), Papunen (1987, 1990), Roos (1987), Korkalo (2006) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Reports | | Yletyinen & Nenonen (1972), Latvalahti (1974), Inkinen (1979), Korkalo (1979), Lehtinen (1987), Papunen (1987, 1990), Roos (1987), Karvinen (1988, 1992) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| Geochemistry | Reports | | Nurmi (1972), Kokkola & Korkalo (1976), Korvuo (1997) |
| Geophysics | Geological Survey of Finland in-house database | | |
| Geophysics | Reports | | Eskola (1972), Ketola (1979), Turunen (1990), Huhtelin (1991), Karvinen (1992), Keinänen (2002), Valli (2002), Salmirinne & Turunen (2007) |
| Exploration | Reports | | Yletyinen & Nenonen (1972), Nenonen (1975), Inkinen (1984), Huhtelin (1991), Anttonen (1992), Karvinen (1992), Hugg (1993), Korvuo (1997), Keinänen (2002), Korkalo (2006), Northern Lion Gold (2006), Taranis Resources (2009, 2010a, 2010b, 2010c, 2011) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

At least three VMS occurrences, and possibly a few more, are known within the tract (Table 3). Another favourable indicator for the tract is the existence of extensive Cu±Zn anomalies in till. However, it is not clear how much of the Cu mineralisation in the region is epigenetic (synorogenic) and unrelated to VMS mineralisation. Quite a lot of drilling has been carried out in the area, but except for Pahtavuoma, mostly on Au targets and Au-Cu targets of uncertain genetic type(s). There are only a few outcrops in the area. No consensus was reached in the discussion and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Pahtavuoma VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 3 | 4 | | | 2.6 | 1.1 | 43 | 1 | 3.6 | 605 | 0.0060 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 2 | 2 | 3 | | |
| Individual 2 | 0 | 1 | 2 | | |
| Individual 3 | 0 | 1 | 2 | | |
| Individual 4 | 2 | 4 | 6 | | |
| Individual 5 | 0 | 1 | 3 | | |
| Individual 6 | 0 | 2 | 3 | | |
| Individual 7 | 4 | 8 | 10 | | |
| Individual 8 | 0 | 1 | 1 | | |
| Individual 9 | 1 | 3 | 3 | | |
| Individual 10 | 1 | 3 | 5 | | |
| Mean | 1 | 3 | 4 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer and Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen, H. Kujala, J. Luukas, J. Nikander, K. Rasilainen, P. Sipilä, P. Sorjonen-Ward, M. Tiainen, T. Törmänen, K. Västi

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Pahtavuoma VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 3,900 | 100,000 | 670,000 | 1,100,000 | 260,000 | 0.28 | 0.060 |
| Zn (t) | 0 | 2,000 | 60,000 | 490,000 | 810,000 | 190,000 | 0.26 | 0.060 |
| Pb (t) | 0 | 10 | 710 | 14,000 | 34,000 | 6,900 | 0.17 | 0.060 |
| Ag (t) | 0 | 1.2 | 40 | 280 | 490 | 110 | 0.28 | 0.060 |
| Au (t) | 0 | 0.0085 | 0.37 | 3.1 | 6.1 | 1.4 | 0.22 | 0.060 |
| Rock (Mt) | 0 | 0.25 | 8.5 | 60 | 81 | 20 | 0.34 | 0.060 |

t – metric tons; Mt – million metric tons.

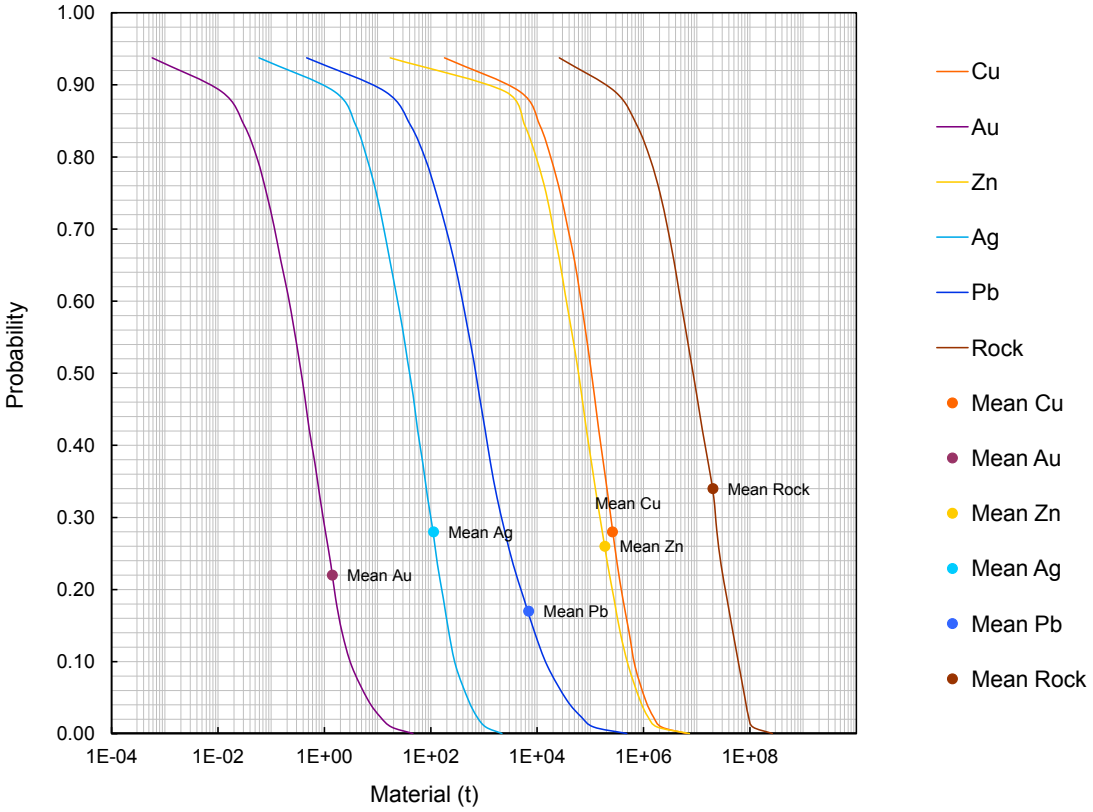


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Pahtavuoma VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT PULJU VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Pulju VMS permissive tract is located in northern Finland in the municipalities of Kittilä, Enontekiö and Inari, 200 km north of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 2742, 2831, 2832, 2833 and 2834. The UTM map sheets containing the tract are V413, V414, V431, V432, V441, V442 and W431. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Pulju VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 10/12/2012 | 1.0 | 623 | Cu | 0 | Cu | 27,000 | Cu | 0 |
| | | | Zn | 0 | Zn | 19,000 | Zn | 0 |
| | | | Pb | 0 | Pb | 730 | Pb | 0 |
| | | | Ag | 0 | Ag | 12 | Ag | 0 |
| | | | Au | 0 | Au | 0.15 | Au | 0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The Pulju VMS permissive tract is defined by the occurrence of the ca. 2000 Ma Pulju schist belt. The delineation is based on the extent of mostly ultramafic rocks of the Mertavaara Formation with the graphite- and sulphide-bearing schists of the Vittaselkä Formation of the Savukoski Group on the Central Lapland Greenstone Belt (CLGB). The Mertavaara and Vittaselkä formations are, in stratigraphic age and lithological sequence, comparable to the Sattasvaara and Matarakoski formations, respectively, of the southern and eastern parts of the CLGB. Most of the ultramafic volcanic rocks are detectable by low altitude airborne magnetic data, whereas the graphite- and sulphide-rich schists can be discriminated by airborne electromagnetic data. These geophysical survey data, outcrop observations and drilling information were used in delineating the tract. The tract extends down to 1000 m depth. The depth extension is based on the assumption that the schist belt rocks continue downwards. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There are no well-explored VMS deposits within the Pulju VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Pulju VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences and related deposit types

Two partially explored VMS occurrences are known within the PuljuVMS permissive tract (Table 3). Other types of metallic mineral occurrences that exist within the tract area include komatiitic Ni and porphyry-like Mo occurrences.

Table 3. Significant VMS occurrences in the Pulju VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Lutsokuru | 7566800 | 3390300 | 2000–2200 | 0.61 m @ 0.47 % Zn | Lahtinen (1979a) |
| Mertavaara | 7561000 | 3396000 | 2000–2200 | 0.5–1 m @ ≤0.5 % Zn | Lahtinen (1979a) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Pulju VMS tract are listed in Table 4. Note that some of the work listed has targeted komatiite-hosted nickel.

Table 4. Exploration history for the Pulju VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Boulder and outcrop observations | No? | Geological Survey of Finland | 1999–2007 |
| | Boulder and outcrop observations | Yes | Outokumpu Oy | 1973–1997 |
| Geochemical surveys | Nationwide till survey | Yes | Geological Survey of Finland | 1970s–1980s |
| | Local and regional till sampling, 7820 sampling points, and also stream sediment sampling | Yes | Outokumpu Oy | 1977–1998 |
| | Till sampling, 211 sampling points | Yes | Anglo American Ltd. | 2004–2008 |
| Airborne geophysical surveys | Low-altitude airborne magnetic and electromagnetic survey 950 km$^2$ | | Outokumpu Oy | 1976 |
| | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1978–1990 |
| Ground geophysical surveys | Local and regional magnetic surveys 238 km$^2$, slingram surveys 245 km$^2$ and gravimetric surveys 4.2 km$^2$, a few IP and charge potential lines | | Outokumpu Oy | 1977–1998 |
| | Local magnetic and slingram survey, 28.4 line km | | Anglo American Ltd. | 2004–2008 |
| Drilling | 4 DDH, 208.9 m | Yes? | University of Turku | 1974–1975 |
| | 93 DDH, 13609 m | Yes | Outokumpu Oy | 1978–1991 |
| | 4 DDH, 289.3 m | Yes | Anglo American Ltd. | 2004–2008 |

DDH – diamond-drill hole.

## Sources of information

The principal sources of information used by the assessment team for the delineation of the Pulju VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Pulju VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Reports | | Papunen et al. (1977), Heikkilä (1984), Papunen (1998) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Report | | Inkinen et al. (1984) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Inkinen et al. (1984), Vihreäpuu (2001a, 2001b, 2001c), Austen (2008) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Rekola (1979), Inkinen (1982), Inkinen et al. (1984), Lahtinen (1992), Vihreäpuu (2001a, 2001b, 2001c) |
| Exploration | Reports | | Lahtinen (1979a, 1979b, 1980, 1992, 1998), Inkinen (1982,1985, 1987), Inkinen et al. (1984), Anttonen (1993), Vihreäpuu (2001a, 2001b, 2001c), Austen (2008) |
| | Geological Survey of Finland in-house drill-core database | | |

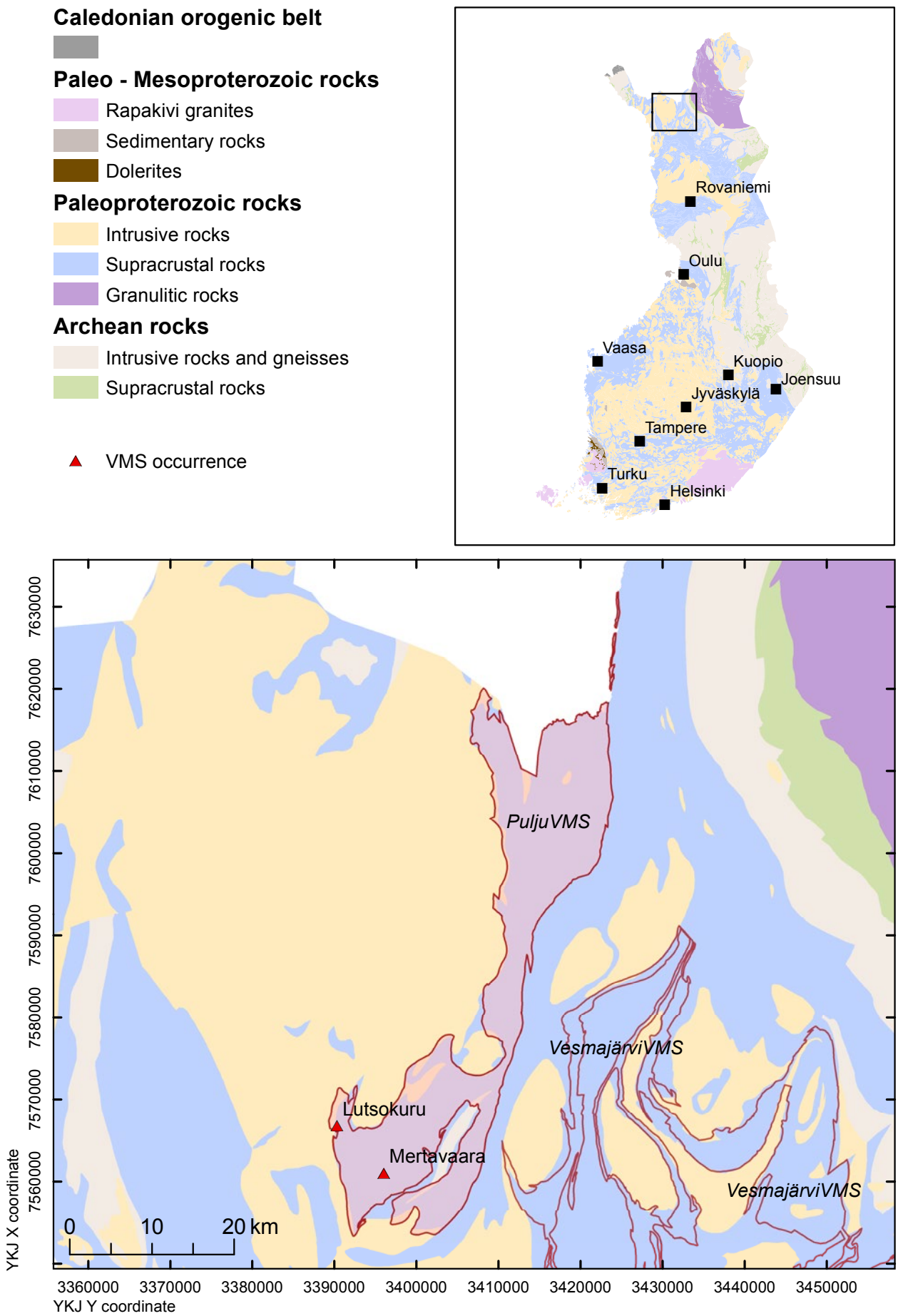


Fig. 1. Location of the Pulju VMS permissive tract.

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Two partially explored VMS occurrences are known within the tract (Table 3). However, these appear to be so small that they may never become economic deposits. Other favourable indicators for the tract include the extensive subaqueous volcanic rocks, and graphite- and Fe sulphide-rich units in the local supracrustal sequence. Very few other indications for VMS-style mineralisation have been detected. Most of drilling in this poorly exposed domain has been carried out on komatiitic Ni targets. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Pulju VMS tract.

| Mean undiscovered deposit estimate | | | | | Summary statistics | | | | | Area (km²) | Deposit density (N/km²) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 0 | 1 | | | 0.30 | 0.50 | 170 | 0 | 0.30 | 623 | 0.00048 |

| | Estimated number of undiscovered deposits | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 1 | | |
| Individual 2 | 0 | 1 | 1 | | |
| Individual 3 | 0 | 1 | 1 | | |
| Individual 4 | 0 | 0 | 1 | | |
| Individual 5 | 0 | 0 | 1 | | |
| Individual 6 | 0 | 0 | 1 | | |
| Consensus | 0 | 0 | 1 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, K. Rasilainen, P. Sorjonen-Ward, T. Törmänen

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Pulju VMS tract.

| Material | At least the indicated amount at the probability of | | | | | Mean | Probability of mean or greater | Probability of zero |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 0 | 39,000 | 130,000 | 27,000 | 0.12 | 0.71 |
| Zn (t) | 0 | 0 | 0 | 21,000 | 68,000 | 19,000 | 0.11 | 0.71 |
| Pb (t) | 0 | 0 | 0 | 260 | 960 | 730 | 0.060 | 0.71 |
| Ag (t) | 0 | 0 | 0 | 14 | 50 | 12 | 0.11 | 0.71 |
| Au (t) | 0 | 0 | 0 | 0.12 | 0.45 | 0.15 | 0.090 | 0.71 |
| Rock (Mt) | 0 | 0 | 0 | 3.1 | 13 | 2.1 | 0.12 | 0.71 |

t – metric tons; Mt – million metric tons.

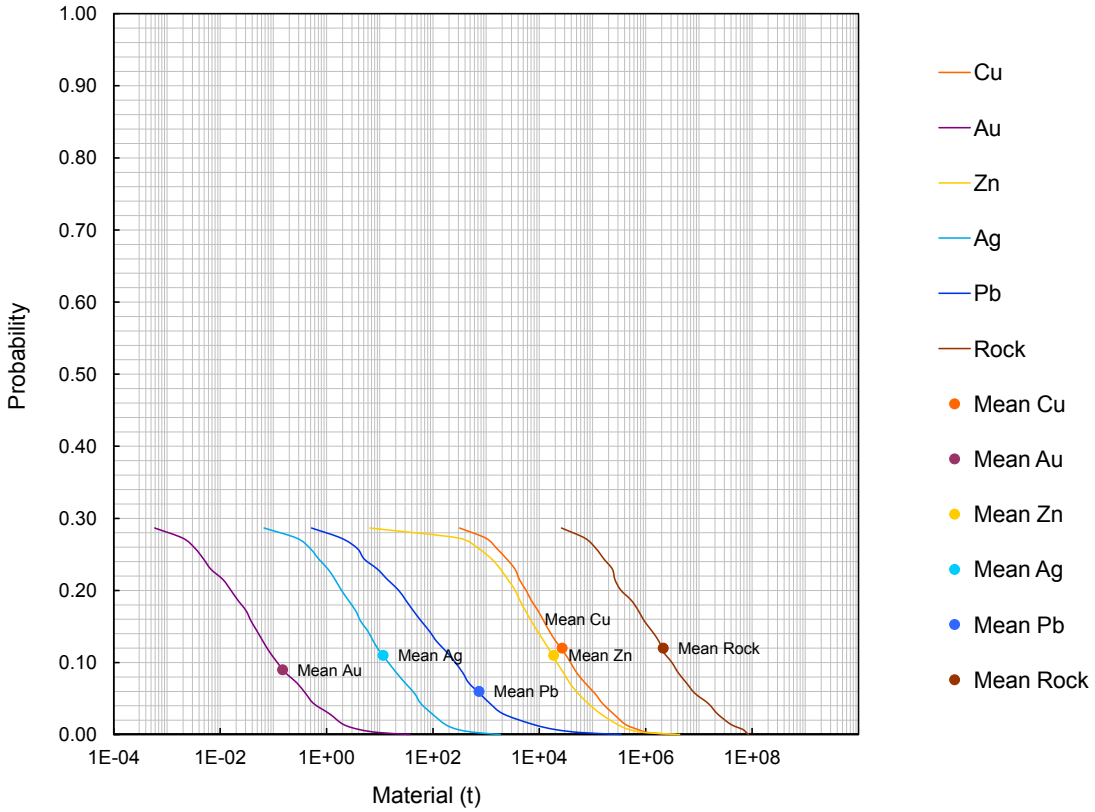


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Pulju VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT PYHÄSALMI VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS felsic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Pyhäsalmi VMS permissive tract is an approximately 25-km-wide and 150-km-long NW-trending zone in central Finland extending from Kärsämäki in the west to Tervo in the east (Fig. 1). The 1:100,000 KKJ map sheets are 3312, 3313, 3314, 3321, 3322, 3323, 3324 and 3411. The UTM map sheets containing the tract are P434, P442, P443, P444, Q431, Q432, Q433, Q434, Q441 and Q443. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Pyhäsalmi VMS tract.

| Date of assessment | Assessment depth (km) | Tract area ($km^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 1981 | Cu | 617,819 | Cu | 130,000 | Cu | 51,000 |
| | | | Zn | 1,528,376 | Zn | 940,000 | Zn | 340,000 |
| | | | Pb | 124 | Pb | 230,000 | Pb | 47,000 |
| | | | Ag | 952 | Ag | 950 | Ag | 300 |
| | | | Au | 27 | Au | 13 | Au | 4.1 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is within the 1.93–1.91 Ga Lower Svecofennian volcanic rocks. The tract delineation is based on the extent of volcanic rocks of the Pyhäsalmi Group. Most of the tract area is geographically inside the VihantiVMS tract, but not in the rocks that define the latter. Presence of Pyhäsalmi-style Cu-Zn mineralisation, as well as bedrock observation, drill core and geophysical survey data were used to define the tract area. The tract extends down to 1000 m depth. The depth extension is based on data from the deep Pyhäsalmi mine and stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There are six well-explored Pyhäsalmi-type VMS deposits within the Pyhäsalmi VMS permissive tract (Table 2). According to the spatial rule used, deposits less than 500 m from each other were combined in this assessment.

Table 2. Known Pyhäsalmi-type VMS deposits in the Pyhäsalmi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hallaperä | 7064130 | 3475700 | | 2.05 | 0.57 | 1.1 | | | | Cu | 11,685 | Helovuori (1980) |
| | | | | | | | | | | Zn | 22,550 | |
| Kangasjärvi | 7031950 | 3455780 | | 0.3 | 0.06 | 5.4 | 0.02 | 5 | 0.3 | Cu | 180 | Puustjärvi (1992b) |
| | | | | | | | | | | Zn | 16,200 | |
| | | | | | | | | | | Pb | 60 | |
| | | | | | | | | | | Ag | 1.5 | |
| | | | | | | | | | | Au | 0.09 | |
| Kaskela | 7079980 | 3447500 | | 0.124 | 0.4 | 3.9 | 0.1 | 12 | | Cu | 496 | Puustjärvi (1994a) |
| | | | | | | | | | | Zn | 4,836 | |
| | | | | | | | | | | Pb | 124 | |
| | | | | | | | | | | Ag | 1.5 | |
| Kurpas | 7084000 | 3445500 | | 0.4 | 0.63 | 0.55 | | | | Cu | 2,520 | Puustjärvi (1992b) |
| | | | | | | | | | | Zn | 2,200 | |
| Pyhäsalmi | 7062380 | 3452930 | 1930 | 65.824 | 0.9 | 2.18 | | 14 | 0.4 | Cu | 592,416 | Inmet Mining Corporation (2009), T. Mäki pers. comm. (2010) |
| | | | | | | | | | | Zn | 1,434,964 | |
| | | | | | | | | | | Ag | 922 | |
| | | | | | | | | | | Au | 26 | |
| Ruoste-suo | 7054660 | 3468160 | | 2.769 | 0.38 | 1.72 | | 9.9 | 0.38 | Cu | 10,522 | Reino (1985), Mäki (1997) |
| | | | | | | | | | | Zn | 47,627 | |
| | | | | | | | | | | Ag | 27.4 | |
| | | | | | | | | | | Au | 1.1 | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

Eleven partially explored Pyhäsalmi-type VMS occurrences are known from the Pyhäsalmi VMS permissive tract (Table 3). In addition, the Mullikkoräme mine and a number of partially explored Vihanti-type deposits are geographically within the Pyhäsalmi tract.

Table 3. Significant Pyhäsalmi-type VMS occurrences in the Pyhäsalmi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Jäniskangas | 7086400 | 3453100 | | Extensive alteration probably related to VMS mineralisation | Iisalo (2007a) |
| Kettuperä | 7064000 | 3453500 | | 10 m @ 0.61% Zn | Reino (1983) |
| Kokkopuro | 7091433 | 3460907 | | New discovery by Inmet | T. Mäki pers. comm. (2013) |
| Korppisjärvi | 7029300 | 3462000 | 1920±10 | 1 m @ 3.03 % Zn, 0.5 m @ 2.72 % Zn; 8 m @ 1.52 % Zn | Nikander (1981) |
| Lehto | 7061500 | 3454000 | | 2 m @ 1.0% Zn, 5 m @ 0.87% Zn | Puustjärvi (1994b) |
| Räsysuo | 7031240 | 3457250 | | | Nikander (1987) |
| Saviselkä | 7102400 | 3452750 | | 0.32-0.60 Mt @ 0.5% Cu, 0.2% Mo, 7.4% S, 15.5% Fe | Puustjärvi (1992a) |
| Sirviö | 7086300 | 3450750 | 1920±10 | 3.4 m @ 0.84 % Zn, 0.11 % Cu | Hakanen & Rekola (1998) |
| Vauhkola | 6993700 | 3482580 | | 5 m @ 1 % Zn, 4 m @ 1 % Zn; 1 m @ 2.5 % Zn | Ekdahl (1980) |
| Vehkalampi | 6997180 | 3495600 | | 9.1 m @ 3.84 % Zn, 0.47 % Cu | Nikander (1994), Nikander & Ruotsalainen (2009) |
| Vuohtojoki | 7099050 | 3447590 | 1920±10 | 0.7 Mt @ 2.6% Zn, 0.3% Cu, 4–15 ppm Ag, 0.2 ppm Au | Puustjärvi (1992b), Marttila (2002) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Pyhäsalmi VMS tract are listed in Table 4.

Table 4. Exploration history for the Pyhäsalmi VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Bedrock mapping, glacial erratic boulder surveys | Yes | Geological Survey of Finland | 1920s– |
| | Bedrock mapping, glacial erratic boulder surveys | Yes | Outokumpu Oy | 1950s–2001 |
| | Bedrock mapping | Yes | Belvedere Resources | 1997–2004 |
| Geochemical surveys | Till and bedrock geochemical survey | Yes | Geological Survey of Finland | 2005–2008 |
| | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| | Till geochemical survey | Yes | Outokumpu Oy | 1950s–2001 |
| | Till and bedrock geochemical survey | Yes | | |
| | Till and bedrock geochemical survey | Yes | | |
| Airborne geophysical surveys | VTEM | | Geological Survey of Finland | 2008 |
| | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1977–1992 |
| | Low-altitude airborne electromagnetic survey | | Outokumpu Oy | 1959, 1962 |
| Ground geophysical surveys | Magnetic, electromagnetic, gravimetric, multi-frequency EM soundings | | Geological Survey of Finland | 1950s– |
| | VTEM, magnetic, electromagnetic, gravimetric, multi-frequency EM soundings | | Inmet Mining Co | 2002– |
| | Regional and targeted seismic reflection surveys | | Geological Survey of Finland | 2000s |
| | Magnetic, electromagnetic, IP, gravimetric surveys: APEX, PROXAN, VLF, AMT, EM37, SP, TDEM, charge potential, slingram, resistance | | Outokumpu Oy | 1950s–2001 |
| | Magnetic, conductivity and gravity survey | | Belvedere Resources | 1997–2004 |
| | | | Inmet Mining Co | |
| Drilling | Diamond drilling | Yes | Geological Survey of Finland | 1950s– |
| | Thousands of diamond-drill holes | Yes | Outokumpu Oy | 1950s–2001 |
| | Diamond drilling | Yes | Inmet Mining Co | 2002– |
| | Diamond drilling | Yes | Belvedere Resources | 1997–2004 |
| Other | Feasibility studies and pilot-plant tests | Yes | Outokumpu Oy | 1950s–2001 |

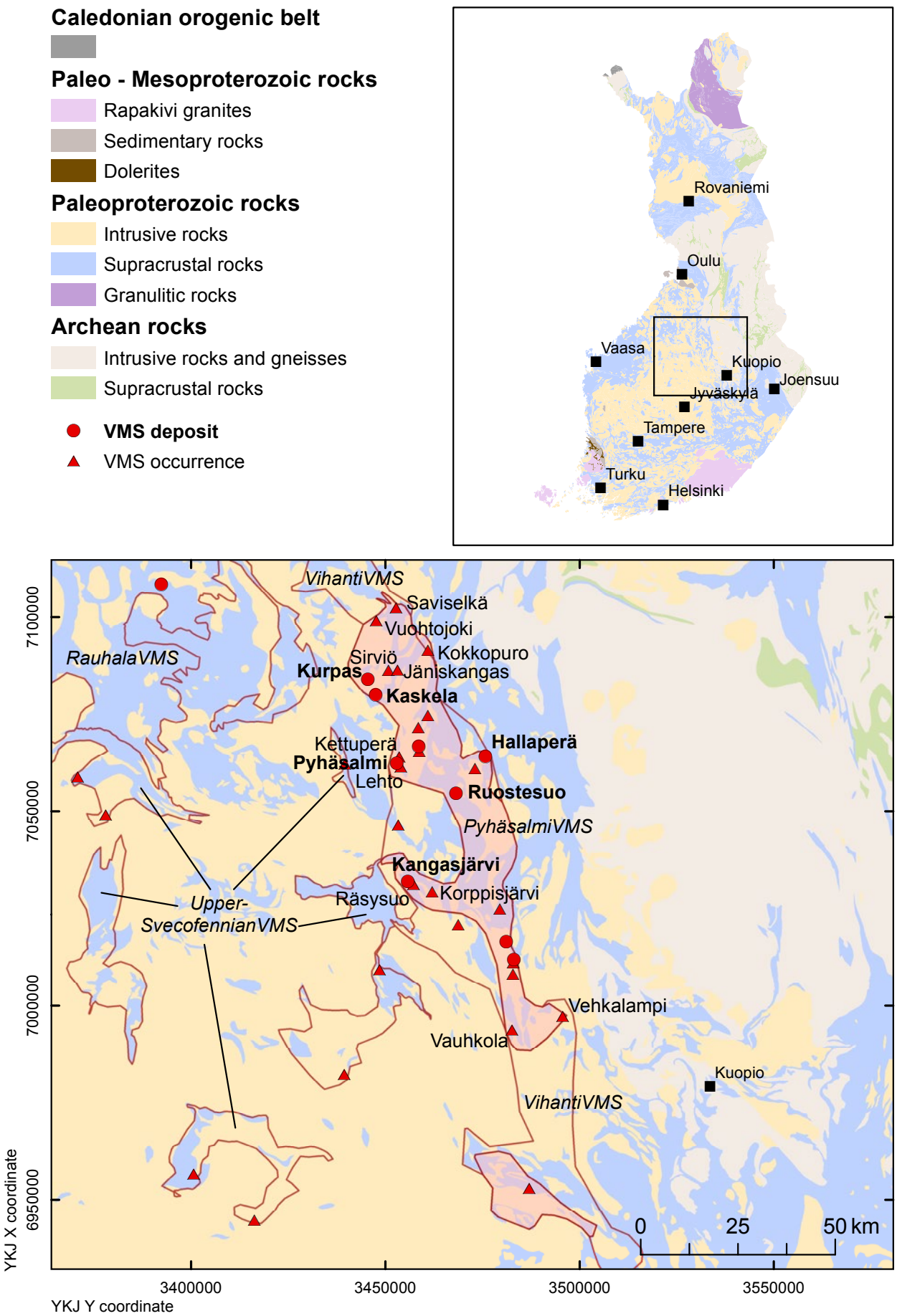


Fig. 1. Location of the Pyhäsalmi VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Pyhäsalmi VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Pyhäsalmi VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Reports | | Puustjärvi (1999), Luukas et al. (2004), Kukkonen & Lahtinen (2006), Kousa (2007) |
| Mineral occurrences | Reports | | Laitakari (1968), Helovuori (1979), Huhtala (1979), Tontti et al. (1981), Reino (1983, 1985), Nikander (1986), Kousa et al. (1997), Puustjärvi (1992a,b, 1999), Roberts et al. (1999, 2003, 2004) |
| | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Theses | | Aatos (1992), Mustonen (1998), Osorio (2003) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Mäki (1986c), Puustjärvi (1999), Iisalo (2005, 2006, 2007a, 2007b, 2008) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Lakanen (1990), Hattula & Rekola (2000), Luukas et al. (2004), Kukkonen & Lahtinen (2006), Kukkonen et al. (2009), Leväniemi et al. (2009) |
| Exploration | Reports | | Huhtala (1981), Nikander (1981, 1983, 1994, 2000, 2003, 2009), Tontti et al. (1981), Reino (1985), Mäki (1986a, 1986b, 1987), Nikander (1987), Damsten & Ekdahl (1989), Puustjärvi (1992a,b, 1994a, 1994b, 1999), Hakanen (1996, 1998), Hakanen et al. (1997), Belvedere Resources (2001, 2003), Luukas et al. (2004) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Nine partially-explored Pyhäsalmi-type VMS occurrences are known within the tract (Table 3). Most of these were considered small and it was considered probable that only a few of them will ever become economic deposits, even under the most favourable circumstances. Besides mines and the number of partially explored deposits, many open along strike or at depth, or both, factors favourable for VMS-style mineralisation within the tract include the numerous mineralised outcrops and glacial erratic boulders. Eight subvolcanic intrusions are known within the tract, all associated with Cu-Zn mineralisation. The following subareas of the tract were considered to be the most suitable for new discoveries: 1) the surroundings of the Kangasjärvi mine, 2) the area between Niemisjärvi and Hallaperä, and 3) country rocks of the Venetpalo Dome. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Pyhäsalmi VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 2 | 4 | 7 | | | 4.2 | 1.9 | 46 | 6 | 10.2 | 1981 | 0.0051 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 3 | 4 | 8 | | |
| Individual 2 | 2 | 5 | 8 | | |
| Individual 3 | 2 | 4 | 7 | | |
| Individual 4 | 1 | 4 | 8 | | |
| Individual 5 | 2 | 3 | 5 | | |
| Individual 6 | 2 | 4 | 8 | | |
| Consensus | 2 | 4 | 7 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen, J. Luukas, J. Nikander, K. Rasilainen, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS felsic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Pyhäsalmi VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 530 | 4,200 | 51,000 | 360,000 | 550,000 | 130,000 | 0.26 | 0.040 |
| Zn (t) | 3,100 | 25,000 | 340,000 | 2,700,000 | 3,900,000 | 940,000 | 0.27 | 0.040 |
| Pb (t) | 240 | 2,100 | 47,000 | 450,000 | 890,000 | 230,000 | 0.20 | 0.040 |
| Ag (t) | 2.2 | 20 | 300 | 2,600 | 4,200 | 950 | 0.24 | 0.040 |
| Au (t) | 0.043 | 0.29 | 4.1 | 30 | 50 | 13 | 0.23 | 0.040 |
| Rock (Mt) | 0.14 | 0.96 | 9.7 | 75 | 93 | 24 | 0.30 | 0.040 |

t – metric tons; Mt – million metric tons.

