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Quantitative assessment of undiscovered resources in orogenic gold deposits in Finland

Eilu, P., Rasilainen, K., Halkoaho, T., Huovinen, I., Kärkkäinen, N., Kontoniemi, O., Lepistö, K., Niiranen, T. and Sorjonen-Ward, P.

GTK

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QUANTITATIVE ASSESSMENT OF UNDISCOVERED RESOURCES IN OROGENIC GOLD DEPOSITS IN FINLAND

Front cover: Gold from the Pahtavaara mine. The height of the larger gold grain is 5 mm.
Photo: Jari Väätäinen, GTK.

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Gold resources in undiscovered orogenic gold deposits were estimated down to the depth of one kilometre in the bedrock of Finland using a three-part quantitative assessment method. A grade-tonnage model was constructed for Finnish orogenic gold deposits using data from 21 known Fennoscandian and 52 known North Australian orogenic gold deposits. Eight permissive tracts were delineated for Archaean orogenic gold deposits, 13 for Palaeoproterozoic Karelian deposits and 11 for Palaeoproterozoic Svecofennian deposits. The Archaean tracts cover 23,800 km^2, the Karelian tracts 61,000 km^2 and the Svecofennian tracts 25,000 km^2. Altogether, the 32 permissive tracts cover 110,000 km^2, which is 33 % of the total land area of Finland. The mean estimate of the number of undiscovered orogenic gold deposits is 18 for the Archaean tracts, 45 for the Karelian tracts and 27 for the Svecofennian tracts. Well-known Finnish orogenic gold deposits contain 317 t of gold, which is 71 % of the total identified gold resources of 444 t in Finland. The undiscovered orogenic gold deposits are estimated to contain, at 50 % probability, at least 750 t of gold. This indicates that at least 70 % of the present total orogenic gold endowment within the uppermost one kilometre of the Finnish bedrock is in poorly explored and entirely unknown deposits. The median undiscovered resources in Archaean, Karelian and Svecofennian deposits are 140 t, 400 t and 210 t of gold, respectively. More than half of the undiscovered orogenic gold resources are located within permissive tracts in the Palaeoproterozoic Karelian greenstones of central and northern Lapland. The adjacent Kittilä Group and Sattanen-Kolari tracts are estimated to contain 46 % of the Karelian undiscovered resources. Of the Svecofennian undiscovered resources, 49 % are estimated to occur in the adjacent Häme and Pirkkala permissive tracts in southern Finland. The Archaean undiscovered gold resources are more evenly spread out, but the Hattu, Oijärvi and Kuhmo-Suomussalmi tracts in eastern Finland jointly contain 83 % of all the undiscovered Archaean gold resources. The 444 t of gold in identified resources in Finnish mineral deposits is less than 0.5 % of the known land-based world resources of at least 130,000 t of gold. The median estimated undiscovered gold resources in orogenic gold, layered intrusion-hosted PGE, porphyry and VMS deposits in Finland are, combined, at least 1366 t of gold. The orogenic undiscovered resources form 55 % of this. Although estimates of global undiscovered gold resources based on the three-part method do not exist, it is evident that the undiscovered Finnish resources are minuscule in comparison to the global resources.

Keywords (GeoRef Thesaurus, AGI): gold, gold ores, orogenic belts, undiscovered resources, evaluation, ore grade, tonnage, quantitative analysis, greenstone belts, Proterozoic, Archean, Finland

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Orogeenisiin kultaesiintymiin liittyvät löytämättömät kultavarannot Suomen kallioperässä arvioitiin yhden kilometrin syvyyteen asti käyttäen kolmivaiheista kvantitatiivista menetelmää. Tonnimäärä-pitoisuusmalli koottiin käyttäen hyvin tunnettuja orogeenisiä kultaesiintymiä Fennoskandian kilven alueelta (21 kpl) ja Pohjois-Australiasta (52 kpl). Arkeeisille kultaesiintymille rajattiin kahdeksan sallittua esiintymisaluetta, paleoproterotsooisille karjalaisille esiintymille 13 ja paleoproterotsooisille svekofennisille esiintymille 11. Arkeeiset alueet kattavat 23 800 km^2, karjalaiset 61 000 km^2 ja svekofenniset 25 000 km^2. Määritetyt 32 sallittua aluetta kattavat yhteensä 110 000 km^2, joka on 33 % Suomen maapinta-alasta. Sallituilla esiintymisalueilla sijaitsevien löytämättömien arkeeisten, karjalaisten ja svekofennisten esiintymien arvioitujen lukumäärien keskiarvot ovat 18, 45 ja 27. Tunnetut suomalaiset orogeeniset kultaesiintymät sisältävät 317 t kultaa; tämä on 71 % Suomen tunnetuista 444 t:n kultavarannoista. Löytämättömien orogeenisten kultaesiintymien arvioidaan sisältävän 50 %:n todennäköisyydellä ainakin 750 t kultaa. Näin ollen ainakin 70 % Suomen orogeenisten kultaesiintymien metallisisällöstä on heikosti tutkituissa ja kokonaan löytämättömissä esiintymissä. Mediaaniarvion mukaan löytämättömät kultavarannot arkeeisissa, karjalaisissa ja svekofennisissa esiintymissä ovat 140 t, 400 t ja 210 t kultaa. Yli puolet löytämättömistä orogeenisista kultavarannoista sijaitsee paleoproterotsooisilla karjalaisilla vihreäkivivyöhykkeillä Keski- ja Pohjois-Lapissa. Vierekkäiset ”Kittilä Group” ja ”Sattanen-Kolari” -sallitut alueet sisältävät arviolta 46 % löytämättömistä karjalaisista varannoista. Svekofennisistä löytämättömistä varannoista 49 %:n arvioidaan sijaitsevan vierekkäisillä Hämeen ja Pirkkalan sallituilla alueilla Etelä-Suomessa. Arkeeiset löytämättömät varannot ovat tasaisemmin jakautuneet, mutta Hatun, Oijärven ja Kuhmo-Suomussalmen sallitut alueet Itä-Suomessa sisältävät yhdessä 83 % löytämättömistä arkeeisista kultavarannoista. Suomen tunnetut 444 t:n kultavarannot ovat alle 0,5 % maailman tunnetuista maalla sijaitsevista vähintään 130 000 t:n kultavarannoista. Arvioidut mediaanivarannot löytämättömissä orogeenisissa esiintymissä, kerrosintruusioisäntäisissä PGE-esiintymissä, porfyyriesiintymissä ja VMS-esiintymissä Suomessa ovat yhteen laskettuina ainakin 1 366 t kultaa. Orogeeniset löytämättömät varannot muodostavat 55 % tästä. Kolmivaiheiseen arviointimenetelmään perustuvia arvioita globaaleista löytämättömistä kultavarannoista ei ole, mutta on ilmeistä, että Suomen löytämättömät kultavarannot ovat mitättömät globaaleihin varantoihin verrattuna.

Julkaisu on englanninkielinen.

Asiasanat (Geosanasto, GTK): kulta, kultamalmit, orogeniavyöhykkeet, löytämättömät varannot, arviointi, malmipitoisuus, tonnimäärä, kvantitatiivinen analyysi, vihreäkivivyöhykkeet, proterotsooinen, arkeeinen, Suomi

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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 of an ever-increasing number of individuals. In tandem with this trend, exploration for and the development of new mineral resources all over the world are facing increasing competition from other land uses (e.g., Briskey et al. 2007, Cunningham et al. 2007, Hitzman 2007, Idman et al. 2007, Rasmussen 2011). Recycling cannot cover all the demand of practically any metal, even where very little of the commodity, such as gold, is lost during production, manufacturing and recycling (e.g., Buchert et al. 2009, Wellmer & Dalheimer 2012). 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, 2014). We need to know our mineral resources and how they might be expanded. The essential information includes the location of the 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 gold (Au) resources in undiscovered orogenic gold deposits in Finland. The report contains two parts. The first part reviews the types of orogenic gold 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 Assessment project of the Geological Survey of Finland

The demands defined above, and requests from 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 minerals 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 will also provide 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. In 2010, the assessment of platinum-group element (PGE) resources was

completed and published (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 gold resources in orogenic gold deposits in Finland are provided is this report. The assessment results for copper, zinc, silver and gold in undiscovered VMS, porphyry copper and Outokumpu-type deposits in Finland are published in another report (Rasilainen et al. 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 a 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 the 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).

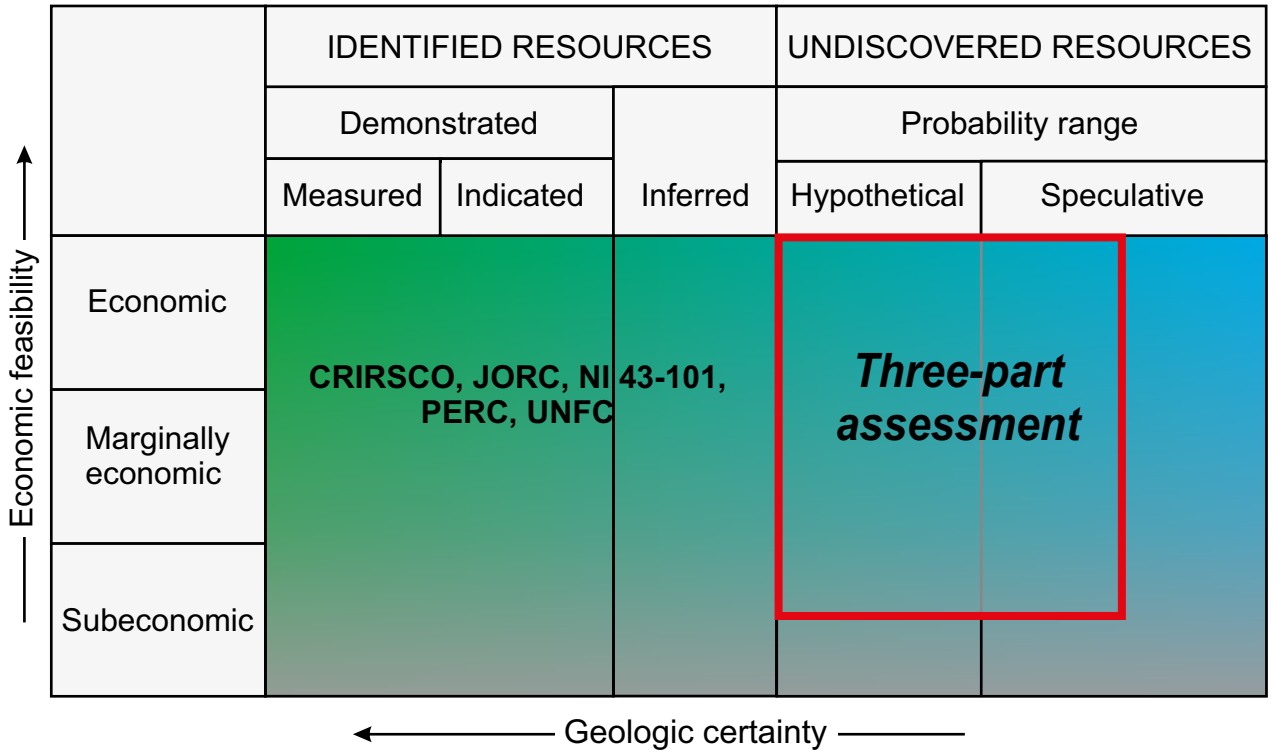

Fig. 1. Classification of mineral resources used in GTK assessments (modified from U.S. Geological Survey National Mineral Resource Assessment Team 2000). Economic feasibility increases upwards and geological uncertainty increases to the right.

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 are 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 Au DEPOSIT TYPES IN FINLAND

In Finland, gold is the main commodity in more than 200 deposits and occurrences of several genetic types (Fig. 2), and a potential by-product in almost all base metal and platinum group element (PGE) deposits (Eilu et al. 2003, Eilu & Pankka 2009, Rasilainen et al. 2010a, 2014). Most of the gold produced so far has come from two deposit types: VMS and orogenic gold, as a by-product and the main product, respectively (Puustinen 2003, Finnish Mining Registry cumulative data; Table 1). Gold production has during the past 25 years gradually moved from VMS deposits to deposits where gold is the main commodity. This development directly reflects the closure of most of the base metal mines in VMS deposits and opening of several gold-only mines.

Fig. 2. Drilling-indicated gold deposits and occurrences in Finland (Eilu & Pankka 2009, Hulkki et al. 2010, Eilu 2012b). Gold belt names given in italics are according to Eilu & Pankka (2009) and the geological map is based on the GTK in-house digital bedrock database (Geological Survey of Finland 2010).

Table 1. Cumulative gold production and remaining identified resources in Finland by the end of 2012.

Deposit class	Production		Identified resources	
	Ore (t)	Gold (t)	Ore (t)	Gold (t)
Orogenic gold	8,950,504	35	97,603,000	317
VMS[1]	86,648,000	39	66,033,000	14
Outokumpu type	41,335,000	23	19,045,000	6
Epithermal (Orivesi)	3,286,485	17	1,162,600	6
Pahtavaara[2]	4,981,687	15	2,756,000	5
IOCG	4,563,080	0.2	314,634,255	24
Kevitsa	3,138,000	0.4	272,200,000	32
Layered intrusions	0	0	188,393,000	26
Porphyry Cu-Au	0	0	25,000,000	14
Placer[3]	-	2	-	-
Total	152,902,756	132	986,826,855	444

[1] This includes one metric ton of gold estimated to be produced from the Hammaslahti Cu deposit; no full Au production data exist from Hammaslahti.

[2] Genetic type unknown.

[3] Rough estimate.

- : Data not available.

Production data are from Puustinen (2003) and the Finnish Mining Registry data; resources as of 31.12.2012 are from mining company media releases as listed in FODD (2013).

Most of the gold mineralisation in Finland is related to two stages of crustal evolution: the Neoarchaean orogeny in ca. 2.72–2.64 Ga, and the Palaeoproterozoic Svecofennian orogeny (or composite of orogenies) in ca. 1.93–1.77 Ga. Interestingly, both time spans are among the globally most significant stages of continental growth and gold mineralisation (Goldfarb et al. 2001). Archaean gold deposits known in Finland are exclusively in greenstone belts, and nearly all occurrences have been classified into the orogenic gold category; in addition, minor indications exist for epithermal gold in the Archaean. On the other hand, the Palaeoproterozoic rocks contain several genetic types of gold deposits: orogenic gold dominates, but epithermal, porphyry Au-Cu, iron oxide-copper-gold (IOCG), Au-rich VMS, palaeoplacer and, possibly, intrusion-related (IRG) occurrences are also present. All the potentially significant by-product gold is also Palaeoproterozoic: the PGE deposits in 2.45 and 2.06 Ga mafic-ultramafic intrusions, porphyry Cu-Au, VMS, and the Outokumpu-type deposits (Rasilainen et al. 2010a, 2014).

Gold contents of the known and undiscovered VMS, porphyry Cu-Au and layered-intrusion PGE deposits have been assessed and published in other reports of the current project (Rasilainen et al. 2010a, 2012, 2014) and are not discussed in detail in the present report. These assessments provide the remaining known and undiscovered gold resources as listed in Table 2. The Pahtavaara deposit in the Central Lapland greenstone belt, currently (October 2014) under care and maintenance, is not included in any assessments, as its genetic type is not clear (Korkiakoski 1992, David Groves, pers. comm. 2006, Patison et al. 2011). Pahtavaara has an anomalous barite-gold association and a very high fineness (>99.5 % Au) of gold. The gold may have been introduced later, but its textural position (nearly all occurs as free native grains with silicates instead of sulphides) and high fineness point to a pre-peak metamorphic genesis. In addition, the interpreted ore zone geometry is compatible with folding of a syngenetic alteration domain, remobilisation of gold, and the formation of mineralised later veins in fractures in folds or in shear zones may explain the late features of the deposit. During 2012, ore bodies were discovered that had a style of mineralisation different from that mined previously at Pahtavaara. These recent discoveries have abundant sulphides and significant copper in addition to gold (Lappland Goldminers 2013).

Table 2. Well-known and undiscovered gold resources in VMS, porphyry copper and layered intrusion-hosted PGE deposits in Finland.

Deposit class	Gold resources (t of metal)		Reference
	Well known	Median undiscovered	
Layered intrusion PGE	26	430	Rasilainen et al. (2010a)
Porphyry copper	14	170	Rasilainen et al. (2014)
VMS	14	16	Rasilainen et al. (2014)

Data for Precambrian epithermal deposits were found too scanty for both Finland and globally, and the global data for Phanerozoic epithermal deposits (e.g., Raw Materials Group 2010) were not considered to be representative of deposits in multiply deformed and metamorphosed environments. This reasoning is based on a comparison of the global Phanerozoic grade-tonnage data with the global grade-tonnage data from about 10 Precambrian epithermal deposits that have been mined and for which we found the grade and tonnage data. We defined two epithermal tracts during the assessment, covering most of the Uusimaa and Tampere volcanic belts in southern Finland (Fig. 8). However, we did not proceed to the simulations, due to the lack of useful grade-tonnage data, nor did we produce epithermal tract reports. It needs to be mentioned here that the one clearly epithermal gold deposit in Finland, Kutemajärvi in the Tampere schist belt, has a pre-mining global resource of 3.4 Mt @ 7.1 g/t Au (Dragon Mining 2012a, and Finnish Mining Registry cumulative data); this is equivalent to 24 t of gold.

The scarcity of grade and tonnage data representing entire deposits was also encountered for Kuusamo-like Au-Co±Cu deposits of any age or area globally (cf. Slack 2012, 2013). We also considered that the Kuusamo gold deposits could be included in the orogenic gold assessment: the deposits in the Kuusamo region were seen to share enough similarities with the typical orogenic gold deposits, as described below in section 2.2. Hence, all the known gold deposits in Kuusamo were included in the orogenic gold assessment in our work. The genetic classification of the Au-Cu and Au±U occurrences in the Peräpohja schist belt is even more difficult. These deposits are also epigenetic and structurally controlled, and they were considered, at least according to present knowledge, to have enough similarities to be treated as orogenic gold deposits *sensu lato*. In the light of the recently released data, the Peräpohja Au±U occurrences have a number of similarities with the Kuusamo deposits, such as high Co contents (Mawson Resources 2014).

Granitoid- or intrusive-related gold deposits (IRG; Lang & Baker 2001, Groves & Bierlein 2007) were considered uncommon or nonexistent in Finland. There is also a general lack of global grade-tonnage data for modelling. For example, the criteria for a tectonic setting well inboard of convergent plate boundaries, regional association with W or Sn provinces, and post-orogenic timing (Lang & Baker 2001, Groves et al. 2009) are completely lacking for gold deposits and occurrences in Finland. We believe that certain gold occurrences in western Finland recently suggested to belong to the IRG class (e.g., Belvedere Resources 2012) are in fact either orogenic gold or porphyry Cu-Au deposits. We have classified such deposits and occurrences as orogenic (e.g., Laivakangas, this report) or porphyry copper-gold (e.g., Kopsa, Rasilainen et al. 2014).

All the possible IOCG systems in Finland (Eilu & Pankka 2009) were regarded as having only a rather minor gold endowment (Table 3). With the exception of Lauttaselkä (0.48 Mt @ 0.48 ppm Au, 0.23 % Cu; Hiltunen 1989), they are essentially iron deposits where copper and gold form less than 10 % of the *in situ* value of the deposit. In addition, the global grade-tonnage data mainly appear to include the subpopulation of large deposits of the entire IOCG deposit population. More importantly, the genetic type still lacks a consistent definition agreed among the majority of researchers in economic geology, resulting in significant uncertainties for a descriptive model (compare, e.g., Partington & Williams 2000, and Groves et al. 2010). Hence, undiscovered IOCG deposits have not been assessed in this project.

Table 3.Ore and metal contents (mined + resources) in Finnish deposits that possibly belong to the IOCG class and contain gold in the reported resource.

Deposit	Tonnage (Mt)	Metal content			Reference
		Fe (t)	Cu (t)	Au (t)	
Hannukainen	202.6	67,403,241	334,820	12.79	Northland Resources (2010)
Kuervitikko	45.0	10,305,000	72,000	7.70	Northland Resources (2010)
Lauttaselkä	0.6	0	1,380	0.29	Hiltunen (1989)
Rautuoja	1.9	697,300	3,610	0.65	Korkalo (2006)
Rautuvaara Cu	2.8	610,400	13,440	0.56	Hiltunen (1982)
Vähäjoki	10.5	4,137,000	17,535	2.10	Korvuo (1982)
Total	263.4	83,152,941	442,785	24.09	

All the deposits are in the Kolari area, westernmost Finnish Lapland. The resource is defined according to the NI 43-101 code for Hannukainen and Kuervitikko; the resource is historic for the other deposits.

For palaeoplacer gold occurrences in Finland, grade data are scanty and tonnage data are lacking. Only two occurrences have been drilled (total of 11 short holes; Härkönen 1984, 1988). Very few indications for this deposit type exist outside of the Kumpu Group conglomerates in northern Finland, and even there the indications suggest only small occurrences, possibly none of economic significance. Most of the global data for palaeoplacer deposits is from Witwatersrand, which is so unique in terms of the enormous size of the deposits that its tonnage data should most probably not be used in assessing undiscovered palaeoplacer gold tonnages elsewhere (H. Frimmel, pers comm. 2013). Due to these reasons, we did not assess the undiscovered palaeoplacer gold in Finland.

A large number of small placer gold occurrences are known from northern Lapland, in Palaeogene(?) to Holocene regoliths, and Pleistocene to Holocene till, sand and gravel. Despite the numerous occurrences, more than 140 years of artisanal exploitation has only produced less than 2000 kg of gold (Puustinen 1991, Finnish Mining Registry data). The metal endowment of these occurrences is difficult to estimate; grades are commonly below 1 g/m^3, but locally in the best pay streaks they can be several tens of grams per cubic metre (A. Peronius, pers. comm. 2013, 2014). All presently available information suggest meagre possibilities for profitable industrial-scale gold production from these occurrences. On the other hand, these occurrences remain a potentially useful tool in exploration for hard-rock gold deposits in parts of northern Finland, as they indicate areas of primary gold mineralisation in the region.

Based on the reasoning above, the only deposit type included in the present assessment is orogenic gold. It is described in more detail in the following subsections.

2.1 Orogenic gold deposits in Finland

The concept of orogenic gold deposits as a distinct genetic mineral deposit class was formulated by Groves (1993) and Groves et al. (1998). Typical features, jointly diagnostic for this deposit category, are presented in the descriptive model in Appendix 1. Based on potential commodities, the deposit class can be divided into two main subtypes: 1) gold only and 2) anomalous (or atypical) metal association. This division follows Goldfarb et al. (2001), who originally suggested the latter subtype. The subtypes, as they occur in Finland, are described below. All three main regions of the Finnish bedrock – Archaean, Palaeoproterozoic Karelian and Palaeoproterozoic Svecofennian domains – contain orogenic gold occurrences of the gold-only subtype (Fig. 2). The anomalous metal association subtype is common in the Karelian domain, locally present but uncommon in the Svecofennian part, but has not been detected in the Archaean areas except for one case.

The economically significant metal in all the deposits is gold. Ore tonnages in the 73 well-known orogenic gold deposits used in the grade-tonnage model in this assessment range from 0.02 Mt to 300 Mt (median 1.9 Mt), and the median concentration of gold is 2.6 g/t Au (Table 4). The grade-

tonnage model used in our assessment is provided in Appendix 2. In the anomalous metal association subclass, the deposits have gold and one or two other metals as potential commodities. However, there are insufficient data to formulate a reliable grade-tonnage model separately for the latter, as the metal association (except for gold) varies. Grade and tonnage information for other metals than gold covering the entire deposit only exist for the Saattopora deposit.

2.1.1 Orogenic gold deposits in Archaean greenstone belts

Orogenic gold deposits in the Archaean parts of Finland exclusively occur in greenstone belts. They have been discovered in all Archaean greenstone belts explored for gold within the Fennoscandian Shield (Eilu et al. 2012, Korsakova et al. 2012). More than ten drilling-indicated occurrences have been discovered from the Ilomantsi and Kuhmo-Suomussalmi greenstone belts, whereas only a few are presently known from the Oijärvi, Savukoski and Enontekiö greenstone belts (Fig. 2), and none from the Archaean region northeast of the Granulite Belt in the northernmost corner of Finland. This variation in the number of known occurrences rather directly reflects the amount of gold exploration carried out in each greenstone belt (Eilu & Pankka 2009). All the greenstone belts contain gold anomalies in till, and some areas also contain auriferous glacial erratic boulders, for which no related mineralisation in bedrock has yet been discovered. One Archaean deposit, Pampalo in the Ilomantsi belt, has been in full-scale production since 2011. A resource has also been estimated for a few deposits within the Archaean Kuhmo-Suomussalmi greenstone belt.

All the known Archaean deposits and occurrences are typical orogenic gold systems (e.g., Sorjonen-Ward & Korsakova 2012) displaying the following characteristics (Eilu & Pankka 2009 and references therein). The deposits occur in 2nd to 4th order fault and shear zones branching from major regional structures (Figs 3 and 4). They are hosted by upper-greenschist to mid-amphibolite facies rocks and any primary rock type within the greenstone belt may host the ore. The structures indicate

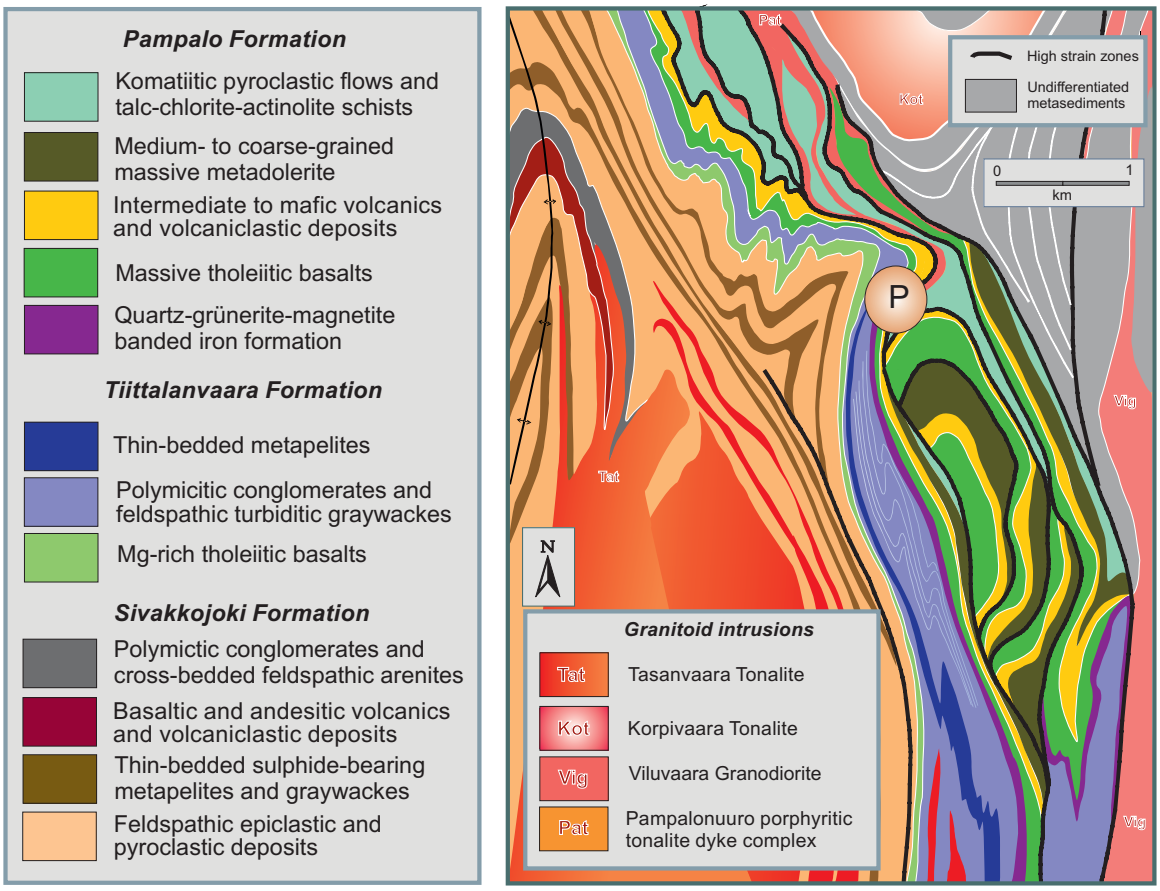

Fig. 3. Structural setting of the Pampalo gold deposit (P in the map) in the Neoarchaean Ilomantsi greenstone belt, eastern Finland. Pampalo is located at 62.987°N, 31.265°E. Modified after Sorjonen-Ward (1993) and Nurmi et al. (1993).

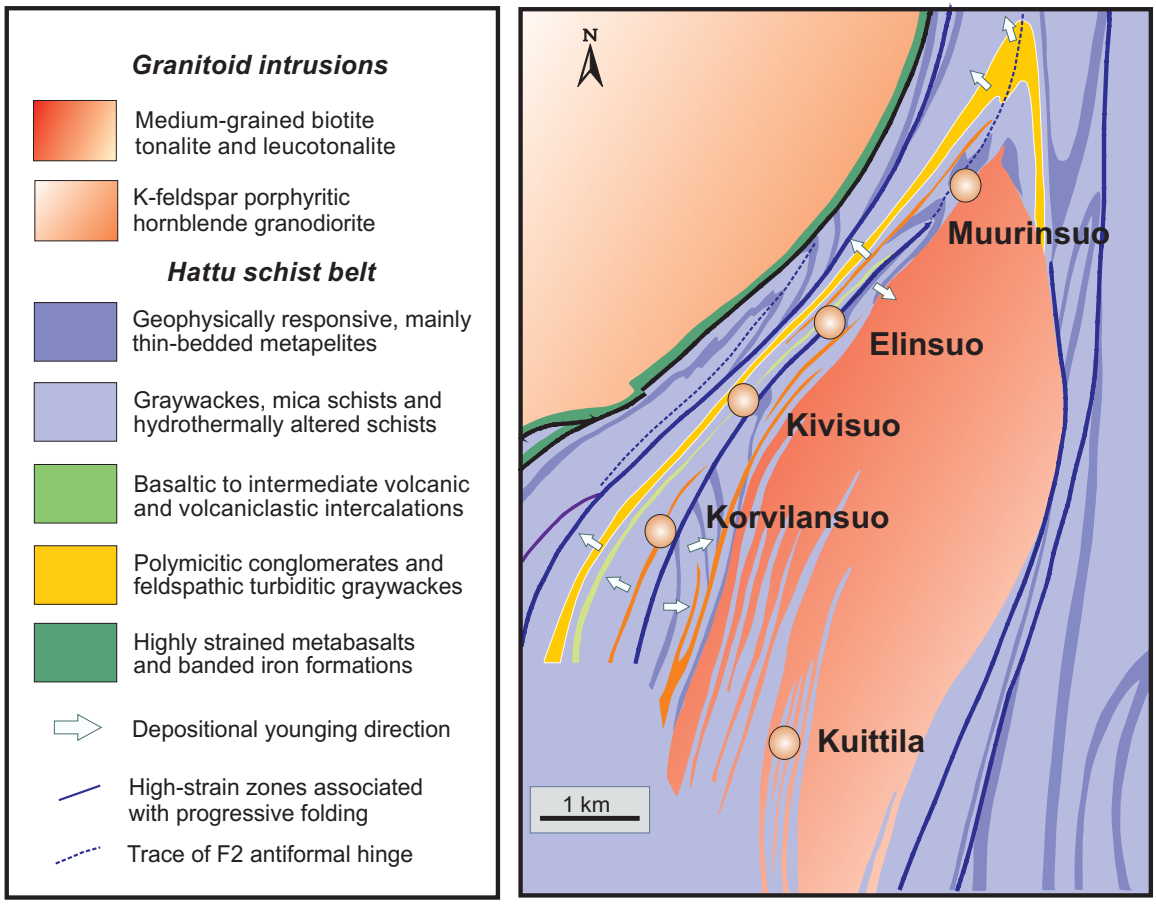

Fig. 4. Geological map of the Kuittila Zone, showing the asymmetric distribution of gold occurrences along and within the western margin of the Kuittila Tonalite, close to a second-order shear zone. Dots mark drilling-indicated gold occurrences. The location of the Kuittila occurrence is 62.773°N, 31.199°E. Modified from Sorjonen-Ward (1993).

that mineralisation took place during the latest major stage of regional deformation and near the regional metamorphic peak. Proximal alteration is characterised by sericite or biotite and calcite, with quartz veins having a calcic amphibole or clinopyroxene selvage in amphibolite-facies rocks. Pyrite, pyrrhotite and arsenopyrite (± löllingite) are the main sulphide minerals and gold occurs in the native form. The volume of the sulphides in the ore is typically 1–3 %. Components enriched in the ore and variably in the altered wall rocks include Ag, Au, As, CO_2, K, Rb, S, Sb, Te and W ± B. The gold–silver ratio is larger than one. Distinct base-metal enrichment has only been detected at Enontekiö, in the Ruossakero occurrence, where orogenic gold spatially overlaps komatiitic Ni-Cu mineralisation (Isomaa 1991). Gold mineralisation in the Finnish Archaean greenstone belts probably took place during the D3–D4 stages of the Neoarchaean orogenesis, at ca. 2.72–2.64 Ga, or more probably during 2.68–2.64 Ga (Luukkonen 2001, Hölttä et al. 2012, Sorjonen-Ward & Korsakova 2012).

2.1.2 Orogenic gold deposits in the Karelian domain

The Karelian domain comprises Palaeoproterozoic rocks to the north and northeast of the Svecofennian domain, mostly in the northern third of Finland. All of this, in contrast to the Svecofennian domain, has an Archaean basement at depths from the present surface to >10 km. At the surface, the Archaean bounds the Karelian domain in many parts, and in northwestern and eastern Lapland it is not clear which rocks are Archaean and which are Palaeoproterozoic. This issue is described in more detail in the respective tract reports in Appendix 3. The Central Lapland greenstone belt (CLGB) is the main gold-mineralised area of the Karelian domain, with 40 drilling-indicated deposits and occurrences, including the largest presently active gold mine in Europe (Kittilä Mine, Suurikuusikko deposit, Fig. 5), one closed mine (Saattopora) and a few test-mined deposits. More than 20 gold occurrences are known from the Kuusamo schist

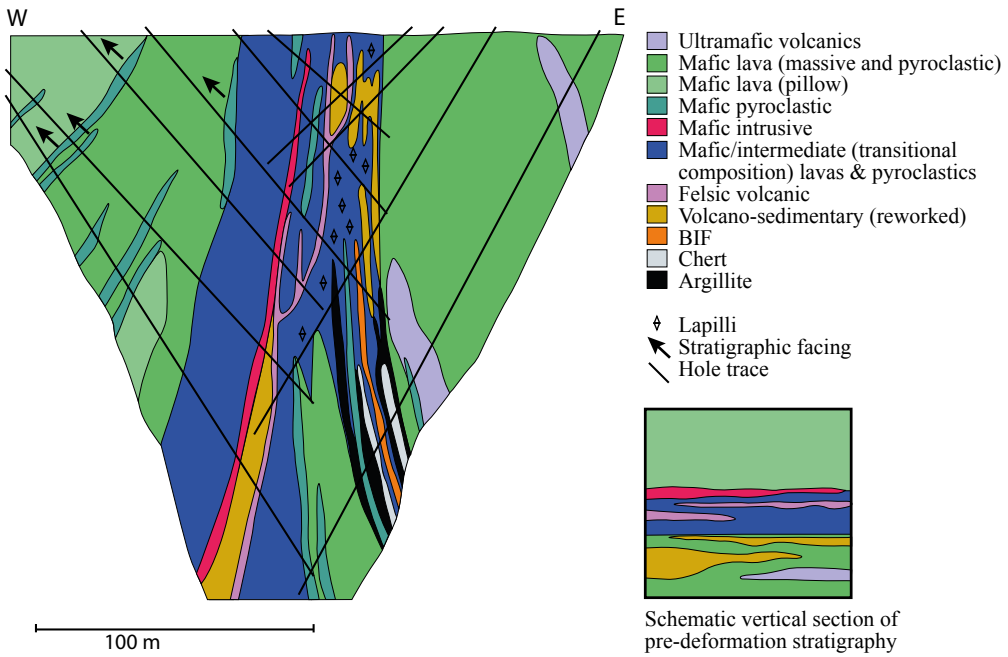

Fig. 5. Section across the Suurikuusikko gold deposit in the Central Lapland greenstone belt (Kittilä Mine). Image by Nicole Patison (2004), modified from Eilu & Weihed (2005).

belt (KuSB) and 11 from the Peräpohja schist belt (PSB), whereas only a few gold occurrences are known from the other subareas of the Karelian domain.

Gold occurrences in the Karelian domain are largely similar to those in the Archaean greenstone belts. The main differences include the dominance of greenschist-facies host rocks, the locally common gold-base metal association, and pre-mineralisation alteration to a variable degree (Hulkki & Keinänen 2007, Patison 2007, Eilu & Pankka 2009, Saalmann & Niiranen 2010). Greenschist-facies rocks display more extensive alteration haloes with alteration mineral assemblages from proximal through intermediate to distal zones as follows: sericite-ferrodolomite-quartz-albite-rutile → chlorite-ferrodolomite-calcite-quartz-albite-rutile → chlorite-calcite-quartz-albite-rutile → unaltered host rock. Pre- and syn-mineralisation fluids were dominated with compositions varying from dilute to moderately saline brines with a variable CO_2 content (Billström et al. 2010, Niiranen et al. 2012), suggesting variable, mixed origins for volatiles and metals with no obvious indications of local sources. There may be several stages of alteration within a deposit environment, both for the gold-only and gold-base metal types. The pre-gold alteration stages typically included albitisation ± carbonatisation of all rock types, resulting in soft rocks turning into the locally most competent units, which thus provided the best sites for local dilation, veining and gold mineralisation (e.g., Grönholm 1999, Vanhanen 2001, Saalmann & Niiranen 2010).

The base-metal-rich occurrences are otherwise like any gold-only orogenic deposit, but they also contain Cu, Co, Ni and/or U as a potential commodity. Moreover, in addition to pyrite, they have pyrrhotite and/or arsenopyrite, and one or two of chalcopyrite, cobaltite, pentlandite, gersdorffite and uraninite among the main ore minerals (Vanhanen 2001, Eilu et al. 2007, Hudson et al. 2011). The presence of more saline fluids during mineralisation appears to be typical. Goldfarb et al. (2001) suggested that orogenic gold deposits with an anomalous metal association formed from anomalously saline fluids in areas where Palaeoproterozoic tectonism included the deformation of older intracratonic basins, for example in the Transvaal basin in the Kaapvaal craton and the Arunta, Tennant Creek and Pine Creek inliers of northern Australia. The formation of saline metamorphic fluids in shallow marine sequences, in continental-self environments and especially in evaporite-bearing sequences was also suggested by Yardley and Graham (2003) and by Yardley and Clerverley (2013). It is additionally suggested

that such environments would be characterised by intense albitisation during progressive metamorphism, and that the fluids are not diluted during progressive metamorphism (Yardley & Graham 2003, Yardley & Clerverley 2013). Similar crustal evolution also characterises the Karelian domain of Finland: during 2.45–1.95 Ga, supracrustal sequences were formed in intracratonic basins with indications that self-environments with evaporates were intruded by several sets of mafic to ultramafic magmas, and were altered before regional metamorphism, multiple deformation and orogenic mineralisation and alteration during 1.93–1.77 Ga (Eilu 1994, Vanhanen 2001, Lahtinen et al. 2005, Kyläkoski 2009, Lahtinen 2012).

2.1.3 Gold deposits and occurrences in Kuusamo schist belt

The Kuusamo schist belt (KuSB) is characterised by Au-Co±Cu±U±LREE mineralisation (Vanhanen 2001). The reported tonnages and grades of gold occurrences vary from 0.04 to over 4 Mt and 0.4–7.5 g/t Au, 0.03–0.25 % Co and 0.02–0.4 % Cu; in a few cases, the resource also contains 0.01–0.03 % U and 0.1 % total REE (Lahtinen 1980, Vanhanen 2001, Dragon Mining 2012b). The available data, mainly from Vanhanen (2001), suggest that most of the reported total REE grades in these occurrences comprise LREE.

The Kuusamo occurrences are hosted by a clastic sedimentary sequence deposited between 2.44 and 2.21 Ga, which also contains basaltic lavas and indications of evaporates (Vanhanen 2001). The sequence was intruded by basaltic dykes and sills prior to regional deformation. All gold occurrences have a distinct structural control and most are located where a regional northeast-trending anticline is cut by northwest-trending faults. The largest deposit, Juomasuo, and its satellites are at the site of a doubly-plunging part of the northeast-trending anticline.

Alteration in the KuSB is extensive and multistage. Rocks in the belt were affected by three regional alteration events: 1) diagenetic, partial albitisation of feldspars and sericitisation of clay minerals in all sedimentary units; 2) local, partial to total albitisation of clastic sedimentary units and spilitisation of volcanic units, either related to the ca. 2.21 Ga intrusion of the mafic sills and dykes or to the later, early stages of orogenic evolution; and 3) overprinting of the early spilitisation and albitisation by much more extensive albite and scapolite alteration and local carbonatisation (Pankka 1992, Pankka & Vanhanen 1992, Vanhanen 2001). The intensity of the latter alteration varied from weak (<10 vol% albite) to strong, locally resulting in almost pure albite rock (99 vol% albite, with traces of carbonate, rutile and quartz). In addition to the regional alteration, local alteration surrounding the metallic mineralisation includes carbonatisation, sericitisation, biotitisation and sulphidation. Deposits are enriched in As, Au, Bi, Co, CO_2, Cu, K, LREE, Mo, Rb, S, Se, Te, U and W; less commonly and to lower degrees, Fe, HREE, Mn, Mo, Ni, Pb and Th are also enriched. The Au–Ag ratio is consistently higher than 1 (Pankka 1992, Vanhanen 2001).

Main ore minerals are pyrite, pyrrhotite, cobaltite, cobaltian pentlandite and chalcopyrite. Native gold occurs free in gangue, and associated with Bi and Te minerals as inclusions and in fractures in pyrite, pyrrhotite, cobaltite and uraninite.

The polymetallic occurrences in the KuSB have historically been classified into various deposit classes, including orogenic gold with atypical metal associations, iron oxide-copper-gold, Blackbird-type, and syngenetic deposits (e.g., Pankka 1992, Pankka & Vanhanen 1992, Vanhanen 2001, D.I. Groves, pers. comm. 2006, Slack 2012, 2013). The timing seems to fit with both the orogenic and Blackbird styles of mineralisation. The alteration style, metal association, and nature of the mineralising fluid(s) fit best with the Blackbird-type model. The characteristics of mineralising fluid(s), the metal association and the rift–shelf setting are consistent with features of the Blackbird-type, and of the orogenic type with an atypical metal association. Structural control and gold fineness are not uncharacteristic of any of the proposed models. In our opinion, the Kuusamo occurrences are epigenetic, pre-metamorphic events prepared ground for later, syndeformation mineralisation, and the occurrences have enough similarities with the orogenic gold deposits of the anomalous metal association subtype to be included into the present, orogenic gold, assessment.

2.1.4 Gold deposits and occurrences in the Peräpohja schist belt

Two types of gold occurrences have been discovered from the Peräpohja schist belt (PSB). One occurs as Au- and Cu-rich quartz vein deposits hosted by metadolerites and their immediate clastic metasedimentary and mafic metavolcanic wall rocks of 2.3–2.1 Ga in age (Rouhunkoski & Isokangas 1974, Perttunen & Vaasjoki 2001, Eilu et al. 2007). The second type includes nuggety gold ± uraninite in multiply veined and altered supracrustal rocks of probably both clastic sedimentary and volcanic origin (Nebocat 2012, Mawson Exploration Team et al. 2013). No published resource estimates covering an entire gold deposit are known from the PSB.

The Au-Cu type could be regarded as an orogenic gold system of the anomalous metal association subclass. These occurrences, such as the Kivimaa deposit (Rouhunkoski & Isokangas 1974), share many features with orogenic gold deposits. The occurrences are epigenetic and hosted by competent lithologies, gold occurs associated with sulphides and silicate gangue in quartz veins and their immediate wall rocks, and the alteration halo is typical of orogenic gold systems in upper greenschist facies rocks: proximal biotite-calcite±sulphides and distal biotite (Eilu & Pankka 2009). The Au-Cu metal association fits well with an intracratonic rift basin environment that contains evaporates, is filled by clastic sedimentary and mafic volcanic rocks, is intruded by mafic dykes and sills, and has a 570 Ma evolutionary history (ca. 2.45–1.88 Ga) before regional deformation and metamorphism (Perttunen & Vaasjoki 2001, Kyläkoski 2009). This environment would easily produce fluids with uncommonly high salinities able to leach, transport and deposit gold and base metals during an orogeny (Goldfarb et al. 2001). However, other deposit models have also been suggested for these PSB deposits, such as distal mineralisation in red bed copper systems (Kyläkoski 2009).

The Au±U type is even more difficult to classify. The discovery of these occurrences was made as recently as 2010, in the Rompas area in the northwestern part of the PSB (Hudson et al. 2011, Nebocat 2012). The host rocks, possibly 2.3–1.95 Ga in age, are so intensely and extensively altered that their primary character is often impossible to define in outcrop or in diamond drill cores. At this early stage of investigations, little is yet known of them. According to current knowledge, gold seems to be controlled by late, dominantly brittle structures, hosted by metabasaltic rocks (the most competent local units?), and the deposits may hence belong to the orogenic gold category. The gold and uranium grades so far detected are locally very high, more than 1000 g/t Au and several per cent U in grab samples from outcrops in an area of 6 x 10 km. The best section from drilling that started in 2012 is reported to include 6 m containing 617 g/t Au (Mawson Exploration Team et al. 2013). High cobalt grades showing a strong positive correlation with gold and uranium grades have recently been reported. The gold appears to be later (if not remobilised) than uranium, and there are gold occurrences with apparently no anomalous uranium. We have no knowledge of similar mineral deposits from elsewhere, but with the present evidence we have included these in the orogenic gold class. Future work may provide clear evidence that the Rompas Au±U system belongs to some other deposit class, and our reasoning here should be regarded with caution.

2.1.5 Orogenic gold deposits in the Svecofennian domain

Orogenic gold occurrences have been detected in almost all supracrustal belts of the Svecofennian domain (Fig. 2). Most of the occurrences are gold only, but parts of western Finland also contain occurrences with an anomalous metal association. Some of the latter may be syngenetic copper occurrences (VMS, porphyry Cu) overprinted by orogenic gold, but due to the lack of data, in many cases we cannot be sure. The antimony-rich occurrences in the Seinäjoki tract area (southern half of the Southern Ostrobothnia domain in Fig. 2) are probably typical orogenic gold-antimony deposits known to occur in other metamorphosed terrains of various ages, for example, in South Africa, Zimbabwe, Yakutia, China, Bolivia and the Variscan metamorphosed massifs across western and central Europe (e.g., Bellot et al. 2003, Jaguin et al. 2013). There is presently (October 2014) one active gold mine (Jokisivu) and one in care and maintenance (Laivakangas) in orogenic gold deposits in the Svecofennian domain (Figs 2 and 6).

Almost all of the orogenic gold occurrences in the Svecofennian domain are in amphibolite-facies rocks. A few may be in lower-granulite grade terrains: these and the occurrences in upper-amphibo-

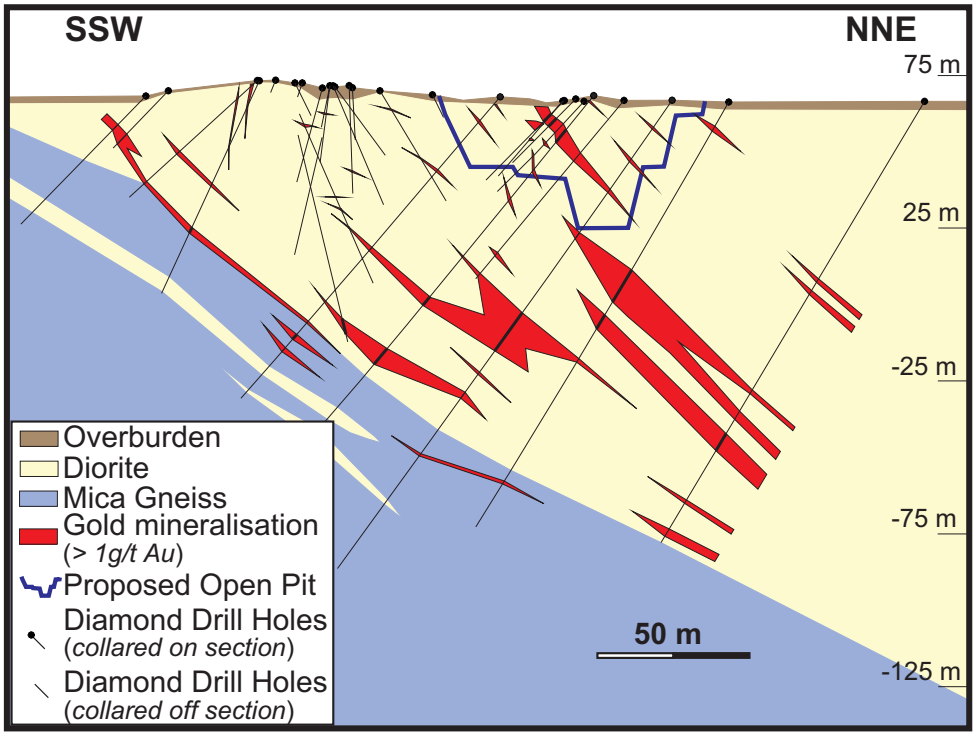

Fig. 6. Section across the Kujankallio lodes at Jokisivu, just before mining started at the deposit. (Image courtesy Dragon Mining, 2009). Modified from Eilu et al. (2012).

lite facies rocks were possibly formed prior to the regional metamorphic peak. The gold and related quartz veins and alteration at least show no signs of a relationship with retrograde mineral assemblages (Kontoniemi 1998, Kärkkäinen et al. 2012). Furthermore, orogenic gold mineralisation under upper-amphibolite to granulite facies conditions appears unlikely in the light of recent research (e.g., Tomkins & Grundy 2009). Intermediate to felsic synorogenic intrusions are more common hosts to ore in the Svecofennian than in the other domains. Largely due to the higher metamorphic grade, the most common sulphides are pyrrhotite, arsenopyrite and löllingite. In the gold-copper and gold-antimony occurrences, chalcopyrite and stibnite plus native antimony, respectively, are also among the main ore minerals. Alteration haloes typically include the mineral assemblage biotite-hornblende-diopside-calcite. Gold may occur in various settings. At Osikonmäki in southeastern Finland, there is chiefly native gold with bismuth-selenium-tellurium minerals, as inclusions and at grain boundaries within and between arsenopyrite, quartz and plagioclase grains (Kontoniemi et al. 1991). At Jokisivu, 90 % of the gold is native and free milling, mainly present in quartz veins (Luukkonen 1994).

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, Barton et al. 1995, Singer 1993, 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, 2012, U.S. Geological Survey National Mineral Resource Assessment Team 2000, Kilby 2004, Lisitsin et al. 2007, 2014, Cunningham et al.

2008, Hammarstrom et al. 2010, 2013, Mihalasky et al. 2011, Rasilainen et al. 2010a, 2012, Ludington et al. 2012a,b, 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 recognised. 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 construc-

tion 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 the 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 10th 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 Au RESOURCES IN FINLAND

4.1 Resources covered by the assessment

Here, we report the results of the assessment of undiscovered resources of gold in orogenic deposits. We also considered other possible genetic types of gold deposits, but did not include them in the final assessment, for reasons described in the introductory part of section 2.

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, western, eastern and southern regional offices of GTK were selected to ensure knowledge of all covered areas. The work started with a two-day workshop on 16–17 March 2011, at which the participants were introduced to the three-part assessment method. The types of known gold deposits in Finland and their characteristics were reviewed and deposit types to be included in the assessment were selected. Five possible types of deposits were discussed: orogenic, epithermal, 'Kuusamo', IOCG and IRG. Responsibilities for the delineation and documentation of initial permissive tracts and for checking the existing grade-tonnage data for the selected deposit types were assigned to the assessment team members.

After the first 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 orogenic gold 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 late 2011 to early 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 in this report.

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 many of 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 3.

4.3.1 Geology

The GTK in-house GIS map database of Finnish bedrock (Geological Survey of Finland 2010) 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 online 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 FINGOLD database of GTK (Eilu & Pankka 2009), the Fennoscandian Ore Deposit Database (FODD 2011, 2013) and a compilation of mineral deposits and metallogenic belts in the Fennoscandian Shield (Eilu 2012a) were the main sources of data for known gold 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, information from orogenic gold deposits in Ahmad et al. (2009), updated with data from mining company web pages for the presently active mines and mine development projects were used in compiling the grade-tonnage model. These data from deposits in the Northern Territory and adjacent areas in Australia were considered to be of equally reliable and consistent quality as the data from Fennoscandia. We also assessed grade and tonnage data from several other sources, including data for the Bendigo Zone in Victoria, Australia (Lisitsin et al. 2007), Barrick data for the Southern Cross greenstone belt in Western Australia (Raelene Kellet, pers. comm. 2011), gold deposits in Zimbabwe (Hokka 2011 and references therein), and available global gold deposit databases. However, these latter sources were not used in the grade-tonnage model due to inconsistencies in the data; there were too high and variable cut-off grades, mixtures of old production and recent resource data, and uncertainties in the genetic type and total pre-mining size of 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 sporadically 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 2011, 2014) were used to estimate exploration activities for gold 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 Orogenic gold deposits

The concept of orogenic gold deposits as a distinct genetic mineral deposit class was formulated by Groves (1993) and Groves et al. (1998), and further developed and refined by several authors (e.g., Goldfarb et al. 2001, 2005, Groves et al. 2003, Tomkins & Grundy 2009, Phillis & Powell 2010, Weatherley & Henley 2013, Pitcairn et al. 2014). A descriptive model for orogenic gold deposits, which summarises the typical features jointly diagnostic for this deposit category, is provided in Appendix 1.

Data from several sources and locations were assessed for suitability to be included in a grade-tonnage model. These are discussed above, in section 4.3.2. After initial evaluation, the grade and tonnage data of deposits in Finland, Sweden and

the Northern Territory in Australia were considered to be of equally reliable and consistent quality to be included in the model.

Only deposits that were considered well-known, wholly delineated and with no missing data for ore tonnage or gold grade were accepted in the grade-tonnage model. A spatial rule was applied according to which deposits were combined into one if the distance between them was less than 500 m. The final model contains five Archaean and 10 Proterozoic deposits from Finland, six Proterozoic deposits from Sweden and 52 Proterozoic deposits from Australia. Statistical tests indicated that there are no significant differences between deposits from various countries or of different ages.

The grade-tonnage model for orogenic gold deposits used in the assessment of undiscovered gold resources in Finland is summarised in Table 4 and Figure 7. The model is provided in detail in Appendix 2.

Table 4. Summary statistics for the orogenic gold grade-tonnage model.

	Tonnage (Mt)	Au (g/t)
N of cases	73	73
Minimum	0.020	0.80
Maximum	300.740	15
Mean	10.644	3.0
St dev	37.329	2.3
10%	0.095	1.1
50%	1.858	2.6
90%	18.003	5.3
S-W p	0.35094	0.39652

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 (test conducted using logarithmic values of tonnages and gold grades). Tonnages are rounded to full thousands and grades to two significant digits.

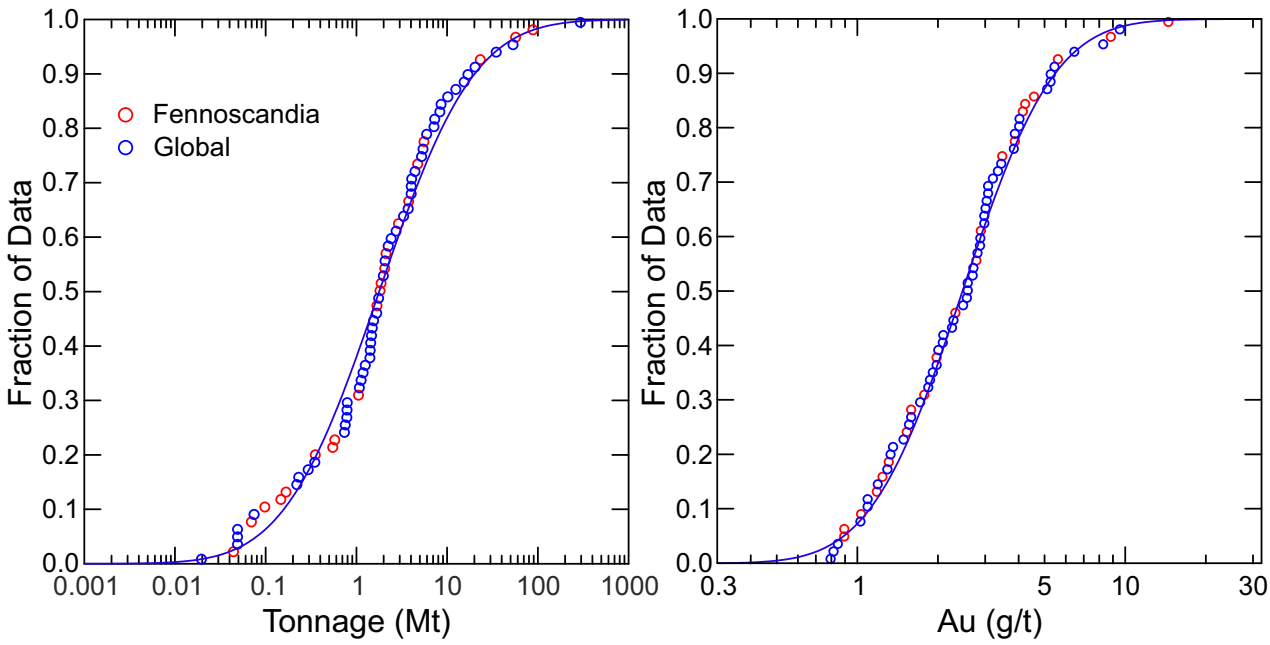

Fig. 7. Cumulative frequency plots of the ore tonnage and gold grade for the orogenic gold deposits in the grade-tonnage model. The blue lines show the fitted lognormal distributions.

4.5 Tract delineation

Permissive tracts were delineated for the orogenic gold deposits (Fig. 8, Table 5), based on the information described in section 4.3. Maps of the individual permissive tracts are included in the tract reports in Appendix 3. In addition to the orogenic permissive tracts, two tracts for epithermal gold deposits were delineated in southern Finland (Fig. 8). However, a number of undiscovered deposits and metal and ore tonnages were not assessed for the epithermal tracts due to the lack of grade-tonnage data that could be applied to metamorphosed terrains.

For each area, the member or members of the assessment team most familiar with the geology

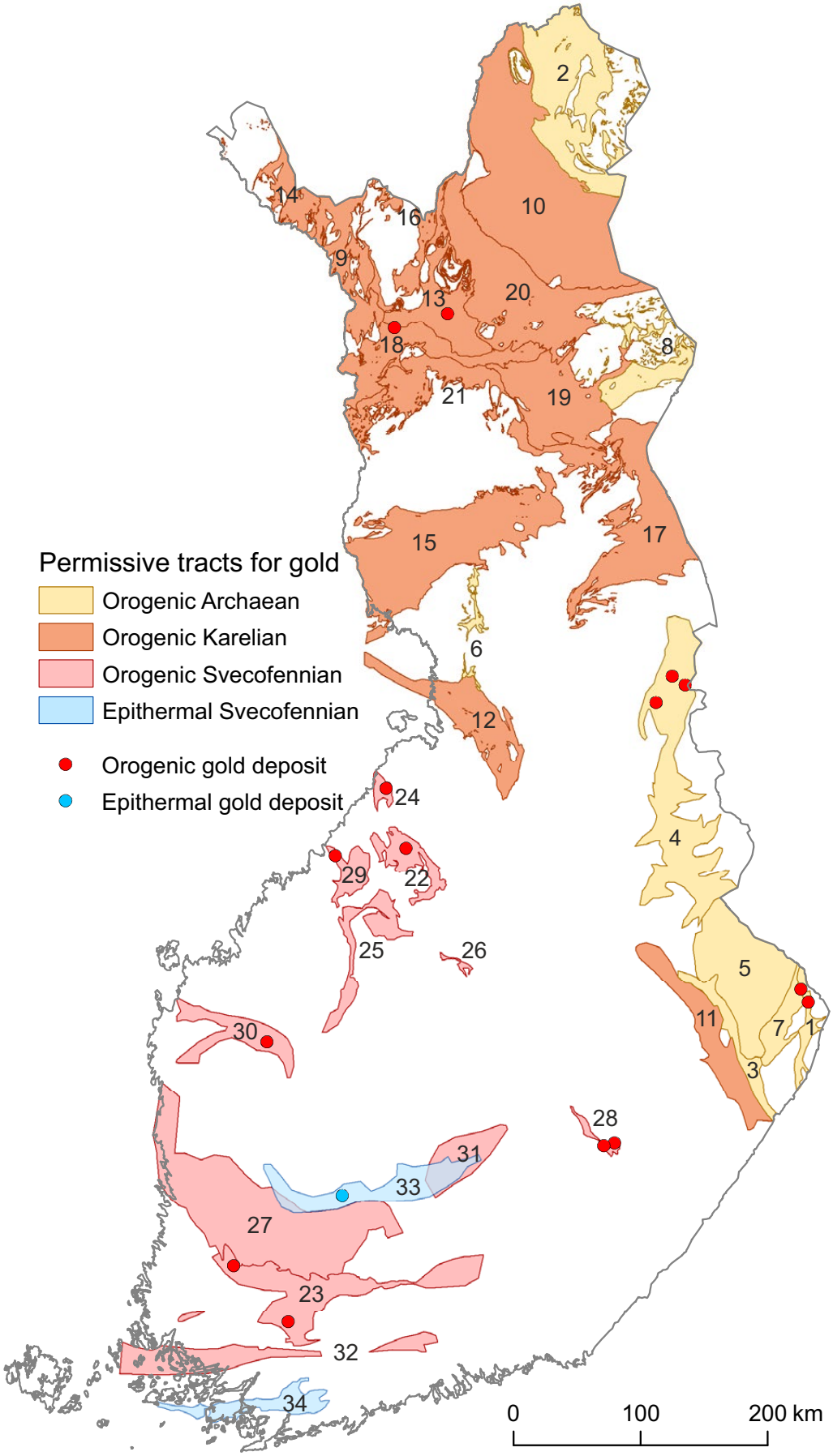

Fig. 8. Location of permissive tracts and well-known deposits for orogenic gold in Finland. The two permissive tracts for epithermal gold deposits are also shown. The numbers refer to Table 5.

and gold mineralisation of the region delineated the tracts. The criteria for the delineation of each tract are given in the tract reports in Appendix 3. 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 units terminate 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.

Table 5. Permissive tracts for orogenic and epithermal gold deposits in Finland.

Map number	Tract name	Tract type	Tract age	Tract area (km²)	N of known deposits
1	Hattu	Orogenic	Archaean	640	2
2	Inarinjärvi–Kaamanen	Orogenic	Archaean	6,321	0
3	Kovero–Nunnanlahti	Orogenic	Archaean	1,167	0
4	Kuhmo–Suomussalmi	Orogenic	Archaean	7,149	3
5	Lieksa–Nurmes	Orogenic	Archaean	5,215	0
6	Oijärvi	Orogenic	Archaean	337	0
7	Sonkaja	Orogenic	Archaean	1,026	0
8	Tulppio-Tuntsa	Orogenic	Archaean	1,895	0
9	Enontekiö–Muonio	Orogenic	Karelian	2,654	0
10	Granulite Belt	Orogenic	Karelian	12,793	0
11	Joensuu	Orogenic	Karelian	2,936	0
12	Kiiminki	Orogenic	Karelian	3,375	0
13	Kittilä Group	Orogenic	Karelian	3,376	1
14	Lätäseno–Ropi	Orogenic	Karelian	5,656	0
15	Peräpohja	Orogenic	Karelian	1,341	0
16	Pulju	Orogenic	Karelian	8,709	0
17	Salla–Kuusamo	Orogenic	Karelian	996	0
18	Sattanen–Kolari	Orogenic	Karelian	3,028	1
19	Sodankylä–Savukoski	Orogenic	Karelian	4,420	0
20	Tana–Lokka	Orogenic	Karelian	7,260	0
21	Vuojärvi Group	Orogenic	Karelian	4,505	0
22	Haapajärvi–Haapavesi	Orogenic	Svecofennian	1,199	1
23	Häme	Orogenic	Svecofennian	4,230	2
24	Laivakangas	Orogenic	Svecofennian	270	1
25	Lesti Arc	Orogenic	Svecofennian	1,486	0
26	Pihtipudas	Orogenic	Svecofennian	86	0
27	Pirkkala	Orogenic	Svecofennian	10,257	0
28	Rantasalmi	Orogenic	Svecofennian	220	2
29	Rautio	Orogenic	Svecofennian	815	1
30	Seinäjoki	Orogenic	Svecofennian	1,842	1
31	Tammijärvi	Orogenic	Svecofennian	1,720	0
32	Turku	Orogenic	Svecofennian	2,835	0
33	Tampere	Epithermal	Svecofennian	2,841	1
34	Uusimaa	Epithermal	Svecofennian	1,468	0

Map number: Number of tract in Figure 8; N of known deposits: Number of well-known gold deposits within the tract.

4.6 Estimation of the number of undiscovered deposits

The number of undiscovered orogenic gold deposits was estimated separately for each permissive tract in a series of workshops by the members of the assessment team and by a few other GTK experts. The names of the estimators for each permissive tract are given in the tract reports in Appendix 3. 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.

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 lognormal 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 produces frequency distributions of ore and metal tonnages in the undiscovered deposits.

Although the ore tonnages and gold grades in the orogenic gold grade-tonnage model do not significantly deviate from a log-normal distribution, the estimated empirical frequency distributions were used in the simulations for the Finnish gold deposits. This was done to avoid the very large estimates of metal tonnages that sometimes result from using log-normal models. The empirical distributions follow the grade-tonnage data closely and 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 orogenic gold deposits were estimated in separate simulation runs.

5 RESULTS AND DISCUSSION

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. The results of the orogenic gold assessment are summarised in Figures 8–10 and in Tables 5–7. Detailed assessment information for each permissive tract is presented in Appendix 3, 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 lognormal than a normal

Table 6. Summary of principal results for orogenic gold permissive tracts in Finland.

Tract name	Age	Estimated number of undiscovered deposits						Discovered resources (t)			Median undiscovered resources (t)		Total deposits	Tract area (km²)	Deposit density
		90	50	10	E	Std	Cv	N	Au	Ore	Au	Ore			
Hattu	Archaean	3	5	7	4.8	1.6	33	2	10.26	2,935,372	42	21,000,000	6.8	640	0.011
Inarinjärvi–Kaamanen	Archaean	0	1	2	1.0	0.79	79	0	0	0	3.9	1,500,000	1.0	6,321	0.00016
Kovero–Nunnanlahti	Archaean	0	1	2	1.0	0.79	79	0	0	0	4.0	1,500,000	1.0	1,167	0.00086
Kuhmo–Suomussalmi	Archaean	2	4	6	3.9	1.5	40	3	2.88	735,000	31	15,000,000	6.9	7,149	0.00096
Lieksa–Nurmes	Archaean	0	0	1	0.30	0.50	170	0	0	0	0	0	0.3	5,215	0.000058
Oijärvi	Archaean	3	4	7	4.4	1.7	38	0	0	0	37	18,000,000	4.4	337	0.013
Sonkaja	Archaean	0	1	3	1.3	1.2	90	0	0	0	5.2	2,000,000	1.3	1,026	0.0013
Tulppio–Tuntsa	Archaean	0	2	3	1.7	1.1	63	0	0	0	9.0	3,700,000	1.7	1,895	0.0090
Total Archaean					18.4			5	13.14	3,670,372	132.1	62,700,000	23.4	23,750	
Enontekiö–Muonio	Karelian	0	1	3	1.3	1.2	90	0	0	0	5.1	1,900,000	1.3	2,654	0.00049
Granulite Belt	Karelian	0	0	1	0.30	0.50	170	0	0	0	0	0	0.3	12,793	0.000023
Joensuu	Karelian	0	0	1	0.30	0.50	170	0	0	0	0	0	0.3	2,936	0.00010
Kiiminki	Karelian	0	1	2	1.0	0.79	79	0	0	0	4.0	1,500,000	1.0	3,375	0.00030
Kittilä Group	Karelian	5	9	14	9.0	3.4	38	1	243.1	58,159,000	100	54,000,000	10	3,376	0.0030
Kovero–Nunnanlahti	Karelian	0	1	2	1.0	0.79	79	0	0	0	4.0	1,500,000	1.0	1,167	0.00086
Lätäseno–Ropi	Karelian	0	2	3	1.7	1.1	63	0	0	0	9.3	3,800,000	1.7	1,341	0.0013
Peräpohja	Karelian	2	5	9	5.2	2.6	50	0	0	0	46	22,000,000	5.2	8,709	0.00060
Pulju	Karelian	0	1	3	1.3	1.2	90	0	0	0	5.1	1,900,000	1.3	996	0.0013
Salla–Kuusamo	Karelian	3	7	11	6.8	2.9	43	0	0	0	70	36,000,000	6.8	5656	0.0012
Sattanen–Kolari	Karelian	4	8	12	7.7	3.0	39	1	6.19	2,166,000	80	43,000,000	8.7	3,028	0.0029
Sodankylä–Savukoski	Karelian	2	4	7	4.2	1.9	46	0	0	0	34	16,000,000	4.2	4,420	0.00095
Tana–Lokka	Karelian	1	2	4	2.2	1.2	54	0	0	0	14	6,000,000	2.2	7,260	0.00030
Vuojärvi Group	Karelian	2	3	6	3.5	1.6	47	0	0	0	27	13,000,000	3.5	4,505	0.00078
Total Karelian					44.5			2	249.29	60,325,000	394.5	199,100,000	46.5	61,049	

Table 6. Cont.

Tract name	Age	Estimated number of undiscovered deposits						Discovered resources (t)			Median undiscovered resources (t)		Total deposits	Tract area (km²)	Deposit density
		90	50	10	E	Std	Cv	N	Au	Ore	Au	Ore			
Häme	Svecofennian	3	5	9	5.4	2.4	44	2	11.64	2,270,657	48	24,000,000	7.4	4,310	0.0017
Laivakangas	Svecofennian	1	2	4	2.2	1.2	54	1	42.42	23,700,000	15	6,100,000	3.2	270	0.012
Lesti Arc	Svecofennian	1	1	2	1.2	0.55	45	0	0	0	6.2	2,300,000	1.2	1,486	0.00081
Pihtipudas	Svecofennian	0	0	1	0.30	0.50	170	0	0	0	0	0	0.3	86	0.0035
Pirkkala	Svecofennian	3	5	10	5.7	2.7	48	0	0	0	54	28,000,000	5.7	10,257	0.00056
Rantasalmi	Svecofennian	0	1	1	0.70	0.41	58	2	10.96	4,988,000	2.3	790,000	2.7	220	0.012
Rautio	Svecofennian	1	2	3	1.9	0.84	43	1	7.08	5,675,000	12	5,200,000	2.9	815	0.0036
Seinäjoki	Svecofennian	2	4	7	4.2	1.9	46	1	0.23	171,000	35	17,000,000	5.2	1,842	0.0028
Tammijärvi	Svecofennian	0	1	2	1.0	0.79	79	0	0	0	3.9	1,500,000	1.0	1,720	0.00058
Turku	Svecofennian	1	2	4	2.2	1.2	54	0	0	0	14	6,000,000	2.2	2,835	0.00078
Total Svecofennian					27.3			8	76.91	40,654,657	207.4	98,290,000	35.3	25,040	
Grand total					90.2			15	339.34	104,650,029	734	360,090,000	105.2	109,839	

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 well-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 well-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 Archaean, Karelian, Svecofennian: Sum across Archaean, Karelian and Svecofennian tracts, respectively; Grand total: Sum across all tracts.
E and Std are calculated using a regression equation (Singer & Menzie 2005). Discovered resources consist of well-known 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 7).

distribution, the probabilities associated with the expected (mean) amounts of undiscovered metals and ore are less than 50 %, generally around 30 % for aggregated results and 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 (value associated with the 50 % quantile) exists. This is why we prefer to report the median estimate of undiscovered metal and ore in Table 6, in which the results for individual permissive tracts are summarised. Table 7, which aggregates the total undiscovered gold endowment over a number of permissive tracts, gives several quantile values to better characterise the frequency distributions of gold and ore tonnages. In the following, median estimates, that is, values corresponding to the 50 % quantile of the cumulative frequency distribution, are used when discussing the amounts of undiscovered gold metal.

Table 7. Summary of the well-known and estimated undiscovered resources in orogenic gold deposits in Finland.

Archaean	**Well known**	**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**
Au (t)	9.18	8.5	24	140	840	1,400	330	0.24	0.03
Ore (Mt)	2.707	2.9	9.2	64	680	1,100	230	0.21	0.03
Karelian	**Well known**	**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**
Au (t)	243.4	30	77	400	2,000	3,000	800	0.28	0.02
Ore (Mt)	59.943	12	31	200	1,600	2,400	550	0.26	0.02
Svecofennian	**Well known**	**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**
Au (t)	63.95	11	33	210	1,200	2,100	490	0.24	0.03
Ore (Mt)	35.439	3.9	12	99	950	1,800	340	0.21	0.03
Total orogenic	**Well known**	**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**
Au (t)	316.53	47	130	750	4,000	6,500	1,600	0.26	0.02
Ore (Mt)	98.089	17	51	360	3,300	5,500	1,100	0.24	0.02

Ore: Mineralised rock containing the metals. Well-known resources as of the end of 2012. Data sources are listed in Appendix 2.
The undiscovered resources are rounded to two significant digits.

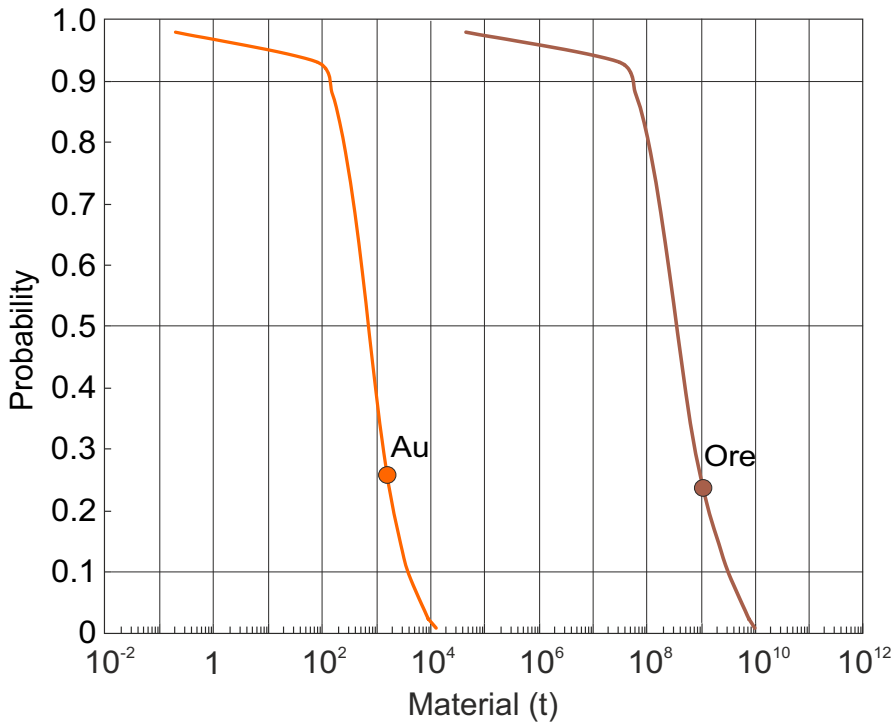

Fig. 9. Summary frequency distributions of simulated undiscovered resources in orogenic gold deposits in Finland.

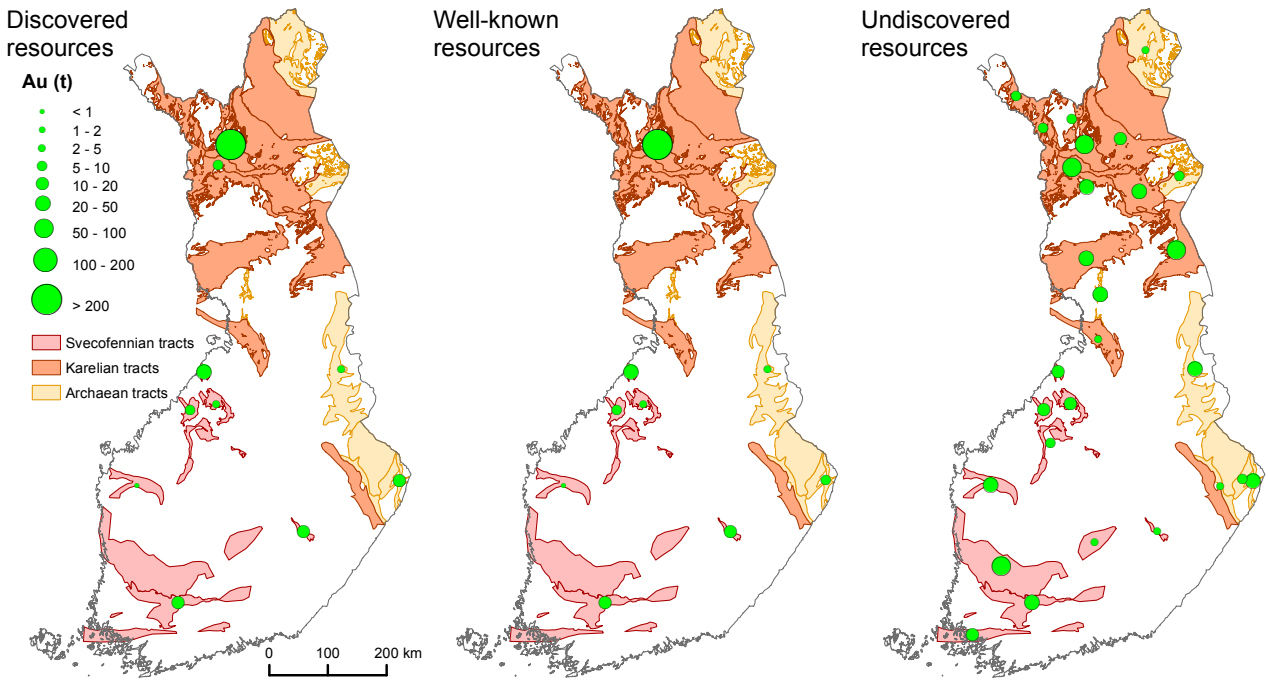

Fig. 10. Geographic distribution of discovered, well-known remaining and estimated undiscovered orogenic gold resources in Finland. The discovered resources include well-known resources plus cumulative production. The undiscovered resources are estimated at 50 % probability.

5.1 Permissive tracts delineated

In total, 32 permissive tracts were delineated for orogenic gold deposits (Fig. 8, Tables 5–6, Appendix 3). These tracts contain all the known orogenic deposits and significant occurrences in Finland. Altogether, the tracts cover an area of approximately 110,000 km^2, which is 33 % of the total land area of Finland. The size of the orogenic gold permissive tracts varies from 86 km^2 to 12,793 km^2, and the median size is 2745 km^2 (Table 6). In addition to the orogenic tracts, two permissive tracts were delineated for epithermal gold deposits (Fig. 8). However, no further assessment of epithermal deposits was carried out, due to the lack of suitable grade and tonnage data to approximate the Finnish epithermal gold deposits.

The permissive tracts can be divided into three groups based on the age of the lithologies covered: Archaean (3.2–2.5 Ga), Palaeoproterozoic Karelian (2.3–1.91 Ga) and Palaeoproterozoic Svecofennian (1.93–1.80 Ga). Eight of the delineated tracts cover Archaean rocks (Tables 5–6). Excluding the Oijärvi tract, the Archaean tracts occur along the eastern border from the southern part up to the northernmost part of the country (Fig. 8). There are 13 Karelian tracts, one in eastern Finland and 12 in northern Finland. The 11 Svecofennian tracts all occur in the southern and southwestern parts of the country. The Archaean tracts cover 23,800 km^2, the Karelian tracts 61,000 km^2 and the Svecofennian tracts 25,000 km^2. Although the tracts from the three groups have comparable size ranges, the Svecofennian tracts tend to be slightly smaller with a median size of 1490 km^2, whereas the Karelian tracts have the largest median size of 3380 km^2.

5.2 Undiscovered resources in orogenic gold deposits

There are 15 well-known orogenic gold deposits in Finland: five in the Archaean, two in the Karelian and eight in the Svecofennian tracts (Tables 5–6). In the context of the three-part assessment method, a deposit is termed 'well known' when it can be considered to be completely delineated and both the present identified resources and past production are known. The mean estimate of the number of undiscovered deposits within a tract varies from 0.3 to 9, and the average is 2.8 deposits per permissive tract. According to our assessment, the mean estimate of the number of undiscovered orogenic gold deposits across all the permissive tracts is 90 deposits (Table 6). For the Archaean tracts, the mean estimate is 18, for the Karelian tracts, 45, and for the Svecofennian tracts, 27 undiscovered deposits. The estimated median deposit density for all the 32 permissive tracts is 9.6 deposits per 10,000 km^2. The median deposit density within the Svecofennian tracts is 28 deposits per 10,000 km^2, which is clearly higher than the median densities for the Archaean and Karelian tracts, 9.3 and 7.8 deposits per 10,000 km^2, respectively.

The well-known Finnish orogenic deposits contain 317 t of Au (Table 7). In comparison, the median estimated undiscovered orogenic gold resources in Finland are at least 750 t of Au. This indicates that at least 70 % of the present total orogenic gold endowment within the uppermost one kilometre of the Finnish bedrock is in poorly explored and entirely unknown deposits.

Separate simulations for the three groups of permissive tracts indicate that, at the 50 % probability level, the undiscovered resources in Archaean, Karelian and Svecofennian tracts are at least 140 t, 400 t, and 210 t of gold, respectively. By far the largest well-known resources, 243 t of gold, occur in the Karelian tracts (Fig. 10, Tables 6 and 7). However, they are solely due to the very large Suurikuusikko deposit in the Kittilä Group tract. The Svecofennian tracts contain 64 t of gold in well-known resources, divided between eight deposits in six tracts, and the Archaean group contains 9 t of gold in five deposits within two tracts. When total discovered resources are considered, an average Archaean orogenic deposit contains 2.6 t of gold and an average Svecofennian deposit contains 9.6 t of gold.

The results for individual permissive tracts indicate that a little more than half of the undiscovered orogenic gold resources are located in northern Finland (Table 6). The majority of these are within Karelian permissive tracts and 46 % occur in the adjacent Kittilä Group and Sattanen–Kolari tracts (Fig. 10). In a similar manner, 49 % of the Svecofennian undiscovered resources are estimated to occur in the adjacent Häme and Pirkkala permissive tracts in southern Finland. The Archaean

undiscovered gold resources are more spread out, with the Hattu, Oijärvi and Kuhmo–Suomussalmi tracts together containing 83 % of all undiscovered Archaean gold resources.

There were six mines in Finland producing gold as their main commodity in 2012 (Jokisivu, Kittilä, Laiva, Orivesi, Pahtavaara and Pampalo), and two additional mines have published their production figures for gold as a side-product (Kevitsa and Kylylahti). The reported production from these mines in 2012 was 8844 kg, whereas the total smelter and refinery production was 10,886 kg of gold (Pokki et al. 2014). In addition to the reported mine production, the Pyhäsalmi Cu-Zn mine is estimated to have produced perhaps 500 kg of gold in its concentrates. This production has not been reported and the estimate is based on the known gold grade in the ore and on the previously reported gold production at Pyhäsalmi. The difference between the reported mine production and smelter and refinery production is 2042 kg of gold, and even if the estimated 500 kg from Pyhäsalmi is added to the reported mine production, the difference is still 1542 kg of gold. This amount is probably derived from imported ore processed in Finland. These figures indicate that the raw material was domestic for at least 81 % of the gold produced in Finland in 2012.

The amount of gold produced annually from the Finnish mines decreased to approximately 8400 kg in 2013. The decline seems to have continued in 2014, mainly due to the closing, at least temporarily, of the Pahtavaara and Laiva mines due to the prolonged poor global economic situation. The annual mine production of gold is estimated to have decreased to about 7000 kg in 2014, and the decline is likely to continue during the remaining half of the 2010s because of the gradual exhaustion of the known resources in some of the gold mines (Pampalo and Orivesi). Of course, the trend could be reversed by new discoveries in the operating mines or currently unknown deposits. The discovery and subsequent bringing to operation of a median-sized undiscovered orogenic gold deposit would increase the annual gold production in Finland by approximately 1000 kg for almost five years. This equals 11 % of the value of gold production from Finnish mines in 2012. Furthermore, 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. There are presently several exploration and development projects that might eventually lead to the opening of a new gold mine in Finland (e.g., Juomasuo, Rompas, Kopsa, Kuotko, Hosko, Muurinsuo, Kuittila and Kuivisto). However, most of these are in rather early stages and it is unlikely for any new gold mines in Finland to start operation before 2020, except for those deposits that are close to existing active mines.

5.3 Finnish Au endowment in the global context

The total world mine production in 2012 was 2700 t of gold, and identified reserves were at least 52,000 t of gold (George 2013). Sixty per cent of the mine production came from China, Australia, the United States, Russia, South Africa, Peru, Canada and Indonesia. In deposits containing at least one million ounces of gold and where gold is among the major commodities, there appears to be a total resource (including reserves) of 94,000 t of gold (Natural Resource Holdings 2012). In reality, the 94,000 t world resource is a considerable underestimate, as the figure does not include any gold from placer, IOCG, PGE, VMS or any submarine deposits. Larger figures have been published by Frimmel (2008) and Kesler & Wilkinson (2010), who have estimated the global known gold resources to be approximately 130,000 t and 140,000 t of gold, respectively, in Carlin-type, epithermal, IOCG, orogenic, porphyry copper, skarn and VMS deposits combined. In total, Finnish mineral deposits contain 444 t of Au in identified resources (Table 1), and orogenic gold deposits contain 71 % of this (317 t Au). All the known Finnish gold resources hence correspond to less than 0.5 % of the known land-based world resources.

The median estimated Au resources in undiscovered orogenic deposits in Finland are at least 750 t of gold (Table 7). The median estimated undiscovered resources in PGE, porphyry, and VMS deposits in Finland are at least 616 t of gold (Table 2; Rasilainen et al. 2010a, 2012, 2014). The undiscovered resources in IOCG and Outokumpu-type deposits have not been estimated. However, the probable amount of gold in the latter types of

deposits in Finland appears to be rather small, perhaps a few tens of tonnes (section 2 in this report and Rasilainen 2014). Hence, the median estimated undiscovered gold resources in Finland are at least 1366 t of gold.

There are no published global estimates of undiscovered gold resources based on the three-part method used in the GTK assessments. Using the tectonic diffusion model, Kesler & Wilkinson (2010 and references therein) evaluated the total gold content in hydrothermal deposit types (see above) in the uppermost one kilometre of the crust to be 1.22 Mt of gold. Subtracting the 140,000 t of gold in known deposits reported by the authors gives an estimate of 1.04 Mt of gold in undiscovered or poorly known deposits. Compared to this figure, the assessed amount of 1366 t of gold in undiscovered deposits in Finland is minuscule. It is also obvious that the discovery of any part of the undiscovered gold resources in Finland would have a negligible influence on the known global gold resources.

It is not statistically correct to sum the median estimates of undiscovered gold in various deposit types from Tables 2 and 7. 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, comparison of the sums of simulation results for individual permissive tracts (Table 6) with simulation results for all tracts (Table 7) 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 indicates 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 (Figure 2 in Singer & Kouda 1999). Consequently, the greatest sources of possible error in the present assessment are associated with the grade-tonnage model used.

Mines have larger average tonnages and gold grades than deposits that have not been mined for both the Fennoscandian and Australian data included in the grade-tonnage model, although the differences are generally only marginally statistically significant, or not at all significant (Appendix 2, Table 1). In spite of the larger proportion of mines in the Australian dataset (69 %) compared to the Fennoscandian dataset (38 %), the differences between the Australian and Fennoscandian deposits are not statistically significant for either tonnage or gold grade (Appendix 2, Table 2). This similarity is also indicated by the fact that the Fennoscandian mines and deposits do not differ significantly from their Australian counterparts in their style of mineralisation. These results support the use of a global grade-tonnage model containing data from both Fennoscandia and Australia to assess the Finnish gold resources.

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 gold deposits and in metallogeny and geostatistics at the Geological Survey of Finland produced this assessment of undiscovered gold resources within the uppermost one kilometre of Finnish bedrock. The resources were assessed using a three-part quantitative method developed at the U.S. Geological Survey, and the assessment covered orogenic gold deposits.

This report provides numerical estimates of the expected endowment of gold in undiscovered, potentially exploitable orogenic gold deposits. Epithermal, intrusion-related (IRG), iron oxide-copper-gold (IOCG) as well as placer and palaeoplacer deposits were not included in the assessment due to the scarcity of suitable grade-tonnage data for modelling and the estimated small significance of these deposit types for the gold endowment in Finland.

The main results include the following:

1. The three-part quantitative assessment method developed by the USGS is suitable for assessing orogenic gold deposits.
2. Well-known Finnish orogenic gold deposits contain 317 t of gold, which is 71 % of the total identified gold resources of 444 t in Finland.
3. Gold grades and ore tonnages in orogenic gold deposits in the Fennoscandian Shield do not differ significantly from data from the Northern Territory of Australia. A global grade-tonnage model was constructed using data from Finland, Sweden and Australia.
4. Eight permissive tracts were delineated for Archaean orogenic gold deposits, 13 for Palaeoproterozoic Karelian deposits and 11 for Palaeoproterozoic Svecofennian deposits. The Archaean tracts cover 23,800 km^2, the Karelian tracts 61,000 km^2 and the Svecofennian tracts 25,000 km^2. Altogether, the 32 permissive tracts cover 110,000 km^2, which is 33 % of the total land area of Finland. In addition to the orogenic tracts, two permissive tracts were delineated for epithermal gold deposits.
5. The Karelian tracts contain 243 t of gold in two well-known deposits within two tracts. These resources are almost solely due to the very large Suurikuusikko deposit in the Kittilä Group tract. The Svecofennian tracts contain 64 t of gold in well-known resources, divided between eight deposits in six tracts, and the Archaean group contains 9 t of gold in five deposits within two tracts.
6. The expected number of undiscovered orogenic gold deposits is 18 for the Archaean tracts, 45 for the Karelian tracts, and 27 for the Svecofennian tracts.
7. The undiscovered orogenic gold deposits are estimated to contain, at 50 % probability, at least 750 t of gold. This indicates that at least 70 % of the present total orogenic gold endowment within the uppermost one kilometre of the Finnish bedrock is in poorly explored and entirely unknown deposits.
8. The median undiscovered resources in Archaean, Karelian and Svecofennian deposits are 140 t, 400 t and 210 t of gold, respectively. The adjacent Kittilä Group and Sattanen–Kolari tracts in northern Finland are estimated to contain 46 % the Karelian undiscovered resources. Similarly, 49 % of the Svecofennian undiscovered resources are estimated to occur in the adjacent Häme and Pirkkala permissive tracts in southern Finland. The Archaean undiscovered gold resources are more evenly spread out, but the Hattu, Oijärvi and Kuhmo–Suomussalmi tracts in eastern Finland contain 83 % of all the undiscovered Archaean gold resources.
9. Finnish mineral deposits contain approximately 444 t of gold in identified resources. This is less than 0.5 % of the known land-based world resources of at least 130,000 t of gold.
10. The median estimated undiscovered gold resources in orogenic gold, PGE, porphyry and VMS deposits in Finland are at least 1366 t of gold. Although estimates of global undiscovered gold resources based on the three-part method do not exist, it is evident that the undiscovered Finnish resources are minuscule in comparison to the global resources.

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APPENDIX 1

DESCRIPTIVE MODEL FOR OROGENIC GOLD DEPOSITS

Eilu, P.[1], Rasilainen, K.[1] and Kontoniemi, O.[2]

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[2] Geological Survey of Finland, P.O. Box 97, FI-67101 Kokkola

APPROXIMATE SYNONYMS Mesothermal gold, turbidite-hosted gold, greenstone gold, slate belt type, quartz-carbonate vein type, Archaean vein gold, synorogenic gold.

DESCRIPTION Structurally controlled gold deposits formed during orogenies by orogenic fluids (Groves et al. 1998, 2003, Goldfarb et al. 2001, 2005, Weatherley & Henley 2013).

DEPOSIT EXAMPLES

Finland:

Pampalo	Nurmi et al. (1993)
Suurikuusikko	Patison (2007)
Saattopora	Korvuo (1997)
Jokisivu	Saalmann et al. (2010)

Global:

Golden Mile	Phillips (1986)
Ballarat	Ramsay et al. (1998)
Hollinger-McIntyre	Smith & Kesler (1985)
Homestake	Caddey et al. (1991)
Mother Lode	Böhlke (1989)

GEOLOGICAL ENVIRONMENT

Host rocks Any rock type within an orogenic belt (i.e., within a greenstone or schist belt). Any metamorphosed supracrustal rock, dyke or intrusion within, or intrusion bounding, such belt. Not present in post- or anorogenic intrusions or unmetamorphosed supracrustal rocks. The favoured host is the locally most reactive and/or most competent lithological unit.

Age In Finland, Neoarchaean (2.70–2.64 Ga) and Palaeoproterozoic (1.91–1.77 Ga). Globally, mineralisation also peaks at ca. 2.1 Ga, Neoproterozoic (700–600 Ma), Silurian to Carboniferous (430–300 Ma) and Cretaceous to early Palaeogene (120–50 Ma). These epochs appear to be related to rapid crustal growth and accretionary stages of supercontinents. Mineralisation typically takes place during the last major stage of an orogeny. This is typically reported as the stage D3 or D4 within an orogen. In greenschist-facies settings, mineralisation typically takes place slightly after the metamorphic peak, but at amphibolite facies at the local regional-metamorphic peak.

Mineralisation environment Orogenic belt (greenstone or schist belt).

Tectonic setting Accretional and, especially, collisional orogenic settings. Subduction under an accretionary wedge and a 'fertile' lower crust (e.g. a subducted oceanic crust) are suggested to significantly enhance the local mineralisation potential.

Associated deposit types Placer deposits.

DEPOSIT DESCRIPTION

Ore minerals Native gold, pyrite, pyrrhotite, arsenopyrite, löllingite (high metamorphic grades), scheelite, rutile, Bi, Sb and Te minerals; also chalcopyrite, cobaltite, gersdorffite in the relatively rare cases where base metals are enriched. In an ore body, the total volume of sulphides is <5 %, commonly in the range 1–2 %; more sulphides only tend to occur in BIF.

Texture and structure The ore bodies typically have a strongly flattened ellipsoidal shape, are plate-like and may have a steep or a gentle dip and plunge of ore shoots. An individual ore body can be 0.5–50 m wide and 100 m to 2 km long, and it can consist of a vein network, an *en echelon* vein swarm or just one single large vein. A deposit may comprise several ore bodies. The depth extent of an ore body may well be much larger than its horizontal extent along strike. An individual vein can be <1 cm to 10 m thick and 20–1000 m long. The vein sets typically record multiple fault fracture, fluid flow and mineral precipitation events. In most cases, gold occurs as native gold, free in gangue and with main sulphides, and as inclusions and in fractures of gangue and sulphide grains. In some cases, such as Suurikuusikko and some ore bodies at Wiluna (Western Australia), most of the gold occurs in the lattice of, or as submicroscopic inclusions in, pyrite or arsenopyrite.

Ore control Hosted by a fault or shear zone. Typically, the host is a second or third degree shear zone branching from a regional-scale fault. Locally, the control for mineralisation can also be a fold hinge, a flexure in a fault, an intersection of a fault and a fold hinge or a lithological contact, or an intersection of two faults. A deposit hosted by a BIF may show an apparent strata-bound character, but a detailed inspection will reveal the diagnostic cross-cutting sulphidation fronts within the mineralised rock.

Weathering products Placer gold and saprolite-hosted gold occurrences.

Geochemical signature As, Au, S, Sb, Te, W ± Ag, B, Bi, Co, Cu, Se. Au/Ag consistently >1, typically 5–10.

Geophysical signature Magnetic and electromagnetic (e.g., VLF-R, IP) surveys can be used to map structures and potentially indicate sulphidised zones. In the case of extensive potassic alteration in mafic–intermediate rocks, a radiometric survey may detect the sericitised or biotitised zones related to mineralisation.

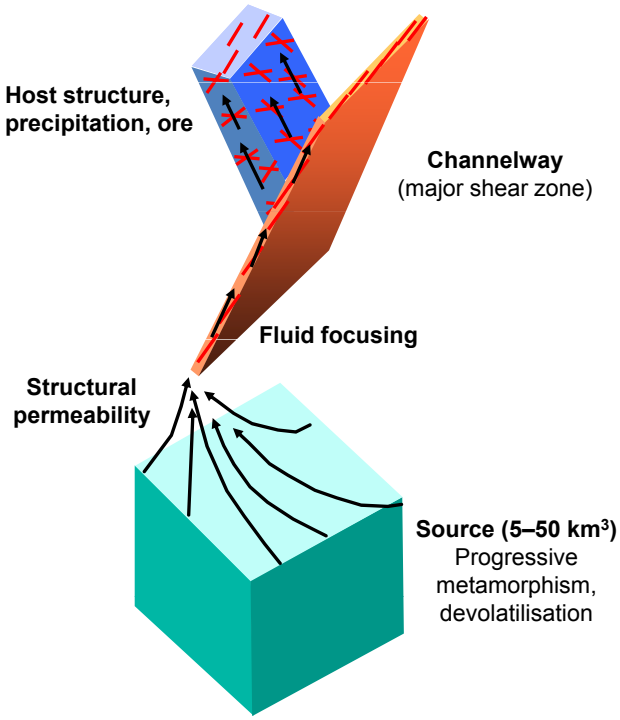

Fig. 1. A schematic view of an orogenic gold system (based on D. Groves, pers. comm. 2003).

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APPENDIX 2

GRADE-TONNAGE MODEL OF OROGENIC GOLD

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INTRODUCTION

This model contains data from 73 orogenic gold deposits (Table 1). A spatial rule has been applied, according to which deposits less than 500 m from each other have been combined.

DATA

The model includes data from Finland, Sweden and the Northern Territory in Australia. The individual deposits in the model are listed in Table 1.

The FINGOLD database of GTK (Eilu & Pankka 2009), the Fennoscandian Ore Deposit Database (FODD 2011) and a compilation of mineral deposits and metallogenic belts in the Fennoscandian Shield (Eilu 2012) were the main sources of data for known gold deposits and occurrences in Finland and the Fennoscandian Shield. Where possible, the grade and tonnage data were updated from company reports and publications.

For global data from outside of the Fennoscandian Shield, information on orogenic gold deposits in Ahmad et al. (2009), updated with data from mining company web pages for the presently active mines and mine development projects, were used in compiling the grade-tonnage model. These data on deposits in the Northern Territory of Australia were considered to be of equally reliable and consistent quality as the data from Fennoscandia.

Grade and tonnage data from several other sources were also assessed, including data for the Bendigo Zone in Victoria, Australia (Lisitsin et al. 2007), Barrick data for the Southern Cross greenstone belt in Western Australia (Raelene Kellet, pers. comm. 2011), gold deposits in Zimbabwe (Hokka 2011 and references therein), and available global gold deposit databases. However, these latter sources were not used in the grade-tonnage model, as the data were considered inconsistent; there were too high and variable cut off grades, mixtures of old production and recent resource data, and uncertainties in genetic type as well as the total pre-mining deposit size.

Only deposits that were considered well known, wholly delineated and with no missing data for ore tonnage or gold grade were accepted in the grade-tonnage model. The model contains five Archaean and 10 Proterozoic deposits from Finland, six Proterozoic deposits from Sweden and 52 Proterozoic deposits from Australia.

Table 1. Orogenic gold deposits included in the grade-tonnage model. The resources include past production and remaining well-known resources.

Deposit	Country	Age	Status	Tonnage (Mt)	Au (g/t)	Reference
Suurikuusikko	Finland	Proterozoic	Mine	58.159	4.18	Agnico Eagle Mines Limited (2013a,b)
Laivakangas	Finland	Proterozoic	Mine	23.700	1.79	Titley (2011)
Hirsikangas	Finland	Proterozoic	Deposit	5.675	1.25	Nally et al. (2009)
Osikonmäki	Finland	Proterozoic	Deposit	4.838	1.99	Belvedere Resources Ltd. (2011)
Ängesneva	Finland	Proterozoic	Deposit	3.850	1.19	Nally et al. (2010)
Saattopora	Finland	Proterozoic	Mine	2.163	2.91	Korvuo (1997), Anttonen R. pers. comm. (1998)
Jokisivu	Finland	Proterozoic	Mine	1.911	5.65	Dragon Mining Ltd. (2009, 2010, 2011a,b)
Pampalo	Finland	Archaean	Mine	1.858	3.9	Endomines Ab (2011a)
Valkeasuo	Finland	Archaean	Deposit	1.077	2.8	Clark (2008)
Pahkalampi	Finland	Archaean	Deposit	0.590	3.5	Nordic Mines Ab (2011)
Satulinmäki	Finland	Proterozoic	Deposit	0.360	2.34	Koistinen & Kärkkäinen (2006)
Sikakangas	Finland	Proterozoic	Deposit	0.171	1.32	Isomaa et al. (2010)
Pirilä	Finland	Proterozoic	Deposit	0.150	8.9	Belvedere Resources Ltd. (2010)
Pahkosuo	Finland	Archaean	Deposit	0.100	1.6	Heino (2001)
Kuikkapuro	Finland	Archaean	Deposit	0.045	14.6	Pietikäinen et al. (2000), Sandberg (2007)
Fäboliden	Sweden	Proterozoic	Deposit	90.190	1.04	Lappland Goldminers Ab (2011)
Svartliden	Sweden	Proterozoic	Mine	2.967	4.26	Raw Materials Group (2011)
Vargbäcken	Sweden	Proterozoic	Deposit	2.100	1.54	Botnia Exploration Holding Ab (2011).
Pahtohavare	Sweden	Proterozoic	Mine	1.720	0.9	FODD (2011)
Långtjärn	Sweden	Proterozoic	Deposit	0.560	0.9	FODD (2011), Nebocat (2006)
Harnäs	Sweden	Proterozoic	Mine	0.071	4.6	FODD (2011)
Mount Todd	Australia	Proterozoic	Mine	300.740	0.82	Ahmad et al. (2009), Ahmad M. pers. comm. (2011)
Rustlers Roost	Australia	Proterozoic	Mine	54.400	1.03	Ahmad M. pers. comm. (2011), Muller et al. (2011)
Callie–Ghan	Australia	Proterozoic	Mine	35.500	5.3	Huston et al. (2007), Lambeck et al. (2012)
Union Reefs	Australia	Proterozoic	Mine	20.754	1.50	Ahmad et al. (2009), Muller et al. (2011)
Pine Creek Goldfield	Australia	Proterozoic	Mine	17.316	2.27	Gillmann et al. (2009), Muller et al. (2011)
Cosmo Howley–Cosmo Deeps	Australia	Proterozoic	Mine	15.727	3.37	Gillmann et al. (2009), Ahmad M. pers. comm. (2011)
Spring Hill	Australia	Proterozoic	Mine	12.750	0.8	Ahmad et al. (2009)
Maud Creek 1	Australia	Proterozoic	Mine	10.378	3.03	Gillmann et al. (2009), Ahmad M. pers. comm. (2011)
Golf–Golf West–Tollis	Australia	Proterozoic	Deposit	8.760	0.85	Ahmad et al. (2009)
Woolwonga	Australia	Proterozoic	Mine	8.500	2.83	Ahmad et al. (2009), Muller et al. (2011)
Moline Dam–Hercules	Australia	Proterozoic	Mine	7.443	2.71	Ahmad et al. (2009)
Dead Bullock Soak	Australia	Proterozoic	Mine	7.321	3.47	Ahmad et al. (2009), Ahmad M. pers. comm. (2011)
Brocks Creek	Australia	Proterozoic	Mine	6.080	1.85	Ahmad et al. (2009), Muller et al. (2011)
Quigley's–Regatta	Australia	Proterozoic	Mine	5.539	1.73	Ahmad M. pers. comm. (2011)
Groundrush	Australia	Proterozoic	Mine	5.330	5.31	Ahmad et al. (2009), Ahmad M. pers. comm. (2011)
Oberon	Australia	Proterozoic	Deposit	4.520	3.1	Ahmad M. pers. comm. (2011)
Jims Find	Australia	Proterozoic	Mine	4.145	2.58	Ahmad et al. (2009)
Titania	Australia	Proterozoic	Deposit	4.110	2.6	Ahmad et al. (2009)
Goodall	Australia	Proterozoic	Mine	4.095	1.99	Ahmad et al. (2009)
Shoe	Australia	Proterozoic	Mine	3.800	5.15	Ahmad et al. (2009), Ahmad M. pers. comm. (2011)

Table 1. Cont.

Deposit	Country	Age	Status	Tonnage (Mt)	Au (g/t)	Reference
Western Arm	Australia	Proterozoic	Deposit	3.383	1.1	Muller et al. (2011)
Bullakitchie	Australia	Proterozoic	Mine	2.800	6.5	Ahmad M. pers. comm. (2011)
Rising Tide	Australia	Proterozoic	Mine	2.466	1.37	Gillmann et al. (2009), Muller et al. (2011)
Quorn	Australia	Proterozoic	Mine	2.290	3.23	Ahmad et al. (2009), Ahmad M. pers. comm. (2011)
Yam Creek–Princess Louise	Australia	Proterozoic	Mine	2.115	1.30	Ahmad M. pers. comm. (2011)
Fountain Head–Tally Ho	Australia	Proterozoic	Mine	2.024	2.11	Gillmann et al. (2009), Muller et al. (2011)
Bridge Creek	Australia	Proterozoic	Deposit	1.796	1.2	Gillmann et al. (2009)
Golden Dyke	Australia	Proterozoic	Mine	1.710	4.05	Ahmad et al. (2009), Ahmad M. pers. comm. (2011)
Kazi	Australia	Proterozoic	Deposit	1.580	2.1	Ahmad et al. (2009)
Coyote	Australia	Proterozoic	Mine	1.524	8.34	Tanami Gold (2011), Tanami Gold quarterly reports 2008–2011 at www.tanami.com.au
Minotaur	Australia	Proterozoic	Mine	1.495	2.73	Ahmad M. pers. comm. (2011)
Tom's Gully	Australia	Proterozoic	Mine	1.469	9.62	Ahmad M. pers. comm. (2011)
Beawer Creek–Bonsai–Banjo	Australia	Proterozoic	Mine	1.450	3.86	Ahmad et al. (2009)
Kookaburra	Australia	Proterozoic	Mine	1.440	2.02	Huston et al. (2007)
Sandpiper	Australia	Proterozoic	Mine	1.279	4.06	Tanami Gold (2011), Tanami Gold quarterly reports 2008–2011 at www.tanami.com.au
Howley Ridge	Australia	Proterozoic	Deposit	1.210	1.34	Ahmad et al. (2009)
Bunkers Hill	Australia	Proterozoic	Mine	1.150	3.06	Ahmad et al. (2009), Ahmad M. pers. comm. (2011)
Tregony	Australia	Proterozoic	Deposit	1.100	1.57	Ahmad M. pers. comm. (2011)
Ios	Australia	Proterozoic	Deposit	0.810	1.6	Ahmad et al. (2009)
Bon's Rush	Australia	Proterozoic	Deposit	0.805	2.3	Muller et al. (2011)
Crusade	Australia	Proterozoic	Deposit	0.800	2.9	Ahmad M. pers. comm. (2011)
Rhodes	Australia	Proterozoic	Deposit	0.770	1.88	Ahmad et al. (2009)
Glencoe	Australia	Proterozoic	Mine	0.753	1.93	Ahmad M. pers. comm. (2011)
Mount Porter	Australia	Proterozoic	Deposit	0.355	3	Gillmann et al. (2009)
Tumbling Dice	Australia	Proterozoic	Mine	0.300	2.6	Ahmad M. pers. comm. (2011)
Sundance	Australia	Proterozoic	Mine	0.236	5.48	Ahmad et al. (2009), Ahmad M. pers. comm. (2011)
Califrey	Australia	Proterozoic	Deposit	0.225	1.1	Ahmad et al. (2009)
Pebbles	Australia	Proterozoic	Deposit	0.076	2.5	Tanami Gold (2011)
Davies 2	Australia	Proterozoic	Mine	0.050	2.89	Ahmad M. pers. comm. (2011)
Kindergarden	Australia	Proterozoic	Mine	0.050	3	Ahmad M. pers. comm. (2011)
Langleys	Australia	Proterozoic	Mine	0.050	3.9	Ahmad M. pers. comm. (2011)
Maud Creek 5	Australia	Proterozoic	Deposit	0.020	3.1	Ahmad et al. (2009)

Status: Mine – Deposit has been mined or is being mined, Deposit – Deposit has not been mined; Mt: Million metric tons. Tonnages are rounded to full thousands.

STATISTICS

Summary statistics of the orogenic gold grade-tonnage model are given in Table 2.

Statistical tests indicate that the distributions of gold grades and ore tonnages do not significantly differ from log-normality for the whole group of deposits in the grade-tonnage model, for Proterozoic or Archaean deposits, or for deposits from any of the individual countries (Table 2, Fig. 1).

Analysis of variance tests on the means of ore tonnages and gold grades indicate that the grade-tonnage model does not contain subgroups based on geographic location or deposit age. Although Archaean deposits have a somewhat smaller tonnage and higher gold grade compared with Proterozoic deposits, the difference is not statistically significant for tonnage and it is only marginally

Table 2. Summary statistics for orogenic gold deposits.

	Finland		**Sweden**		**Australia**	
	Tonnage (Mt)	Au (g/t)	Tonnage (Mt)	Au (g/t)	Tonnage (Mt)	Au (g/t)
N of cases	15	15	6	6	52	52
Minimum	0.045	1.2	0.071	0.90	0.020	0.80
Maximum	58.159	15	90.190	4.6	300.740	9.6
Mean	6.976	3.9	16.268	2.2	11.054	2.9
St dev	15.384	3.6	36.229	1.7	42.024	1.8
90 %	0.1	1.3	0.120	0.90	0.180	1.1
50 %	1.858	2.8	1.910	1.3	1.910	2.6
10 %	23.7	8.9	81.468	4.6	16.204	5.3
S-W p	0.94578	0.36724	0.67470	0.05661	0.21632	0.71995
T p FI-SW	0.712	0.155				
T p FI-AU	0.418	0.348				
T p SW-AU	0.934	0.164				

	Fennoscandia		**Proterozoic**		**Archaean**	
	Tonnage (Mt)	Au (g/t)	Tonnage (Mt)	Au (g/t)	Tonnage (Mt)	Au (g/t)
N of cases	21	21	68	68	5	5
Minimum	0.045	0.90	0.020	0.80	0.045	1.6
Maximum	90.190	15	300.740	9.6	18.584	15
Mean	9.631	3.4	11.373	2.9	0.734	5.3
St dev	22.617	3.2	38.594	1.9	0.755	5.3
90 %	0.880	0.98	0.156	1.1	0.045	1.6
50 %	1.858	2.3	2.062	2.5	0.590	3.5
10 %	37.484	7.0	19.723	5.3	1.858	15
S-W p	0.61670	0.38802	0.42351	0.43478	0.52332	0.4287
T p FE-AU	0.492	0.913				
T p Ar-Pr	0.047	0.092				

Orogenic gold grade-tonnage model

	Tonnage (Mt)	Au (g/t)
N of cases	73	73
Minimum	0.020	0.80
Maximum	300.740	15
Mean	10.644	3.0
St dev	37.329	2.3
90 %	0.095	1.1
50 %	1.858	2.6
10 %	18.003	5.3
S-W p	0.35094	0.39652

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 FI-SW, T p FI-AU, T p SW-AU, T p FE-AU, T p Ar-Pr: Tukey's Honestly-Significant-Difference Test p-values for comparisons of means between the Finnish and Swedish (FI-SW), Finnish and Australian (FI-AU), Swedish and Australian (SW-AU), Fennoscandian and Australian (FE-AU) and Archaean and Proterozoic (Ar-Pr) deposits. The statistical tests were conducted using logatithmic values of tonnages and gold grades. Tonnages are rounded to full thousands and grades to two significant digits.

significant for gold (p = 0.047). Hence, no separate submodels based on deposit age were created.

There is a marginally significant (p = 0.012) weak negative correlation (r^2 = -0.293) between the logarithmic values of ore tonnage and gold grade (Fig. 2).

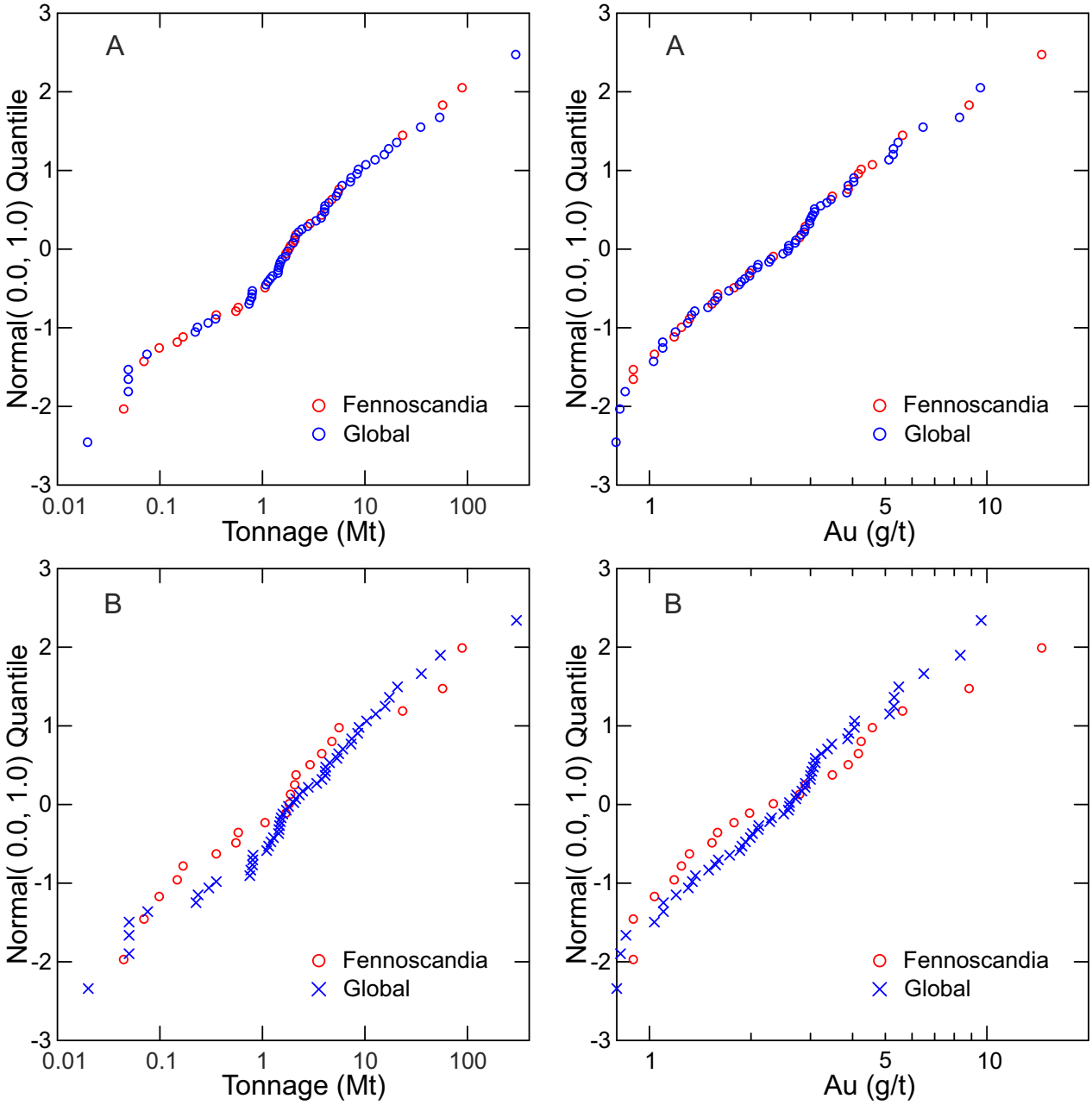

Fig. 1. Normal probability plots of tonnage and gold grade for the orogenic gold deposits in Table 1.

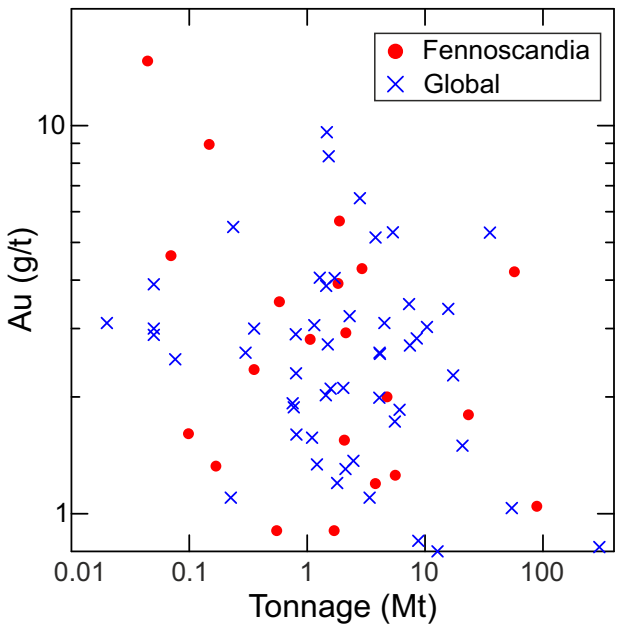

Fig. 2. Tonnage versus gold grade for the orogenic gold deposits in Table 1.

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APPENDIX 3

PERMISSIVE TRACT REPORTS

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OROGENIC Au ASSESSMENT FOR THE TRACT ENONTEKIÖ–MUONIO OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Enontekiö–Muonio Orogenic Au permissive tract is located in northwestern Finland in the municipalities of Enontekiö, Muonio and Kittilä, 155–275 km NW of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 2714, 2723, 2724, 2741, 2811, 2812, 2813 and 2814. The UTM map sheets containing the tract are U422, U424, V411, V412, V413, V414, V421, V422, V423, V424 and W413. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Enontekiö–Muonio Orogenic Au 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)	
17/1/2012	1	2654	Au	0	Au	23	Au	5.1

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is defined by the known extent of the Olostunturi Suite and Ounastunturi Formation rocks as well as Haparanda Suite intrusions within and at immediate contacts with these units in northwestern Finnish Lapland. To the west, the tract is bounded by the Finnish–Swedish border, to the north by the Finnish–Norwegian border, and to the east by the Hetta Complex and Kittilä Group rocks. Low-altitude airborne magnetic data were extensively used to define the extent of the tract rocks. The northernmost part of the tract overlaps with the Fennoscandian metallogenic area 'Kautokeino Au-Cu', which contains the Bidjovagge orogenic Au-Cu deposit 70 km to the north of the Finnish–Norwegian border. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to 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 orogenic Au deposits within the 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 orogenic Au deposits in the Enontekiö–Muonio Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are no partially explored orogenic Au occurrences within the permissive tract (Table 3).

Table 3. Significant orogenic Au occurrences in the Enontekiö–Muonio Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
None					

Ga – billion years.

Exploration history

Exploration activities for orogenic gold within the tract are listed in Table 4. Exploration in the region has also targeted iron, copper and uranium.

Table 4. Exploration history for the Enontekiö–Muonio Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	No	Geological Survey of Finland	1930–
	Outcrop observations and boulder survey	Yes	Rautaruukki Oy	1958–1985
	Outcrop observations and boulder survey	Yes	Outokumpu Oy	1969–1999
Geochemical surveys	Nationwide till survey	Yes	Geological Survey of Finland	1980s
	Detailed/targeted till geochemical survey with 1029 sample points	No	Geological Survey of Finland	1977–1982
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1983–2004
Ground geophysical surveys	Magnetic survey, systematic, 50 m line spacing (partially outside the tract) 14.8 km^2		Geological Survey of Finland	2005
	Magnetic profile survey, tot. 6.5 km		Geological Survey of Finland	2005
Drilling	Diamond drilling, 1 DDH 45.7 m	Yes	Geological Survey of Finland	2005
	Diamond drilling 1 DDH 115.2 m	No	Rautaruukki Oy	1977

DDH – Diamond drill hole

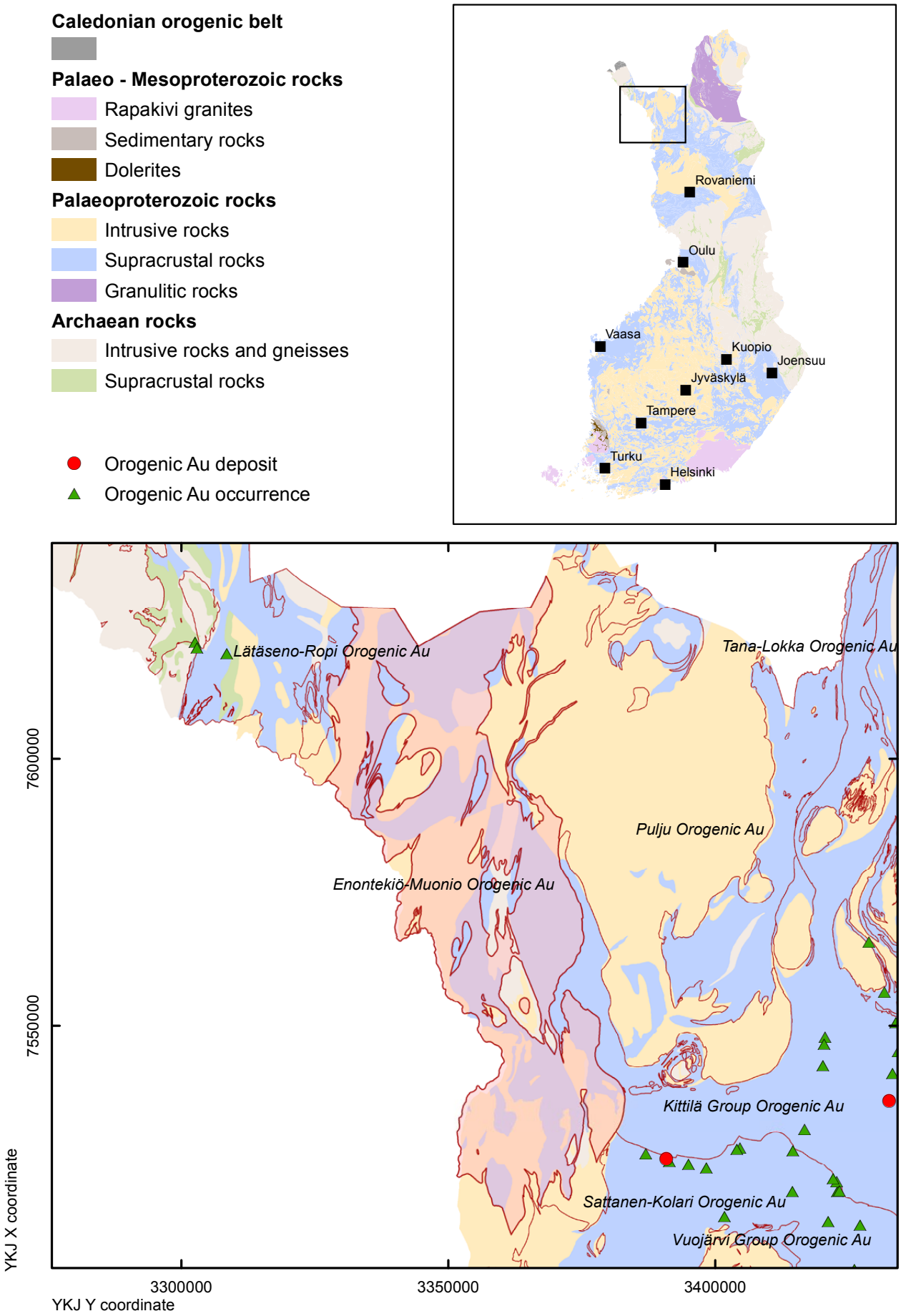

Fig. 1. Location of the Enontekiö–Muonio Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Enontekiö–Muonio Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Enontekiö–Muonio Orogenic Au permissive 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 (1959, 1969)
	Geological maps	1:100,000	Lehtonen (1980, 1981)
	Thematic geology reports		Inkinen (1970), Hiltunen (1970), Niiniharju (1976)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Wennervirta (1973), Hirvas (1974), Kokkola (1976, 1977)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Elo (1976), Pelkonen (1978), Heiskanen (1978)
Exploration	Reports		Reino (1975), Appelqvist (1976), Auranen (1975, 1976), Korvuo (1978a, 1978b), Mattila (1978), Isomaa (1988, 1991)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

No partially explored orogenic gold occurrences are known within the tract (Table 3). The following were considered to indicate a good potential for orogenic gold deposits in the tract: 1) the same rocks in Norway contain the Bidjovagge orogenic gold-copper mine, 2) there are a few, scattered, slightly gold-anomalous points in regional till survey data, including one at 133 ppb (single point) in the central-western part of the tract, and 3) the rocks of apparently the same age contain a few deposits and numerous occurrences 50–100 km to the east, in the Kittilä Group Orogenic Au tract. On the other hand, regional metamorphic grade within the Enontekiö–Muonio tract is rather high (mid to upper amphibolite facies), which is commonly seen as an unfavourable factor for orogenic gold mineralisation to take place. One of the estimators considered the probability high that at least one undiscovered economic deposits exist 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 Enontekiö–Muonio Orogenic Au 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	1	3			1.3	1.2	90	0	1.3	2654	0.00049

	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	2		
Individual 3	0	1	2		
Individual 4	1	3	5		
Individual 5	0	0	2		
Mean	0	1	3		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Keinänen, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Enontekiö–Muonio Orogenic Au 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			
Au (t)	0	0	5.1	46	110	23	0.20	0.30
Rock (Mt)	0	0	1.9	26	65	16	0.15	0.30

t – metric tons; Mt – million metric tons.

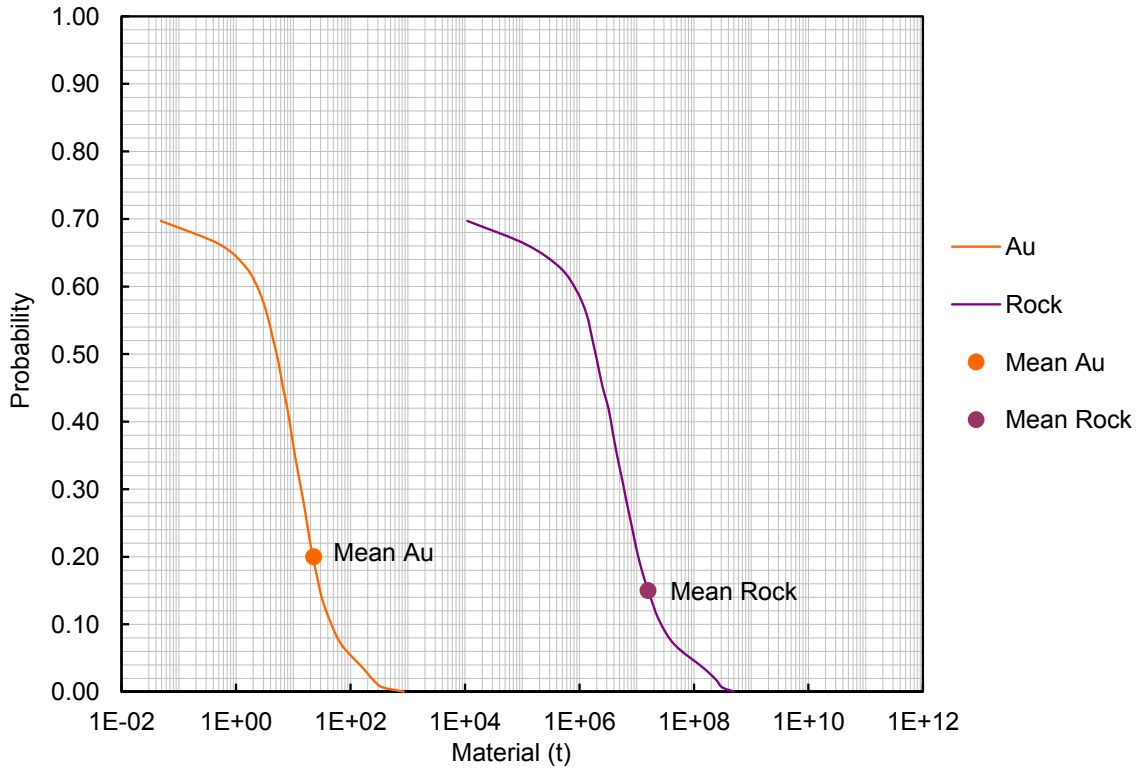

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Enontekiö–Muonio Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT GRANULITE BELT OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Granulite Belt Orogenic Au permissive tract is located in northern Finland in the municipalities of Inari, Savukoski, Sodankylä and Utsjoki, 200–390 km NW of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 3724, 3742, 3744, 3811, 3812, 3813, 3814, 3821, 3822, 3823, 3824, 3831, 3832, 3833, 3834, 3841, 3842, 3911, 3912, 3913, 3914, 3923, 3931, 4722, 4811 and 4812. The UTM map sheets containing the tract are V434, V442, V443, V444, V511, V512, V513, V514, V521, V522, V523, V524, W431, W432, W433, W434, W441, W443, W444, W511, W512, W513, W521, W522, X433 and X434. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Granulite Belt Orogenic Au 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)
17/1/2012	1	12,793	Au 0	Au 4.9	Au 0

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is defined by the extent of the Lapland Granulite Belt in Finland. This comprises the Saariselkä and Kuttura Suite rocks. To the west, the tract is bounded by the Finnish–Norwegian border, to the east by the Finnish–Russian border, to the north by the Kaamanen Complex rocks and to the south by the Vuotso Complex and the Savukoski and Salla Group rocks. Low-altitude airborne magnetic data were extensively used to define the extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to 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 orogenic Au deposits within the 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 orogenic Au deposits in the Granulite Belt Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are no partially explored orogenic Au occurrences within the permissive tract (Table 3). There are auriferous magnetite-quartz±baryte veins, such as the Hirvasselkä occurrence. However, this high-oxidation mineral assemblage and the late timing of the veins suggest either a post-orogenic Nattanen granite-related or IOCG style of mineralisation.

Table 3. Significant orogenic Au occurrences in the Granulite Belt Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
None					

Ga – billion years.

Exploration history

Exploration activities for gold within the tract are listed in Table 4. Exploration in the region has targeted gold-enriched magnetite-quartz±hematite±baryte±carbonate±chalcopyrite veins of possibly IOCG type (or simply related to post-orogenic granitoids), placer gold, intrusion- and komatiite-hosted nickel and banded iron formations. Below, all recent gold-related work is listed, as there is no clear idea what the so far detected auriferous mineralisation is in its genetic type(s).