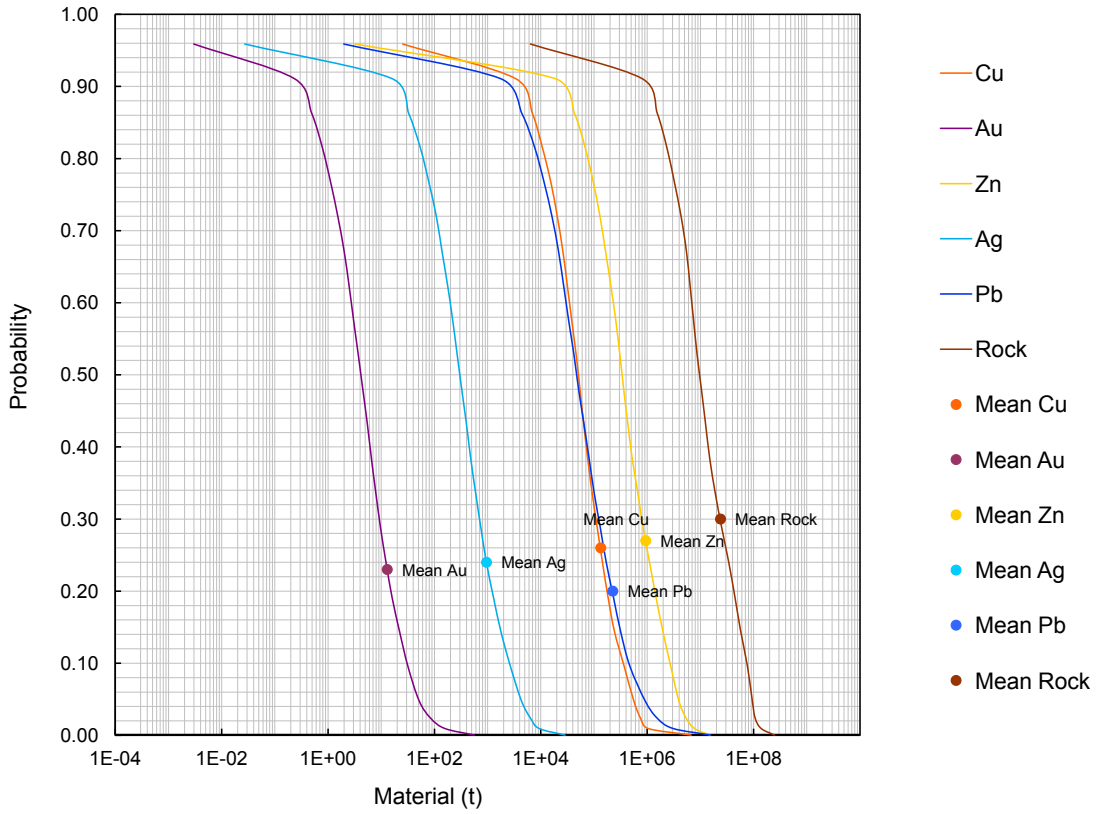


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Pyhäsalmi VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT RAUHALA VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS bimodal-mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The central part of the Rauhala VMS permissive tract is an approximately 90-km-long and 60-km-wide area between Kannus and Haapajärvi in central Finland. The tract has narrow 1–4-km-wide extensions trending 65 km NNE to Raahe and 100 km SSW to Alajärvi (Fig. 1). The 1:100,000 KKJ map sheets are 2313, 2323, 2324, 2331, 2332, 2341, 2342, 2343, 2344, 2431 and 2432. The UTM map sheets containing the tract are P411, P412, P421, P422, P423, Q411, Q412, Q413, Q414, Q421, Q423, Q424, Q431 and Q432. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Rauhala VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 3477 | Cu | 22,610 | Cu | 24,000 | Cu | 9,900 |
| | | | Zn | 81,430 | Zn | 51,000 | Zn | 20,000 |
| | | | Pb | 16,320 | Pb | 2,500 | Pb | 210 |
| | | | Ag | 90 | Ag | 13 | Ag | 3.2 |
| | | | Au | 0.68 | Au | 0.40 | Au | 0.22 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The Rauhala VMS permissive tract is within the 1.88 Ga Upper Svecofennian supracrustal rocks. The tract delineation is based on the extent of the Ylivieska Group supracrustal rocks and similar supracrustal rocks in the northern part of the central Finland granitoid complex and the Ostrobothnian mafic suite. The presence of Rauhala-style Cu-Zn-Pb mineralisation, as well as bedrock observation, drill core and geophysical survey data were used to define the tract area. The tract extends down to 1000 m depth. The depth extension is based on stratigraphic and tectonic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There is one well-explored VMS deposit within the Rauhala VMS permissive tract (Table 2). According to the spatial rule used, deposits less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Rauhala VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rauhala | 7108422 | 3392322 | 1880 | 1.7 | 1.33 | 4.97 | 0.96 | 53 | 0.4 | Cu | 22,610 | Västi (1989) |
| | | | | | | | | | | Zn | 81,430 | |
| | | | | | | | | | | Pb | 16,320 | |
| | | | | | | | | | | Ag | 90 | |
| | | | | | | | | | | Au | 0.68 | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as t onnage * grade.

### Prospects, mineral occurrences and related deposit types

Three partially explored VMS occurrences are known within the Rauhala VMS permissive tract (Table 3).

Table 3. Significant VMS occurrences in the Rauhala VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Aittoneva | 7117797 | 3398392 | | At least 3 weakly mineralised zones (widest 12 m wide) with up to 0.7 % Zn, 0.5 Cu. | Iisalo (1993a) |
| Juurakkolampi | 7040808 | 3358771 | | Up to 100-m-wide mineralised zone. Best section 2.5 m @ 0.71 % Cu. | Sipilä (1983) |
| Pattijoki | 7178135 | 3383300 | | 1300 m x 40 m mineralised belt. Best 3 m drill core sections have 0.9 % Zn, 0.2 % Cu, 18 % S, 28 ppm Ag. | Nikander (2000) |

Ma – million years

### Exploration history

Exploration activities for VMS deposits within the RauhalaVMS tract are listed in Table 4. The tract intersects with the Central Ostrobothnia porphyry copper tract, the Ylivieska, Kumiseva and Hitura intrusive nickel tracts and the Haapajärvi-Haapavesi, Laivakangas, LestinKaari and Rautio orogenic gold tracts. Hence, exploration of several metals, as well as industrial minerals, has been carried out in the Rauhala VMS tract. These exploration activities for other deposit types and metals are summarised in the Central Ostrobothnia porphyry Cu tract report in this Appendix, in the Ylivieska,

Kumiseva and Hitura intrusive Ni-Cu tract reports in Rasilainen et al. (2012) and in the Haapajärvi-Haapavesi, Laivakangas, Lestinkaari and Rautio orogenic Au tract reports in Eilu et al. (2014).

Table 4. Exploration history for the Rauhala VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Bedrock mapping, glacial erratic boulder surveys | Yes | Geological Survey of Finland | 1920s– |
| Geochemical surveys | Nationwide till survey | Yes | Geological Survey of Finland | 1982–1994 |
| | Targeted till geochemical surveys and lithogeochemical surveys | Yes | Geological Survey of Finland | 1976–1979, 1983–1992 |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1976–2002 |
| Ground geophysical surveys | Magnetic, VLF-R, charged potential, slingram, Maxi-Probe, sirotem, radiometric and gravimetric surveys, | | Geological Survey of Finland | 1977–1979, 1985–1988 |
| Drilling | Rauhala: 61 diamond-drill holes, total 9138 m | Yes | Geological Survey of Finland | 1986–1987 |
| | Other targets: At least 44 diamond-drill holes, total 3548 m. | Yes | Geological Survey of Finland | 1979–1982, 1987, 1991–1992 |
| | Rauhala: 9 diamond-drill holes, total 1287 m | Yes | Outokumpu Oy | 1988 |
| Other | Rauhala: Feasibility studies and pilot-plant tests | Yes | Outokumpu Oy | 1987–1991 |

## Sources of information

The principal sources of information used by the assessment team for the delineation of the Rauhala VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Rauhala VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Reports | | Kojonen et al. (1987), Västi (1993) |
| Mineral occurrences | FINZINC database | | Eilu & Västi (2009) |
| | Reports | | Puustjärvi (1988), Kojonen et al. (1987, 1989), Västi (1989a), Korkalo (1991), Kousa et al. (1997) |
| | Thesis | | Västi (1988) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Iisalo (1989), Rasilainen & Västi (1989) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Jokinen et al. (1989) |
| Exploration | Reports | | Tontti et al. (1982), Sipilä (1983, 1989a–n, 1990), Iisalo (1989, 1993a,b, 1994), Nikander (2000), Västi (1989b, 1991, 1993) |
| | Geological Survey of Finland in-house drill-core database | | |

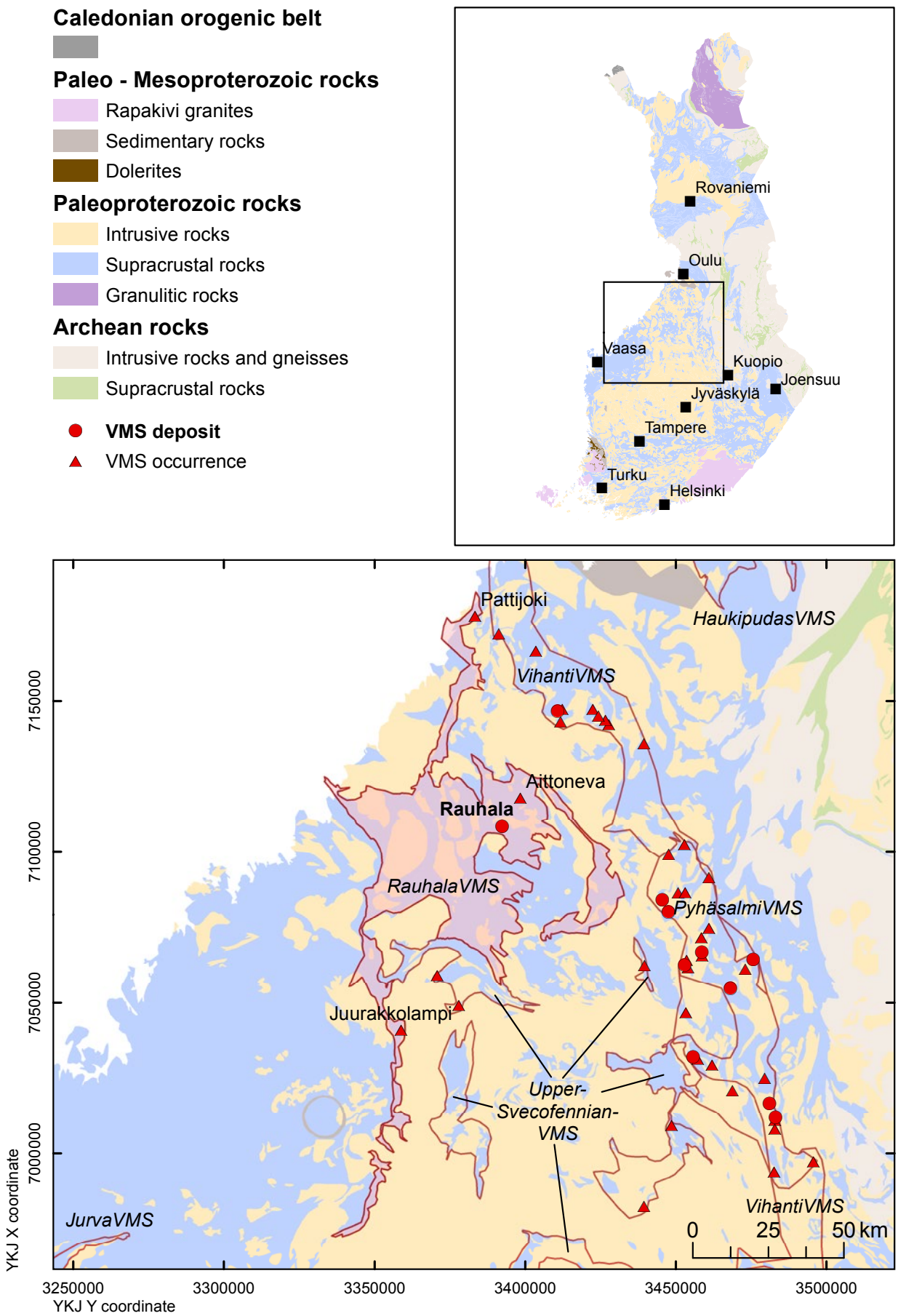


Fig. 1. Location of the Rauhala VMS permissive tract.

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Three partially explored possibly VMS-type Cu-Zn occurrences are known within the tract (Table 3). All of these were considered so small that most of the estimators believed it possible that none of them will ever become economic, even under the most favourable conditions. The Rauhala VMS tract is much less explored and investigated than the Pyhäsalmi VMS and Vihanti VMS tracts, and a large part of the exploration in the tract has targeted gold, Ti-V and industrial mineral deposits. Favourable factors for VMS deposits within the Rauhala VMS tract include the Rauhala deposit, abundant mafic and intermediate volcanic rocks and the apparently subvolcanic intrusions. On the other hand, no obvious felsic volcanic rocks have been detected, and the several Rauhala-like geophysical anomalies that have been drilled were all found to be black schists with abundant iron sulphides and negligible base metals. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Rauhala VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 1 | 3 | | | 1.3 | 1.2 | 90 | 1 | 2.3 | 3477 | 0.00066 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 1 | 2 | | |
| Individual 2 | 0 | 1 | 2 | | |
| Individual 3 | 0 | 1 | 2 | | |
| Individual 4 | 1 | 1 | 2 | | |
| Individual 5 | 0 | 0 | 1 | | |
| Individual 6 | 0 | 1 | 2 | | |
| Individual 7 | 2 | 4 | 8 | | |
| Consensus | 0 | 1 | 3 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen, J. Luukas, J. Nikander, K. Rasilainen, P. Sorjonen-Ward, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS bimodal-mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Rauhala VMS tract.

| Material | At least the indicated amount at the probability of | | | | | Mean | Probability of mean or greater | Probability of zero |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 9,900 | 68,000 | 95,000 | 24,000 | 0.35 | 0.31 |
| Zn (t) | 0 | 0 | 20,000 | 140,000 | 200,000 | 51,000 | 0.32 | 0.31 |
| Pb (t) | 0 | 0 | 210 | 7,300 | 13,000 | 2,500 | 0.22 | 0.31 |
| Ag (t) | 0 | 0 | 3.2 | 33 | 58 | 13 | 0.24 | 0.31 |
| Au (t) | 0 | 0 | 0.22 | 1.0 | 1.4 | 0.40 | 0.36 | 0.31 |
| Rock (Mt) | 0 | 0 | 0.92 | 5.6 | 7.5 | 2.0 | 0.36 | 0.31 |

t – metric tons; Mt – million metric tons.

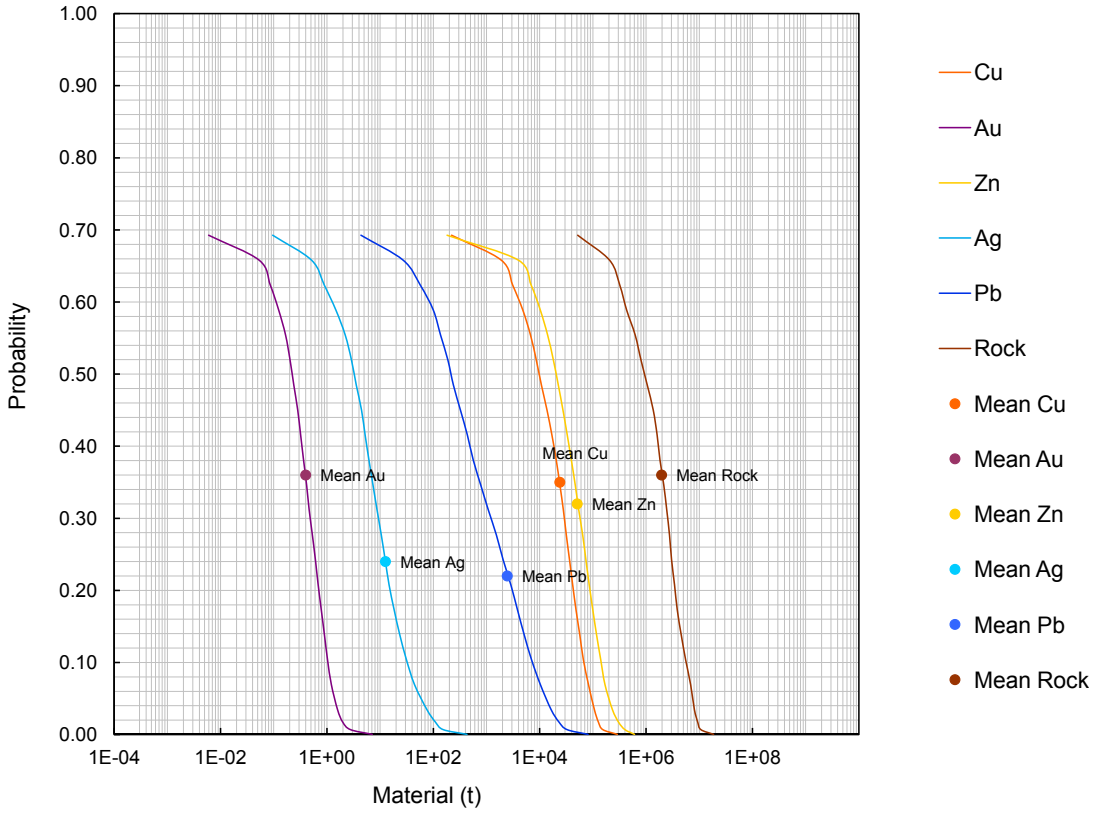


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Rauhala VMS permissive tract.

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# PORPHYRY Cu ASSESSMENT FOR THE TRACT RUOKOLAHTI PORCU, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: Porphyry Cu
**Descriptive model**: Porphyry Cu (Appendix 3)
**Grade-tonnage model**: Porphyry Cu (Appendix 4)

## LOCATION AND RESOURCE SUMMARY

The Ruokolahti PorCu permissive tract is located in southern Finland in the municipalities of Imatra, Lappeenranta, Puumala and Ruokolahti, immediately to the NW of the city of Imatra (Fig. 1). The 1:100,000 KKJ map sheets are 3143, 4112 and 4121. The UTM map sheets containing the tract are M5142, M5143, M5144, M5231, M5233, M5321, M5322 and M5411. The resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Ruokolahti PorCu permissive tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 8–9/11/2012 | 1 | 806 | Cu | 0 | Cu | 230,000 | Cu | 0 |
| | | | Mo | 0 | Mo | 11,000 | Mo | 0 |
| | | | Ag | 0 | Ag | 210 | Ag | 0 |
| | | | Au | 0 | Au | 25 | Au | 0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The Ruokolahti PorCu permissive tract is defined by probably ca. 1.89–1.88 Ga early to synorogenic granitoids. The delineation is based on the extent of these intrusions. The tract extends down to 1000 m depth. The depth extension is based on interpretation of the geology of the region. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored porphyry Cu deposits within the Ruokolahti PorCu permissive tract (Table 2). According to the spatial rule used, deposits located less than 2 km from each other were combined in this assessment. An exception was allowed if two occurrences <2 km apart could be shown to be products of separate mineralising systems.

Table 2. Known porphyry Cu deposits in the Ruokolahti PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade (%) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|
| None | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric tons. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

There is one partially explored Mo-Cu occurrence possibly of porphyry type within the Ruokolahti PorCu permissive tract (Table 3). No other types of mineral occurrences of any significant size are known to exist in the tract area.

Table 3. Possible porphyry Cu occurrences in the Ruokolahti PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Luukkolansaari | 6811230 | 3566960 | 1890 | Mo-Cu mineralised synorogenic granitoid intrusion; mineralisation in an area of 1200 x 1800 m | Nurmi (1984), Nurmi et al. (1984) |

Ma – million years

## Exploration history

Exploration activities targeting porphyry Cu and potentially related styles of mineralisation are listed in Table 4.

Table 4. Exploration history for the Ruokolahti PorCu permissive tract.

| Theme | Type of work | Cu analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1950s–1990s |
| | Detailed outcrop observations and boulder survey | Yes | Outokumpu | 1980 |
| | Detailed outcrop observations and boulder survey | Yes | University of Helsinki | 1981–1982 |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| Airborne geophysical surveys | Regional low-altitude airborne magnetic, electromagnetic and radiometric survey | | Geological Survey of Finland | 1979–1992 |
| Ground geophysical surveys | Magnetic and IP survey | | Outokumpu | 1977 |
| Drilling | Three diamond-drill holes, total 253 m | Yes | Outokumpu | 1980 |

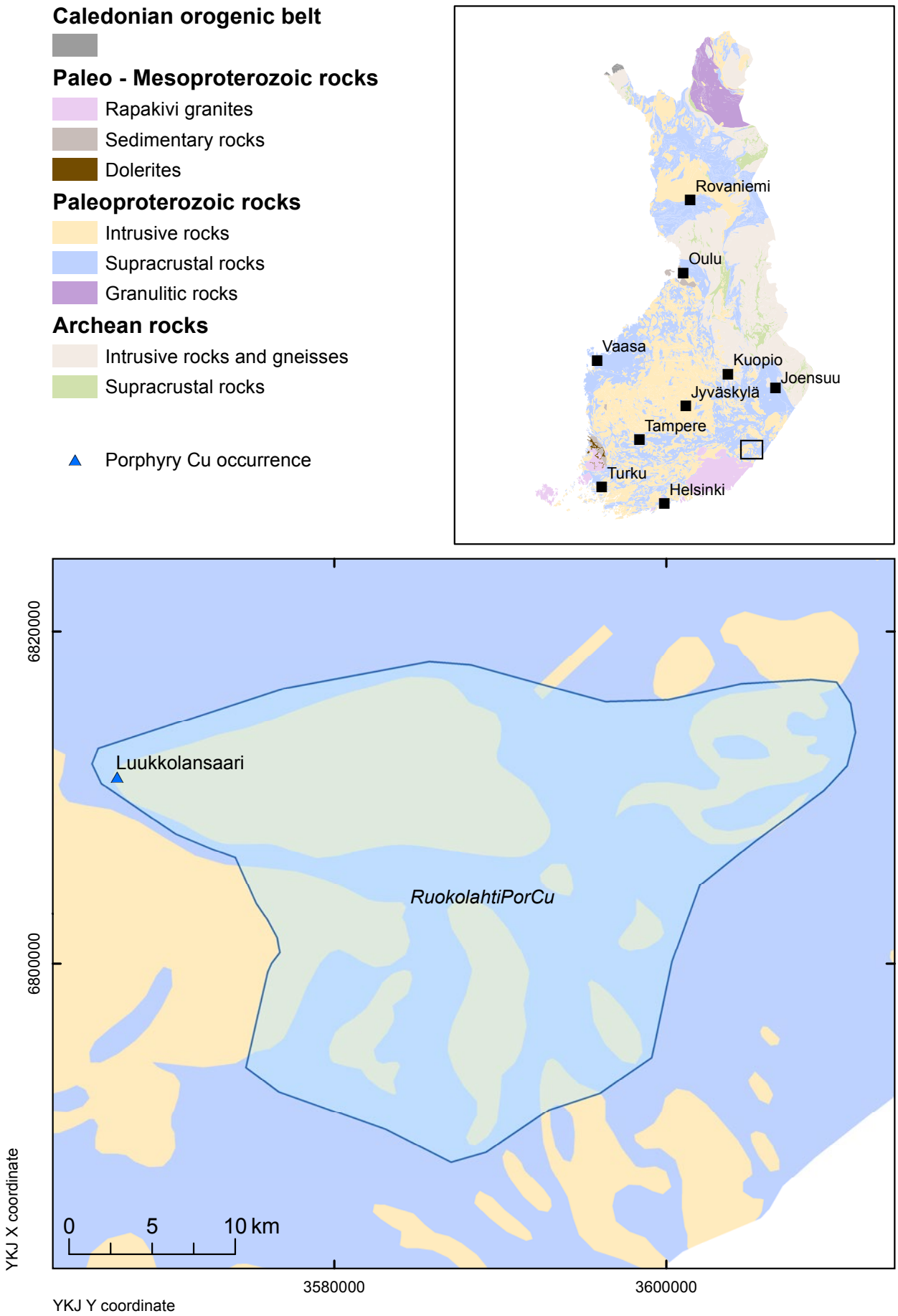


Fig. 1. Location of the Ruokolahti PorCu permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Ruokolahti PorCu tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Ruokolahti PorCu permissive tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:1000–1:10,000 | Sarikkola (1977, 1981), Berger (1981), Front (1981) |
| Mineral occurrences | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Geological Survey of Finland gold deposit database | | Eilu & Pankka (2009) |
| | Metallogenic assessment | | Nurmi (1984, 1985), Nurmi et al. (1984) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Sarikkola (1977, 1981) |
| Exploration | Reports | | Sarikkola (1977, 1981) |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

One porphyry Mo-Cu occurrence is known within the Ruokolahti PorCu permissive tract. The possibility of it becoming an economic deposit was considered very small. However, the existence of the Luukkolansaari occurrence and the few Mo- and Cu-enriched granitoid outcrops and boulders known from the area were considered as positive indications for undiscovered porphyry Cu deposits. Furthermore, there are overlapping lithogeochemical Mo and Cu anomalies in the NW corner of the tract, which have not been drilled. On the other hand, the small size of the tract and scarcity of known indirect indications lessens the potential for undiscovered deposits. Drilling within the tract has been restricted to a few holes at the Luukkolansaari occurrence. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Ruokolahti PorCu permissive tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area ($km^2$)** | **Deposit density ($N/km^2$)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 0 | 1 | | | 0.30 | 0.50 | 170 | 0 | 0.30 | 806 | 0.00037 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 1 | 2 | | |
| Individual 2 | 0 | 0 | 1 | | |
| Individual 3 | 0 | 1 | 2 | | |
| Individual 4 | 0 | 0 | 0 | | |
| Individual 5 | 0 | 0 | 1 | | |
| Individual 6 | 0 | 0 | 0 | | |
| Individual 7 | 0 | 0 | 1 | | |
| Individual 8 | 0 | 0 | 1 | | |
| Mean | 0 | 0 | 1 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variation; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per $km^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, L. Lauri, J. Luukas, T. Niiranen, M. Tiainen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the porphyry Cu grade-tonnage model (Appendix 4) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Ruokolahti PorCu permissive tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 0 | 350,000 | 1,100,000 | 230,000 | 0.12 | 0.71 |
| Mo (t) | 0 | 0 | 0 | 14,000 | 43,000 | 11,000 | 0.11 | 0.71 |
| Ag (t) | 0 | 0 | 0 | 170 | 700 | 210 | 0.09 | 0.71 |
| Au (t) | 0 | 0 | 0 | 26 | 93 | 25 | 0.10 | 0.71 |
| Rock (Mt) | 0 | 0 | 0 | 110 | 490 | 85 | 0.11 | 0.71 |

t – metric tons; Mt – million metric tons.

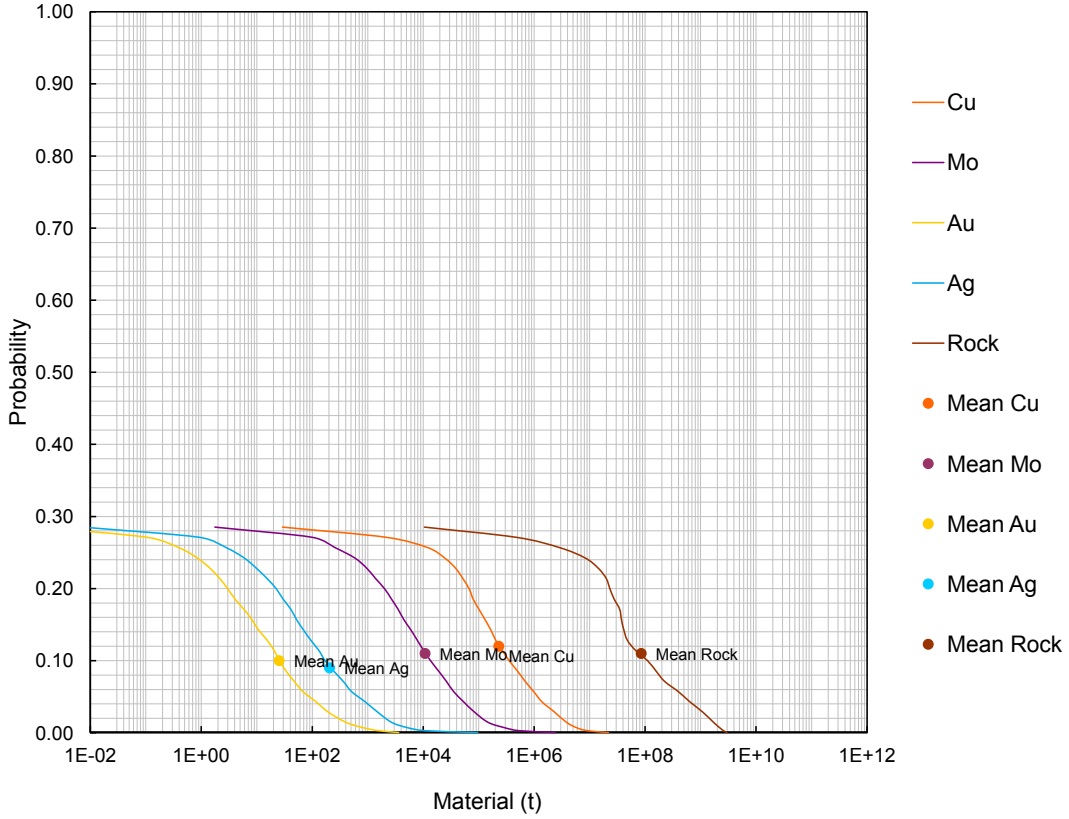


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Ruokolahti PorCu permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT SALO-ISSAKKA VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Salo-Issakka VMS permissive tract is located in southeastern Finland. It is a 70-km-long and 30-km-wide, NW-striking zone, extending for 60 km to the WNW and 10 km to the ESE of the town of Imatra (Fig. 1). The 1:100,000 KKJ map sheets are 3132, 3134, 3141, 3143, 4112 and 4121. The UTM map sheets containing the tract are M511, M512, M513 and M514. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Salo-Issakka VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 10/12/2012 | 1 | 1323 | Cu | 5,940 | Cu | 98,000 | Cu | 10,000 |
| | | | Zn | 29,520 | Zn | 71,000 | Zn | 6,000 |
| | | | Pb | 0 | Pb | 2,500 | Pb | 42 |
| | | | Ag | 25 | Ag | 41 | Ag | 3.6 |
| | | | Au | 0 | Au | 0.51 | Au | 0.032 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by ca. 1900 Ma Svecofennian volcanic rocks of the suggested eastern extensions of the Uusimaa supracrustal belt. The tract covers the potential hosting sequences containing granulite-facies felsic to mafic rocks of possibly volcanic origin. The tract is based on the existence of tholeiitic to calc-alkaline dominated volcanic rocks and VMS indications in that area. The tract extends down to 1000 m depth. The depth extension is based on stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There is one well-explored VMS deposit within the Salo-Issakka VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Salo-Issakka VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Salo-Issakka | 6777557 | 3596335 | 1900 | 1.8 | 0.33 | 1.64 | | 14.0 | | Cu | 4,940 | Kurki (1980) |
| | | | | | | | | | | Zn | 29,520 | |
| | | | | | | | | | | Pb | 0 | |
| | | | | | | | | | | Ag | 25 | |
| | | | | | | | | | | Au | 0 | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences, and related deposit types

There is one partially explored VMS deposit within the Salo-Issakka VMS permissive tract (Table 3).

Table 3. VMS occurrences in the Salo-Issakka VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Mäntysaari | 6783650 | 3572150 | 1900 | 2.2 m at 2.1 % Zn, 0.76 % Cu, 13 ppm Ag; 2.35 m at 1.0 % Zn, 0.38 % Cu; hosted by mica gneiss | Koistinen & Ahokas (1979) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Salo-Issakka VMS tract are listed in Table 4.

Table 4. Exploration history for the Salo-Issakka VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1900s– |
| | Outcrop and boulder observations | Yes | Outokumpu | 1950s–1990s |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1979–2007 |
| Ground geophysical surveys | Magnetic, IP and electromagnetic surveys | | Geological Survey of Finland | 1960s–1990s |
| | Magnetic, slingram, VLF, charged potential and gravimetric surveys | | Outokumpu | 1960s–1980s |
| Drilling | A few tens of diamond-drill holes | Yes | Outokumpu | 1960s–1980s |

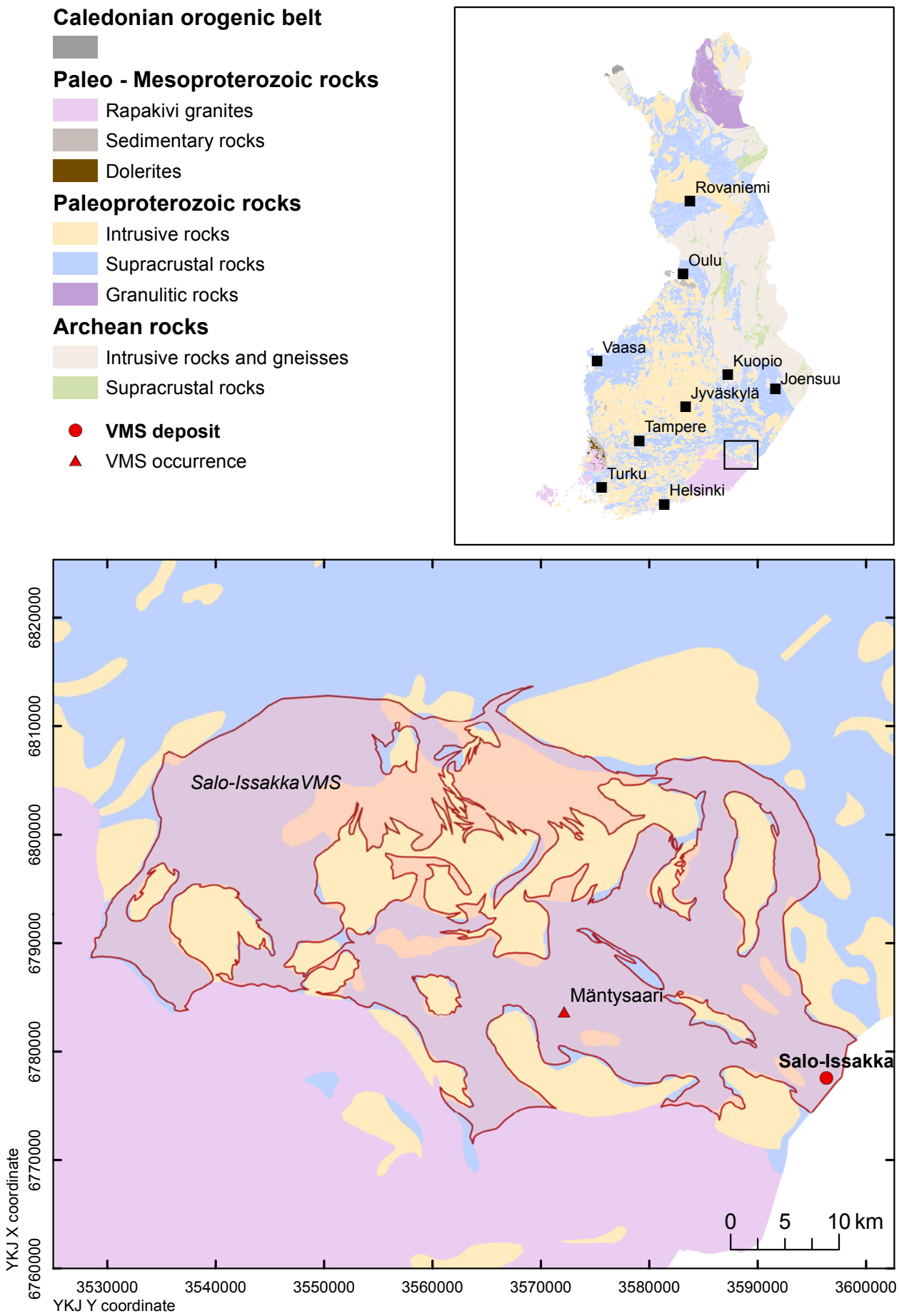


Fig. 1. Location of the Salo-Issakka VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Salo-Issakka VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Salo-Issakka VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:100–1:10,000 | Kurki (1976, 1978, 1980), Koistinen & Ahokas (1979) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Reports | | Kurki (1976, 1978, 1980), Papunen (1990) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Papunen (1990) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Kurki (1978) |
| Exploration | Reports | | Kurki (1976, 1978, 1980), Koistinen & Ahokas (1979) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

One partially explored VMS occurrence is known within the tract (Table 3). However, this occurrence is so small that it was considered probably not to become an economic deposit, even under the most favourable circumstances. Favourable factors for VMS deposits within the Salo-Issakka VMS tract include the so far discovered occurrences and the presence of felsic to intermediate metavolcanic rocks, which probably form a continuation of the Uusimaa belt rocks. Factors restricting the reliability of the assessment include the extensive lake coverage of the tract (>50 %) and the fact that most of the exploration in the region has not targeted VMS deposits but has focussed on Ni. No consensus was reached in the discussion and the mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Salo-Issakka VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 1 | 2 | | | 1.0 | 0.79 | 79 | 1 | 2.0 | 1323 | 0.0015 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 1 | | |
| Individual 2 | 0 | 1 | 4 | | |
| Individual 3 | 0 | 1 | 3 | | |
| Individual 4 | 0 | 0 | 2 | | |
| Individual 5 | 0 | 1 | 2 | | |
| Individual 6 | 0 | 1 | 2 | | |
| Individual 7 | 0 | 0 | 1 | | |
| Individual 8 | 0 | 1 | 2 | | |
| Mean | 0 | 1 | 2 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, K. Rasilainen, P. Sipilä, M. Tiainen, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Salo-Issakka VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 10,000 | 260,000 | 510,000 | 98,000 | 0.20 | 0.29 |
| Zn (t) | 0 | 0 | 6,000 | 170,000 | 340,000 | 71,000 | 0.18 | 0.29 |
| Pb (t) | 0 | 0 | 42 | 2,800 | 10,000 | 2,500 | 0.10 | 0.29 |
| Ag (t) | 0 | 0 | 3.6 | 100 | 200 | 41 | 0.19 | 0.29 |
| Au (t) | 0 | 0 | 0.032 | 1.1 | 2.0 | 0.51 | 0.16 | 0.29 |
| Rock (Mt) | 0 | 0 | 0.72 | 23 | 44 | 7.4 | 0.21 | 0.29 |

t – metric tons; Mt – million metric tons.