Table 4. Exploration history for the Granulite Belt Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder tracing	No	Geological Survey of Finland	1930–
	Outcrop observations and boulder tracing	Yes	Rautaruukki	1970–1984
Geochemical surveys	Nationwide till survey, total 3080 sample points	Yes	Geological Survey of Finland	1980s
	Till and regolith geochemical surveys, total 203 sample points, total 11.3 km profile sampling	Yes	Geological Survey of Finland	1970s–2000s
	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1980s–2000s
Airborne geophysical surveys	Magnetic survey, systematic total 30.3 km^2, profile total 30 km		Geological Survey of Finland	1970s–2000s
Ground geophysical surveys	Gravimetric survey, profile total 19.5 km		Geological Survey of Finland	1970s–2000s
	Slingram, systematic total 7.0 km^2, profile total 11.4 km		Geological Survey of Finland	1970s–2000s
	VLF, systematic total 15.2 km^2, profile total 28 km		Geological Survey of Finland	1970s–2000s
	Slingram, regional total 8 km^2		Outokumpu Oy	1970s
	Magnetic, systematic total 2.8 km^2		Outokumpu Oy	1970s
	Ground gravimetric, systematic total 2.3 km^2		Outokumpu Oy	1989
	Diamond drilling, 77 DDH, total 4985.2 m	Earlier no, later yes	Geological Survey of Finland	1950s–2000s
Drilling	A few diamond drill holes	Earlier no, later yes	Rautaruukki	1980–1984

DDH – Diamond drill hole

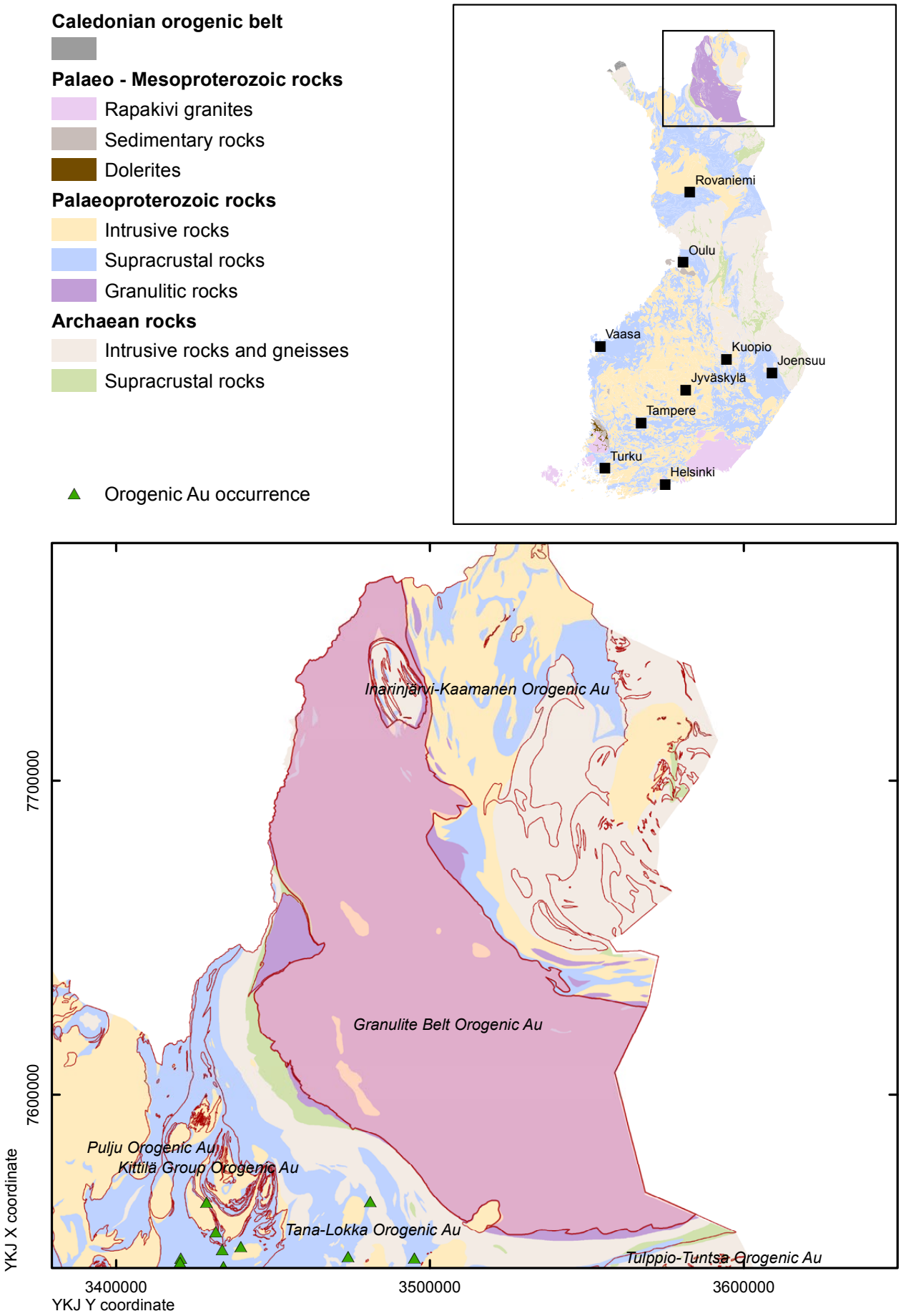

Fig. 1. Location of the Granulite Belt Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Granulite Belt Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Granulite Belt Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:400,000	Meriläinen (1965)
	Thematic geology reports		Tuisku & Huhma (2006)
	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
Mineral occurrences	Deposit descriptions		Ollila (1976), Kinnunen (1980), Hugg & Heiskanen (1983), Airas (1984), Härkönen (1987), Keinänen et al. (2010), Sarapää & Sarala (2011) Pulkkinen (2012)
	Geological Survey of Finland in-house database		
Geochemistry	Reports		Saarinen (1976), Härkönen (1987), Nenonen (2003), Sarapää et al. (2008), Keinänen et al. (2010), Lehmuspelto & Pohjola (2010a,b)
	Geological Survey of Finland in-house database		
Geophysics	Reports		Rahkola (1982), Airas (1984), Härkönen (1987), Turunen (1992), Sarapää et al. (2008), Keinänen et al. (2010)
	Reports		Jalander et al. (1937–1956), Hiltunen (1972), Auranen (1973), Kortman (1976), Helppi (1977), Puustinen (1977), Heiskanen & Mattila (1979), Makkonen (1979), Rahkola (1982), Hugg & Heiskanen (1983), Airas (1984), Härkönen (1985, 1987), Rossi (1989)Tertiary Minerals (2003), Sarapää et al. (2008), Keinänen et al. (2010), Lehtonen et al. (2011)
Exploration	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

No partially explored orogenic gold occurrences are known within the tract (Table 3). The tract is very large and contains locally abundant and extensive regolith and placer gold. There also are several auriferous quartz veins within the tract, but their high-oxidation mineral assemblage and late timing suggest either a post-orogenic granitoid-related (non-skarn) or IOCG style of mineralisation, and they are hence not regarded as an indication of orogenic gold. Also, the regional metamorphic grade within the tract is high (mostly granulite facies), which is commonly seen as an unfavourable factor for orogenic gold mineralisation to occur at all. Overall, the probability of orogenic gold deposits occurring within the tract was seen as very low. A consensus was reached in the discussion and the consensus values were used as input to Eminers software (Table 6).

Table 6. Undiscovered deposit estimates, deposit numbers, tract area and deposit density for the Granulite Belt Orogenic Au permissive tract.

Consensus 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	12,793	0.000023

	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	0		
Individual 4	0	0	1		
Individual 5	0	0	2		
Consensus	0	0	1		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Keinänen, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Granulite Belt Orogenic Au 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			
Au (t)	0	0	0	7.9	17	4.9	0.15	0.69
Rock (Mt)	0	0	0	3.8	8.6	3.6	0.10	0.69

t – metric tons; Mt – million metric tons.

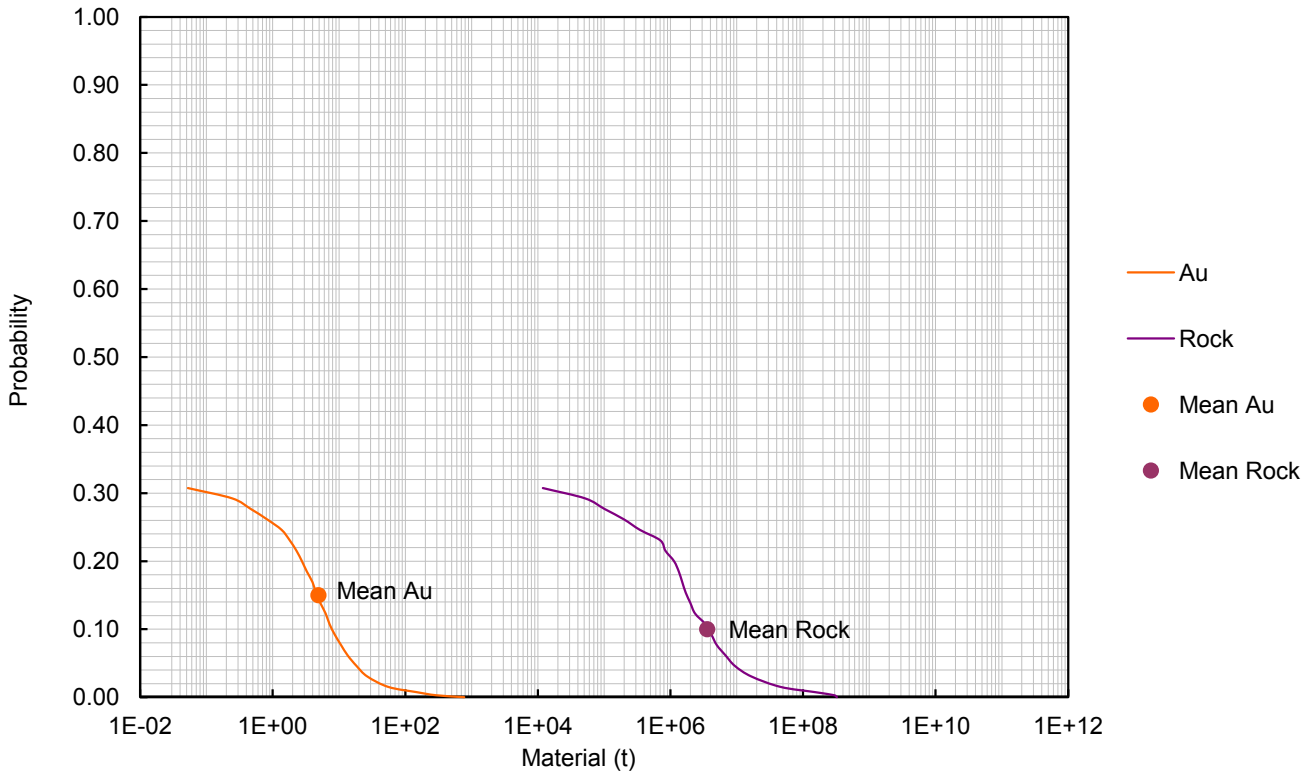

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Granulite Belt Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT HAAPAJÄRVI–HAAPAVESI OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Haapajärvi–Haapavesi Orogenic Au permissive tract is located in western Finland in the municipalities of Alavieska, Haapajärvi, Haapavesi, Nivala, Oulainen, Reisjärvi and Ylivieska, 110 km south of Oulu (Fig. 1). The 1:100,000 KKJ map sheets are 2342, 2343, 2344, 2431, 2432, 2433 and 3322. The UTM map sheets containing the tract are Q413, Q414, Q423, Q424, Q431, Q432 and Q441. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Haapajärvi–Haapavesi Orogenic Au 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)	
7/11/2011	1	1199	Au	4.58	Au	43	Au	17

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is defined by Palaeoproterozoic younger Svecofennian (1.90–1.87 Ga) Ylivieska group volcanic and subvolcanic rocks with syntectonic (1.89–1.87 Ga) granitoids. The delineation is based on the extent of the rocks mentioned above, suitable second- and third-order shear structures and the presence of gold occurrences and gold-indicative outcrops and boulders. Low-altitude aeromagnetic data of the Geological Survey of Finland (GTK) were used to define the margins of the tract, especially the eastern contact to the Vihanti–Pyhäsalmi block of higher metamorphic grade rocks. The tract was extended to the south to cover the area of the Kopsa Cu-Au deposit, based on the existence of Kuusaa formation volcanic rocks (Ylivieska group) and indications of orogenic gold. The Kopsa deposit comprises a quartz vein stockwork and is historically interpreted as

a porphyry-type Cu-Au deposit or an intrusion-related gold deposit (Gaal & Isohanni 1979, Eilu et al. 2003). The tract extends down to 1000 m depth. The sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

There is one well-explored orogenic Au deposit within the 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 orogenic Au deposits in the Haapajärvi–Haapavesi Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
Ängesneva	7115190	3399920		3.85	1.19	4.6	Nally et al. (2010)

Ga – billion 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 14 partially explored orogenic Au occurrences are known within the permissive tract (Table 3).

Table 3. Significant orogenic Au occurrences in the Haapajärvi–Haapavesi Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Alakylä	7108070	3406120		Best section 4.0 m @ 4.0 g/t Au	Lestinen & Mursu (2007)
Ängeslampi	7114280	3399810		0.27 Mt @ 3.1 g/t Au	Sipilä (1988b)
Antikanperä	7123340	3401390		Best section 1.0 m @ 1.1 g/t Au	Kontoniemi & Lestinen (2003)
Kiimala 2	7115850	3400500		Best section 1.0 m @ 9.0 g/t Au	Västi (1991a)
Kurula	7112910	3380720		Best section 5.0 m @ 2.2 g/t Au	Sipilä (1988c)
Lehto	7074040	3403920		Best section 1.0 m @ 1.1 g/t Au	Kontoniemi & Mursu (2007)
Pääneva	7106090	3407930		Best section 1.0 m @ 1.5 g/t Au	Lestinen & Mursu (2007)
Pirttineva	7104175	3412346		Auriferous, 5–15 cm wide, arsenopyrite-bearing quartz veins within a 200 m x 300 m area.	Ervamaa (1952), Lestinen (2001)
Pöhlölä	7111750	3401940		Best section 0.6 m @ 13.1 g/t Au	Sandberg (1986)
Pöntiö1	7122969	3402319		Best section 62 m @ 1.1 g/t Au	Belvedere Resources (2012)
Pöntiö2	7121465	3402352		Best section 22 m @ 0.6 g/t Au	Belvedere Resources (2013)
Pöntiö3	7120829	3402645		Best section 84 m @ 0.47 g/t Au	Belvedere Resources (2013)
Sarjankylä	7105354	3407496		Best portable drill core samples: 3.82 g/t Au, 2.82 g/t Au	Sipilä (1990b)
Teerineva	7108030	3402720		Best section 1.0 m @ 2.0 g/t Au	Lestinen & Mursu (2006)
Tiitola	7113400	3400270		Best section 1.25 m @ 4.6 g/t Au	Västi (1997)
Vesiperä	7113130	3401290		0.3 Mt @ 2.5 g/t Au	Sipilä (1988a), Västi (1991b)

Ga – billion years.

Exploration history

Exploration already commenced in the Haapajärvi–Haapavesi Orogenic Au tract area in the 1930s when the Kopsa Cu-Au outcrop was found (Gaal 1978). Serious gold exploration began in the region in the 1980s, when the global gold price rapidly increased. Since then, Outokumpu Oy, GTK and Belvedere Resources have intensely explored the area. Exploration activities for orogenic Au deposits and occurrences within the tract are listed in Table 4.

Table 4. Exploration history for the Haapajärvi–Haapavesi Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Bedrock mapping, boulder tracing	Yes	Outokumpu	1980s
	Bedrock mapping, boulder tracing	Yes	GTK	1983–2005
Geochemical surveys	Regional till geochemistry	Yes	GTK	1982–1994
	Targeting till survey, lithogeochemical assessments	Yes	Outokumpu	1980s
	Targeting till survey, lithogeochemical assessments	Yes	GTK	1983–2005
Airborne geophysical surveys	MMI survey	Yes	Bevedere Resources	2004–
	Low-altitude magnetic, electromagnetic and radiometric survey		GTK	1976–1985
Ground geophysical surveys	Magnetic, slingram, IP		Outokumpu	1980s
	Magnetic, gravimetry, slingram, VLF-R, IP		GTK	1983–2005
Drilling	Percussion and diamond drilling	Yes	Outokumpu	1980s
	Percussion and diamond drilling	Yes	GTK	1983–2005
	Percussion and diamond drilling	Yes	Belvedere Resources	2004–
Other	Resource estimation, Beneficiation tests	Yes	Belvedere Resources	2008–

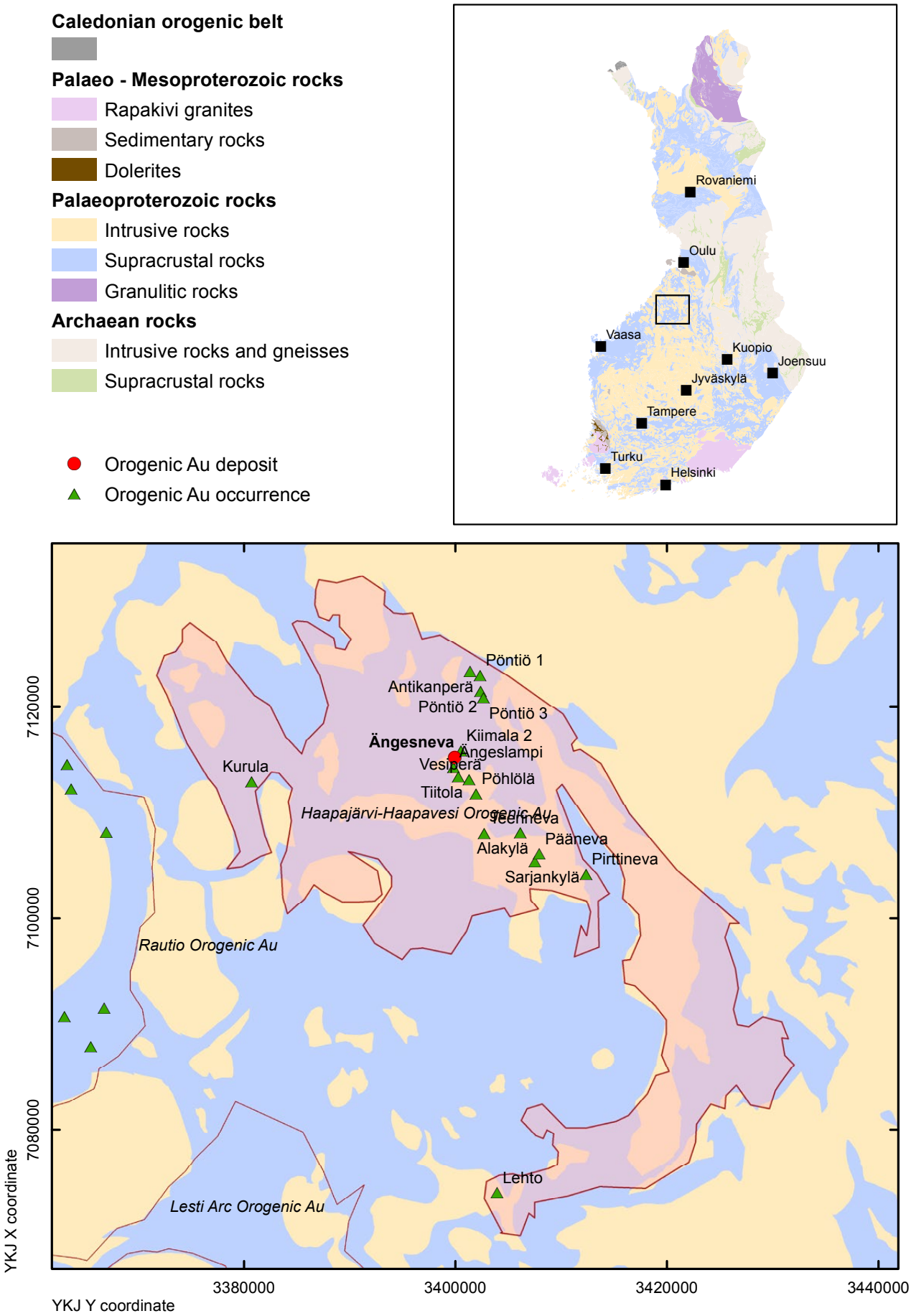

Fig. 1. Location of the Haapajärvi–Haapavesi Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Haapajärvi–Haapavesi Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Haapajärvi–Haapavesi Orogenic Au permissive 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 gold deposit database		Eilu & Pankka (2009)
	Reports		Sandberg (1986), Sipilä (1988a,b,c, 1990a,b), Västi (1991a,b, 1997), Taipale (2000), Kontoniemi & Lestinen (2003), Lestinen & Mursu (2006, 2007), Kontoniemi & Mursu (2007), Nally et al. (2010),Belvedere Resources (2012, 2013)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Iisalo (1987, 1989, 1994), Sipilä (1988a, 1988c, 1990a), Lestinen (2001, 2002), Lestinen & Mursu (2006, 2007)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Sipilä (1988a,b,c, 1990a), Västi (1997), Taipale (2000), Lestinen (2001, 2002), Makkonen et al. (2003), Lestinen & Mursu (2007), Kontoniemi & Mursu (2007)
Exploration	Data of gold-bearing outcrops and boulders		Makkonen et al. (2003)
	Reports		Sandberg (1986), Iisalo (1987, 1989), Sipilä (1988a,b,c 1990a,b), Västi (1991a,b, 1997), Lestinen (2001, 2002), Kontoniemi & Lestinen (2003), Lestinen & Mursu (2006, 2007), Kontoniemi & Mursu (2007), Belvedere Resources (2012, 2013)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

More than ten partially explored orogenic gold occurrences are known within the tract (Table 3), most of them rather modest. The existence of one well explored orogenic gold deposit and a large number of partially explored occurrences, a large number of gold-mineralised boulders with no indicated bedrock source, and abundant structurally favourable (but unexplored) locations indicate the good potential for undiscovered orogenic gold deposits for the tract. All the drilling has so far been shallow, which leaves a lot of space for further discoveries in this rather large tract, and the potentially very promising Kuusaa subarea in the eastern part of the tract still is almost totally unexplored. The individual estimators considered the probability high that at least one to two undis-

covered economic deposits exist 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 Haapajärvi–Haapavesi Orogenic Au 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}		
2	2	4			2.5	0.98	40	1	3.5	1199	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	3		
Individual 3	2	3	5		
Individual 4	2	3	5		
Individual 5	1	2	3		
Individual 6	2	2	4		
Mean	2	2	4		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Hartikainen, Kontoniemi, Nikander, Sorjonen-Ward, Västi.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Haapajärvi–Haapavesi Orogenic Au 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			
Au (t)	0.51	2.9	17	100	200	43	0.23	0.04
Rock (Mt)	0.11	1.0	7.4	62	200	30	0.19	0.04

t – metric tons; Mt – million metric tons.

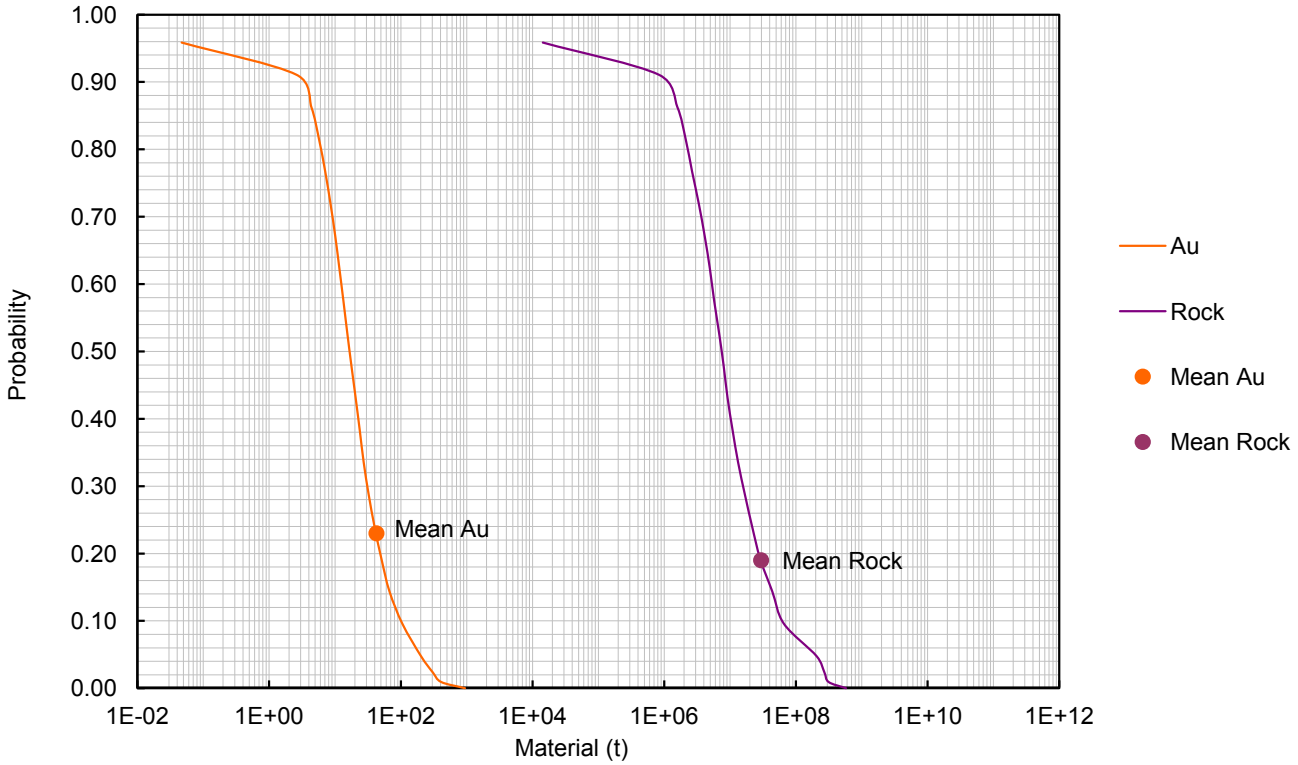

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Haapajärvi–Haapavesi Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT HATTU OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Hattu Orogenic Au permissive tract is located in eastern Finland in the municipalities of Lieksa, Ilomantsi and Joensuu (Fig. 1). The 1:100,000 KKJ map sheets covering the tract are 4234, 4244, 4333, 4334 and 5222. The UTM map sheets containing the tract are N621, N622, P611, P612 and P621. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Hattu Orogenic Au 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)	
8/11/2011	1	640	Au	10.26	Au	87	Au	42

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The Hattu schist belt is, at present, the only Archaean area in eastern Finland that has been shown to be highly prospective for gold, with the Endomines Oy Pampalo Mine being the first Archaean gold deposit in Fennoscandia to be commercially exploited. The geology of the region has been systematically mapped (Frosterus & Wilkman 1920, 1924, Lavikainen 1973, 1975, 1986, Sorjonen-Ward 1993a,b), such that the overall structural architecture and lithostratigraphic units are well defined, providing a framework for exploration and interpretation of controls on mineralisation.

The Hattu Orogenic Au permissive tract circumscribes the 2750–2890 Ma supracrustal rocks of the Hattu schist belt (Sorjonen-Ward & Luukkonen 2005); the tract also includes granitoid intrusions within and along the margins of the Hattu belt. The justification for extrapolation of the tract to a depth of 1 km is based on the down-plunge

projection of major structural features and mappable lithic units. The sources of information used in the delineation of the tract are summarised in Table 5.

The area of the permissive tract experienced a renewed metamorphic event under greenschist to lower-amphibolite facies conditions, as a consequence of Svecofennian orogenic deformation between 1.9–1.8 Ga (Kontinen et al. 1992). However, the lack of significant deformation, in part constrained by the low strain state of Proterozoic mafic dykes, and microstructural studies of recrystallisation of mineral assemblages, provides strong evidence against significant remobilisation or introduction of gold during the Palaeoproterozoic (Sorjonen-Ward 1993a).

Known deposits

There are two well-known orogenic Au deposits within the 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 orogenic Au deposits in the Hattu Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
Valkeasuo (Hosko)	710900	7001000	2.7?	1.077	2.8	3.02	Clark (2008)
Pampalo	715900	6991250	2.7?	1.858	3.9	7.25	Endomines Ab (2011)

Ga – billion 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

A large number of partially explored orogenic Au occurrences are known within the permissive tract (Table 3).

Table 3. Significant orogenic Au occurrences in the Hattu Orogenic Au permissive tract.

Name	X coord	Y coord	Comments	Reference
Elinsuo	6975445	3713653	6.1 m @ 1.6 g/t Au; 1.8 m @ 3.1 g/t Au	Damsten et al. (1994)
Iso-Kivijärvi	7005029	3711220	1.2 m @ 1.35 g/t Au	Heino et al. (1995)
Kelokorpi	6969159	3715248	5 m @ 2.5 g/t Au; 4 m @ 3.5 g/t Au	Damsten et al. (1994)
Kivisuo	6974396	3713702	4.9 m @ 4.0 g/t, 2 m @ 9.5 g/t Au	Nurmi et al. (1993)
Korpilampi	6998240	3713841	1 m @ 1.4 g/t Au	Heino et al. (1995)
Korvilansuo	6972959	3712968	0.256 Mt @ 2.0 g/t Au	Endomines AB (2014d)
Kuittila	6970226	3714497	0.275 Mt @ 2.6 g/t Au	Damsten (1990), Endomines AB (2014e)
Kuivisto East	6999275	3712400	0.182 Mt @ 1.4 g/t Au	Endomines AB (2013, 2014f)
Muurinsuo	6976532	3715706	0.599 Mt @ 1.8 g/t Au	Endomines AB (2014d,g)
Palosuo	6984086	3717457	1 m @ 2.7 g/t Au; 1 m @ 1.1 g/t Au	Damsten et al. (1994)
Pampalo NW	6995019	3715644	5.7 m @ 4.7g/t; 11.5 m @ 2.7 g/t Au; 3.1 m @ 2.6 g/t Au	Endomines (2008, 2012)
Rämepuro	6984263	3716948	0.305 Mt @ 2.2 g/t Au	Endomines AB (2014c,d)
Sivakko	6997453	3714128	1.7 m @ 4.0 g/t Au; 0.5 m @ 24.4 g/t Au	Heino et al. (1995)
Viinivaara	6964266	3714475	1 m @ 4.7 g/t Au	Damsten et al. (1994)

Mt – million metric tons; t – metric ton.

Exploration history

Exploration based on till geochemical sampling has been systematically successfully applied in the Hattu tract, from reconnaissance to prospect scale, with a well-recognised suite of pathfinder elements accompanying gold (Hartikainen & Nurmi 1993, Nurmi et al. 1993). Bedrock drilling, mostly on the basis of till geochemical anomalies, has confirmed the presence of gold in almost all rock types, indicating that mechanical and compositional contrasts within and between rock units have been influential in localising fluid–rock interaction and mineralisation. Hydrothermal alteration occurs within well-defined domains, but differs in some respects from typical Archaean orogenic Au deposits in that there is evidence for superimposition on early, perhaps volcanic-related alteration (Rasilainen 1993, 1996, Sorjonen-Ward 1993a). Moreover, the abundance of scheelite and molybdenite, tourmaline and numerous minerals containing bismuth and tellurium (Kojonen et al. 1993), particularly within and proximal to mineralisation in granitoids, is suggestive of a possible involvement of synorogenic magmatic fluids, consistent with, but not proven by, the results of isotopic studies (Vaasjoki et al. 1993, Stein et al. 1998).

Archaean banded iron formations in the area covered by the permissive tract were assessed with respect to the iron resource potential during the 1970s (Lehto & Niiniskorpi 1977). Subsequent interest in gold potential can be attributed to a growing recognition of geological similarities with gold-endowed Archaean terrains on other cratons, but was specifically stimulated by two independent discoveries in 1983: regional till sampling surveys by GTK revealed anomalous Mo and W in the Kuittila area, in the southern part of the Hattu belt, and follow-up bedrock sampling showed that Au was also anomalous (Hartikainen & Nurmi 1993, Nurmi et al. 1993). At the same time, Outokumpu Exploration (OKME) commenced routine analysis of archived samples for Au and found that one sample submitted by an amateur prospector many years earlier returned an assay of 93 ppm Au and 75 ppm Ag (Pekkarinen 1989). This led in 1985 to a drilling programme and resource delineation at the Rämepuro prospect, which is located within a tonalitic dyke intruded between two metasedimentary units (Pekkarinen 1989, Ojala et al. 1990).

Following the discovery of anomalous Au in association with the Mo and W mineralisation identified at Kuittila, the Geological Survey of Finland (GTK) embarked upon a systematic assessment of the gold potential in the Hattu belt, with priority given to multielement till geochemical surveys for assessing the gold potential in the Hattu schist belt (Hartikainen & Nurmi 1993), combined with detailed geological and structural mapping (Sorjonen-Ward 1993a,b). Ground geophysical surveys were conducted over areas defined as anomalous on the basis of till geochemistry. Following this, diamond drilling was used to verify the bedrock expression of targets and also to characterise the underlying bedrock in poorly exposed terrain; most of the drill holes were only 30 m or so in length, and very few exploratory holes exceeded a depth of 100 m.

During the main GTK programme from 1984–1992, exploration was initially focused on the southern part of the schist belt, resulting in confirmed bedrock mineralisation in six discrete occurrences (from south to north, Kelokorpi, Kuittila, Korvilansuo, Kivisuo, Elinsuo and Muurinsuo), each of which, like Kuittila, was drilled on the basis of encouraging till geochemical anomalies (Nurmi et al. 1993). The discovery of visible gold in an outcrop at Pampalo in 1990 during structural mapping in the northern part of the belt stimulated further geochemical exploration and drilling in order to delineate the extent of mineralisation. An additional phase of exploration was undertaken by GTK from 1992–1995, resulting in the demonstration of bedrock mineralisation at a number of locations, namely, from south to north, Pampalo, Korpilampi, Kuivisto, Kuivisto E and Valkeasuo/Hosko (Heino et al. 1995).

After a public tendering process, the Pampalo deposit was granted to Outokumpu Mining, while from 1996, Endomines Oy held the ground to the north of Pampalo. Test mining was undertaken at Pampalo in two stages during 1996–1999 when 1784 kg of gold was produced from 11,4372 t of ore, at a grade of 15.3 g/t. Following a restructuring of corporate policy, Outokumpu Oyj relinquished its gold mining concessions in Finland in 2003, transferring its properties in the Hattu belt to Polar Mining Oy, a Finnish subsidiary of Australian Dragon Mining NL. Subsequently, in

2006, Endomines Oy acquired the rights to both Pampalo and Rämepuro, as well as the remaining deposits in the southern part of the Hattu belt. A decision to commence full-scale mining at Pampalo was made, with environmental permitting approved in 2008, and the mine commenced production on schedule in the first quarter of 2011. Total gold production for Pampalo over the first three years of mining amounts to 2448 kg (Endomines AB 2014a).

Metallurgical tests and pilot mining were undertaken by Endomines Oy at Hosko in 1999, with 760 t of ore mined at a grade of 4.3 g/t (Endomines AB 2014b). Endomines AB currently holds a mining concession over Rämepuro and mining was started there in mid-2014.

Table 4. Exploration history for the Hattu Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	No	Geological Survey of Finland	1895–1913, 1967–1975
	Outcrop observations and boulder survey	No	Rautaruukki Oy	1970s
	Outcrop observations and boulder survey	Yes	Geological Survey of Finland	1984–1996
	Outcrop observations and boulder survey	Yes	Outokumpu Mining Oy	1984–2003
	Outcrop observations and boulder survey	Yes	Endomines Oy	1995–
Geochemical surveys	Nationwide till sampling	Yes	Geological Survey of Finland	1980s
	Till and bedrock geochemical surveys	After 1984	Geological Survey of Finland	1970s to 1995
	Till and bedrock geochemical surveys	Yes	Outokumpu Mining Oy	1985–2003
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1990s
	Low-altitude airborne magnetic, electromagnetic surveys		Rautaruukki Oy	1970s
	Helimag and EM		Endomines Oy	2010s
Ground geophysical surveys	Magnetic, slingram and IP surveys		Geological Survey of Finland	1984–1995, 2007
	Magnetic, slingram and IP surveys		Outokumpu Oy	1985–2003
	Magnetic, IP and resistivity surveys		Endomines Oy	2010s
Drilling	Verification of till and bedrock Au indications	Yes	Geological Survey of Finland	1984–1995
	Diamond drilling for BIF	No	Rautaruukki Oy	1970s
	Resource delineation at Rämepuro and Pampalo	Yes	Outokumpu Oy	1985–2003
	Resource and reserves delineation at Pampalo mine and other deposits	Yes	Endomines Oy/Endomines AB	1996–

DDH – Diamond drill hole

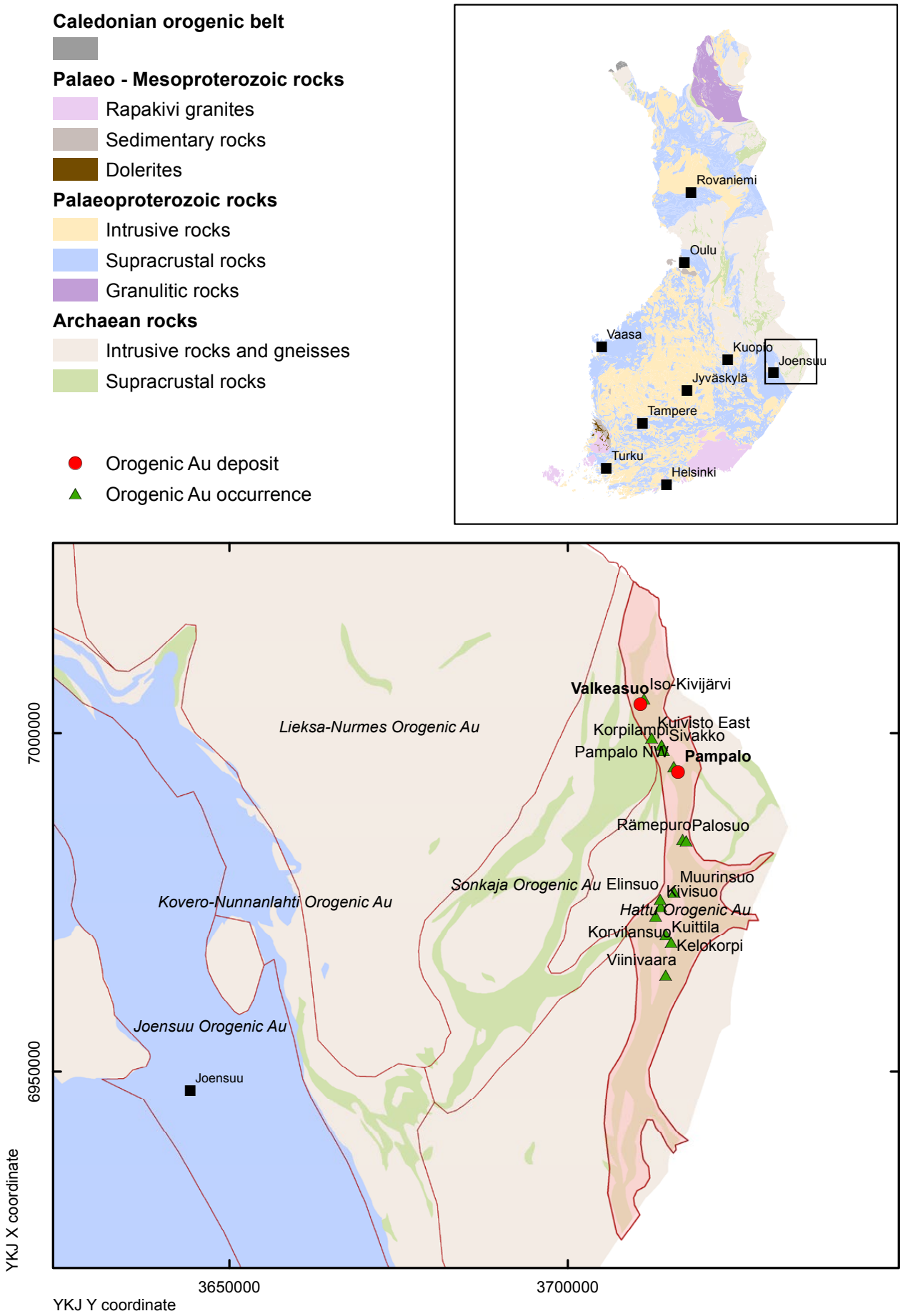

Fig. 1. Location of the Hattu Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Hattu Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Hattu Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:400,000	Frosterus & Wilkman (1920, 1924)
	Regional bedrock maps	1:100,000	Lavikainen (1973, 1975, 1986)
	Regional bedrock map	1:50,000	Sorjonen-Ward (1993b)
	Thematic geology reports		Piirainen & Vuollo (1991), Kojonen et al. (1993), Nurmi et al. (1993), Ojala et al. (1990), Sorjonen-Ward (1993a), Vaasjoki et al. (1993)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu (1999), Eilu & Pankka (2009)
	Deposit descriptions		Ojala (1988), Pekkarinen (1989), Piirainen & Vuollo (1991), Ojala et al. (1990), Hartikainen & Nurmi (1993), Kojonen et al. (1993), Nurmi et al. (1993), Ojanen (1993), Sorjonen-Ward (1993a), Parkkinen (2003), Poutiainen & Partamies (2003)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Hartikainen & Nurmi (1993), Nurmi et al. (1993), Rasilainen (1993, 1996), Pietikäinen et al. (2005)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Pekkarinen (1989), Nurmi et al. (1993)
Exploration	Reports		Damsten et al. (1994), Heino et al. (1995), Parkkinen (2001, 2003), Dragon Mining NL (2004), Pietikäinen et al. (2005), Endomines AB (2011, 2014a,b,c,d,e,f,g)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

There are two well-explored and 14 partially explored orogenic gold deposits within the tract (Tables 2 and 3). The following features were considered to indicate good (further) potential for the discovery of orogenic gold deposits in the tract, particularly with respect to the northern part of the Hattu belt: 1) a large number of drilling-indicated occurrences in a Neoarchaean greenstone belt deformed and metamorphosed in a 2.74–2.65 Ga orogeny, 2) a favourable structural architecture with the main N-trending shear zone, being anomalous for gold for the entire length of the belt, 3) the presence of extensive gold and pathfinder anomalies in till, and 4) the southern part of the tract still being poorly explored. In terms of scale and overall geological aspect, the tract has been considered analogous to the Southern Cross Province of the Yilgarn craton in Western Australia, for which production figures over the past century (>10 Moz Au) provide both realistic and optimistic upper limits (St Barbara Ltd. 2012, Ekberg 2013) for estimating the tract potential. The

southern part of the Hattu belt has not been explored in detail, but by analogy with the northern part, it is considered prospective, especially given the presence of gold mineralisation in the southwards continuation of the belt in adjacent Russia (Feoktistov et al. 2007, Korsakova et al. 2012). The individual estimators considered the probability high that at least one to six undiscovered economic deposits exist within the tract. A consensus was not 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 Hattu Orogenic Au 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}		
3	5	7			4.8	1.6	33	2	6.8	640	0.011

	Estimated number of undiscovered deposits				
Estimator	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
Individual 1	2	3	4		
Individual 2	3	6	10		
Individual 3	5	6	8		
Individual 4	1	2	4		
Individual 5	6	10	15		
Individual 6	1	1	3		
Individual 7	1	2	4		
Individual 8	4	6	10		
Mean	3	5	7		

N_{xx} – Estimated number of deposits associated with the xxth 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): Damsten, Eilu, Halkoaho, Hartikainen, Kontoniemi, Luukkonen, Sorjonen-Ward, Västi.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Hattu Orogenic Au 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			
Au (t)	4.4	11	42	230	340	87	0.27	0.03
Rock (Mt)	1.6	4.1	21	220	290	61	0.24	0.03

t – metric tons; Mt – million metric tons.

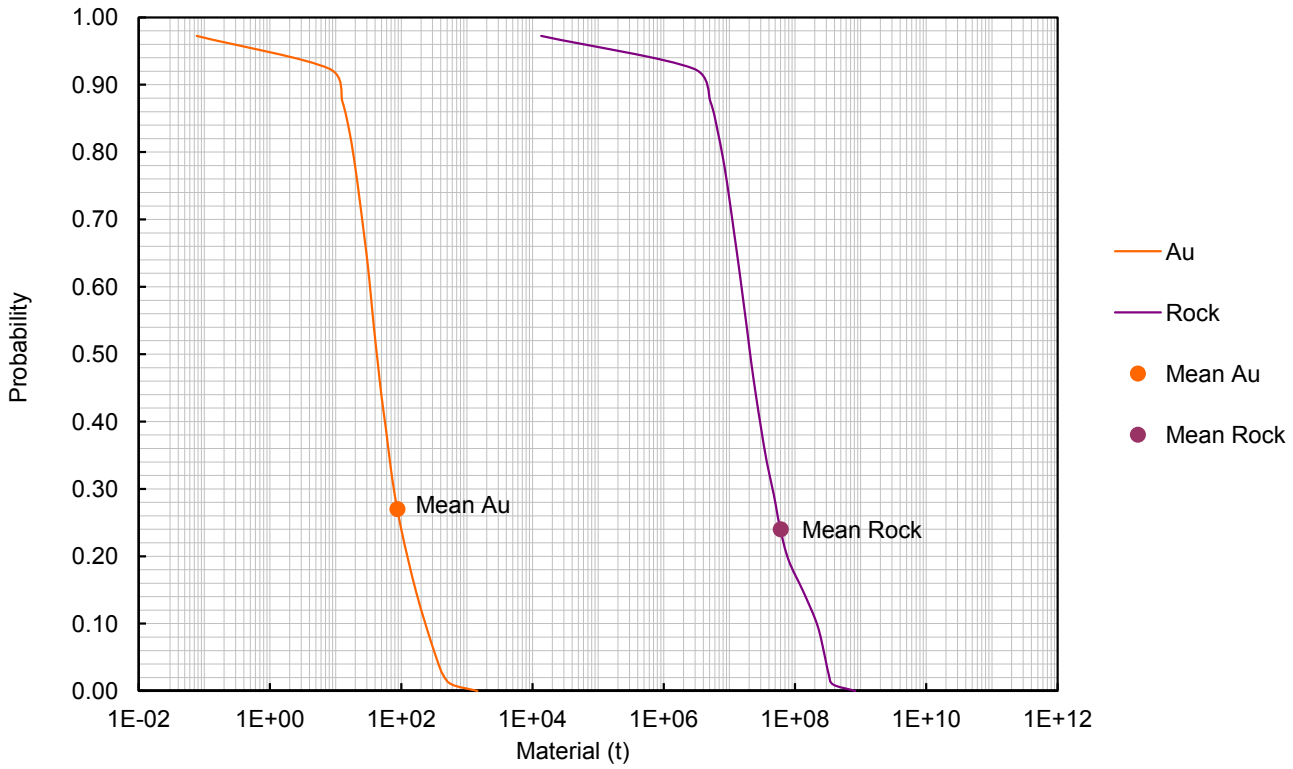

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Hattu Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT HÄME OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The W-trending Häme Orogenic Au permissive tract is located in southwestern Finland in the municipalities of Akaa, Asikkala, Forssa, Hämeenkoski, Hämeenlinna, Hattula, Heinola, Hollola, Huittinen, Humppila, Iitti, Janakkala, Jokioinen, Koski TL, Köyliö, Loimaa, Nastola, Punkalaidun, Somero, Tammela, Urjala and Ypäjä. It extends for 100 km to the east and 115 km to the west of the city of Hämeenlinna (Fig. 1). The 1:100,000 KKJ map sheets are 1134, 2024, 2111, 2112, 2113, 2114, 2131, 2132, 2133, 2134 and 3112. The UTM map sheets containing the tract are L343, L344, L421, L422, L424, M331, M332, M333, M411, M413, M431, M432, M433 and M434. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Häme Orogenic Au 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)	
04/03/2013	1	4310	Au	11.64	Au	94	Au	48

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract covers Palaeoproterozoic Svecofennian supracrustal and subvolcanic rocks and syntectonic (1.89–1.87 Ga) granitoids in the northern and central parts of the Häme belt (Kähkönen 2005, Vaasjoki et al. 2005). The tract is mostly defined by the low and mid-amphibolite facies parts of the Häme and Forssa volcanic suites and the Häme migmatite suite (Geological Survey of Finland 2010). A separate upper amphibolite area occurs in the eastern end of the tract outside of the Häme belt. The tract is bordered in the southeast by the Southern Finland granite suite rocks and in the north by the southern boundary of the Pirkanmaa migmatite suite. In

the east, the tract extends to the western boundary of the Ahvenisto rapakivi massif. The delineation is based on the extent of rocks mentioned above, suitable second- and third-order shear structures, and the presence of known gold occurrences and indications. Low-altitude aeromagnetic data of the Geological Survey of Finland (GTK) were used to define the margins of the tract. The tract extends down to 1000 m depth. The sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

Two well-explored orogenic Au deposits are known within the 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 orogenic Au deposits in the Häme Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
Jokisivu	6786609	3264119	1.802–1.801	1.91	5.65	10.8	Saalmann et al. (2010)
Satulinmäki	6742572	3307240	1.805±0.005	0.36	2.34	0.84	Kärkkäinen et al. (2006), Saalmann et al. (2009)

Ga – billion 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 orogenic Au occurrences are known within the permissive tract (Table 3).

Table 3. Possible orogenic Au occurrences in the Häme Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Liesjärvi	6761236	3326120		6 m @ 2 g/t Au	Kokkola (1986)
Pääjärvi	6772148	3393907		1 m @ 2.9 g/t Au with up to 3 % Cu	Mäkelä (1981)
Palokallio	6786213	3279393		1 m sections @ 1–41.8 g/t	Grönholm & Voipio (2012)
Palpaset	6781000	3442000		3.3 g/t Au in grab sample from outcrop	Lindmark (1981)
Ritakallio	6785345	3271040		4.7 m @ 1.7 g/t Au	Vuori et al. (2005)
Riukka	6740522	3310451		9 m @ 4.3 g/t Au; 6.5 m @ 6.7 g/t Au, 0.4 % Zn, 0.04 % Cu, 0.29 % Pb	Etelämäki (2007)
Sukula	6743700	3308844		1 m @ 1.7 g/t Au	Eilu (2012)
Uunimäki	6774049	3274717		1 m @ 12.2 g/t	Eilu (2012)

Ga – billion years.

Exploration history

The exploration history of the tract area is extensive. Most of the work has been aimed at VMS Cu-Zn, pegmatite Li, skarn W and, recently, porphyry Cu. Before the 1980s, gold was rarely analysed from samples taken. Exploration activities for gold within the tract are listed in Table 4.

Table 4. Exploration history for the Häme Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Bedrock mapping, boulder tracing	?	Outokumpu	1950s–1980s
		Yes	GTK	1980s–2010s
		Yes	Dragon Mining	2003–
Geochemical surveys	Regional till geochemistry	Yes	GTK	1980s
	Till geochemical and heavy-mineral surveys; MMI surveys	Yes	GTK	1960s–2010s
	Till geochemical surveys	Yes	Outokumpu	1960s–1980s
Airborne geophysical surveys	Low-altitude magnetic, electromagnetic and radiometric survey		GTK	1978–2000
Ground geophysical surveys	Magnetic, IP, slingram		Outokumpu	1960s–1980s
	Magnetic, IP, slingram		GTK	1960s–2010s
Drilling	Diamond and percussion drilling	Yes	Outokumpu	1970s–1980s
	Diamond and percussion drilling	Yes	GTK	1970s–2010s
	Diamond and percussion drilling	Yes	Dragon Mining	2003–

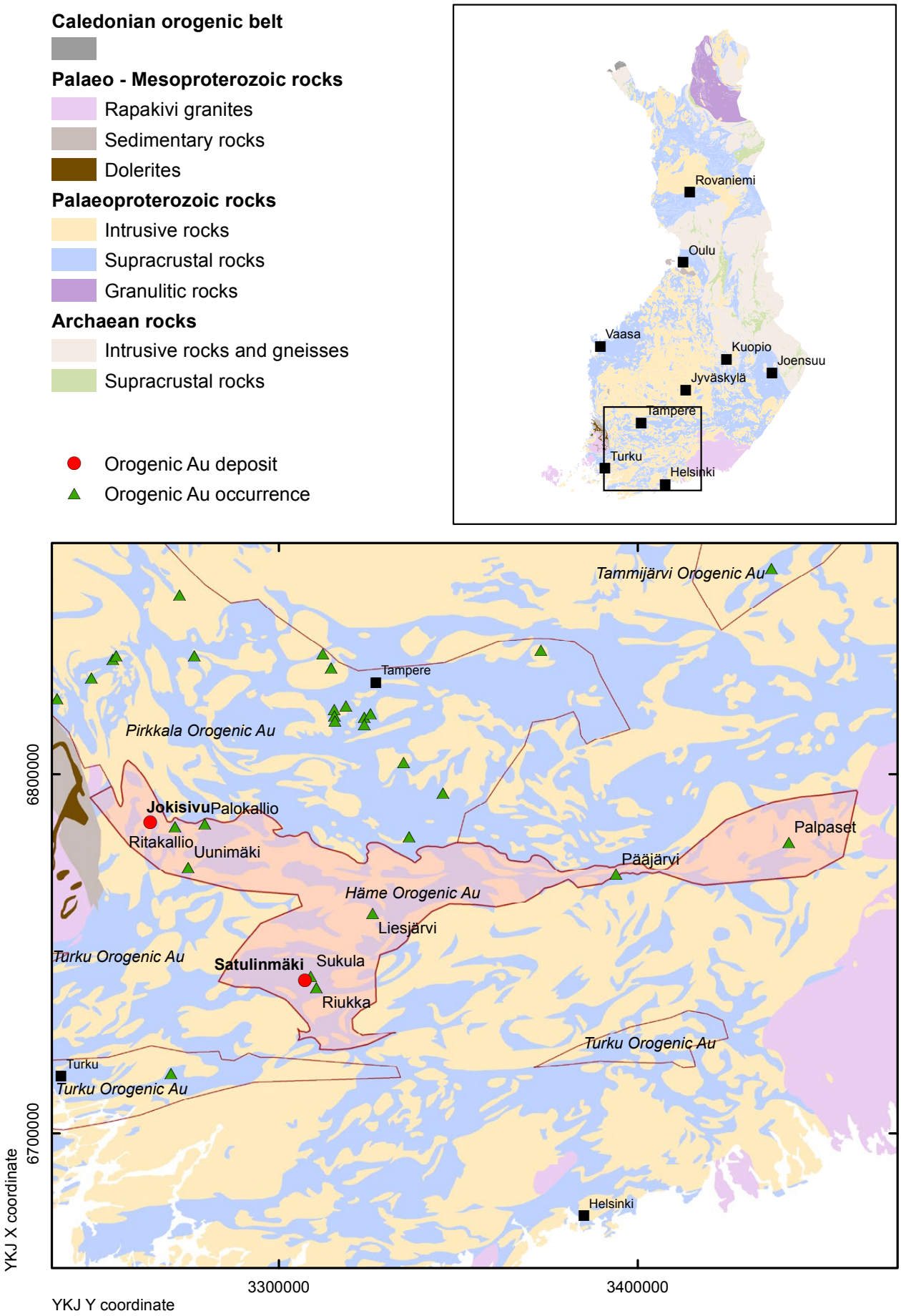

Fig. 1. Location of the Häme Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Häme Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Häme Orogenic Au permissive 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 gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Mäkelä (1981), Kokkola (1986), Kärkkäinen et al. (2003, 2006, 2007), Perälä (2003), Kärkkäinen & Lehto (2004), Vuori et al. (2005), Lahtinen (2006), Etelämäki (2007), Saalmann et al. (2009, 2010), Kärkkäinen & Koistinen (2010), Grönholm & Voipio (2012)
	Regional metallogenic assessments		Kärkkäinen et al. (2003), Saalmann et al. (2009), Eilu (2012)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Kärkkäinen et al. (2003, 2006), Kärkkäinen & Lehto (2004), Vuori et al. (2005), Kärkkäinen et al. (2007), Al-Ani & Kärkkäinen (2012), Huhta et al. (2012)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Kärkkäinen et al. (2003, 2006), Kärkkäinen & Lehto (2004), Vuori et al. (2005), Kärkkäinen et al. (2007), Airo & Leväniemi (2012), Grönholm & Voipio (2012), Lohva & Jokinen (2012)
Exploration	Reports		Lindmark (1981), Mäkelä (1981), Kokkola (1986), Kärkkäinen et al. (2003, 2006, 2007), Kärkkäinen & Lehto (2004), Vuori et al. (2005), Dragon Mining (2008), Kärkkäinen & Koistinen (2010), Grönholm & Voipio (2012)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Nearly ten partially explored orogenic gold occurrences are known within the tract (Table 3). The existence of two known deposits, a large number of partially explored occurrences and gold-mineralised boulders with yet no indicated bedrock source, undrilled outcrop indications, very extensive gold and pathfinder element (As, Te, Sb) anomalies in till, micro-nugget anomalies in till, and the idea that the tract apparently contains porphyry Cu-Au mineralisation, which may provide good source rocks for orogenic gold, indicate significant potential for undiscovered gold deposits for the tract. The best discovery potential is in the Jokisivu–Ritakallio, Satulinmäki and Forssa gabbro regions of the tract. Exploration in the area has not been extensive, however. The individual

estimators considered the probability high that at least two to five undiscovered economic deposits exist 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 Häme Orogenic Au 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}		
3	5	9			5.4	2.4	44	2	7.4	4310	0.0017

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Grönholm, Kärkkäinen, Kontoniemi, Niiranen, Sorjonen-Ward, Tiainen, Vuori.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Orogenic Au 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			
Au (t)	3.7	9.7	48	250	350	94	0.28	0.03
Rock (Mt)	1.3	3.7	24	230	310	66	0.24	0.03

t – metric tons; Mt – million metric tons.

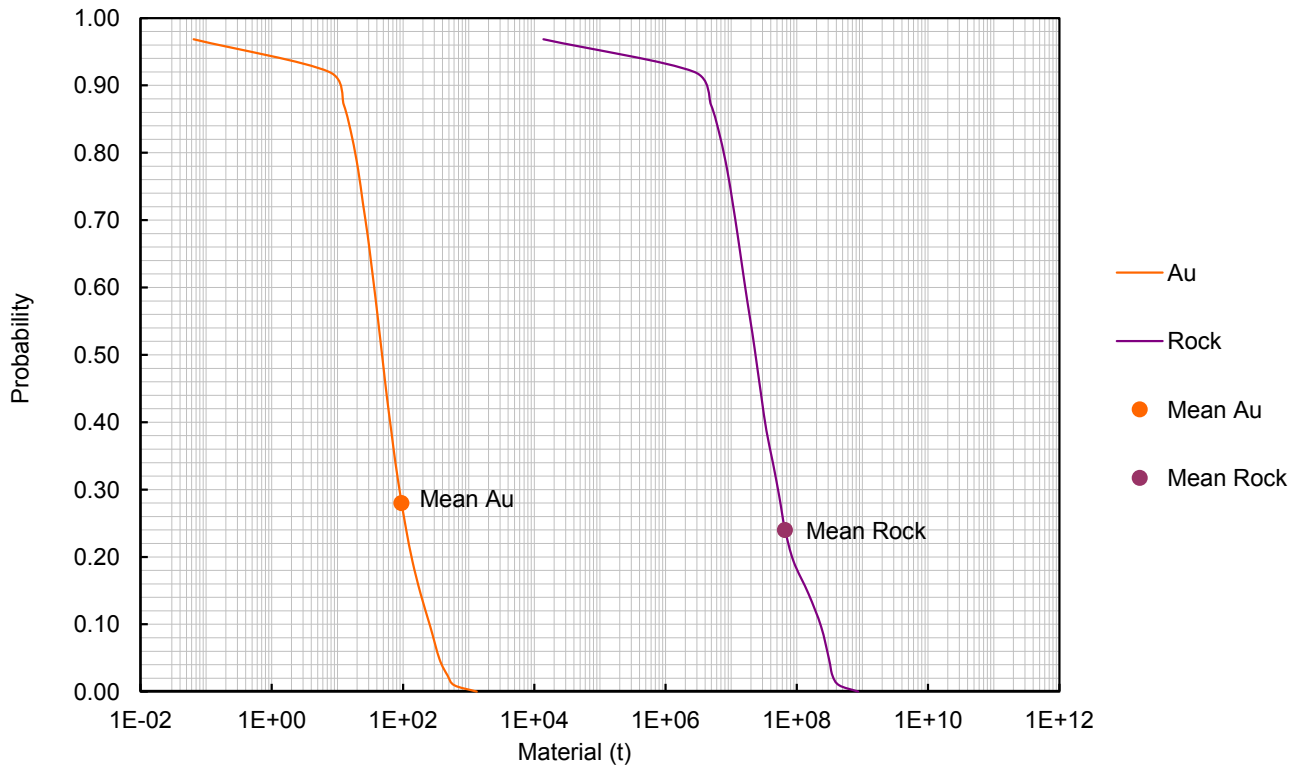

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Häme Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT INARINJÄRVI–KAAMANEN OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Inarinjärvi–Kaamanen Orogenic Au permissive tract is located in the northernmost Finland in the municipalities of Inari and Utsjoki, 270–410 km NNW of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 3824, 3834, 3841, 3842, 3843, 3844, 3913, 3914, 3923, 3931, 3932, 3933, 3934, 3941, 3943, 4812, 4821, 4822, 4824, 4911, 4912, 4913 and 4914. The UTM map sheets containing the tract are V524, W443, W444, W511, W512, W513, W514, W521, W522, W523, W524, X433, X434, X511, X512, X513, X514 and X521. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Inarinjärvi–Kaamanen Orogenic Au 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)	
17/1/2012	1	6321	Au	0	Au	18	Au	3.9

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract covers all the Archaean supracrustal terrain NE of the Lapland Granulite Belt in Finland. It is defined by the extent of the Archaean Kaamanen Complex, Inarinjärvi Complex, Luossavarri Suite and Silisjoki Suite rocks in northernmost Finland. To the north and east, the tract is bounded by the Finnish–Norwegian border, to the southeast by the Finnish–Russian border, and to the south and west by the Lapland Granulite Belt rocks. Low-altitude airborne magnetic data were extensively used to define the extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to 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 orogenic Au deposits within the 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 orogenic Au deposits in the Inarinjärvi–Kaamanen Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are no partially explored orogenic Au occurrences within the permissive tract (Table 3). However, there is the Gjeddevann gold showing in Norway, 7 km to the east of the Finnish–Norwegian border (FODD 2013). Gjeddevann is of the orogenic gold type and hosted by metavolcanic rocks that extend to Finland and the Inarinjärvi–Kaamanen Orogenic Au permissive tract. The Supru, Koppalsaari and Vätsäri 1-4 BIF-type iron occurrences and the Naittujärvi Cu-Zn occurrence are located within the permissive tract.

Table 3. Significant orogenic Au occurrences in the Inarinjärvi–Kaamanen Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
None					

Ga – billion years.

Exploration history

Exploration activity within the tract is listed in Table 4. Most of the exploration was related to iron, nickel, copper and zinc.

Table 4. Exploration history for the Inarinjärvi–Kaamanen Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder tracing	No	Geological Survey of Finland	1930–
	Outcrop observations and boulder tracing	Yes	Rautaruukki	1970s–1980s
	Outcrop observations and boulder tracing	No?	Outokumpu Oy	1975–1995
	Outcrop observations and boulder tracing	Yes	Inco	2000s
Geochemical surveys	Nationwide till survey, total 1605 points	Yes	Geological Survey of Finland	1980s
	Targeted till geochemical surveys, profile sampling, total 3600 m, non-systematic scattered sampling	Yes	Geological Survey of Finland	1980s–2000s
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1984–2006
Ground geophysical surveys	Magnetic surveys, systematic total 10.3 km^2		Geological Survey of Finland	1983–1988
	Gravity, systematic 1 km^2, profiles total 15.8 km		Geological Survey of Finland	1989, 2000
	Slingram, systematic 10.3 km^2		Geological Survey of Finland	1983–1988
	VLF-R, profiles total 3.7 km		Geological Survey of Finland	1997
	Magnetic, systematic total 19.3 km^2, profile total 31.2 km		Outokumpu Oy	1975–1986
	Slingram, systematic total 10.3 km^2		Outokumpu Oy	1975–2000
	IP, systematic total 11.65 km^2		Outokumpu Oy	1995
	Gravity, systematic total 3.3 km^2		Outokumpu Oy	1989
Drilling	Diamond drilling 16 DDH, total 2377.7 m	Earlier no, later yes	Geological Survey of Finland	1988, 2010
	Diamond drilling	Yes?	Inco	2000s
	Diamond drilling	No?	Outokumpu Oy	1975–1995

DDH – Diamond drill hole

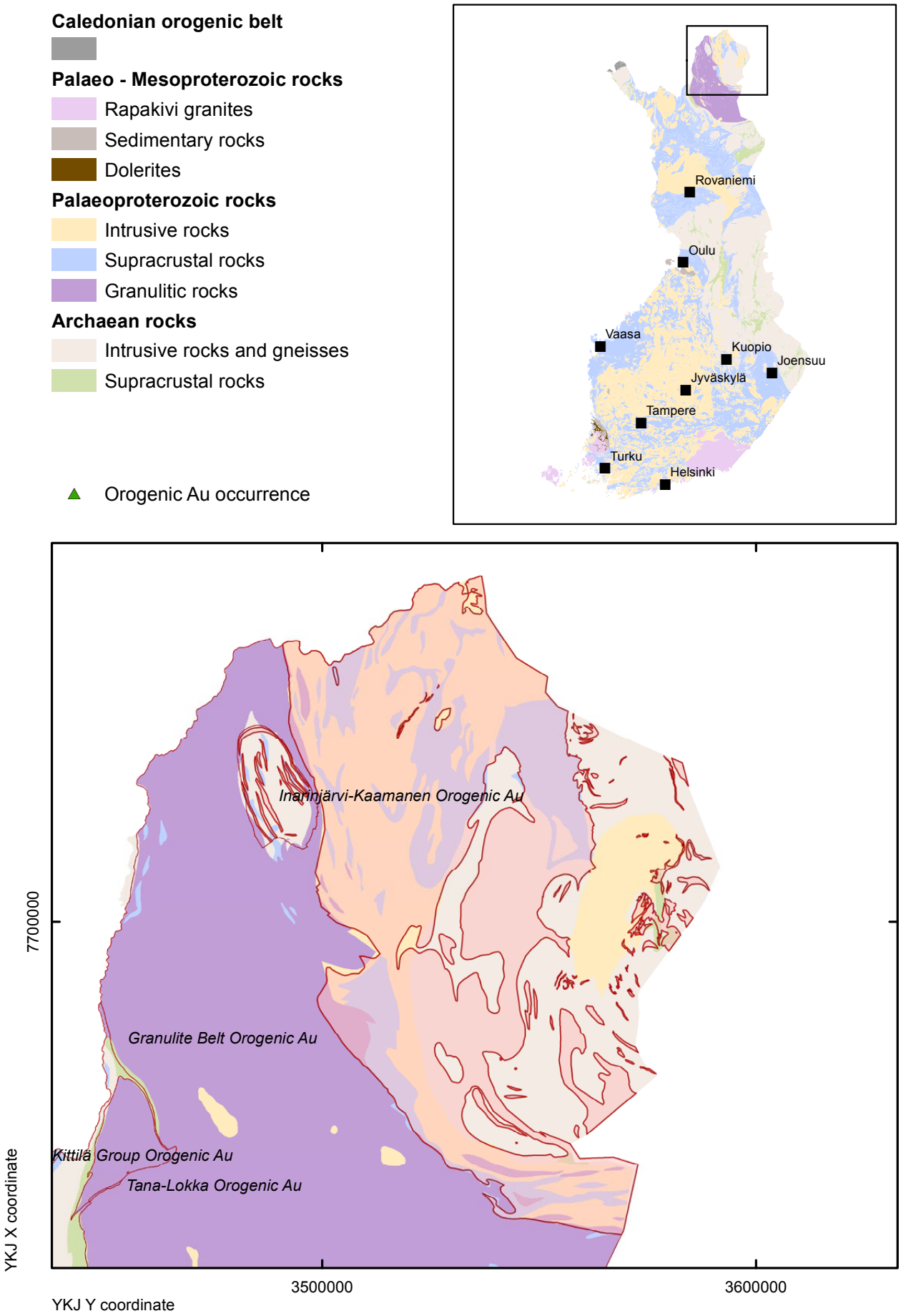

Fig. 1. Location of the Inarinjärvi–Kaamanen Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Inarinjärvi–Kaamanen Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Inarinjärvi–Kaamanen Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:400,000	Meriläinen (1965)
	Geological maps	1:100,000	Kesola (1994)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Hugg & Heiskanen (1983), Al-Ani & Sarapää (2010)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Wennevirta (1971), Peuraniemi (1979), Lehmuspelto & Pohjola (2010a,b), Sarala & Johansson (2011)
Geophysics	Geological Survey of Finland in-house database		
Exploration	Reports		Sipilä (1973), Vartiainen (1973), Mutanen (1974a,b), Heiskanen & Mattila (1979), Makkonen (1980), Hugg & Heiskanen (1983), Törmänen et al. (2011), Iljina (2003)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

No partially explored orogenic gold occurrences are known within the tract (Table 3). The tract is large, it contains Archaean greenstones, and there is one partially explored orogenic gold occurrence in Norway, only 7 km across the border. On the other hand, no direct indications of gold occurrences are known from the tract area, where the degree of regional metamorphism appears dominantly to be at mid-amphibolite facies or higher. Overall, the probability of orogenic gold deposits occurring within the tract was seen as low, but higher than in the Granulite Belt Orogenic Au tract. Little exploration has been performed in the area, and most of the work has targeted iron and nickel, not gold. It is consequently difficult to assess the number of undiscovered orogenic gold deposits in the tract. One of the estimators considered the probability high that at least one undiscovered economic deposits exists 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 Inarinjärvi–Kaamanen Orogenic Au 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			1.00	0.79	79	0	1	6321	0.00016

	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	3		
Individual 3	1	2	3		
Individual 4	0	1	1		
Individual 5	0	0	2		
Mean	0	1	2		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Keinänen, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Inarinjärvi–Kaamanen Orogenic Au 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			
Au (t)	0	0	3.9	37	83	18	0.19	0.29
Rock (Mt)	0	0	1.5	22	54	13	0.15	0.29

t – metric tons; Mt – million metric tons.

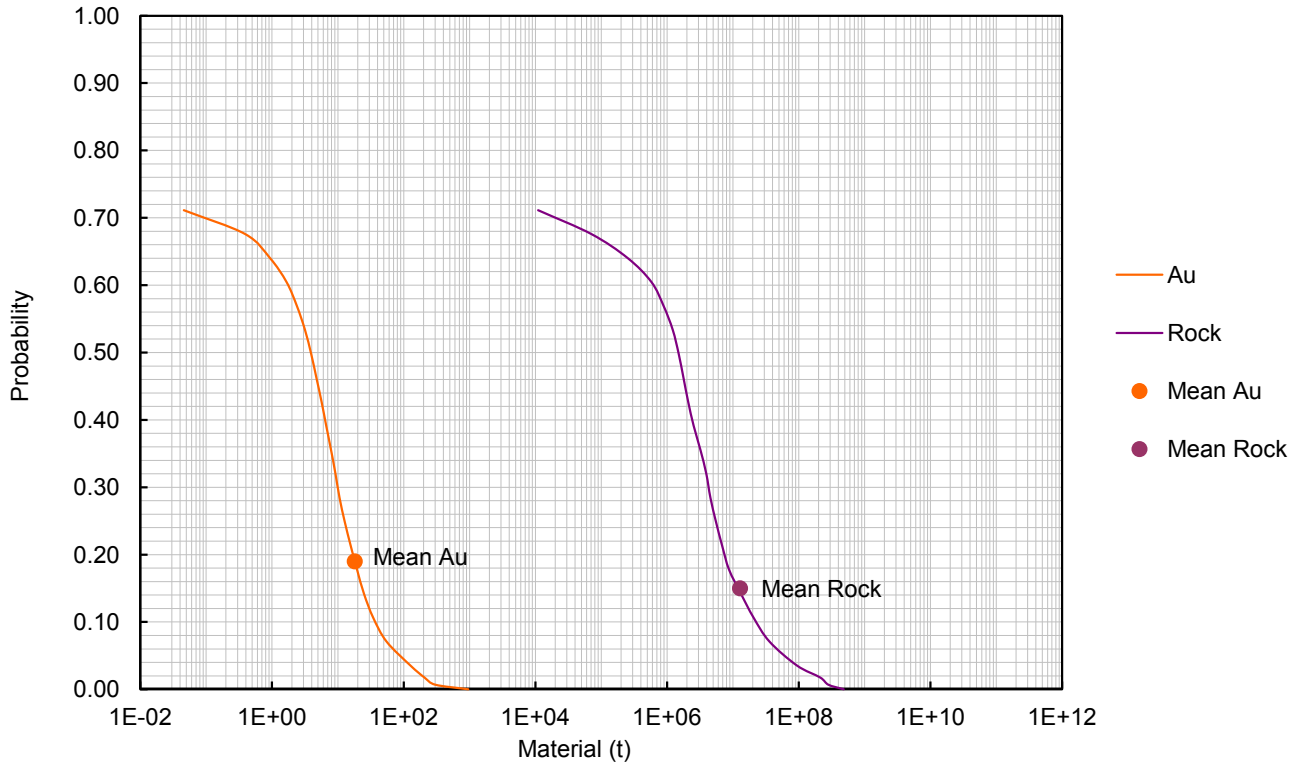

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Inarinjärvi–Kaamanen Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT JOENSUU OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The NW-trending Joensuu Orogenic Au permissive tract is located in eastern Finland in the municipalities of Joensuu, Juuka, Kitee, Kontiolahti, Liperi, Nurmes, Polvijärvi, Rääkkylä, Rautavaara and Tohmajärvi (Fig. 1). The 1:100,000 KKJ map sheets covering the tract are 4214, 4223, 4224, 4231, 4232, 4241, 4242, 4311, 4312, 4313 and 4314. The UTM map sheets containing the tract are N534, N542, N543, N544, P523, P524, P531, P532, P533, P534, P541 and P542. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Joensuu Orogenic Au 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)	
8/11/2011	1	2936	Au	0	Au	5.5	Au	0

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The Joensuu Orogenic Au permissive tract is bounded to the NE by the Kovero–Nunnanlahti Orogenic Au tract, to the SW by Palaeoproterozoic rocks with no indications of orogenic gold mineralisation, and around its northwestern part by Archaean high-metamorphic grade TTG terrain considered not to contain any orogenic gold mineralisation. The tract consists of Palaeoproterozoic metasedimentary rocks with mafic sills. In the southern part of the tract, mafic volcanic rocks occur unconformably overlying the Archaean basement upon which they were tectonically emplaced. The area of the permissive tract experienced a prograde and a retrograde metamorphic

event under greenschist to lower-amphibolite facies conditions, as a consequence of Svecofennian orogenic deformation between 1.9–1.8 Ga (Ward 1987, Ward and Kohonen 1989, Kohonen et al. 1991). The structural architecture of the tract resembles that of many Phanerozoic fold and thrust belts that contain orogenic gold systems, especially of the 'slate-belt' subtype (Goldfarb et al. 2001). The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to that depth. The sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

There are no known orogenic Au deposits within the 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 orogenic Au deposits in the Joensuu Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are no known partially explored gold occurrences in the permissive tract (Table 3). The Hammaslahti Cu-Zn(-Au) mine is within the tract area. It was operated by Outokumpu Oy during 1973–1985 and has been interpreted as a VMS deposit with a strong tectonic overprint (Loukola-Ruskeeniemi et al. 1991, 1993, Ward 1987).

Table 3. Significant orogenic Au occurrences in the Joensuu Orogenic Au permissive tract.

Name	X coord	Y coord	Comments	Reference
None				

Exploration history

There has been no systematic exploration for gold within the tract. The only reported gold production is from the Hammaslahti Cu-Zn mine, which was operated by Outokumpu Oy in 1973–1986 (Urpo Kuronen pers. comm. 2013).

Table 4. Exploration history for the Joensuu Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	No	Geological Survey of Finland	1895–1913, 1967–1975, 1984–1996
	Outcrop observations and boulder survey	Yes	Geological Survey of Finland	2007–2012
	Outcrop observations and boulder survey	Partially	Outokumpu Mining Oy	1960s–2003
	Outcrop observations and boulder survey	Yes	FinnAust Mining Oy	2011–
Geochemical surveys	Nationwide till sampling	Yes	Geological Survey of Finland	1980s
	Till and bedrock geochemical surveys	After 1984	Geological Survey of Finland	1970s–1995
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1990s
	Low-altitude airborne gravity surveys		Geological Survey of Finland	2008
	ZTEM, VTEM		FinnAust Mining Oy	2010–
Ground geophysical surveys	Magnetic, slingram and IP surveys		Geological Survey of Finland	1968–1973
	Magnetic, slingram and IP surveys		Outokumpu Oy	1973–1986
	Magnetic, IP, and resistivity surveys		Geological Survey of Finland	2008–2011
Drilling	Bedrock drilling	Yes	Geological Survey of Finland	2008–2011
	Soapstone resource drilling at Nunnanlahti	No	Tulikivi Oy	1980–
	Resource delineation at Hammaslahti	Yes	Outokumpu Oy	1973–1986
	Resource and reserves delineation at Hammaslahti mine and other deposits	Yes	FinnAust Mining Oy	2011–

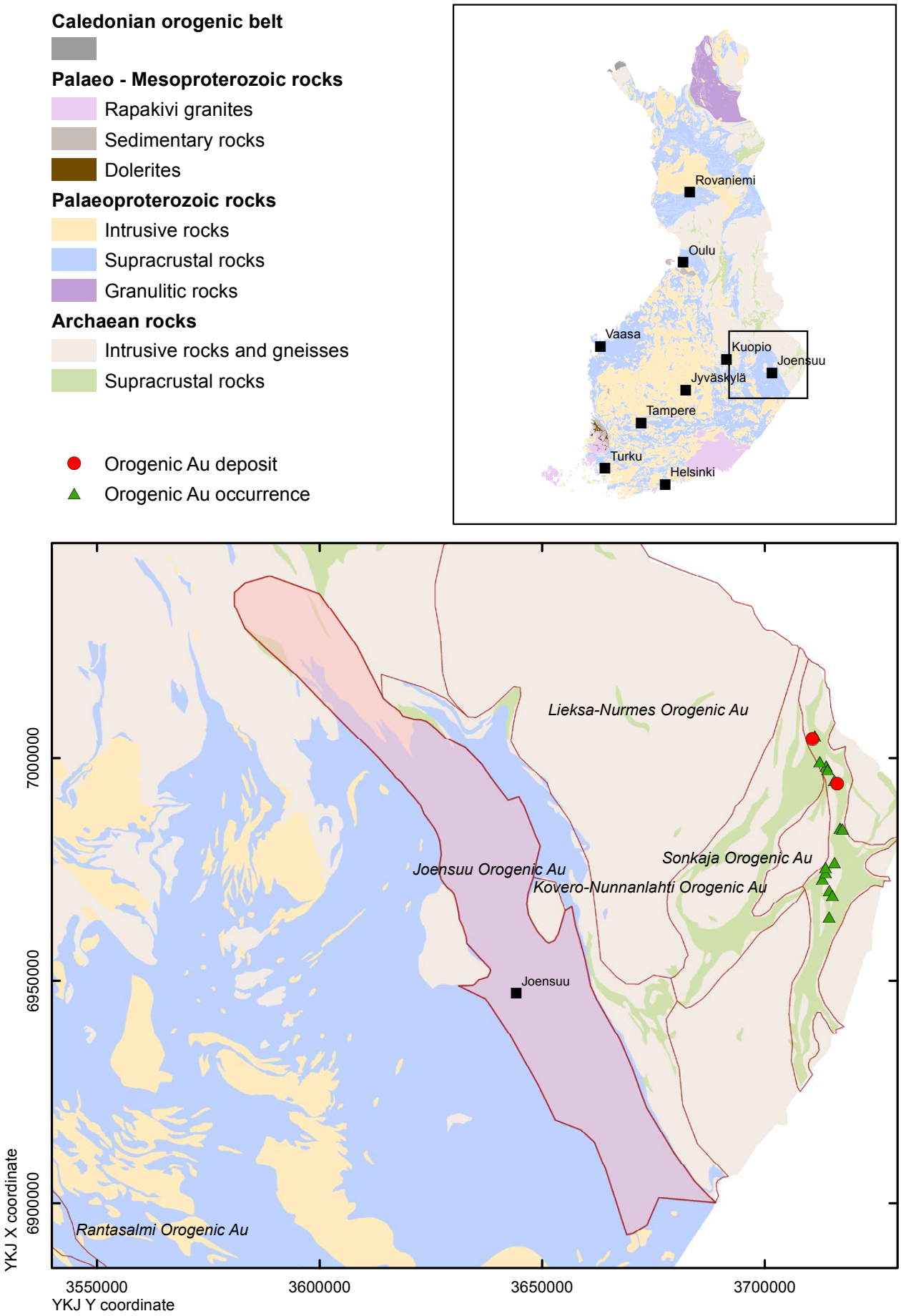

Fig. 1. Location of the Joensuu Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Joensuu Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Joensuu Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:400,000	Frosterus & Wilkman (1920, 1924)
	Regional bedrock maps	1:100,000	Nykänen (1971), Laiti (1983, 1985), Pekkarinen et al. (2006)
	Thematic geology reports		Pekkarinen (1979), Ward & Kohonen (1989), Kohonen et al. (1991), Loukola-Ruskeeniemi et al. (1991, 1993), Pekkarinen & Lukkarinen (1991), Kohonen (1995), Säntti et al. (2006), Sorjonen-Ward (2006)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu (1999), Eilu & Pankka (2009)
Geochemistry	Reports		Hartikainen and Nurmi (1993)
	Geological Survey of Finland in-house database		
Geophysics	Geological Survey of Finland in-house database		
Exploration	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

There are no known occurrences in the tract that might be used as references or constraints on the type, abundance and distribution of mineralisation. The positive indications for orogenic gold for the tract include: 1) a large slate-belt type environment, 2) several auriferous glacial erratic boulders and geochemical anomalies in till for which there is no direct connection to bedrock mineralisation and 3) extensive alteration recorded by soapstones in the Nunnanlahti greenstone belt immediately to the east of the tract area. The structural architecture of the tract resembles that of many Phanerozoic fold and thrust belts that contain orogenic gold systems (Goldfarb et al. 2001), but there is no evidence of gold enrichment in the abundant structurally controlled vein networks, which in lower-amphibolite facies rocks typically contain quartz + calcite + pyrrhotite and have distinct, albeit narrow, alteration haloes characterised by biotite and calcite.

The Outokumpu ore district to the west of the Joensuu tract contains the polymetallic Cu-Co-Zn-Ni-Au Outokumpu-type ore deposits, which have yielded some 28 tonnes of gold. However, it has been suggested that the gold was introduced into the system by early orogenic mineralising processes (Koistinen 1981, Säntti et al. 2006). The currently mined Kylylahti copper deposit also contains significant gold tenors in ore that exhibits substantial recrystallisation and remobilisation in steeply dipping high-strain zones. There, too, it seems unlikely that gold would have been introduced along late-orogenic deformation zones post-dating peak metamorphism, as is characteristic of orogenic gold deposits (Goldfarb et al. 2001). Therefore, we consider it inappropriate to

use Au in the Outokumpu district as an indicator of the Au potential in similar deformation zones in the Joensuu permissive tract. Moreover, there are no known occurrences of the Outokumpu assemblage rock types in the Joensuu Orogenic Au permissive tract.

Accordingly, the prospectivity of the Joensuu tract was assessed through comparison with metamorphosed turbiditic sequences and slate belts in other terrains, which represent particularly significant orogenic gold systems, particularly in Palaeozoic and Mesozoic terrains. The fact that the Joensuu tract is Palaeoproterozoic does not in itself indicate lower prospectivity, but the depositional and tectonic context of the tract differs from that of typical orogenic turbiditic basins (Ward 1987, Sorjonen-Ward 2006). This has potential implications through the thermal structure of the lithosphere beneath the basin during inversion and deformation, and hence the timing of metamorphic fluid production and migration, even though the fold- and thrust-belt architecture, with deeply penetrating crustal scale fault systems, is analogous to that in highly endowed provinces (Sorjonen-Ward 2006).

The Nunnanlahti greenstone belt, which could equally be assigned to the Joensuu and Kovero–Nunnanlahti tracts but which we included into the latter tract, is an allochthonous Archaean unit emplaced within Palaeoproterozoic metasediments and contains extensive indications of hydrothermal alteration. The soapstone deposits within the ultramafic rock types of the Nunnanlahti belt are some of the largest mining and dressing operations of their kind. Adcumulate dunitic bodies had also been investigated by Outokumpu Mining for their nickel sulphide potential. The carbonation and hydrothermal alteration of the peridotitic to dunitic protoliths was probably a Neoarchaean event and is of interest in that soapstone and talc-chlorite-tremolite assemblages are also characteristic of the ultramafic rocks at the Pampalo gold mine in the Hattu Orogenic Au tract. It is therefore plausible that regional-scale fluid flow could have transported gold in the Nunnanlahti belt and its surroundings to the west in the Joensuu tract as well. There are unconfirmed reports of anomalous gold in felsic mylonite containing pyrite at Nunnanlahti. Because of the structural setting, in the footwall of the greenstone belt, within the high-strain zone that emplaced it over the Palaeoproterozoic metasediments, this mineralisation could conceivably have been Proterozoic orogenic, and would also have implications for the Joensuu Orogenic Au tract. If, on the other hand, gold was introduced during Archaean hydrothermal and carbonation processes, there is accordingly less potential for orogenic gold within the enclosing Palaeoproterozoic metasediments in the Joensuu tract.

The final and intriguing feature in relation to orogenic gold in the Joensuu tract, which has not been studied in detail, is the presence of a regional till anomaly for Au that straddles the Archaean-Proterozoic boundary in the southern part of the tract (Hartikainen and Nurmi 1993). This cannot be attributed to glacial transport from the Kovero-Nunnanlahti tract greenstone belts, since they are situated to the east of the anomaly, and glacial transport was from the west and northwest. A point source such as the Hammaslahti Cu-Zn mine is plausible, but nevertheless quite distant. Mineralised boulders with chalcopyrite, sphalerite and gold exceeding 4–5 ppm Au have also been found to the south of Hammaslahti; these are usually associated with vein quartz, but the abundance of Cu and Zn suggests that they represent local late remobilisation of massive sulphide rather than of orogenic Au mineralisation.

None of the individual estimators considered the probability high that any undiscovered economic deposits exist 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 Joensuu Orogenic Au 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	2936	0.00010

	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	1	1		
Individual 4	0	1	2		
Individual 5	0	0	2		
Mean	0	0	1		

N_{xx} – Estimated number of deposits associated with the xxth 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): Damsten, Eilu, Kontoniemi, Sorjonen-Ward, Västi.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Joensuu Orogenic Au 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			
Au (t)	0	0	0	8.4	19	5.5	0.14	0.70
Rock (Mt)	0	0	0	4.0	8.8	3.6	0.11	0.70

t – metric tons; Mt – million metric tons.

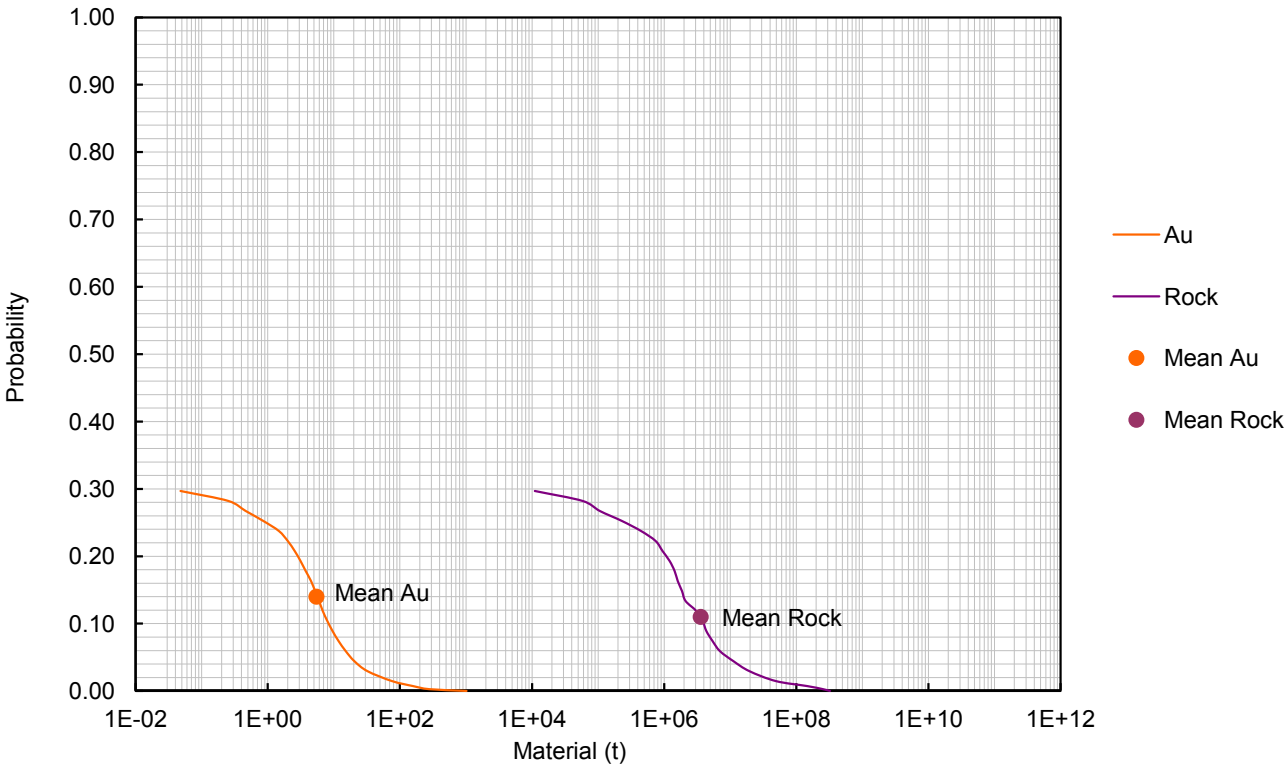

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Joensuu Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT KIIMINKI OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Kiiminki Orogenic Au permissive tract is located in western Finland in the municipalities of Ii, Kemi, Muhos, Oulu, Simo, Utajärvi and Vaala, about 20 km NE of Oulu and 150 km south of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 2531, 2532, 2533, 3414, 3421, 3422, 3423, 3424, 3511, 3512 and 3513. The UTM map sheets containing the tract are R424, R433, R434, R441, R442, R443, R444, S413, S414, S431 and S433. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Kiiminki Orogenic Au 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)	
17/1/2012	1	3375	Au	0	Au	20	Au	4.0

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is defined by the known extent of Palaeoproterozoic supracrustal rocks of the Kiiminki and Utajärvi Groups in western Finland. To the north and east, the tract is bounded by Archaean rocks, to the south by Svecofennian schists, to the west by the Kajaani Suite granitoids and by the Mesoproterozoic Muhos Formation rocks, and to the NW by the Finnish–Swedish border at the bottom of the Bothnian Bay. Archaean inliers and Proterozoic granitoids and dolerites form holes in the tract. Low-altitude airborne magnetic data is extensively used to define the extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to 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 orogenic Au deposits within the 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 orogenic Au deposits in the Kiiminki Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are three partially explored orogenic Au occurrences within the permissive tract (Table 3). Orogenic gold mineralisation in these occurrences possibly overprints an earlier, syngenetic base metal mineralisation. Parts of the tract area have been considered potential for VMS and/or SEDEX base metal mineralisation (Rasilainen et al. 2014).

Table 3. Significant orogenic Au occurrences in the Kiiminki Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Honkanen	7232190	3435900	1.83?	1.2 m @ 1.47 g/t Au, 0.745 % Cu; 0.5 m @ 1.54 g/t Au, 0.655 % Cu	Korkiakoski (2002)
Kumpuselkä	7232500	3436700	1.83?	0.3 m @ 4 g/t	Alapieti et al. (2000), Saari (2000)
Mietunoja	7236600	3422900	1.83?	1.5 m @ 1.20 g/t Au	Korkiakoski (2002)

Ga – billion years.

Exploration history

Exploration activities for gold within the tract are listed in Table 4. Nearly all exploration in the tract area has focused on base metals.

Table 4. Exploration history for the Kiiminki Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	Yes	Geological Survey of Finland	1970–
	Outcrop observations	Yes	University of Oulu	1976
	Outcrop observations and boulder survey	Partly	Outokumpu	1960s–1970s
	Outcrop observations and boulder survey	No	Rautaruukki	1973–1985
Geochemical surveys	Nationwide till survey, systematic, 446 points	Yes	Geological Survey of Finland	1984, 1987
	Nationwide till survey, systematic, 647 points	No	Geological Survey of Finland	1984, 1987
	Till and regolith geochemical surveys, grid total 187.8 km^2, profile total 11.1 km, additional scattered sampling 638 points	Yes	Geological Survey of Finland	1991–1998
	Till, regolith and heavy mineral geochemical surveys, grid total 52.4 km^2, profiles total 27.5 km and scattered sampling from 586 points	No	Rautaruukki	1973–1985
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1974–2006
Ground geophysical surveys	Magnetic surveys, grid total 65.2 km^2, profile total 337.7 km		Geological Survey of Finland	1970s–2000s
	Gravimetric surveys, grid total 59.3 km^2, profile total 246.7 km		Geological Survey of Finland	1980s–2000s
	IP surveys, grid total 1 km^2, profile total 6.6 km		Geological Survey of Finland	1990s
	Slingram multifrequency surveys, grid total 16.4 km^2		Geological Survey of Finland	1991
	Slingram one frequency surveys, grid total 2.4 km^2, profile total 65.5 km		Geological Survey of Finland	1970s, 1990s
	Self-potential surveys, grid total 0.3 km^2, profile total 24.7 km		Geological Survey of Finland	1970s, 1990s
	VLF-R surveys, grid total 43.2 km^2, profile total 286.7 km		Geological Survey of Finland	1990s–2000s
	Slingram surveys, grid total 28.8 km^2		Outokumpu	1981–1984
	Magnetic (proton) surveys, grid total 0.7 km^2		Outokumpu	1981
	Magnetic (jalander) surveys, grid total 24.2 km^2		Outokumpu	1981–1984
Drilling	Diamond drilling, 225 DDH, total 16,467.90 m	Yes, from 1990s onwards	Geological Survey of Finland	1980s–2000s
	Diamond drilling, 54 DDH, total 3606.80 m	No	Malminetsijä Oy	1940s–1960s
	Diamond drilling, 1 DDH, 37.80 m	?	Rio Tinto Zinc, Mining and Exploration	1996
	Diamond drilling, 59 DDH, total 8378.50 m	Partly	Rautaruukki	1970s–1980s

DDH – Diamond drill hole

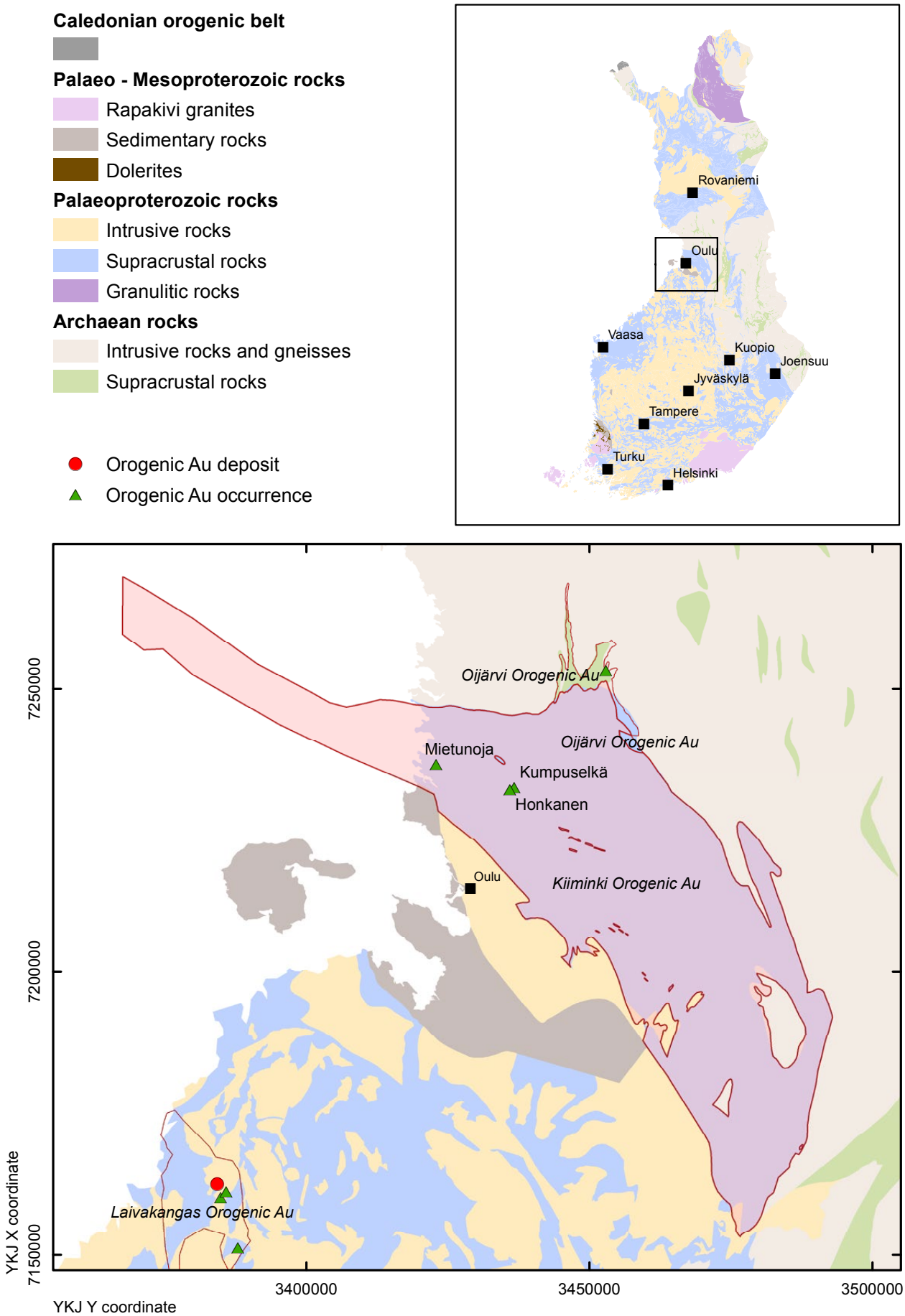

Fig. 1. Location of the Kiiminki Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Kiiminki Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Kiiminki Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:100,000	Kesola (1983, 1985), Honkamo (1984, 1988, 1992a, 1994),
	Thematic geology reports		Honkamo (1987, 1989, 1992b), Honkamo & Kousa (1994), Ahtonen (1996), Alapieti et al. (2000), Korkiakoski & Heikura (2012), Hölttä (2013)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Alapieti et al. (2000), Saari (2000), Korkiakoski (2002)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Peuraniemi (1987), Vanhanen (1995), Rossi (1997), Korkiakoski (1999, 2002), Alapieti et al. (2000), Hartikainen et al. (2008), Peuraniemi & Eskola (2011)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Vanhanen (1995), Rossi (1997), Korkiakoski (1999, 2002), Alapieti et al. (2000)
Exploration	Reports		Ahre (1983), Vanhanen (1995), Tanskanen (1996), Rossi (1997), Korkiakoski (1999, 2002), Alapieti et al. (2000)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Three partially explored orogenic gold deposits are known within the tract (Table 3). However, they were all considered small. The tract covers a Palaeoproterozoic supracrustal belt, comprising mafic metavolcanic rocks and turbidite sequences that are generally favourable host rocks for orogenic gold deposits. Few Au-anomalous locations in till have been detected in regional geochemical work, and three small drilled occurrences are known within the tract. The lower amphibolite facies metamorphic grade dominating within the belt is also favourable. Most of the exploration carried out has focused on base metals. On the other hand, geology of the Kiiminki belt is analogous to the Hammaslahti region in southeastern Finland, where no gold occurrences have been discovered, despite rather intense exploration. None of the individual estimators considered the probability high that any undiscovered economic deposits exist 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 Kiiminki Orogenic Au 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	3375	0.00030

	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	2	4		
Individual 4	0	0	1		
Individual 5	0	0	0		
Individual 6	0	0	2		
Mean	0	1	2		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Karvinen, Keinänen, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Kiiminki Orogenic Au 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			
Au (t)	0	0	4.0	37	82	20	0.17	0.29
Rock (Mt)	0	0	1.5	21	55	13	0.14	0.29

t – metric tons; Mt – million metric tons.

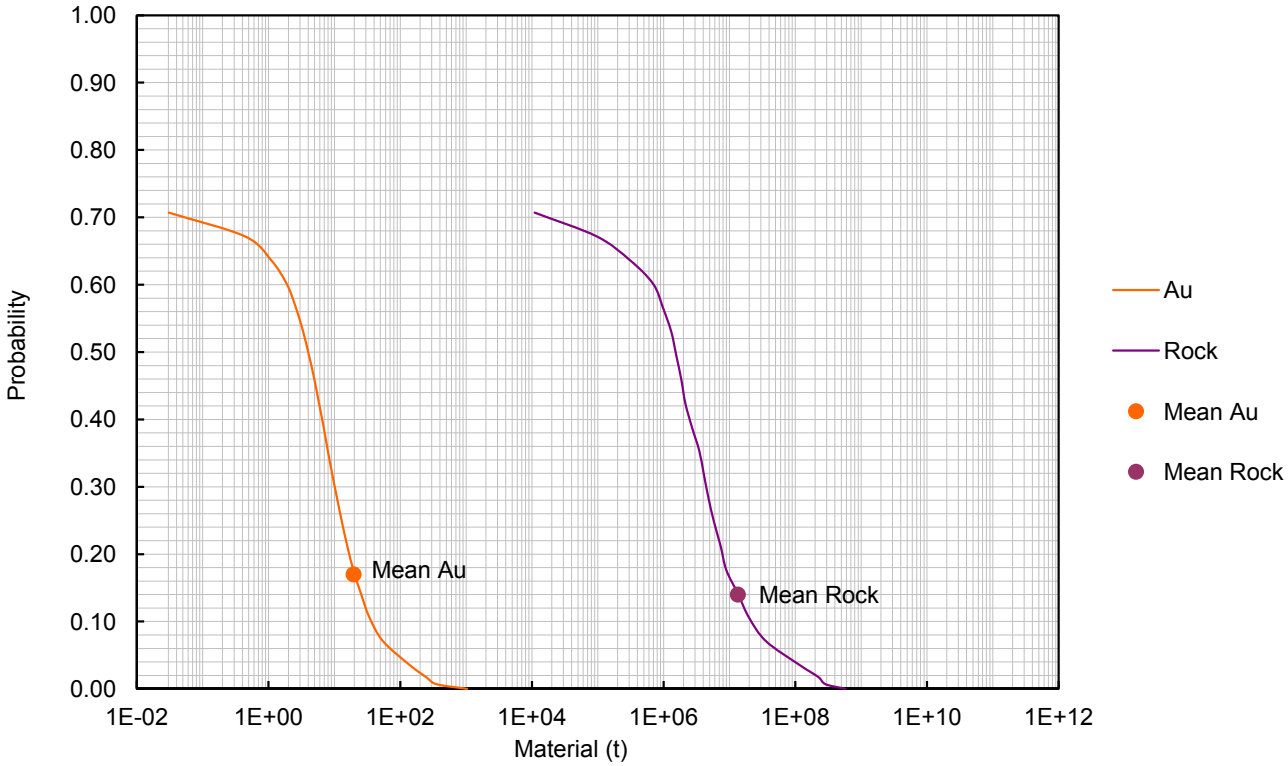

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Kiiminki Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT KITTILÄ GROUP OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Kittilä Group Orogenic Au permissive tract is located in northern Finland in the Enontekiö, Inari, Kittilä, Muonio and Sodankylä municipalities, about 160 km N to NW of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 2723, 2724, 2734, 2741, 2742, 2743, 2744, 2813, 2831, 2833, 2834, 2843, 3712, 3714, 3721, 3722 and 3811. The UTM map sheets containing the tract are U424, U441, U442, U443, U444, V413, V414, V423, V431, V432, V433, V434, V441, V442 and W431. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Kittilä Group Orogenic Au 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)	
17/1/2012	1	3376	Au	243.1	Au	160	Au	100

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is defined by the known extent of Palaeoproterozoic supracrustal Kittilä Group rocks in northern Finland. To the NE, the tract is bounded by the Tana–Lokka Orogenic Au permissive tract, to the S, SW and NW by the Sattanen–Kolari, Enontekiö–Muonio and Pulju tracts, respectively. The tract does not include the south-dipping Sirkka Thrust rocks. Palaeoproterozoic granitoids form holes in the tract, as they are regarded to be barren for orogenic gold. Low-altitude airborne magnetic data were extensively used to define the extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks

continue downwards to that depth. The sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

There is one well-explored orogenic Au deposit within the 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 orogenic Au deposits in the Kittilä Group Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
Suurikuusikko	7535913	3432604	1.89-1.852?	58.16	4.18	243.1	Agnico-Eagle (2013a,b)

Ga – billion 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 15 partially explored orogenic Au occurrences within the permissive tract (Table 3). There is also one reported palaeoplacer gold occurrence, Outapää, in the tract area, hosted by the Kumpu Group rocks.

Table 3. Significant orogenic Au occurrences in the Kittilä Group Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Hakokodanmaa	7541091	3433190	1.852-1.89?	7.7 m @ 2.6 g/t; 1.1 m @ 8.4 g/t Au; 2.9 m @ 4.2 g/t Au; 2.2 m @ 6.25 g/t Au; 0.3 m @ 170 g/t Au	Agnico-Eagle (2006, 2007)
Kellolaki	7547812	3420566		5 m @ 10 g/t Au; 8.00 m @ 1.95 g/t Au; 8.55m @ 1.51 g/t Au	Talikka & Eilu (2011)
Kerolaki	7526215	3447350		1 m @ 12.6 g/t Au	Hulkki et al. (2010)
Kiimalaki	7546522	3420396		11.70 m @ 4.48 g/t Au; 7.50 m @ 5.88 g/t Au; 5.00 m @ 5.96 g/t Au; enriched in Cu, Pb and Zn	Talikka & Eilu (2011)
Kiimakuusikko	7542640	3420255		3.45 m @ 3.94 g/t Au; grab samples up to 3.82 g/t Au, 954 g/t Ag, 0.36 % Cu, 8.09 % Pb, 0.42 % Zn, 1.97 % Sb	Talikka & Eilu (2011)
Kuotko	7550572	3433816	1.852-1.89?	1.823 Mt @ 2.89 g/t Au	Agnico-Eagle (2013a)
Mantovaara	7530577	3416726	1.9-1.8	1 m @ 1.61 g/t Au, local enrichment of base metals	Hulkki (2002a)
Paha	7545144	3434253	1.852-1.89?	1 m @ 7.63 g/t Au; 0.7 m@ 4.22 g/t Au	Agnico-Eagle (2007)
Palolaki (Petäjäselkä)	7523050	3448100	1.9-1.8	1 m @ 1.63 g/t Au; 1 m @ 1.46 g/t Au	Hulkki (2002b), Hulkki et al. (2010)
Ranta-Mäntypää	7530230	3444510		1 m @ 3.1 g/t Au	Hulkki et al. (2010)
Rovaselkä	7565676	3428764		1.30 m @ 2.6 g/t Au, enriched in Cu	Anttonen (1991)
Ruoppapalo	7551600	3439700	<1.914	4.0 m @ 2.7 g/t Au; 1.0 m @ 3.2 g/t Au (channel sampling on outcrop); 1.0 m @ 6.78 g/t Au	Härkönen (1998)
Selkä-Mäntypää	7529075	3446995		Several grab samples from outcrop @ >1 g/t Au	Hulkki et al. (2010)
Soretiavuoma N	7520772	3422758	1.852-1.89?	3 m @ 5 g/t Au; 1.5 m @ 5.1 g/t Au; 1.1 m @ 48 g/t Au; 1 m @ 24.5 g/t Au; several 1–3 m sections @ 1–3 g/t Au	Keinänen (1990, 1997)
Sukseton	7556282	3431691		4.6 m @ 2.8 g/t Au; 6.48 m @ 0.35 g/t Au, anomalous Cu	Roos (1987), Korkalo (2006)

Ga – billion years.

Exploration history

Exploration activities for gold within the tract are listed in Table 4. Most of the exploration in the region has targeted on Au, base metals and iron.

Table 4. Exploration history for the Kittilä Group Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	Yes	Geological Survey of Finland	1950–
	Outcrop observations and boulder survey	?	Outokumpu	1960s–1990s
	Outcrop observations and drill core revision	No	University of Turku	1984–1985
	Outcrop observations	Yes	Agnico-Eagle	2006–
	Outcrop observations	Yes	Riddarhyttan Resources	1998–
Geochemical surveys	Nationwide till survey, systematic, 837 points	Yes	Geological Survey of Finland	1970–1990s
	Till and regolith geochemical surveys, line till profiles: systematic profiles 2133 km, additional sampling 1388 points	No	Geological Survey of Finland	1970s–1980s
	Stream sediment surveys, organic sampling, total 2135 points	No	Geological Survey of Finland	1970s
	Stream sediment surveys, inorganic sampling, total 1031 points	No	Geological Survey of Finland	1970s
	Targeted till and regolith geochemical surveys, grid total 164.7 km^2, profile total 313.7 km, scattered sampling 398 points	Yes	Geological Survey of Finland	1970s–2010s
	Targeted till and regolith geochemical surveys, profile total 132.8 km, scattered sampling 130 points	No	Geological Survey of Finland	1970–1980s
	Targeted till and regolith geochemical surveys, profile total 25.8 km, additional scattered sampling points	Yes	Outokumpu	1970s–1990s
	Targeted till and regolith geochemical surveys, grid total 8.8 km^2, profile total 333.9 km, additional scattered sampling points	No	Outokumpu	1970s–1990s
	Heavy mineral surveys, scattered sampling, 496 points	Partly	Outokumpu	1982–1984
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1970s, 1990s–2000s
	Dense low-altitude airborne magnetic, electromagnetic and radiometric surveys, Kolvakero, 9.5 km^2		Geological Survey of Finland	2001
	Till geochemical surveys		Agnico-Eagle	2006–
	Till geochemical surveys		Riddarhyttan Resources	1998–
	Dense low-altitude airborne magnetic, electromagnetic and radiometric surveys, Levijoki, 183.2 km^2		Geological Survey of Finland	2001
	Dense low-altitude airborne magnetic, electromagnetic and radiometric surveys, Petäjäselkä, 244.6 km^2		Geological Survey of Finland	2004

Table 4. Cont.

Theme	Type of work	Au analysed	Organisation	When carried out
Ground geophysical surveys	Magnetic surveys, grid total 252.2 km^2, profiles total 276.4 km		Geological Survey of Finland	1970s–2000s
	Gravimetric surveys, grid total 3.7 km^2, profile total 163.6 km		Geological Survey of Finland	1970s–1990s
	IP surveys, grid total 23.4 km^2, profile total 1.3 km		Geological Survey of Finland	1980s–1990s
	Resistivity survey, grid 3.4 km^2		Geological Survey of Finland	1987
	Slingram multifrequency surveys, grid total 20.5 km^2		Geological Survey of Finland	1988, 1993
	Slingram one frequency surveys, grid total 239.6 km^2, profile total 21.7 km		Geological Survey of Finland	1970s–1990s
	VLF surveys, grid total 0.2 km^2, profile total 7.7 km		Geological Survey of Finland	1984–1985
	VLF-R surveys, grid total 42.4 km^2, profile total 123.7 km		Geological Survey of Finland	1980s–2000s
	Self potential surveys, grid total 7.2 km^2, profile total 10.4 km		Geological Survey of Finland	1990s–2000s
	Reflection seismics, FIRE 4a,b, profile total 93.7 km		Geological Survey of Finland, University of Helsinki, University of Oulu	2001–2005
	Reflection seismics, HIRE Suurikuusikko, E1, V1-V5, profile total 77.7 km		Geological Survey of Finland, University of Helsinki	2007–2008
	Reflection seismics, HIRE Petäjäselkä, V6, V7, profile total 45.5 km		Geological Survey of Finland, University of Helsinki	2007–2008
	Ground surface and underground surveys		Agnico-Eagle	2006–
	Ground magnetic, IP and slingram surveys		Riddarhyttan Resources	1998–
	Magnetic surveys (jalander), grid total 17.3 km^2		Outokumpu	1970s
	Magnetic surveys (proton), grid total 68.8 km^2		Outokumpu	1970s–1980s
	IP surveys, grid total 0.3 km^2		Outokumpu	1979
	Slingram surveys, grid total 63.4 km^2		Outokumpu	1970s–1980s
	VLF surveys, grid total 9.0 km^2		Outokumpu	1974–1981
Drilling	Diamond drilling, 731 DDH, total 61,104.35 m	Yes, from 1980s onwards	Geological Survey of Finland	1980s–2010s
	Diamond drilling, 114 DDH, total 12,929.35 m	Partly	Outokumpu	1960s–1990s
	Diamond drilling, 6 DDH, total 649.85 m	No	Rautaruukki	1966–1969
	Diamond drilling, hundreds of holes	Yes	Agnico-Eagle	2006–
	Diamond drilling, >400 holes	Yes	Riddarhyttan Resources	1998–
	Diamond drilling, 5 DDH, total 200.20 m	?	Rio Tinto Zinc, Mining and Exploration	1995–1996
	Diamond drilling, 6 DDH, total 194.55 m	?	Taranis Resources Inc.	2010–2011

DDH – Diamond drill hole

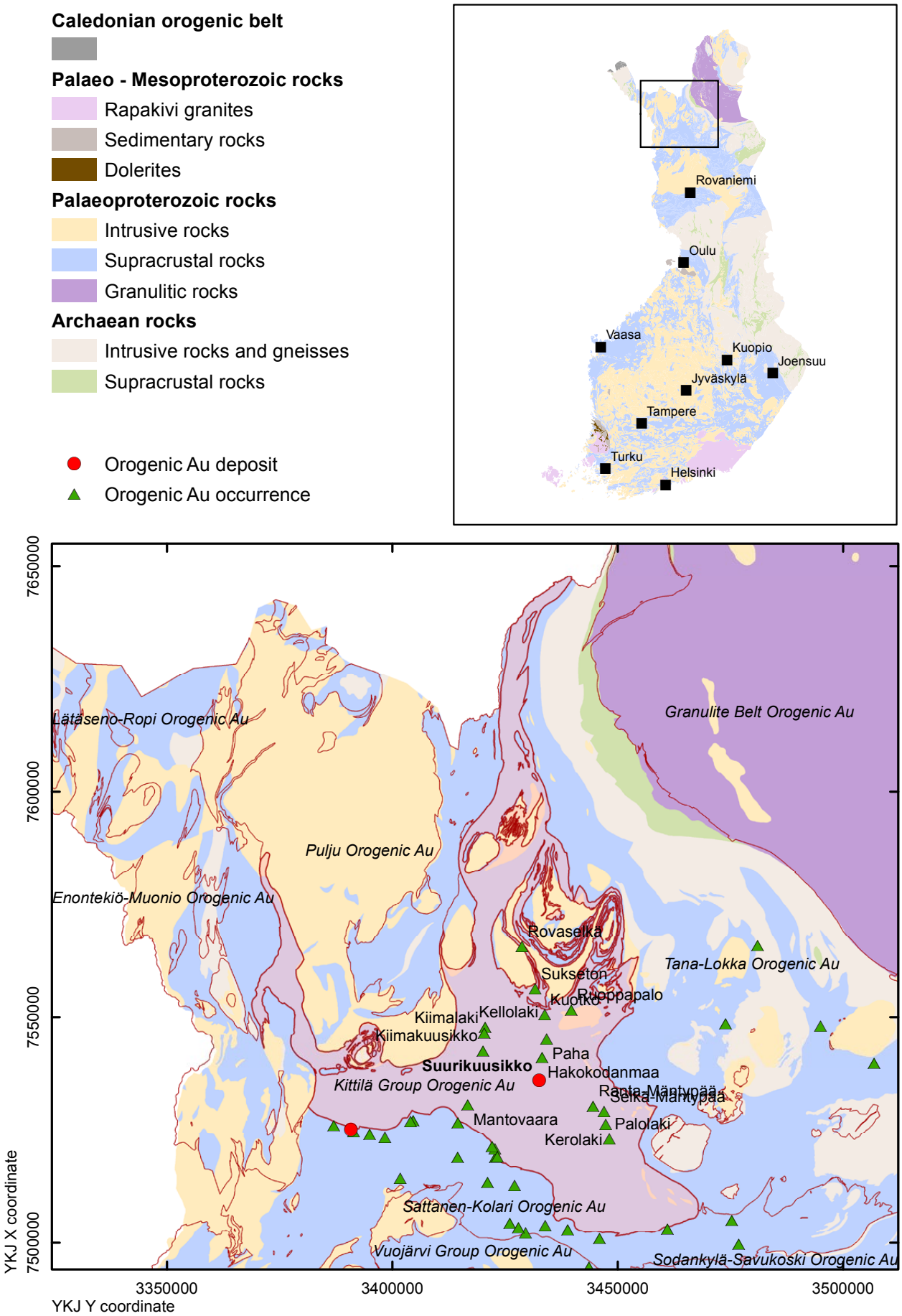

Fig. 1. Location of the Kittilä Group Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Kittilä Group Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Kittilä Group Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:300,000	Lehtonen et al. (1998)
	Geological maps	1:100,000	Lehtonen (1980, 1984), Manninen (2003)
	Thematic geology reports		Mänttäri (1995), Lehtonen et al. (1998), Rastas et al. (2001), Väisänen (2002), Korkalo (2006), Airo (2007), Eilu et al. (2007), Hartikainen et al. (2008), Hölttä et al. (2007), Ojala & Nykänen (2007), Patison (2007), Patison et al. (2007), Salmirinne & Turunen (2007), Airo & Mertanen (2008), Sarapää et al. (2008), Niiranen et al. (2009), Pulkkinen & Sarala (2009), Saalmann & Niiranen (2010), Eilu et al. (2012)
Mineral deposits and occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Eeronheimo (1981), Härkönen et al. (1987), Anttonen (1987, 1991), Keinänen et al. (1988), Suoperä (1988), Keinänen (1990, 1992, 1997), Hugg (1990, 1993), Keinänen & Hulkki (1992), Härkönen (1994a,b, 1997), Härkönen et al. (2000, 2001), Patison (2001, 2011), Hulkki (2002a,b), Pankka (2002), Mikkola (2006), Eilu et al. (2007), Patison et al. (2007), Al-Ani et al. (2008), Chernet et al. (2008), Kojonen et al. (2008), Sarapää et al. (2008), Hulkki et al. (2010, 2011a,b), Peltoniemi-Taivalkoski & Sarala (2009, 2011), Saalmann & Niiranen (2010), Numminen (2011), Sarala & Patison (2011), Talikka & Eilu (2011), Eilu et al. (2012), Patison et al. (2013)
	Metallogenic assessment		Nykänen & Salmirinne (2007), Patison et al. (2008), Nykänen (2008, 2010)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Ayräs (1979), Eeronheimo (1981), Äyräs & Koivisto (1984), Johansson & Keinänen (1987), Härkönen et al. (1987), Anttonen (1987, 1991), Keinänen et al. (1988, 1995), Hugg (1990, 1992, 1993), Keinänen (1992, 1993, 1997), Härkönen (1994a,b, 1997), Parkkinen (1997), Pankka (2002), Sarala et al. (2007), Al-Ani et al. (2008), Hartikainen et al. (2008), Sarapää et al. (2008), Peltoniemi-Taivalkoski & Sarala (2009, 2011), Pulkkinen & Sarala (2009), Hulkki et al. (2010, 2011a,b), Numminen (2011), Sarala & Patison (2011)

Table 5. Cont.

Theme	Type of source	Scale	Reference
Geophysics	Geological Survey of Finland in-house database		
	Reports		Eeronheimo (1981), Härkönen et al. (1987), Turunen (1987), Anttonen (1987,1991), Hugg (1990, 1993), Keinänen (1992, 1993), Härkönen (1994a,b, 1997), Keinänen et al. (1995), Parkkinen (1997), Pernu (2000), Hulkki (2002a,b), Pankka (2002), Niemi (2005), Airo (2007), Salmirinne & Turunen (2007), Airo & Mertanen (2008), Sarapää et al. (2008), Kukkonen et al. (2009), Niiranen et al. (2009), Hulkki et al. (2010)
Exploration	Reports		Eeronheimo (1981), Anttonen (1987,1991), Härkönen et al. (1987), Johansson & Keinänen (1987), Keinänen et al. (1988, 1995), Keinänen (1990, 1992, 1993, 1997), Hugg (1990, 1992, 1993), Härkönen (1994a,b, 1997), Parkkinen (1997), Pernu (2000), Hulkki (2002a,b), Hulkki et al. (2010), Pankka (2002), Sarapää et al. (2009), Karinen et al. (2011)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

One well-explored orogenic gold deposit exists within the tract (Table 2), and 15 partially explored orogenic gold occurrences are known within the tract (Table 3). The following were considered to indicate a high potential for orogenic gold deposits in the tract: 1) the presence of the world-class Suurikuusikko deposit within the tract, 2) the presence of 15 partially explored orogenic gold occurrences, 3) a thick sequence of tholeiitic volcanic rocks favourable for the deposit type, 4) greenschist-facies metamorphic grade within most of the tract area, 5) a structural architecture with a number of significant shear zones, 6) a crustal-scale thrust zone at the southern boundary of the tract and 7) extensive gold anomalies in till. Exploration within the tract has focused on the southern margin of the tract and along the Kiistala Shear Zone. Exploration has been carried out for orogenic gold, VMS Zn-Cu, komatiitic Ni and BIF deposits. However, as a whole the tract is not extensively explored, which leaves possibilities for 1–5 Mt orogenic gold deposits. The Kittilä Group Orogenic Au tract has the best potential for large (>3 Moz) deposits within northern Finland. The individual estimators considered the probability high that at least three to nine undiscovered economic deposits exist 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 Kittilä Group Orogenic Au 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}		
5	9	14			9.0	3.4	38	1	10	3376	0.0030

	Estimated number of undiscovered deposits				
Estimator	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
Individual 1	3	5	10		
Individual 2	4	6	12		
Individual 3	6	9	15		
Individual 4	5	10	15		
Individual 5	9	12	15		
Individual 6	5	10	15		
Mean	5	9	14		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Karvinen , Keinänen, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Kittilä Group Orogenic Au 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			
Au (t)	12	26	100	390	490	160	0.34	0.02
Rock (Mt)	4.9	11	54	310	370	110	0.31	0.02

t – metric tons; Mt – million metric tons.

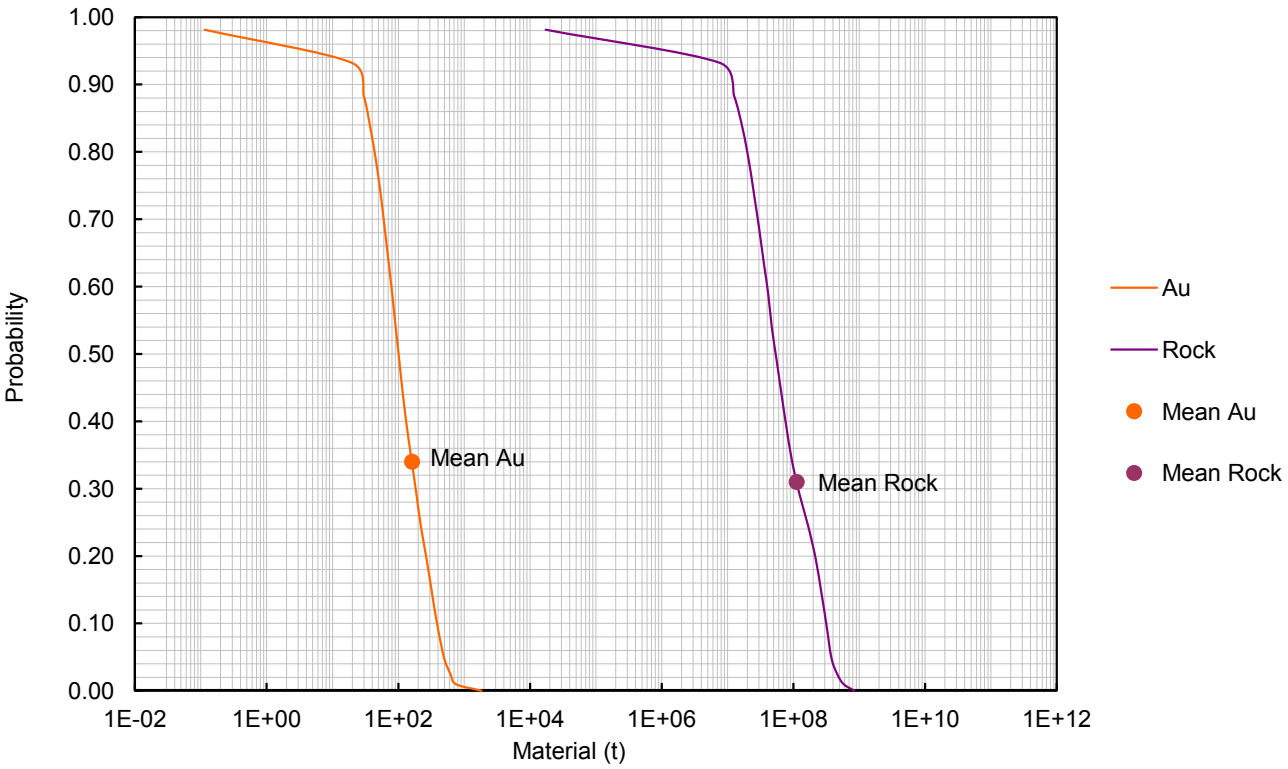

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Kittilä Group Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT KOVERO–NUNNANLAHTI OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Kovero–Nunnanlahti Orogenic Au permissive tract is located in eastern Finland in the municipalities of Ilomantsi, Joensuu, Juuka, Kontiolahti, Lieksa and Tohmajärvi (Fig. 1). The 1:100,000 KKJ map sheets covering the tract are 4224, 4232, 4241, 4242, 4313, 4314 and 4331. The UTM map sheets containing the tract are N534, N543, N544, P532, P533, P534, P541 and P543. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Kovero–Nunnanlahti Orogenic Au 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)	
8/11/2011	1	1167	Au	0	Au	19	Au	4.0

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The Kovero–Nunnanlahti Orogenic Au permissive tract circumscribes the 2750–2890 Ma supracrustal rocks forming the western part of the Ilomantsi greenstone belt, which is conventionally known as the Kovero belt. The tract also includes the discontinuous Archaean rock units along the Archaean–Proterozoic boundary, including the Nunnanlahti and Ipatti greenstone belts (Piirainen & Vuollo 1991, Sorjonen-Ward & Luukkonen 2005). Archaean supracrustal rocks of the Kovero–Nunnanlahti tract comprise a greater proportion of mafic and ultramafic rocks than the easternmost, highly mineralised part of the Ilomantsi greenstone belt, which has been assessed as the Hattu Orogenic Au tract. The Kovero belt consists of two bifurcating NW- and NE-trending branches. The latter has been assessed separately as the Sonkaja Orogenic Au tract, and the NW-trending branch is

treated here as the Kovero–Nunnanlahti Orogenic Au tract. The tract is bounded to the west by Proterozoic rocks of the Joensuu tract, and the westernmost part of the tract is below Palaeoproterozoic clastic metasedimentary units.

The justification for extrapolation of the tract to a depth of 1 km is based on down-plunge projection of major structural features and mappable lithic units; reflection seismic profiling across the tract is not informative concerning the extrapolation of greenstone belts to depth (Sorjonen-Ward 2006a). Sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

No orogenic Au occurrences or deposits are currently known within the 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 orogenic Au deposits in the Kovero–Nunnanlahti Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are no known partially explored gold occurrences in the Kovero–Nunnanlahti Tract (Table 3). Some exploration and documentation has been carried out with respect to other types of hydrothermal mineralisation within the tract: For example, during the 1950s and 1960s, the quartzites overlying the Archaean basement along the western margin of the tract were considered prospective for palaeoplacer gold, as well as uranium, based on a perceived analogy with the Witwatersrand Basin of the Kapvaal Craton (Marmo 1983, Piirainen & Vuollo 1991).

The area of the permissive tract experienced a renewed metamorphic event under greenschist to lower amphibolites facies conditions, as a consequence of Svecofennian orogenic deformation between 1.9–1.8 Ga (Kontinen et al. 1992). However, the lack of significant deformation, in part constrained by the low strain state of Proterozoic mafic dykes, and microstructural studies of recrystallisation of mineral assemblages, suggests no significant remobilisation or introduction of gold during the Palaeoproterozoic (Sorjonen-Ward 1993). Along the northwestern boundary of the tract, diverse Archaean greenstones and metasediments are juxtaposed against Proterozoic sediments and mafic sills, with unconformable, intrusive and in some places, faulted contacts. Wall-rock sulphidation reactions in shear zones have been observed in both cover and basement rocks, which may be related to the numerous historical copper workings, and also the Paukkajanvaara and Riutta uranium occurrences, both of which show mineralogical evidence of redox-sensitive alteration and mineralizing processes. These qualify as late-orogenic hydrothermal systems, but there are, however, no records of gold enrichment (Äikäs 2000, Sorjonen-Ward 2006b).

Table 3. Significant orogenic Au occurrences in the Kovero–NunnanlahtiOrogenic Au permissive tract.

Name	X coord	Y coord	Comments	Reference
None				

Exploration history

All recorded exploration and mining activity within the tract has been for uranium, nickel, zinc and soapstone. Uranium was found within both cover and basement rocks, close to the unconformity, along the northwestern boundary zone of the tract (Piirainen 1968, Äikäs 2000). Although evidence exists for wall-rock sulphidation of Archaean felsic volcanic rocks and banded iron formations at the Riutta uranium occurrence, there is no evidence for gold enrichment.

The Nunnanlahti greenstone belt lies along the rather arbitrarily defined boundary between the Joensuu and Kovero–Nunnanlahti tracts, being an allochthonous Archaean unit emplaced within Palaeoproterozoic metasediments. The soapstone deposits within ultramafic rock types in the Nunnanlahti greenstone belt are some of the largest mining and dressing operations of their kind. Adcumulate dunitic bodies have also been investigated by Outokumpu Mining for their nickel sulphide potential.

Table 4. Exploration history for the Kovero–Nunnanlahti Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	No	Geological Survey of Finland	1895–1913, 1960s–1980, 1990–2010
	Outcrop observations and soapstone mining	No	Tulikivi Oy	1970s–
	Outcrop observations and exploration trenches	No	Outokumpu Mining Oy	1970s–1990s
	Outcrop observations	No	University of Oulu	1986–1992
	Outcrop mapping and exploration trenches	No	Areva Finland Oy	2006–2010
Geochemical surveys	Nationwide till sampling	Yes	Geological Survey of Finland	1980s
	Till and bedrock geochemical surveys	After 1984	Geological Survey of Finland	1970s to 1995
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1990s
Ground geophysical surveys	Magnetic, slingram and IP surveys		Geological Survey of Finland	2007–2010
	Magnetic, slingram and IP surveys		Outokumpu Oy	1985–2003
	Diamond drilling for VHMS and nickel	Yes	Outokumpu Oy	1985–2003
	Diamond drilling	No	Areva	2008–2009

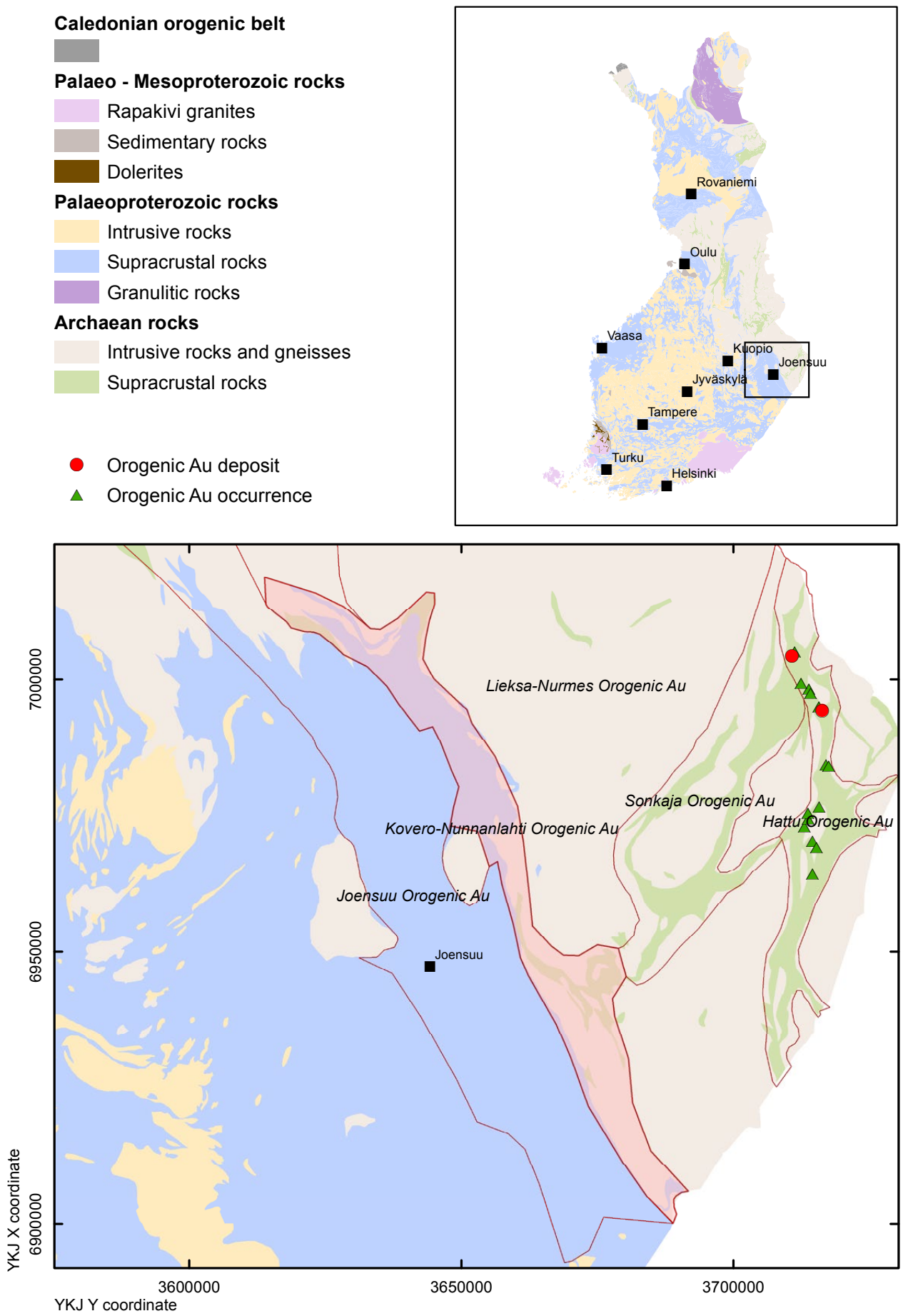

Fig. 1. Location of the Kovero–Nunnanlahti Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Kovero–Nunnanlahti Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Kovero–Nunnanlahti Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:400,000	Frosterus & Wilkman (1920)
	Regional bedrock maps	1:100,000	Laiti (1983), Nykänen (1971), Pekkarinen et al. (2006)
	Thematic geology reports		Pekkarinen (1979), Männikkö et al. (1987), Piirainen (1968), Piirainen & Vuollo (1991), Nurmi et al. (1993), Sorjonen-Ward (1993, 2006b), Äikäs (2000)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Hartikainen & Nurmi (1993), Nurmi et al. (1993), Rasilainen (1993, 1996), Pietikäinen et al. (2005), Salminen & Hartikainen (1985)
Geophysics	Geological Survey of Finland in-house database		
Exploration	Reports		Luukkonen et al. (2002), Pietikäinen et al. (2005)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

There are no known occurrences in the tract that might be used as references or constraints on the type, abundance and distribution of mineralisation. The positive indications for orogenic gold for the tract include: 1) seemingly favourable structures and metamorphic grade, 2) a prominent Au anomaly in regional till geochemistry (Hartikainen & Nurmi 1993), 3) geological similarity with the Hattu and Kuhmo–Suomussalmi orogenic gold tracts, 4) extensive alteration recorded by soapstones in the Nunnanlahti greenstone belt, 5) the occurrence of reactive lithological units, such as BIF, 6) a few weakly auriferous glacial erratic boulders and outcrops, and 7) favourable structural architecture and proximity to the Hattu schist belt, which has known gold deposits. In scale and overall geological aspect, the tract has been considered analogous to the Southern Cross Province of the Yilgarn craton in Western Australia, for which production figures over the past century (>10 Moz Au) provide an optimistic upper limit for estimating the tract potential.