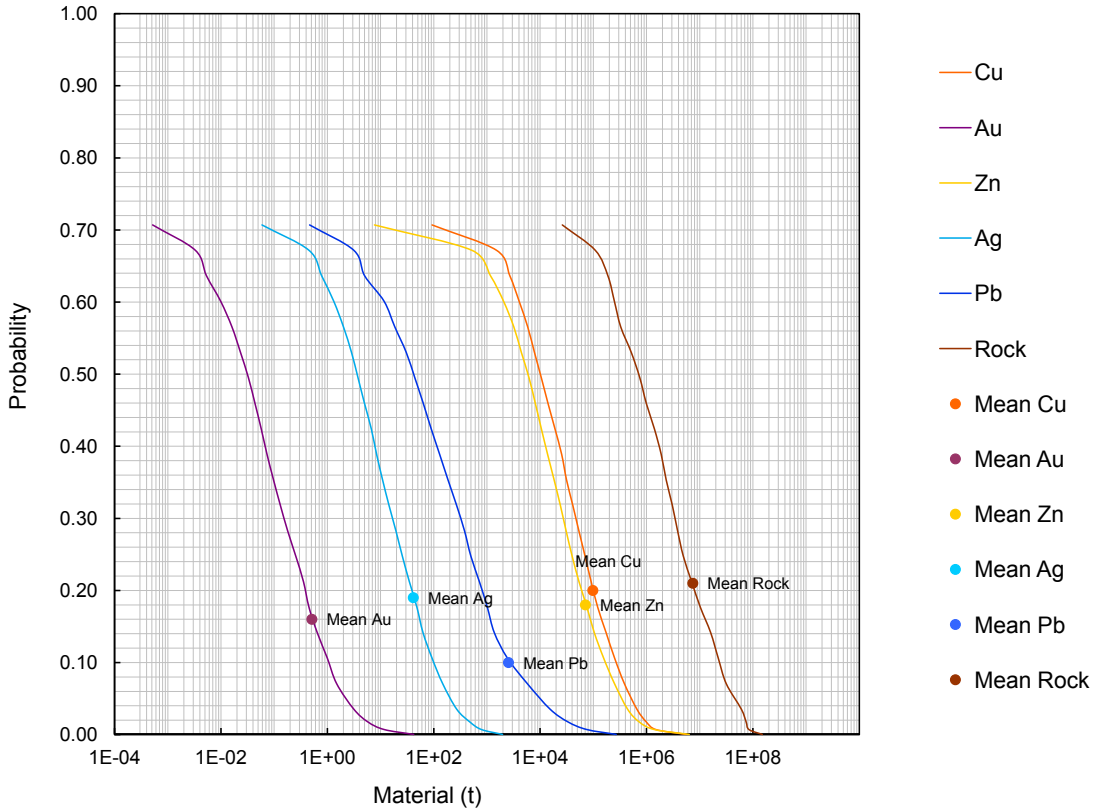


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Salo-Issakka VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT SATTASVAARA VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Sattasvaara VMS permissive tract is located in northern Finland in the municipalities of Sodankylä and Kittilä, 150 km NE of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 3712, 3721, 3722, 3714, 3723, 3724, 3732 and 3741. The UTM map sheets containing the tract are V431, V433, U443, U444, U521, U522 and V511. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Sattasvaara VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 10/12/2012 | 1 | 1176 | Cu | 0 | Cu | 230,000 | Cu | 77,000 |
| | | | Zn | 0 | Zn | 160,000 | Zn | 45,000 |
| | | | Pb | 0 | Pb | 5,700 | Pb | 510 |
| | | | Ag | 0 | Ag | 96 | Ag | 30 |
| | | | Au | 0 | Au | 1.2 | Au | 0.28 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geologic criteria

The permissive tract is defined by the occurrence of Proterozoic 2000–2200 Ma graphitic metasedimentary rocks. The delineation is based on the extent of the graphite- and sulphide-rich schists of the 2.15–2.05 Ga Matarakoski Formation, and the associated ultramafic-mafic volcanic rocks of the Sattasvaara Formation. Both of these formations belong to the Savukoski Group of the Central Lapland Greenstone Belt (CLGB). To the west, the tract is bordered by younger Kittilä Group rocks and to the east by older Sodankylä Group rocks. Most of the komatiitic rocks of the Sattasvaara Formation are detectable by low-altitude airborne magnetic data, whereas the graphite- and sulphide-rich schists of the Matarakoski Formation can be delineated by airborne electromagnetic data. Geophysical data, drilling and outcrop observations were used to define the margins of the tract. The tract extends down to 1000 m depth. The depth extension is based on the assumption that the Matarakoski and Sattasvaara rocks continue downwards beyond that depth. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There are no well-explored VMS deposits within the Sattasvaara VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Sattasvaara VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences and related deposit types

No partially explored VMS occurrences are known within the Sattasvaara VMS permissive tract (Table 3). Other types of metallic mineral occurrences known from the tract area include the Pahtavaara Au mine and Kirakka-Aapa Cu-Au occurrence of unclear genetic type, a few orogenic gold occurrences, the Kevitsa and Sakatti intrusive-hosted Ni-Cu-PGE deposits and the Lomalampi komatiitic Ni-Cu-PGE prospect.

Table 3. Significant VMS occurrences in the Sattasvaara VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| None | | | | | |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Sattasvaara VMS tract are listed in Table 4. Note that most of the work listed was targeted to komatiite- and intrusion-hosted nickel, and some to gold mineralisation, whereas only little exploration has been carried out for VMS or stratiform base metal deposits in general.

Table 4. Exploration history for the Sattasvaara VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop and boulder observations | (Yes) | Geological Survey of Finland | 1973–2010 |
| Geochemical surveys | Line till sampling covers the whole tract | Yes | Geological Survey of Finland | 1970s–1980s |
| | Extensive line and grid sampling in the southern and NE part of the tract: | Yes | Geological Survey of Finland | 1980s–2000s |
| | 3614 till samples | Yes | Outokumpu Oy | 1970s–1990s |
| | 227 till samples | Yes | Anglo American Exploration B.V. | 2004 |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1975–2004 |
| | Low-altitude magnetic and EM survey | | RTZ Mining and Exploration Ltd. | 1994? |
| Ground geophysical surveys | Most of tract is covered by regional gravity survey (APV) | | Geological Survey of Finland | 1970s–2000s |
| | 174 km2 magnetic, 154 $km^2$ slingram, 39 $km^2$ VLF-R, and 48 $km^2$ gravity surveys | | Geological Survey of Finland | 1970s–2000s |
| | 5.6 $km^2$ magnetic and slingram surveys + 27 line-km, 2.9 $km^2$ VLF-R, and 1 $km^2$ IP surveys | | Outokumpu Oy | 1970s, 1990s |
| | Magnetic measurements 13.64 line-km | | RTZ Mining and Exploration Ltd. | 1995 |
| | Magnetic and EM measurements, 38.6 line-km | | Anglo American Exploration B.V. | 2004 |
| Drilling | 1111 DDH, 83922 m | Yes | Geological Survey of Finland | 1970s–2000s |
| | 32 DDH, 5311 m | Yes | Outokumpu Oy | 1962–1998 |
| | 1 DDH, 41 m | No? | RTZ Mining and Exploration Ltd. | 1995 |
| | 4 DDH; 515 m | Yes | Anglo American Exploration B.V. | 2004 |

DDH – diamond-drill hole.

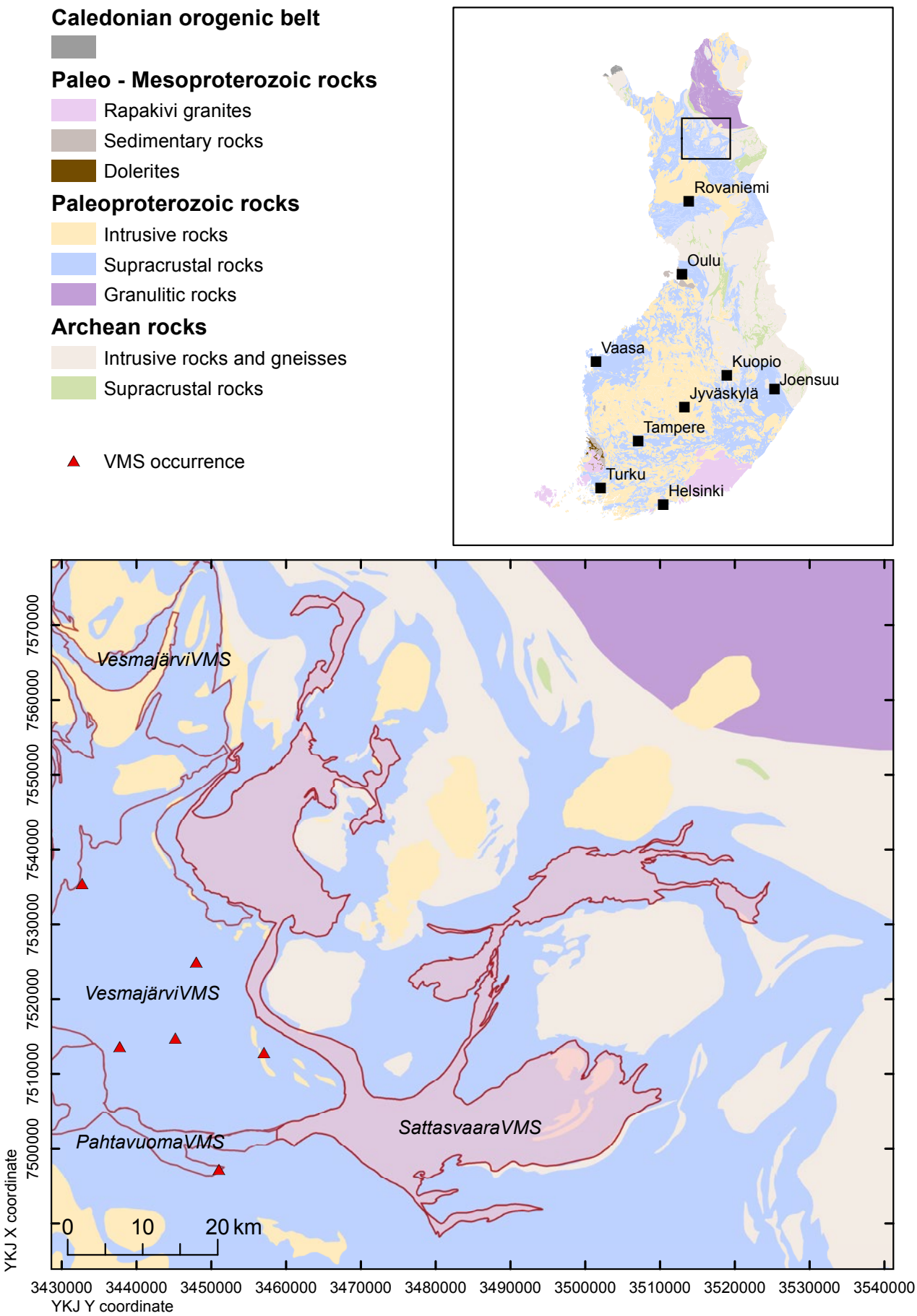


Fig. 1. Location of the Sattasvaara VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Sattasvaara VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Sattasvaara VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Report | | Räsänen (2005) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Reports | | Karvinen (1990), Mutanen (1994), Keinänen et al. (2007), Törmänen et al. (2010) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Pulkkinen et al. (1991), Rossi (1991) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Pulkkinen et al. (1991), Pernu (1994), Turunen (2004), Salmirinne & Turunen (2007) |
| Exploration | Report | | Lahtinen (1979), RTZ (1995a, 1995b, 1995c, 1995d, 1995e), Korkalo (2000), Alitalo (2005a, 2005b, 2005c), Pulkkinen & Salmirinne (2006), Räsänen & Turunen (2006), Pulkkinen et al. (2007) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

No VMS occurrences are known within the tract (Table 3). There are very few clear or direct indications for VMS mineralisation, except for the obvious geological similarity with the Pahtavuoma VMS tract, which can be seen as a major favourable indicator for VMS mineralisation within this rather large area. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Sattasvaara VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 2 | 4 | | | 2.2 | 1.2 | 54 | 0 | 2.2 | 1176 | 0.0019 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 2 | 4 | | |
| Individual 2 | 0 | 2 | 4 | | |
| Individual 3 | 2 | 4 | 6 | | |
| Individual 4 | 1 | 2 | 3 | | |
| Individual 5 | 0 | 1 | 2 | | |
| Individual 6 | 0 | 1 | 2 | | |
| Consensus | 1 | 2 | 4 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, K. Rasilainen, P. Sorjonen-Ward, T. Törmänen

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Sattasvaara VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 2,300 | 77,000 | 620,000 | 950,000 | 230,000 | 0.28 | 0.070 |
| Zn (t) | 0 | 1,100 | 45,000 | 400,000 | 690,000 | 160,000 | 0.24 | 0.070 |
| Pb (t) | 0 | 4.5 | 510 | 11,000 | 26,000 | 5,700 | 0.15 | 0.070 |
| Ag (t) | 0 | 0.69 | 30 | 250 | 430 | 96 | 0.27 | 0.070 |
| Au (t) | 0 | 0.0049 | 0.28 | 2.9 | 5.8 | 1.2 | 0.21 | 0.070 |
| Rock (Mt) | 0 | 0.018 | 5.9 | 52 | 73 | 17 | 0.33 | 0.070 |

t – metric tons; Mt –million metric tons.

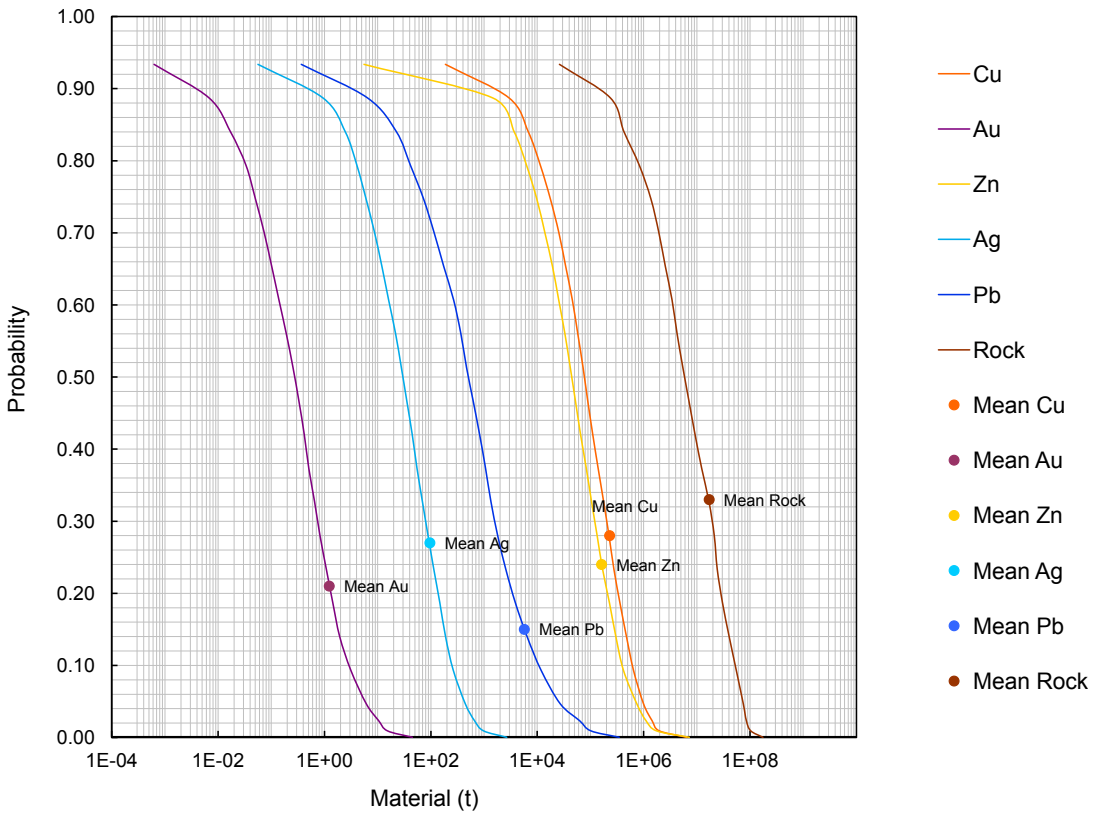


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Sattasvaara VMS permissive tract.

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# PORPHYRY Cu ASSESSMENT FOR THE TRACT SOUTHERN OSTROBOTHNIA PORCU, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: Porphyry Cu
**Descriptive model**: Porphyry Cu (Appendix 3)
**Grade-tonnage model**: Porphyry Cu (Appendix 4)

## LOCATION AND RESOURCE SUMMARY

The Southern Ostrobothnia PorCu permissive tract is located in southern Finland in the municipalities of Honkajoki, Ilmajoki, Isojoki, Karijoki, Kankaanpää, Kauhajoki, Kurikka, Merikarvia and Teuva, 40–200 km north of the city of Pori, in western Finland (Fig. 1). The 1:100,000 KKJ map sheets are 1142, 1144, 1231, 1232, 1233, 1234, 1241, 1243 and 1244. The UTM map sheets containing the tract are M342, N331, N332, N341, N342, N344, P331 and P333. The resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Southern Ostrobothnia PorCu permissive tract.

| Date of assessment | Assessment depth (km) | Tract area ($km^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 8/11/2012 | 1 | 2321 | Cu | 0 | Cu | 310,000 | Cu | 0 |
| | | | Mo | 0 | Mo | 11,000 | Mo | 0 |
| | | | Ag | 0 | Ag | 430 | Ag | 0 |
| | | | Au | 0 | Au | 33 | Au | 0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The Southern Ostrobothnia PorCu permissive tract is defined by probably ca. 1.89–1.88 Ga early to synorogenic granitoids along the western margin of the Central Finland granitoid complex. The delineation is based on the extent of these intrusions. The tract extends down to 1000 m depth. The depth extension is based on interpretation of the geology of the region. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored porphyry Cu deposits within the Southern Ostrobothnia PorCu permissive tract (Table 2). According to the spatial rule used, deposits located less than 2 km from each other were combined in this assessment. An exception was allowed if two occurrences <2 km apart could be shown to be products of separate mineralising systems.

Table 2. Known porphyry Cu deposits in the Southern Ostrobothnia PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade (%) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|
| None | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric tons. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

There are no partially explored Cu occurrences that would clearly go into the porphyry category within the Southern Ostrobothnia PorCu permissive tract (Table 3). Only the partially investigated Majajärvi occurrence in the SE part could perhaps be of the porphyry Mo type.

Table 3. Possible porphyry Cu occurrences in the Southern Ostrobothnia PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Majajärvi | 6858150 | 3256325 | 1890 | Molybdenite-mineralised granodiorite detected in outcrop, covering an area of 200 x 500 m | Pehkonen (1978), Nurmi et al. (1984) |

Ma – million years.

## Exploration history

Exploration activities targeting porphyry Cu and potentially related styles of mineralisation are listed in Table 4.

Table 4. Exploration history for the Southern Ostrobothnia PorCu permissive tract.

| Theme | Type of work | Cu analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1880s–1990s |
| | Detailed outcrop observations and boulder survey | Yes | University of Helsinki | 1980–1983 |
| | Detailed outcrop observations and boulder survey | Yes | Outokumpu | 1970s |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Lithogeochemical assessment in detail target areas | Yes | University of Helsinki | 1980–1983 |
| | Pedogeochemical survey | Yes | Outokumpu | 1970s |
| Airborne geophysical surveys | Regional low-altitude airborne magnetic, electromagnetic and radiometric survey | | Geological Survey of Finland | 1975–1993 |
| Ground geophysical surveys | Scattered magnetic and IP survey lines | | Geological Survey of Finland | 1980s–1990s |
| Drilling | 12 diamond-drill holes | ? | Outokumpu Oy | 1976–1978 |
| | 20 diamond-drill holes | ? | Geological Survey of Finland | 2008–2012 |

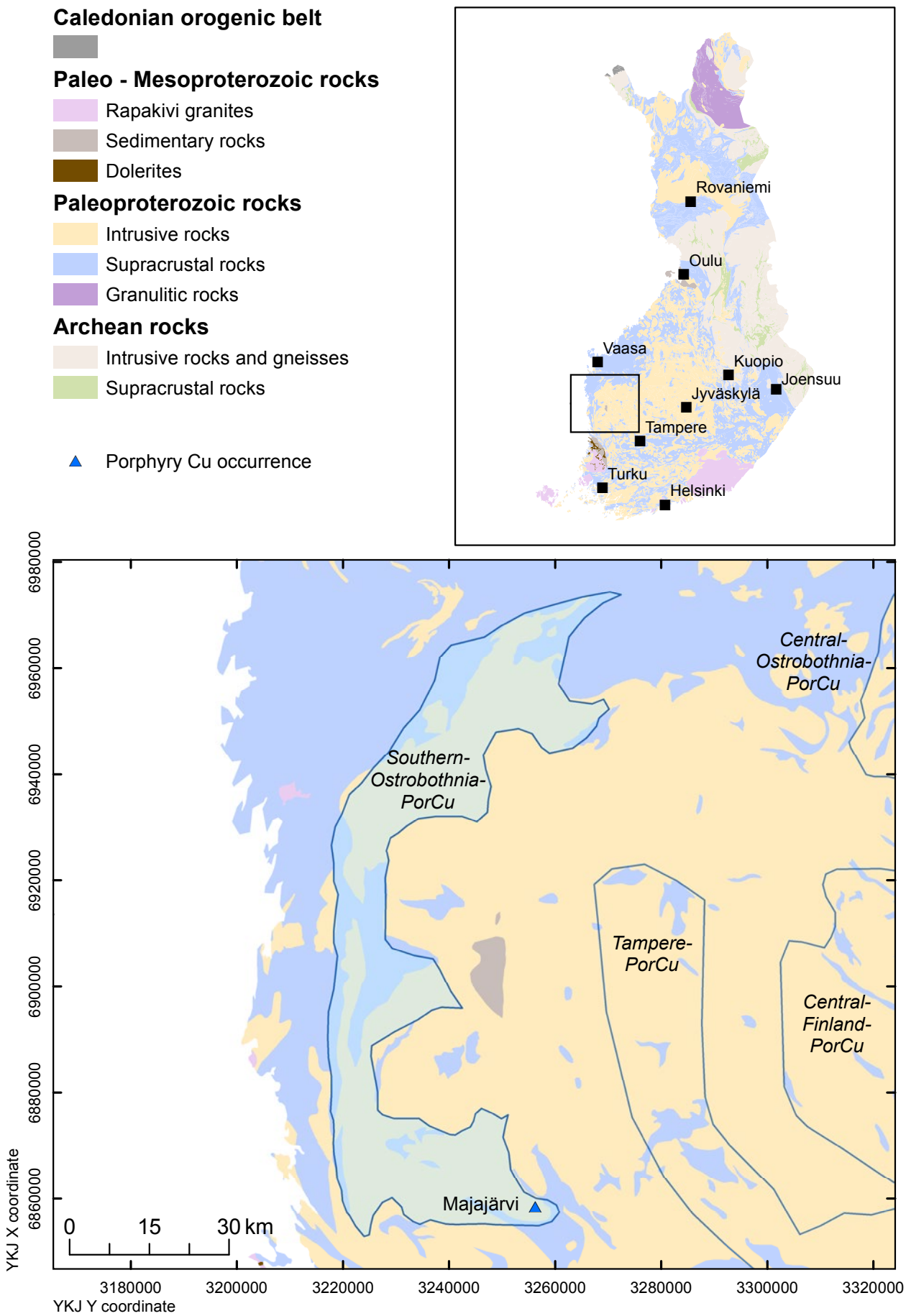


Fig. 1. Location of the Southern Ostrobothnia PorCu permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Southern Ostrobothnia PorCu tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Southern Ostrobothnia PorCu permissive tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Regional mapping | 1:10,0000 | Lehtonen et al. (2005) |
| | Detailed mapping | 1:500–1:4000 | Pehkonen (1978), Nironen & Front (1981) |
| Mineral occurrences | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Geological Survey of Finland gold deposit database | | Eilu & Pankka (2009) |
| | Metallogenic assessment | 1:4000–1:10,000 | Lampio (1983), Nurmi et al. (1984) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Pehkonen (1978) |
| Geophysics | Geological Survey of Finland in-house database | | |
| Exploration | Reports | 1:4000 | Pehkonen (1978) |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

No obvious porphyry Cu occurrences are known within the Southern Ostrobothnia PorCu permissive tract.

The existence of the porphyry-style Majajärvi Mo occurrence, five Mo-mineralised outcrops and an few Cu-mineralised granitoid(?) boulders were considered to indicate the potential for undiscovered porphyry Cu deposits. On the other hand, the lack of obvious porphyry-style Cu-occurrences and scarcity of known indirect indications lowers the potential for undiscovered deposits within the tract. Little exploration has been carried out in the tract area, which made assessing the potential for porphyry deposits difficult. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Southern Ostrobothnia PorCu permissive tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 0 | 1 | | | 0.30 | 0.50 | 170 | 0 | 0.30 | 2321 | 0.00013 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 2 | | |
| Individual 2 | 0 | 0 | 2 | | |
| Individual 3 | 0 | 0 | 1 | | |
| Individual 4 | 0 | 0 | 1 | | |
| Individual 5 | 0 | 0 | 2 | | |
| Individual 6 | 0 | 0 | 0 | | |
| Individual 7 | 0 | 0 | 1 | | |
| Individual 8 | 0 | 0 | 0 | | |
| Individual 9 | 0 | 0 | 2 | | |
| Individual 10 | 0 | 0 | 1 | | |
| Mean | 0 | 0 | 1 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variation; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, L. Lauri, J. Luukas, F. Molnar, T. Niiranen, P. Sorjonen-Ward, M. Tiainen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the porphyry Cu grade-tonnage model (Appendix 4) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Southern Ostrobothnia PorCu permissive tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 0 | 400,000 | 1,200,000 | 310,000 | 0.11 | 0.70 |
| Mo (t) | 0 | 0 | 0 | 16,000 | 44,000 | 11,000 | 0.12 | 0.70 |
| Ag (t) | 0 | 0 | 0 | 160 | 730 | 430 | 0.070 | 0.70 |
| Au (t) | 0 | 0 | 0 | 28 | 97 | 33 | 0.090 | 0.70 |
| Rock (Mt) | 0 | 0 | 0 | 140 | 630 | 96 | 0.11 | 0.70 |

t – metric tons; Mt – million metric tons.

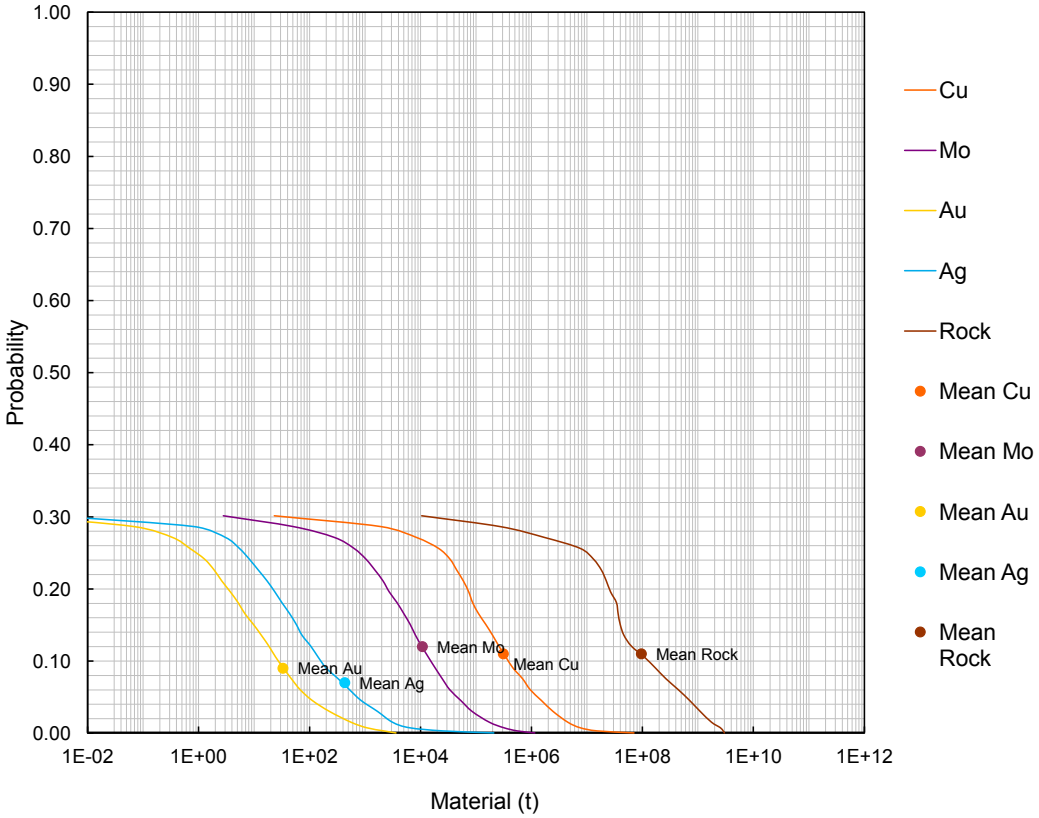


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Southern Ostrobothnia PorCu permissive tract.

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# PORPHYRY Cu ASSESSMENT FOR THE TRACT SOUTHERN SAVO PORCU, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: Porphyry Cu
**Descriptive model**: Porphyry Cu (Appendix 3)
**Grade-tonnage model**: Porphyry Cu (Appendix 4)

## LOCATION AND RESOURCE SUMMARY

The Southern Savo PorCu permissive tract is located in southeastern Finland in the municipalities of Savonlinna, Enonkoski, Rantasalmi, Juva and Joroinen, immediately to the NW of the city of Savonlinna (Fig. 1). The 1:100,000 KKJ map sheets are 3232, 3233, 3234 and 4211. The UTM map sheets containing the tract are N511, N512, N513, N514 and N531. The resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Southern Savo PorCu permissive tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 8/11/2012 | 1 | 603 | Cu | 0 | Cu | 280,000 | Cu | 0 |
| | | | Mo | 0 | Mo | 14,000 | Mo | 0 |
| | | | Ag | 0 | Ag | 330 | Ag | 0 |
| | | | Au | 0 | Au | 28 | Au | 0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The 60-km-long and 8–15-km-wide Southern Savo PorCu permissive tract is defined by probably ca. 1.89–1.88 Ga synorogenic granitoids, which have intruded into Svecofennian mica gneisses and mafic volcanic rocks. The tract extends down to 1000 m depth. The depth extension is based on interpretation of the geology of the region. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored porphyry Cu deposits within the Southern Savo PorCu permissive tract (Table 2). According to the spatial rule used, deposits located less than 2 km from each other were combined in this assessment. An exception was allowed if two occurrences <2 km apart could be shown to be products of separate mineralizing systems.

Table 2. Known porphyry Cu deposits in the Southern Savo PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade (%) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|
| None | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric tons. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

There is one partially explored Mo occurrence of possibly porphyry type within the Southern Savo PorCu permissive tract (Table 3). The Osikonmäki, Pirilä and Hakojärvi orogenic Au deposits are entirely within the tract, as well as the Viholanniemi Zn-Cu-Ag-Au deposit hosted by quartz-carbonate-amphibole-sulphide veins or dykes in a felsic to intermediate volcanic environment.

Table 3. Possible porphyry Cu occurrences in the Southern Savo PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Varparanta | 6878341 | 3593552 | 1880 | Mo-mineralised synorogenic granitoid intrusion; mineralisation in an area of 60 x 150 m: 0.04 Mt @ 0.25 % Mo | Saltikoff (1965, 1972), Nironen (1981), Penninkilampi (1983), Nurmi (1984), Nurmi et al. (1984) |

Ma – million years

## Exploration history

Exploration activities targeting porphyry Cu and potentially related styles of mineralisation are listed in Table 4.

Table 4. Exploration history for the Southern Savo PorCu permissive tract.

| Theme | Type of work | Cu analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1950s–1990s |
| | Detailed outcrop observations and boulder survey | Yes | Geological Survey of Finland Outokumpu | 1960s-1970s<br>1980s |
| | Detailed outcrop observations and boulder survey | Yes | University of Helsinki | 1981–1982 |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Stream sediment survey | Yes | Outokumpu | 1980s |
| | Lithogeochemical survey | Yes | University of Helsinki | 1981 |
| Airborne geophysical surveys | Regional low-altitude airborne magnetic, electromagnetic and radiometric survey | | Geological Survey of Finland | 1979–1992 |
| Ground geophysical surveys | Magnetic, slingram, IP and gravimetric survey | | Outokumpu, Geological Survey of Finland | 1960s-1980s |
| Drilling | Twenty six diamond-drill holes, total 1932.9 m | Yes | Geological Survey of Finland | 1960s |

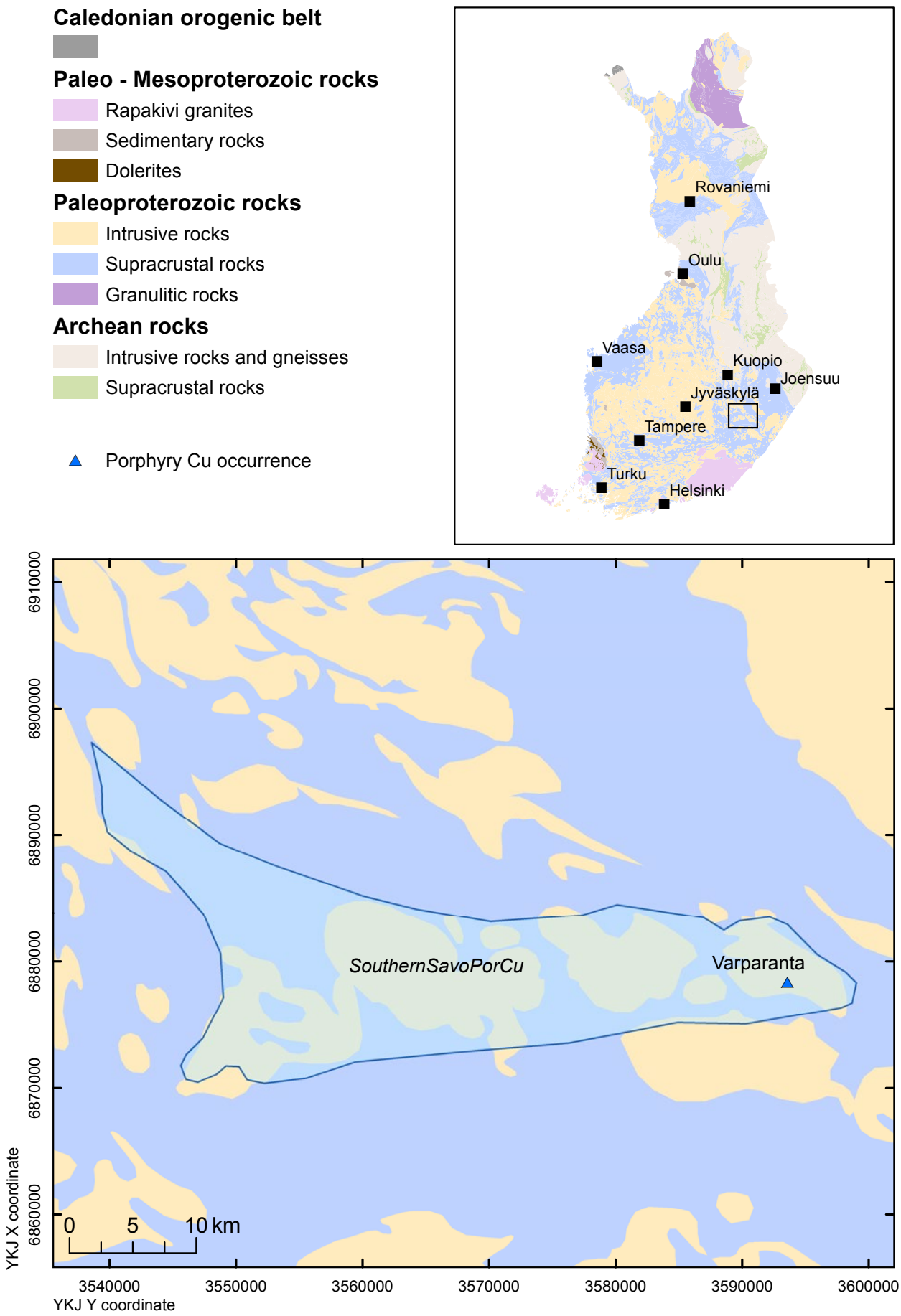


Fig. 1. Location of the Southern Savo PorCu permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Southern Savo PorCu tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Southern Savo PorCu permissive tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:1000–1:10,000 | Saltikoff (1965, 1972), Berger (1981), Nironen (1981) |
| | Regional geology assessment | | Gaal & Rauhamäki (1971) |
| Mineral occurrences | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Metallogenic assessment | | Saltikoff (1972), Nurmi (1984, 1985), Nurmi et al. (1984), Kontoniemi (1998) |
| | Deposit descriptions | | Nironen (1981), Nurmi et al. (1984), Eeronheimo (1988) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | |
| Geophysics | Geological Survey of Finland in-house database | | |
| Exploration | Reports | | Saltikoff (1965, 1972), Eeronheimo (1988) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

One porphyry Mo occurrence is known within the Southern Savo PorCu permissive tract. However, not all estimators considered it large enough to ever become an economic deposit. Nevertheless, the existence of the Varparanta occurrence and a few Mo- and Cu-enriched granitoid outcrops and boulders were considered to indicate the potential for undiscovered porphyry Cu deposits. On the other hand, the small size of the tract and scarcity of known indirect indications lowers the potential for undiscovered deposits within the tract. Drilling for porphyry-type targets within the tract has been restricted to 19 holes at the Varparanta Mo occurrence. Relatively dense drilling has been carried in the vicinity of the known Au and VMS targets within the tract (Osikonmäki, Pirilä, Viholanniemi). No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Southern Savo PorCu permissive tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 0 | 1 | | | 0.30 | 0.50 | 170 | 0 | 0.30 | 603 | 0.00050 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 2 | | |
| Individual 2 | 0 | 0 | 1 | | |
| Individual 3 | 0 | 0 | 2 | | |
| Individual 4 | 0 | 0 | 1 | | |
| Individual 5 | 0 | 1 | 2 | | |
| Individual 6 | 0 | 0 | 0 | | |
| Individual 7 | 0 | 0 | 1 | | |
| Individual 8 | 0 | 0 | 1 | | |
| Mean | 0 | 0 | 1 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variation; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, J. Kousa, N. Kärkkäinen, L. Lauri, J. Luukas, T. Niiranen, M. Tiainen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the porphyry Cu grade-tonnage model (Appendix 4) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Southern Savo PorCu permissive tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 0 | 340,000 | 1,300,000 | 280,000 | 0.11 | 0.70 |
| Mo (t) | 0 | 0 | 0 | 16,000 | 49,000 | 14,000 | 0.11 | 0.70 |
| Ag (t) | 0 | 0 | 0 | 150 | 660 | 330 | 0.070 | 0.70 |
| Au (t) | 0 | 0 | 0 | 28 | 92 | 28 | 0.10 | 0.70 |
| Rock (Mt) | 0 | 0 | 0 | 110 | 610 | 100 | 0.10 | 0.70 |

t – metric tons; Mt – million metric tons.

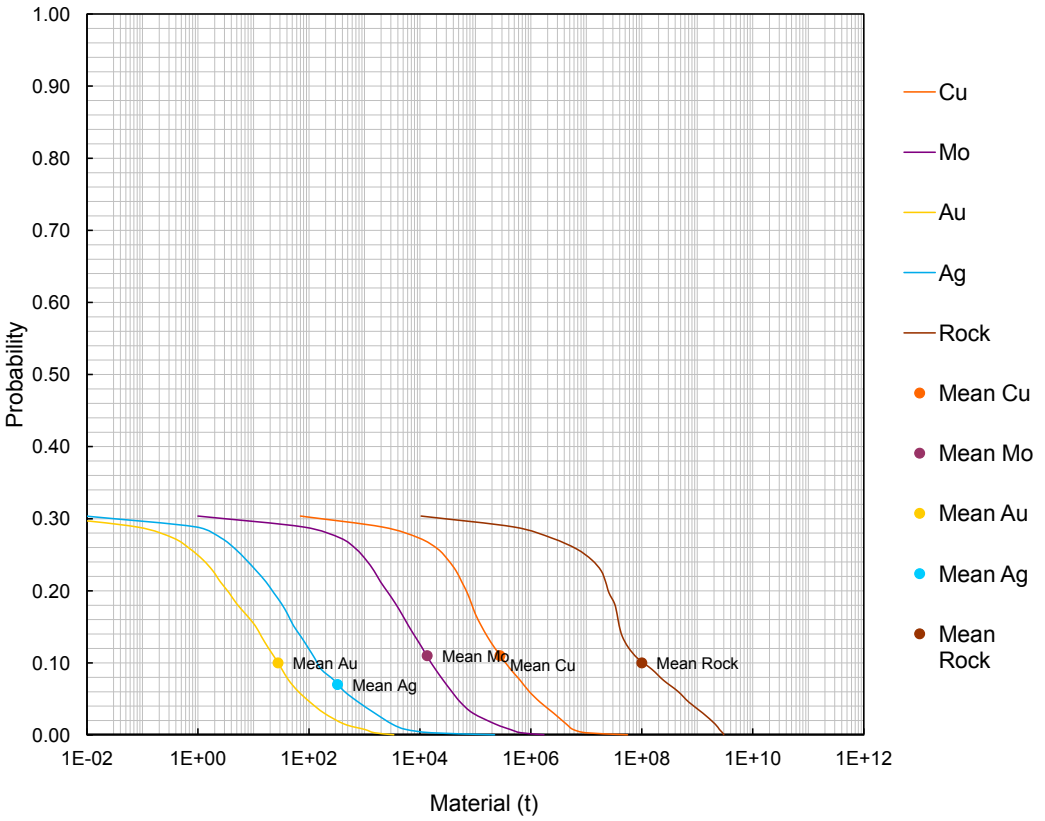


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Southern Savo PorCu permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT TAIVALJÄRVI VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS felsic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Taivaljärvi VMS permissive tract is an approximately 8-km-wide and 120-km-long N-trending zone in eastern Finland, extending from Suomussalmi and Valtimo in the south to Hyrynsalmi in the north (Fig. 1). The 1:100,000 KKJ map sheets are 4322, 4324, 4411, 4412, 4413, 4414, 4421, 4423 and 4424. The UTM map sheets containing the tract are Q514, Q523, Q532, Q524, Q541, Q542, R513, R531 and R532. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Taivaljärvi VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 678 | Cu | 0 | Cu | 66,000 | Cu | 14,000 |
| | | | Zn | 0 | Zn | 470,000 | Zn | 93,000 |
| | | | Pb | 0 | Pb | 140,000 | Pb | 11,000 |
| | | | Ag | 0 | Ag | 480 | Ag | 75 |
| | | | Au | 0 | Au | 6.0 | Au | 1.0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geologic criteria

The Taivaljärvi VMS permissive tract is within the 2.79 Ga Archaean Kianta Supergroup, covering the Tipasjärvi and Kuhmo greenstone belts. The delineation is based on the extent of supracrustal rocks of the Kuhmo and Tipasjärvi Groups. The presence of Taivaljärvi-style Zn-Ag-Pb mineralisation as well as bedrock observation, drill core and geophysical survey data was used to delineate the tract. The tract extends down to 1000 m depth. The depth extension is based on data from the Taivaljärvi deposit and stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There are no well-explored VMS deposits within the TaivaljärviVMS permissive tract (Table 2). The Taivaljärvi deposit, which occurs in the southern part of the tract, has epithermal characteristics. Hence, it is not considered a typical VMS deposit and has not been included in the VMS grade-tonnage model. According to the spatial rule used, deposits less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Taivaljärvi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. Contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences, and related deposit types

Ten partially explored VMS occurrences are known within the Taivaljärvi VMS permissive tract (Table 3).

Table 3. Significant VMS occurrences in the Taivaljärvi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Härmäkangas | 7143282 | 3602636 | | ~40 m wide zone with 0.1–0.9 % Zn | Tenhola & Niskanen (2001), Luukkonen et al. (2002) |
| Kylmäpuro | 7155287 | 3626893 | | 1–3 m @ 0.4 % Zn, 0.1 % Pb, 50 g/t Ag | Kopperoinen (1990) |
| Lapasuo | 7087452 | 3593956 | | 9.8 m @ 0.314 % Zn | Pietikäinen et al. (2008) |
| Myllylahti | 7091446 | 3606681 | | 13 m @ 0.34 % Zn, 1 m @ 1.43 % Zn | Pietikäinen et al. (2008) |
| Palo | 7154627 | 3600244 | | 3 m @ 1.3 % Zn | Heino (1995) |
| Poukama | 7119339 | 3607773 | | 1–5 m @ 1–2 % Zn, 0.4–0.9 % Pb, up to 15 g/t Ag | Kopperoinen (1984) |
| Räkkärinaho | 7097383 | 3598847 | | 1 m @ 0.5 % Zn, another 2 m @ 0.12 % Zn | Pietikäinen et al. (2008) |
| Sauna-aho | 7083010 | 3594110 | | Best section 3 m @ 0.55 % Zn, 0.11 % Pb | Pietikäinen et al. (2008) |
| Taivaljärvi | 7094973 | 3600602 | | 5.004 Mt @ 0.71 % Zn, 0.32 % Pb, 92 g/t Ag, 0.26 g/t Au | Sotkamo Silver (2011) |
| Tipasjärvi (Kiisula) | 7096514 | 3601433 | | 1000 t Fe sulphides (40 % S) mined 1918–1920; 1.7 m @ 0.15 % Zn; 2 m @ 0.12 g/t Au | Puustinen (2003), Rautio (2013) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Taivaljärvi VMS tract are listed in Table 4.

Table 4. Exploration history for the Taivaljärvi VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Bedrock mapping, glacial erratic boulder surveys | Yes | Geological Survey of Finland | 1970s–2000s |
| | Bedrock mapping, glacial erratic boulder surveys | Yes | Kajaani Oy | 1970s–1990 |
| | Bedrock mapping at and around the Taivaljärvi deposit | Yes | Taivalhopea Oy | 1988–1991 |
| | Outcrop observations and boulder survey | Yes | Sotkamo Silver Oy | 2010s |
| Geochemical surveys | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| | Till and bedrock geochemical surveys | Yes | Geological Survey of Finland | 1970s–1990s |
| | Till and bedrock geochemical surveys | Yes | Kajaani Oy | 1970s–1990 |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1977–2007 |
| Ground geophysical surveys | Magnetic, electromagnetic, IP, VLF-R surveys | | Geological Survey of Finland | 1990s |
| | Magnetic, slingram, turam, IP, SP, VLF-R and gravimetric ground survey | | Kajaani Oy | 1970s–1990 |
| | Magnetic, slingram, turam, IP, SP, VLF-R and gravimetric ground survey | | Taivalhopea Oy | 1988–1991 |
| Drilling | A few tens of diamond-drill holes | Yes | Geological Survey of Finland | 1990s |
| | 190 diamond-drill holes, total 35 km; percussion drilling | Yes | Kajaani Oy | 1970s–1990 |
| | 156 diamond-drill holes, total 12 km | Yes | Taivalhopea Oy | 1988–1991 |
| | Diamond drilling | Yes | Sotkamo Silver | 2010– |
| Other | Feasibility studies, pilot-plant tests and test mining for the Taivaljärvi deposit | Yes | Taivalhopea Oy | 1988–1991 |
| | Feasibility studies and pilot-plant tests for the Taivaljärvi deposit | Yes | Sotkamo Silver | 2010– |

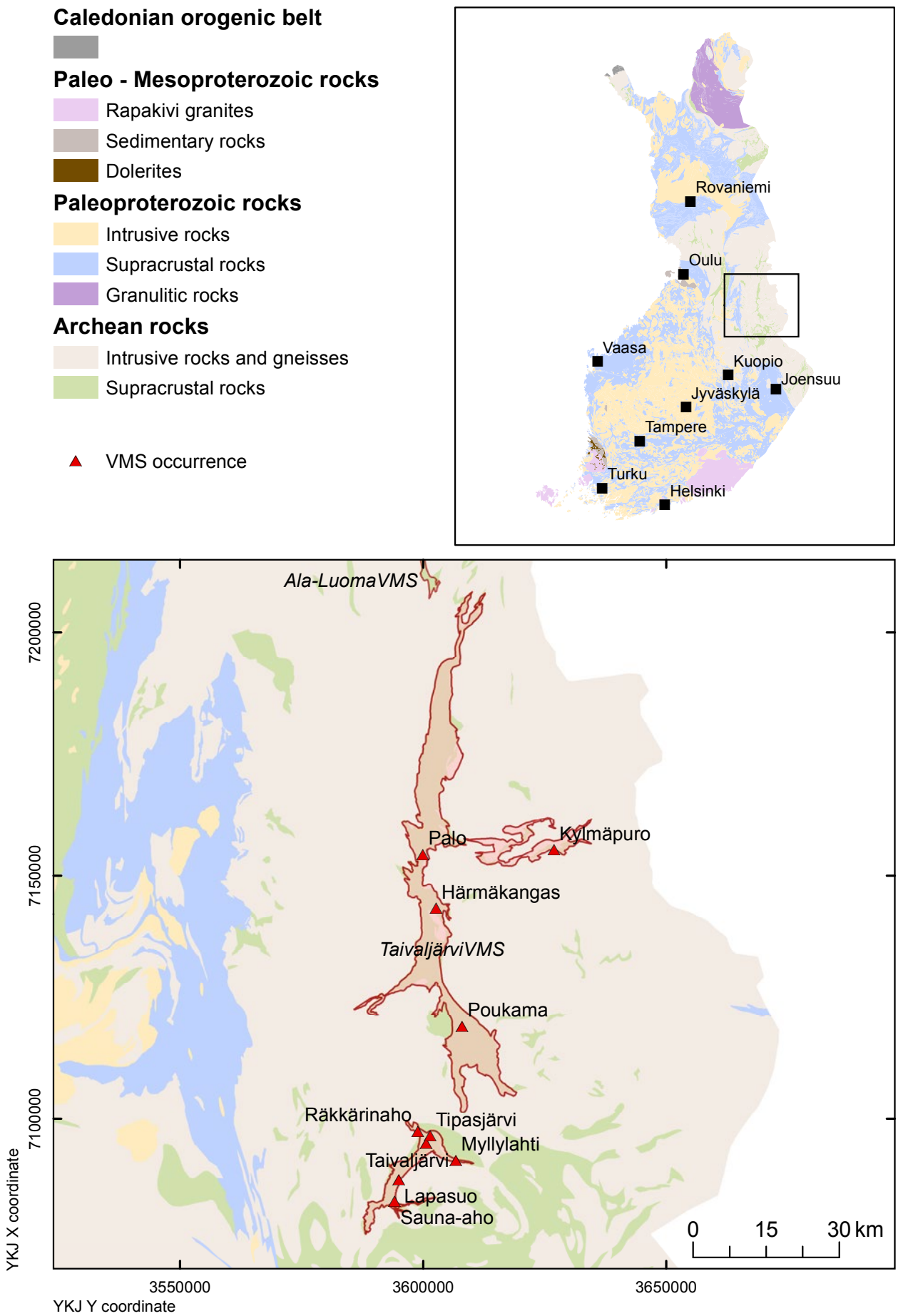


Fig. 1. Location of the Taivaljärvi VMS permissive tract.

### Sources of information

Principal sources of information used by the assessment team for the delineation of the TaivaljärviVMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the TaivaljärviVMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Reports | | Tenhola & Niskanen (2001), Luukkonen et al. (2002) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Reports | | Kopperoinen (1984, 1990), Kopperoinen & Tuokko (1988), Papunen et al. (1989), Tuokko (1989, 1992), Heino (1995), Parkkinen (2010), Sotkamo Silver (2011), Rautio (2013) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Kopperoinen (1987), Heino (1995), Tenhola & Niskanen (2001), Luukkonen et al. (2002), Rautio (2013) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Kopperoinen (1990), Heino (1995), Tenhola & Niskanen (2001), Luukkonen et al. (2002), Rautio (2013) |
| Exploration | Reports | | Kopperoinen (1984,1990), Heino (1995), Tenhola & Niskanen (2001), Luukkonen et al. (2002), Rautio (2013) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Ten partially explored Taivaljärvi-type VMS occurrences are known within the tract (Table 3). However, these were considered so small that it was seen possible that none of them would ever become an economic deposit even under the most favourable circumstances. Very little exploration has been carried out for VMS deposits within the tract. Most of the exploration in the region has targeted gold and nickel. Only the Taivaljärvi deposit has been extensively drilled. Large parts of the tract are covered by lakes and thick overburden (till + sand). This general lack of information makes it difficult to estimate the undiscovered VMS deposits in the area. Favourable factors for VMS deposits within the Taivaljärvi VMS tract include the Taivaljärvi deposit, the nine other occurrences, the extensive occurrence of felsic volcanic rocks in the southern part of the tract and the Zn±Cu±Ag±Au- and Cu-anomalous bedrock and boulder indications throughout the Taivaljärvi belt (the latter summarised in Rautio 2013). Also, bedrock source areas for a few Zn±Cu-rich boulders have not been located. After discussions, a consensus was reached and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Taivaljärvi VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 2 | 3 | | | 1.9 | 0.84 | 43 | 0 | 1.9 | 678 | 0.0029 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 1 | 2 | 3 | | |
| Individual 2 | 1 | 1 | 2 | | |
| Individual 3 | 1 | 1 | 2 | | |
| Individual 4 | 2 | 3 | 4 | | |
| Individual 5 | 2 | 2 | 4 | | |
| Individual 6 | 1 | 2 | 3 | | |
| Individual 7 | 2 | 3 | 3 | | |
| Consensus | 1 | 2 | 3 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen J. Luukas, J. Nikander, K. Rasilainen, P. Sorjonen-Ward, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS felsic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Taivaljärvi VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 360 | 14,000 | 160,000 | 310,000 | 66,000 | 0.20 | 0.070 |
| Zn (t) | 0 | 1,300 | 93,000 | 1,200,000 | 2,500,000 | 470,000 | 0.20 | 0.070 |
| Pb (t) | 0 | 120 | 11,000 | 200,000 | 470,000 | 140,000 | 0.13 | 0.070 |
| Ag (t) | 0 | 1.1 | 75 | 1,000 | 2,200 | 480 | 0.17 | 0.070 |
| Au (t) | 0 | 0.021 | 1.0 | 13 | 26 | 6.0 | 0.18 | 0.070 |
| Rock (Mt) | 0 | 0.086 | 2.9 | 38 | 69 | 11 | 0.21 | 0.070 |

t – metric tons; Mt – million metric tons.

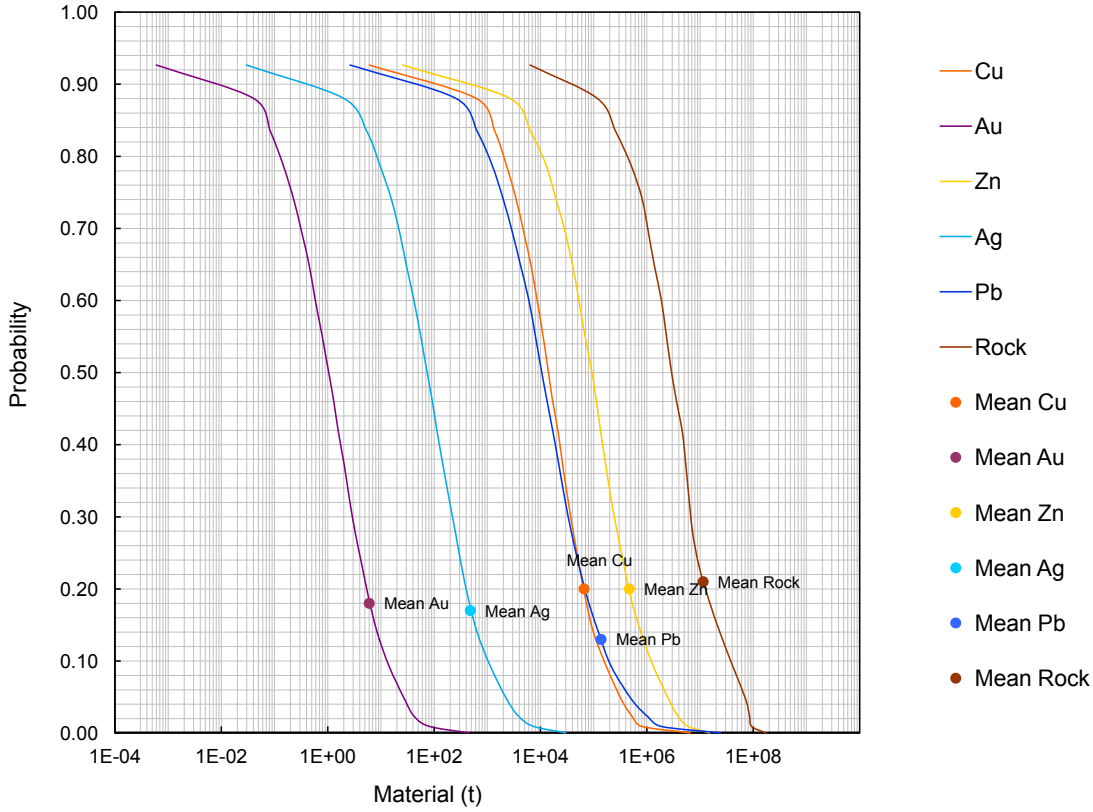


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Taivaljärvi VMS permissive tract.

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# PORPHYRY Cu ASSESSMENT FOR THE TRACT TAMPERE PORCU, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: Porphyry Cu
**Descriptive model**: Porphyry Cu (Appendix 3)
**Grade-tonnage model**: Porphyry Cu (Appendix 4)

## LOCATION AND RESOURCE SUMMARY

The Tampere PorCu permissive tract is located in southern Finland in the municipalities of Hämeenkyrö, Ikaalinen, Jämsä, Jyväskylä, Juupajoki, Kangasniemi, Karvia, Laukaa, Luhanka, Muurame, Nokia, Orivesi, Parkano, Tampere, Toivakka and Ylöjärvi, extending for 120 to the NW and 200 km to the ENE of the city of Tampere, in SW Finland (Fig. 1). The 1:100,000 KKJ map sheets are 2122, 2123, 2124, 2142, 2144, 2211, 2212, 2233, 3122, 3211, 3213 and 3214. The UTM map sheets containing the tract are M343, M344, M421, M422, M424, M441, N333, N334, N343, N413, N431, N433 and N434. The resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Tampere PorCu permissive tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 9/11/2012 | 1 | 5023 | Cu | 0 | Cu | 2,000,000 | Cu | 660,000 |
| | | | Mo | 0 | Mo | 97,000 | Mo | 29,000 |
| | | | Ag | 0 | Ag | 2,600 | Ag | 280 |
| | | | Au | 0 | Au | 230 | Au | 47 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The arched 330 km long and 15–30 km wide Tampere PorCu permissive tract is defined by early to synorogenic 1.89–1.88 Ga granitoid rocks along the southern margin of the Central Finland granitoid complex. The tract includes the supracrustal rocks of the Tampere schist belt. The tract extends down to 1000 m depth. The depth extension is based on interpretation of the geology of the region. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored porphyry Cu deposits within the Tampere PorCu permissive tract (Table 2). According to the spatial rule used, deposits located less than 2 km from each other were combined in this assessment. An exception was allowed if two occurrences <2 km apart could be shown to be products of separate mineralising systems.

Table 2. Known porphyry Cu deposits in the Tampere PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade (%) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|
| None | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric tons. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

There are no partially explored Cu occurrences that could clearly go into the porphyry category within the Tampere PorCu permissive tract. However, the Ylöjärvi W-Cu deposit in a quartz-tourmaline breccia, the high-sulphidation epithermal Kutemajärvi (Orivesi Mine) and Järvenpää gold deposits, and the gold occurrences at Lavajärvi and Tammijärvi may be genetically related to synorogenic granitoid magmatism (Table 3). Other types of occurrences that exist within the tract include the Haveri VMS Cu-Au mine, Ahvenlammi W skarn deposit and a few small VMS-like Zn occurrences and orogenic gold occurrences.

Table 3. Possible porphyry Cu-related occurrences in the Tampere PorCu permissive tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Järvenpää | 6841903 | 3316309 | 1990? | 1.6–3.4 m @ 1.0–2.2 g/t Au, 10.4–22.4 g/t Ag, in intensely sericitised intermediate metavolcanic rock | Ratia (1991), Luukkonen (1994) |
| Kutemajärvi | 6841672 | 3349545 | 1990? | Premining: 3 Mt @ 6 g/t Au, in intensely silicified intermediate metavolcanic rock | Poutiainen & Grönholm (1996), Kinnunen (2008), Dragon Mining (2012) |
| Lavajärvi | 6842151 | 3313536 | 1890? | 4 m @ 1 ppm, 1 m @ 1.9 g/t Au; quartz ± tourmaline veining at granodiorite contact | Lehto & Vuori (2006) |
| Tammijärvi | 6857300 | 3437200 | | 4.5 m @ 0.4 ppm Au and 0.84 % Cu; 6 m @ 0.92 % W | Luukkonen (1994) |
| Ylöjärvi | 6838500 | 3314500 | 1890? | Mined 4 Mt @ 0.75 % Cu, 0.11 % W, 13.9 g/t Ag, 0.04 g/t Au | Clark (1965), Himmi et al. (1979) |

Ma – million years

## Exploration history

Exploration targeting porphyry and potentially related styles of mineralisation is listed in Table 4.

Table 4. Exploration history for the Tampere PorCu permissive tract.

| Theme | Type of work | Cu analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1880s–2000s |
| | Detailed outcrop observations | Yes | University of Helsinki | 1980–1992 |
| | Detailed outcrop observations and boulder survey | Yes | Outokumpu | 1950s–2003 |
| | Detailed outcrop observations and boulder survey | Yes | Lohja Oy | 1975–1990 |
| | Detailed outcrop observations and boulder survey | Yes | Rautaruukki Oy | 1950s–1970s |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Lithogeochemical assessment in detail target areas | Yes | University of Helsinki | 1980–1992 |
| | Geochemical survey of basal till and lithogeochemical survey | Yes | Geological Survey of Finland | 1970s–2000s |
| | Geochemical survey of basal till and lithogeochemical survey | Yes | Outokumpu | 1960s–1990s |
| | Geochemical survey of basal till and lithogeochemical survey | ? | Lohja Oy | 1980s |
| | Geochemical survey of basal till | Yes | SES Finland | 1990s |
| Airborne geophysical surveys | Regional low-altitude airborne magnetic, electromagnetic and radiometric survey | | Geological Survey of Finland | 1977–2007 |
| Ground geophysical surveys | Magnetic, IP, VLF, slingram surveys | | Geological Survey of Finland | 1930s–2000s |
| | Magnetic, IP, slingram surveys | | Outokumpu | 1960s–2000s |
| | Magnetic, SP surveys | | SES Finland | 1990s |
| Drilling | Diamond drilling at exploration targets | Yes | Geological Survey of Finland | 1930s–2000s |
| | Diamond drilling at exploration targets | Yes | Lohja Oy | 1975–1990 |
| | Diamond drilling at exploration targets and at Kutema mine site | Yes | Dragon Mining | 2003– |
| | Diamond drilling at exploration targets and at mine sites | Yes | Outokumpu | 1960s–2003 |

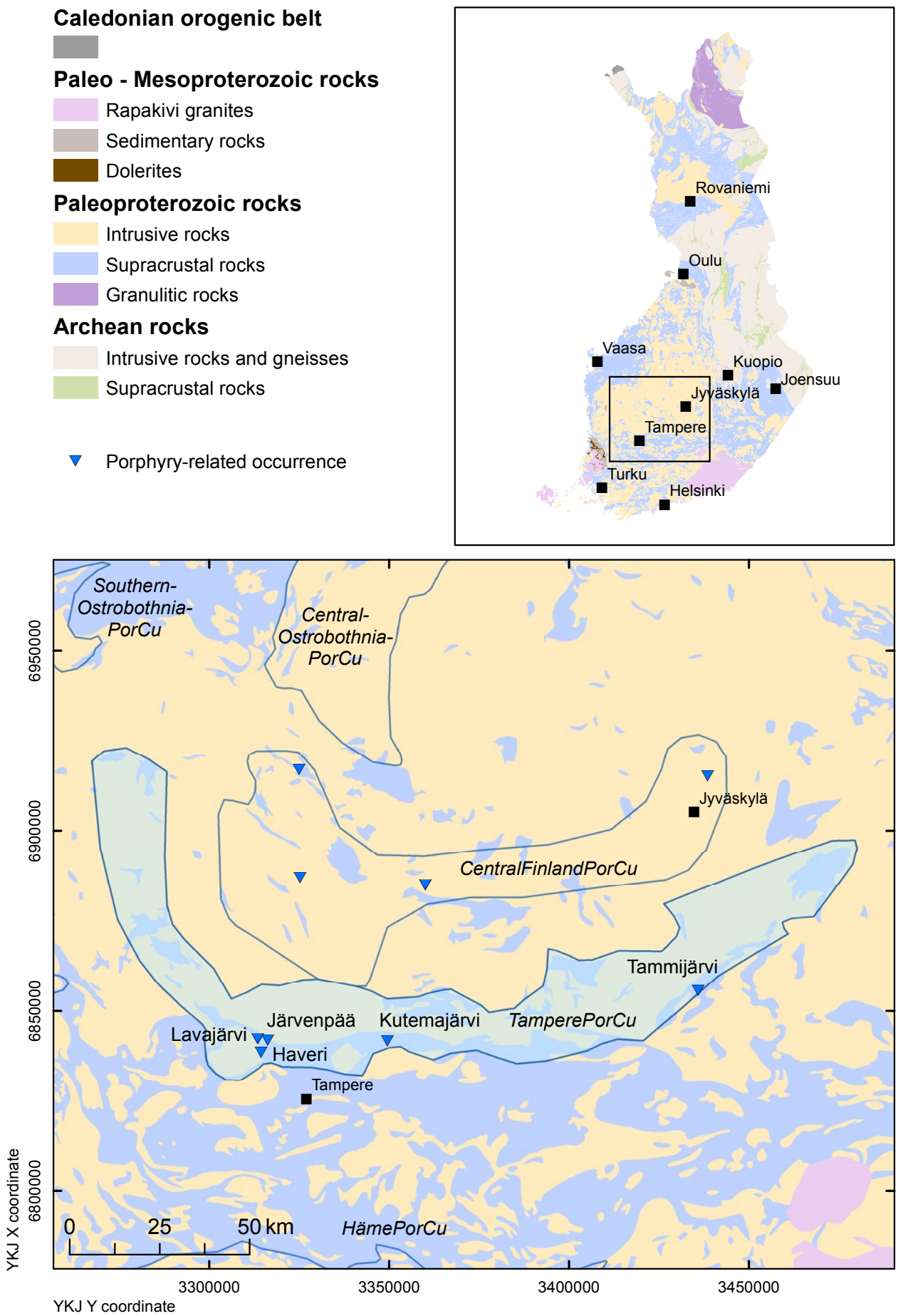


Fig. 1. Location of the Tampere PorCu permissive tract.

### Sources of information

Principal sources of information used by the assessment team for the delineation of the Tampere PorCu tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Tampere PorCu permissive tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:500–1:4000 | Front (1981), Nironen (1981), Nurmi (1981), Kähkönen (1989), Ratia (1991), Luukkonen (1994), Poutiainen & Grönholm (1996), Kärkkäinen et al. (2003) |
| Mineral occurrences | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Geological Survey of Finland gold deposit database | | Eilu & Pankka (2009) |
| | Metallogenic assessment | 1:4000–1:10,000 | Lampio (1983), Nurmi (1984, 1985), Nurmi et al. (1984), Kärkkäinen et al. (2003), Talikka & Mänttäri (2005), Talikka & Vuori (2010) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Ratia (1991), Kärkkäinen et al. (2003), Lehto & Vuori (2006) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Ratia (1991), Kärkkäinen et al. (2003), Lehto & Vuori (2006) |
| Exploration | Reports | 1:4000–1:10,000 | Ratia (1991), Kärkkäinen et al. (2003), Lehto & Vuori (2006) |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

No obvious porphyry Cu occurrences are known within the Tampere PorCu permissive tract. The existence of several deposits and occurrences possibly genetically related to porphyry-style mineralisation and synorogenic subvolcanic granitoid intrusions was seen as the most favourable indication for porphyry copper mineralisation in the tract area. Other favourable indications are the Pukala hypabyssal intrusion near the Kutemajärvi high-sulphidation epithermal deposit, the Cu- and Mo-mineralised outcrops and boulders across the tract, and the locally (western part of the tract) relatively shallow palaeolevel of the present surface. Parts of the tract are extensively explored, whereas other parts have seen very little exploration, which thus weakens the quality of assessment to some extent. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Tampere PorCu permissive tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 2 | 4 | | | 2.2 | 1.2 | 54 | 0 | 2.2 | 5023 | 0.00044 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 1 | 2 | 4 | | |
| Individual 2 | 1 | 2 | 3 | | |
| Individual 3 | 1 | 2 | 4 | | |
| Individual 4 | 2 | 3 | 5 | | |
| Individual 5 | 1 | 2 | 4 | | |
| Individual 6 | 1 | 4 | 6 | | |
| Individual 7 | 1 | 2 | 3 | | |
| Individual 8 | 1 | 2 | 4 | | |
| Individual 9 | 1 | 2 | 3 | | |
| Individual 10 | 0 | 1 | 3 | | |
| Individual 11 | 0 | 1 | 1 | | |
| Mean | 1 | 2 | 4 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variation; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, L. Lauri, J. Luukas, F. Molnar, T. Niiranen, M. Nironen, P. Sorjonen-Ward, M. Tiainen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the porphyry Cu grade-tonnage model (Appendix 4) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Tampere PorCu permissive tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 9,800 | 660,000 | 5,100,000 | 7,700,000 | 2,000,000 | 0.29 | 0.070 |
| Mo (t) | 0 | 410 | 29,000 | 270,000 | 460,000 | 97,000 | 0.24 | 0.070 |
| Ag (t) | 0 | 3.3 | 280 | 4,100 | 8,100 | 2,600 | 0.16 | 0.070 |
| Au (t) | 0 | 0.42 | 47 | 680 | 1,200 | 230 | 0.23 | 0.070 |
| Rock (Mt) | 0 | 2.9 | 240 | 2,400 | 2,900 | 750 | 0.33 | 0.070 |

t – metric tons; Mt – million metric tons.