The carbonation and hydrothermal alteration of the peridotitic to dunitic protoliths was probably a Neoarchaean event and is of interest in that soapstone and talc-chlorite-tremolite assemblages are also characteristic of the ultramafic rocks at the Pampalo gold mine in the Hattu tract. It is therefore plausible that regional scale fluid flow could have transported gold in the Nunnanlahti belt as well. There are unconfirmed reports of anomalous gold in felsic mylonite containing pyrite, which was exposed during the construction of the Tulikivi Oy soapstone showrooms and visitor's centre.

Because of the structural setting, in the footwall of the greenstone belt, within the high-strain zone that emplaced it over the Palaeoproterozoic metasediments, this mineralisation could conceivably have been Proterozoic orogenic, and would have positive implications for the gold prospectivity of the tract area.

However, the local geology has not yet been shown to have significant local-scale anomalies in till, nor have structures with hydrothermally altered mineralisation characteristic of orogenic gold deposits been identified. Also, a more detailed sampling survey and outcrop investigations have shown very little evidence for structurally constrained hydrothermal alteration or anomalous concentrations of gold or associated pathfinder elements. Nevertheless, little of the exploration effort has focused on gold, so it remains difficult to judge the positives and negatives for orogenic gold for the tract area.

None of the individual estimators considered the probability high that any undiscovered economic deposits exist 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 Kovero–Nunnanlahti Orogenic Au 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%	Nknown	Ntotal		
0	1	2			1.0	0.79	79	0	1.0	1167	0.00086

	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	1		
Individual 3	0	0	1		
Individual 4	0	1	1		
Individual 5	0	2	4		
Individual 6	0	0	1		
Individual 7	0	1	2		
Mean	0	1	2		

N_{xx} – Estimated number of deposits associated with the xxth 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): Damsten, Eilu, Halkoaho, Hartikainen, Kontoniemi, Luukkonen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Kovero–Nunnanlahti Orogenic Au 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			
Au (t)	0	0	4.0	34	78	19	0.17	0.30
Rock (Mt)	0	0	1.5	20	54	13	0.13	0.30

t – metric tons; Mt – million metric tons.

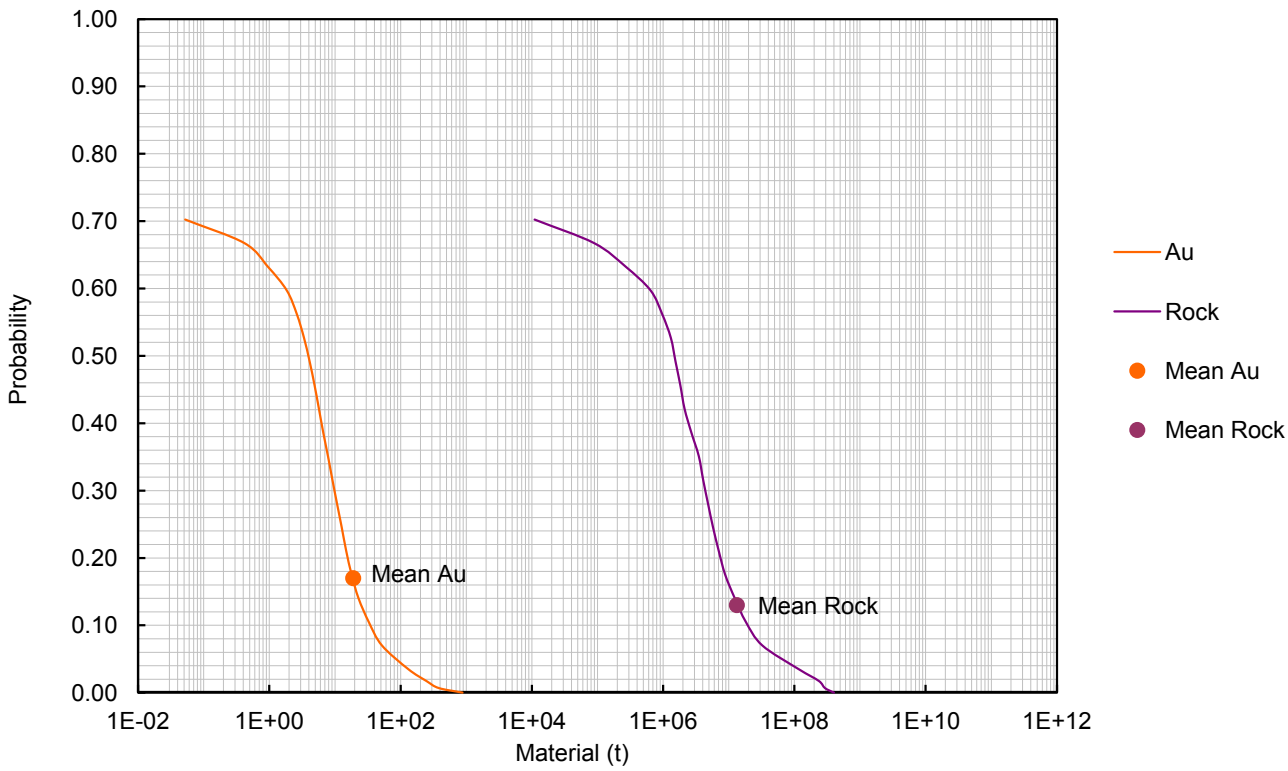

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Kovero–Nunnanlahti Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT KUHMO–SUOMUSSALMI OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Kuhmo–Suomussalmi Orogenic Au permissive tract is located in eastern Finland in the municipalities of Hyrynsalmi, Kuhmo, Kuusamo, Lieksa, Nurmes, Sotkamo, Suomussalmi and Valtimo about 60 km N of Kuhmo (Fig. 1). The 1:100,000 KKJ map sheets are 4322, 4323, 4324, 4342, 4411, 4412, 4413, 4414, 4421, 4422, 4423, 4424, 4431, 4432, 4511, 4512, 4513, 4514 and 4523. The UTM map sheets containing the tract are Q513, Q514, Q523, Q524, Q531, Q532, Q534, Q541, Q542, Q543, Q544, R513, R514, R523, R524, R531, R532, R541, R542, S531, S532 and S541. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Kuhmo–Suomussalmi Orogenic Au 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)	
8/11/2011	1	7149	Au	2.88	Au	69	Au	31

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is defined by the presence of 2750–2850 Ma komatiitic rocks in the Suomussalmi, Kuhmo and Tipasjärvi greenstone belts and by several remnants of the deeper eroded greenstone belts south and southeast of the Tipasjärvi belt. The greenstone belts contain 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 and by granitic rocks (e.g. Luukkonen 1991, Luukkonen et al. 2002, Pietikäinen et al. 2005, Pietikäinen et al. 2008, Halkoaho & Niskanen 2006, Mikkola 2008, Papunen et al. 2009). The tract delineation is based on the extent of Archaean greenstones and on low-altitude airborne magnetic data suggesting subsurface extensions to the exposed greenstones (Tables 4 and 5). The extension of the tract to the depth of 1 km is based on the assumption that the greenstone belts continue downwards to that depth. The sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

There are three well-explored orogenic Au deposits within the permissive tract: Kuikkapuro, Pahkalampi and Pahkosuo (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 orogenic Au deposits in the Kuhmo–Suomussalmi Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
Kuikkapuro	7230190	3596500	2.7?	0.045	14.6	0.66	Heino (2000), Pietikäinen et al. (2001), Saarela (2003), Sandberg (2007)
Pahkalampi	7243750	3619540	2.7?	0.59	3.5	2.07	Heino & Koistinen (1997), Nordic Mines (2007)
Pahkosuo	7250670	3609150	2.7?	0.10	1.6	0.16	Tenhola et al. (2001), Heino (2001), Luukkonen et al. (2002)

Ga – billion 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

A large number of partially explored orogenic Au occurrences are known within the permissive tract (Table 3).

Table 3. Significant orogenic Au occurrences in the Kuhmo–Suomussalmi Orogenic Au permissive tract.

Name	X coord	Y coord	Age (ga)	Comments	Reference
Hetteilä	7140885	3603945	2.7?	Best section 1.5 m @ 1.6 g/t Au	Halkoaho et al. (2006), Pietikäinen et al. (2005)
Jousijärvi	7143090	3600585	2.7?	Best sections about 3 m @ 1.44–3.82 g/t Au	Tenhola & Niskanen (2001b), Luukkonen et al. (2002)
Karvosenvaara	7111350	3612445	2.7?	Best section 1 m @ 2.9 g/t Au	Hartikainen et al. (2004), Pietikäinen et al. (2005)
Kokkokorpi	7097050	3604940	2.7?	Best section 1 m @ 3.16 g/t Au	Hartikainen et al. (2007), Pietikäinen et al. (2008)
Lokkiluoto	7117250	3609970	2.7?	Several sections: 1 m @ 1–9 g/t Au	Heino & Kilpelä (1995), Luukkonen et al. (2002)
Löttö	7096920	3615580	2.7?	Best section 1 m @ 0.5 g/t Au; outcrop sample 4 g/t Au	Pietikäinen et al. (2005)
Louhiniemi	7138885	3601835	2.7?	Best section 0.9 m @ 6.2 g/t Au	Tenhola & Niskanen (2001a), Pietikäinen et al. (2005)
Mataralampi	7150913	3597913	2.7?	Best section 1.2 m @ 10.2 g/t Au	Eilu & Ojala (2003, 2007)
Moukkori	7246330	3620840	2.7?	0.0204 Mt @ 10.57 g/t Au	Heino & Koistinen (1997), Luukkonen et al. (1997), Parkkinen (2001)
Mujesuo	7142390	3599820	2.7?	Best section 1 m @ 9.06 g/t Au; boulder sample 850 g/t Au	Tenhola & Niskanen (2001b), Luukkonen et al. (2002)
Naurispuro	7148980	3598305	2.7?	A set of N-trending subvertical lodes. Up to 0.27 g/t Au in till.	Halkoaho et al. (2001)
Palovaara	7154130	3599810	2.7?	Best section 0.5 m @ 3.1 g/t Au; outcrop sample 15 g/t Au	Heino (1995) & Luukkonen et al. (2002)
Piilola	7141250	3600920	2.7?	Best section 1 m @ 6.6 g/t Au; 4.65 m @ 2.26 g/t Au	Pietikäinen et al. (2005, 2006), Kellaway (2013)
Putaala	7122960	3605990	2.7?	Best section 1 m @ 11.8 g/t Au; boulder sample 47.3 g/t Au	Pietikäinen et al. (2005, 2006)
Roninlampi	7111385	3613145	2.7?	Best section 1 m @ 3.62 g/t Au; outcrop sample 8.24 g/t Au	Hartikainen et al. (2004), Pietikäinen et al. (2005)
Seipelä	7242310	3610250	2.7?	Best section 1 m @ 1.33 g/t Au	Pietikäinen & Niskanen (2001), Luukkonen et al. (2002)
Sepponen	7086845	3636380	2.7?	Several ppm Au per several cm in channel sampling on outcrop	Luukkonen et al. (2002)
Syrjälä-N	7229155	3596555	2.7?	0.057 Mt @ 1.55 g/t Au	Pietikäinen et al. (2000), Luukkonen et al. (2002)
Syrjälä-S	7228550	3596265	2.7?	0.090 Mt @ 1.55 g/t Au	Pietikäinen et al. (2000), Luukkonen et al. (2002), Sandberg (2007)
Taipale	7095374	3601240	2.7?	2 m @ 0.78 g/t Au; genetic type not known	Rautio (2013)
Tammasuo	7170400	3603450	2.7?	Best section about 1 m @ 2–2.5 g/t Au	Luukkonen et al. (1998, 2002)
Timola	7149820	3599180	2.7?	Best section 1 m @ 2.8 g/t Au	Hartikainen (2001)

Ga – billion years.

Exploration history

Several kinds of exploration have been performed in the Kuhmo–Suomussalmi Orogenic Au tract. The targets have mostly been nickel, copper, gold and zinc. The Geological Survey of Finland (GTK) commenced gold exploration in the tract area in the late 1980s, and it continued to 2006. During this period, GTK found 22 Au occurrences (Tables 2 and 3). Outokumpu Mining explored for gold in the tract area during 1993–2003 (e.g., Sandberg 2007), followed by Polar Mining after 2003. Polar Mining has not reported anything about its work in the area. Presently, Mineral Exploration Network (Finland), Anglo American Exploration and Kuhmo Metals are active in the tract area. Anglo American has not yet reported anything (probably only focused on Ni±PGE), Kuhmo metals has only focused on nickel and Mineral Exploration Network on gold (Kellaway 2013). Exploration activities for orogenic Au deposits within the tract are listed in Table 4.

Table 4. Exploration history for the Kuhmo–Suomussalmi Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	No	Geological Survey of Finland	1900–1953
	Outcrop observations and boulder survey	Yes	Geological Survey of Finland	1969–1990, 2003–2008
	Outcrop observations and boulder survey	Yes	Outokumpu Mining Oy	1990–2003
	Outcrop observations and boulder survey	Yes	Kajaani Oy	1970s–1990
	Outcrop observations and boulder survey	Yes	Mineral Exploration Network	2010–
	Outcrop observations and boulder survey	Yes	Sotkamo Silver Oy	2010s
Geochemical surveys	Nationwide till sampling	Yes	Geological Survey of Finland	1980s
	Detailed till and humus geochemical surveys	Yes	Outokumpu	1950s–1990s
	Till and bedrock geochemical surveys	Earlier no, later yes	Geological Survey of Finland	1960s–
	Till and bedrock geochemical surveys	Earlier no, later yes	Outokumpu Oy	1960s–1990s
	Till and bedrock geochemical surveys	Earlier no, later yes	Suomen Malmi Oy	1960s–1970s
	Till and bedrock geochemical surveys	Earlier no, later yes	Kajaani Oy	1970s–1990
	Till and bedrock geochemical surveys	Earlier no, later yes	Malmikaivos Oy	1960s–1970s
	Till and bedrock geochemical surveys	Yes	Mineral Exploration Network	2010–
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1976–2007
Ground geophysical surveys	Magnetic, slingram and IP surveys		Geological Survey of Finland	Years
	Magnetic, slingram and IP surveys		Outokumpu Oy	Years
	Magnetic, IP, and resistivity surveys		Mineral Exploration Network	2010–
Drilling	Large amount of diamond drilling for Ni, Au, Ag, Zn	Earlier no, later yes	Geological Survey of Finland	1960s–
	At least 24 DDH, total >2 km	Yes	Outokumpu Oy	1993–2003
	Diamond drilling	Earlier no, later yes	Kajaani Oy	1970s–1990
	At least 542 DDH, total about 42.3 km	Yes	Geological Survey of Finland	1987–2006
	A few diamond-drill holes	Yes	Mineral Exploration Network	2010–

DDH – Diamond drill hole.

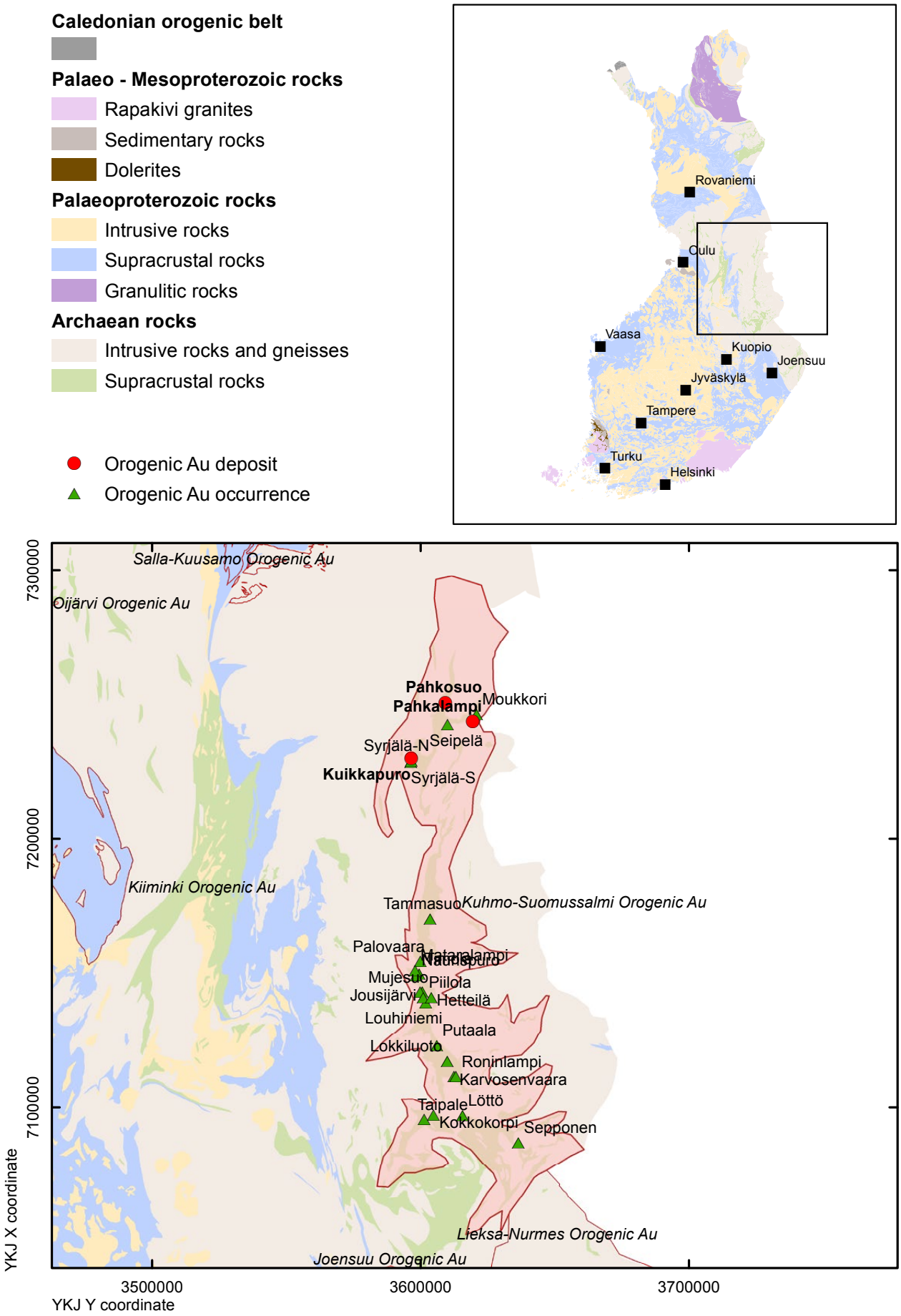

Fig. 1. Location of the Kuhmo–Suomussalmi Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Kuhmo–Suomussalmi Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Kuhmo–Suomussalmi Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:400,000	Wilkman (1921, 1924), Matisto (1954, 1958)
	Regional bedrock maps	1:100,000	Hyppönen (1973, 1976, 1978, 1983), Luukkonen (1986, 1987, 1988, 1993, 2001, 2003), Taipale et al. (1993)
	Regional bedrock map	1:200,000	Mikkola (2008)
	Thematic geology reports		Piirainen (1985), Luukkonen (1991), Luukkonen et al. (1992, 2002), Ojala (2002a,b), Papunen et al. (2009), Kellaway (2013)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Heino & Koistinen (1997), Heino (2000, 2001), Tenhola et al. (2001), Luukkonen et al. (2002), Eilu (2003), Eilu & Ojala (2003, 2007), Ojala (2002c, 2003), Saarela (2003), Pietikäinen et al. (2005, 2008), Halkoaho & Niskanen (2006), Papunen et al. (2009), Titley (2011), Kellaway (2013), Rautio (2013)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Luukkonen et al. (2002), Eilu (2003), Eilu & Ojala (2007), Pietikäinen et al. (2005, 2008), Papunen et al. (2009), Kellaway (2013), Rautio (2013)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Luukkonen et al. (2002), Pietikäinen et al. (2005, 2008), Kellaway (2013), Rautio (2013)
Exploration	Reports		Heino (1995), Heino & Kilpelä (1995), Luukkonen et al. (1997, 1998, 2002), Hartikainen (2001), Parkkinen (2001), Pietikäinen et al. (2000, 2004, 2005, 2006, 2008), Pietikäinen & Niskanen (2001), Tenhola & Niskanen (2001a,b), Tenhola et al. (2001), Hartikainen et al. (2004, 2007), Lampinen (2005), Halkoaho et al. (2006), Sandberg (2007), Kellaway (2013), Rautio (2013)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

More than 20 partially explored orogenic gold occurrences are known within the tract (Table 3), but many of these are very modest. Several factors were considered to indicate a good potential for orogenic gold deposits in the tract: a large number of drilling-indicated gold occurrences in a Neo-

archaean greenstone belt deformed and metamorphosed in a ca. 2.72–2.65 Ga orogeny, the presence of extensive gold and pathfinder anomalies in till (many unexplored or only partially explored), the presence of several gold-mineralised glacial erratic boulders with no obvious bedrock source, and many 2nd and 3rd order fault and shear zones yet to be explored. Large parts of the tract are poorly explored for any commodity, and the greenstone belt largely resembles (size, rock types, structures, metamorphic grade) the West-Australian Southern Cross greenstone belt with >10 Moz gold so far produced. The individual estimators considered the probability high that at least zero to four undiscovered economic deposits exist 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 Kuhmo–Suomussalmi Orogenic Au 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}		
2	4	6			3.9	1.5	40	3	6.9	7149	0.00096

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Damsten, Eilu, Halkoaho, Hartikainen, Kontoniemi, Luukkonen, Sorjonen-Ward, Västi.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Kuhmo–Suomussalmi Orogenic Au 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			
Au (t)	0.4	5.1	31	190	290	69	0.25	0.05
Rock (Mt)	0.098	2.0	15	160	260	48	0.22	0.05

t – metric tons; Mt – million metric tons.

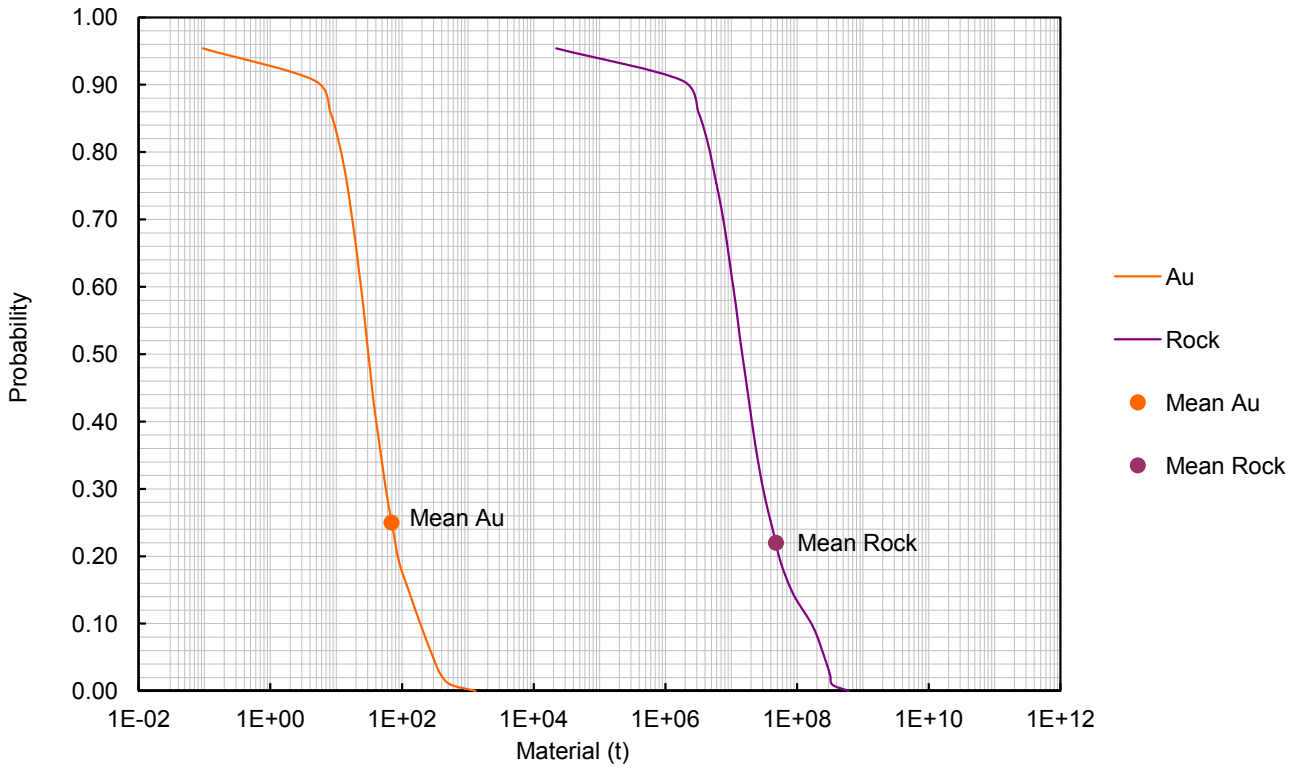

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Kuhmo–Suomussalmi Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT LAIVAKANGAS OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Laivakangas Orogenic Au permissive tract is located in western Finland in the municipalities of Raahe and Pyhäjoki, 70 km southwest of Oulu (Fig. 1). The 1:100,000 KKJ map sheets are 2432 and 2441. The UTM map sheets containing the tract are Q424, R413 and R414. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Laivakangas Orogenic Au 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)	
07/11/2011	1	270	Au	42.4	Au	40	Au	15

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is defined by Palaeoproterozoic Older Svecofennian (1.93–1.90 Ga) Vihanti group sedimentary and Younger Svecofennian (1.90–1.87 Ga) Ylivieska group volcanic and subvolcanic rocks with syntectonic (1.89–1.87 Ga) granitoids. The delineation is based on the extent of rocks mentioned above, suitable second- and third-order shear structures and presence of gold occurrences and gold-indicative outcrops and boulders. Low-altitude aeromagnetic data of the Geological Survey of Finland (GTK) were used to define the margins of the tract, especially the eastern contact to the Vihanti block of higher metamorphic-grade rocks. The tract was extended to the southeast based on the presence of orogenic-type gold occurrences in that area. There are no indications of gold mineralisation in granulite-facies rocks in the entire Ostrobothnia. Hence, the

high-grade rocks are excluded from the permissive tracts. The tract extends down to 1000 m depth. The sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

There is one well-explored orogenic Au deposit within the 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 orogenic Au deposits in the Laivakangas Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
Laiva	7162470	3384260		22.16	2.03	45	Nordic Mines (2012)

Ga – billion 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 orogenic Au occurrences are known within the permissive tract (Table 3).

Table 3. Significant orogenic Au occurrences in the Laivakangas Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Musunneva	7160050	3384870		Surface grab samples up to 7.3 ppm Au, best section 2.0 m @ 1.2 ppm Au	Sandberg (1987), Nordic Mines (2011)
Kaukainen	7161140	3385830		Surface grab samples up to 3.4 ppm Au	Nordic Mines (2011)
Oltava	7151190	3387890		Best section 2.3 m @ 18.5 ppm Au. One of the many lodes: 718 t @ 30 ppm Au	Nikander (1999, 2001)

Ga – billion years.

Exploration history

Serious gold exploration commenced in the Laivakangas Orogenic Au tract area in 1980, when a layman sent a good gold-rich boulder sample to Outokumpu Oy from Laivakangas. Since then, Outokumpu Oy, Endomines Oy and Nordic Mines Ab have explored the Laivakangas area and the Laiva deposit, and GTK and Nordic Mines have explored the area of Oltava. Exploration activities for orogenic Au deposits and occurrences within the tract are listed in Table 4.

Table 4. Exploration history for the Laivakangas Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Bedrock mapping, boulder tracing	Yes	Outokumpu	1980s
	Bedrock mapping, boulder tracing	Yes	GTK	1998–2000
	Bedrock mapping, boulder tracing	Yes	Endomines	1997–2005
	Bedrock mapping	Yes	Nordic Mines	2005–
Geochemical surveys	Regional till geochemistry	Yes	GTK	1982–1994
	Till and stream sediment survey	Yes	Outokumpu	1980s
	Till and stream sediment survey	Yes	GTK	1998–2000
Airborne geophysical surveys	Low-altitude geophysical survey		GTK	1978–2006
Ground geophysical surveys	Magnetic, IP survey		Outokumpu	1980s
	Magnetic, slingram survey		GTK	1949–2000
Drilling	Percussion and diamond drilling	Yes	Outokumpu	1980s
	Percussion and diamond drilling	Yes	GTK	1949–2000
	Percussion and diamond drilling	Yes	Endomines	1997–2005
	Percussion and diamond drilling	Yes	Nordic Mines	2005–
Other	Test mining, pilot plant tests, resource estimates	Yes	Outokumpu	1980s
		Yes	Endomines	1997–2005
		Yes	Nordic Mines	2005–

Sources of information

Principal sources of information used by the assessment team for the delineation of the Laivakangas Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Laivakangas Orogenic Au permissive 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 gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Sandberg (1987), Mäkelä et al. (1988), Nordic Mines (2011, 2012)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Mäkelä et al. (1988)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Sandberg (1987)
Exploration	Reports		Mäkelä et al. (1988), Sandberg (1987), Korkalo (1991), Parkkinen (2000), Nikander (2001), Makkonen et al. (2003), Nordic Mines (2011)
	Mineral resource summary of the Laiva deposit		Titley (2011)
	Geological Survey of Finland in-house drill-core database		

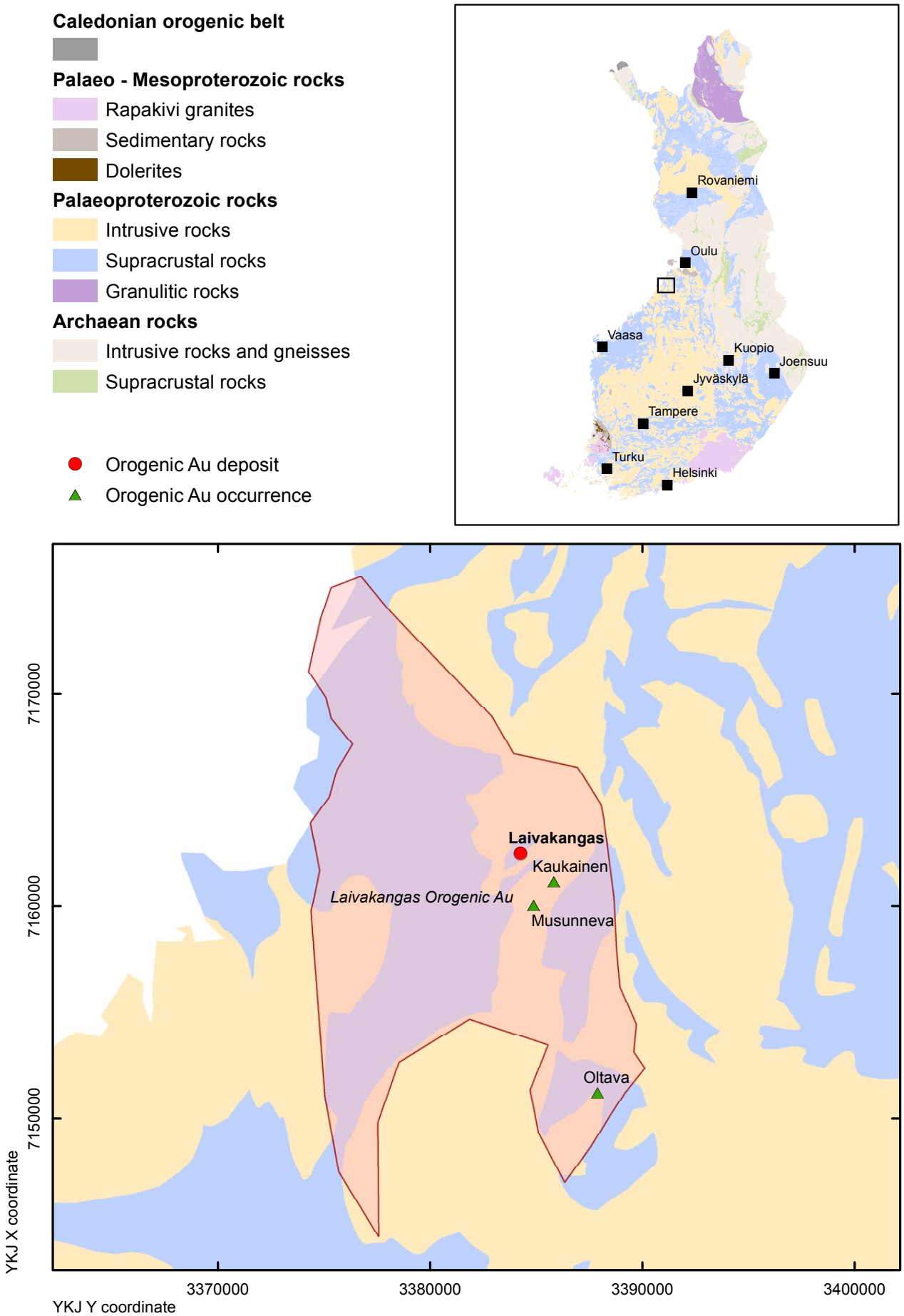

Fig. 1. Location of the Laivakangas Orogenic Au permissive tract.

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Three partially explored orogenic gold occurrences are known within the tract (Table 3). These occurrences are rather modest. The existence of the >1 Moz Laiva deposit, the partially explored occurrences, and a number of gold-mineralised boulders of Laiva type, but probably unrelated to the known deposit, indicate the good potential for undiscovered orogenic gold deposits for the tract. On the other hand, the tract is rather small and cannot accommodate very many deposits. The individual estimators considered the probability high that at least one to three undiscovered economic deposits exist 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 Laivakangas Orogenic Au 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	270	0.012

	Estimated number of undiscovered deposits				
Estimator	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
Individual 1	1	3	5		
Individual 2	1	1	3		
Individual 3	3	3	4		
Individual 4	1	2	3		
Individual 5	1	2	3		
Mean	1	2	4		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Hartikainen, Kontoniemi, Nikander, Västi.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Laivakangas Orogenic Au 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			
Au (t)	0	0.64	15	94	200	40	0.22	0.07
Rock (Mt)	0	0.16	6.1	60	170	27	0.19	0.07

t – metric tons; Mt – million metric tons.

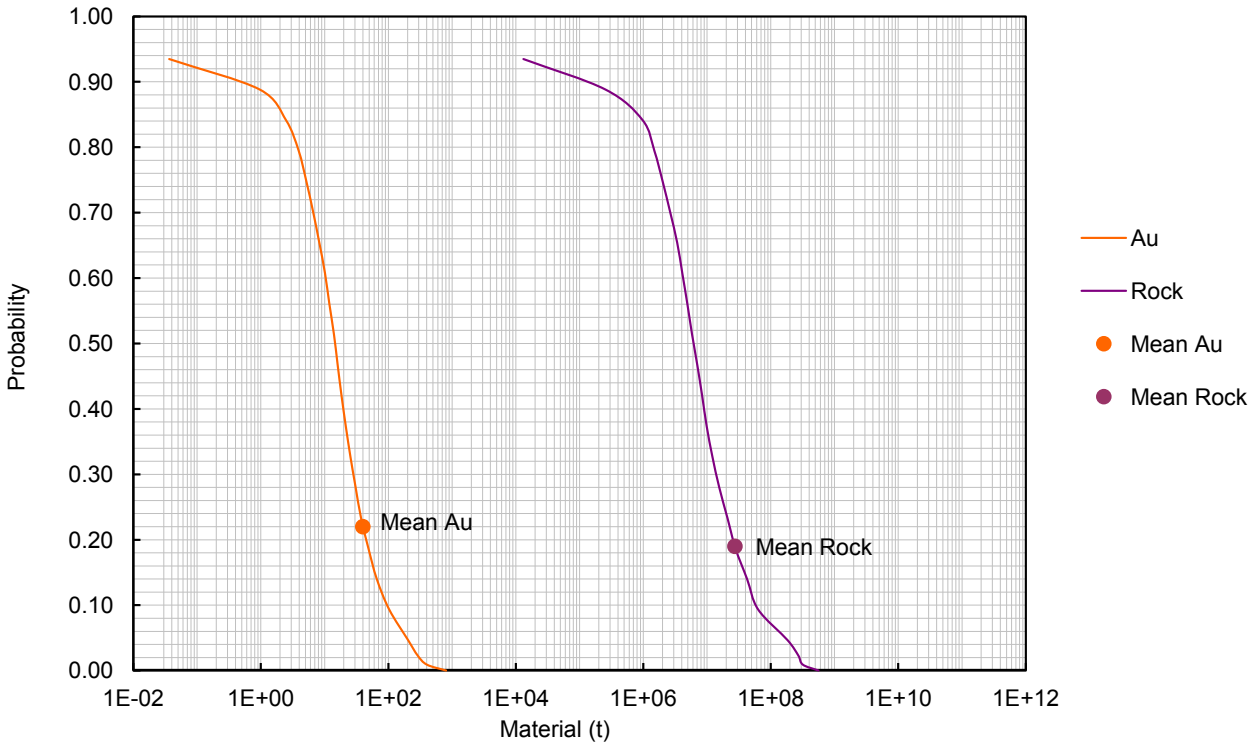

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Laivakangas Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT LESTI ARC OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Lesti Arc Orogenic Au permissive tract is located in western Finland in the municipalities of Alajärvi, Halsua, Kaustinen, Kokkola, Lestijärvi, Perho, Reisjärvi, Sievi, Soini, Toholampi, Veteli and Vimpeli, 170 km south of Oulu (Fig. 1). The 1:100,000 KKJ map sheets are 2224, 2242, 2313, 2323, 2331, 2332, 2341, 2342 and 2343. The UTM map sheets containing the tract are P411, P412, P414, P421, P422, P423, P424, P442, Q411, Q413 and Q414. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Lesti Arc Orogenic Au 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)
07/11/2011	1	1486	Au 0	Au 22	Au 6.2

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is defined by Palaeoproterozoic Svecofennian (1.93–1.78 Ga) Lestijärvi suite volcanic rocks and younger Svecofennian (1.90–1.87 Ga) Ylivieska group sedimentary, volcanic and subvolcanic rocks with syntectonic (1.89–1.87 Ga) granitoids. The delineation is based on the extent of rocks mentioned above, suitable second- and third-order shear structures, and the presence of gold occurrences and gold-mineralised outcrops and boulders. Low-altitude aeromagnetic data of the Geological Survey of Finland (GTK) were used to define the margins of the tract. The tract extends from the Lestijärvi area to the south along the northwestern margin of the Central Finland Granitoid complex, based on the existence of typical volcanic rocks of the Ylivieska group and indications of orogenic gold mineralisation. The tract extends down to 1000 m depth. The sources of information used in the delineation of the tract are summarised in Table 4.

Known deposits

There are no well-explored orogenic Au deposits within the 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 orogenic Au deposits in the Lesti Arc Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

Five partially explored orogenic Au occurrences are known within the permissive tract (Table 3).

Table 3. Significant orogenic Au occurrences in the Lesti Arc Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Haasiakangas	7005800	3352760		Best outcrop grab sample 5.8 ppm Au	Nikander (1987a)
Suolasalmenneva	7005590	3357610		Best outcrop grab sample 8.0 ppm Au	Nikander (1987b)
Kangaskylä	7065900	3389490		Best section 1 m @ 26.7 ppm Au	Sandberg (1985)
Ahveroinen	7064410	3390800		Best section 0.15 m @ 28.7 ppm Au	Sandberg (1986)
Katajaneva (Kataja 1)	7060930	3390830		Best section 0.8 m @ 1.15 ppm Au	Kontoniemi & Mursu (2007)

Ga – billion years.

Exploration history

Gold potential of the Kangaskylä area at Reisjärvi has been known for more than 100 years (Sandberg 1985). GTK and Outokumpu Oy explored the area in the 1940s, 1950s and 1970s. Serious gold exploration commenced in the tract area in the 1980s when the global gold price rapidly increased. Since then, Outokumpu Oy, GTK, SES Finland Oy, Tertiary Minerals, and Belvedere Resources Finland Oy have explored the Lestin Arc area. Exploration activities for orogenic Au deposits and occurrences within the tract are listed in Table 4.

Table 4. Exploration history for the Lesti Arc Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Bedrock mapping, boulder tracing	Yes	Outokumpu	1972–1986
	Bedrock mapping, boulder tracing	Yes	GTK	1956–2007
	Bedrock mapping, boulder tracing	Yes	Tertiary Minerals	2004–2005
Geochemical surveys	Regional till geochemistry	Yes	GTK	1982–1994
	Targeting till survey	Yes	Outokumpu	1972–1986
	Targeting till survey	Yes	GTK	1981–2005
	Targeting till survey	Yes	Belvedere Resources	2005–2008
	MMI survey	Yes	SES Finland	1996–1997
Airborne geophysical surveys	Low-altitude geophysical survey		GTK	1980–2002
Ground geophysical surveys	Magnetic, gravimetric, slingram, VLF, IP survey		Outokumpu Oy	1972–1986
	Gravimetric, magnetic, slingram		GTK	2003–2007
			SES Finland	1996–1997
			Tertiary Minerals	2004–2005
Drilling	Percussion and diamond drilling	Yes	Outokumpu	1972–1986
	Diamond drilling	Yes	GTK	1958–2007
	Diamond drilling	Yes	SES Finland	1996–1997
	Diamond drilling	Yes	Tertiary Minerals	2004–2005
	Diamond drilling	Yes	Belvedere Resources	2005–2008
Other	Trenching	Yes	Outokumpu	1972–1986

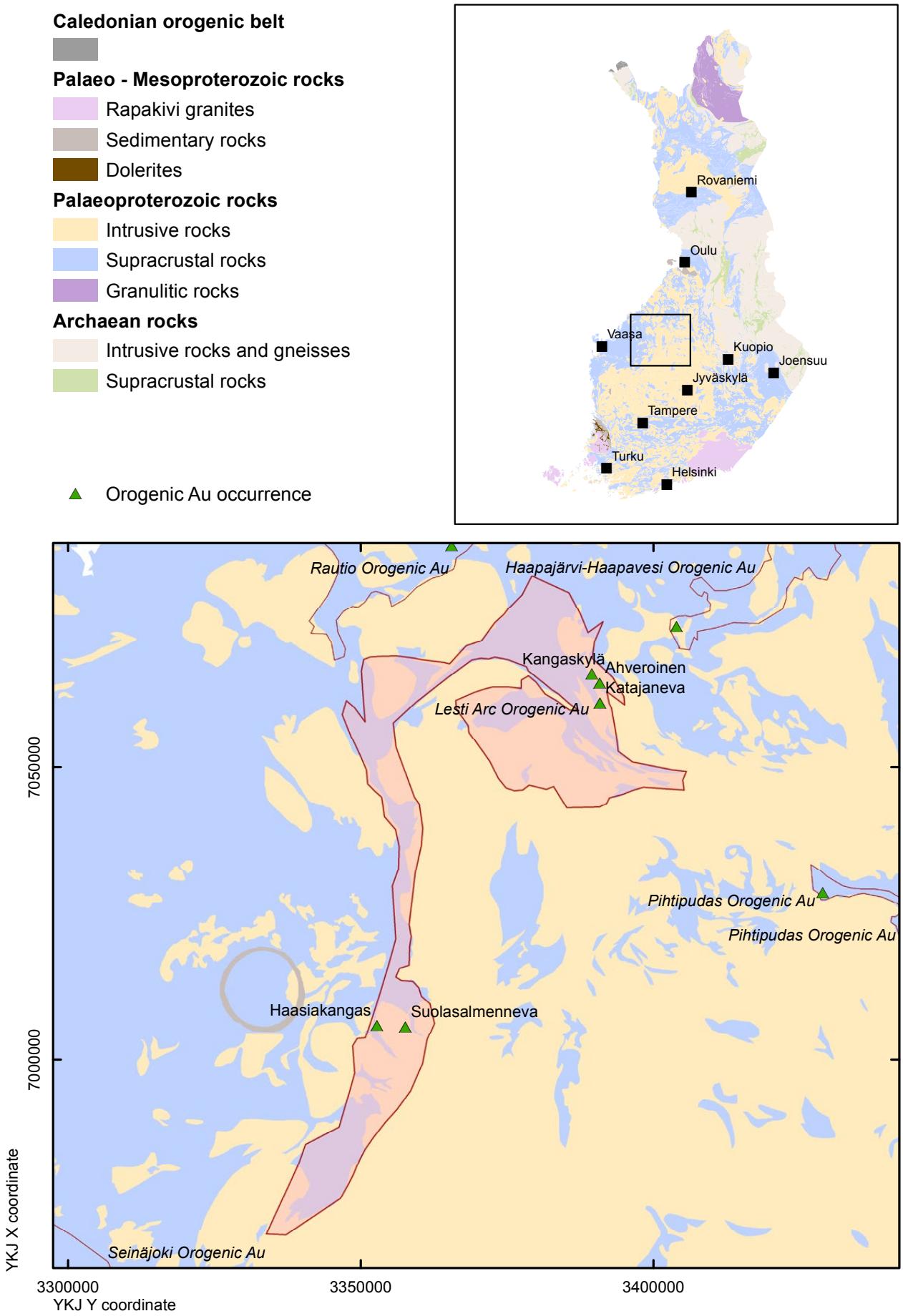

Fig. 1. Location of the Lesti Arc Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Lesti Arc Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Lesti Arc Orogenic Au permissive 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 gold deposit database		Eilu & Pankka (2009)
	Reports		Sandberg (1985, 1986), Nikander (1987a,b), Kontoniemi & Mursu (2007)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Kokkola & Pehkonen (1976), Sandberg (1985, 1986), Mäkelä et al. (1988)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Sandberg (1985, 1986),
Exploration	Data of gold bearing outcrops and boulders		Makkonen et al. (2003)
	Reports		Pehkonen (1959), Huhtala (1984), Sandberg (1985, 1986), Nikander (1987a,b), Västi (1992), Kontoniemi & Mursu (2006, 2007), S. Chakraborty (pers. comm. 2008)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Five partially explored orogenic gold occurrences are known within the tract (Table 3). Most of these occurrences are small. The existence of the partially explored gold occurrences and a number of gold-mineralised boulders with no recognised bedrock source indicate the good potential for undiscovered orogenic gold deposits for the tract. Also, all the drilling has so far been shallow and not much gold exploration has been carried out – this leaves considerable space for further discoveries. The individual estimators considered the probability high that at least zero to one undiscovered economic deposits exist 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 Lesti Arc Orogenic Au 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	1	2			1.2	0.55	45	0	1.2	1486	0.00081

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Hartikainen, Kontoniemi, Nikander, Sorjonen-Ward, Västi.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Lesti Arc Orogenic Au 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			
Au (t)	0	0.27	6.2	41	96	22	0.18	0.06
Rock (Mt)	0	0.061	2.3	25	61	15	0.15	0.06

t – metric tons; Mt – million metric tons.

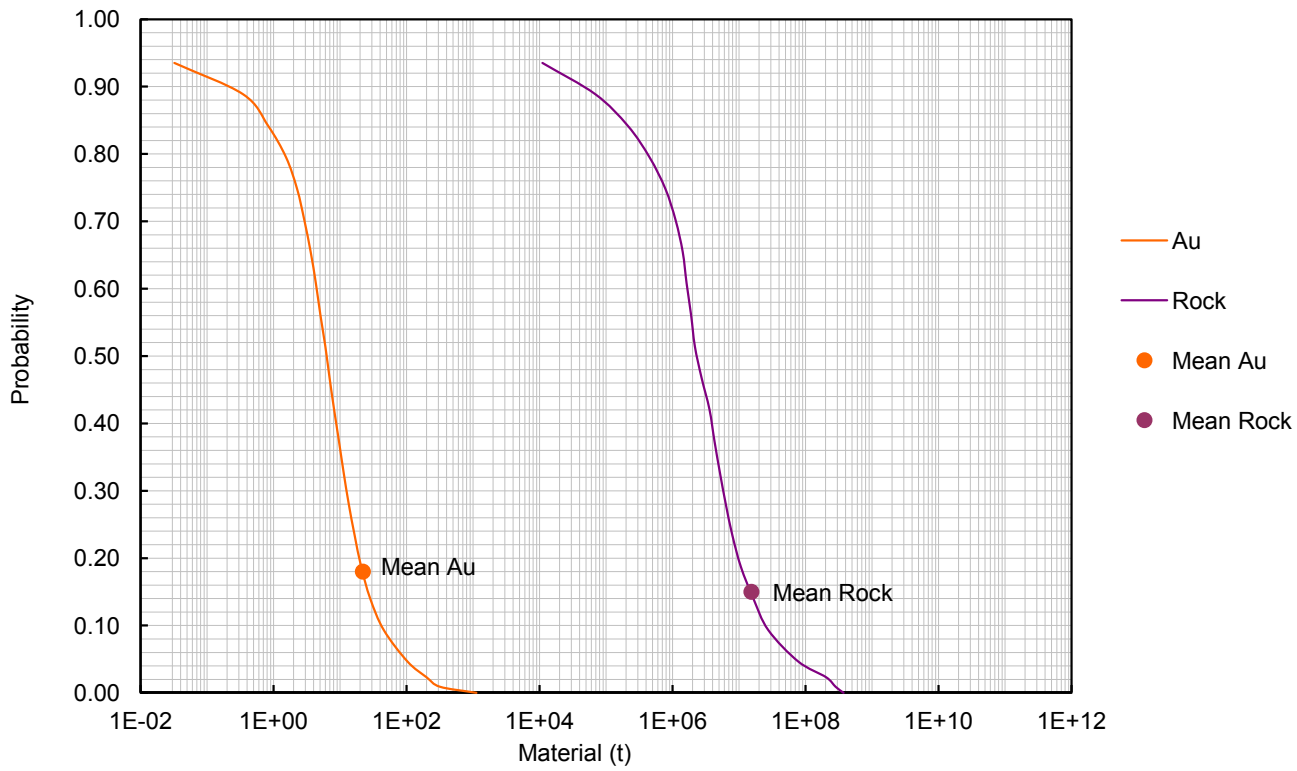

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Lesti Arc Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT LIEKSA–NURMES OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Lieksa–Nurmes Orogenic Au permissive tract is located in eastern Finland in the municipalities of Ilomantsi, Joensuu, Juuka, Kontiolahti, Lieksa and Nurmes (Fig. 1). The 1:100,000 KKJ map sheets covering the tract are 4241, 4242, 4313, 4314, 4323, 4324, 4331, 4332, 4333, 4334 and 4341. The UTM map sheets containing the tract are N544, P533, P534, P541, P542, P543, P544, P612, P621, P622, Q531 and Q533. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Lieksa–Nurmes Orogenic Au 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)	
8/11/2011	1	5215	Au	0	Au	5.7	Au	0

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The Lieksa–Nurmes Orogenic Au permissive tract is bounded to the NE by the Finnish-Russian border, to the SE by the Sonkaja tract, to the SW by the Kovero–Nunnanlahti tract, to the NNW by the Kuhmo–Suomussalmi tract, and to the NW by a high-metamorphic grade TTG terrain considered not to contain any orogenic gold mineralisation.

This extensive tract differs from the adjacent permissive tracts in that instead of being characterised by supracrustal greenstone and metasedimentary rock units, it consists of granitoids and paragneisses and migmatites that record late orogenic melting of both granitoids and metasediments at 2710–2690 Ga (Käpyaho et al. 2007, Kontinen et al. 2007, Hölttä et al. 2012), somewhat older than greenstone belt assemblages (Sorjonen-Ward & Luukkonen 2005, Huhma et al. 2012). Nevertheless, the volume of paragneisses in the

tract records significant rapid orogenic recycling (Kontinen et al. 2007), such as characterising terranes endowed with late-orogenic gold deposits (Goldfarb et al. 2001). The justification for extrapolation of the tract to a depth of 1 km is based on projection of major structural trends and is not particularly robust. Also, the tract appears to represent the juxtaposition of major crustal units and must have considerable depth continuity. It seems evident that the evolution of the tract is closely coupled with that of the adjoining and mineralised Hattu Orogenic Au tract (Sorjonen-Ward 1993a,b, , Sorjonen-Ward & Luukkonen 2005). Sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

There are no known orogenic Au deposits within the 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 orogenic Au deposits in the Lieksa–Nurmes Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are no known partially explored gold occurrences in the permissive tract (Table 3). The Mätäsvaara molybdenite deposit, which was mined from 1940–1947, is the only known metallic mineral deposit in the tract and is of potential interest in that molybdenite is known to be spatially associated with gold in the adjoining Hattu Orogenic Au tract.

As with the adjoining Hattu, Sonkaja and Kovero permissive tracts, the area of the Lieksa–Nurmes tract experienced a renewed metamorphic event under greenschist to lower-amphibolite facies conditions, as a consequence of Svecofennian orogenic deformation between 1.9–1.8 Ga (Kontinen et al. 1992). However, the lack of significant deformation, in part constrained by the low strain state of Proterozoic mafic dykes, and microstructural studies of recrystallisation of mineral assemblages, provides strong evidence against significant remobilisation or introduction of gold during the Palaeoproterozoic (Sorjonen-Ward 1993a).

Table 3. Significant orogenic Au occurrences in the Lieksa–Nurmes Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
None					

Exploration history

There has been no systematic exploration for gold in the Lieksa–Nurmes Orogenic Au permissive tract. Regional exploration-oriented mapping and research has been undertaken by the Eastern Finland Unit of GTK in two projects, in 2001–2004 (Pietikäinen et al. 2005) and 2008–2011 (Mikkola et al. 2013), but no indications of gold mineralisation were found within the permissive tract area.

The only recorded exploration activity was early in the 19th century, which resulted in the discovery of the Mätäsvaara molybdenite deposit in stromatic migmatitic granitoids during construction of the Joensuu–Nurmes railway in 1903. Attempts to exploit the deposit began immediately and after several changes of ownership, culminating in the transfer of mining rights to Vuoksenniska Oy, the mine proved to be viable and of strategic importance during the war years. After the economic disruption at the end of the war, molybdenum demand rapidly declined and the mine ceased

production in 1947, despite attempts at financial intervention from the Finnish government. Total production in 1940–1947 was 1,154,000 tonnes of ore with a mean molybdenum grade of 0.14 %.

Table 4. Exploration history for the Lieksa–Nurmes Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	No	Geological Survey of Finland	1895–1913, 2001–2004
	Outcrop observations and boulder survey	Yes	Geological Survey of Finland	2008–2011
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	1990s
Ground geophysical surveys	Magnetic, slingram and IP surveys		Geological Survey of Finland	2001–2004
Drilling	Mining at Mätäsvaara	No	Vuoksenniska Oy	1938–1947

Sources of information

Principal sources of information used by the assessment team for the delineation of the Lieksa–Nurmes Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Lieksa–Nurmes Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:400,000	Frosterus & Wilkman (1920)
	Regional bedrock maps	1:100,000	Nykänen (1971), Laiti (1983, 1985)
	Regional bedrock map	1:200,000	Mikkola et al. (2013)
	Thematic geology reports		Kontinen et al. (1992), Rasilainen (1996), Pietikäinen et al. (2005), Sorjonen-Ward & Luukkonen (2005), Käpyaho et al. (2007), Hölttä et al. (2012), Mikkola et al. (2013)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Pietikäinen et al. (2005), Mikkola et al. (2013)
Geophysics	Geological Survey of Finland in-house database		
Exploration	Reports		Luukkonen et al. (2002), Pietikäinen et al. (2005), Mikkola et al. (2013)
	Geological Survey of Finland in-house drill-core database		

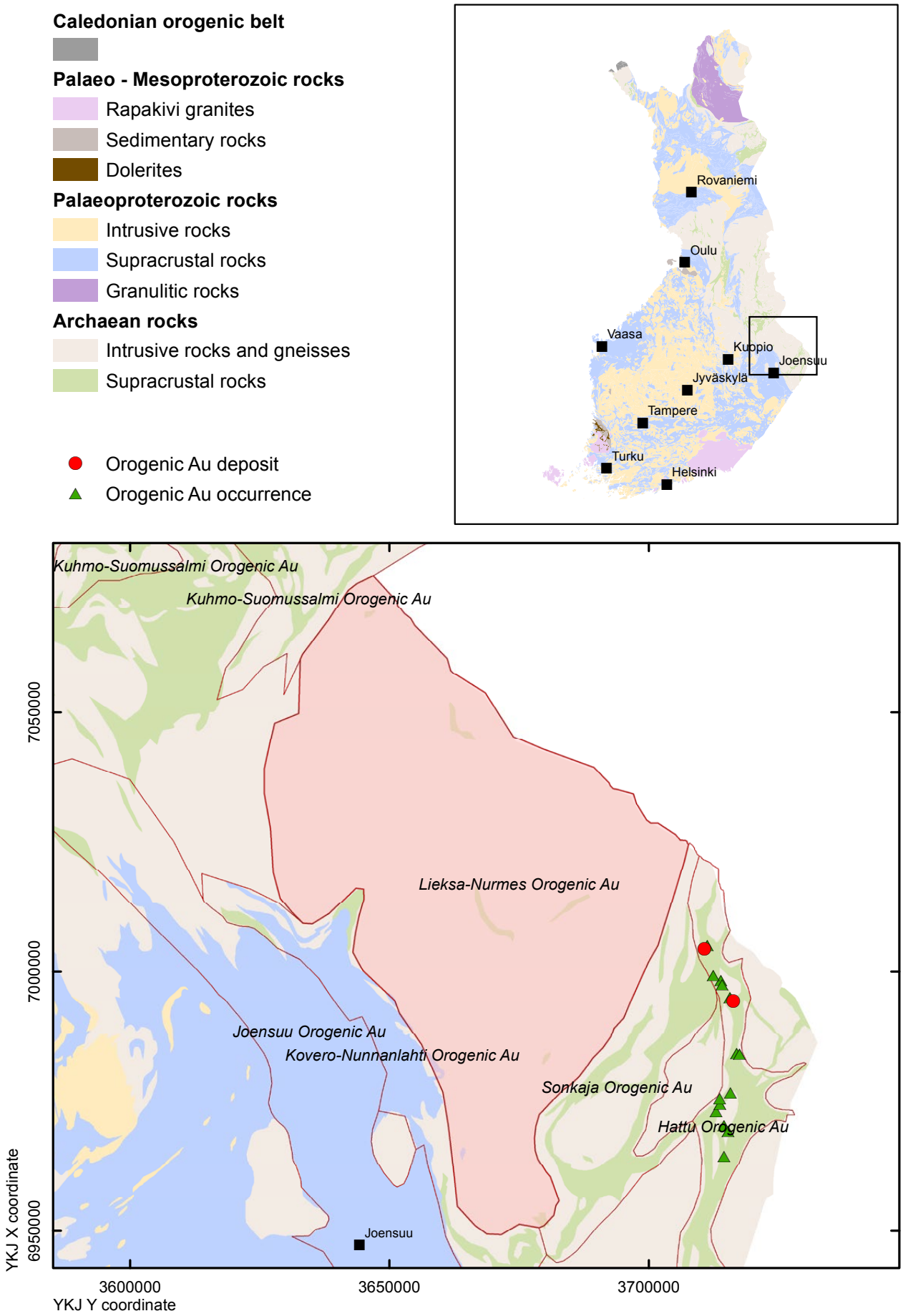

Fig. 1. Location of the Lieksa–Nurmes Orogenic Au permissive tract.

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

There are no known examples of orogenic gold mineralisation in the Lieksa–Nurmes permissive tract. Moreover, the bedrock geology differs substantially from that of less metamorphosed greenstone and metasedimentary belts that characterise most of the Archaean orogenic gold tracts in Finland, such as the adjacent Hattu permissive tract. The strongest rationales for a positive assessment are 1) the presence of small remains of Archaean greenstone belts, 2) a few auriferous glacial erratic boulders without clear indication of their bedrock source, and 3) the existence of the Mätäsvaara molybdenite deposit, since there is a well-documented spatial association between Mo and Au in the intrusive-hosted occurrences, such as Kuittila within the Hattu tract. On the other hand, it has been argued that the Mo-W vein networks at Kuittila distinctly predate the orogenic gold mineralising event, at least on structural and microstructural grounds (Sorjonen-Ward 1993a), and also possibly in alteration geochemistry patterns in till and bedrock (Hartikainen and Nurmi 1993, Rasilainen et al. 1993, Rasilainen 1996). However, Stein et al. (1995) recorded two Re-Os molybdenite ages from Mätäsvaara, so that it is important to further assess the potential significance of Mo as a vector for gold potential, and to compare Re–Os systematic between Kuittila (Stein et al.1998) and Mätäsvaara. None of the individual estimators considered the probability high that any undiscovered economic deposits exist 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 Lieksa–Nurmes Orogenic Au 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	5215	0.000058

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Damsten, Eilu, Halkoaho, Hartikainen, Kontoniemi, Luukkonen, Sorjonen-Ward, Västi.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Lieksa–Nurmes Orogenic Au 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			
Au (t)	0	0	0	8.5	19	5.7	0.14	0.70
Rock (Mt)	0	0	0	4.0	9.3	4.0	0.10	0.70

t – metric tons; Mt – million metric tons.

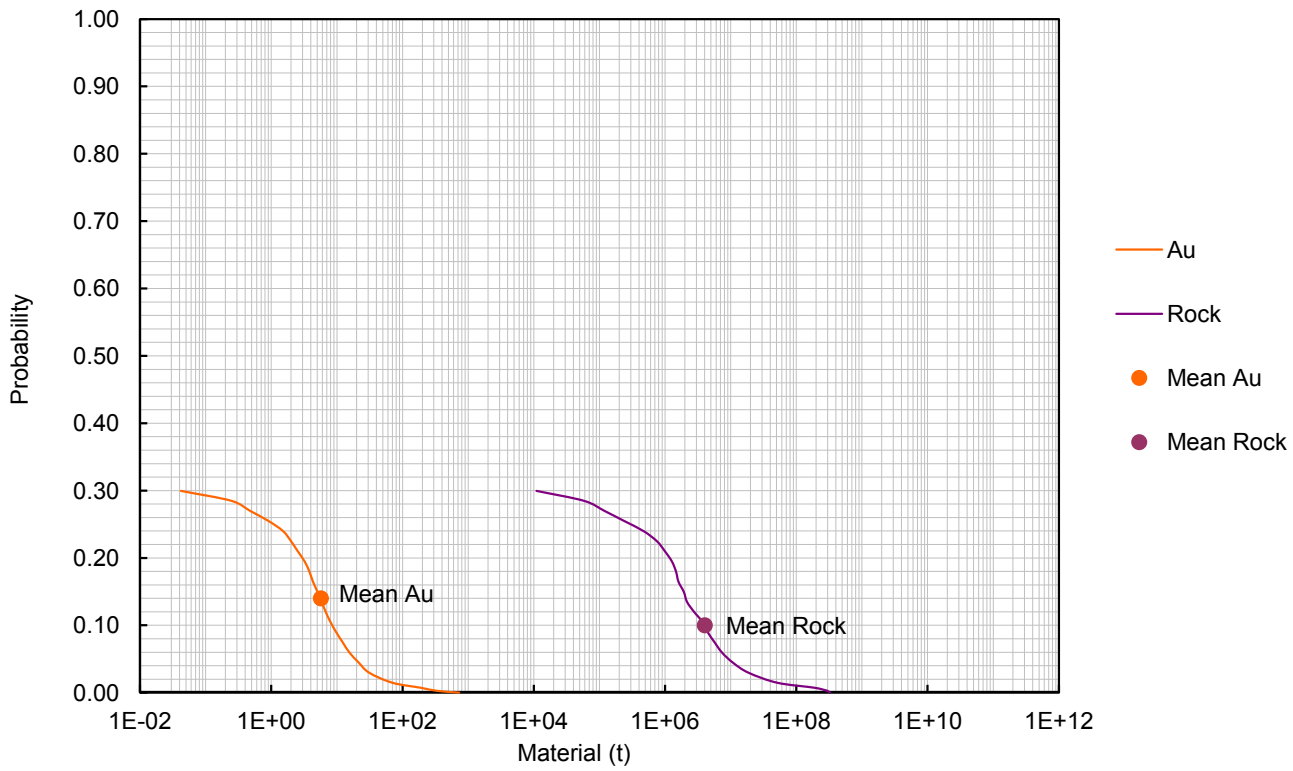

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Lieksa–Nurmes Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT LÄTÄSENO–ROPI OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Lätäseno–Ropi Orogenic Au permissive tract is located in northwestern Finland in the Enontekiö municipality, 250–350 km NW of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 1823, 1831, 1832, 1833, 1834, 1841, 1842, 1843, 2811 and 2812. The UTM map sheets containing the tract are V344, V421, V422, W332, W333, W334, W343, W411 and W412. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Lätäseno–Ropi Orogenic Au 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)	
17/1/2012	1	1341	Au	0	Au	30	Au	9.3

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is defined by the known extent of Lätäseno Group and Rommaeno Complex rocks and 2.5–1.86 Ga intrusions within these units in northwesternmost Finland. Both Archaean and Palaeoproterozoic greenstones are included. Due to the lack of reliable dating, the division between these two groups is based on circumstantial evidence only. To the west, the tract is bounded by Archaean TTG rocks, to the east by the Enontekiö–Muonio orogenic gold tract, to the south by the Finnish–Swedish border and to the north by the Finnish–Norwegian border. Low-altitude airborne magnetic data were extensively used in defining the extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to 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 orogenic Au deposits within the 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 orogenic Au deposits in the Lätäseno–Ropi Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are three partially explored orogenic Au occurrences within the permissive tract (Table 3). In addition to these, the Tshohkoaivi and Sarvisoaivi Ni, the Kaamajoki Cu-Ni-PGE, the Palkiskuru U-REE and the Nunastunturi Mo occurrences are located within the permissive tract.

Table 3. Significant orogenic Au occurrences in the Lätäseno–Ropi Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Ruossakero N	7621857	3302549	2.7?	R401: 0.6 m @ 2.2 % Cu, 13 g/t Au	Isomaa (1988b, 1991a)
Ruossakero S	7620813	3302949	2.7?	R421: 0.35 m @ 1.7 % Cu, 5.6 g/t Au	Isomaa (1988b, 1991a)
Vähäkurkkio	7619700	3308500	1.9–1.8?	0.3–1.5 % Cu in boulders, Au not analysed; drilling in 1975 unsuccessful due to major technical problems	Inkinen (1975), Lehtinen & Eilu (1987)

Ga – billion years.

Exploration history

Exploration activities for gold within the tract are listed in Table 4. Exploration in the region has also targeted Ni, PGE, Cu, Mo, REE, and U; most of the drilling has been for nickel.

Table 4. Exploration history for the Lätäseno–Ropi Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	No	Geological Survey of Finland	1940–
	Outcrop observations	Yes	University of Turku	1985
	Outcrop observations and boulder survey	Yes in the1990s	Outokumpu Oy	1960s–1990s
Geochemical surveys	Nationwide till survey, systematic, 366 points	Yes	Geological Survey of Finland	1991
	Till, stream sediment and regolith geochemical surveys, grid total 7.0 km^2, profiles total 33.6 km, and additional scattered sampling	Yes?	Geological Survey of Finland	1980s
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1983, 2002
	Airborne TEM		Geological Survey of Finland	2012
Ground geophysical surveys	Ground magnetic survey, systematic, total 74.4 km^2		Geological Survey of Finland	1976–1982
	Ground gravimetric survey, systematic, total 10.5 km^2, additional profile surveys total 47.8 km		Geological Survey of Finland	1979–1995
			Geological Survey of Finland	1978, 1987
	IP surveys, systematic, total 3.3 km^2		Geological Survey of Finland	1976–1987
	Slingram surveys, systematic, total 75.5 km^2 VLF-R surveys, systematic, total 9.52 km^2		Geological survey of Finland	1985–1995
	Ground magnetic survey, systematic, total 1.2 km^2		Outokumpu Oy	1995
Drilling	Diamond drilling, 184 DDH, 23,497.99 m	Yes from 1990s onwards	Geological Survey of Finland	1978–2012
	Attempted diamond drilling	No	Outokumpu Oy	1975

DDH – Diamond drill hole

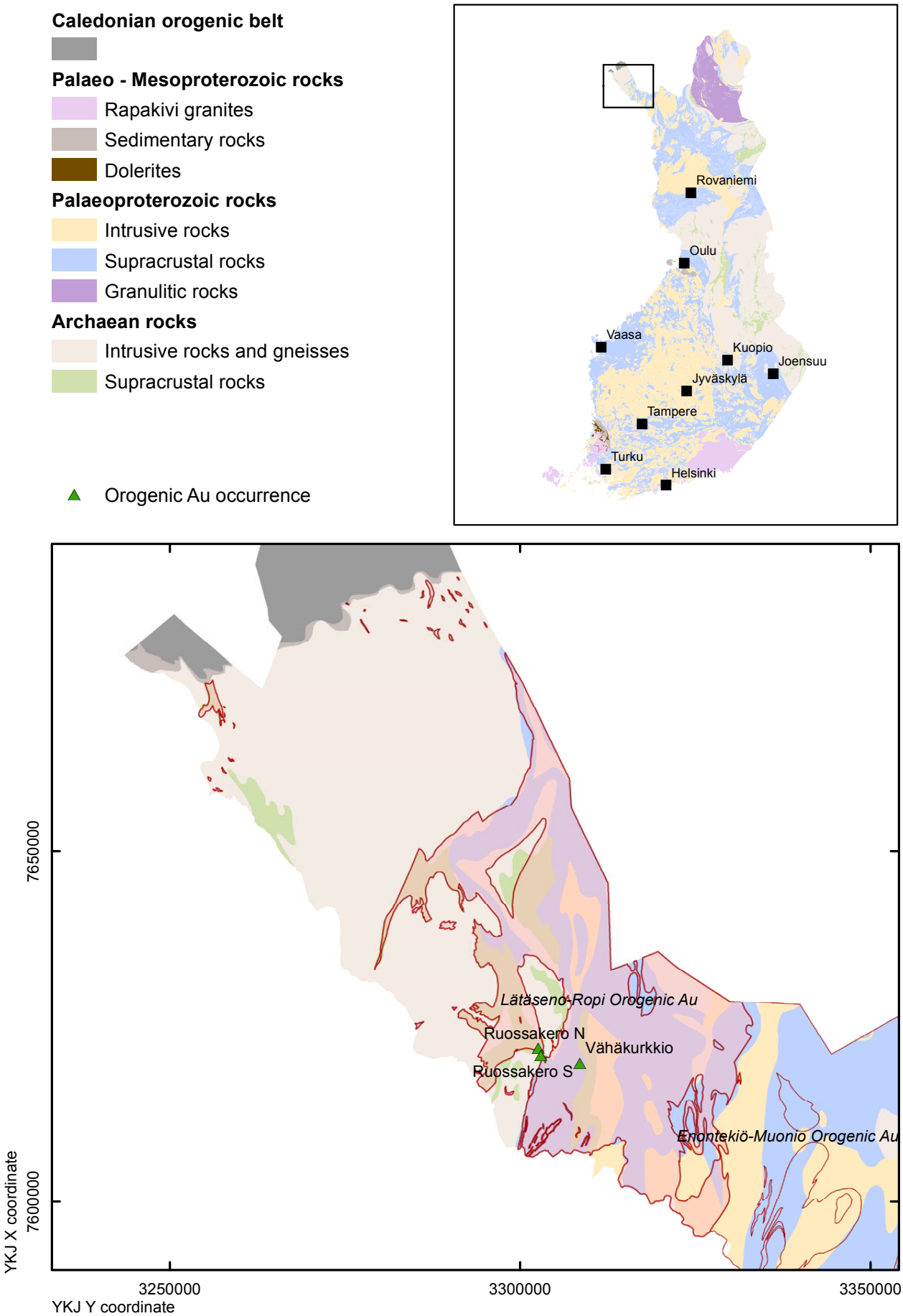

Fig. 1. Location of the Lätäseno–Ropi Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Lätäseno–Ropi Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Lätäseno–Ropi Orogenic Au permissive 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 (1959)
	Geological maps	1:100,000	Idman (1988)
	Thematic geology reports	1:5000–10,000	Idman (1983), Lehtinen & Eilu (1987), Eilu (1984), Eilu & Idman (1988)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Karttunen (1987), Lehtinen & Eilu (1987), Isomaa (1988a, 1991a), Koistinen (1991a,b), Lahtinen (1996a,b), Al-Ani et al. (2010)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Wennevirta (1963, 1966), Johansson & Keinänen (1984, 1987), Isomaa (1988c, 1991c), Lahtinen (1996b), Sarala et al. (2011)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Turunen (1982), Isomaa (1988c, 1991b), Lanne (2004)
Exploration	Reports		Inkinen (1975), Lahtinen (1977, 1996a,b), Isomaa & Keinänen (1982), Isomaa (1982, 1983, 1986, 1987a,b, 1988a,b, 1991b,c, 1996), Nousiainen (1995), Heikura et al. (2010)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Three partially explored orogenic gold occurrences are known within the tract (Table 3). These occurrences were regarded as modest. The following were considered to indicate a good potential for orogenic gold deposits in the tract: 1) three known gold occurrences, 2) anomalous gold points in regional till and regolith data, 3) the upper-greenschist to lower-amphibolite facies Palaeoproterozoic supracrustal rocks in the eastern part of the tract are similar to the rocks in the Bidjovagge area and 4) minor As-Au indications in bedrock near Kilpisjärvi. Little exploration (except locally for nickel) or mapping has been carried out in the tract and its surroundings. The overburden cover is thick in the eastern part of the tract. Most exploration has focused on other metals than gold, and drilling has concentrated almost exclusively on a few Ni targets and a few geological profiles. The individual estimators considered the probability high that at least zero to one undiscovered economic deposits exist within the tract. No consensus was not 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 Lätäseno–Ropi Orogenic Au 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	1341	0.0013

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Karvinen, Keinänen, Konnunaho, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Lätäseno–Ropi Orogenic Au 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			
Au (t)	0	0	9.3	66	150	30	0.21	0.20
Rock (Mt)	0	0	3.8	45	130	21	0.17	0.20

t – metric tons; Mt – million metric tons.

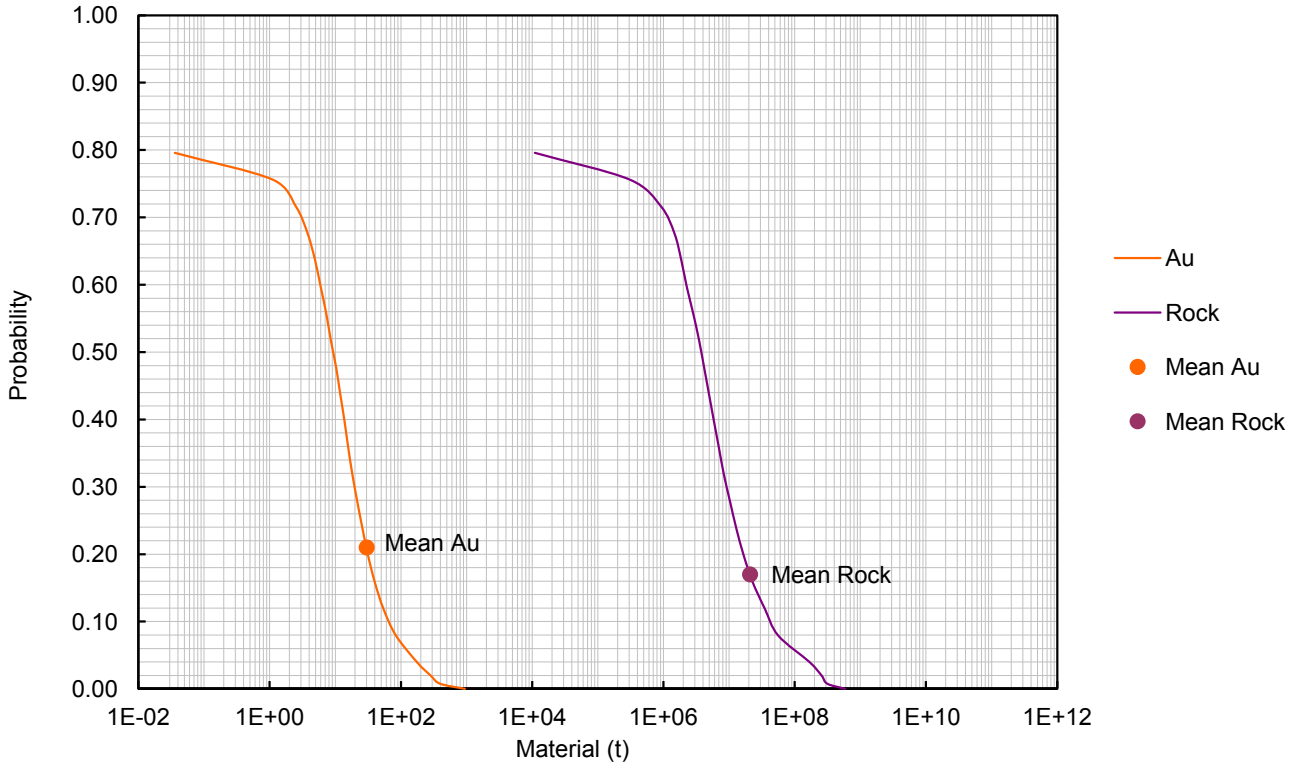

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Lätäseno–Ropi Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT OIJÄRVI OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Oijärvi Orogenic Au permissive tract is located in northern Finland in the Ii, Oulu, Pudasjärvi, Ranua and Simo municipalities, 25–100 km NE of the city of Oulu (Fig. 1). The 1:100,000 KKJ map sheets are 3511, 3512, 3521, 3522 and 3523. The UTM map sheets containing the tract area R442, R444, S431, S432, S433, S434, S441, S442, S443 and S444. The Au resource assessment carried out for this report is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Oijärvi Orogenic Au 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)
17/1/2012	1	337	Au	Au 79	Au 37

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The Oijärvi Orogenic Au permissive tract is defined by the known existence of the Neoarchaean Oijärvi Group rocks. The tract is bound to the south by Palaeoproterozoic Utajärvi Suite rocks and elsewhere surrounded by the Archaean TTG suite rocks of the Simo and Siuruanjoki Complexes. Low-altitude airborne magnetic data were extensively used to define the extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to 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 orogenic Au deposits within the 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 orogenic Au deposits in the Oijärvi Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are four partially explored Au occurrences of possibly orogenic type within the permissive tract (Table 3). Of these, Kylmäkangas may be an orogenic or a metamorphosed epithermal occurrence; mineral assemblages, Au/Ag values, and the elements enriched and depleted suggest a high-sulphidation epithermal mineralisation style.

Table 3. Significant orogenic Au occurrences in the Oijärvi Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Karahkalehto	7291800	3453000	?	2 m @ 4.9 g/t Au; 2 m @ 3.66 g/t Au	Juopperi & Karvinen (1999), Rossi (2000), Juopperi et al. (2001)
Kompsa	7293900	3454900	?	3.2 m @ 9.5 g/t Au; 3.3 m @ 8.3 g/t Au	Juopperi & Karvinen (1999), Rossi (2000), Juopperi et al. (2001)
Kupsusselkä	7253200	3452900	?	1 m @ 1.70 g/t Au	Rossi & Konnunaho (2006)
Kylmäkangas	7292900	3450200	?	1.896 Mt @ 4.11 g/t Au, 31.11 g/t Ag; 13 m @ 19 g/t Au, 105 g/t Ag, 0.2 % Cu, 0.3 % Pb, 0.2 % Zn	Juopperi & Karvinen (1999), Rossi (2000), Juopperi et al. (2001), Agnico-Eagle (2013)

Ga – billion years.

Exploration history

Exploration activities for orogenic Au deposits within the Oijärvi Orogenic Au permissive tract are listed in Table 4.

Table 4. Exploration history for the Oijärvi Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	Yes	Geological Survey of Finland	1980s–1990s
Geochemical surveys	Nationwide till survey, systematic, 95 points	Yes	Geological Survey of Finland	1980s–1990s
	Line till geochemistry, systematic, total 61 points	No	Geological Survey of Finland	1983
	Targeting geochemistry, profile surveys, 1006 points	Partly yes	Outokumpu	1980s–1990s?
Airborne geophysical surveys	Regional low-altitude airborne magnetic, electromagnetic and radiometric survey		Geological Survey of Finland	1977–1995
Ground geophysical surveys	VLF-R survey, profile surveys, total 450 km		Geological Survey of Finland	1990s–2000s
	Slingram survey, profile surveys total 161 km		Geological Survey of Finland	1966
	IP profile surveys total 12 km		Geological Survey of Finland	1990s
	Gravimetric survey, profile surveys, total 299 km		Geological Survey of Finland	1990s–2000s
	Magnetic surveys, profile surveys, total 767 km		Geological Survey of Finland	1960s, 1980s–2000s
Drilling	Diamond drilling, 244 DDH, total 36,144 m	Yes	Geological Survey of Finland	1996–2008
	Tens of DDHs	Yes	Agnico-Eagle	2008–

DDH – Diamond drill hole

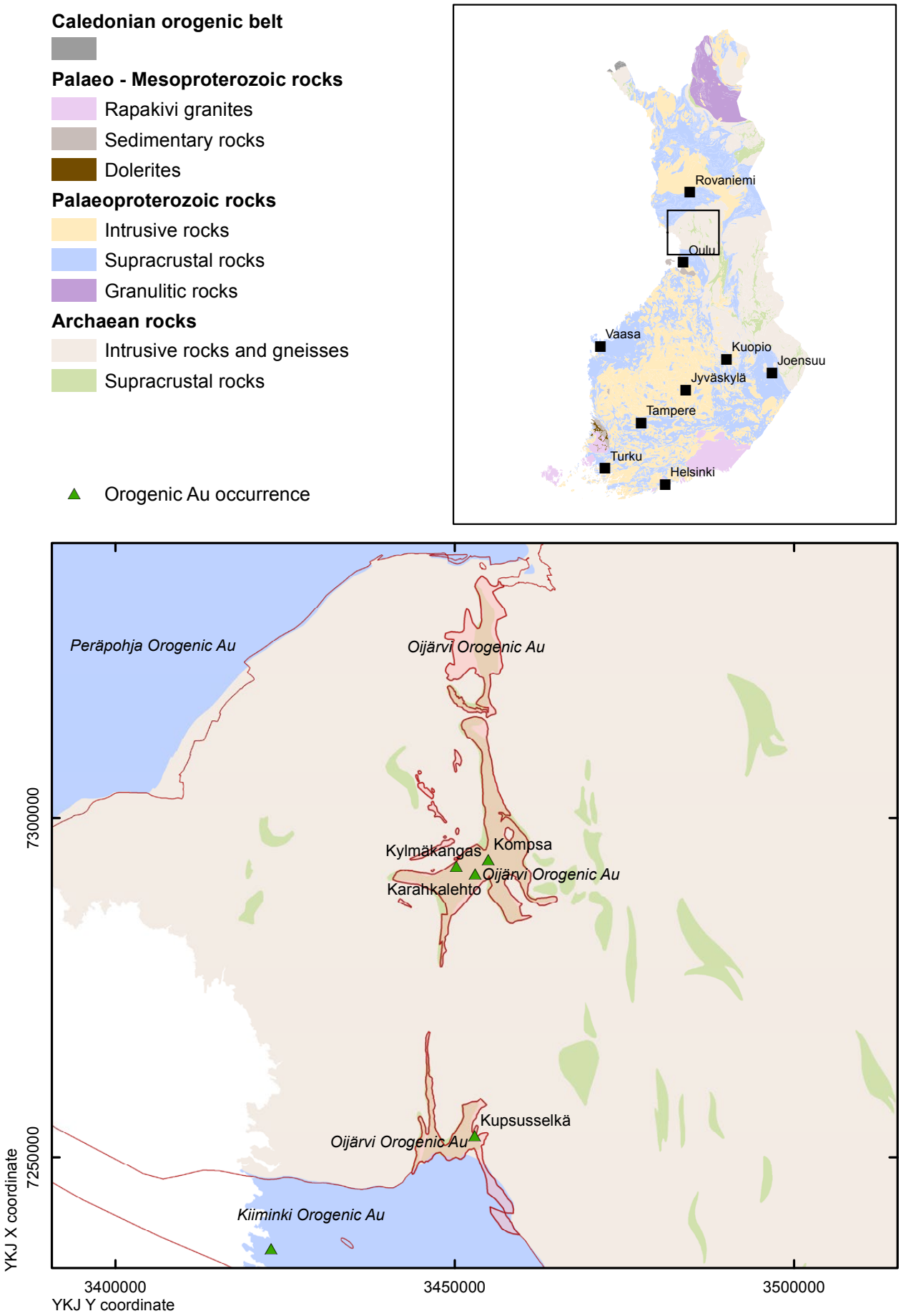

Fig. 1. Location of the Oijärvi Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Oijärvi Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Oijärvi Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:100,000	Honkamo (1984, 1988)
	Thematic geology reports		Tolppi (1999), Juopperi et al. (2012)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Eilu (1996), Juopperi & Karvinen (1999), Tolppi (1999), Rossi (2000), Juopperi et al. (2001), Rossi & Konnunaho (2006), Juopperi et al. (2012)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Rossi & Konnunaho (2006)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Juopperi & Karvinen (1999), Rossi (2000), Rossi & Konnunaho (2006)
Exploration	Reports		Juopperi & Karvinen (1999), Karvinen (1999), Rossi (2000), Juopperi et al. (2001), Rossi & Konnunaho (2006), Agnico-Eagle (2010)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Three or four partially explored orogenic gold occurrences are known within the tract. The following were considered to indicate good potential for undiscovered orogenic gold deposits in the Oijärvi Orogenic Au tract: 1) the existence of known gold occurrences, 2) favourable metamorphic grade, for the most part mid- or upper greenschist facies, 3) similarity to the Archaean Hattu schist belt, eastern Finland with >15 known Au occurrences, 4) good, up to ppm-level Au indications in bedrock in the northern part of the tract, 5) abundant favourable (mafic-ultramafic) host rocks and 6) the discovery of some of the known deposits by accident during a bedrock mapping campaign. Despite the known occurrences, no significant anomalies occur in till geochemical data. The individual estimators considered the probability high that at least two to three undiscovered economic deposits exist 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 Oijärvi Orogenic Au 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}		
3	4	7			4.4	1.7	38	0	4.4	337	0.013

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Karvinen, Keinänen, Konnunaho, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Orogenic Au 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			
Au (t)	3.7	8.8	37	210	320	79	0.26	0.03
Rock (Mt)	1.4	3.2	18	200	280	55	0.23	0.03

t – metric tons; Mt – million metric tons.

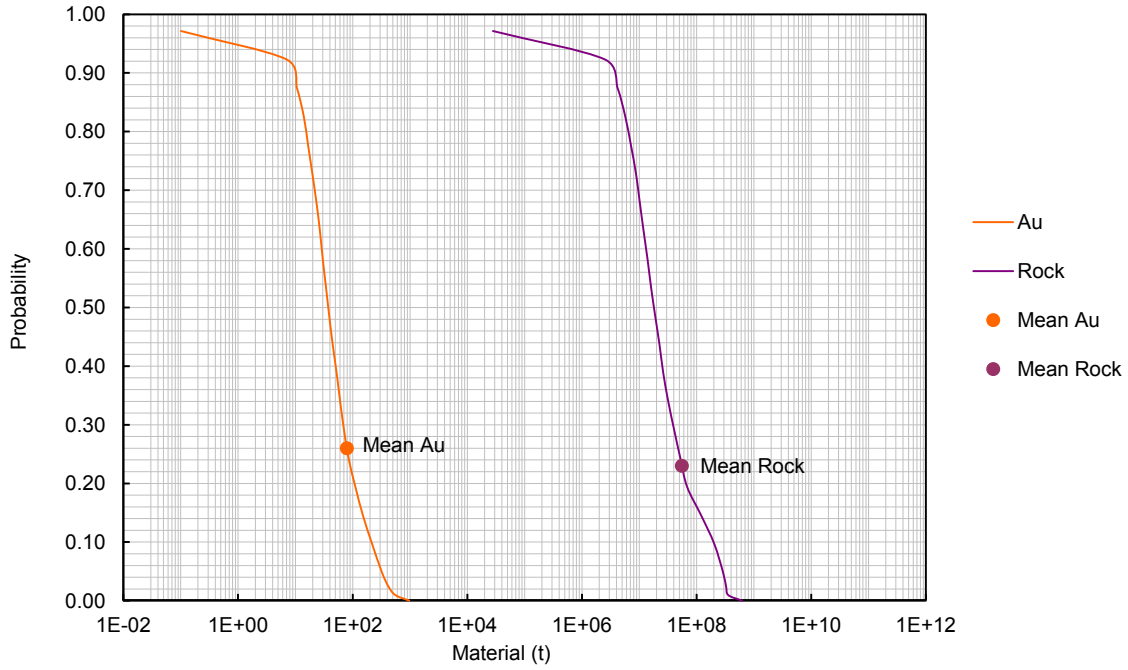

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Oijärvi Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT PERÄPOHJA OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Peräpohja Orogenic Au permissive tract is located in northern Finland in the Kemi, Kemijärvi, Keminmaa, Ranua, Rovaniemi, Simo, Tervola, Tornio and Ylitornio municipalities and extends about 75 km to the NE and 100 km to the SE of the city of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 2524, 2532, 2541, 2542, 2543, 2544, 2613, 2614, 2631, 2632, 2633, 2634, 3522, 3524, 3611, 3612, 3613, 3614, 3623, 3631, 3632 and 3641. The UTM map sheets containing the tract are S414, S423, S424, S441, S442, S444, T411, T413, T414, T431, T432, T433, T434, T443, T511, T512, T521 and T522. The Au resource assessment carried out for this report is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Peräpohja Orogenic Au 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)	
17/1/2012	1	8709	Au	0	Au	93	Au	46

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The Peräpohja Orogenic Au tract is defined by the known extent of Palaeoproterozoic Kivalo and Martimo Group rocks and 2.44–1.89 Ga intrusions and dykes within these units. The ca. 1.80 Ga granitoids of the Central Lapland granitoid complex are excluded and form holes within the tract. The tract is bounded by Archaean TTG rocks to the south, by the Central Lapland Granitoid Complex granites and migmatites to the north and east, and by the Finnish–Swedish border and the Baltic Sea to the west. Low-altitude airborne magnetic data is extensively used to define the extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to 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 orogenic Au deposits within the Peräpohja Orogenic Au 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 orogenic Au deposits in the Peräpohja Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are five partially explored Au-Cu occurrences of possibly orogenic type, and a number of Au±U or 'Rompas-type' occurrences within the Peräpohja Orogenic Au permissive tract (Table 3). They may all be of orogenic gold type, going into the subcategory 'orogenic gold occurrences with anomalous metal association', as this subcategory is defined by Goldfarb et al. (2001) based on epigenetic gold–base metal deposits elsewhere in the world. Laurila may be an orogenic occurrence based on the style of alteration, veins and their timing, but the metal association Au ± Ag, Cu and Pb may indicate something else. There are magmatic layered intrusion-hosted Cr and PGE-Cu-Ni deposits as well as orogenic mafic intrusion-hosted Ni deposits within the tract area. Many other types of metallic mineral occurrences also exist within the tract: possibly IOCG (Misi belt Fe in the east and Vähäjoki Fe-Au-Cu-Co in the SE), BIF, epigenetic Mo, black schist-hosted Zn-Cu-Co-Ag, metamorphosed phosphate-uranium, and Cu and W skarn.

Table 3. Significant orogenic Au occurrences in the Peräpohja Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Au-Cu type					
Kivimaa	7348763	3401946	<2.2	0.022 Mt @ 1.87 % Cu, 5.3 g/t Au; best section 6.2 m @ 4.9 g/t Au, 2.2% Cu	Aulanko (1968), Rouhunkoski & Isokangas (1974), Rossi (2000)
Laurila	7302970	3388039	?	10 m @ 1.1 g/t Au; 1 m @ 36 g/t Au; 1.2 m @ 3.4 g/t Au, 77 g/t Ag, 5.25 % Pb, 0.13 % Cu	Stigzelius & Ervamaa (1962)
Petäjävaara (Rosvohotu)	7355209	3428287	<2.2	1 m @ 19.6 g/t Au; 1 m @ 3 g/t Au; 0.75 m @ 4.4 % Cu, 1.5 g/t Au	Sarala & Rossi (1998), Rossi (1998)
Sivakkajoki	7348387	3401427	<2.2	1 m @ 2.19 g/t Au; 1 m 1.5 g/t Au	Rossi (1993a,b, 2000)
Vinsa	7364152	3412997	< 2.2	1 m @ 2.63 pp Au; 1 m @ 2.4 g/t Au; 1 m @ 1.44 g/t Au	Äyräs (1987a,b), Lehtinen & Eilu (1987b), Hulkki & Turunen (2008)
Au-U type (Rompas type)					
Rajapalot	7373830	3408690	?	Four potential ore bodies known; 19.5 m @ 7.4 g/t Au; grab samples up to 2817 g/t Au; 2.0 m @ 21.5 g/t Au, 44 g/t U	Mawson Resources (2012, 2013a,d)
C Rompas	66.4479	24.7793	?	Channel sample 0.5 m @ 269 g/t Au, 1.9 % U_3O_8	Hudson (2013)
N Rompas	7378400	3399450	?	0.4 m @ 395 g/t Au, 0.41 % U_3O_8; channel sample 1.4 m @ 2529 g/t Au, 5.1 % U_3O_8	Hudson (2013), Mawson Resources (2013c)
S Rompas	7373770	3401350	?	6 m @ 617 g/t Au; 1 m @ 3540 g/t Au	Hudson (2013), Mawson Resources (2013b)

Ga – billion years.

Exploration history

Exploration activity within the tract has focused on iron, chromium, base metals, PGE and gold, and exploration has mostly been limited to the layered intrusions in the southern margin of the tract, the Misi belt in the eastern part of the tract, and the central part of the Kivalo Group. As a whole, exploration has been limited, especially in the northern part of the tract. Exploration activities for orogenic Au deposits within the Peräpohja Orogenic Au permissive tract are listed in Table 4.

Table 4. Exploration history for the Peräpohja Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	Partly yes	Geological Survey of Finland	1946–2007
	Outcrop observations and boulder survey	Partly yes	Outokumpu	1960s–1980s
	Outcrop observations, trenching and boulder survey	Yes	Mawson Resources	2009–
	Outcrop observations and boulder survey	Yes	AREVA	2007–2009
	Outcrop observations and boulder survey	Yes	Inmet	2006–2008
	Outcrop observations and boulder survey	No	Otanmäki, Rautaruukki	1950s–1970s
Geochemical surveys	Nationwide till survey, systematic, 2133 points	Yes	Geological Survey of Finland	1981–1990
	Line till geochemistry, total 3290 points	No	Geological Survey of Finland	1981–1982

Table 4. Cont.

Theme	Type of work	Au analysed	Organisation	When carried out
Geochemical surveys	Targeting geochemistry, profile sampling, total 140 km	Partly yes	Geological Survey of Finland	1980–1990
	Grid sampling, total 1212 km^2	Partly yes	Geological Survey of Finland	1982–1997
	Till and bedrock surface geochemical survey, MMI-survey	Yes	Inmet	2009–2012
	Targeting geochemistry, total 9733 points	Partly yes	Outokumpu, Lapin Malmi, Rautaruukki	1970s–1980s
	Organic sampling, total 3291 points	No	Geological Survey of Finland	1970s–1980s
	Inorganic sampling, total 493 points	No	Geological Survey of Finland	1981–1983
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1980s–2000s
	Radiometric, magnetic and VTEM surveys		Mawson Resources	2010
	Airborne gravimetry		Inmet	2010
Ground geophysical surveys	Magnetic survey, profile surveys, total 3044 km		Geological Survey of Finland	1970s–2000s
	IP, radiometric, slingram, gravity surveys		Mawson Resources	2009–
	Radiometric survey		AREVA	2007–2009
	Electromagnetic, magnetic and IP surveys		Inmet	2006–2009
	Gravimetric survey, profile surveys, total 605 km		Geological Survey of Finland	1960s–2000s
	IP survey, profile surveys, total 69 km		Geological Survey of Finland	1990s–2000s
	Slingram multifrequency survey, profile surveys, total 55 km		Geological Survey of Finland	1989
	Slingram one frequency survey, profile surveys, total 1652 km		Geological Survey of Finland	1970s–1990s
	VLF measurements, profile surveys, total 3.3 km		Geological Survey of Finland	1991
	Self potential survey, profile surveys, total 3.1 km		Geological Survey of Finland	1994
	VLF-R measurements, profile surveys, total 813 km		Geological Survey of Finland	1980s–2000s
	Slingram regional survey, systematic surveys total 33 km^2		Outokumpu	1970s–1980s
	Proton regional survey, systematic surveys total 133 km^2		Outokumpu	1970s–1980s
	IP regional survey, systematic survey, total 25 km^2		Outokumpu	1970s–1980s
	Gravimetric survey, regional, systematic, total 79 km^2		Outokumpu	1970s–1980s
Drilling	Diamond drilling, 832 DDH, total 12,743.99 m	Partly yes	Geological Survey of Finland	1940s–2010s
	A few tens of DDHs	Yes	Mawson Resources	2012–
	42 DDH, total 5.4 km	Yes	Inmet	2007–2011
	A few tens of DDHs	No	Otanmäki, Rautaruukki	1950s–1970s
	Diamond drilling, 8151 DDH, total 22,672.57 m	Partly yes	Outokumpu	1960s–1980s

DDH – Diamond drill hole

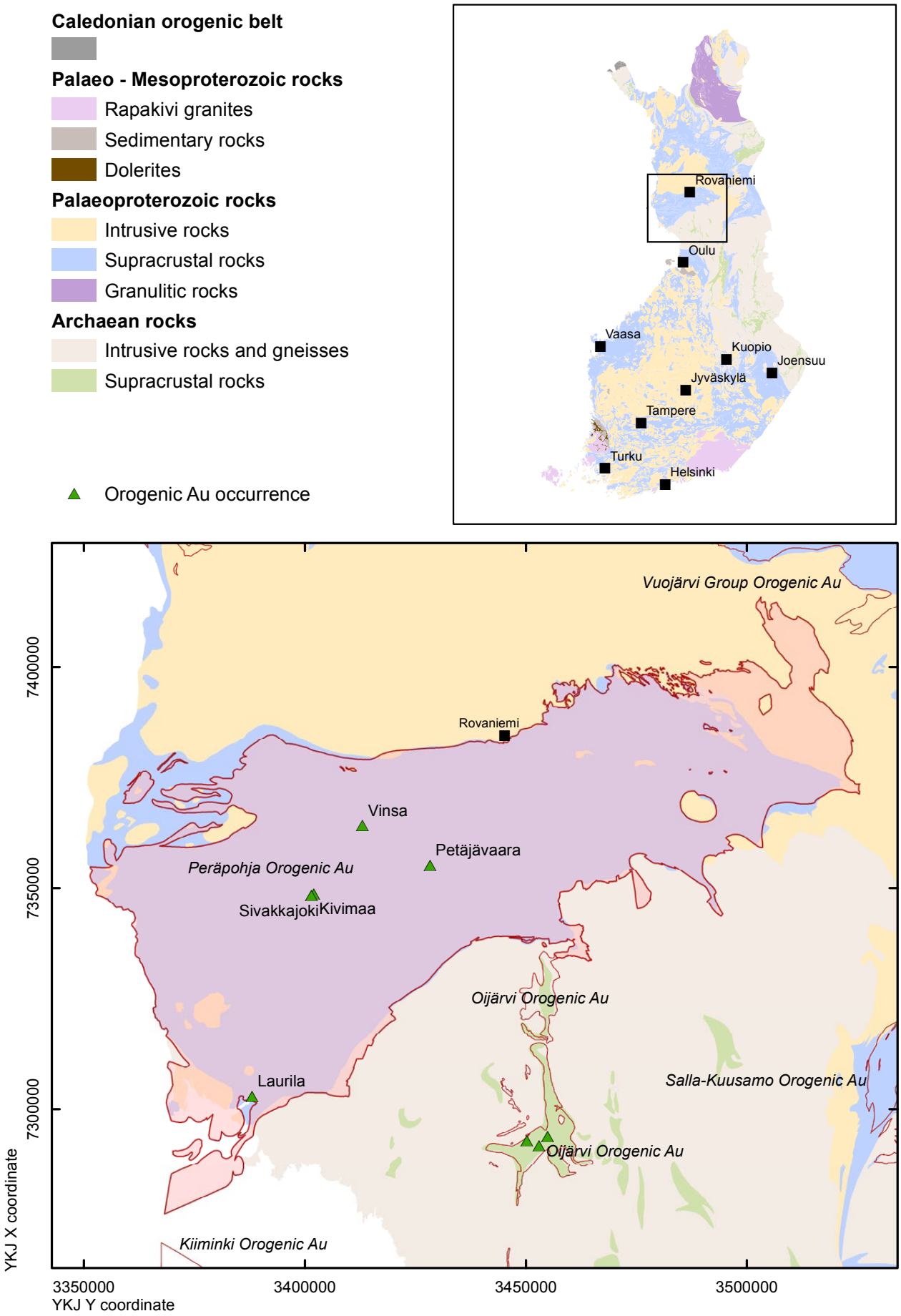

Fig. 1. Location of the Peräpohja Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Peräpohja Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Peräpohja Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:100,000	Hanski (2002, 2003), Perttunen (1971a,b,c, 1975, 1991, 2002, 2003, 2005a,b), Perttunen et al. (1995), Perttunen & Hanski (2003), Väänänen & al. (1997)
	Thematic geology reports	1:5000–10,000	Liipo & Laajoki (1991), Eilu (1987), Perttunen & Vaasjoki (2001), Eilu et al. (2007), Kyläkoski (2007), Kyläkoski et al. (2012), Niiranen (2012), Mustonen (2012)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Stigzelius & Ervamaa (1962), Aulanko (1968), Rouhunkoski (1969), Rouhunkoski & Isokangas (1974), Koivisto (1984), Äyräs (1987a,b, 1991a,b), Lehtinen & Eilu (1987a,b), Rossi (1993a,b, 1998, 2000), Sarala (1995), Sarala & Rossi (1998), Hulkki & Turunen (2008), Hudson et al. (2011), Nebcot (2012), Hudson (2013)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Wennervirta (1966, 1967), Koivisto (1984), Äyräs (1987a,b, 1988, 1991a,b), Eilu (1987), Nurmi et al. (1991), Sarala & Rossi (1998), Sarala et al. (1999), (Rossi 2000), Sarala (2005), Huovinen (2010, 2013), Hudson (2013)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Isokangas (1968a,b, 1974), Isokangas (1974), Rouhunkoski & Isokangas (1974), Äyräs (1987a), Rossi (1993a, 2000), Sarala & Rossi (1998), Hulkki & Turunen (2008), Huovinen (2010, 2013), Hudson (2013)
Exploration	Reports		Isokangas (1968a,b, 1974), Rouhunkoski (1967, 1969, 1971), Rouhunkoski & Isokangas (1974), Korvuo (1982), Rossi (1991, 1993a,b, 2000, 2001), Isomaa et al. (2008), Kyläkoski (2007), Sarala (2005), Sarala & Rossi (2006), Sarala et al. (2007), Huovinen (2010, 2013), Hudson et al. (2011), Nebcot (2012), Hudson (2013)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

A number of partially explored possibly orogenic Au occurrences are known within the Peräpohja Orogenic Au tract (Table 3). According to the present information, these occurrences are fairly small. The following were considered to indicate a good potential for orogenic gold deposits in the tract: 1) the presence of a number of epigenetic Au-Cu-occurrences (one even test mined), 2) the recent discovery in 2010 of the Au±U occurrences in the Rompas area, 3) the occurrence of abundant Au-rich boulders across the tract, 4) elevated gold values in till in the northern part of the tract, 5) favourable structural architecture and favourable metamorphic gradient within the tract and 6) the potential of the area for very large-scale hydrothermal systems of several types (at least orogenic gold, red bed Cu, IOCG, epigenetic Mo, skarn Cu and W, black schist-hosted polymetallic). The late discovery of the Rompas U-Au occurrences in outcrop, with visible gold, illustrates the very limited extent of exploration so far carried out within the rather large tract. The genetic type of all the gold occurrences within the tract is problematic and it is uncertain whether they really belong to the orogenic gold category. This significantly adds into the uncertainties in assessing the undiscovered orogenic gold potential in the entire Peräpohja Orogenic Au tract. All the estimators regarded the Au-Cu occurrences as probably belonging in the orogenic class, whereas views on the genetic type of the Rompas Au±U occurrences varied widely. The individual estimators considered the probability high that at least one to four undiscovered economic deposits exist 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 Peräpohja Orogenic Au 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}		
2	5	9			5.2	2.6	50	0	5.2	8709	0.00060

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Karvinen, Keinänen, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Peräpohja Orogenic Au 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			
Au (t)	0.84	6.3	46	260	360	93	0.28	0.04
Rock (Mt)	0.2	2.3	22	220	310	65	0.25	0.04

t – metric tons; Mt – million metric tons.

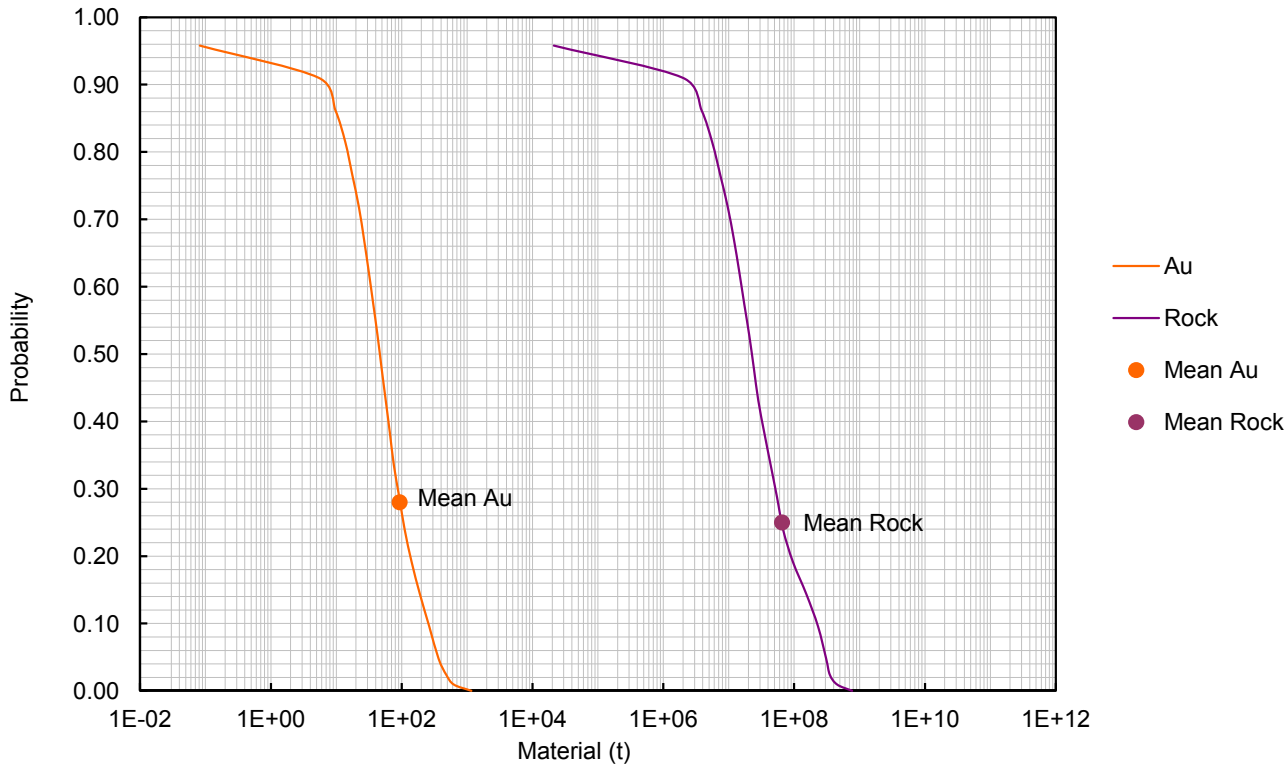

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Peräpohja Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT PIHTIPUDAS OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Pihtipudas Orogenic Au permissive tract is located in western Finland in the municipalities of Pihtipudas and Viitasaari, 120 km north of Jyväskylä (Fig. 1). The 1:100,000 KKJ map sheet is 3312. The UTM map sheets containing the tract are P441 and P442. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Pihtipudas Orogenic Au 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)
7/11/2011	1	86	Au 0	Au 4.5	Au 0

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The tract contains sedimentary, volcanic and subvolcanic rocks of the northwestern part of the Palaeoproterozoic Younger Svecofennian (1.90–1.87 Ga) Pihtipudas suite, as well as syntectonic (1.89–1.87 Ga) granitoids. The tract delineation is based on the extent of the rocks described above, to the south of the major Pihtipudas fault, and on shear structures and presence of gold occurrences and gold-indicative outcrops and boulders. Low-altitude aeromagnetic data of the Geological Survey of Finland (GTK) were used to define the margins of the tract. The tract extends down to 1000 m depth. The sources of information used in the delineation of the tract are summarised in Table 4.

Known deposits

There are no well-explored orogenic Au deposits within the 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 orogenic Au deposits in the Pihtipudas Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

Two partially explored orogenic Au occurrences are known within the permissive tract: Pirunkoukku and Ritovuori (Table 3).

Table 3. Significant orogenic Au occurrences in the Pihtipudas Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Pirunkoukku	7024500	3443500		Best section 5.0 m @ 1.4 ppm Au	Kontoniemi & Mursu (2004)
Ritovuori	7028500	3428900		Best section 1.3 m @ 3.0 ppm Au	Nikander (1987)

Ga – billion years.

Exploration history

GTK has investigated the area since the 1950s. Serious gold exploration commenced in the tract area in the 1980s, when the global gold price rapidly increased. Since then, GTK has explored the Pihtipudas area, especially the Ritovuori and Pirunkoukku occurrences. Exploration activities for orogenic Au deposits and occurrences within the tract are listed in Table 4.

Table 4. Exploration history for the Pihtipudas Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Bedrock mapping, boulder tracing	Yes	GTK	1958–2003
Geochemical surveys	Regional till geochemistry Targeting till survey	Yes Yes	GTK GTK	1982–1994 1979–2003
Airborne geophysical surveys	Low-altitude magnetic, electromagnetic and radiometric survey		GTK	1980
Ground geophysical surveys	Magnetic, slingram, IP surveys		GTK	1982–1986, 1998–2003
Drilling	Percussion and diamond drilling	Yes	GTK	1958–2003
Other	Trenching	Yes	GTK	1979–1986

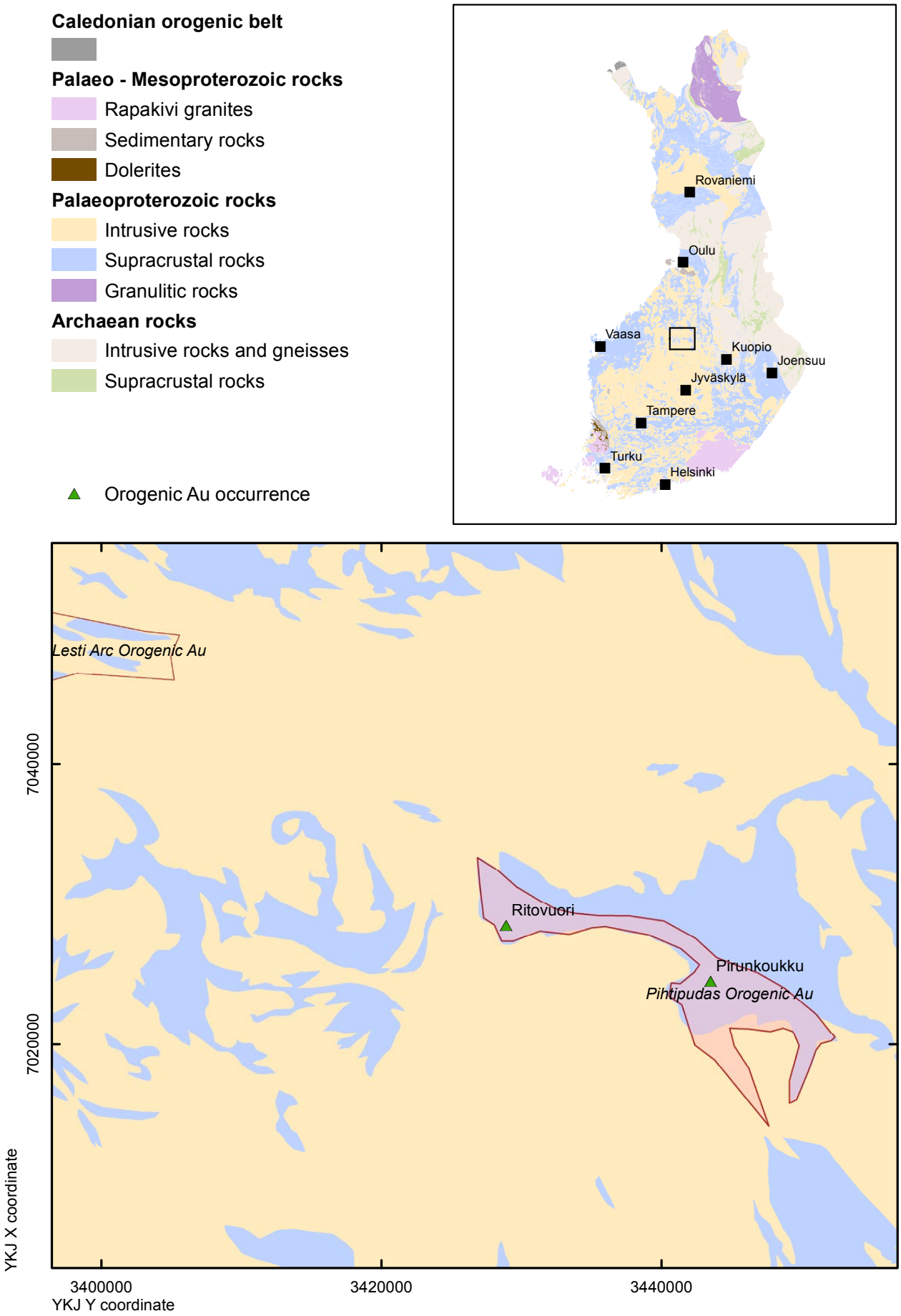

Fig. 1. Location of the Pihtipudas Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Pihtipudas Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Pihtipudas Orogenic Au permissive 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 gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Aho (1973, 1975), Nikander (1987), Kontoniemi & Mursu (2004)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Makkonen et al. (2003), Kontoniemi & Mursu (2004)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Kontoniemi & Mursu (2004)
Exploration	Data of gold-enriched outcrops and boulders		Makkonen et al. (2003)
	Reports		Aho (1973, 1975), Nikander (1987, 1990), Kontoniemi & Mursu (2004), Mäkinen (2004)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Two partially explored orogenic gold occurrences are known within the tract (Table 3). These occurrences are rather modest, and they were considered not to easily become economic deposits, even under the most favourable circumstances. The existence of the partially explored gold occurrences and a few gold-mineralised boulders with no identified bedrock source indicates a rather poor potential for undiscovered orogenic gold deposits for this small tract. None of the individual estimators considered the probability high that any undiscovered economic deposits exist 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 Pihtipudas Orogenic Au 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	0.3	86	0.0035

	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	1	1		
Individual 5	0	0	0		
Individual 6	0	0	1		
Mean	0	0	1		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Hartikainen, Kontoniemi, Nikander, Sorjonen-Ward, Västi.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Pihtipudas Orogenic Au 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			
Au (t)	0	0	0	7.5	15	4.5	0.15	0.70
Rock (Mt)	0	0	0	3.7	7.3	3.2	0.11	0.70

t – metric tons; Mt – million metric tons.

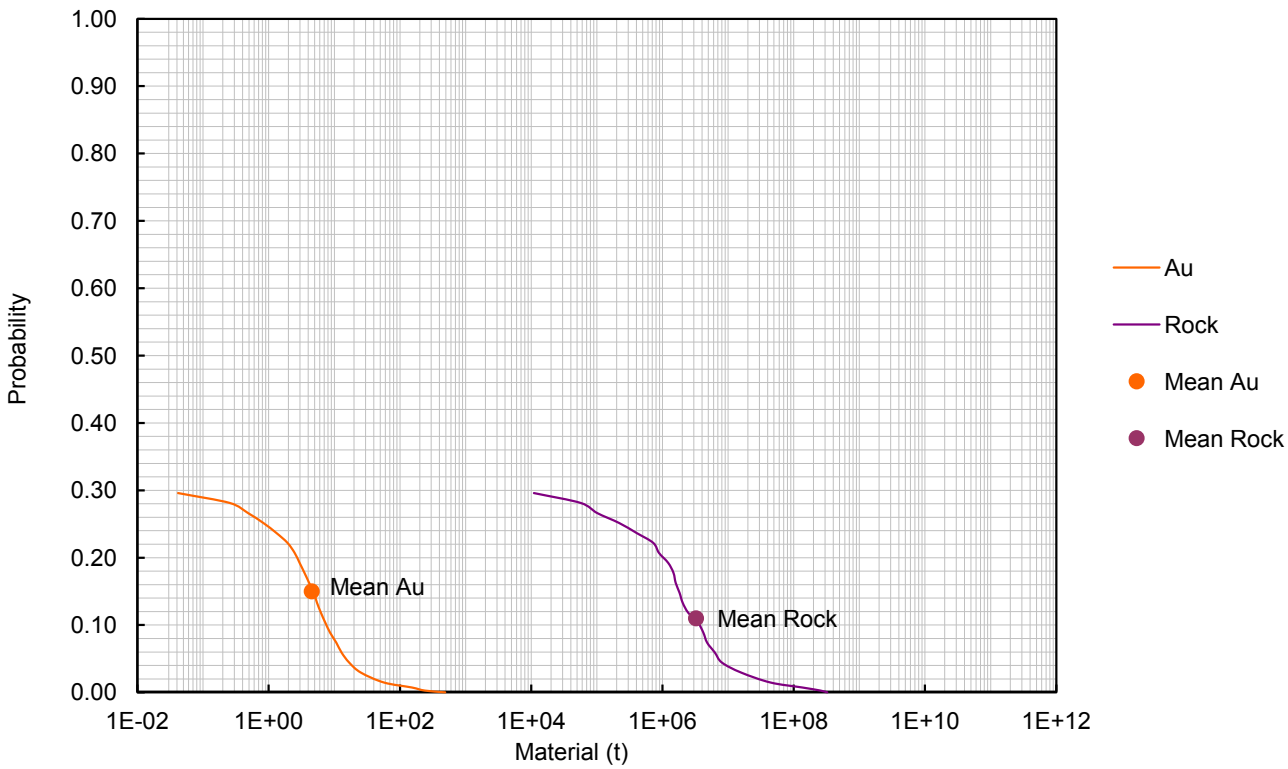

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Pihtipudas Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT PIRKKALA OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The NW-trending Pirkkala Orogenic Au permissive tract is located in southwestern Finland in the municipalities of Akaa, Hämeenkyrö, Hämeenlinna, Harjavalta, Hattula, Huittinen, Ikaalinen, Jämijärvi, Kangasala, Kankaanpää, Kiikoinen, Kristiinankaupunki, Kokemäki, Kuhmoinen, Lavia, Lempäälä, Merikarvia, Nakkila, Närpiö, Nokia, Orivesi, Padasjoki, Pälkäne, Pirkkala, Pomarkku, Pori, Punkalaidun, Sastamala, Siikainen, Tampere, Ulvila, Urjala, Valkeakoski, Vesilahti and Ylöjärvi. It continues 50 km to the south, 70 km to the east and 160 km to the northwest of the city of Tampere, extending to the Gulf of Bothnia in the west (Fig. 1). The 1:100,000 KKJ map sheets are 1141, 1142, 1143, 1144, 1231, 1232, 1233, 2112, 2114, 2121, 2122, 2123, 2124, 2132, 2141, 2142, 2143 and 2144. The UTM map sheets containing the tract are M324, M332, M333, M334, M341, M342, M343, M344, M411, M412, M414, M421, M423, N313, N314, N323, N331, N332, N333 and N341. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Pirkkala Orogenic Au 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)	
04/03/2013	1	10,257	Au	0	Au	110	Au	54

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The Pirkkala Orogenic Au permissive tract contains Palaeoproterozoic Svecofennian supracrustal rocks of the Hirsilä, Pirttikylä, Jurva and Lapua suites and the Pirkanmaa migmatite suite and syntectonic intrusive rocks of the Pirkanmaa and Southern Ostrobothnia intrusive suites and the Central Finland Granitoid Complex (Geological Survey of Finland 2010). The tract covers the central and western parts of the Pirkanmaa migmatite and intrusive suits and extends to the north along the coast to cover the southernmost rocks of the Pirttikylä suite. To the south, the tract is bordered by the terrain boundary between the Pirkanmaa and Häme belts and to the north by the southern boundary of the Tampere belt (Kähkönen 2005, Vaasjoki et al. 2005). The delineation is based on the extent of rocks mentioned above, suitable second- and third-order shear structures, and the presence of known gold occurrences and indications. Low-altitude aeromagnetic data of the Geological Survey of Finland (GTK) were used to define the margins of the tract. The tract extends down to 1000 m depth. The sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

No well-explored orogenic Au deposits are known within the 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 orogenic Au deposits in the Pirkkala Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

Close to 20 partially explored orogenic Au occurrences are known within the permissive tract (Table 3).

Table 3. Significant orogenic Au occurrences in the Pirkkala Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Ania	6816215	3315446	*	0.5–0.8 m @ 3.3–4.2 g/t Au	Kärkkäinen et al. (2006)
Erkkilä	6814797	3315576	*	3–6 m @ 1–8 g/t Au	Kärkkäinen & Lehto (2004)
Eräjärvi	6834522	3373010	*	1 m @ 1 g/t Au	Eilu (2012)
Hopeavuori	6782682	3336256	*	17.5 m @ 13.1 g/t Au	Lindmark & Koistinen (1996)
Isovesi	6849892	3272308	*	3.7 m @ 5.3 g/t Au	Luukkonen (1994)
Kaakkolammi	6803200	3334700	*	4–7 g/t Au in grab samples from outcrop	Rosenberg (1996), Kärkkäinen et al. (2008)
Kaapelinkulma	6794715	3345711	*	0.183 Mt @ 4.1 g/t Au	Rosenberg (1997), Dragon Mining (2013)
Kaitajärvi	6815869	3323822	*	1 m @ 0.6 g/t Au	Lehto (2004)
Kalliojärvi	6806226	3323378	*	4.3 m @ 7.2 g/t Au	Lehto (2000)
Kivikesku	6829596	3314550	*	5 m @ 3.4 g/t Au	Lindmark (1995a)
Metsäkylä	6833517	3312247			
Paiskallio	6833006	3276397	*	0.5–2 m @ 0.16–62.9 g/t Au	Rosenberg (2000)
Sääksjärvi	6816800	3325470	*	1 m @ 1.2–2.38 g/t Au	GTK unpubl. data
Saarijärvi	6833055	3254678	*	1 m @ 2.3 g/t Au	Kärkkäinen et al. (2012)
Silmussuo	6831980	3253775	*	1.2 m @ 3.2 g/t Au	Kärkkäinen et al. (2012)
Tikkarinvuori	6817949	3315405	*	1 m @ 8.1 g/t; visible gold in outcrop	Rosenberg (1998)
Välimäki	6826832	3247823	*	1 m @ 2–18 g/t Au	Kärkkäinen et al. (2003, 2012)
Valkeasuo	6821125	3238226	*	31–70 g/t Au in grab samples from outcrop	GTK unpublished data
Vatanen	6818982	3318647	*	10 m @ 0.5 g/t Au	Rosenberg (1990)

Ga – billion years.
* All deposit ages are between 1.89 and 1.77 Ga.

Exploration history

The exploration history of the tract area is extensive. Most of the work has been aimed at nickel, copper, tungsten and gold. Before the 1980s, gold was rarely analysed from samples taken. Exploration activities for gold within the tract are listed in Table 4.

Table 4. Exploration history for the Pirkkala Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Bedrock mapping, boulder tracing	?	Outokumpu	1950s–1980s
		Yes	GTK	1980s–2000s
		Yes	Dragon Mining	2003–
Geochemical surveys	Regional till geochemistry	Yes	GTK	1980s
	Till geochemical survey	Yes	Terra Mining	1990s
	Till geochemical and heavy-mineral surveys; MMI surveys	Yes	GTK	1960s–2000s
	Till and peat geochemical surveys	Yes	Outokumpu	1960s–1980s
Airborne geophysical surveys	Low-altitude magnetic, electromagnetic and radiometric survey		GTK	1975–1994
Ground geophysical surveys	Magnetic, IP, slingram		Outokumpu	1970s–1980s
	Magnetic, IP, slingram		GTK	1960s–2000s
Drilling	Diamond and percussion drilling	Yes	Outokumpu	1970s–1980s
	Diamond and percussion drilling	Yes	GTK	1970s–2000s
	Diamond and percussion drilling	Yes	Dragon Mining	2003–

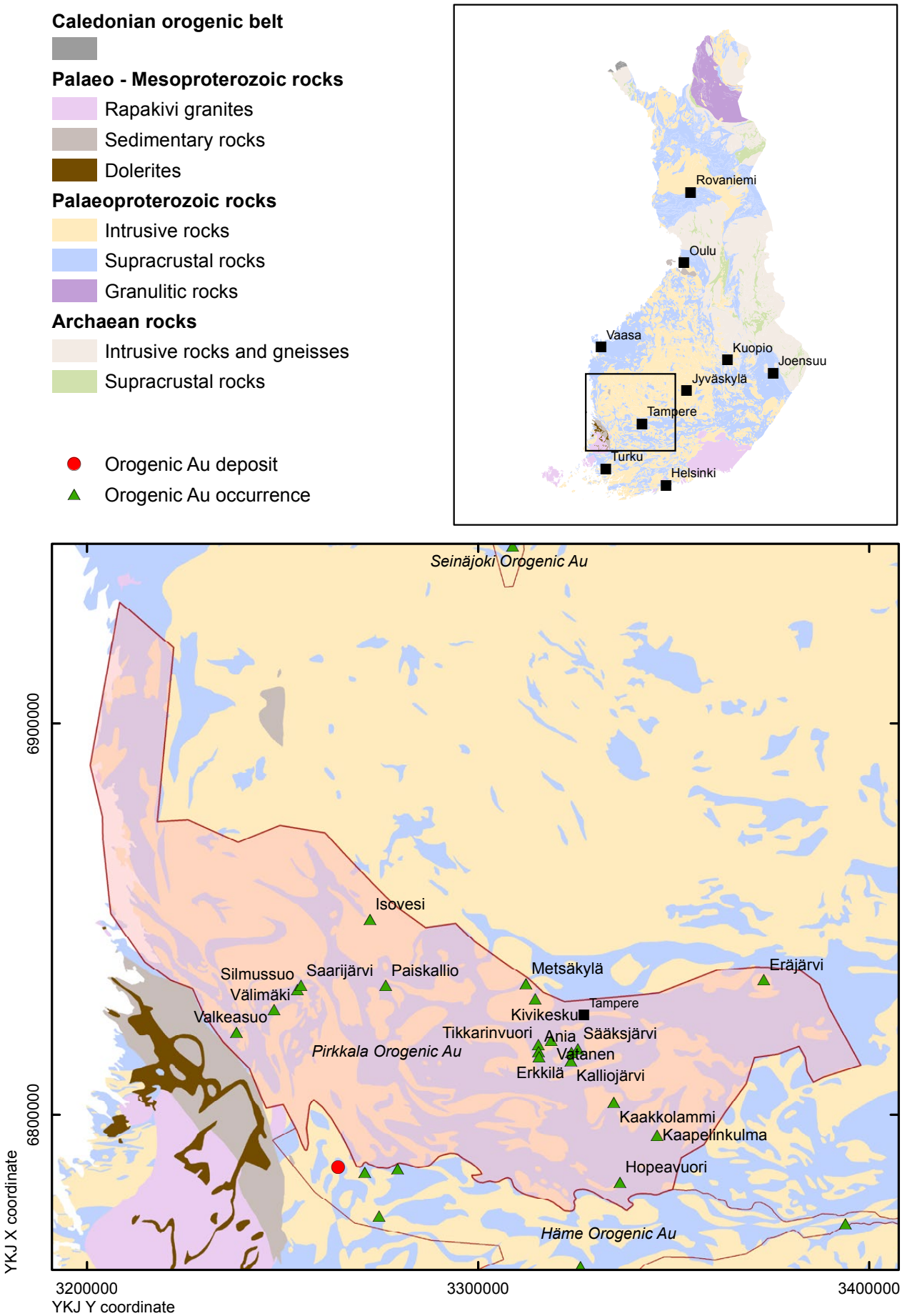

Fig. 1. Location of the Pirkkala Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Pirkkala Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Pirkkala Orogenic Au permissive 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 gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Rosenberg (1990, 1992, 1997, 1996, 1998, 2000a,b), Luukkonen (1994), Lindmark (1995a,b), Lindmark & Koistinen (1996), Lehto (2000, 2004), Nironen (2002), Kärkkäinen & Lehto (2004), Kärkkäinen et al. (2006, 2012), Kärkkäinen & Pelkkala (2013)
	Regional metallogenic assessments		Luukkonen (1994), Nironen (2002), Kärkkäinen et al. (2003, 2008), Eilu (2012)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Lestinen (1987), Hakala (1988), Rosenberg (1990, 2000a), Lindmark (1995a,b), Lindmark & Koistinen (1996), Sandberg (2000), Lehto (2004), Tarvainen et al. (2007), Kärkkäinen et al. (2008, 2012), Al-Ani & Kärkkäinen (2012), Huhta et al. (2012)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Rosenberg (1990, 1992, 2000a), Lindmark (1995a,b), Lindmark & Koistinen (1996), Sandberg (2000), Lehto (2004), Airo & Leväniemi (2012), Lohva & Jokinen (2012)
Exploration	Reports		Lestinen (1987), Rosenberg (1990, 1992, 1996, 1998, 2000a,b), Kokkola (1991), Lindmark (1995a,b), Lindmark & Koistinen (1996), Lehto (2000, 2004), Sandberg (2000), Kärkkäinen et al. (2003, 2006, 2008, 2012), Kärkkäinen & Lehto (2004), Lehto & Kärkkäinen (2006), Dragon Mining (2008, 2013)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Close to 20 partially explored orogenic gold occurrences are known within the tract (Table 3). Some of these are rather modest. The existence of a large number of partially explored occurrences and gold-mineralised boulders still having no indicated bedrock source, undrilled outcrops, boulder and till indications, very extensive gold and pathfinder element (As, Te, Sb) anomalies in till and

micro nugget anomalies in till indicate significant potential for undiscovered orogenic gold deposits for the tract. On the other hand, the rather high regional metamorphic grade was seen as unfavourable for orogenic gold. The individual estimators considered the probability high that at least two to five undiscovered economic deposits exist 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 Pirkkala Orogenic Au 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}		
3	5	10			5.7	2.7	48	0	5.7	10,257	0.00056

	Estimated number of undiscovered deposits				
Estimator	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
Individual 1	3	5	10		
Individual 2	5	10	20		
Individual 3	3	5	10		
Individual 4	2	3	6		
Individual 5	2	4	8		
Individual 6	2	5	8		
Individual 7	3	6	6		
Mean	3	5	10		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Grönholm, Kärkkäinen, Kontoniemi, Niiranen, Sorjonen-Ward, Tiainen.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Pirkkala Orogenic Au 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			
Au (t)	4.1	11	54	290	400	110	0.28	0.03
Rock (Mt)	1.5	4.1	28	240	320	73	0.25	0.03

t – metric tons; Mt – million metric tons.