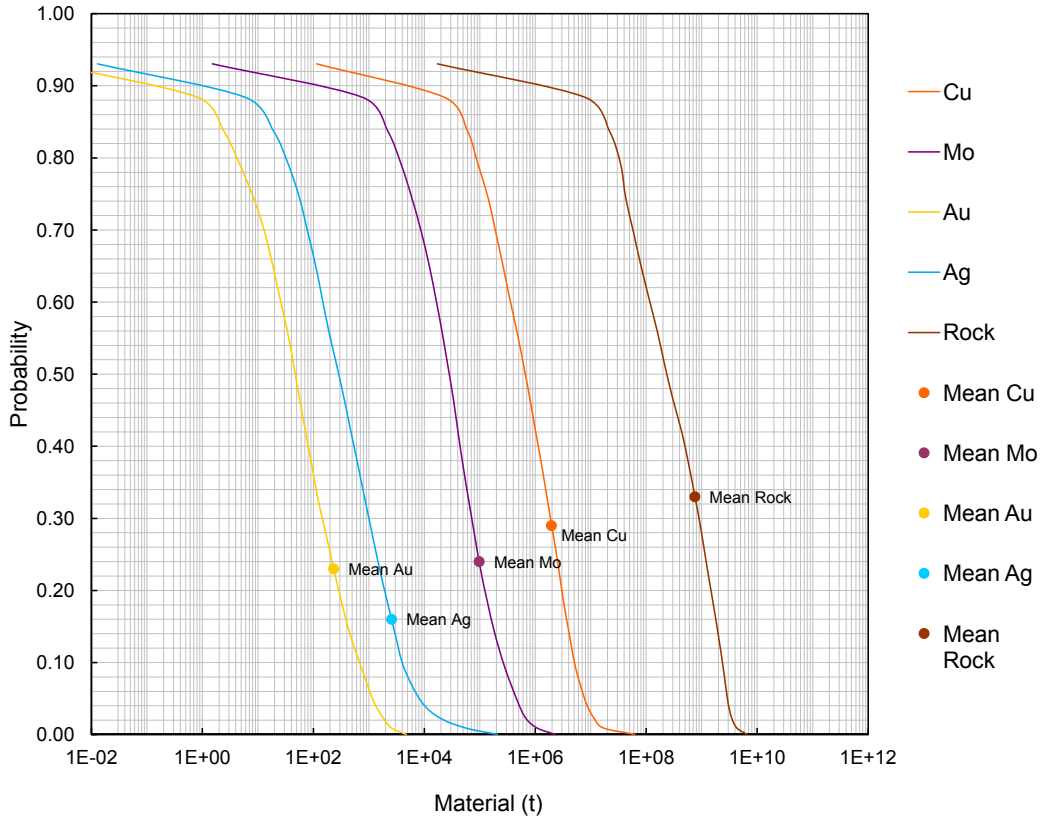


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Tampere PorCu permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT TAMPERE VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS bimodal-mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Tampere VMS permissive tract is located in southern Finland. The 10–25-km-wide domain consists of several parts and extends 85 km NW and 175 km ENE from the city of Tampere (Fig. 1). The 1:100,000 KKJ map sheets are 1144, 1233, 2121,2122, 2123, 2124, 2142, 2144, 3122 and 3211. The UTM map sheets containing the tract are M342, M343, M344, M421, M422, M424, M442, M444, N331, N333, N413, N431, N433 and N434. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Tampere VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 2818 | Cu | 0 | Cu | 54,000 | Cu | 44,000 |
| | | | Zn | 0 | Zn | 120,000 | Zn | 89,000 |
| | | | Pb | 0 | Pb | 5,500 | Pb | 2,200 |
| | | | Ag | 0 | Ag | 29 | Ag | 15 |
| | | | Au | 0 | Au | 0.90 | Au | 0.75 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by 1.91–1.89 Ga Svecofennian volcanic rocks. The delineation is based on the extent of mafic and intermediate volcanic rocks within the Tampere schist belt and the Hirsilä suite. The tract is based on the existence of bimodal, tholeiitic to calc-alkaline dominated volcanic rocks and indications of VMS-style mineralisation. The tract extends down to 1000 m depth. The depth extension is based on stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

No well-explored VMS deposits are known within the Tampere VMS permissive tract (Table 2). According to the spatial rule used, deposits less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Tampere VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences, and related deposit types

Three partially explored VMS occurrences are known within the Tampere VMS tract (Table 3). The Haveri Cu-Au deposit (mined 1.56 Mt @ 0.37 % Cu, 2.8 g/t Au) and the Ylöjärvi Cu-W deposit (Mined 4 Mt @ 0.75 % Cu, 0.11 % W, 14 g/t Ag) located within the tract are not considered typical VMS deposits. The Kutemajärvi epithermal-type gold deposit is located within the tract, as well as one other epithermal gold occurrences and one porphyry Cu occurrence.

Table 3. VMS occurrences in the Tampere VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Koukkujärvi | 6842166 | 3354023 | 1900–1890 | 1.3 m @ 0.5 % Zn; 1.5 m @ 0.9 % Cu | Mäkelä (1979) |
| Töllinmäki (Kierikkala) | 6836878 | 3299302 | 1900–1890 | 4 m @ 1.1 % Zn | Rosenberg (1993) |
| Verttuunjärvi (Verttuu) | 6857315 | 3259856 | 1900–1890 | 1.4 m @ 2.38 % Zn, 0.2 % Pb; 1.25 m @ 2.1 % Zn, 0.82 % Pb; 5 m @ 0.87 % Zn; 41 m @ 0.18 % Zn | Pehkonen (1983) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Tampere VMS tract are listed in Table 4.

Table 4. Exploration history for the TampereVMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1900s–2010s |
| | Outcrop and boulder observations | Yes | Northern Lion | 2003–2006 |
| | Outcrop and boulder observations | Yes | Outokumpu | 1950s–1990s |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Detailed till geochemical survey | Yes | Geological Survey of Finland | 1990s |
| | Detailed till and humus geochemical survey | Yes | Outokumpu | 1950s–1990s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1975–2001 |
| Ground geophysical surveys | Magnetic, slingram, minmax, IP surveys | | Geological Survey of Finland | 1960s–2010s |
| | Magnetic surveys | | Rautaruukki | |
| | Magnetic, slingram, VLF, gravimetric and IP surveys | | Outokumpu | 1950s–1990s |
| Drilling | Tens of diamond and percussion-drill holes | Yes | Outokumpu | 1950s–1990s |
| | Haveri, before mining: 137 diamond-drill holes, total 8150 m | Cu, Au | Vuoksenniska | 1935–1940 |
| | A few diamond-drill holes | Yes | Lohja | 1980s |
| | Haveri: 45 diamond-drill holes | Cu, Au | Glenmore Highlands | 1996–2000 |
| | Haveri: 76 diamond-drill holes, total 20,931 m, and percussion drilling | Cu, Au | Northern Lion | 2003–2005 |
| | Not known | Cu, Au | Lappland Goldminers | 2008–2009 |
| | Tens of diamond-drill holes | Yes | Geological Survey of Finland | 1960s– |
| Other | Stratigraphic, structural, metallogenic and Pb-isotopic investigations | Yes | Geological Survey of Finland, University of Helsinki, Åbo Akademi University, University of Turku | 1900s–2010s |

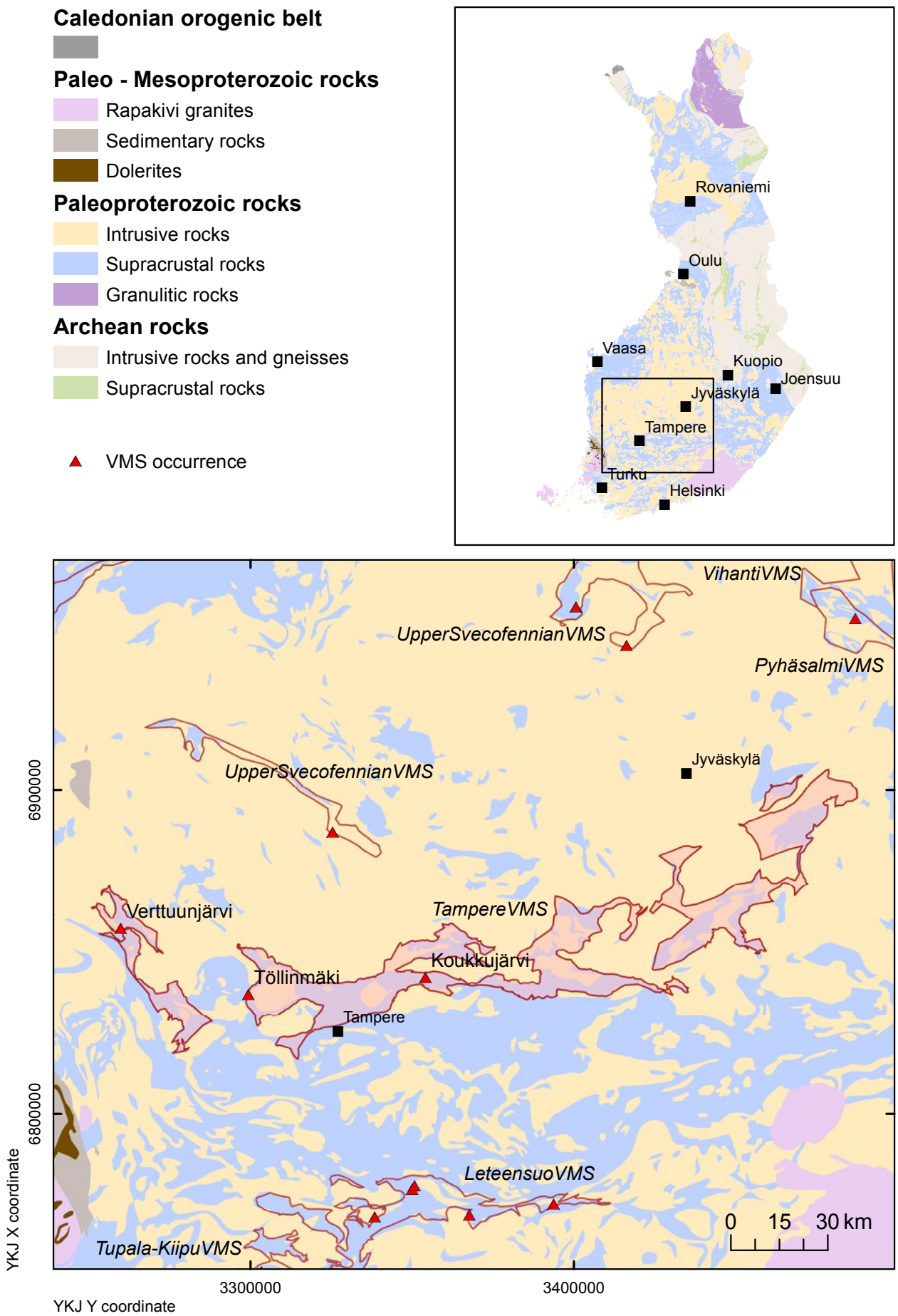


Fig. 1. Location of the Tampere VMS permissive tract.

### Sources of information

Principal sources of information used by the assessment team for the delineation of the Tampere VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Tampere VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:100–1:10,000 | Stigzelius (1944), Mäkelä (1980a), Kähkönen (1989), Luodes (1989), Kähkönen & Nironen (1994), Nironen (1994), Strauss (2004), Forss (2006) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Geological Survey of Finland gold deposit database | | Eilu & Pankka (2009) |
| | Deposit descriptions | | Stigzelius (1944), Mäkelä (1980a), Papunen (1990), Strauss (2004), Eilu (2012) |
| | Reports | | Lupander & Räisänen (1954), Mäkelä (1979, 1980b), Pehkonen (1980, 1983), Rosenberg (1993), Glennmore Hinglands (1997), Grönholm (1997), Karvinen (2003), Eilu et al. (2004) |
| | Metallogenic assessments | | Stigzelius (1944), Mäkelä (1980a), Papunen (1990), Vaasjoki & Huhma (1999), Strauss (2004), Forss (2006), Eilu (2012) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Mäkelä (1979, 1980b), Pehkonen (1980, 1983), Rosenberg (1993), Grönholm (1997) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Mäkelä (1979, 1980b), Pehkonen (1980, 1983), Rosenberg (1993), Grönholm (1997), Ruotoistenmäki (2012) |
| Exploration | Reports | | Mäkelä (1979, 1980b), Pehkonen (1980, 1983), Rosenberg (1993), Grönholm (1997), Karvinen (2003) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Three partially explored Cu-Zn occurrences of possibly VMS type are known within the tract (Table 3). However, these occurrences were considered so modest that most of the estimators believed it possible that no more than one of them will ever become economic, even under the most favourable circumstances. The existence of the Haveri mine, three partially explored occurrences and sets of Zn-rich boulders, some Cu-rich boulders with no source identified in the western part of the tract, and extensive bimodal volcanism were considered to indicate the potential for VMS de-

posits. Also, most of the exploration and drilling carried out in the area has targeted gold, especially since 1990. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Tampere VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 2 | 3 | 4 | | | 2.9 | 0.88 | 31 | 0 | 2.9 | 2818 | 0.0010 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 2 | 2 | 2 | | |
| Individual 2 | 2 | 2 | 3 | | |
| Individual 3 | 2 | 3 | 5 | | |
| Individual 4 | 2 | 2 | 3 | | |
| Individual 5 | 1 | 2 | 4 | | |
| Individual 6 | 1 | 3 | 5 | | |
| Individual 7 | 2 | 3 | 3 | | |
| Individual 8 | 2 | 3 | 3 | | |
| Individual 9 | 2 | 3 | 3 | | |
| Individual 10 | 2 | 4 | 5 | | |
| Individual 11 | 2 | 3 | 4 | | |
| Consensus | 2 | 3 | 4 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen, H. Kujala, J. Luukas, J. Nikander, M. Nironen, K. Rasilainen, P. Sipilä, P: Sorjonen-Ward, T. Törmänen, M. Tiainen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS bimodal-mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Tampere VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 2,000 | 8,200 | 44,000 | 120,000 | 150,000 | 54,000 | 0.40 | 0.040 |
| Zn (t) | 4,300 | 17,000 | 89,000 | 250,000 | 330,000 | 120,000 | 0.39 | 0.040 |
| Pb (t) | 29 | 170 | 2,200 | 15,000 | 22,000 | 5,500 | 0.29 | 0.040 |
| Ag (t) | 0.63 | 2.7 | 15 | 71 | 110 | 29 | 0.28 | 0.040 |
| Au (t) | 0.057 | 0.21 | 0.75 | 1.8 | 2.2 | 0.90 | 0.40 | 0.040 |
| Rock (Mt) | 0.22 | 0.79 | 3.8 | 9.1 | 11 | 4.5 | 0.41 | 0.040 |

t – metric tons; Mt – million metric tons.

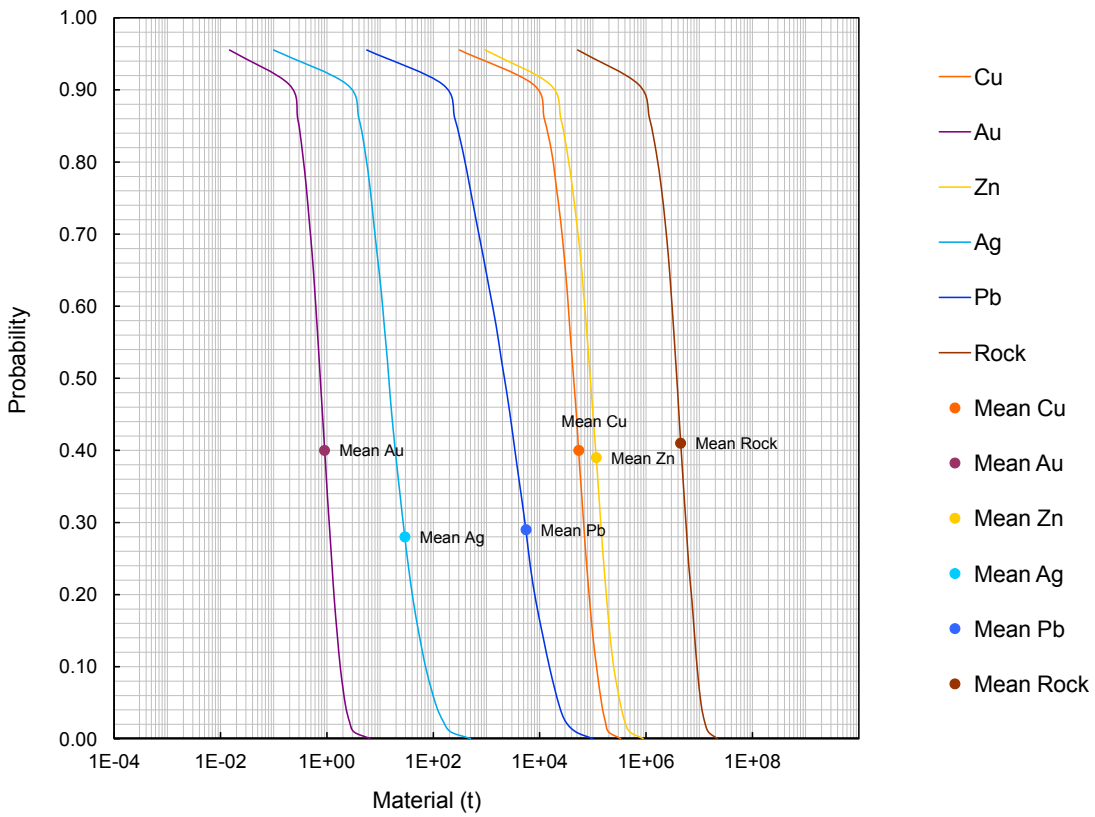


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Tampere VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT TUPALA-KIIPU VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS felsic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Tupala-Kiipu VMS permissive tract is located in southwestern Finland, extending for 50 km to the west, 40 to the south and 20 km to the north of Forssa (Fig. 1). The 1:100,000 KKJ map sheets are 2022, 2024, 2111 and 2113. The UTM map sheets containing the tract are L343, L344, L421 and L422. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Tupala-Kiipu VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 843 | Cu | 0 | Cu | 63,000 | Cu | 14,000 |
| | | | Zn | 0 | Zn | 460,000 | Zn | 89,000 |
| | | | Pb | 0 | Pb | 120,000 | Pb | 11,000 |
| | | | Ag | 0 | Ag | 470 | Ag | 75 |
| | | | Au | 0 | Au | 6.1 | Au | 1.1 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The Tupala-KiipuVMS permissive tract is within 1.90–1.88 Ga Svecofennian volcanic rocks. The tract is defined by the extent of the Forssa Volcanic Suite in the Häme belt. Other criteria used in the tract delineation include the existence of distal Kuroko type Zn-Pb occurrences and the extent of the associated mainly calc-alkaline volcanic rocks, as well as bedrock observation, drill core and geophysical survey data. The tract extends down to 1000 m depth. The depth extension is based on stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored VMS deposits within the tract (Table 2). According to the spatial rule used, deposits less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Tupala-Kiipu VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

Two partially explored VMS occurrences are known within the Tupala-Kiipu VMS permissive tract (Table 3). Another type of occurrence that exists within the tract, and is possibly related to VMS mineralising systems, is the Kotka hydrothermal stringer-type Cu-Co occurrence for which there is no resource data.

Table 3. Significant VMS occurrences in the Tupala-Kiipu VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Kiipu | 6751160 | 3303370 | | 0.1 m @ 8.2 % Zn. Banded lenses few tens cm in thickness | Lakanen (1983), Papunen (1990), Kokkola (1991) |
| Tupala | 6727500 | 3311100 | | 0.76 Mt @ 3.86 % Zn, 0.71 % Pb, 39 g/t Ag, 12 % S | Mäkelä (1983, 1989), Papunen (1990) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Tupala-Kiipu VMS tract are listed in Table 4.

Table 4. Exploration history for the Tupala-Kiipu VMS tract.

| Theme | Type of work | Cu, Zn, Pb analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Bedrock mapping, glacial erratic boulder surveys | Yes | Geological Survey of Finland | 1950s–2000s |
| | Bedrock mapping, glacial erratic boulder surveys | Yes | Outokumpu Oy | 1964–1990 |
| | Bedrock mapping, glacial erratic boulder surveys | Yes | Malmikaivos Oy | 1954–1979 |
| Geochemical surveys | Till and lithogeochemical surveys | Yes | Geological Survey of Finland | 1950s–2000s |
| | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| | Till and lithogeochemical surveys | Yes | Outokumpu Oy | 1964–1990 |
| Airborne geophysical surveys | Regional low-altitude airborne magnetic electric and radiometric survey | | Geological Survey of Finland | 1978–1992 |
| Detailed airborne geophysical surveys | Targeted low-altitude airborne magnetic electric and radiometric survey | | Geological Survey of Finland | 2007 |
| Ground geophysical surveys | Magnetic, slingram, VLF, VLF-R, Sirotem, gravity and IP surveys | | Outokumpu Oy | 1974–1983 |
| | Magnetic and electromagnetic surveys | | Malmikaivos Oy | 1954–1979 |
| | Magnetic and electromagnetic surveys | | Suomen Malmi Oy | 1960s |
| Drilling | Diamond drilling | Yes | Outokumpu Oy | 1974–1983 |
| | Diamond drilling | Yes | Malmikaivos Oy | 1955–1957 |
| Other | Feasibility study | Yes | Outokumpu Oy | 1983 |
| | Regional ore potential survey and deposit modelling | Yes | Geological Survey of Finland | 1990s–2000s |

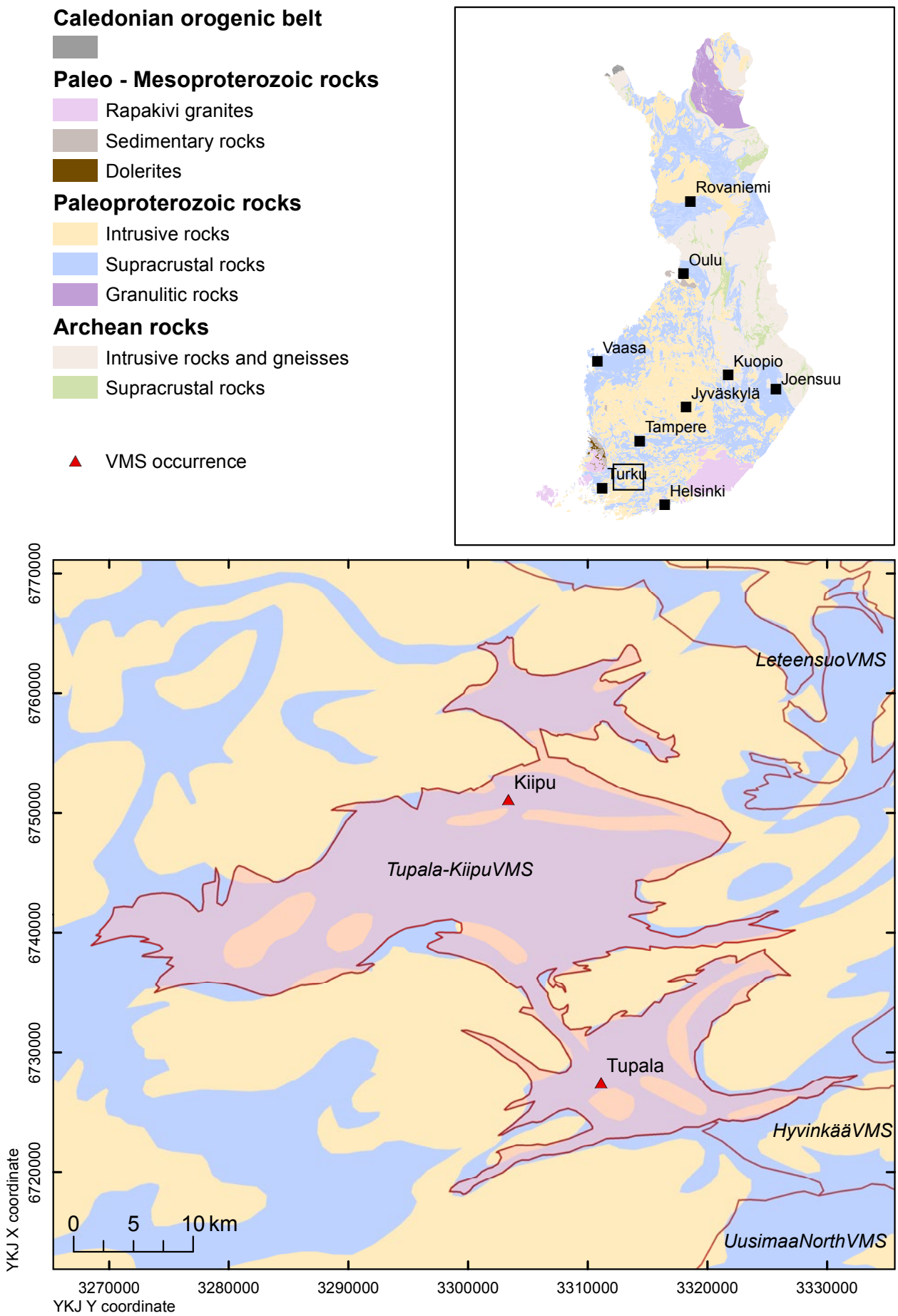


Fig. 1. Location of the Tupala-Kiipu VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Tupala-Kiipu VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Tupala-Kiipu VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Reports | | Mäkelä (1980, 1989), Hakkarainen (1994), Tiainen & Viita (1994) |
| Mineral occurrences | Reports | | Heiskanen (1959), Lakanen (1983), Mäkelä (1980, 1983, 1989), Porkka et al. (1983), Isomäki (1984), Papunen (1990), Ruskeeniemi (1990), Kokkola (1991), Tiainen & Viita (1994) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Metallogenic assessments | | Hakkarainen (1994), Tiainen & Viita (1994) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Isomäki (1984), Kokkola (1991), Tiainen & Viita (1994) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Lakanen (1983), Isomäki (1984), Kokkola (1991), Tiainen & Viita (1994) |
| Exploration | Reports | | Heiskanen (1959), Mäkelä (1983), Isomäki (1984), Kokkola (1991), Tiainen & Viita (1994) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Two partially explored VMS occurrences are known within the tract (Table 3). Other factors favourable for VMS deposits within the tract include the extensive calc-alkaline bimodal volcanism in a volcanic arc setting, the presence of an 8-km-long domain of hydrothermal alteration around the Kiipu occurrence, and the indications of subvolcanic intrusions. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Tupala-Kiipu VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 2 | 3 | | | 1.9 | 0.84 | 43 | 0 | 1.9 | 843 | 0.0023 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 1 | 2 | 3 | | |
| Individual 2 | 0 | 0 | 1 | | |
| Individual 3 | 0 | 1 | 2 | | |
| Individual 4 | 0 | 1 | 3 | | |
| Individual 5 | 1 | 1 | 2 | | |
| Individual 6 | 1 | 1 | 3 | | |
| Individual 7 | 1 | 2 | 3 | | |
| Individual 8 | 1 | 2 | 3 | | |
| Individual 9 | 1 | 3 | 4 | | |
| Individual 10 | 2 | 3 | 4 | | |
| Mean | 1 | 3 | 4 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen, H. Kujala, J. Luukas, J. Nikander, M. Nironen, K. Rasilainen, P. Sipilä, T. Törmänen, M. Tiainen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS felsic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Tupala-Kiipu VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 450 | 14,000 | 140,000 | 300,000 | 63,000 | 0.19 | 0.070 |
| Zn (t) | 0 | 2,000 | 89,000 | 1,200,000 | 2,400,000 | 460,000 | 0.19 | 0.070 |
| Pb (t) | 0 | 150 | 11,000 | 180,000 | 390,000 | 120,000 | 0.13 | 0.070 |
| Ag (t) | 0 | 1.6 | 75 | 1,000 | 2,200 | 470 | 0.17 | 0.070 |
| Au (t) | 0 | 0.029 | 1.1 | 12 | 25 | 6.1 | 0.18 | 0.070 |
| Rock (Mt) | 0 | 0.10 | 2.9 | 38 | 66 | 11 | 0.21 | 0.070 |

t – metric tons; Mt – million metric tons.

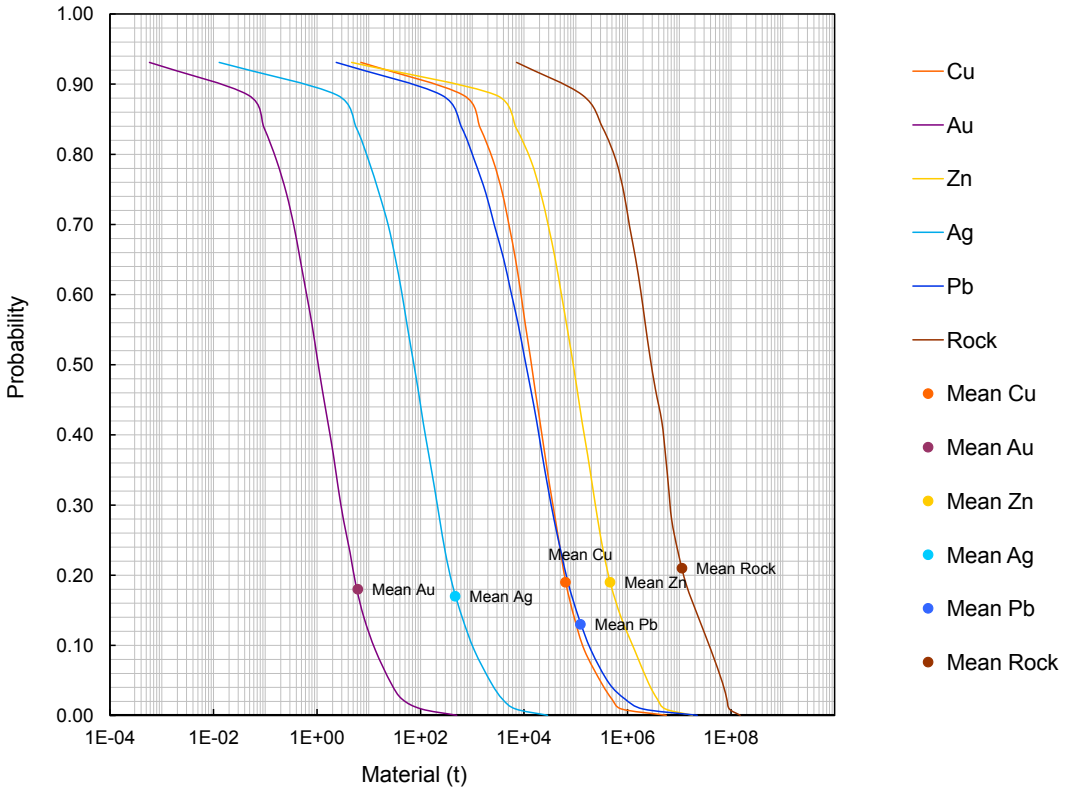


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Tupala-Kiipu VMS permissive tract.

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# VMS Zn-Cu ASSESSMENT FOR THE TRACT UPPER SVECOFENNIAN VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS bimodal-mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Upper Svecofennian VMS permissive tract consists of several areas of supracrustal rocks within the Central Finland granitoid complex, which is an approximately 200-km-wide and 300-km-long circular area in central Finland (Fig. 1). The 1:100,000 KKJ map sheets are 2212, 2213, 2214, 2243, 2244, 2331, 2332, 2341, 2343, 3222, 3311, 3312, 3321 and 3322. The UTM map sheets containing the tract are N343, N411, N412, N424, N442, P413, P414, P423, P424, P431, P432, P434, P441, P442, P443, Q411, Q413 and Q431. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Upper Svecofennian VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 17/10/2010, 10/12/2012 | 1 | 2224 | Cu | 0 | Cu | 33,000 | Cu | 21,000 |
| | | | Zn | 0 | Zn | 68,000 | Zn | 41,000 |
| | | | Pb | 0 | Pb | 3,400 | Pb | 560 |
| | | | Ag | 0 | Ag | 17 | Ag | 6.4 |
| | | | Au | 0 | Au | 0.54 | Au | 0.39 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The Upper Svecofennian VMS permissive tract is within the Central Finland granitoid complex. The tract is delineated on the basis of the extent of the 1.88 Ga Upper Svecofennian supracrustal rocks in the area and it includes the Kovelahti, Haukkamaa, Mustajärvi, Kalmari, Saunakylä, Pihtipudas, Karttula and Perho Suites and the Haasiapuro Formation. Indications of VMS-style Zn-Cu mineralisation as well as bedrock observation, drill core and geophysical survey data were used to define the tract area. The tract extends down to 1000 m depth. The depth extension is based on geological interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There are no well-explored VMS deposits within the Upper Svecofennian VMS permissive tract (Table 2). According to the spatial rule used, deposits less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Upper Svecofennian VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences and related deposit types

Eight partially explored occurrences of possible VMS type are known within the Upper Svecofennian VMS permissive tract (Table 3). In addition to these, a potential VMS exploration target is known at Saunakylä (x=7003083, y=3383974; Nikander 1993).

Table 3. Known VMS occurrences in the Upper Svecofennian VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Eltoneva | 7049097 | 3377964 | | 5 m 0.18 % Cu, 2 m 17.9 % S; a deep gravity anomaly possibly related to a massive sulphide deposit | Kärkkäinen & Sarapää (1999) |
| Haasiapuro | 7062200 | 3439550 | | 3 m @ 1.4 % Zn, 0.3 % Pb | Hakanen et al. (1997), Hakanen (1998) |
| Kärnä | 7009190 | 3448500 | | 1.25 m @ 4.0 % Zn, 3.59 % Pb, 58 g/t Ag | Ekdahl (1980), Oivanen (1974a), Rasilainen (1984) |
| Muittari | 6956651 | 3400631 | | 1 m @ 11.5 % Zn, 128 g/t Ag, 3.1 m @ 1.6 % Zn, 1.9 %; 3 m @ 0.60 % Cu | Sipilä (1985a, 1985b) |
| Pirttilampi | 6944711 | 3416253 | | 1 m 1–2 % Zn | Oivanen (1974b) |
| Riuttaskorpi | 6886990 | 3325311 | | 8 m @ 116 ppm Ag, 0.23 % Cu, 0.59 % Pb, 0.30 % Zn | Oivanen (1981), Kärkkäinen (1991) |
| Sykäräinen | 7058946 | 3370801 | | 0.195 Mt @ 1.95 % Cu, 0.25 % Zn, 52 ppm Ag, 3.02 % S | Sandberg (1986), Lindmark (1976) |
| Tökrö | 6982350 | 3439400 | | Sphalerite as an irregular dissemination and in narrow veins in mica gneiss | Sipilä (1987), Västi (1992) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Upper Svecofennian VMS tract are listed in Table 4.

Table 4. Exploration history for the Upper Svecofennian VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Bedrock mapping, glacial erratic boulder surveys | Yes | Geological Survey of Finland | 1950s–2000s |
| | Bedrock mapping, glacial erratic boulder surveys | Yes | Outokumpu Oy | 1970s–2000s |
| Geochemical surveys | Targeted till and lithogeochemical surveys | Yes | Geological Survey of Finland | 1960s–1990s |
| | Targeted till and lithogeochemical surveys | Yes | Outokumpu Oy | 1970s–2000s |
| | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electro-magnetic and radiometric surveys | | Geological Survey of Finland | 1977–2002 |
| Ground geophysical surveys | Magnetic, electromagnetic, gravimetric, multi frequency EM-soundings, IP, reflection seismics | | Geological Survey of Finland | 1960s–1990s |
| | Magnetic, gravity, IP, Gefinex-400S and slingram surveys | | Outokumpu Oy | 1970s–2000s |
| Drilling | A few tens of diamond-drill holes | Yes | Geological Survey of Finland | 1960s–1990s |
| | A few tens of diamond-drill holes | Yes | Outokumpu Oy | 1970s–2000s |

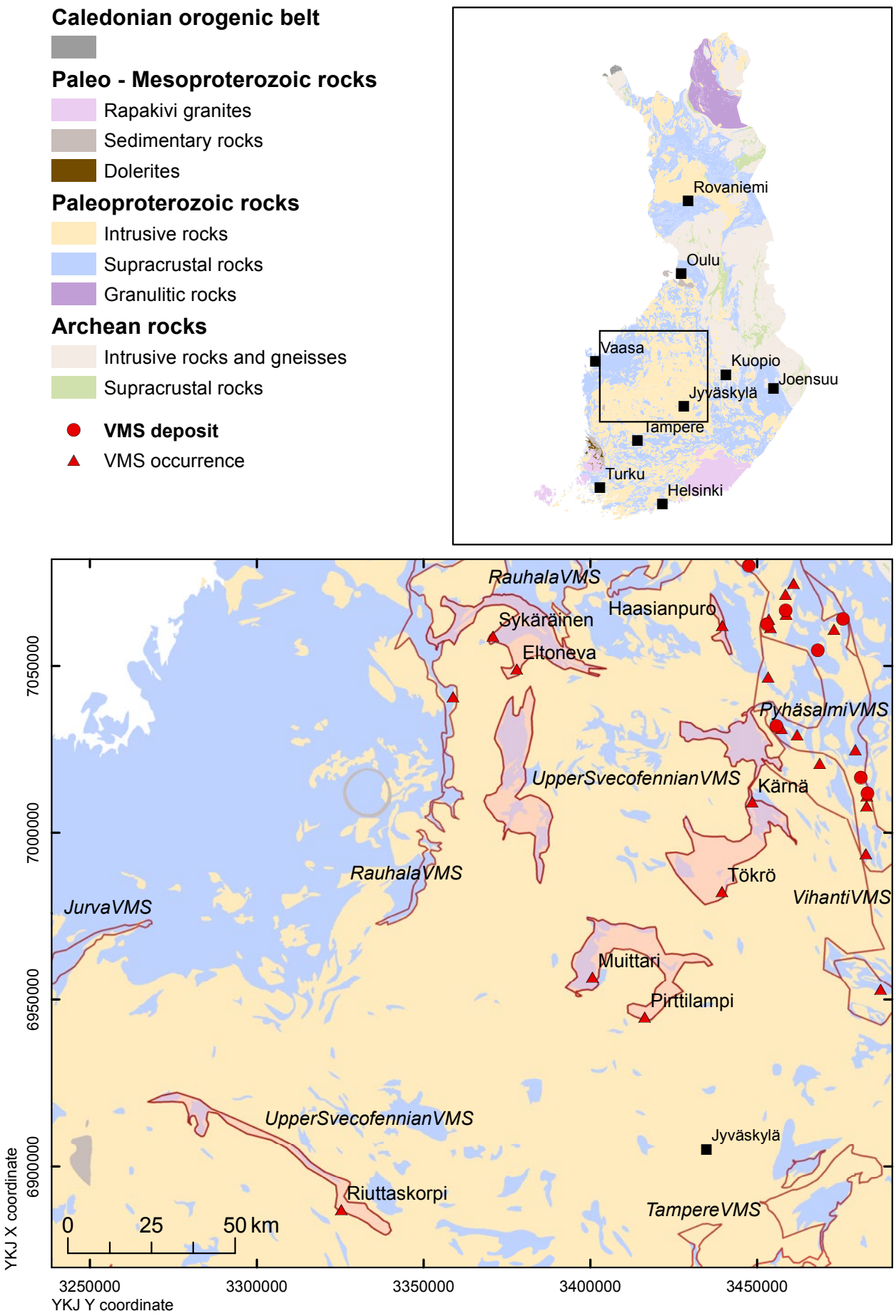


Fig. 1. Location of the Upper Svecofennian VMS permissive tract.

### Sources of information

Principal sources of information used by the assessment team for the delineation of the Upper Svecofennian VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Upper Svecofennian VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Reports | | Rasilainen (1984) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Reports | | Oivanen (1974a, 1974b, 1981), Lindmark (1976b), Ekdahl (1980), Rasilainen (1984), Sipilä (1985a, 1985b, 1987), Sandberg (1986), Nikander (1993), Hakanen et al. (1997) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Oivanen (1974b, 1981), Rasilainen (1984), Sipilä (1985a, 1987), Kärkkäinen (1991), Nikander (1993), Hakanen et al. (1997), Hakanen (1998), Kärkkäinen & Sarapää (1999) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Oivanen (1974b, 1981), Lindmark (1976b), Sipilä (1985a, 1987), Sandberg (1986), Nikander (1993), Hakanen et al. (1997), Hakanen (1998) Kärkkäinen & Sarapää (1999), Kukkonen & Lahtinen (2006) |
| Exploration | Reports | | Laitakari (1968), Oivanen (1974a, 1974b, 1981), Lindmark (1976a, 1976b), Ekdahl (1980), Sipilä (1985a, 1985b, 1987), Sandberg (1986), Kärkkäinen (1991), Västi (1992), Nikander (1993), Hakanen et al. (1997), Hakanen (1998), Kärkkäinen & Sarapää (1999) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Eight partially explored VMS occurrences are known within the Upper Svecofennian VMS permissive tract (Table 3). However, most of the estimators believed that none of these could become economic, even under the most favourable circumstances. The existence of the VMS occurrences listed in Table 3, the locally abundant felsic volcanic and subvolcanic rocks and Cu-Zn mineralised boulders, and the fact that the supracrustal rocks belong to the same age group as the extensively mineralised Skellefte Belt in Sweden were considered to indicate the potential for VMS deposits. Drilling within the tract has been scarce and limited to the known occurrences. Large parts of the felsic volcanic-dominated subareas are poorly explored. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Upper Svecofennian VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 2 | 3 | | | 1.7 | 1.1 | 63 | 0 | 1.7 | 2224 | 0.00076 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 1 | 2 | | |
| Individual 2 | 0 | 1 | 2 | | |
| Individual 3 | 2 | 4 | 6 | | |
| Individual 4 | 0 | 2 | 3 | | |
| Individual 5 | 0 | 1 | 2 | | |
| Individual 6 | 0 | 2 | 5 | | |
| Individual 7 | 0 | 0 | 1 | | |
| Individual 8 | 0 | 1 | 2 | | |
| Mean | 0 | 2 | 3 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, O. Kontoniemi, J. Kousa, K. Rasilainen, P. Sipilä, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS bimodal-mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Upper Svecofennian VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 21,000 | 84,000 | 110,000 | 33,000 | 0.37 | 0.18 |
| Zn (t) | 0 | 0 | 41,000 | 170,000 | 230,000 | 68,000 | 0.36 | 0.18 |
| Pb (t) | 0 | 0 | 560 | 10,000 | 17,000 | 3,400 | 0.24 | 0.18 |
| Ag (t) | 0 | 0 | 6.4 | 45 | 81 | 17 | 0.25 | 0.18 |
| Au (t) | 0 | 0 | 0.39 | 1.3 | 1.6 | 0.54 | 0.39 | 0.18 |
| Rock (Mt) | 0 | 0 | 1.9 | 6.8 | 8.3 | 2.7 | 0.39 | 0.18 |

t – metric tons; Mt – million metric tons.

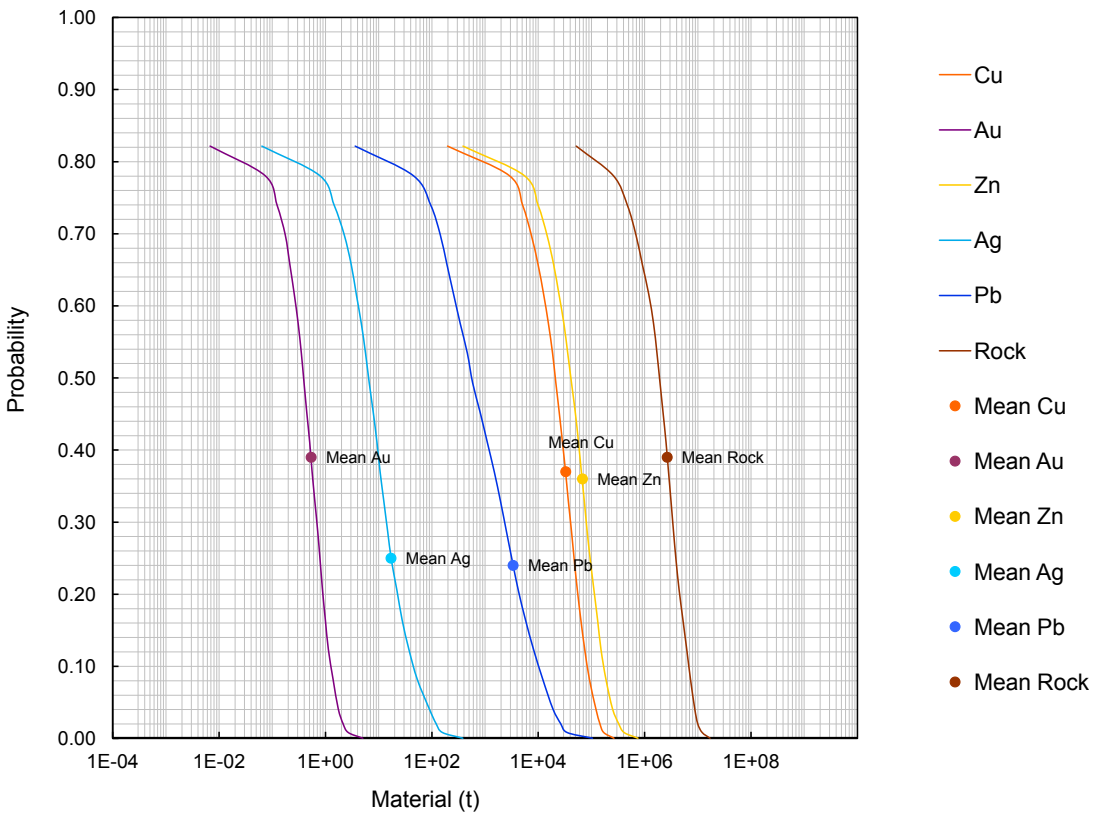


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Upper Svecofennian VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT UUSIMAA EAST VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS felsic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Uusimaa East VMS permissive tract is located in southwestern Finland. It is a domain comprising several irregular parts within an area 160 km long and 70 km wide. It extends for 100 km to the WSW and 70 km to the E of the city of Helsinki (Fig. 1). The 1:100,000 KKJ map sheets are 2011, 2013, 2014, 2023, 2031, 2032, 2041, 2034, 2043, 3012 and 3022. The UTM map sheets containing the tract are K343, K344, K421, K422, K424, L333, L411, L412, L413, L414, L431, L432 and L433. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Uusimaa East Cu-Zn tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 3061 | Cu | 248 | Cu | 64,000 | Cu | 15,000 |
| | | | Zn | 630 | Zn | 450,000 | Zn | 93,000 |
| | | | Pb | 368 | Pb | 110,000 | Pb | 11,000 |
| | | | Ag | 3.0 | Ag | 460 | Ag | 78 |
| | | | Au | 0 | Au | 6.0 | Au | 1.1 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by ca. 1900 Ma Svecofennian volcanic rocks of the Uusimaa supracrustal belt. The tract covers the potential hosting sequences containing felsic fine-grained volcanic or volcanic-sedimentary rocks between the Orijärvi tract and the Viborg rapakivi massif. The tract is based on the extent of felsic to intermediate calc-alkaline volcanic rocks and the existence numerous VMS occurrences in the area. The tract extends down to 1000 m depth. The depth extension is based on stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There is one well-explored VMS deposit within the Uusimaa East Cu-Zn permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other are counted as one in this assessment.

Table 2. Known VMS deposits in the Uusimaa East Cu-Zn tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Backgränd | 6672448 | 3315400 | 1900 | 0.046 | 0.54 | 1.37 | 0.80 | 65 | | Cu | 248 | Isomäki (1984) |
| | | | | | | | | | | Zn | 630 | |
| | | | | | | | | | | Pb | 368 | |
| | | | | | | | | | | Ag | 3 | |
| | | | | | | | | | | Au | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

There are more than nine partially explored VMS occurrences within the Uusimaa East Cu-Zn tract (Table 3). These include a few very small historic mines.

Table 3. Significant VMS occurrences in the Uusimaa East Cu-Zn tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Fiskars | 6673328 | 3306607 | 1900 | 5 m @ 1.2 % Zn, 6 g/t Ag; 0.8 m @ 2.52 % Zn, 0.13 % Pb, 15 g/t Ag; 2.1 m @ 1.34 % Zn | Mäkelä (1981a), Isomäki (1982a) |
| Grundsjö | 6665895 | 3320770 | 1900 | 3.1 m @ 0.41% Cu, 0.70 % Zn | Isomäki (1990a), Kokkola (1991) |
| Hermala | 6683381 | 3324920 | 1900 | 1.1 m @ 2.24 % Zn, 0.3 % Pb, 9 g/t Ag; 0.9 m @ 3.54 % Zn, 0.22 % Cu; 10.6 m @ 0.77 % Zn, 0.57 % Pb, 23 g/t Ag | Mäkelä (1981b), Papunen (1990) |
| Karhuniemi | 6686992 | 3330291 | 1900 | 4.2 m @ 7.1% Zn, 2.65 % Pb, 44 g/t Ag; 1.45 m @ 3.5 % Zn, 1.7 % Pb, 23 g/t Ag; 2.35 m @ 1.6 % Zn, 0.26 % Pb | Latvalahti (1979a), Isomäki (1982b) |
| Kuovila | 6675802 | 3299989 | 1900 | 10,000 t @ 1.4 % Zn, 0.4 % Pb, 6 g/t Ag | Isomäki (1990b), Skyttä et al. (2005) |
| Lågnäs | 6661547 | 3336014 | 1900 | 4.8 m @ 6.8 % Zn; 15.3 m @ 3.3 % Zn; 2.9 m @ 1.74 % Zn; 0.35 m @ 21.6 % Zn, 0.25 % Cu, 12 g/t Ag | Latvalahti (1979b) |
| Nyckeln | 6676658 | 3302532 | 1900 | Known extent 20 x 37 x 100 m; historic mining: 566 t @ 0.5 % Cu | Isomäki (1989), Puustinen (2003) |
| Paavola | 6683586 | 3328114 | 1900 | 4.35 m @ 1.0 % Cu, 0.65 % Zn, 0.43 % Pb, 23 g/t Ag; 0.5 m @ 6.0 % Zn, 0.23 % Cu, 12 g/t Ag; 0.1 m @ 16.7 % Zn | Latvalahti (1981), Papunen (1990) |
| Soukka | 6673086 | 3370762 | 1900 | 2.2 m @ 2.17 % Zn, 0.15 % Cu, 0.23 % Pb; 1.9 m @ 13.9 % Zn, 0.16 % Cu, 8 g/t Ag; 1.4 m @ 4.23 % Zn, 0.12 % Cu, 0.25 % Pb, 15 g/t Ag | Latvalahti (1980) |

Ma – million years; Mt – million metric tons; t – metric ton.

## Exploration history

Exploration activities for VMS deposits within the Uusimaa East Cu-Zn tract are listed in Table 4.

Table 4. Exploration history for the Uusimaa East Cu-Zn tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1860s– |
| | Outcrop and boulder observations | Yes | Suomen Malmi | 1940s–1950s |
| | Outcrop and boulder observations | Yes | Outokumpu | 1950s–1990s |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Detailed till geochemical survey | Yes | Geological Survey of Finland | |
| | Detailed till and biogeochemical geochemical surveys | Yes | Outokumpu | 1950s–1990s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1975–2002 |
| Ground geophysical surveys | Magnetic and electromagnetic surveys | | Geological Survey of Finland | 1930s–2000s |
| | Magnetic, slingram, VLF, charged potential, EM-31, and IP surveys | | Outokumpu | 1950s–1990s |
| Drilling | Tens of diamond-drill holes | Yes | Outokumpu | 1950s–1990s |
| | A few diamond-drill holes | Yes | Suomen Malmi | 1940s–1950s |
| | A few diamond-drill holes | Yes | Finnish American Mining Co | 1907–1912 |
| | A few diamond-drill holes | Yes | Vuoksenniska | 1940s |
| | A few diamond-drill holes | Yes | Geological Survey of Finland | 1970s–2000s |
| Other | Stratigraphic, structural, mineralogical, metallogenic and Pb-isotopic investigations | Yes | Geological Survey of Finland, University of Helsinki, Åbo Akademi University, University of Turku | 1900s–2010s |

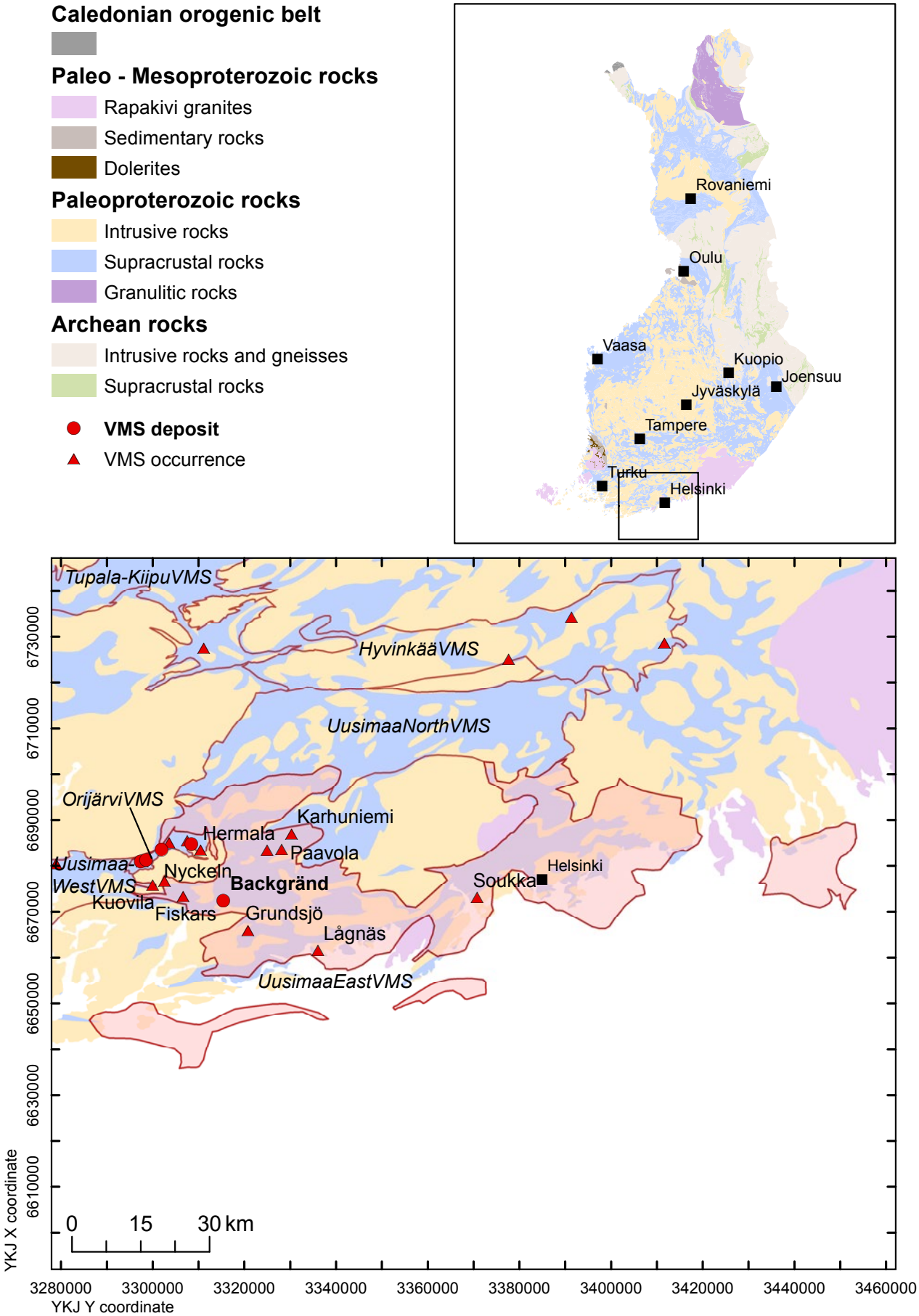


Fig. 1. Location of the Uusimaa East VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Uusimaa East Cu-Zn tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Uusimaa East Cu-Zn tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:100–1:10,000 | Mäkelä (1989), Colley & Westra (1987), Kokkola (1991), Väisänen et al. (2002), Skyttä et al. (2005) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Deposit descriptions | | Mäkelä (1989), Papunen (1990) |
| | Reports | | Latvalahti (1979a, 1979b, 1980, 1981), Isomäki (1984, 1986, 1990a, 1990b), Mäkelä (1981a, 1981b, 1989), Papunen (1990) |
| | Metallogenic assessments | | Outokumpu Oy malminetsintä (1986), Mäkelä (1989), Papunen (1990) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Isomäki (1987), Papunen (1990), Kokkola (1991) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Latvalahti (1979a, 1979b, 1980), Mäkelä (1981a, 1981b), Isomäki (1982a, 1982b, 1984, 1986, 1987, 1990a, 1990b) |
| Exploration | Reports | | Saastamoinen (1975), Latvalahti (1979a, 1979b, 1980, 1981), Mäkelä (1981a, 1981b), Isomäki (1982a, 1982b, 1984, 1986, 1987, 1989, 1990a 1990b), Outokumpu Oy malminetsintä (1986), Kokkola (1991), Sarapää, O. pers. comm. (22/09/2000, 14/11/2000) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

A large number of partially explored VMS occurrences are known within the tract (Table 3). However, these occurrences were considered so modest that most of the estimators believed it possible that no more than one of them will ever become economic, even under the most favourable circumstances. The existence of the large number of partially explored occurrences and extensive bimodal volcanism were considered to indicate the potential for VMS deposits. Very little exploration for metallic ores has been carried out in the area since the mid-1980s. No consensus was reached in the discussion, and mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Uusimaa East Cu-Zn tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 2 | 3 | | | 1.9 | 0.84 | 43 | 1 | 2.9 | 3061 | 0.00096 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 1 | 2 | 4 | | |
| Individual 2 | 1 | 1 | 2 | | |
| Individual 3 | 1 | 3 | 5 | | |
| Individual 4 | 0 | 0 | 1 | | |
| Individual 5 | 1 | 2 | 3 | | |
| Individual 6 | 1 | 1 | 3 | | |
| Individual 7 | 0 | 2 | 3 | | |
| Individual 8 | 0 | 1 | 1 | | |
| Individual 9 | 0 | 2 | 4 | | |
| Individual 10 | 1 | 2 | 4 | | |
| Individual 11 | 1 | 5 | 8 | | |
| Mean | 1 | 2 | 3 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen, H. Kujala, J. Luukas, J. Nikander, M. Nironen, K. Rasilainen, P. Sipilä, P. Sorjonen-Ward, M. Tiainen, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS felsic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Uusimaa East Cu-Zn tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 540 | 15,000 | 130,000 | 280,000 | 64,000 | 0.19 | 0.060 |
| Zn (t) | 0 | 2,600 | 93,000 | 1,100,000 | 2,300,000 | 450,000 | 0.20 | 0.060 |
| Pb (t) | 0 | 200 | 11,000 | 190,000 | 420,000 | 110,000 | 0.16 | 0.060 |
| Ag (t) | 0 | 1.7 | 78 | 1,000 | 2,200 | 460 | 0.18 | 0.060 |
| Au (t) | 0 | 0.035 | 1.1 | 12 | 26 | 6.0 | 0.18 | 0.060 |
| Rock (Mt) | 0 | 0.11 | 2.9 | 36 | 68 | 11 | 0.21 | 0.060 |

t – metric tons; Mt – million metric tons.

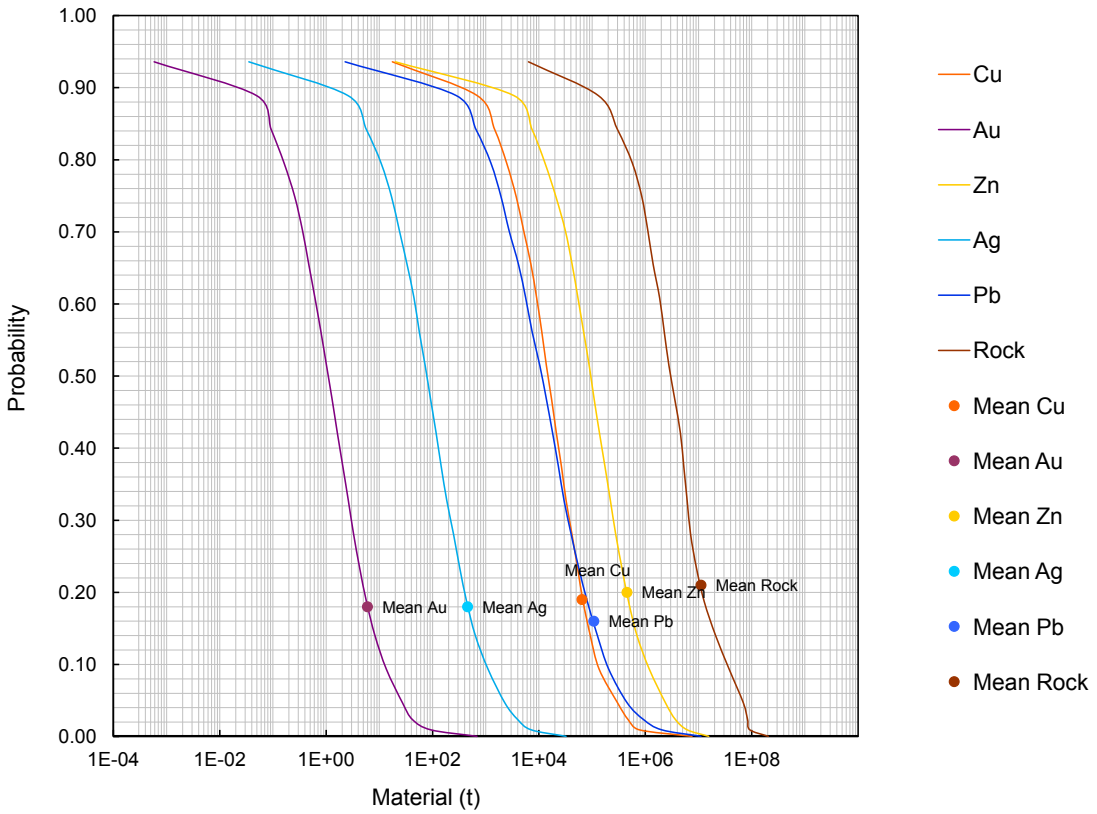


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Uusimaa East VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT UUSIMAA NORTH VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS felsic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Uusimaa North VMS permissive tract is located in southwestern Finland. It is an 80-km-long and 20-km-wide zone striking WSW, 40–80 km to the NE and WNW of the city of Helsinki (Fig. 1). The 1:100,000 KKJ map sheets are 2023, 2024, 2041, 2042, 2043 and 2044. The UTM map sheets containing the tract are L334, L412, L421, L414 and L423. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Uusimaa North VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 1436 | Cu | 0 | Cu | 8,000 | Cu | 0 |
| | | | Zn | 0 | Zn | 61,000 | Zn | 0 |
| | | | Pb | 0 | Pb | 14,000 | Pb | 0 |
| | | | Ag | 0 | Ag | 57 | Ag | 0 |
| | | | Au | 0 | Au | 0.94 | Au | 0 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by ca. 1900 Ma Svecofennian volcanic rocks of the Uusimaa supracrustal belt. The tract covers the potential hosting sequences containing granulite-facies, felsic to intermediate rocks of possibly volcanic origin in the northern part of the Uusimaa belt. The tract is based on the existence of calc-alkaline, felsic to intermediate volcanic rocks potential to host VMS-style mineralisation. The tract extends down to 1000 m depth. The depth extension is based on

stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There are no well-explored VMS deposits within the Uusimaa North VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Uusimaa North VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

There are no partially explored VMS occurrences within the Uusimaa North VMS permissive tract (Table 3).

Table 3. Significant VMS occurrences in the Uusimaa North VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| None | | | | | |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Uusimaa North VMS tract are listed in Table 4.

Table 4. Exploration history for the Uusimaa North VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1900s– |
| | Outcrop and boulder observations | Yes | Outokumpu | 1950s–1990s |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Detailed till geochemical survey | Yes | Geological Survey of Finland | 1960s–1990s? |
| | Detailed till and humus geochemical surveys | Yes | Outokumpu | 1950s–1990s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1978–1999 |
| Ground geophysical surveys | Magnetic and electromagnetic surveys | | Geological Survey of Finland | 1960s–1990s? |
| | Magnetic, slingram, VLF, gravimetric and IP surveys | | Outokumpu | 1960s–1980s |
| Drilling | A few tens(?) of diamond-drill holes | Yes | Outokumpu | 1960s–1980s |
| | A few tens(?) of diamond-drill holes | Yes | Geological Survey of Finland | 1960s–2000s |
| Other | Stratigraphic, structural, mineralogical, metallogenic and Pb-isotopic investigations | Yes | Geological Survey of Finland, University of Helsinki, Åbo Akademi University, University of Turku | 1900s–2010s |

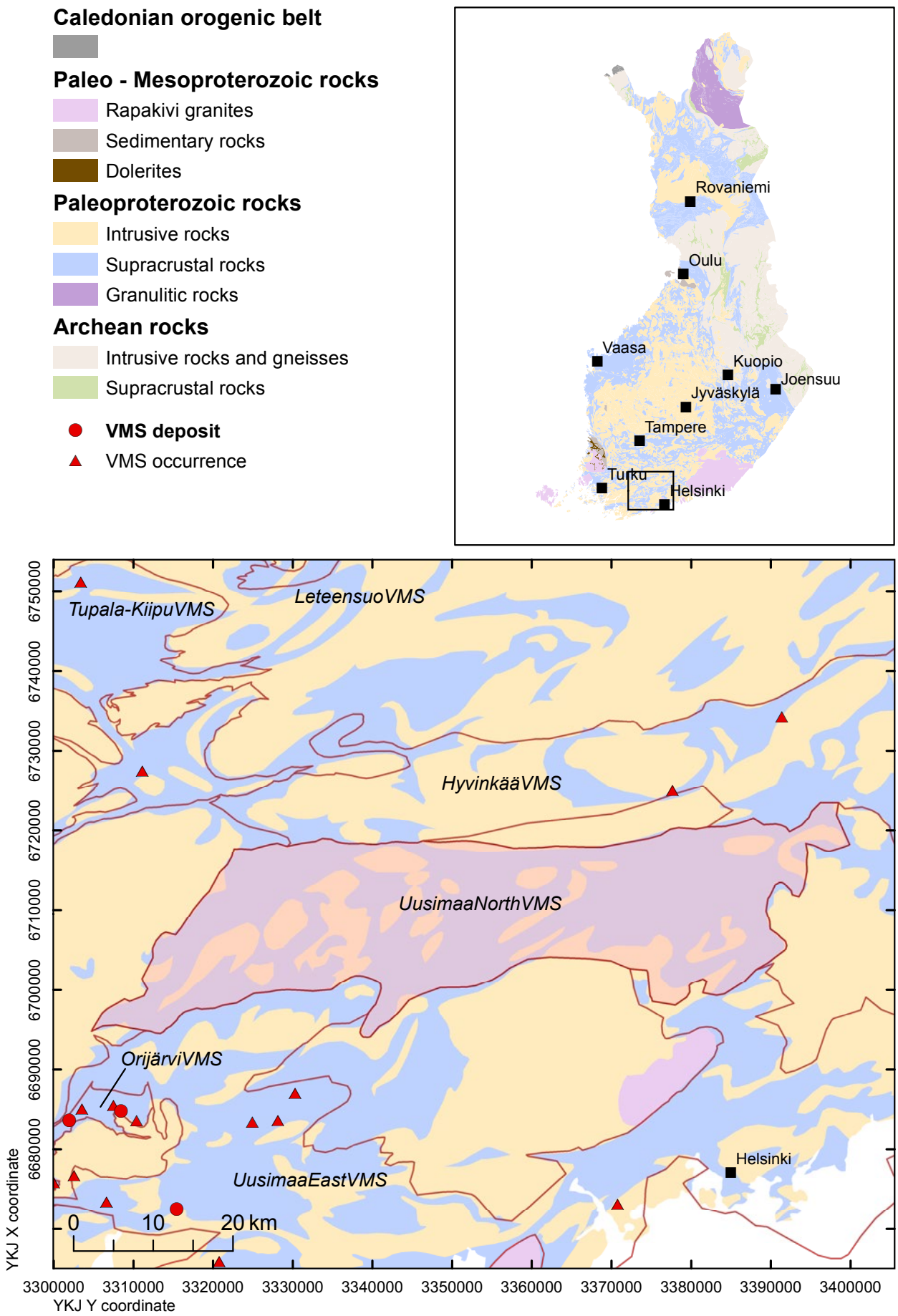


Fig. 1. Location of the Uusimaa North VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Uusimaa North VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Uusimaa North VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:100–1:10,000 | Colley & Westra (1987), Väisänen et al. (2002) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Deposit descriptions | | Papunen (1990) |
| | Metallogenic assessments | | Mäkelä (1989) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Isomäki (1987), Papunen (1990) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Isomäki (1987) |
| Exploration | Reports | | Isomäki (1987), Papunen (1990) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

No partially explored VMS occurrences are known within the tract (Table 3). A few variably Zn- or Cu-mineralised boulders without an obvious source exist within the area. The possible existence of felsic to intermediate volcanic rocks in an extensive area within the Uusimaa belt, which contains the Orijärvi VMS tract with several Cu-Zn mines, was seen as the main positive factor for any economic deposit to occur within the Uusimaa North VMS tract. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Uusimaa North VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 0 | 0 | 1 | | | 0.30 | 0.50 | 170 | 0 | 0.30 | 1436 | 0.00021 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 0 | 0 | | |
| Individual 2 | 0 | 0 | 1 | | |
| Individual 3 | 0 | 0 | 1 | | |
| Individual 4 | 0 | 0 | 1 | | |
| Individual 5 | 0 | 0 | 1 | | |
| Individual 6 | 0 | 0 | 1 | | |
| Individual 7 | 0 | 1 | 2 | | |
| Individual 8 | 0 | 0 | 1 | | |
| Individual 9 | 0 | 1 | 2 | | |
| Individual 10 | 0 | 0 | 1 | | |
| Individual 11 | 0 | 1 | 2 | | |
| Consensus | 0 | 0 | 1 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): O. Kontoniemi, H. Kujala, J. Luukas, J. Nikander, M. Nironen, K. Rasilainen, P. Sipilä, P. Sorjonen-Ward, M. Tiainen, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS felsic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Uusimaa North VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 0 | 0 | 9,700 | 29,000 | 8,000 | 0.11 | 0.70 |
| Zn (t) | 0 | 0 | 0 | 61,000 | 180,000 | 61,000 | 0.10 | 0.70 |
| Pb (t) | 0 | 0 | 0 | 8,500 | 28,000 | 14,000 | 0.080 | 0.70 |
| Ag (t) | 0 | 0 | 0 | 55 | 180 | 57 | 0.10 | 0.70 |
| Au (t) | 0 | 0 | 0 | 0.76 | 2.7 | 0.94 | 0.090 | 0.70 |
| Rock (Mt) | 0 | 0 | 0 | 2.1 | 5.5 | 1.6 | 0.11 | 0.70 |

t – metric tons; Mt –million metric tons.