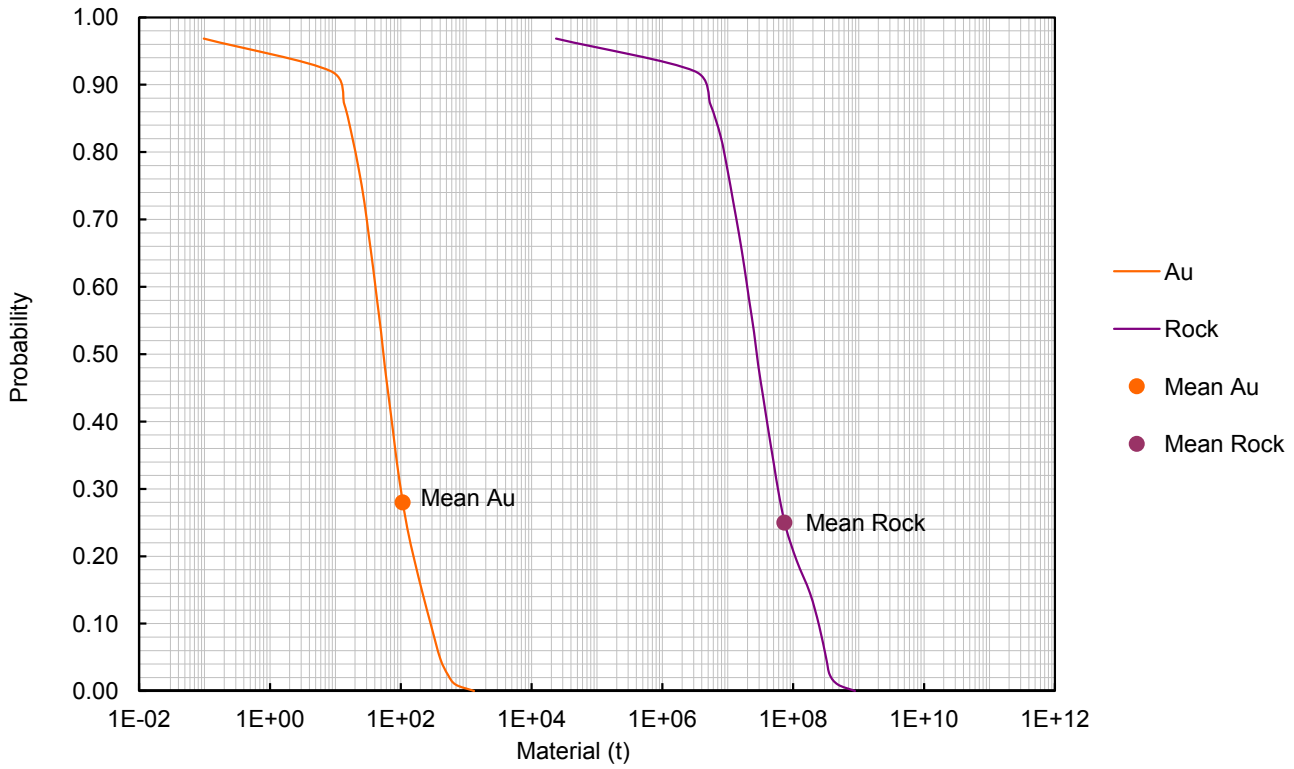

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Pirkkala Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT PULJU OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Pulju Orogenic Au permissive tract is located in northwestern Finland in the Enontekiö, Inari and Kittilä municipalities, 180–250 km N of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 2741, 2742, 2814, 2831, 2832, 2833 and 2834. The UTM map sheets containing the tract are V413, V414, V424, V431, V432, V441, V442, W413 and W431. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Pulju Orogenic Au 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)	
17/1/2012	1	996	Au	0	Au	23	Au	5.1

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is defined by the known extent of Palaeoproterozoic supracrustal Sietkuoja, Vittaselkä and Mertavaara Formation rocks in northern Finland. To the west and south the tract is bounded by Hetta Complex rocks, to the east by Haparanda Suite intrusive rocks and the Kittilä Group Orogenic Au tract, and to the north by the Finnish–Norwegian border. Low-altitude airborne magnetic data were extensively used to define the extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to 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 orogenic Au deposits within the 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 orogenic Au deposits in the Pulju Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are no partially explored orogenic Au occurrences within the permissive tract (Table 3).

Table 3. Significant orogenic Au occurrences in the Pulju Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
None					

Ga – billion years.

Exploration history

Exploration activities for gold within the tract are listed in Table 4. Most of the exploration in the region, including all drilling, has targeted nickel.

Table 4. Exploration history for the Pulju Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	No	Geological Survey of Finland	1940–
	Outcrop observations	No	University of Turku	1970s
	Outcrop observations and boulder survey	?	Outokumpu	1960s–1990s
Geochemical surveys	Nationwide till survey, total 243 samples	Yes	Geological Survey of Finland	1980s
	Targeting till surveys, total 750 sample points	Yes	Geological Survey of Finland	1980s
	Targeting till surveys, total 7957 samples points	No	Outokumpu	1960s–1990s
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1979–2004
Ground geophysical surveys	Magnetic, systematic total 8.4 km^2, profile total 41.2 km		Geological Survey of Finland	1970s–2000s?
	Gravimetric, profile total 13.4 km		Geological Survey of Finland	2004
	IP profiles, total 7.8 km		Geological Survey of Finland	2004
	Slingram, systematic total 7.6 km^2		Geological Survey of Finland	1977
	VLF, systematic total 0.8 km^2, profile total 40.5 km		Geological Survey of Finland	2004
	Magnetic, systematic total 244.2 km^2		Outokumpu	1970s–1990s
	Gravimetric, systematic total 23.8 km^2, profile total 16.4 km		Outokumpu	1970s–1990s
	Slingram, systematic total 245 km^2		Outokumpu	1970s–1990s
Drilling	Diamond drilling, 12 DDH, total 418.65 m	Yes	Geological Survey of Finland	2006
	Diamond drilling, 41 DDH, total 5702. 35 m	?	Outokumpu	1986–1997
	Diamond drilling, 40 DDH, total 4931.27 m	No	Lapin malmi	1968–1986

DDH – Diamond drill hole

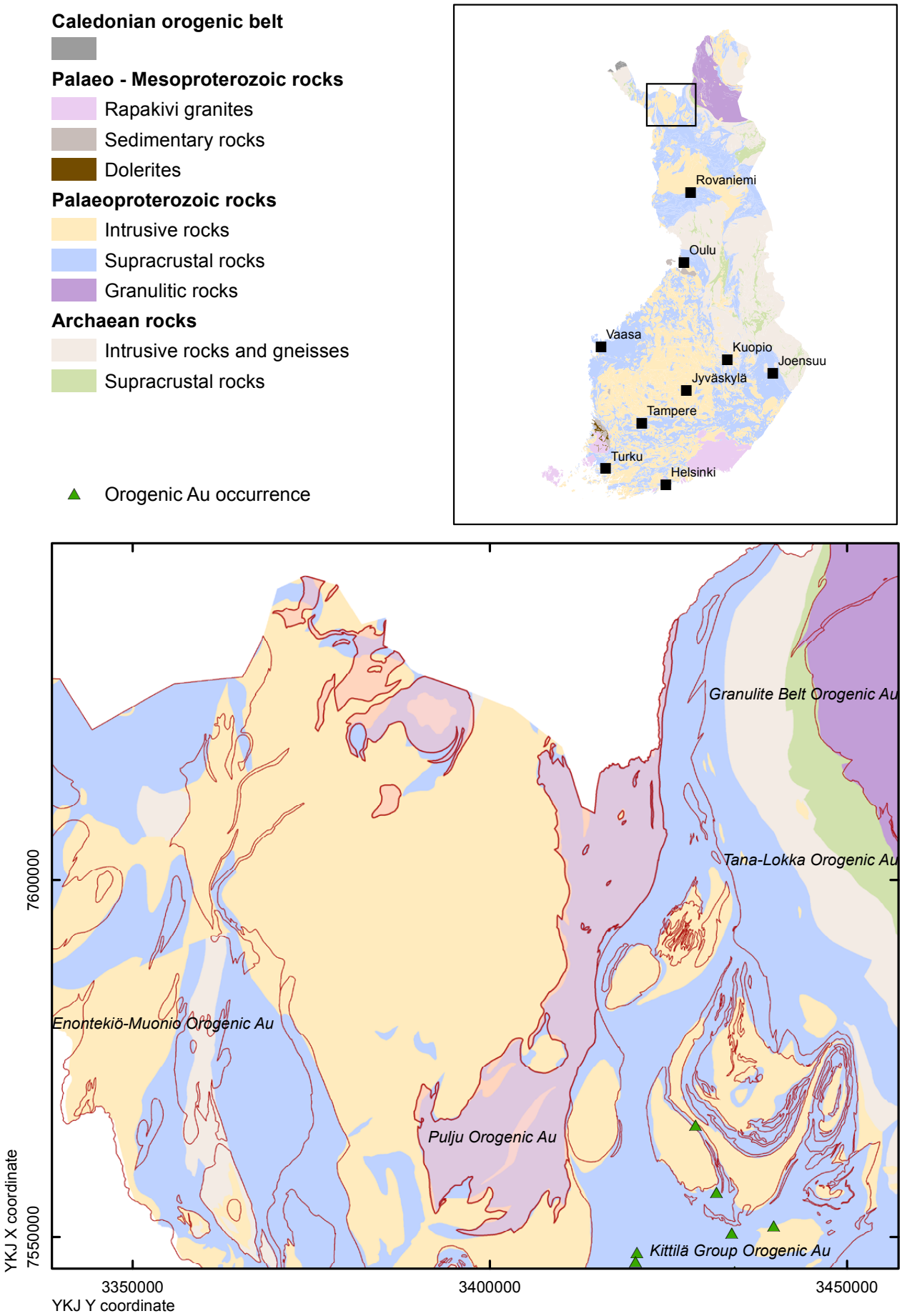

Fig. 1. Location of the Pulju Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Pulju Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Pulju Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:300,000	Lehtonen et al. (1998)
	Thematic geology reports	1:5000–10,000	Johansson & Nenonen (1991), Rastas & Kilpeläinen (1991), Papunen (1993, 1998), Lehtonen et al. (1998)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Meriläinen (1993)
Geochemistry	Geological Survey of Finland in-house database		
Geophysics	Geological Survey of Finland in-house database		
	Reports		Airo & Kurimo (1999)
Exploration	Reports		Auranen (1975), Anttonen (1993), Heikkilä (1984), Inkinen (1976, 1978, 1982, 1985a,b, 1987, 1988), Lahtinen (1979a,b,c, 1980, 1992), Inkinen et al. (1984), Vihreäpuu (2001a,b,c)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

No partially explored orogenic gold occurrences are known within the tract (Table 3). The following were considered to indicate a good potential for orogenic gold deposits in the tract: 1) the main part of this tract is an immediate continuation to the south of the Karasjok Au-Cu metallogenic area (Sandstad et al. 2012) in Norway, where a few Au occurrences have been discovered, and 2) the tract is bounded to the east and south by, and apparently has the same supracrustal units as, the gold-rich Kittilä Group Orogenic Au tract. No direct indications for gold deposits exist in the Pulju tract, however. Most of the exploration in the region has been for nickel. Hence, assessing the gold potential of the tract is rather difficult. The best potential for orogenic gold might be in the SW corner, where the regional metamorphic grade is lowest, at lower amphibolite facies. None of the individual estimators considered the probability high that any undiscovered economic deposits exist 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 Pulju Orogenic Au 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	1	3			1.3	1.2	90	0	1.3	996	0.0013

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Keinänen, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Orogenic Au 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			
Au (t)	0	0	5.1	45	110	23	0.19	0.30
Rock (Mt)	0	0	1.9	26	71	16	0.15	0.30

t – metric tons; Mt – million metric tons.

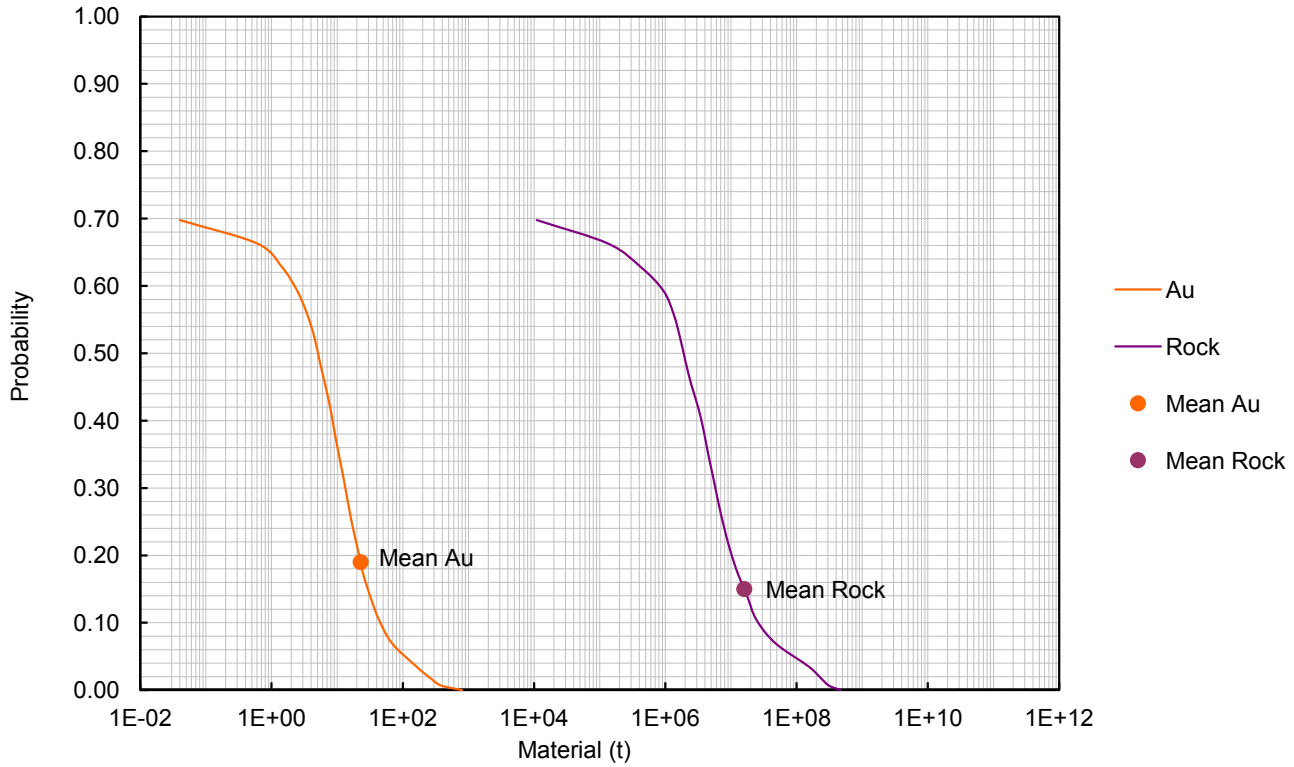

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Pulju Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT RANTASALMI OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Rantasalmi Orogenic Au permissive tract is located in western Finland in the municipalities of Rantasalmi, Juva, Pieksämäki and Joroinen, 100 km south of Kuopio (Fig. 1). The 1:100,000 KKJ map sheets are 3231, 3232, 3233 and 3234. The UTM map sheets containing the tract are N512, N513, N514 and N521. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Rantasalmi Orogenic Au 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)	
8/11/2011	1	220	Au	10.96	Au	12	Au	2.3

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is contains Palaeoproterozoic Svecofennian sedimentary, volcanic and subvolcanic rocks in the northeastern end of the Häme migmatite suite, as well as syntectonic (1.89–1.87 Ga) granitoids. The tract is confined between the high metamorphic-grade Pieksämäki and Haukivesi blocks and the Sulkava thermal dome (Korsman et al. 1988), in the vicinity of Kolkonjärvi major fault and shear structures (Kontoniemi 1998). Gold occurrences and gold-indicative outcrops and boulders were used as additional guidelines in delineating the tract. Low-altitude aeromagnetic data of the Geological Survey of Finland (GTK) were used to define the margins of the tract. The tract extends down to 1000 m depth. The sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

There are two well-explored orogenic Au deposits within the 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 orogenic Au deposits in the Rantasalmi Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
Osikonmäki	6883100	3563800		4.84	2.0	9.6	Belvedere Resources (2011)
Pirilä	6880960	3555385		0.15	8.9	1.3	Belvedere Resources (2010)

Ga – billion 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 orogenic Au occurrences are known within the permissive tract (Table 3).

Table 3. Significant orogenic Au occurrences in the Rantasalmi Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Hakojärvi	6877600	3556900		Best section 2.5 m @ 1.0 ppm Au	Makkonen (1987b)
Osikko 4	6883100	3561800		Probable resources 0.09 Mt @ 4.9 ppm Au	Kontoniemi (1992), Parkkinen (2001)
Pirilä 2	6882000	3554780		Best section 2 m @ 3.4 ppm Au	Makkonen (1987a)

Ga – billion years.

Exploration history

Exploration activities in the Rantasalmi region began in the 1970s, when GTK explored mostly for base metals and molybdenum. Serious gold exploration commenced in the Rantasalmi area in the 1980s, when the global gold price rapidly increased, and after the discovery of the Pirilä deposit in 1983. Since then, GTK has mainly explored and studied two targets, Pirilä and Osikonmäki. Exploration activities for orogenic Au deposits and occurrences within the tract are listed in Table 4.

Table 4. Exploration history for the Rantasalmi Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Bedrock mapping, boulder tracing	Yes	GTK	1983–1993
Geochemical surveys	Regional till geochemistry	Yes	GTK	1982–1994
	Targeting till survey	Yes	GTK	1983–1993
Airborne geophysical surveys	Low-altitude magnetic, electromagnetic and radiometric survey		GTK	1981–1988
Ground geophysical surveys	Magnetic, slingram, IP surveys		GTK	1983–1993
Drilling	Percussion and diamond drilling	Yes	GTK	1983–1993
	Percussion and diamond drilling	Yes	Belvedere Resources	2005–
Other	Trenching	Yes	GTK	1983–1987
	Beneficiation tests	Yes	GTK	1993–1998
	Beneficiation tests	Yes	Outokumpu	1993–1998
	Resource estimates	Yes	Endomines	2001–2005
	Resource estimates	Yes	Belvedere Resources	2005–

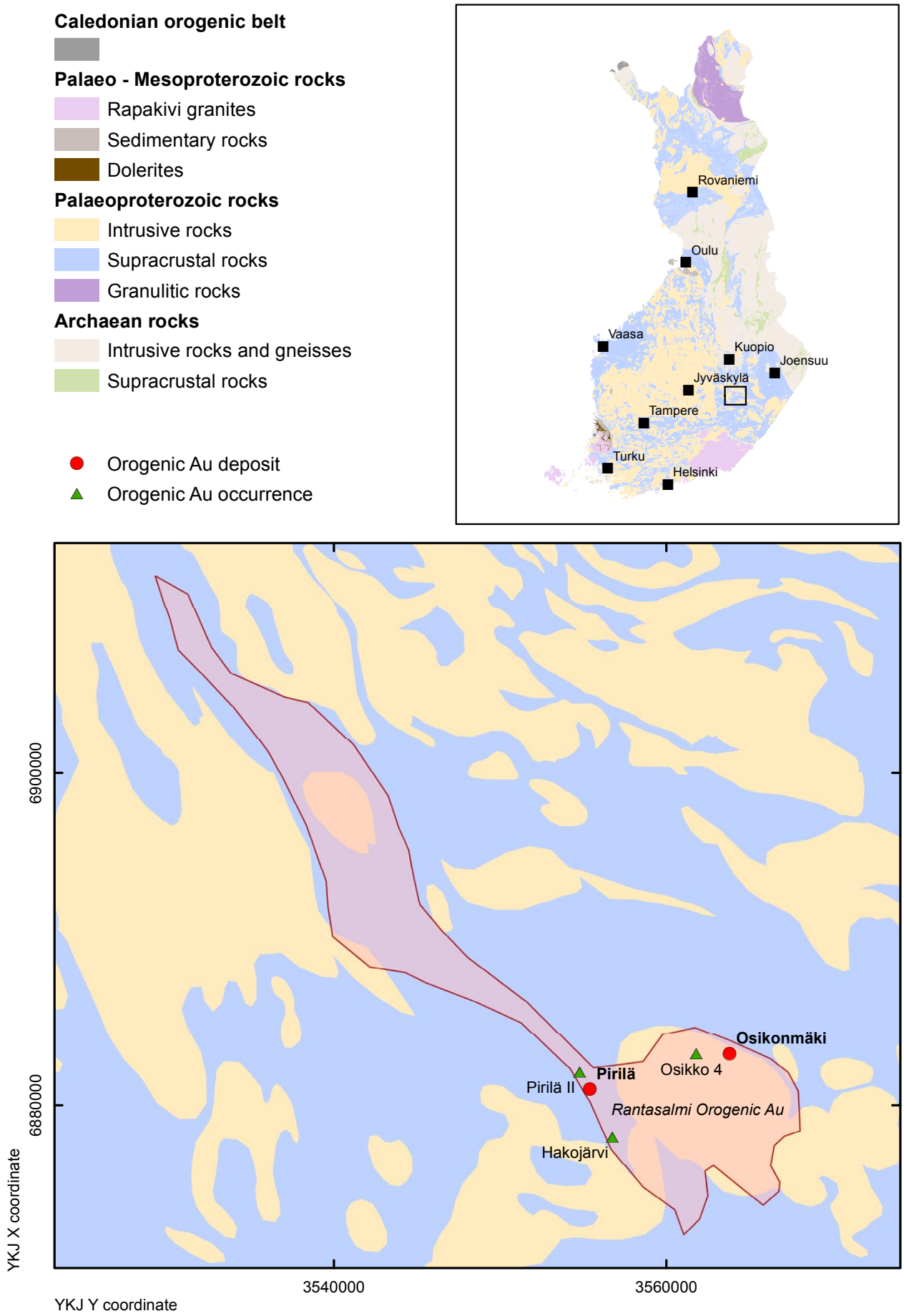

Fig. 1. Location of the Rantasalmi Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Rantasalmi Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Rantasalmi Orogenic Au permissive 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 gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Makkonen (1986, 1987a,b), Kontoniemi (1992, 1998), Parkkinen (2001), Belvedere Resources (2011)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Lestinen (1989, 1991), Lestinen & Kontoniemi (1991), Bornhorst et al. (1998), Kontoniemi (1998),
Geophysics	Geological Survey of Finland in-house database		
	Reports		Makkonen (1987a), Kontoniemi (1990, 1998),
Exploration	Data of gold-enriched outcrops and boulders		Makkonen et al. (2003)
	Reports		Makkonen (1986, 1987a,b), Kontoniemi (1990, 1992, 1994), Lestinen (1989, 1991), Leppinen & Kontoniemi (1998), Wahyudi et al. (1998), Parkkinen (2001), Belvedere Resources (2011)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Three partially explored orogenic gold occurrences are known within the tract (Table 3). These occurrences are rather modest. The existence of the known Osikonmäki and Pirilä deposits, three partially explored occurrences, a few gold-mineralised boulders and suitable structures indicate the good potential for undiscovered orogenic gold deposits for the tract. On the other hand, the tract is small, and it is uncertain whether the lodes within the Osinkonmäki shear zone form one or two deposits. The individual estimators considered the probability high that at least zero to one undiscovered economic deposits exist within the tract. A consensus was not 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 Rantasalmi Orogenic Au 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	1	1			0.70	0.41	58	1	1.7	220	0.012

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Hartikainen, Kontoniemi, Nikander, Sorjonen-Ward, Västi.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Rantasalmi Orogenic Au 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			
Au (t)	0	0	2.3	20	46	12	0.16	0.31
Rock (Mt)	0	0	0.79	9.7	45	8.3	0.12	0.31

t – metric tons; Mt – million metric tons.

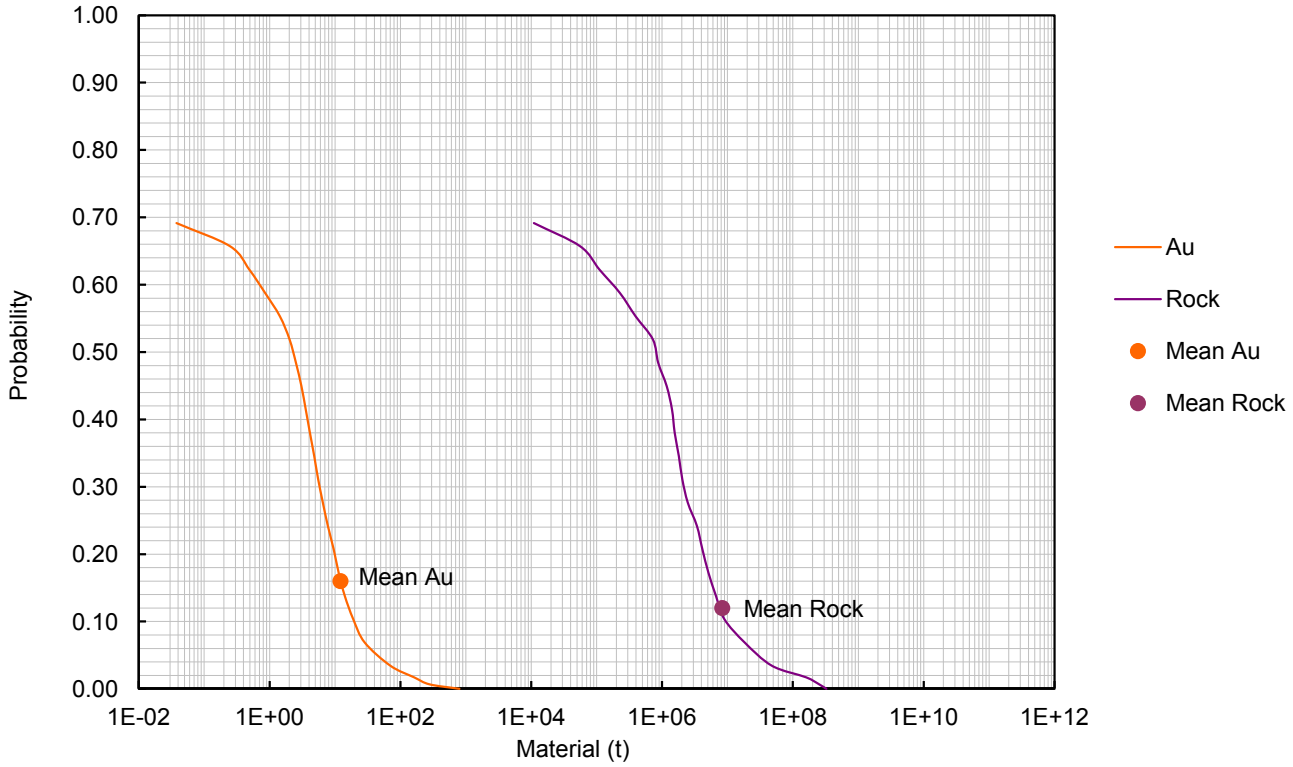

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Rantasalmi Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT RAUTIO OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Rautio Orogenic Au permissive tract is located in western Finland in the municipalities of Alavieska, Kalajoki, Kannus, Kokkola, Sievi, Toholampi and Ylivieska, 140 km southwest of Oulu (Fig. 1). The 1:100,000 KKJ map sheets are 2323, 2324, 2342, 2413 and 2431. The UTM map sheets containing the tract are Q411, R412, Q414, Q421 and Q423. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Rautio Orogenic Au 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)	
07/11/2011	1	815	Au	7.1	Au	35	Au	12

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract contains Palaeoproterozoic Younger Svecofennian (1.90–1.87 Ga) sedimentary, volcanic and subvolcanic rocks in the northwesternmost part of the Ylivieska group, some supracrustal rocks of the Lappfors, Lapua and Pirttikylä suites of the Western Finland supersuite along the western margin, and syntectonic (1.89–1.87 Ga) granitoids. The tract is centred on the Rautio granitoid intrusion and based on the existence of orogenic gold occurrences, gold-indicative outcrops and boulders, and suitable second- and third-order shear structures in that area. Low-altitude aeromagnetic data of the Geological Survey of Finland (GTK) were used to define the margins of the tract. The tract extends down to 1000 m depth. The sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

There is one well-explored orogenic Au deposit (Hirsikangas) within the 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 orogenic Au deposits in the Rautio Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
Hirsikangas	7109290	3344150		5.675	1.25	7.1	Nally et al. (2009)

Ga – billion 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 orogenic Au occurrences are known within the permissive tract (Table 3).

Table 3. Significant orogenic Au occurrences in the Rautio Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Ala	7114550	3363270		Best section 2.5 m @ 2.7 ppm Au	Lestinen & Mursu (2005)
Antinoja	7090710	3363000		Best section 8.2 m @ 3 ppm Au	Sandberg (1985)
Hietajärvi	7111020	3356300		A few cases of 1 m @ 5–6 ppm Au	Makkonen et al. (2003a)
Huhta	7108120	3366980		Best sections 5 m @ 1.5 ppm Au; 33 m @ 0.71 ppm Au	Lestinen & Mursu (2006)
Kaakkurinkangas	7097240	3353750		Best section 3.4 m @ 1.2 ppm Au	Kontoniemi (2009)
Kokkoharju	7087860	3365520		Best section 10.5 m @ 1.6 ppm Au; typically across a lode 5 m @ 2–5 ppm Au	Kärkkäinen (2004)
Louetjärvi	7091502	3366773		Best outcrop samples 14.9 g/t Au, 1.3 % As; 2.1 g/t Au, 1.6 % As	Sipilä (1989a)
Sipilä	7112226	3363664		0.5 m @ 5.6 g/t Au, 60 g/t Ag, 9.4% Cu; 0.45 m @ 0.5 g/t Au, 0.49 % Co	Sipilä (1989b)

Ga – billion years.

Exploration history

The exploration history of the Rautio area is long. In the 1950s–1970s, work was mostly focused on base metals and molybdenum by Vuoksenniska Oy, Rautaruukki Oy, Outokumpu Oy and GTK. Serious gold exploration commenced in the Rautio Orogenic Au tract area in the 1980s, when the global gold price rapidly increased. Since then, Outokumpu Oy, GTK and Belvedere Resources Ltd. have explored the region, including the occurrences listed in Table 3. The Hirsikangas deposit was discovered in 2004 by GTK. Exploration activities for orogenic Au deposits and occurrences within the tract are listed in Table 4.

Table 4. Exploration history for the Rautio Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Bedrock mapping, boulder tracing	Yes	Outokumpu	1980s
		Yes	GTK	1985–2008
		Yes	Belvedere Resources	2003–
Geochemical surveys	Regional till geochemistry	Yes	GTK	1982–1994
	Till and stream sediment survey	Yes	Outokumpu	1980s
	Till and stream sediment survey	Yes	GTK	1984–2005
Airborne geophysical surveys	Low-altitude magnetic, electromagnetic and radiometric survey		GTK	1976–2001
Ground geophysical surveys	Magnetic, IP, slingram		Outokumpu	1974–1981
	Magnetic, IP, slingram		GTK	1984–2006
Drilling	Percussion and diamond drilling	Yes	Outokumpu	1980s
	Percussion and diamond drilling	Yes	GTK	1989–2008
	Percussion and diamond drilling	Yes	Belvedere Resources	2004–

Sources of information

Principal sources of information used by the assessment team for the delineation of the Rautio Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Rautio Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps		Kousa et al. (2000)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Isokoski (1982), Sandberg (1985, 1986), Kärkkäinen (2004), Lestinen & Mursu (2005), Makkonen et al. (2003b), Lestinen & Mursu (2006), Kontoniemi (2009)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Isohanni (1984), Sandberg (1985, 1986, 1987), Tenhola (1990), Makkonen et al. (2003a), Kärkkäinen (2004), Lestinen & Mursu (2006)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Isokoski (1982), Isohanni (1984), Sandberg (1985, 1986), Makkonen et al. (2003a), Kärkkäinen (2004), Lestinen & Mursu (2005, 2006)
Exploration	Data on gold-enriched outcrops and boulders		Makkonen et al. (2003a)
	Reports		Isohanni (1984), Sandberg (1985, 1986, 1987), Sipilä (1989a,b), Kärkkäinen (2004), Lestinen & Mursu (2005), Makkonen et al. (2003b), Lestinen & Mursu (2006), Kontoniemi & Mursu (2006), Kontoniemi (2009)
	Mineral Resource summary of Hirsikangas		Nally et al. (2009)
	Geological Survey of Finland in-house drill-core database		

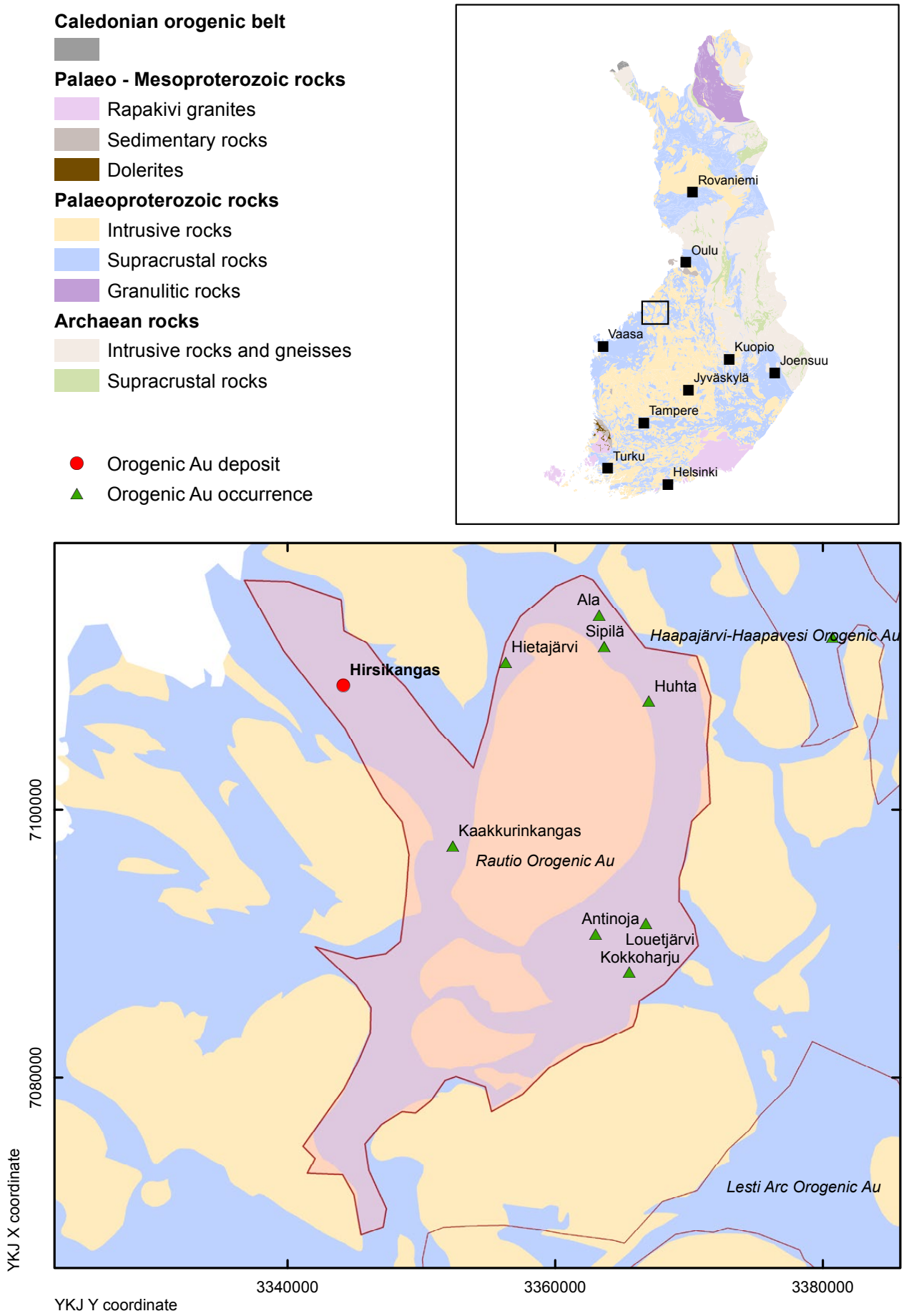

Fig. 1. Location of the Rautio Orogenic Au permissive tract.

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Six partially explored orogenic gold occurrences are known within the tract (Table 3). These occurrences are rather modest. The existence of the known Hirsikangas deposit, several partially explored gold occurrences, and a large number of gold-mineralised boulders with no identified bedrock source indicate the good potential for undiscovered orogenic gold deposits for the tract. Also, all the drilling has so far been shallow, leaving considerable room for further discoveries. The individual estimators considered the probability high that at least zero to one undiscovered economic deposits exist 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 Rautio Orogenic Au 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	3			1.9	0.84	43	1	2.9	815	0.0036

	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	4		
Individual 3	0	1	1		
Individual 4	1	2	4		
Individual 5	0	1	2		
Mean	1	2	3		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Hartikainen, Kontoniemi, Nikander, Västi.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Rautio Orogenic Au 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			
Au (t)	0	0.61	12	77	170	35	0.21	0.07
Rock (Mt)	0	0.13	5.2	51	170	25	0.17	0.07

t – metric tons; Mt – million metric tons.

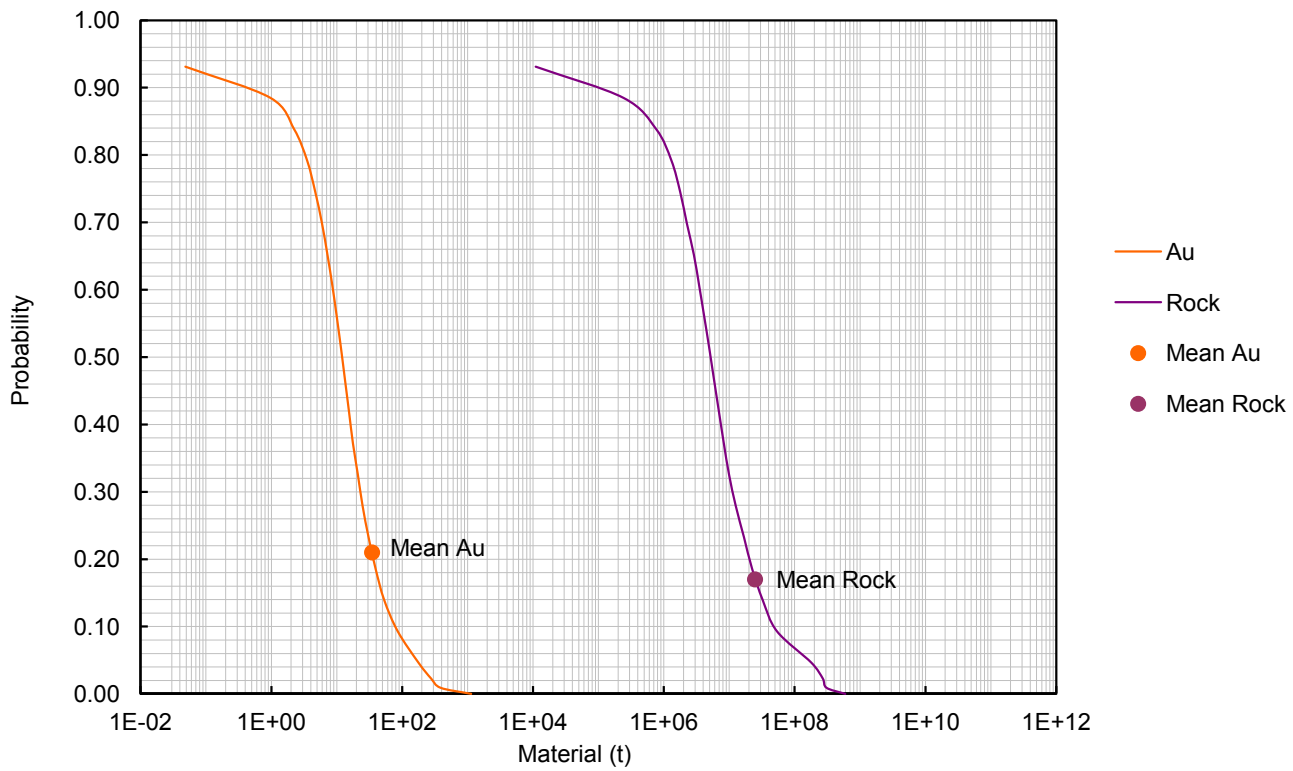

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Rautio Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT SALLA–KUUSAMO OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Salla–Kuusamo Orogenic Au permissive tract is located in northwestern Finland in the Kuusamo, Posio, Salla, Taivalkoski, Pudasjärvi and Savukoski municipalities, about 150 km E-SE of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 3541, 3542, 3543, 3544, 3633, 3634, 3643, 3644, 4522, 4524, 4611, 4612, 4613, 4614, 4621, 4622, 4623 and 4624. The UTM map sheets containing the tract are S512, S521, S522, S523, S524, S542, T513, T514, T523, T524, T531, T532, T541, U513 and U531. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Salla–Kuusamo Orogenic Au 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)
17/1/2012	1	5656	Au 0	Au 120	Au 70

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is defined by the known extent of Palaeoproterozoic supracrustal Salla, Kuusamo, Sodankylä and Savukoski group rocks in northeastern Finland and the 2.2–2.0 Ga dykes and sills within these units, in an area geographically mostly separated by an Archaean TTG terrain from the Sodankylä–Savukoski Orogenic Au tract in the northwest. To the north, the tract is bounded by the Archaean Eastern Lapland Complex (a TTG terrain), to the east by the Finnish–Russian border, to the south by Archaean Eastern Finland Complex (another TTG terrain), and to the west by Central Lapland Granitoid Complex rocks. Archaean TTG inliers form holes in the tract, as they are regarded barren for orogenic gold. Low-altitude airborne magnetic data is extensively used to define the

extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to 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 orogenic Au deposits within the 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 orogenic Au deposits in the Salla–Kuusamo Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are more than 20 partially explored orogenic Au occurrences within the permissive tract (Table 3). All gold occurrences so far detected from the tract area are of the Kuusamo type, considered to be 'orogenic gold occurrences with anomalous metal association', as this subcategory is defined by Goldfarb et al. (2001) based on epigenetic gold-base metal deposits elsewhere in the world. We did not use the recent 'metasedimentary-hosted Co-Cu-Au' deposit model (Slack 2013) for the Kuusamo deposits, as we did not consider that model to be well enough constrained to be a genetic model. Within the Salla–Kuusamo tract, the characteristic metal association is Au-Co-Cu±U±REE. There also are small U, Th, Cu, and Fe occurrences within the tract.

Table 3. Significant orogenic Au occurrences in the Salla–Kuusamo Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Apajalahti	7338470	3579654	*	0.1 Mt @ 5 g/t Au, 0.02 % Co, 0.05 % Cu, 0.04 % W	Lahtinen (1980)
Haarakumpu	7371031	3570272	*	4.68 Mt @ 0.17 % Co, 0.34 % Cu, Au not analysed. Later reanalysis of core has indicated 'significant Au values'	Vartiainen (1984)
Hangaslampi	7356023	3599107	1.85-1.82	0.403 Mt @ 5.1 g/t Au, 0.06 % Co, 0.1 % Cu, enveloped by 0.18 Mt @ 0.2 g/t Au, 0.09 % Co, enriched in Ag, REE, Mo and U	Vanhanen (2001), Dragon Mining (2012)
Hangaspuro (Juomasuo II)	7357088	3598355	1.85-1.82	3 m @ 4 g/t Au, enriched in Cu, Co and Mo	Vanhanen (1992a,c, 2001)
Honkilehto	7344584	3590244	*	1 m @ 1.5–6.0 g/t Au, enriched in Cu and Co	Pankka (1995), Vanhanen (2001)
Isoaho 1 (Rytisuo 6)	7354648	3599674	1.85-1.82	3 m @ 4 g/t Au, enriched in U	Vanhanen (1992a, 2001)
Isoaho 2 (Rytisuo 2)	7354824	3599165	1.85-1.82	Unreported grades, enriched in Au, Co, U	Korteniemi (1993), Vanhanen (2001)
Iso-Rehvi	7348284	3594322	*	~0.04 Mt @ 4 g/t Au, 0.05 % Co, 0.1 % Cu	Vanhanen (1991e)
Juomasuo	7356913	3598894	1.85-1.82	1.955 Mt @ 4.9 g/t Au, 0.15 % Co, 0.03 % Cu, enveloped by 3.084 Mt @ 0.1 g/t Au, 0.12 % Co	Vanhanen (2001), Dragon Mining (2011, 2012)

Table 3. Cont.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Kantolahti (Kantosuo)	7351006	3590537	*	1 m @ 3.0 g/t Au; 2 m @ 4.7 g/t Au; 0.9 m @ 10.2 g/t Au; 1 m @ 13.4 g/t Au; 4.7 m @ 0.20 % Co, enriched in Cu	Pankka (2000), Vanhanen (2001)
Konttiaho (Mutka-Aho 14)	7344718	3593041	1.85-1.82	8 m @ 10 g/t Au, enriched in Cu, Co, U, LREE and Mo	Vanhanen (1991b,c, 2001)
Kouvervaara	7338797	3582312	*	1.58 Mt @ 0.1 % Co, 0.4 g/t Au, 0.2 % Cu	Tarvainen (1985)
Kuusamon Hanhilampi	7354695	3598570	1.85-1.82	5 m @ 3 g/t Au	Vanhanen (1992a, 2001)
Lavasuo	7364467	3586467	*	1 m @ 2 g/t Au; 1 m @ 1.6 g/t Au, enriched in Cu and Co	Inkinen (1987a), Vanhanen (2001)
Lemmonlampi	7340172	3581745	*	0.14 Mt @ 0.37 g/t Au, 0.25 % Co, 0.41 % Cu	Lahtinen (1980)
Likalampi	7371155	3576034	*		Vanhanen (2001)
Meurastuksen-aho (Mutka-Aho 4)	7346659	3593849	*	0.892 Mt @ 2.3 g/t Au, 0.20 % Co, 0.1 % Cu, enriched in Mo and REE	Vanhanen (2001), Dragon Mining (2011)
Murronmaa	7342072	3590064	1.85-1.82	2 m @ 6 g/t Au, enriched in Cu and Co	Vanhanen (1990c, 2001)
Ollinsuo	7338874	3586013	*	14 m @ 3.3 g/t Au; 16 m @ 1.7 g/t Au, 0.11 % Co, 0.12 % Cu; 9.1 m @ 0.6 g/t Au, 0.88% Co, 0.10% Cu	Pankka (1989b), Vanhanen (2001)
Pohjaslampi	7354928	3599260	1.85-1.82	4 m @ 4 g/t Au, enriched in Cu, Co and U	Vanhanen (1992a, 2001)
Pohjasvaara	7355752	3599721	1.85-1.82	0.13 Mt @ 4.0 g/t Au, 0.09 % Co, 0.3 % Cu	Vanhanen (2001), Dragon Mining (2011)
Sakarinkaivu-lamminsuo (Juomasuo II)	7357326	3599145	1.85-1.82	2 m @ 5 g/t Au; 1 m @ 5.25 g/t Au, enriched in Cu and Co	Vanhanen (1992a,c, 2001)
Sarkanniemi	7353422	3590822	1.85-1.82	Up to 10 g/t Au detected, extent unknown, enriched in U	Pankka (1994), Vanhanen (2001)
Säynäjävaara	7342318	3584746	*	0.03 Mt @ 4.5 g/t Au or 0.4 Mt @ 1 g/t Au, 0.06 % Co, 0.02 % Cu	Pankka et al. (1991)
Sivakkaharju	7345778	3592190	1.85-1.82	0.05 @ 7.5 g/t Au, 0.03 % Co, 0.12 % Cu, 0.03 % U, enriched in Mo	Vanhanen (2001), Dragon Mining (2011)

Ga – billion years; * 2.07–2.02 Ga or 1.90–1.82 Ga; if these deposits are orogenic, their age is probably within the latter period.

Exploration history

Exploration activities for gold within the tract are listed in Table 4. Most of the exploration in the region has been carried out for Au, but copper, uranium and talc have also been explored for within the tract area.

Table 4. Exploration history for the Salla–Kuusamo Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	Yes	Geological Survey of Finland	1960–
	Outcrop observations and boulder survey	Yes since mid-1980s	Outokumpu	1960s–1990s
Geochemical surveys	Nationwide till survey, systematic, 1487 points	Yes	Geological Survey of Finland	1970s–1980s
	Targeted till survey, line till, systematic 100.1 km^2 and scattered sampling, profile total 85.5 km	No	Geological Survey of Finland	1970s–1980s
	Targeted till and regolith surveys, grid total 130.0 km^2	Yes	Geological Survey of Finland	1989–1990s
	Targeted till and regolith surveys, profile total 0.9 km	No	Geological Survey of Finland	1984
	Targeted till and regolith surveys, profile total 29.5 km	Yes	Geological Survey of Finland	1984–1995
	Regional lake sediment surveys, 175 points	No	Geological Survey of Finland	1980s
	Regional stream sediment surveys, organic, 256 points	No	Geological Survey of Finland	1970s
	Regional stream sediment surveys, inorganic, 32 points	No	Geological Survey of Finland	1975
	Targeted till and regolith surveys, grid total 2.4 km^2, profile total 29.5 km	Yes	Outokumpu	1980s–1990s
	Targeted till and regolith surveys, profile total 2.5 km, scattered uneven grid sampling 331 points	No	Outokumpu	1980s
	Targeted till and regolith surveys, profile total 127.3 km	No	Rautaruukki	1980s
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1980s–2000s
Ground geophysical surveys	Magnetic surveys, grid total 374.6 km^2, profile total 620.1 km		Geological Survey of Finland	1960s–2000s
	Gravimetric surveys, grid total 36.8 km^2, profile total 408.1 km		Geological Survey of Finland	1970s–2000s
	IP surveys, grid total 63.4 km^2, profile total 37.1 km		Geological Survey of Finland	1980s–2000s
	Slingram one frequency surveys, grid total 229.6 km^2, profile total 653.7 km		Geological Survey of Finland	1970s–1990s
	VLF surveys, grid total 6.9 km^2, profile total 12.0 km		Geological Survey of Finland	1988, 1996
	VLF-R surveys, grid total 166.0 km^2, profile total 300.7 km		Geological Survey of Finland	1980s–2000s
	Radiation (scintillometer) surveys, grid total 10.5 km^2		Geological Survey of Finland	1981
	Self-potential surveys, profile total 9.2 km		Geological Survey of Finland	1996

Table 4. Cont.

Theme	Type of work	Au analysed	Organisation	When carried out
Ground geophysical surveys	Magnetic (jalander) surveys, grid total 27.0 km^2		Outokumpu	1960s–1980s
	Magnetic (proton) surveys, grid total 21.9 km^2		Outokumpu	1980s–1990s
	Gravimetric surveys, grid total 6.2 km^2		Outokumpu	1970s
	IP surveys, grid total 5.3 km^2		Outokumpu	1970s–1990s
	Slingram surveys, grid total 30.2 km^2		Outokumpu	1970s–1990s
	VLF surveys, grid total 12.8 km^2		Outokumpu	1980s–1990s
	VLF-R surveys, grid total 10.1 km^2		Outokumpu	1990s
Drilling	Diamond drilling, 864 DDH, 70,486.00 m	Yes from 1980s onwards	Geological Survey of Finland	1960s–2010s
	Diamond drilling, 119 DDH, 10,913.05 m	Yes from 1985(?) onwards	Outokumpu	1960s–1990s
	Diamond drilling, 3 DDH, 277.50 m	No	Rautaruukki	1963
	Diamond drilling, 6 DDH, 262.35 m	No	Maa ja Vesi Oy	1989
	Diamond drilling, 5 DDH, 88.30 m	?	Malmikaivos Oy, Luikonlahden kaivos	1996
	Diamond drilling, 3 DDH, 92.20 m	?	Rio Tinto Zinc, Mining and Exploration	1996
	Diamond drilling, 14 DDH, 529.85 m	?	Ilmari Exploration Oy	2004–2007
	Diamond drilling, >100 DDH	Yes	Dragon Mining	2003–
	Diamond drilling, 8 DDH, 654.90 m	Yes	Belvedere Resources Ltd	2005

DDH – Diamond drill hole

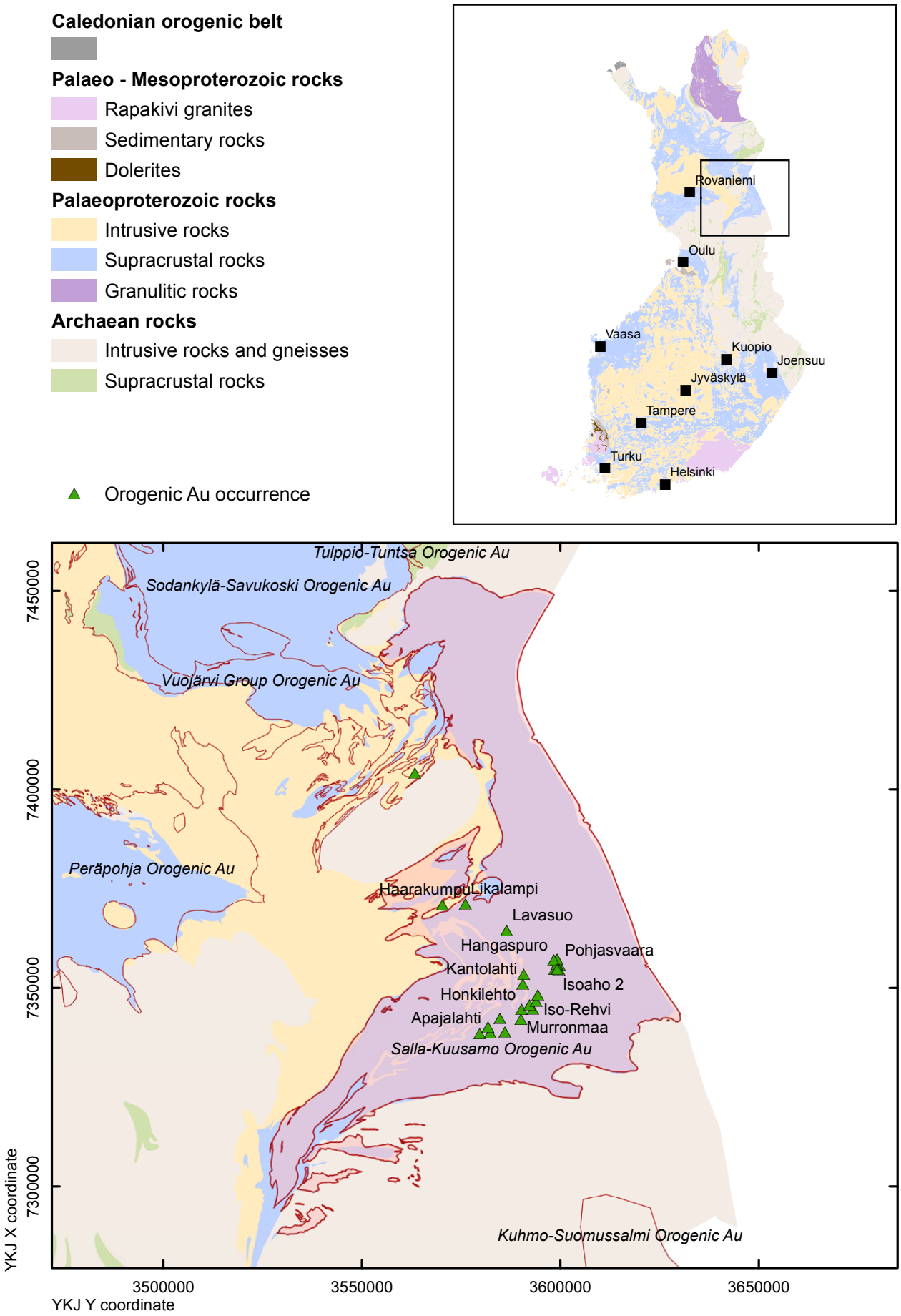

Fig. 1. Location of the Salla–Kuusamo Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Salla–Kuusamo Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Salla–Kuusamo Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:100,000	Lauerma (1967, 1995), Silvennoinen (1973, 1989, 1991), Honkamo (1979), Lahti & Honkamo (1980), Räsänen (1983)
	Thematic geology reports		Vanhanen (1989c, 1990b, 1991a, 2001), Manninen (1991), Pankka et al. (1991), Pankka (1992, 1997a), Pankka & Vanhanen (1992), Sorjonen-Ward (1992), Mänttäri (1995), Airo (1999), Arkimaa (1997), Turunen (2000b), Manninen & Huhma (2001), Räsänen & Vaasjoki (2001), Laajoki & Wanke (2002), Turunen et al. (2005), Eilu et al. (2007, 2012)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Kuronen (1981), Tarvainen (1985), Roos (1987), Vanhanen (1988a,b, 1989a,b,c, 1990a,b,c, 1991a,b,c,d,e, 1992a,b,c, 1997, 2001), Pankka (1989a,b, 1992, 1993, 1994, 1995, 1997b,c, 1999, 2000), Parkkinen (1989), Pankka et al. (1991), Pankka & Vanhanen (1992), Sorjonen-Ward (1992), Korteniemi (1993), Mänttäri (1995), Dragon Mining (2011, 2012, 2013), Eilu et al. (2007, 2012)
	Metallogenic assessment		Vanhanen (2001), Nykänen & Vanhanen (2003), Patison et al. (2008), Eilu et al. (2012)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Vartiainen (1985a), Vanhanen (1988a,b, 1989a, 1990c, 1991b,c,d, 1992a,b,c, 1997, 2001), Johansson & Nenonen (1990), Pankka (1994, 1995, 1997b), Pulkkinen (1996), Lahtinen (1997)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Vartiainen (1985a,b), Turunen (1986, 1989, 1990, 1991, 1995, 1996, 1997, 1999, 2000a,b), Inkinen (1987a,b), Vanhanen (1988a,b, 1989b,c, 1990a,c, 1991b,c,d,e, 1992a,b,c, 1997), Pankka (1989a,b, 1993, 1994, 1995, 1997b,c, 2000), Hugg (1994), Airo (1999), Arkimaa (1997), Lahtinen (1997), Turunen et al. (2005), Strauss (2006a,b)
Exploration	Reports		Lahtinen (1980, 1993, 1997), Tarvainen (1985, 1986), Vartiainen (1985a,b), Inkinen (1987a,b), Vanhanen (1988a,b,c, 1989a,b, 1990a,b,c, 1991b,c,d,e, 1992a,b,c, 1997), Pankka (1989a,b, 1994, 1995, 1997b,c, 1999, 2000), Parkkinen (1989), Turunen (1989, 1990, 1991, 1995, 1996, 1997, 1999, 2000a), Johansson & Nenonen (1990), Anttonen (1994), Hugg (1994, 1997), Strauss (2006a,b), Dragon Mining (2011, 2012, 2013), Lauri et al. (2013)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

More than 20 partially explored orogenic Au-Co±Cu±REE±U occurrences are known within the Salla–Kuusamo Orogenic Au tract (Table 3). Most of these occurrences are modest. The following were considered to indicate a good potential for orogenic gold deposits in the tract: 1) the presence of a large number of epigenetic Au-Co±Cu±U±REE occurrences, 2) a relatively low regional metamorphic grade, transitional between greenschist and amphibolite facies, for most of the tract area 3) abundant indications of extensive hydrothermal systems across the tract, 4) increasing of the size of the known occurrences with ongoing drilling and 5) a number of untested Au, Co and Cu indications especially in the southern part of the tract. Considerable amount of exploration has been carried out in the central parts of the tract around the known occurrences, but the northern and southern margins of the tract are less explored. The individual estimators considered the probability high that at least two to four undiscovered economic deposits exist 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 Salla–Kuusamo Orogenic Au 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}		
3	7	11			6.8	2.9	43	0	3	5656	0.0012

	Estimated number of undiscovered deposits				
Estimator	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
Individual 1	4	10	20		
Individual 2	2	8	10		
Individual 3	4	7	10		
Individual 4	2	3	5		
Individual 5	4	6	8		
Individual 6	4	8	15		
Mean	3	7	11		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Karvinen, Keinänen, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Salla–Kuusamo Orogenic Au 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			
Au (t)	5.6	15	70	310	420	120	0.31	0.03
Rock (Mt)	2.1	6.0	36	270	330	85	0.27	0.03

t – metric tons; Mt – million metric tons.

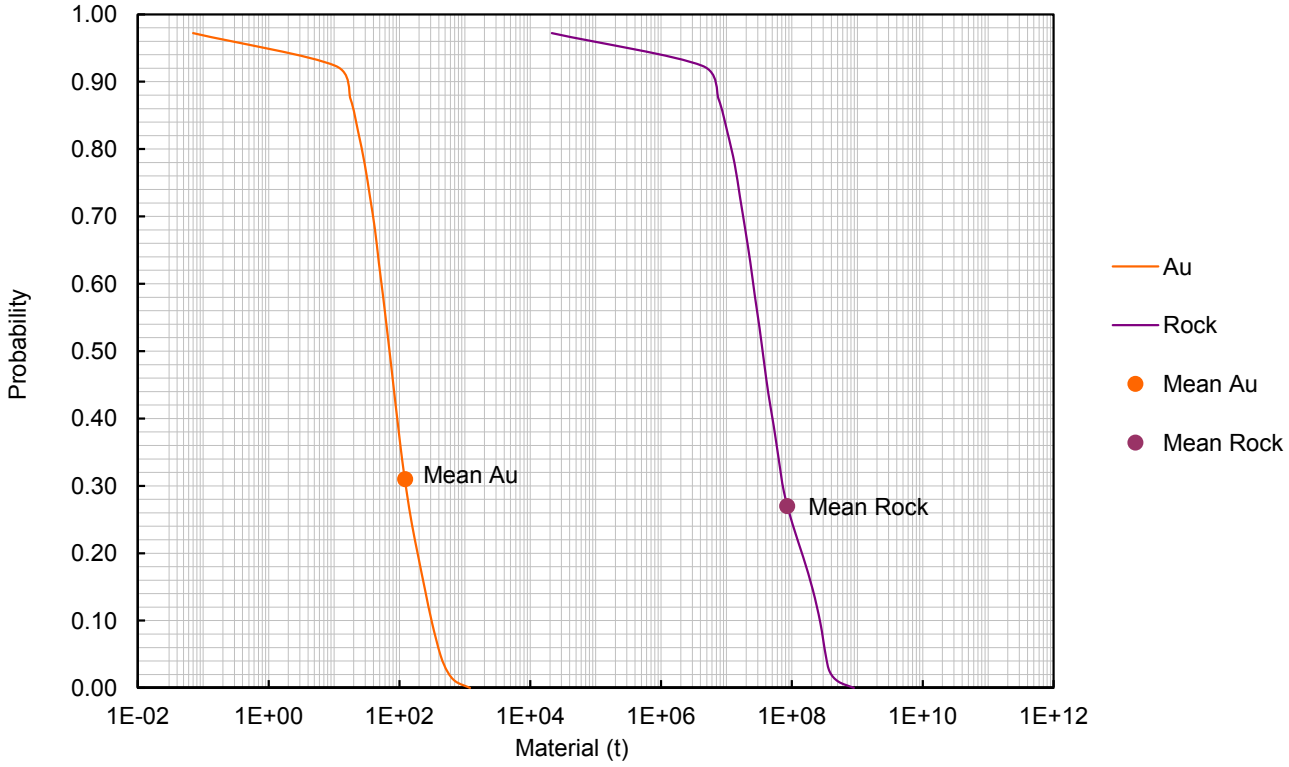

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Salla–Kuusamo Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT SATTANEN–KOLARI OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Sattanen–Kolari Orogenic Au permissive tract is located in northwestern Finland in the Kittilä, Kolari, Muonio and Sodankylä muncipalities 15-135 km N and NW of the city of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 2624, 2713, 2714, 2731, 2732, 2734, 2741, 2743, 3711, 3712, 3714 and 3732. The UTM map sheets containing the tract are U412, U413, U414, U421, U423, U424, U441, U442, U443, U444, U521 and U522. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Sattanen–Kolari Orogenic Au 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)	
17/1/2012	1	3028	Au	6.2	Au	140	Au	80

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The Sattanen–Kolari Orogenic Au tract is defined by the known extent of Palaeoproterozoic Savukoski Group rocks adjacent to the Sirkka Thrust Zone, and it includes the 2.44–2.05 Ga mafic dykes and intrusions within this unit. In the Kolari region in the western part of the tract, the Palaeoproterozoic Kuusamo Group rocks and 1.89–1.86 Ga Haparanda Suite intrusions are included in the tract. The tract is bounded by the Kittilä and Sodankylä Group rocks (includes the Sirkka Thrust Zone), the Sieppijärvi Suite migmatites and Vuojärvi and Sodankylä Group rocks to the east and south, and by the Kihlanki Suite granites and the Finnish–Swedish border to the west. Low-altitude

airborne magnetic data were extensively used to define the extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to that depth. The sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

There is one well-explored orogenic Au deposit within the Sattanen–Kolari Orogenic Au 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 orogenic Au deposits in the Sattanen–Kolari Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
Saattopora	7525055	3390825	1.9–1.87	2.163	2.91	6.3	Korvuo (1992, 1997a)

Ga – billion 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

More than 20 partially explored possibly orogenic Au occurrences are known within the Sattanen–Kolari Orogenic Au permissive tract (Table 3). Some of the occurrences display both syngenetic and epigenetic features, indicating that they are either entirely syngenetic, partially remobilised during deformation, or syngenetic base metal occurrences overprinted by orogenic gold (± orogenic base metals). For the rest of the occurrences, the base metal enrichment is also of orogenic style and epigenetic. There also are several IOCG-type occurrences within the westernmost part of the tract; these include the Hannukainen and Rautuvaara deposits (closed iron mines) and over ten smaller occurrences located within or next to the Pajala-Kolari shear zone. There is one major magmatic Ni-Cu-PGE deposit, the Kevitsa Mine, within the tract. Other types of occurrences within the tract include small U and Cu-Zn occurrences.