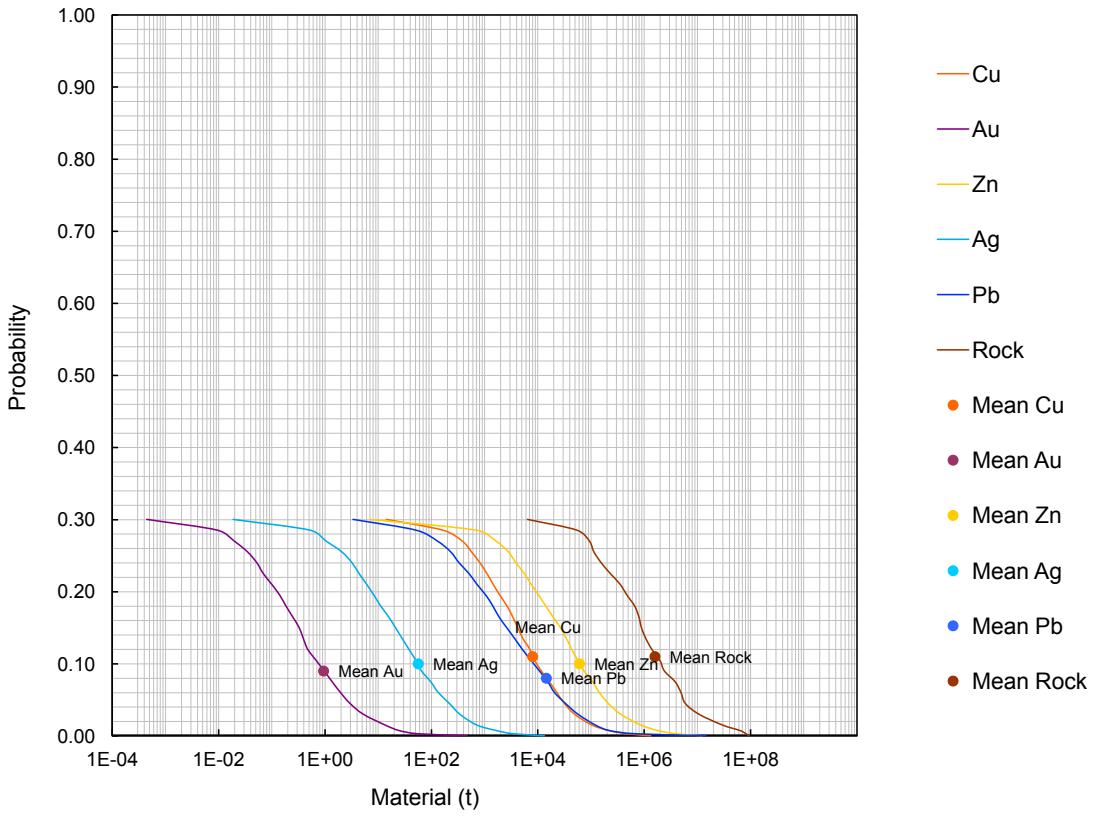


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Uusimaa North VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT UUSIMAA WEST VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS felsic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Uusimaa West VMS permissive tract is located in southwesternmost Finland. It is a domain comprising several irregular parts within an area 150 km long and 100 km wide. It extends for 65 km to the southeast and 80 km to the west of the city of Turku (Fig. 1). The 1:100,000 KKJ map sheets are 1014, 1023, 1024, 1031, 1032, 1033, 1041, 1042, 1043, 2011, 2012, 1023 and 1024. The UTM map sheets containing the tract are K322, K323, K324, K341, K342, K344, L311, L312, L313, L314, L321, L323, L331, L332, L333 and L341. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Uusimaa West VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km$^2$) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 3163 | Cu | 6,912 | Cu | 47,000 | Cu | 8,400 |
| | | | Zn | 76,032 | Zn | 320,000 | Zn | 53,000 |
| | | | Pb | 45,360 | Pb | 82,000 | Pb | 5,700 |
| | | | Ag | 186 | Ag | 340 | Ag | 42 |
| | | | Au | 0 | Au | 4.1 | Au | 0.60 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by ca. 1900 Ma Svecofennian volcanic rocks of the Uusimaa supracrustal belt. The tract covers the potential hosting sequences containing felsic fine-grained volcanic or volcanic-sedimentary rocks from west of the Orijärvi VMS tract to the eastern contact of the Åland rapakivi batholith. The tract is based on the existence of felsic to intermediate calc-alkaline volcanic rocks and a few VMS occurrences in that area. The tract extends down to 1000 m depth. The depth extension is based on stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There is one well-explored VMS deposit within the Uusimaa West VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Uusimaa West VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Attu | 6684494 | 3240243 | 1900 | 4.32 | 0.16 | 1.76 | 1.05 | 43 | | Cu<br>Zn<br>Pb<br>Ag<br>Au | 6,912<br>76,032<br>45,360<br>186 | Hangala (1987), Anttonen (1992) |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences and related deposit types

There are four partially explored VMS occurrences within the Uusimaa West VMS tract (Table 3). These include very small historical copper mines.

Table 3. VMS occurrences in the Uusimaa West VMS tract. Murom, Nurkkila and Vestlax are old historical mines with tonnages and grades estimated more than 200 years after mining.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Murom | 6672688 | 3272655 | 1900 | Mined: 14 t @ 0.5 % Cu | Puustinen (2003) |
| Nurkkila | 6680468 | 3278868 | 1900 | Mined: 14 t @ 0.5 % Cu | Puustinen (2003) |
| Träskböle | 6680158 | 3274247 | 1900 | 1 m @ 1.3 % Zn, 1.5 % Cu, 23 ppm Ag; 0.2 m @ 7.7 % Zn and 0.3 % Cu | Latvalahti (1980), Isomäki (1981) |
| Vestlax | 6671377 | 3265133 | 1900 | Mined: 14 t @ 0.5 % Cu | Puustinen (2003) |

Ma – million years; Mt – million metric tons; t – metric ton.

## Exploration history

Exploration activities for VMS deposits within the Uusimaa West VMS tract are listed in Table 4.

Table 4. Exploration history for the Uusimaa West VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop observations and boulder survey | Yes | Geological Survey of Finland | 1880s– |
| | Outcrop and boulder observations | Yes | Vuoksenniska | 1942–1958 |
| | Outcrop and boulder observations | Yes | Suomen Malmi | 1950s |
| | Outcrop and boulder observations | Yes | Outokumpu | 1958–1993 |
| Geochemical surveys | Nationwide till sampling | Yes | Geological Survey of Finland | 1980s |
| | Detailed till geochemical survey | Yes | Geological Survey of Finland | |
| | Detailed till and humus geochemical surveys | Yes | Outokumpu | 1950s–1990s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1978–2005 |
| Ground geophysical surveys | Magnetic and electromagnetic surveys | | Vuoksenniska | 1942–1958 |
| | Magnetic, slingram and IP surveys | | Outokumpu | 1940s–1980s |
| Drilling | Hundreds of diamond-drill holes. Total drilling at Attu 16,249 m. | Yes | Outokumpu | 1958–1993 |
| | Attu: >40 diamond-drill holes | Yes | Vuoksenniska | 1942–1958 |
| | Unknown number of diamond-drill holes | Yes | Suomen Malmi | 1950s |
| Other | Stratigraphic, structural, mineralogical, metallogenic and Pb-isotopic investigations | Yes | Geological Survey of Finland, University of Helsinki, Åbo Akademi University, University of Turku | 1900s–2010s |

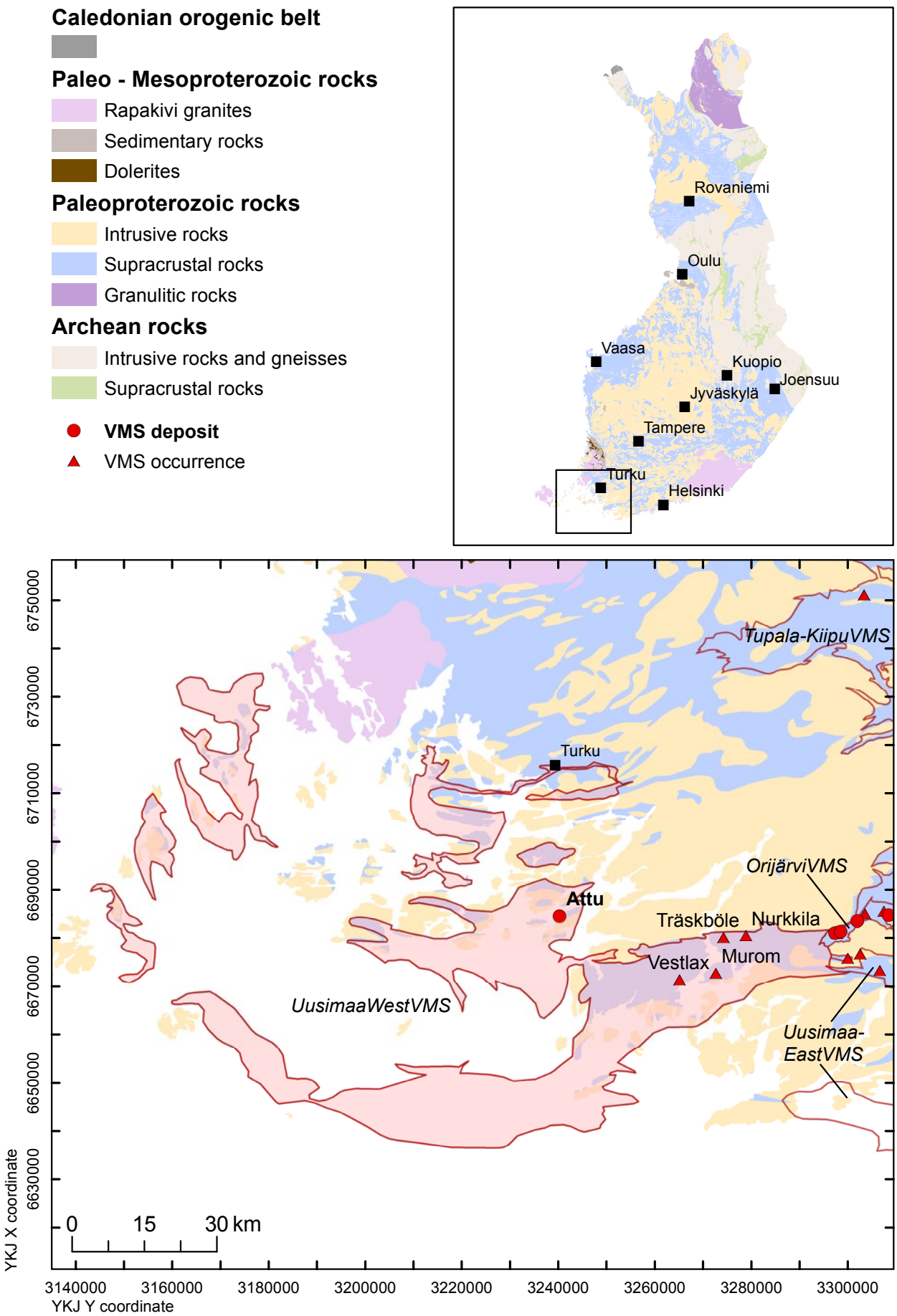


Fig. 1. Location of the Uusimaa West VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Uusimaa West VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Uusimaa West VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Detailed mapping | 1:100–1:10,000 | Edelman (1980), Colley & Westra (1987), Hangala (1987), Väisänen & Hölttä (1999), Väisänen et al. (2002) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Deposit descriptions | | Edelman (1980), Isomäki (1981, 1983), Latvalahti (1980), Hangala (1987), Papunen (1990), Anttonen (1992) |
| | Metallogenic assessments | | Lunden (1964), Outokumpu Oy malminetsintä (1986), Hangala (1987), Mäkelä (1989), Papunen (1990) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Isomäki (1987), Papunen (1990) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Sipilä (1966), Isomäki (1981, 1983, 1987), Latvalahti (1980) |
| Exploration | Reports | | Lunden (1964), Sipilä (1966), Edelman (1980), Isomäki (1981, 1983, 1987), Latvalahti (1980), Outokumpu Oy malminetsintä (1986), Anttonen (1992), Ratia (2000) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

A large number of partially explored VMS occurrences are known within the tract (Table 3). However, these occurrences were considered so modest that most of the estimators believed it possible that no more than one of them will ever become economic, even under the most favourable circumstances. The four partially explored occurrences, the extensive bimodal volcanic sequences, and the fact that most of the tract is under water, restricting exploration, were seen as positive indications for the deposit potential. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Uusimaa West VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 1 | 3 | | | 1.5 | 0.93 | 61 | 1 | 2.5 | 3163 | 0.00080 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 2 | 3 | | |
| Individual 2 | 0 | 0 | 1 | | |
| Individual 3 | 0 | 1 | 3 | | |
| Individual 4 | 1 | 1 | 1 | | |
| Individual 5 | 1 | 2 | 4 | | |
| Individual 6 | 0 | 1 | 3 | | |
| Individual 7 | 0 | 0 | 1 | | |
| Individual 8 | 1 | 2 | 2 | | |
| Individual 9 | 1 | 2 | 3 | | |
| Individual 10 | 1 | 2 | 5 | | |
| Consensus | 1 | 1 | 3 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen, H. Kujala, J. Luukas, J. Nikander, M. Nironen, K. Rasilainen, P. Sipilä, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS felsic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Uusimaa West VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 220 | 8,400 | 100,000 | 220,000 | 47,000 | 0.19 | 0.070 |
| Zn (t) | 0 | 740 | 53,000 | 770,000 | 1,700,000 | 320,000 | 0.18 | 0.070 |
| Pb (t) | 0 | 51 | 5,700 | 130,000 | 280,000 | 82,000 | 0.14 | 0.070 |
| Ag (t) | 0 | 0.64 | 42 | 660 | 1,500 | 340 | 0.18 | 0.070 |
| Au (t) | 0 | 0.011 | 0.60 | 9.0 | 18 | 4.1 | 0.18 | 0.070 |
| Rock (Mt) | 0 | 0.053 | 1.8 | 24 | 50 | 8.3 | 0.18 | 0.070 |

t – metric tons; Mt – million metric tons.

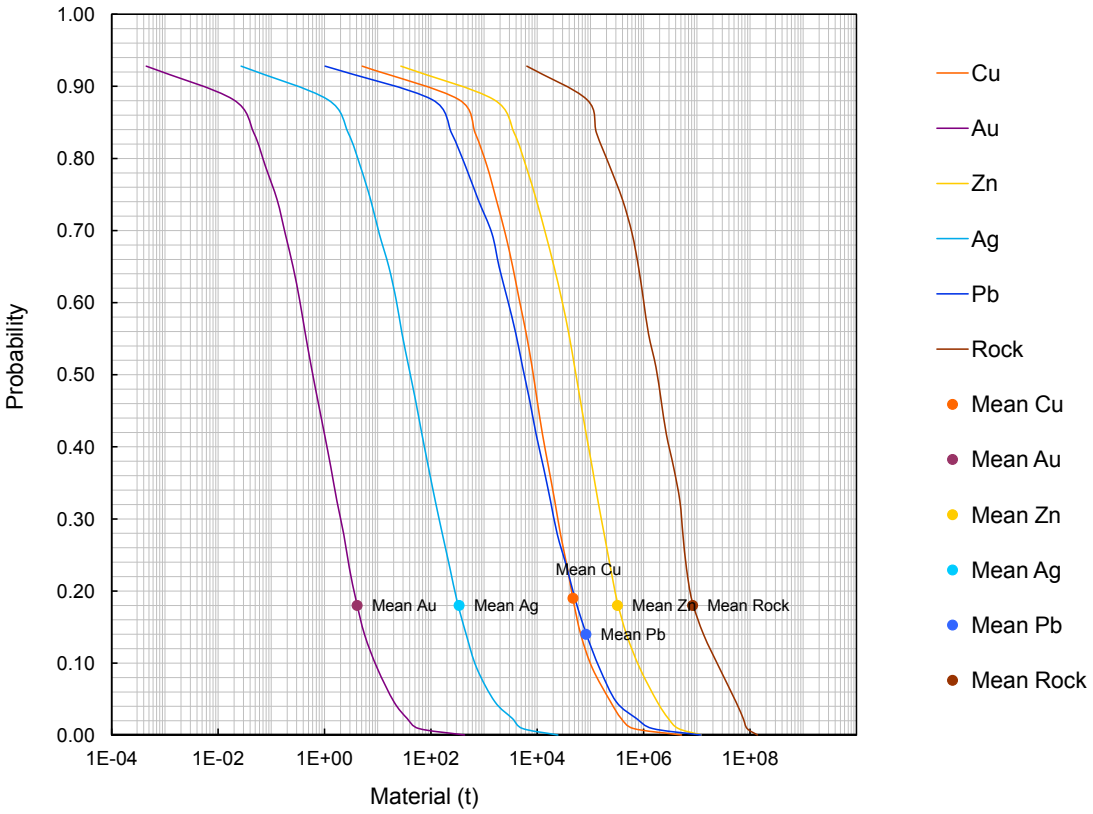


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Uusimaa West VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT VESMAJÄRVI VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Vesmajärvi VMS permissive tract is located in northern Finland in the municipalities of Kittilä, Sodankylä and Inari, 150–200 km north of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 2734, 2742, 2743, 2744, 2833, 3712, 3714, 3721 and 3722. The UTM map sheets containing the tract are U441, U442, U443, U444, V431, V432, V433, V434 and V441. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Vesmajärvi VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 10/12/2012 | 1 | 1575 | Cu | 0 | Cu | 220,000 | Cu | 74,000 |
| | | | Zn | 0 | Zn | 180,000 | Zn | 41,000 |
| | | | Pb | 0 | Pb | 6,500 | Pb | 490 |
| | | | Ag | 0 | Ag | 99 | Ag | 29 |
| | | | Au | 0 | Au | 1.2 | Au | 0.27 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is defined by the ca. 2000 Ma volcano-sedimentary rocks of the Kittilä Group. The delineation is based on the extent of graphitic tuffs and iron formations of the Porkonen Formation and tholeiitic basalts of the Vesmajärvi Formation of the Kittilä Group. Information from diamond drill core observations and outcrops, together with geophysical data were used to define the extent of the tract. The tract is mostly bordered by the Savukoski Group rocks to the south and east, and by the Kautoselkä Formation and Palaeoproterozoic plutonic rocks to the north and west. The tract extends down to 1000 m depth. The depth extension is based on the assumption that the Kittilä Group rocks extend downwards beyond that depth. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There are no well-explored VMS deposits within the Vesmajärvi VMS permissive tract (Table 2). According to the spatial rule used, deposits located less than 500 m from each other were combined in this assessment.

Table 2. Known VMS deposits in the Vesmajärvi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade | | | | | Contained metal (t) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | | |
| None | | | | | | | | | | | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

### Prospects, mineral occurrences and related deposit types

Seven partially explored VMS occurrences are known within the Vesmajärvi VMS permissive tract (Table 3). Other types of occurrences that exist within the tract are intrusion-hosted Fe-V, orogenic Au and Au-Cu, and palaeoplacer Au occurrences.

Table 3. Significant VMS occurrences in the Vesmajärvi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Palolaki | 7524960 | 3447980 | 2000 | 1 m @ 1.86 % Zn, 0.06 % Cu, 0.05 % Ni; 1 m @ 1.01 % Zn, 0.15 % Cu, 0.1 % Ni | Hulkki et al. (2010a, 2010b) |
| Outapää | 7513680 | 3437750 | 2000 | 1 m @ 0.69 % Zn, 0.02 % Cu, 0.01 % Ni | GTK drill core database |
| Jänesvaara | 7514780 | 3445200 | 2000 | 6 m @ 1.31 % Zn, 0.06 % Cu, 0.05 % Pb, 0.04 % Ni; 2 m @ 1.19 % Zn, 0.09 % Ni, 0.04 % Cu; 1 m @ 0.8 % Zn, 0.07 % Ni, 0.03 % Cu | GTK drill core database |
| Nuttio | 7512850 | 3457040 | 2000 | 1.45 m @ 0.65 % Zn, 0.33 % Ni, 0.03 % Co, 0.01 % Cu | Sarapää et al. (2009) |
| Suurikuusikko | 7535450 | 3432720 | 2000 | 2.3 m @ 0.56 % Zn, 0.06 % Cu, 0.04 % Ni | GTK drill core database |
| Mantovaara | 7530450 | 3417820 | 2000 | 9 m @ 0.53 % Zn, 0.03 % Cu, 0.02 % Ni, including 2 m @ 0.73 % Zn | Hulkki (2002a) |
| Puuroniemi | 7533070 | 3423060 | 2000 | 5.05 m @ 0.33 % Zn, 0.05 % Cu, 0.04 % Ni, including 2 m @ 0.54 % Zn, 0.05 % Cu, 0.04 % Ni | Keinänen & Salmirinne (2006) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Vesmajärvi VMS tract are listed in Table 4.

Table 4. Exploration history for the Vesmajärvi VMS tract.

| Theme | Type of work | Cu. Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Outcrop and boulder observations | (Yes) | Geological Survey of Finland | 1970s– |
| Geochemical surveys | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| | Line till sampling covers nearly the whole tract | Yes | Geological Survey of Finland | 1970s–1980s |
| | Extensive line and grid sampling in the south-central part of the tract | Yes | Geological Survey of Finland | 1980s–2000s |
| | 3416 targeted till samples | Yes | Outokumpu Oy | 1980s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1976–1996 |
| | Low-altitude dense flight magnetic, electromagnetic and radiometric survey | | Geological Survey of Finland | 2004 |
| | Low-altitude magnetic and EM survey | | RTZ Mining and Exploration | 1994? |
| Ground geophysical surveys | Most of tract is covered by regional gravity survey (APV) | | Geological Survey of Finland | 1970s–2000s |
| | 160 $km^2$ systematic magnetic, 157 $km^2$ slingram, 25 $km^2$ VLF-R, 7 $km^2$ SP, and 1.5 $km^2$ IP surveys | | Geological Survey of Finland | 1980s–2009 |
| | At least, 1.6 $km^2$ magnetic and slingram surveys | | Rautaruukki Oy | 1964–1983 |
| | 17 $km^2$ systematic magnetic and slingram surveys | | Outokumpu Oy | 1980s–1990s |
| Drilling | 7 DDH, 533 m | ? | Kemi Oy | 1977 |
| | 82 DDH, 8992 m | Yes | Rautaruukki Oy, Outokumpu Oy | 1964–1995 |
| | 5 DDH | ? | RTZ Mining and Exploration | 1995–1996 |
| | 428 DDH, 40749 m | Yes | Geological Survey of Finland | 1979–2009 |

DDH – diamond-drill hole.

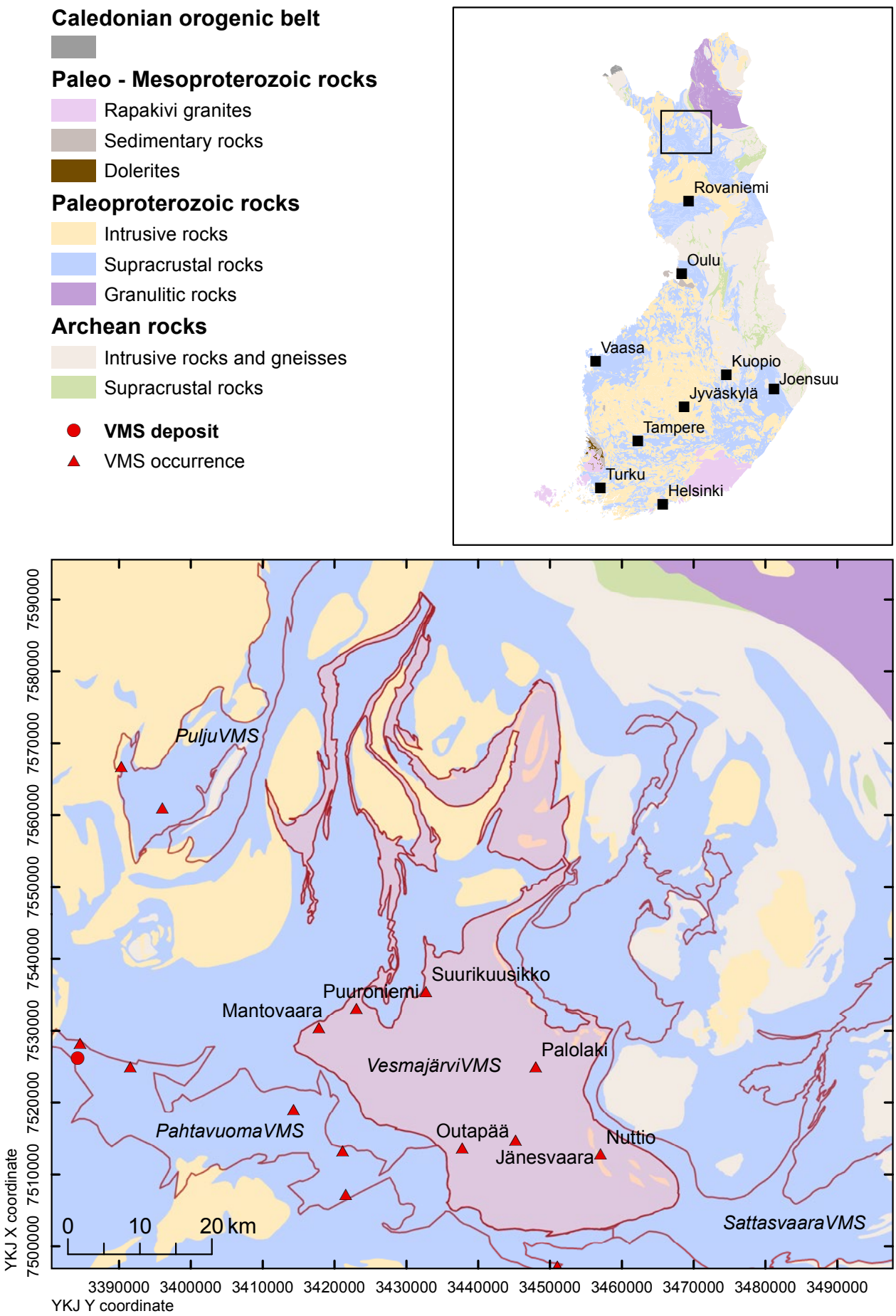


Fig. 1. Location of the Vesmajärvi VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Vesmajärvi VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Vesmajärvi VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Report | | Lehtonen et al. (1998) |
| Mineral occurrences | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| | Geological Survey of Finland copper deposit database | | Västi (2009) |
| | Reports | | Härkönen (1997), Hulkki et al. (2010b) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Report | | Hulkki et al. (2010b) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Report | | Hulkki et al. (2010b) |
| Exploration | Reports | | Korvuo (1979), Anttonen (1984), Hugg (1987, 1990), RTZ Mining and Exploration (1995a, 1995b, 1995c,1996), Hulkki (2002a, 2002b), Keinänen & Salmirinne (2006), Sarapää et al. (2009) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Seven partially explored VMS occurrences are known within the tract (Table 3). However, these occurrences were considered so modest that the estimators believed that no more than one could become economic, even under the most favourable circumstances. The existence of the known base metal occurrences, the extensive juvenile submarine mafic-ultramafic volcanic sequence, the widespread sulphide- and oxide-facies iron formations, and Cu anomalies in till were considered to indicate the potential for undiscovered VMS deposits within the tract. A consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Vesmajärvi VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 2 | 4 | | | 2.2 | 1.2 | 54 | o | 2.2 | 1575 | 0.0014 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 1 | 2 | 6 | | |
| Individual 2 | 0 | 1 | 2 | | |
| Individual 3 | 0 | 1 | 3 | | |
| Individual 4 | 1 | 2 | 4 | | |
| Individual 5 | 0 | 1 | 3 | | |
| Individual 6 | 1 | 2 | 3 | | |
| Consensus | 1 | 2 | 4 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): P. Eilu, N. Kärkkäinen, J. Kousa, K. Rasilainen, P. Sorjonen-Ward, T. Törmänen

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2) and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Vesmajärvi VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 2,200 | 74,000 | 620,000 | 990,000 | 220,000 | 0.28 | 0.070 |
| Zn (t) | 0 | 740 | 41,000 | 430,000 | 770,000 | 180,000 | 0.24 | 0.070 |
| Pb (t) | 0 | 4.1 | 490 | 13,000 | 29,000 | 6,500 | 0.15 | 0.070 |
| Ag (t) | 0 | 0.55 | 29 | 260 | 450 | 99 | 0.25 | 0.070 |
| Au (t) | 0 | 0.0047 | 0.27 | 2.9 | 5.7 | 1.2 | 0.21 | 0.070 |
| Rock (Mt) | 0 | 0.13 | 5.6 | 52 | 75 | 17 | 0.32 | 0.070 |

t – metric tons; Mt – million metric tons.

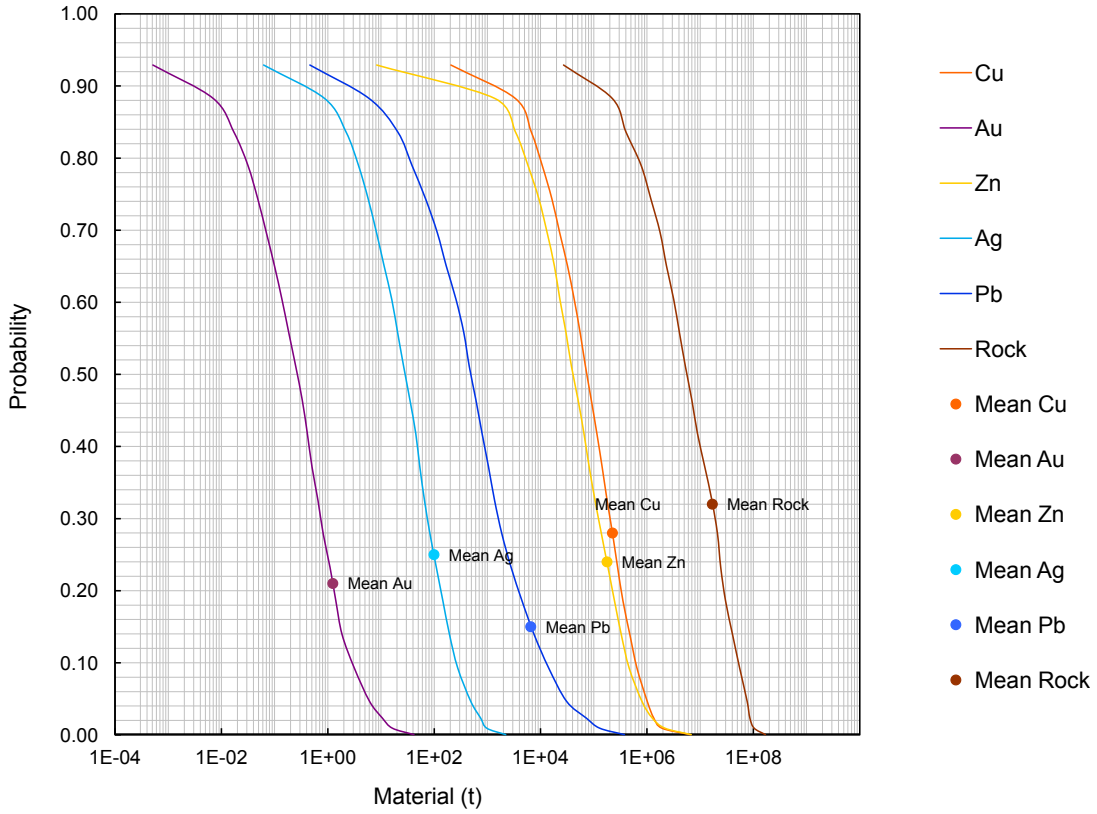


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Vesmajärvi VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT VIHANTI VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS felsic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Vihanti VMS permissive tract is an approximately 25-km-wide and 300-km-long NW-trending zone in central Finland, extending from Siikajoki in the NW to Rautalampi in the SE (Fig. 1). The 1:100,000 KKJ map sheets are 2432, 2434, 2441, 2442, 2443, 3223, 3224, 3241, 3242, 3312, 3313, 3314, 3321, 3322, 3323, 3324, 3331, 3411 and 3412. The UTM map sheets containing the tract are N444, N521, N522, P433, P434, P442, P443, P444, P511, P512, P521, Q424, Q431, Q432, Q433, Q434, Q441, Q442, Q443, R413, R414, R431, R432 and R423. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Vihanti VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 5226 | Cu | 217,504 | Cu | 140,000 | Cu | 52,000 |
| | | | Zn | 1,642,655 | Zn | 970,000 | Zn | 340,000 |
| | | | Pb | 155,150 | Pb | 230,000 | Pb | 48,000 |
| | | | Ag | 1,079 | Ag | 930 | Ag | 300 |
| | | | Au | 20 | Au | 13 | Au | 4.2 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The permissive tract is within the 1.93–1.91 Ga Lower-Svecofennian volcanic rocks. The delineation is based on the extent of the volcanic-sedimentary Vihanti Group rocks. The presence of Vihanti-style Cu-Zn-Pb mineralisation, as well as bedrock observation, drill core and geophysical survey data were used to define the tract area. The tract extends down to 1000 m depth. The depth extension is based on data from the Vihanti mine and stratigraphic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

### Known deposits

There are two well-explored Vihanti-type VMS deposits within the Vihanti VMS permissive tract (Table 2). According to the spatial rule used, deposits less than 500 m from each other have been combined in this assessment.

Table 2. Known Vihanti-type VMS deposits in the Vihanti VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mullikko-räme | 7066700 | 3458600 | 1921 | 2.1 | 0.27 | 7.13 | 1.0 | 51 | 0.47 | Cu | 5,670 | Puustjärvi (1992, pers. comm. 2001) |
| | | | | | | | | | | Zn | 149,730 | |
| | | | | | | | | | | Pb | 21,000 | |
| | | | | | | | | | | Ag | 107 | |
| | | | | | | | | | | Au | 1.0 | |
| Paloniemi | 7016450 | 3481100 | | 0.112 | 0.13 | 0.89 | | 4.1 | | Cu | 146 | Damsten & Ekdahl (1989), Tontti et al. (1981) |
| | | | | | | | | | | Zn | 997 | |
| | | | | | | | | | | Ag | 0.46 | |
| Säviä | 7011800 | 3483050 | | 5.0 | 0.88 | 0.40 | | 8.0 | 0.2 | Cu | 44,000 | Laitakari (1968) |
| | | | | | | | | | | Zn | 20,000 | |
| | | | | | | | | | | Ag | 40 | |
| | | | | | | | | | | Au | 1.0 | |
| Vihanti | 7146622 | 3410694 | 1922 | 37.264 | 0.45 | 3.95 | 0.36 | 25 | 0.49 | Cu | 167,688 | Mäki (1997, pers. comm. 2006), Luukas et al. (2004a), Nikander et al. (2004), Nikander (2006), Kousa (2007) |
| | | | | | | | | | | Zn | 1,471,928 | |
| | | | | | | | | | | Pb | 134,150 | |
| | | | | | | | | | | Ag | 932 | |
| | | | | | | | | | | Au | 18 | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

At least 19 partially-explored Vihanti-type VMS occurrences are known within the Vihanti VMS permissive tract (Table 3). In addition, practically all mines and deposits of the Pyhäsalmi VMS tract are geographically within the Vihanti VMS tract.

Table 3. Significant Vihanti-type VMS occurrences in the Vihanti VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | Reference |
|---|---|---|---|---|---|
| Aittola | 7166567 | 3403478 | | | Puustjärvi (1993) |
| Arkala | 7074700 | 3460900 | | 1.8 m @ 0.77 % Zn; 1 m @ 1.02 % Zn | Belvedere Resources (2001) |
| Isoneva | 7147316 | 3412315 | | 0.5 m @ 1.2 % Zn | Kuronen (1986) |
| Katvala | 7065400 | 3458700 | | <1 m @ 6 %; <1 m @ 9 % Zn | H. Puustjärvi (pers. comm. 17 April 2000) |
| Kitusalo | 7144959 | 3424282 | 1922±6 | 1.7 m @ 1.4 % Zn, 0.2 g/t Au; 1.75 m @ 1.1 % Zn, 0.4 g/t Au | Nikander et al. (2002a) |
| Kokkoneva | 7143647 | 3426622 | 1922±6 | 3.2 m @ 2.3 % Zn, 0.4 % Cu, 40 g/t Ag, 0.4 g/t Au; 1.15 m @ 5 % Zn, 0.2 % Cu, 41 g/t Ag, 0.3 g/t Au | Nikander et al. (2002a,b) |
| Kuuhkamo | 7143051 | 3411677 | | 0.15 Mt @ 4.0 % Zn | Pekkarinen (1990), Luukas et al. (2004a), Nikander et al. (2004, 2005a) |
| Leväniemi | 7008000 | 3482800 | | | Ekdahl (1989) |
| Niemisjärvi | 7061000 | 3473000 | | | Nikander (1994) |
| Näsälänperä | 7142120 | 3427780 | | 0.1 Mt @ 2 % Zn, 15 g/t Ag | Mäkelä (1980), Nikander et al. (2002a) |
| Ollinniemi | 7046600 | 3453300 | | | Mäki (1987) |
| Puironniemi | 7024840 | 3479460 | | 0.1 Mt @ 1 % Zn, 0.05 % Cu, 3 g/t Ag | Tontti et al. (1981) |
| Pukkiharju | 6953000 | 3487000 | | 2 m @ 0.21 % Zn, 14 g/t Ag | Koistinen & Vihreäpuu (1982) |
| Säviänkannas | 7011000 | 3482850 | 1924 | 0.27 Mt @ 0.37 % Zn, 0.12 % Cu, 10.7 ppm Ag | Mäki (1986a, 1986b) |
| Teerimäki | 7020750 | 3468750 | | 1.4 m @ 20.1 % Zn; 0.3 m @ 1.7 % Zn, 12 g/t Ag, 48 g/t Au | Nikander (1983) |
| Vattumurto | 7071500 | 3458500 | 1921±2 | 7.7 m @ 2.35 % Zn | H. Puustjärvi (pers. comm. 16/11/2001), Eilu & Västi (2009) |
| Viita | 7135800 | 3439400 | | 0.95 m @ 0.60 % Zn; 0.5 m @ 0.67 % Cu | Västi (1998) |
| Vilminko | 7147251 | 3422388 | 1920±10 | 2.4 m @ 1.0 % Zn; 0.9 m @ 0.9 % Zn | Vesanto (1981a) |
| Ylipää | 7172207 | 3391130 | | 0.5–1 m sections @ 1.5 % Zn; 0.3 m @ 2.2 % Zn, 2.26 % Pb, 53 g/t Ag | Vesanto (1981b) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Vihanti VMS tract are listed in Table 4.

Table 4. Exploration history for the Vihanti VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Bedrock mapping, glacial erratic boulder surveys | Yes | Geological Survey of Finland | 1930s– |
| | Bedrock mapping, glacial erratic boulder surveys | Yes | Outokumpu Oy | 1950s–1990s |
| | Bedrock mapping | Yes | Belvedere Resources | 1997–2002 |
| Geochemical surveys | Till, stream-sediment, humus and bedrock geochemical surveys | Yes | Geological Survey of Finland | 1940s– |
| | MMI | Yes | Geological Survey of Finland | 2007 |
| | Till and pedogeochemical surveys | Yes | Outokumpu Oy | 1950s–1980s |
| | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electro-magnetic and radiometric surveys | | Geological Survey of Finland | 1977–1992 |
| | VTEM | | Geological Survey of Finland | 2008 |
| | Low-altitude airborne magnetic and electric survey | | Outokumpu Oy | 1960 |
| Ground geophysical surveys | Magnetic, conductivity and gravity survey | Yes | Belvedere Resources | 1997–2002 |
| | Magnetic, electromagnetic, IP, gravimetric, and multi-frequency EM surveys, reflection seismics | Yes | Geological Survey of Finland | 1930s– |
| | Magnetic, gravimetric, IP and electro-magnetic (turam, slingram, VLF-R, charge potential) surveys | Yes | Outokumpu Oy | 1950s–1990s |
| Drilling | Hundreds of diamond-drill holes | Yes | Geological Survey of Finland | 1930s– |
| | Thousands of diamond-drill holes | Yes | Outokumpu Oy | 1950s–1990s |
| | Diamond drilling | Yes | Belvedere Resources | 1997–2000 |
| Other | Feasibility studies and pilot-plant tests | Yes | Outokumpu Oy | 1950s–1990s |

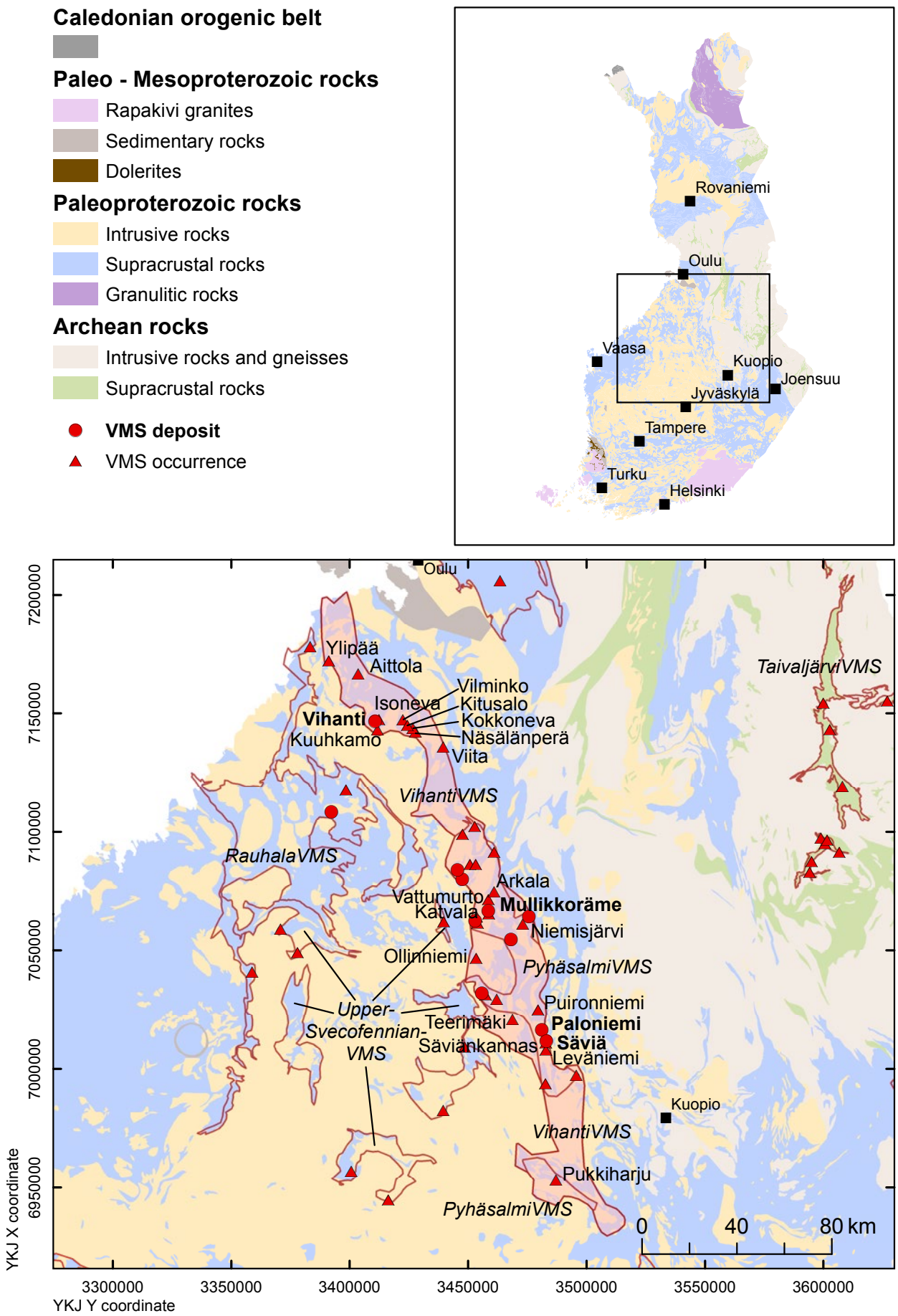


Fig. 1. Location of the Vihanti VMS permissive tract.

### Sources of information

The principal sources of information used by the assessment team for the delineation of the Vihanti VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Vihanti VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Reports | | Tontti et al. (1981), Puustjärvi (1999), Luukas et al. (2004a, 2004b), Kukkonen & Lahtinen (2006), Kousa (2007) |
| Mineral occurrences | Reports | | Rouhunkoski (1968), Ekdah (1980), Mäkelä (1980), Vesanto (1981a, 1981b), Pekkarinen (1990), Pekkarinen & Rekola (1990), Nikander (1983, 2000, 2006), Kousa et al. (1997), Västi (1998, 2001), Nikander et al. (2002a, 2002b, 2005a, 2005b) |
| | Geological Survey of Finland zinc deposit database | | Eilu & Västi (2009) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Björklund et al. (1976), Lahtinen (1989), Loukola-Ruskeeniemi et al. (1997), Puustjärvi (1999), Iisalo (2004a, 2004b, 2004c, 2006, 2007a, 2007b), Hartikainen et al. (2008), Västi (2008) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Kukkonen & Lahtinen (2006), Nousiainen et al. (2008), Leväniemi et al. (2009) |
| Exploration | Exploration reports | | Ekdah (1980), Tontti et al. (1981), Koistinen & Vihreäpuu (1982), Vesanto (1981a, 1981b), Nikander (1983, 1986), Kuronen & Ahokas (1986), Damsten & Ekdahl (1989), Pekkarinen & Rekola (1990), Pelkonen (1992a, 1992b), Västi (1998, 2008), Belvedere Resources (2001), Luukas et al. (2004a, 2004b), Nikander et al. (2002b, 2005a, 2005b) |
| | Geological Survey of Finland in-house drill-core database | | |

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

At least 19 partially explored Vihanti-type VMS occurrences are known within the tract (Table 3). However, most of these occurrences were considered so small that it was believed possible for only a few of them ever to become economic deposits, even under the most favourable circumstances. Factors favourable for VMS-style mineralisation within the tract include the two mines, two other well-known deposits and the large number of partially explored deposits, many of which are open along strike, at depth, or both. Furthermore, numerous mineralised outcrops and glacial erratic boulders are known within the tract. No consensus was reached in the discussion and the mean values of the numbers given by the individual estimators were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Vihanti VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area (km²)** | **Deposit density (N/km²)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 2 | 4 | 7 | | | 4.2 | 1.9 | 46 | 4 | 8.2 | 5226 | 0.0016 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 2 | 2 | 4 | | |
| Individual 2 | 2 | 4 | 8 | | |
| Individual 3 | 1 | 2 | 4 | | |
| Individual 4 | 3 | 5 | 7 | | |
| Individual 5 | 4 | 6 | 10 | | |
| Individual 6 | 1 | 3 | 8 | | |
| Mean | 2 | 4 | 7 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per km$^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen J. Luukas, J. Nikander, K. Rasilainen, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS felsic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Vihanti VMS tract.

| **Material** | **At least the indicated amount at the probability of** | | | | | **Mean** | **Probability of mean or greater** | **Probability of zero** |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 680 | 4,600 | 52,000 | 340,000 | 560,000 | 140,000 | 0.25 | 0.040 |
| Zn (t) | 3,900 | 27,000 | 340,000 | 2,800,000 | 4,200,000 | 970,000 | 0.26 | 0.040 |
| Pb (t) | 310 | 2,400 | 48,000 | 480,000 | 970,000 | 230,000 | 0.19 | 0.040 |
| Ag (t) | 2.3 | 21 | 300 | 2,400 | 4,100 | 930 | 0.25 | 0.040 |
| Au (t) | 0.045 | 0.27 | 4.2 | 30 | 50 | 13 | 0.24 | 0.040 |
| Rock (Mt) | 0.14 | 0.99 | 10 | 75 | 92 | 24 | 0.30 | 0.040 |

t – metric tons; Mt – million metric tons.

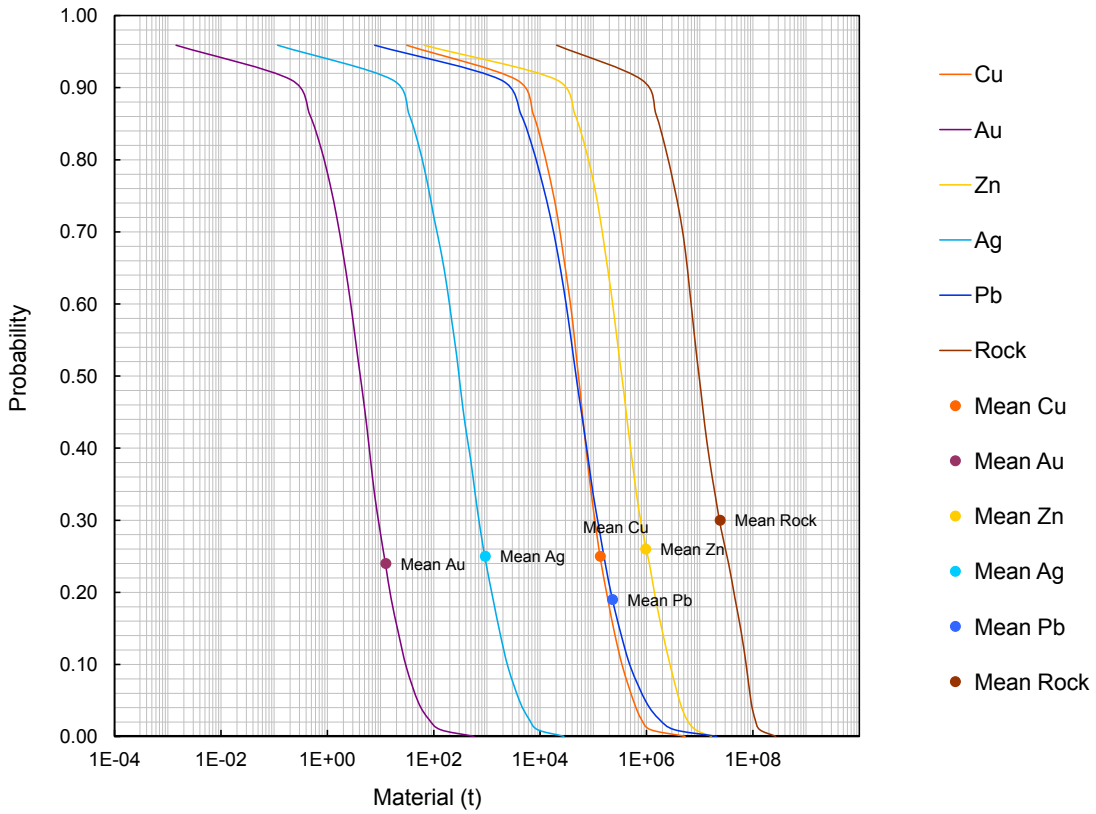


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Vihanti VMS permissive tract.

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# VMS Cu-Zn ASSESSMENT FOR THE TRACT VIRTASALMI VMS, FINLAND

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## DEPOSIT TYPE ASSESSED

**Deposit type**: VMS
**Descriptive model**: VMS (Appendix 1)
**Grade-tonnage model**: VMS mafic (Appendix 2)

## LOCATION AND RESOURCE SUMMARY

The Virtasalmi VMS permissive tract is an approximately 20-km-wide and 50-km-long NNW–SSE-trending zone in central Finland in the municipalities of Pieksämäki and Juva (Fig. 1). The 1:100,000 KKJ map sheets are 3231, 3232, 3233, 3234, and 3241. The UTM map sheets containing the tract are N511, N512, N514, and N521. The Cu-Zn resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Virtasalmi VMS tract.

| Date of assessment | Assessment depth (km) | Tract area (km²) | Known metal resources (t) | | Mean estimate of undiscovered resources (t) | | Median estimate of undiscovered resources (t) | |
|---|---|---|---|---|---|---|---|---|
| 14–17/10/2010 | 1 | 1483 | Cu | 32,604 | Cu | 220,000 | Cu | 71,000 |
| | | | Zn | 0 | Zn | 160,000 | Zn | 41,000 |
| | | | Pb | 0 | Pb | 5,500 | Pb | 480 |
| | | | Ag | 0 | Ag | 93 | Ag | 28 |
| | | | Au | 0.42 | Au | 1.2 | Au | 0.26 |

t – metric tons.

## DELINEATION OF THE PERMISSIVE TRACT

### Geological criteria

The Virtasalmi VMS permissive tract is within the ca. 1.90 Ga Svecofennian mafic volcanic rocks. The delineation is based on the extent of the supracrustal rocks of the Virtasalmi Suite. The presence of Cu occurrences, bedrock observation, drill core and geophysical survey data have been used to delineate the tract. The tract is delimited by a major fault in the NE, whereas the extent of permissive host rocks defines its area into other directions. The tract extends down to 1000 m depth. The depth extension is based on data from the Virtasalmi mine and on stratigraphic and tectonic interpretation. The sources of information used in the delineation of the tract are summarised in Table 5.

## Known deposits

There is one well-explored VMS deposit within the Virtasalmi VMS permissive tract (Table 2).

Table 2. Known VMS deposits in the Virtasalmi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Tonnage (Mt) | Grade Cu (%) | Zn (%) | Pb (%) | Ag (g/t) | Au (g/t) | Contained metal (t) | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Virtasalmi (Hällimäki) | 6883600 | 3529050 | ca. 1900 | 4.18 | 0.78 | | | | 0.1 | Cu | 32,604 | Pulkkinen (1985) |
| | | | | | | | | | | Zn | 0 | |
| | | | | | | | | | | Pb | 0 | |
| | | | | | | | | | | Ag | 0 | |
| | | | | | | | | | | Au | 0.42 | |

Ma – million years; Mt – million metric tons; t – metric ton. The contained metal is given in metric tons and computed as tonnage * grade.

## Prospects, mineral occurrences and related deposit types

Eight partially explored possibly VMS-type mineral occurrences are known within the Virtasalmi VMS permissive tract (Table 3).

Table 3. Significant VMS occurrences in the Virtasalmi VMS tract.

| Name | X coordinate | Y coordinate | Age (Ma) | Comments | References |
|---|---|---|---|---|---|
| Karankalahti | 6894800 | 3524130 | ca. 1900 | 0.37 Mt @ 1.02 % Cu, 1.93 % S. Best sections: 5.63 m @ 1.73 % Cu and 2.67 % S | Grundström et al. (1986) |
| Karhuniemi | 6884350 | 3530080 | ca. 1900 | ~0.013–0.018 Mt @ 0.5–0.6 % Cu. Best sections: 23.55 m @ 0.61 % Cu; 4.0 m @ 0.94 % Cu | Grundström (1976) |
| Lari | 6884800 | 3526750 | ca. 1900 | ~0.003–0.005 Mt @ 1.28 % Cu. Best sections: 1.69 m @ 4.19 % Cu; 3.30 m @ 0.84 % Cu | Grundström (1977a) |
| Luomanen | 6868000 | 3537100 | ca. 1900 | Best sections: 0.9 m @ 3.43 % Zn, 0.02 % Cu; 1.35 m @ 1.14 % Zn, 0.01 % Cu; 1 m @ 1.03 % Zn, 0.03 % Cu; 10.5 m @ 0.34 % Zn, 0.04 % Cu | Makkonen (1992) |
| Mustalampi | 6875200 | 3527300 | ca. 1900 | N orebody: ~0.026 Mt @ 1.75 % Zn; S orebody: ~0.011 Mt @ 5.6 % Zn | Makkonen (1989) |
| Sahinjoki | 6886250 | 3526150 | ca. 1900 | ~0.003 Mt @ 1.0 % Cu. Best sections: 3.35 m @ 1.02 % Cu; 1.64 m @ 1.95 % Cu | Grundström (1977b) |
| Sarkaniemi | 6900503 | 3523944 | ca. 1900 | ~0.029–0.086 Mt @ 2.85 % Cu. Best sections: 2.47 m @ 3.53 % Cu, 2.60 % S; 2.81 m @ 2.67 % Cu, 2.70 % S; 3.49 m @ 1.33 % Cu, 1.37 % S | Grundström (1979) |
| Viholanniemi | 6892700 | 3541000 | ca. 1900 | S orebody: ~0.19 Mt @ 2.31 % Zn, 0.19 % Cu, 0.7 ppm Au, 26 ppm Ag; N orebody: ~0.058 Mt @ 1.97 % Zn, 0.12 % Cu, 0.64 % Pb, 1.11 ppm Au, 105 ppm Ag | Makkonen (1991a,b) |

Ma – million years

## Exploration history

Exploration activities for VMS deposits within the Virtasalmi VMS tract are listed in Table 4.

Table 4. Exploration history for the Virtasalmi VMS tract.

| Theme | Type of work | Cu, Zn analysed | Organisation | When carried out |
|---|---|---|---|---|
| Mapping | Bedrock mapping, glacial erratic boulder surveys | Yes | Geological Survey of Finland | 1940s– |
| | Bedrock mapping, glacial erratic boulder surveys | Yes | Outokumpu Oy | 1960s–1980s |
| Geochemical surveys | Nationwide till survey | Yes | Geological Survey of Finland | 1980s |
| | Targeted till geochemical surveys | Yes | Geological Survey of Finland | 1960s–1980s |
| Airborne geophysical surveys | Low-altitude airborne magnetic, electromagnetic and radiometric surveys | | Geological Survey of Finland | 1981–1992 |
| Ground geophysical surveys | Magnetic, electromagnetic, gravimetric surveys | | Geological Survey of Finland | 1960s |
| | Magnetic, electromagnetic, gravimetric surveys | | Outokumpu Oy | 1960s–1980s |
| Drilling | Diamond drilling | Yes | Outokumpu Oy | 1960s–1980s |
| | Diamond drilling | Yes | Geological Survey of Finland | 1960s |
| Other | Feasibility studies and pilot-plant tests | Yes | Outokumpu Oy | 1960s |

## Sources of information

The principal sources of information used by the assessment team for the delineation of the Virtasalmi VMS tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Virtasalmi VMS tract.

| Theme | Type of source | Scale | Reference |
|---|---|---|---|
| Geology | Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland | | |
| | Reports | | Hyvärinen (1969), Lawrie (1987) |
| Mineral occurrences | Geological Survey of Finland zinc and copper databases | | Eilu & Västi (2009), Västi (2009) |
| | Reports | | Hyvärinen (1969), Lawrie (1987) |
| Geochemistry | Geological Survey of Finland in-house database | | |
| | Reports | | Nurmi (1970), Grundström (1977b, 1979), Grundström et al. (1986) |
| Geophysics | Geological Survey of Finland in-house database | | |
| | Reports | | Siikarla (1966, 1967), Grundström (1976,1977b, 1979) |
| Exploration | Reports | | Grundström (1976, 1977a, 1977b), Grundström et al. (1986) |
| | Geological Survey of Finland in-house drill-core database | | |

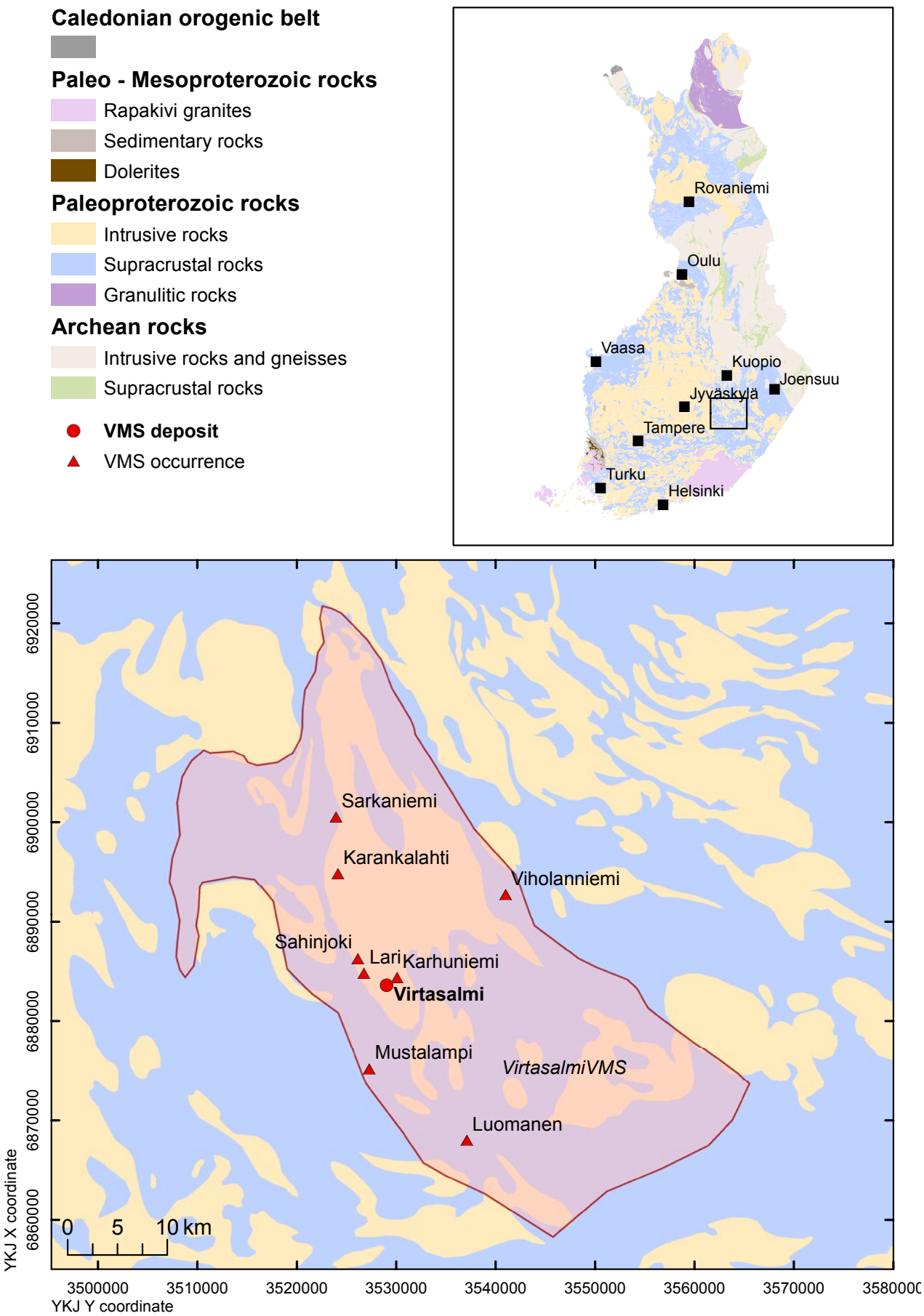


Fig. 1. Location of the Virtasalmi VMS permissive tract.

## ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

### Rationale for the estimate

Eight VMS occurrences are known within the tract (Table 3). However, most of these were considered so small that it was believed possible for only a few of them to become economic deposits, even under the most favourable circumstances. Drilling is locally dense within the tract, and all the known occurrences have been fairly extensively drilled in parts close to the surface. Much of the drilling within the tract has targeted kaolinite and marble occurrences. Large parts of the tract are covered by lakes, which has been a major obstacle to exploration within the region. Favourable factors for VMS deposits within the Virtasalmi VMS tract include the Virtasalmi copper mine, the partially explored Cu occurrences, and the abundant mafic volcanic rocks. Despite the different deposit numbers originally assessed by the estimators, a consensus was reached in the discussion and the consensus estimates were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Virtasalmi VMS tract.

| **Mean undiscovered deposit estimate** | | | | | **Summary statistics** | | | | | **Area ($km^2$)** | **Deposit density ($N/km^2$)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ | $N_{und}$ | s | Cv% | $N_{known}$ | $N_{total}$ | | |
| 1 | 2 | 4 | | | 2.2 | 1.2 | 54 | 1 | 3.2 | 1483 | 0.0022 |

| | **Estimated number of undiscovered deposits** | | | | |
|---|---|---|---|---|---|
| Estimator | $N_{90}$ | $N_{50}$ | $N_{10}$ | $N_{05}$ | $N_{01}$ |
| Individual 1 | 0 | 1 | 2 | | |
| Individual 2 | 0 | 1 | 3 | | |
| Individual 3 | 0 | 0 | 3 | | |
| Individual 4 | 1 | 1 | 4 | | |
| Individual 5 | 0 | 1 | 4 | | |
| Individual 6 | 0 | 1 | 4 | | |
| Individual 7 | 1 | 2 | 3 | | |
| Individual 8 | 3 | 6 | 9 | | |
| Individual 9 | 1 | 2 | 3 | | |
| Individual 10 | 1 | 3 | 6 | | |
| Individual 11 | 0 | 2 | 5 | | |
| Consensus | 1 | 2 | 4 | | |

$N_{xx}$ – Estimated number of deposits associated with the xx$^{th}$ percentile; $N_{und}$ – expected number of undiscovered deposits; s – standard deviation; Cv% – coefficient of variance; $N_{known}$ – number of known deposits in the tract that are included in the grade-tonnage model; $N_{total}$ – total of expected number of deposits plus known deposits; Area – area of permissive tract; Deposit density – deposit density reported as the total number of deposits per $km^2$. $N_{und}$, s and Cv% were calculated using a regression equation (Singer & Menzie 2005). In cases where individual estimates were tallied, in addition to the consensus estimate, individual estimates are listed. Estimators (not in the order of the list above): A. Karvinen, H. Kujala, J. Luukas, J. Nikander, M. Nironen, K. Rasilainen, P. Sipilä, P. Sorjonen-Ward, M. Tiainen, T. Törmänen, K. Västi.

## QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the VMS mafic grade-tonnage model (Appendix 2) using Eminers software (Root et al. 1991, Duval 2012). Results of the Monte Carlo simulation are presented as cumulative frequency plots (Fig. 2), and selected simulation results are reported in Table 7. The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralised rock.

Table 7. Results of Monte Carlo simulations of undiscovered resources in the Virtasalmi VMS tract.

| Material | At least the indicated amount at the probability of | | | | | Mean | Probability of mean or greater | Probability of zero |
|---|---|---|---|---|---|---|---|---|
| | 0.95 | 0.90 | 0.50 | 0.10 | 0.05 | | | |
| Cu (t) | 0 | 2,500 | 71,000 | 590,000 | 930,000 | 220,000 | 0.27 | |
| Zn (t) | 0 | 1,200 | 41,000 | 400,000 | 680,000 | 160,000 | 0.24 | |
| Pb (t) | 0 | 5.2 | 480 | 11,000 | 26,000 | 5,500 | 0.16 | |
| Ag (t) | 0 | 0.78 | 28 | 250 | 410 | 93 | 0.26 | |
| Au (t) | 0 | 0.0050 | 0.26 | 2.7 | 5.5 | 1.2 | 0.21 | |
| Rock (Mt) | 0 | 0.18 | 5.5 | 52 | 74 | 17 | 0.31 | |

t – metric tons; Mt – million metric tons.

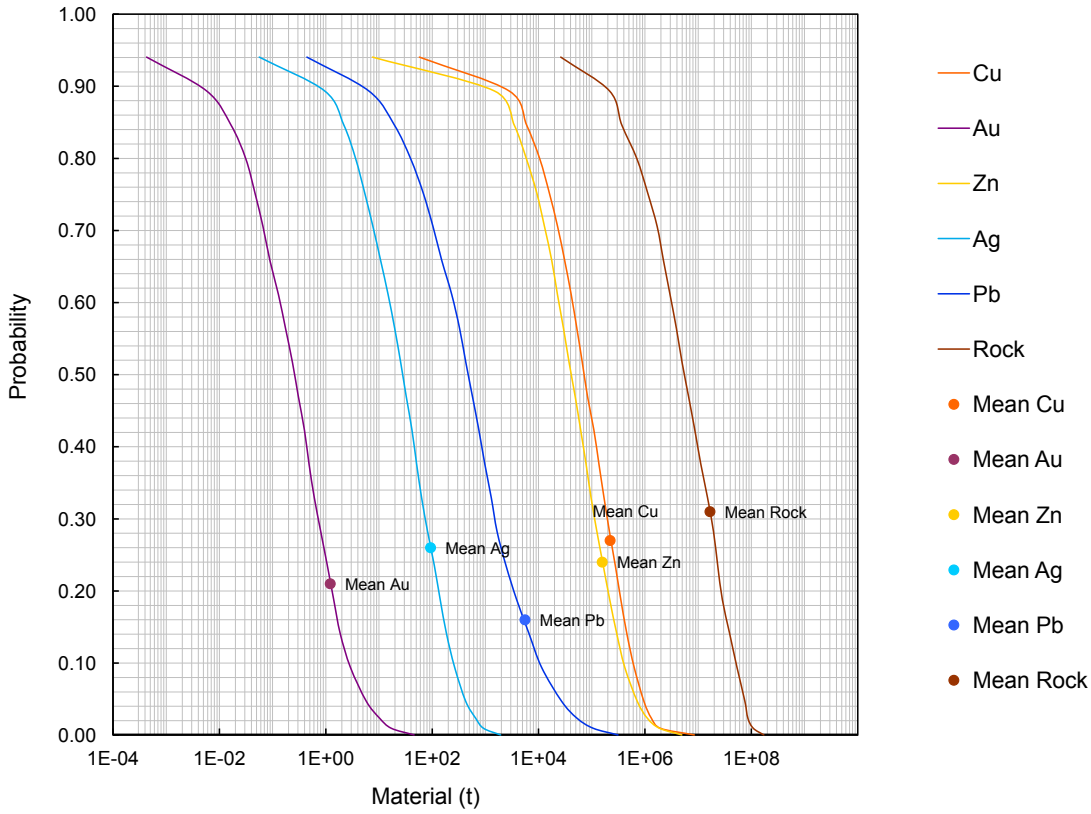


Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Virtasalmi VMS permissive tract.

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The present work uses statistical and expert assessment methods to estimate undiscovered resources in VMS, porphyry copper and Outokumpu-type deposits in the uppermost one kilometre of the bedrock in Finland. It provides numerical estimates for the expected endowment of copper and zinc in undiscovered, but potentially exploitable deposits in Finland.

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