Table 3. Significant orogenic Au occurrences in the Sattanen–Kolari Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Aakenusvaara	7524022	3394980	?	18 m @ 1.12 g/t Au, 0.36 % Cu; 7 m @ 5.8 g/t Au; 4.8 m @ 2.76 g/t Au; 5.1 m @ 2.3 g/t Au	Korkalo (2006)
Ahvenjärvi (Isomaa)	7504362	3426067	?	1 m @ 4.9 g/t Au; 1 m @ 3.8 g/t Au; 5 m @ 1.3 g/t Au; 3 m @ 2.34 g/t Au; 1 m @ 2.63 g/t Au	Ilvonen (1994), Keinänen (2002b)
Harrilommol	7524596	3391403	1.9–1.87	3 m @ 5.0 g/t Au; several 1.2 m sections @ 2–7 g/t Au; 12 m @ 0.51 g/t Au, 0.16 % Cu	Lehtinen (1987), Korvuo (1997b)
Hirvilavanmaa	7519045	3423275	1.85–1.89	0.11 Mt @ 2.9 g/t Au. Best sections 3.5 m @ 6.5 g/t Au; 28 m @ 5.2 g/t Au	Keinänen et al. (1988), Hulkki & Keinänen (2007)
Hookana	7499725	3476825	?	1 m @ 1 g/t Au	Pulkkinen et al. (1986)
Kittilän Hanhilampi	7514263	3401716	?	1 m @ 13.3 g/t Au	Inkinen (1991a)
Kittilän Palovaara (Jerusaleminjänkä)	7512651	3427120	?	2 m @ 4.8 g/t Au; 13 m @ 2.74 g/t Au, 0.08 % Cu	Anttonen (1994)
Koppelokangas	7503000	3461000	?	2 m @ ~1 g/t Au	Inkinen (1992b), Korkalo (2006)

Table 3. Cont.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Kutuvuoma	7500970	3445970	?	0.068 Mt @ 7.3 g/t Au, 0.1 % Cu. Best sections: four 4–16 m sections @ ~11 g/t Au	Anttonen (1995), Korkalo (2006)
Lammasvuoma	7502169	3429595	?	1.2 m @ 25 g/t Au; 1 m @ 3.5 g/t Au; 1 m @ 1.5 g/t Au; 3 m @ 2.2 g/t Au; 3 m @ 1.8 g/t Au; 10 m @ 1.7 g/t Au	Hugg (1987b), Korkalo (2006)
Levijärvi–Loukinen	7526578	3414529	?	One lode 0.114 Mt @ 0.5 g/t Au, 0.45 % Ni; Four other lodes 1–10 m @ 1–5 g/t Au, up to 12 m @ 1.25 % Cu, 12.7 m @ 2.85 % Ni, all with 0.1–5 g/t Au	Holma et al. (2003), Eilu et al. (2007), Holma & Keinänen (2007)
Mustajärvi (Akharama-1)	7503401	3427923	?	2.7 m @ 14.6 g/t Au; 12 m @ 2.7 g/t Au	Korkalo (2006), Hugg (1996)
Muusanlammit	7523358	3398353	?	2.9 m @ 1.1 % Cu; 1.7 m @ 7.9 g/t Au; several 1.5 m sections @ 1–7 g/t Au, 5-14 g/t Ag	Inkinen (1991b), Roos (1987)
Naakenavaara*	7513391	3421148	?	1 m @ 10.3 g/t Au; 1 m @ 6.9 g/t Au; 1 m @ 2.60 g/t Au; 1 m @ 2.60 g/t Au; 1 m @ 1.4 g/t Au	Keinänen (2002a)
Pahtavaara*	7504900	3475300	?	2.8 Mt @ 1.9 g/t Au	Lappland Goldminers (2014)
Päivänenä (Kettukuusikko)	7521406	3422088	1.85–1.89	20.35 m @ 4.33 g/t Au; 2.43 m @ 14.62 g/t Au; 12.2 m @ 1.75 g/t Au; 31.4 m @ 1.25 g/t Au; 1.8 m @ 27.7 g/t Au; 28.9 m @ 1.4 g/t Au; 1 m @ 8.31 g/t Au	Hugg (1991b,c, 1997), Keinänen & Salmirinne (2003), Ronacher et al. (2011)
Pikku-Mustavaara (Eksymäselkä)	7503710	3433945	?	1 m @ 11.8 g/t Au; 2.5 m @ 10 g/t Au; 5 m @ 2.8 g/t Au, 0.3 % Cu	Härkönen & Keinänen (1989), Keinänen (1990a)
Pittarova*	7526838	3404028	?	Best sections 2.13 m @ 1.75 g/t Au, 0.13 % Cu, 0.006 % U; 1.45 m @ 0.85 g/t Au; 1.96 m @ 0.8 g/t Au; 4.02 m @ 0.66 g/t Au	Inkinen (1984)
Riikonkoski*	7518933	3414449	?	2.13 m @ 10.97 g/t Au; 24.0 m @ 1.43 % Cu; 9.56 Mt @ 0.48 % Cu, 0.1 to 12 g/t Au	Lehtinen (1987), Papunen (1987), Lång (1989)
Sirkka kaivos	7527061	3404590	?	Test mining 30 t @ 1 g/t Au, 0.16 % Co, 0.5 % Cu, 0.9 % Ni; best section 0.51 m @ 8.3 g/t Au, 1.95 % Cu	Lehtinen (1987), Holma et al. (2006), Eilu et al. (2007)
Sirkka W	7526838	3404028	?	11 m @ 0.5 g/t Au, 0.5% Cu; 40 m @ 0.8 g/t Au	Hugg (1987a), Eilu et al. (2007)
Soretialehto	7518965	3422870	1.85–1.89	0.013 Mt @ 3.5 g/t Au. Best sections 8 m @ 3–4 g/t Au; 5 m @ 1.88 g/t Au; 3.1 m @ 3.6 g/t Au; 1 m @ 7.5 g/t Au	Keinänen & Holma (2001), Keinänen et al. (1988)
Soretiavuoma N	7520772	3422758	?	3 m @ 5 g/t Au; 1.5 m @ 5.1 g/t Au; 1.1 m @ 48 g/t Au; 1 m @ 24.5 g/t Au; several 1–3 m sections @ 1–3 g/t Au	Keinänen (1990b, 1997)
Tuongankuusikko	7502900	3438900	?	17.5 m @ 1.18 g/t Au, 1.73 % Cu	Inkinen (1992a), Korkalo (2006)

Mt – million metric tons; t – metric ton. Occurrences marked by * display both syngenetic and epigenetic features.

Exploration history

Exploration within the tract has focused on iron, base metals, uranium, PGE and gold. Most of the gold exploration has been carried out in close proximity to the Sirkka thrust zone in the northern margin of the tract. Exploration activities for orogenic Au deposits within the Sattanen–Kolari Orogenic Au permissive tract are listed in Table 4.

Table 4. Exploration history for the Sattanen–Kolari Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	?	Outokumpu	1960s–1980s
	Outcrop observations and boulder survey	Partly yes	Geological Survey of Finland	1970s–2010s
	Outcrop observations and drill core revision	No	University of Turku	1984–1985
	Outcrop observations and boulder survey	Yes	SES Finland	1997–2003?
	Outcrop observations and boulder survey	Yes	Vuoksenniska	1955–1956
	Outcrop observations and boulder survey	Yes	Atri	1939–1953
Geochemical surveys	Nationwide till survey, systematic, 717 points	Yes	Geological Survey of Finland	1971–1991
	Line till geochemistry, systematic, total 24,041 points	No	Geological Survey of Finland	1975–1983
	Targeting geochemistry, profile sampling, total 320 km	Partly yes	Geological Survey of Finland	1970s–2000s
	Grid sampling, total 40 km^2		Geological Survey of Finland	1980s–2000s
	Organic sampling, total 3946 points	No	Geological Survey of Finland	1977–1980
	Inorganic sampling, total 3479 points	No	Geological Survey of Finland	1976–1981
	Targeting geochemistry on till, total 57,339 points	Partly yes	Outokumpu, Lapin Malmi, and Rautaruukki	1970s–1990s
Airborne geophysical surveys	Regional low-altitude airborne magnetic, electromagnetic and radiometric survey		Geological Survey of Finland	1975–2004
Ground geophysical surveys	VLF-R survey, profile surveys, total 355 km		Geological Survey of Finland	1980s–2000s
	Slingram survey one frequency, profile surveys, total 3604 km		Geological Survey of Finland	1972–1995
	Slingram survey multifrequency, profile surveys, total 81 km		Geological Survey of Finland	1987–1992
	Ip measurements, profile surveys, total 109 km		Geological Survey of Finland	1980s, 2003
	Gravimetric survey, profile surveys, total 574 km		Geological Survey of Finland	1972–1986
	Magnetic surveys, profile surveys, total 3978 km		Geological Survey of Finland	1970s–2000s
	Self potential survey, profile surveys, total 631 km		Geological Survey of Finland	1994, 2000

Table 4. Cont.

Theme	Type of work	Au analysed	Organisation	When carried out
	Slingram survey, profile surveys, total 1 km		Outokumpu	1991
	Ip survey, profile surveys, total 0.25 km		Outokumpu	1991
	VLF-R regional survey, systematic, total 31 km^2		Outokumpu	1991
	VLF regional survey, systematic surveys, total 5 km^2		Outokumpu	1983–1992
	Protem survey, profile surveys, total 28.5 km		Outokumpu	1989–1992
	Slingram regional survey, systematic surveys, total 230 km^2		Outokumpu	1970–1993
	Protem regional survey, systematic surveys, total 109 km^2		Outokumpu	1970–1993
	Jalander regional survey, systematic surveys, total 109 km^2		Outokumpu	1970–1993
	Ip regional survey, systematic surveys, total 6 km^2		Outokumpu	1980s–1990s
	Gravimetric regional survey, systematic surveys, total 23 km^2		Outokumpu	1980s
	Ground magnetic and electromagnetic surveys		Atri	1939–1953
Drilling	Diamond drilling, 1559 DDH, 170,258 m	Partly yes	Outokumpu	1967–2000
	Diamond drilling, 2053 DDH, 50,625 m	Partly yes	Geological Survey of Finland	1956–2011
	RC drilling, a few holes	Yes	SES	1997
	Diamond drilling, about 70 holes	Yes	Vuoksenniska	1955–1956
	Diamond drilling, >300 holes	Yes	Atri	1939–1953

DDH – Diamond drill hole

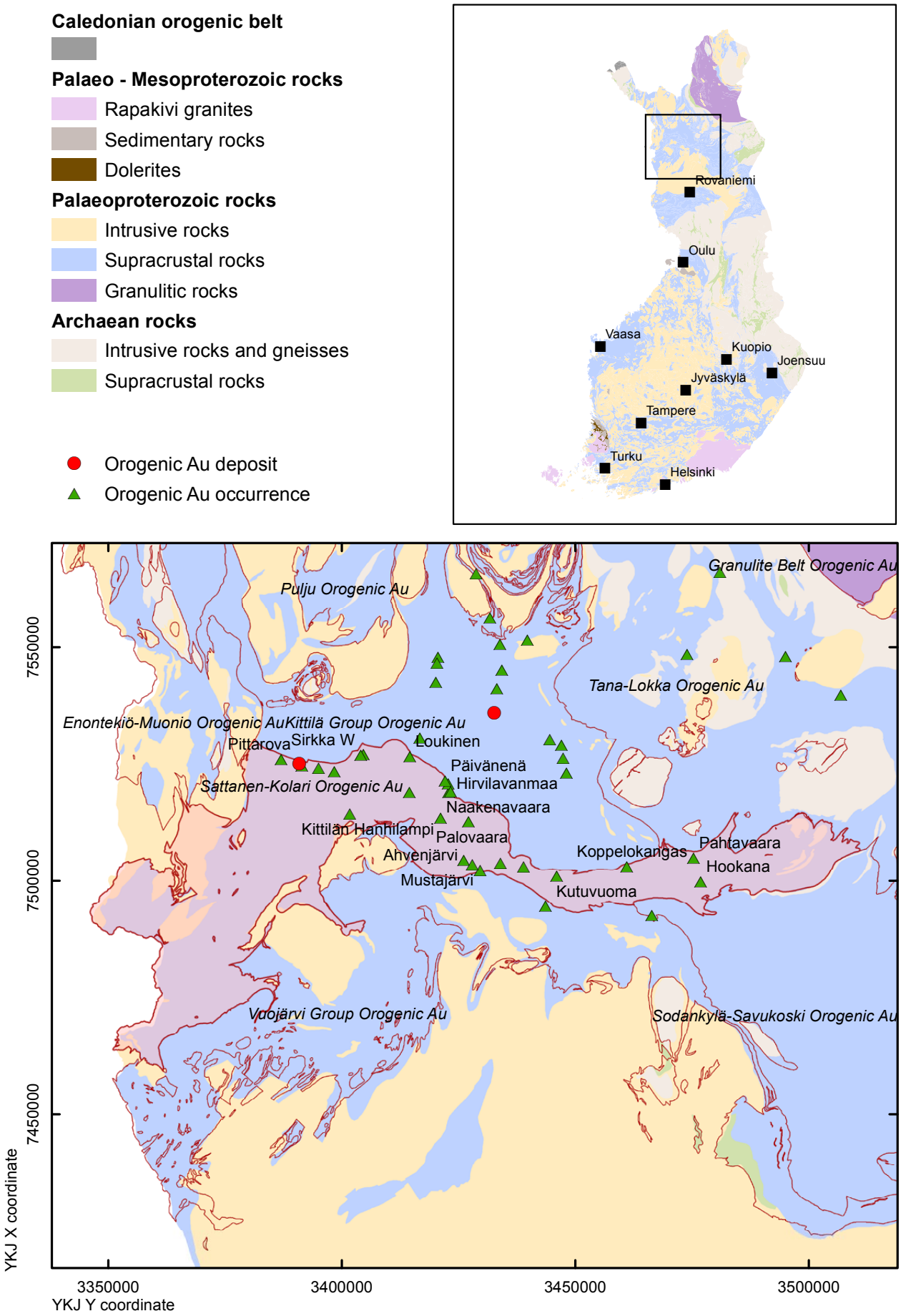

Fig. 1. Location of the Sattanen–Kolari Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Sattanen–Kolari Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Sattanen–Kolari Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:300,000	Lehtonen et al. (1998)
	Geological maps	1:100,000	Rastas (1984), Tyrväinen (1980, 1983), Väänänen & Leppinen (2002), Väänänen (1984, 1988, 1992, 2004)
	Thematic geology reports		Lehtinen (1987), Papunen (1987), Roos (1987), Mänttäri (1995), Lehtonen et al. (1998), Patinson & Oliver (2001), Väisänen (2002), Korkalo (2006), Eilu et al. (2007), Hölttä et al. (2007), Patison (2007), Saalmann & Niiranen (2010), Eilu et al. (2012)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Mikkola & Sandström (1964), Nurmi (1972), Hänninen (1977), Pulkkinen et al. (1986), Hugg (1987a,b, 1991a,b, 1996, 1997), Lehtinen (1987), Papunen (1987), Roos (1987), Härkönen & Keinänen (1989), Ilvonen (1994), Inkinen (1985, 1991a,b, 1992a,b), Keinänen et al. (1988), Lång (1989), Keinänen (1990a,b, 1997, 2002a,b), Anttonen (1992, 1994, 1995), Lanne (1995), Korvuo (1997a, 1997b), Keinänen & Holma (2001), Patison & Oliver (2001), Holma et al. (2003), Keinänen & Salmirinne (2003), Korkalo (2006), Holma & Keinänen (2007), Hulkki & Keinänen (2007), Eilu et al. (2007), Ronacher et al. (2011)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Kokkola (1975), Wennervirta (1972), Nurmi (1972), Pulkkinen (1983), Johansson et al. (1986), Keinänen et al. (1988), Nurmi et al. (1991), Hartikainen et al. (2008), Lehmuspelto et al. (2009), Pulkkinen & Sarala (2009), Lauri et al. (2013)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Eskola (1972), Turunen (1987), Lanne (1995), Keinänen & Salmirinne (2003), Lauri et al. (2013)
Exploration	Reports		Hugg (1987a,b, 1991a,b, 1997), Härkönen & Keinänen (1989), Keinänen (1990a,b, 1997, 2002a,b), Inkinen (1991a,b, 1992a,b), Anttonen (1994, 1995), Hölttä et al. (2007), Vartiainen & Keinänen (2008), Karvinen et al. (2010), Ronacher et al. (2011), Lauri et al. (2013)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

One well-explored orogenic gold deposit is known within the Sattanen–Kolari Orogenic Au tract. In addition, more than 20 possibly orogenic gold (± base metal) occurrences are known within the tract (Table 3). Most of these are modest. The following facts were considered to indicate high potential for undiscovered orogenic gold deposits within the tract: the presence of one well explored deposit and a large number of partially explored occurrences, the presence of a major thrust zone with proven orogenic Au potential, favourable metamorphic conditions, as most of the tract area is in greenschist facies, indications of large hydrothermal systems, and drilling of the known occurrences is limited to their upper 100 to 150 m. Most of the gold exploration has focused on the area around the Sirkka Thrust Zone and the exploration for gold has been limited in the central and the westernmost parts. The individual estimators considered the probability high that at least three to five undiscovered economic deposits exist 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 Sattanen–Kolari Orogenic Au 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}		
4	8	12			7.7	3.0	39	1	8.7	3028	0.0029

	Estimated number of undiscovered deposits				
Estimator	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
Individual 1	5	8	15		
Individual 2	3	6	8		
Individual 3	4	8	12		
Individual 4	5	8	10		
Individual 5	5	10	15		
Mean	4	8	12		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Keinänen, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Sattanen–Kolari Orogenic Au 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			
Au (t)	8.7	19	80	340	460	140	0.32	0.02
Rock (Mt)	3.1	8.0	43	290	350	96	0.29	0.02

t – metric tons; Mt – million metric tons.

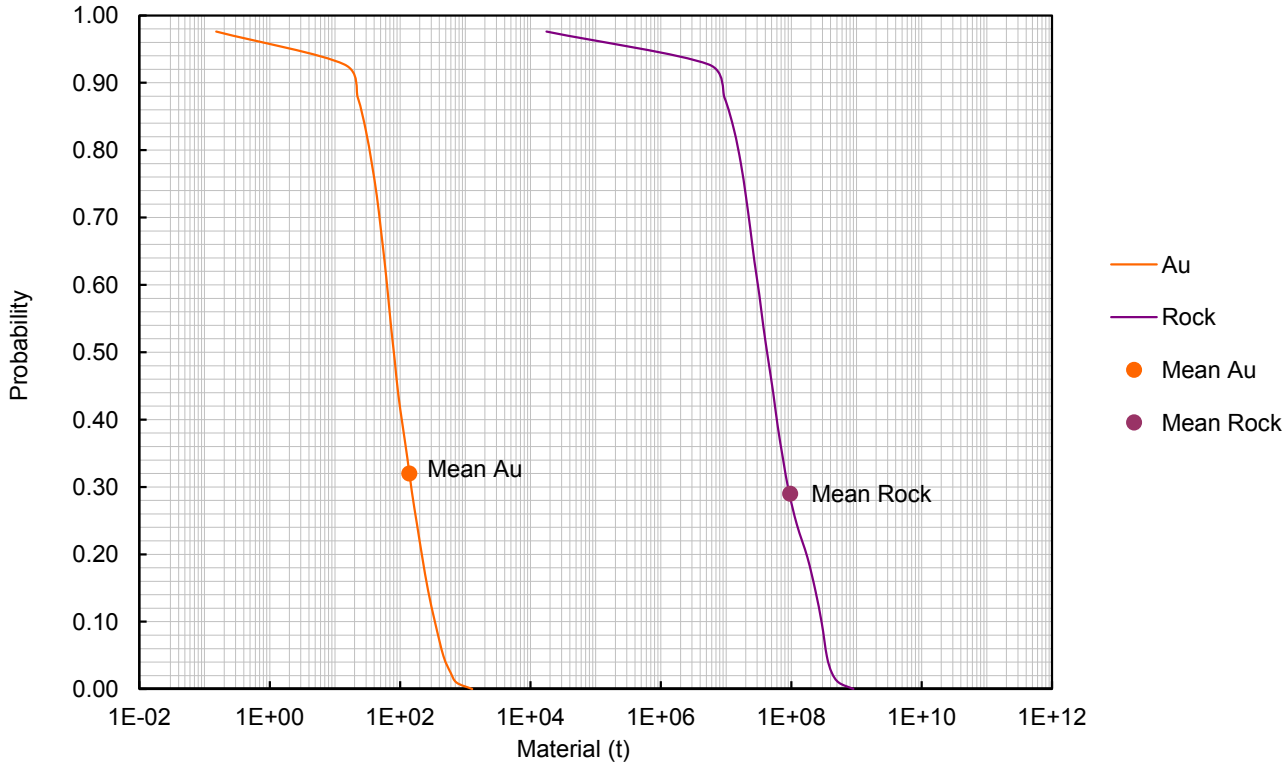

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Sattanen–Kolari Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT SEINÄJOKI OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Seinäjoki Orogenic Au permissive tract is located in western Finland in the municipalities of Alavus, Ilmajoki, Isokyrö, Kurikka, Laihia, Maalahti, Mustasaari, Närpiö, Seinäjoki and Teuva. It extends 70 km to the west-northwest, 40 km to the southeast and 70 km to the southwest of the town of Seinäjoki (Fig. 1). The 1:100,000 KKJ map sheets are 1241, 1242, 1243, 1244, 1331, 2221, 2222, 2223 and 2224. The UTM map sheets containing the tract are N342, N344, N422, P331, P332, P333, P334 and P411. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Seinäjoki Orogenic Au 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)	
04/03/2013	1	1842	Au	0.23	Au	75	Au	35

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The Seinäjoki Orogenic Au permissive tract is located along the northwestern margin of the Central Finland Granitoid Complex (CFGC) between the CFGC in the south and the Vaasa Complex in the north. The tract contains Palaeoproterozoic Svecofennian metasedimentary rocks (mica gneisses) of the central parts of the Pirttikylä and Teuva suites, metavolcanic rocks of the northern part of the Jurva suite and syntectonic intrusive rocks of the Central Finland Granitoid Complex (Geological Survey of Finland 2010). The delineation is based on suitable second- and third-order shear structures and presence of gold occurrences and gold-indicative outcrops and boulders. Low-altitude aeromagnetic data of Geological Survey of Finland (GTK) were used to define the margins of the tract. The tract extends down to 1000 m depth. The sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

There is one well-explored orogenic Au deposit within the 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 orogenic Au deposits in the Seinäjoki Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
Sikakangas (Tulisilmä)	6962679	3290560	1.9–1.8	0.171	1.32	0.23	Kärkkäinen (1993a), Isomaa et al. (2010)

Ga – billion 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

Ten partially explored orogenic Au occurrences are known within the permissive tract (Table 3).

Table 3. Significant orogenic Au occurrences in the Seinäjoki Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Kalliosalo	6964966	3293070		0.3 Mt @ 0.85 % Sb, 0.7 g/t Ag, 1.0 g/t Au	Tyni (1983), Kärkkäinen (1992a)
Koppelomäki	6968208	3281522		3 m @ 0.5 g/t Au, up to 0.453 % Sb	Kärkkäinen & Karttunen (2000)
Larvanmäki	6953965	3302284		1 m @ 4.85 g/t Au	Eilu (2012)
Marttalanniemi	6963817	3293827		87.4 m @ 0.90 g/t Au; 1 m @ 14.8 g/t Au; high Sb values	Kärkkäinen (1989, 1990), Nortec (2013)
Pihlajaniemi	6964583	3291097		1 m @ 1 g/t Au	Oivanen (1982)
Sudenkylä (Haudankylä)	6956998	3283382		1 m @ 3.5 g/t Au; high Sb values	Lestinen et al. (1991)
Tervasmäki	6966171	3291924		5 m @ 1.3 g/t Au, 0.55 % Sb	Oivanen (1982)
Timanttimaa	6945305	3308780		1.5 m @ 15.5 g/t Au; 3 m @ 1.8 g/t Au; possibly 1 Mt @ 1 g/t Au	Kärkkäinen (1993b)
Välikorpi	6969654	3256889		1 m @ 10.3 g/t Au; 7 m @ 2.7 g/t Au	Isomaa (2012)
Ylijoki	6955533	3298145		7 m @ 1 g/t Au; 1 m @ 6.7 g/t Au	Kärkkäinen (1992b)

Ga – billion years.

Exploration history

The exploration history of the Seinäjoki area is long. From the 1930s to the 1950s, work was mostly focused on base metals and antimony. W, Sb, Mo, Nb-Ta and feldspars have also been explored for in the region. Serious gold exploration commenced in the Seinäjoki Orogenic Au tract area in the 1980s when the global gold price rapidly increased. Since then, Outokumpu Oy, GTK and Nortec have explored the region, including the occurrences listed in Table 3. Presently, Au exploration is going on in the SE part of the tract. Exploration activities for orogenic-type Au±Sb deposits and occurrences within the tract are listed in Table 4.

Table 4. Exploration history for the Seinäjoki Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Bedrock mapping, boulder tracing	Yes	Outokumpu	1980s
	Bedrock mapping, boulder tracing	Yes	GTK	1930s–2000s
	Bedrock mapping, boulder tracing	Yes	Malmikaivos	1970s–1980s
	Bedrock mapping	Yes	Nortec	2010–
Geochemical surveys	Regional till geochemistry	Yes	GTK	1980s
	Till and stream sediment survey	Yes	GTK	1960s–2000s
	Targeted till survey	Yes	Nortec	2012–
Airborne geophysical surveys	Low-altitude magnetic, electromagnetic and radiometric survey		GTK	1976–2004
Ground geophysical surveys	Magnetic, IP, slingram		GTK	1960s–2000s
Drilling	Diamond and percussion drilling	Yes	GTK	1970s–2000s
	Diamond drilling	Yes	Malmikaivos	1980s
	Diamond drilling	Yes	Nortec	2010–

Sources of information

Principal sources of information used by the assessment team for the delineation of the Seinäjoki Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Seinäjoki Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Regional mapping	1:100,000	Lehtonen et al. (2005)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Pääkkönen (1966), Oivanen (1982), Tyni (1983), Kärkkäinen (1990, 1992a,b, 1993a,b), Appelqvist (1993), Kärkkäinen & Karttunen (2000), Isomaa et al. (2010), Isomaa (2012)
	Regional metallogenic assessments		Pääkkönen (1966), Oivanen (1982), Eilu (2012)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Oivanen (1982), Lestinen (1988), Kärkkäinen (1989, 1992b, 1993a,b), Lestinen et al. (1991), Isomaa et al. (2010), Hartikainen (2012)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Oivanen (1982), Kärkkäinen (1992b, 1993b), Isomaa et al. (2010), Isomaa (2012)
Exploration	Reports		Oivanen (1982), Tyni (1983), Kärkkäinen (1989, 1990, 1992a,b, 1993a,b), Lestinen et al. (1991), Kärkkäinen & Karttunen (2000), Isomaa et al. (2010), Isomaa (2012), Nortec Minerals (2012, 2013)
	Geological Survey of Finland in-house drill-core database		

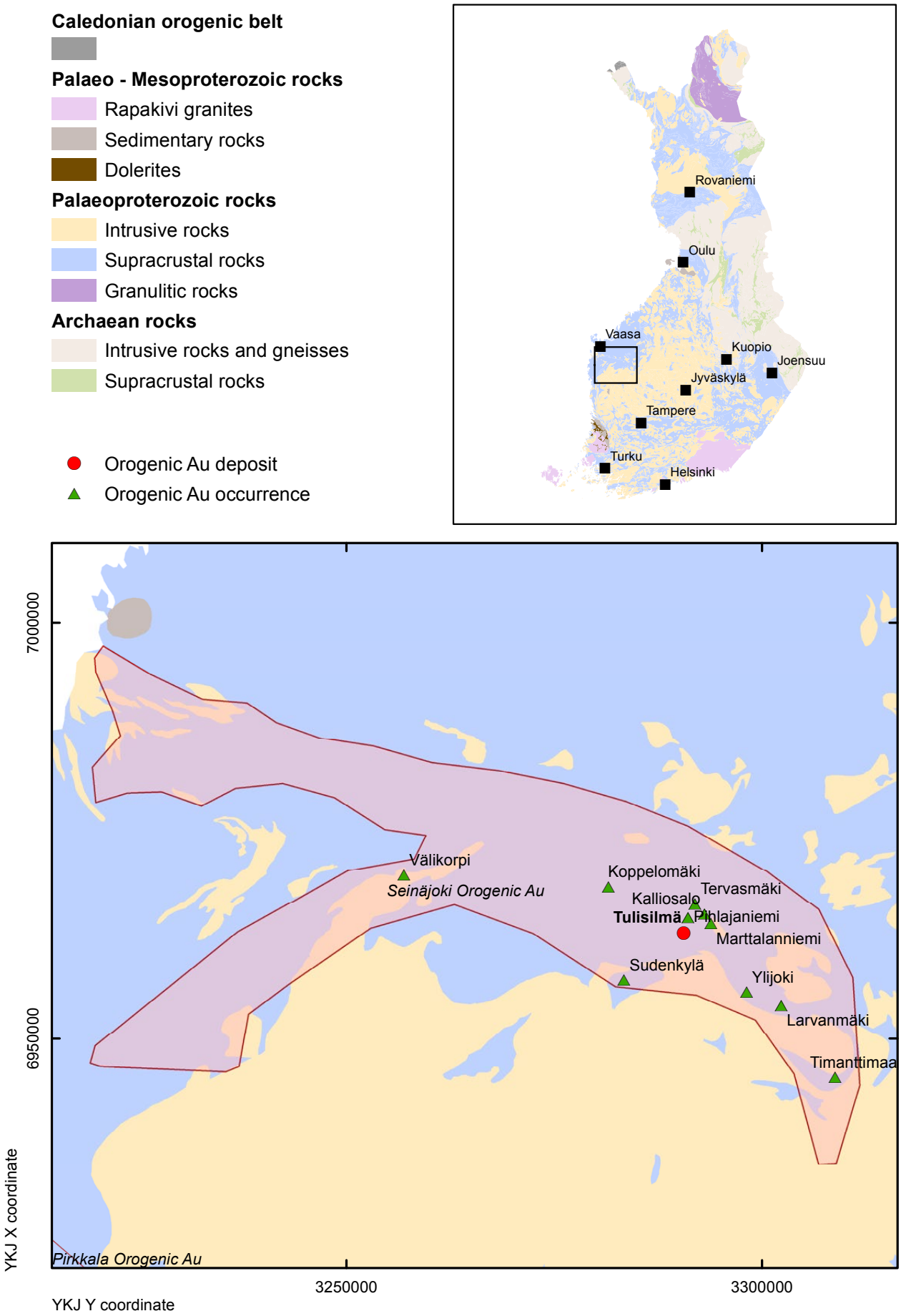

Fig. 1. Location of the Seinäjoki Orogenic Au permissive tract.

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Ten partially explored orogenic gold occurrences are known within the tract (Table 3). These occurrences are rather modest. The existence of the known orogenic gold deposit, a large number of partially explored gold±antimony deposits, a number of mineralised outcrops not drilled, a large number of gold-mineralised boulders with no indicated bedrock source, and the extensive lower amphibolite facies subareas indicate the good potential for undiscovered orogenic gold deposits for the tract. Also, all the drilling has so far been shallow, leaving considerable room for further discoveries. The individual estimators considered the probability high that at least one to four undiscovered economic deposits exist 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 Seinäjoki Orogenic Au 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}		
2	4	7			4.2	1.9	46	1	5.2	1842	0.0028

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Grönholm, Kärkkäinen, Kontoniemi, Niiranen, Sorjonen-Ward, Tiainen.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Seinäjoki Orogenic Au 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			
Au (t)	1.2	5.8	35	200	310	75	0.26	0.04
Rock (Mt)	0.33	2.1	17	180	280	52	0.23	0.04

t – metric tons; Mt – million metric tons.

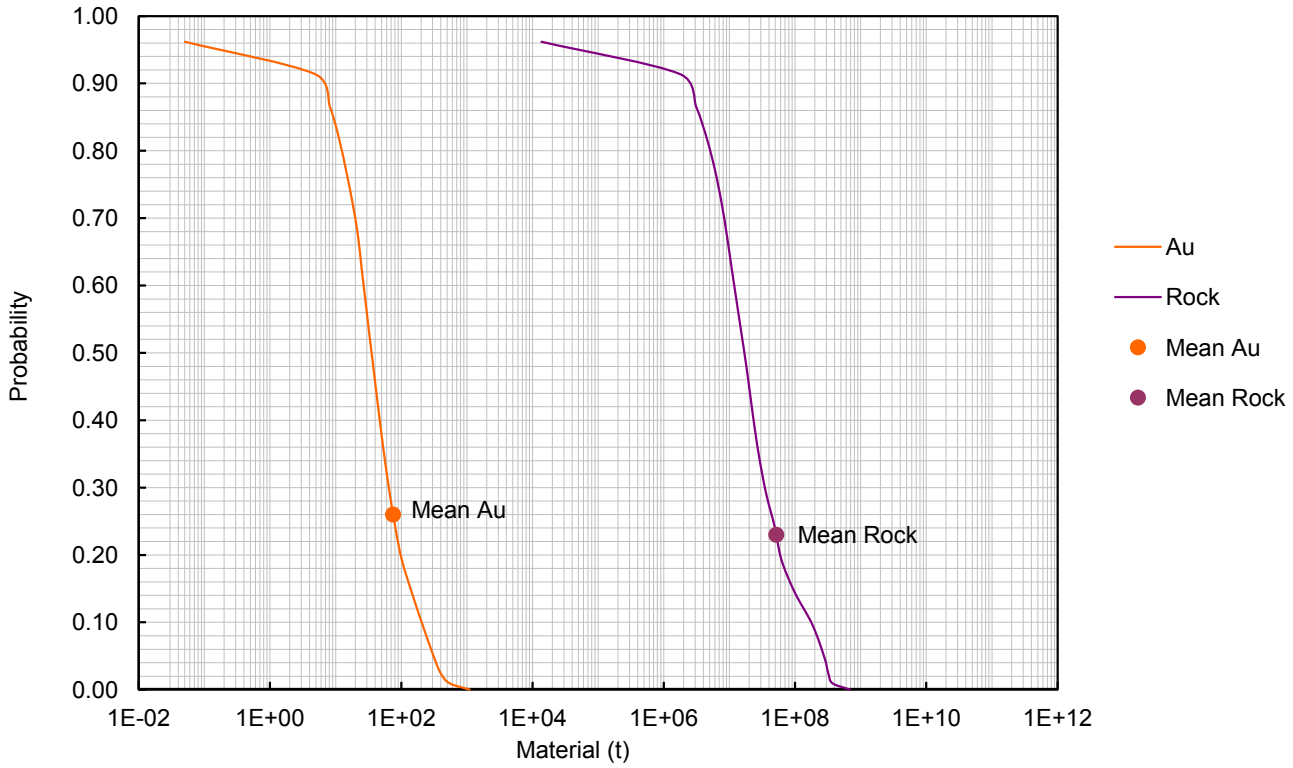

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Seinäjoki Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT SODANKYLÄ–SAVUKOSKI OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Sodankylä–Savukoski Orogenic Au permissive tract is located in northern Finland in the Savukoski, Pelkosenniemi, Sodankylä, Kemijärvi and Salla municipalities, about 125 km NE of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 3624, 3641, 3642, 3643, 3644, 3713, 3714, 3731, 3732, 3733, 3734, 4622, 4711 and 4712. The UTM map sheets containing the tract are T444, T522, T524, U433, U434, U443, U511, U512, U513, U514, U521, U522, U523 and U524. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Sodankylä–Savukoski Orogenic Au 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)
18/1/2012	1	4420	Au 0	Au 73	Au 34

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is defined by the known extent of Palaeoproterozoic supracrustal Salla, Kuusamo, Sodankylä, Savukoski and Kumpu Group rocks in northern Finland, as well as the 2.44–2.0 Ga mafic intrusions, dykes and sills within these units. To the N, the tract is bounded by the Sattanen–Kolari and Tana–Lokka Orogenic Au tracts, to the NE and E by the Tulppio–Tuntsa, to the SE by the Salla–Kuusamo and to the SW by the Vuojärvi Group Orogenic Au tracts. Archaean TTG inliers form a few holes in the tract, as they are regarded barren for orogenic gold. Low-altitude airborne magnetic data were extensively used to define the extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to 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 orogenic Au deposits within the 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 orogenic Au deposits in the Sodankylä–Savukoski Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences, and related deposit types

There is one partially explored orogenic Au occurrence within the permissive tract (Table 3).

Table 3. Significant orogenic Au occurrences in the Sodankylä–Savukoski Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Kaaresselkä	7492637	3466390		0.3 Mt @ 5 g/t Au, enriched in Cu	Pulkkinen (1999)

Ga – billion years.

Exploration history

Exploration activities for gold within the tract are listed in Table 4. Most of the exploration in the region has targeted base metals, Cr and PGE and Fe.

Table 4. Exploration history for the Sodankylä–Savukoski Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	Partly	Geological Survey of Finland	1960–
	Outcrop observations	?	University of Oulu	1990s
	Outcrop observations and boulder survey	?	Outokumpu	1960s–1970s
Geochemical surveys	Nationwide till survey, systematic, 1040 points	Yes	Geological Survey of Finland	1970s–1980s
	Targeting till and regolith surveys, line till, systematic 3365.4 km^2 and scattered sampling 1458 points	No	Geological Survey of Finland	1970s
	Targeted till and regolith surveys, grid total 175.4 km^2	Yes	Geological Survey of Finland	1980s–2000s
	Targeted till and regolith surveys, scattered sampling, 550 points	No	Geological Survey of Finland	1978–1979
	Targeted till and regolith surveys, profile total 38.1 km	No	Geological Survey of Finland	1978–1990s
	Targeted till and regolith surveys, profile total 18.9 km	Yes	Geological Survey of Finland	1978–1990s
	Regional stream sediment surveys, organic, 5595 points	No	Geological Survey of Finland	1970s–1980s
	Regional stream sediment surveys, inorganic, 4320 points	No	Geological Survey of Finland	1970s–1980s

Table 4. Cont.

Theme	Type of work	Au analysed	Organisation	When carried out
Geochemical surveys	Targeted till and regolith surveys, profile total 72.2 km	No	Outokumpu, Rautaruukki	1980s
	Targeted till and regolith surveys, hydromorphic, scattered sampling, 19 points	No	Rautaruukki	1980s
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1970s–2000s
Ground geophysical surveys	Magnetic surveys, grid total 213.3 km^2, profile total 422.9 km		Geological Survey of Finland	1970s–2000s
	Gravimetric surveys, grid total 66.86 km^2, profile total 149.6 km		Geological Survey of Finland	1970s–2000s
	IP surveys, grid total 1.44 km^2, profile total 8.9 km		Geological Survey of Finland	1990s–2000s
	Slingram multifrequency surveys, grid total 32.1 km^2		Geological Survey of Finland	1991
	Slingram one frequency surveys, grid total 81.5 km^2, profile total 311.0 km		Geological Survey of Finland	1970s–1990s
	VLF surveys, grid total 3.8 km^2, profile total 63.8 km		Geological Survey of Finland	1987, 1995
	VLF-R surveys, grid total 90.1 km^2, profile total 195.2 km		Geological Survey of Finland	1980s–2000s
	Self potential surveys, grid total 1.3 km^2, profile total 4.0 km		Geological Survey of Finland	1990s
	Magnetic (proton) surveys, grid total 1.5 km^2		Outokumpu	1988
	Slingram surveys, grid total 1.5 km^2		Outokumpu	1988
Drilling	Diamond drilling, 1015 DDH, 67,493.90 m	Yes, from 1990s onwards	Geological Survey of Finland	1970s–2010s
	Diamond drilling, 49 DDH, 6933.40 m	No	Outokumpu	1950s–2000s
	Diamond drilling, 2 DDH, 140.35 m	No	Rautaruukki	1950s
	Diamond drilling, 15 DDH, 333.40 m	No	Kemijoki Oy	1970s
	Diamond drilling, 4 DDH, 127.40 m	?	Rio Tinto Zinc, Mining and Exploration	1990s
	Diamond drilling, 2 DDH, 201.40 m	?	Conroy – Diamonds and Gold	2007
	Diamond drilling, 2 DDH, 65.20m	?	Suomen Malmi Oy	2007

DDH – Diamond drill hole

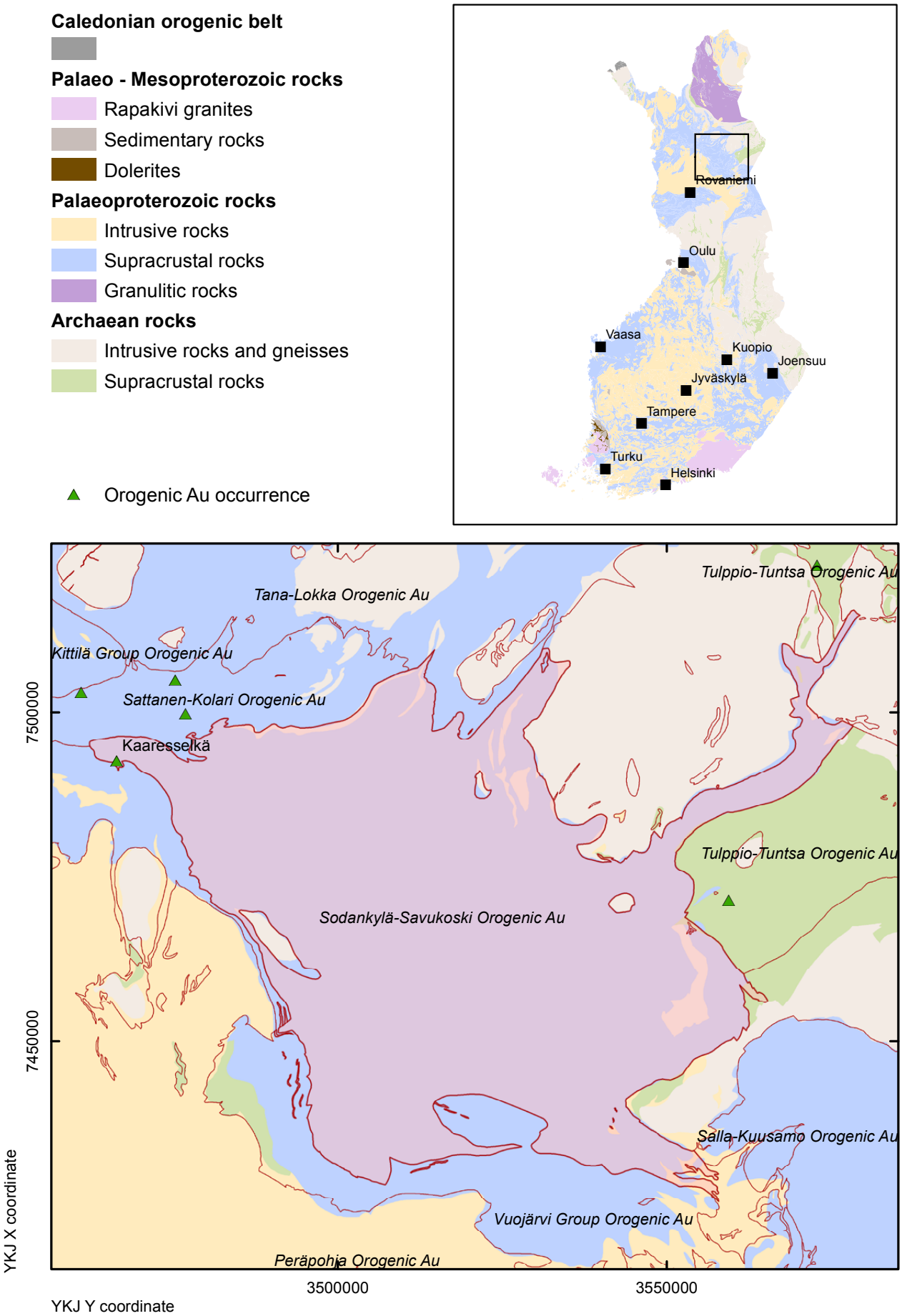

Fig. 1. Location of the Sodankylä–Savukoski Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Sodankylä–Savukoski Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Sodankylä–Savukoski Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:100,000	Lauerma (1967), Mielikäinen (1979), Tyrväinen (1979, 1980, 1983), Räsänen (1983), Juopperi (1986), Lauerma (1995)
	Thematic geology reports		Lehtonen et al. (1998), Räsänen & Huhma (2001), Korkalo (2006), Eilu et al. (2007, 2012), Hölttä et al. (2007), Patison (2007), Salmirinne & Turunen (2007), Räsänen (2008)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Hulkki (1998), Pulkkinen (1993, 1998a,b, 1999), Pankka (1998), Eilu et al. (2007), Hulkki & Pulkkinen (2007)
	Metallogenic assessment		Nykänen & Salmirinne (2007), Nykänen (2008, 2010), Patison et al. (2008)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Lehmuspelto (1978, 1994), Lehmuspelto & Vuojärvi (1979, 1981), Pulkkinen (1979, 1983, 1993, 1998b), Härkönen & Pulkkinen (1981), Karvinen (1981a), Pulkkinen & Hulkki (1999), Hulkki & Pulkkinen (2007), Lehmuspelto et al. (2009), Pulkkinen & Sarala (2009), Lauri et al. (2013)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Härkönen (1980), Turunen (1980), Karvinen (1981a), Pulkkinen & Hulkki (1999), Airo (2007), Hulkki & Pulkkinen (2007), Salmirinne & Turunen (2007), Lauri et al. (2013)
Exploration	Reports		Lehmuspelto & Vuojärvi (1979, 1981), Pulkkinen (1979, 1998b, 1999), Härkönen (1980), Karvinen (1981b, 1997), Hulkki (1998), Pulkkinen & Hulkki (1999), Hulkki & Pulkkinen (2007), Karvinen & Sandgren (2010), Lauri et al. (2013)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

One partially explored orogenic Au occurrence is known within the Sodankylä–Savukoski Orogenic Au tract (Table 3). This occurrence is so modest that it was considered possible that it will never become an economic deposit, even under the most favourable circumstances. The following were con-

sidered to indicate the potential for undiscovered orogenic gold deposits in the tract: 1) the presence of one partially explored orogenic Au deposit, 2) the presence of two major crustal-scale thrust zones in the western part of the tract, 3) greenschist facies metamorphic grade in the westernmost part of the tract, 4) minor(?) palaeoplacers in the Kumpu formation rocks of the tract and 5) abundant anomalous gold values (up to ppm grade) in till geochemical data. Gold exploration has been limited for most of the tract area. The individual estimators considered the probability high that at least zero to three undiscovered economic deposits exist 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 Sodankylä–Savukoski Orogenic Au 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}		
2	4	7			4.2	1.9	46	0	4.2	4420	0.00095

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Karvinen, Keinänen, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Sodankylä–Savukoski Orogenic Au 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			
Au (t)	0.78	5.3	34	190	310	73	0.26	0.04
Rock (Mt)	0.22	2.0	16	180	270	51	0.23	0.04

t – metric tons; Mt – million metric tons.

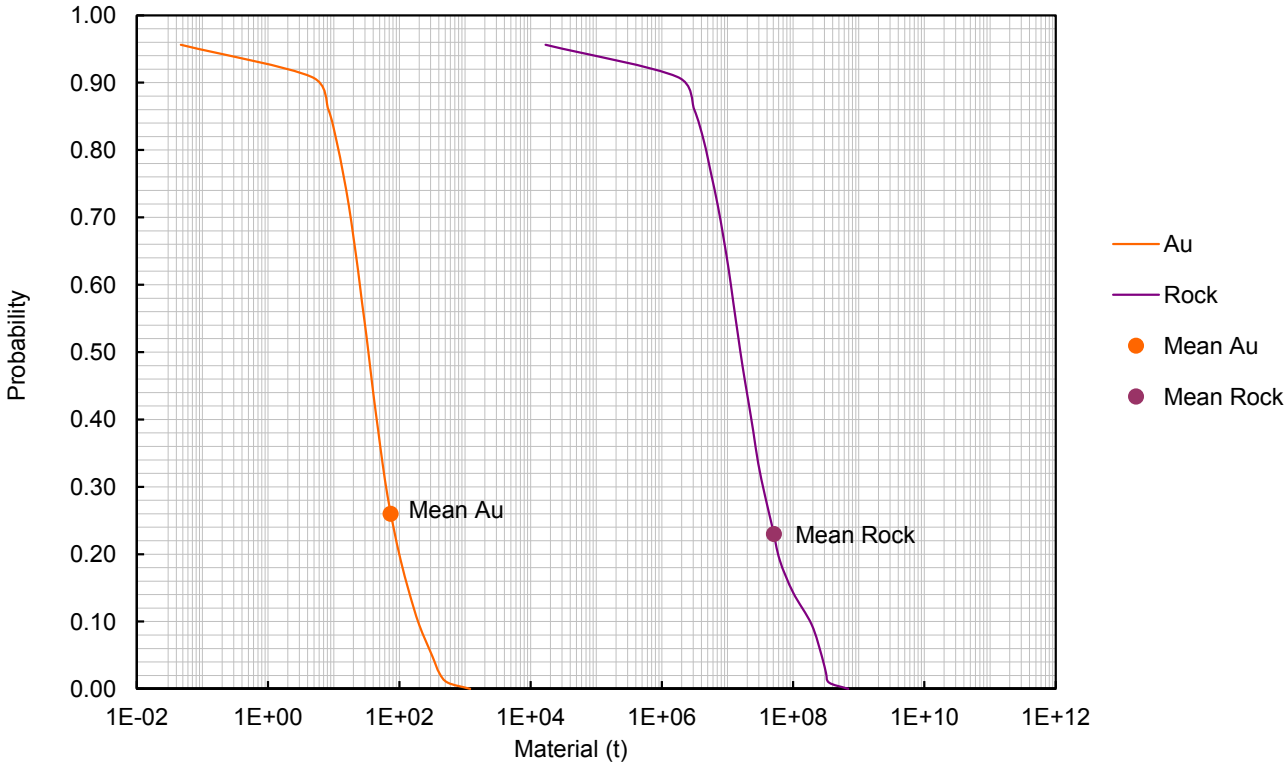

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Sodankylä–Savukoski Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT SONKAJA OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Sonkaja Orogenic Au permissive tract is located in eastern Finland in the municipalities of Ilomantsi, Joensuu and Lieksa (Fig. 1). The 1:100,000 KKJ map sheets covering the tract are 4241, 4242, 4244, 4333, and 4334. The UTM map sheets containing the tract are N544, N622, P533, P534, P611, P612 and P621. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Sonkaja Orogenic Au 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)	
8/11/2011	1	1026	Au	0	Au	24	Au	5.2

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The Sonkaja Orogenic Au permissive tract comprises a relatively poorly exposed NE-trending segment of the Ilomantsi greenstone belt, between the NW-trending Kovero–Nunnanlahti permissive tract to the southwest and N-trending Hattu permissive tract in the east. The Sonkaja permissive tract comprises mafic rocks, strongly recrystallised and metamorphosed, with some turbiditic metasediments, but stratigraphical correlations and structural geometry are poorly understood (Nykänen 1971, Laiti 1983, Piirainen & Vuollo 1991). The tract passes along the western margin of the large Silvevaara Granodiorite pluton and trends north towards the western margin of the Hattu Orogenic Au tract. In this area, there are metasediments with higher metamorphic grade, almost anatectic, and leucogranitoid intrusions. The tract also includes granitoid intrusions.

As with the adjacent Hattu and Kovero-Nunnanlahti Orogenic Au tracts, the area experienced

a renewed metamorphic event under greenschist to lower-amphibolite facies conditions, as a consequence of Svecofennian orogenic deformation between 1.9–1.8 Ga (Kontinen et al. 1992). However, the lack of significant deformation, in part constrained by the low strain state of Proterozoic mafic dykes, and microstructural studies of recrystallisation of mineral assemblages, provides strong evidence against significant hydrothermal activity and mineralisation potential during the Palaeoproterozoic (Sorjonen-Ward 1993a).

The justification for extrapolation of the tract to a depth of 1 km is based on down-dip extrapolation of foliation and is independently supported by geophysical data. Sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

There are no orogenic Au deposits within the Sonkaja 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 orogenic Au deposits in the Sonkaja Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences, and related deposit types

There are presently no partially explored gold occurrences in the Sonkaja permissive tract (Table 3). The only recorded metal exploration is in the Huhus area, where Rautaruukki Oy conducted preliminary investigations into the extent of banded iron ore formations. Outokumpu Mining also tested the Zn-Pb potential near Huhus (Kurki 1980).

Table 3. Significant orogenic Au occurrences in the Sonkaja Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
None					

Ga – billion years.

Exploration history

Archaean banded iron formations in the area covered by the permissive tract were assessed with respect to the iron resource potential during the 1970s (Lehto & Niiniskorpi 1977). Several holes were drilled by Outokumpu Mining in 1980 near Huhus while testing for the Zn-Pb potential (Kurki 1980). However, no other exploration activity has been recorded, apart from an expression of interest by Stonerol Oy in 2012, which was subsequently abandoned (Markku Iljina personal comm. 2013).

Table 4. Exploration history for the Sonkaja Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	No	Geological Survey of Finland	1895–1913, 1967–1975
	Outcrop observations and boulder survey	No	Rautaruukki Oy	1970s
	Outcrop observations and boulder survey	No	University of Oulu	1985–1992
	Outcrop observations and boulder survey	No	Outokumpu Mining Oy	1984–2003
Geochemical surveys	Nationwide till sampling	Yes	Geological Survey of Finland	1980s
	Till and bedrock geochemical surveys	After 1984	Geological Survey of Finland	1970s–1995
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1990s
	Low-altitude airborne magnetic, electromagnetic surveys		Rautaruukki Oy	1970s
Ground geophysical surveys				
	Magnetic, slingram and IP surveys		Outokumpu Oy	1985–2003
	Diamond drilling for BIF	No	Rautaruukki Oy	1970s
	Diamond drilling for Zn-Pb exploration	No	Outokumpu Oy	1980

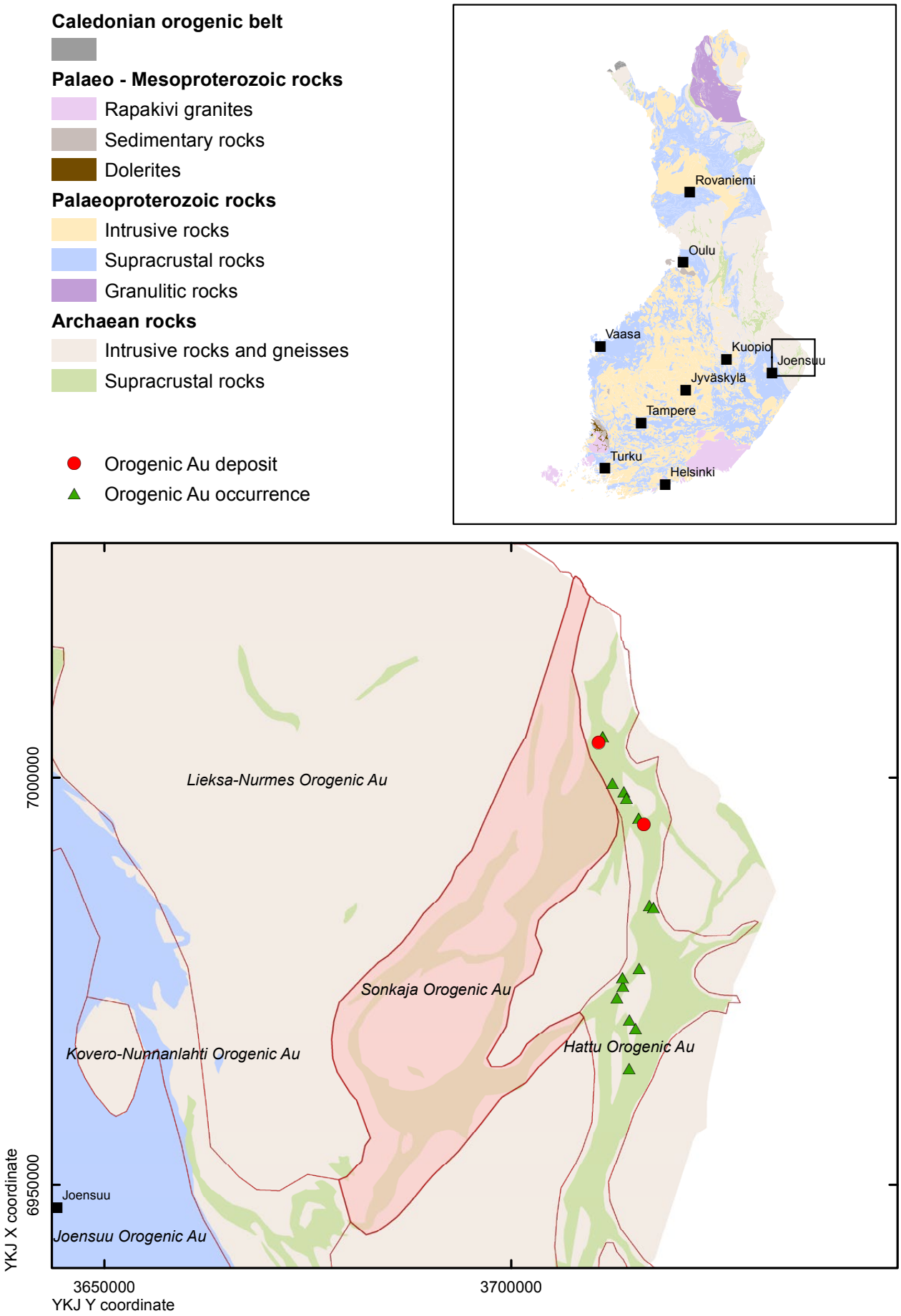

Fig. 1. Location of the Sonkaja Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Sonkaja Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Sonkaja Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:400,000	Frosterus & Wilkman (1920)
	Regional bedrock maps	1:100,000	Laiti (1983)
	Regional bedrock map	1:50,000	Sorjonen-Ward (1993b)
	Thematic geology reports		Piirainen & Vuollo (1991), Sorjonen-Ward (1993a)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Luukkonen et al. (2002), Pietikäinen et al. (2005)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Luukkonen et al. (2002), Pietikäinen et al. (2005)
Exploration	Reports		Luukkonen et al. (2002), Pietikäinen et al. (2005)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

No orogenic gold deposits or occurrences are known in the tract. The rationale for the estimate is largely influenced by a relatively unfavourable comparison with the Hattu permissive tract to the east, which is more mature in terms of exploration and which already has an operating gold mine and a number of extensively drilled targets. Although the Sonkaja permissive tract is inferentially of similar age to the adjacent Kovero–Nunnanlahti tract to the west, there are few known structural features that might appear to be potentially mineralised, whereas the metamorphic grade in the northern and western part is somewhat higher than in typically prospective orogenic Au terrains. Unlike the Hattu tract, there have been no systematic detailed geochemical surveys and the tract does not coincide with Au anomalies in the regional data. On the other hand, there is little direct geological information from the tract, as large parts are under thick overburden, the BIFs have not been explored for gold, a few localities may be structurally favourable for orogenic gold, and the detailed geochemical surveys have been very restricted. The individual estimators considered the probability high that at least zero to one undiscovered economic deposits exist 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 Sonkaja Orogenic Au 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	1	3			1.3	1.2	90	0	1.3	1026	0.0013

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Damsten, Eilu, Halkoaho, Hartikainen, Kontoniemi, Luukkonen, Sorjonen-Ward, Västi.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Sonkaja Orogenic Au 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			
Au (t)	0	0	5.2	49	110	24	0.20	0.30
Rock (Mt)	0	0	2.0	28	72	16	0.16	0.30

t – metric tons; Mt – million metric tons.

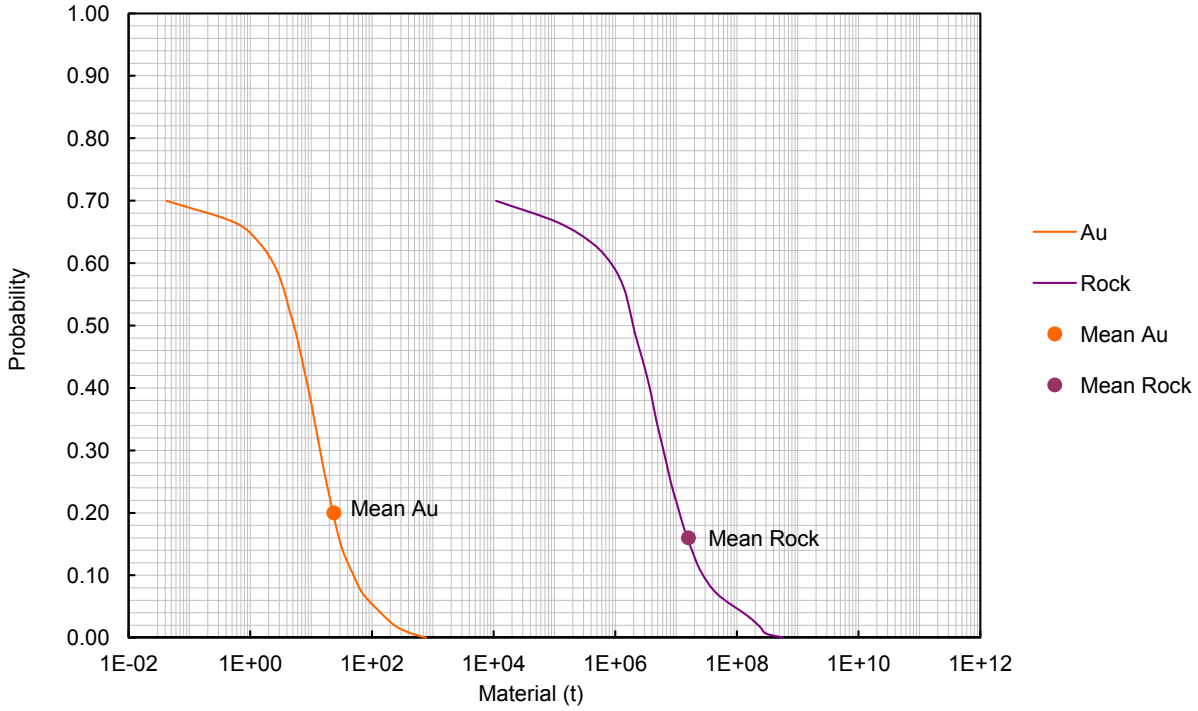

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Sonkaja Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT TAMMIJÄRVI OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The NW-trending Tammijärvi Orogenic Au permissive tract is located in south-central Finland in the municipalities of Hartola, Jämsä, Joutsa, Jyväskylä, Kangasniemi, Kuhmoinen, Luhanka, Sysmä and Toivakka, about 40 km to the south of the city of Jyväskylä (Fig. 1). The 1:100,000 KKJ map sheets are 2144, 2233, 3122, 3211, 3212, 3213 and 3214. The UTM map sheets containing the tract are M442, M444, N431, N432, N433 and N434. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Tammijärvi Orogenic Au 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)	
4/3/2013	1	1720	Au	0	Au	18	Au	3.9

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract includes the eastern extension of the Tampere Schist Belt. It covers Palaeoproterozoic Svecofennian sedimentary, volcanic and subvolcanic rocks and syntectonic (1.89–1.87 Ga) granitoids. The tract covers a small area of lower amphibolite facies rocks of the Hirsilä suite (Geological Survey of Finland 2010) and associated synorogenic intrusions. The delineation is based on the extent of rocks mentioned above, suitable second- and third-order shear structures, and the presence of known gold indications. Low-altitude aeromagnetic data of the Geological Survey of Finland (GTK) were used to define the margins of the tract. The tract extends down to 1000 m depth. The sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

No well-explored orogenic Au deposits are known within the 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 orogenic Au deposits in the Tammijärvi Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

Two partially explored, possibly orogenic Au occurrences are known within the permissive tract (Table 3).

Table 3. Possible orogenic Au occurrences in the Tammijärvi Orogenic Au permissive tract.

Name	X coord	Y coord	Age (Ga)	Comments	Reference
Tammijärvi	6857300	3437200		4.5 m @ 0.4 g/t Au, 0.84 % Cu	Lindmark (1988), Luukkonen (1994)
Vatsa	6867170	3438520		7 m @ 6.5 g/t Au; 1 Mt @ 1.73 g/t Au was published in the late 1990s, but this estimate is presently seen as based on too few data to be relied on.	William Resources (1997)

Ga – billion years.

Exploration history

Tungsten has been the dominant exploration target within the tract. Some gold exploration has also been performed, as listed in Table 4.

Table 4. Exploration history for the Tammijärvi Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Bedrock mapping, boulder tracing	Yes	Geological Survey of Finland	1940s–2010s
	Bedrock mapping, boulder tracing	No	Rautaruukki	1950s–1970s
	Bedrock mapping, boulder tracing	Yes?	Outokumpu	1950s–1970s
	Bedrock mapping, detailed work	Yes	University of Helsinki	1990s
	Bedrock mapping, boulder tracing	Yes	Dragon Mining	2000s
Geochemical surveys	Regional till geochemistry	Yes	Geological Survey of Finland	1980s
	Till geochemical and heavy mineral surveys	Yes	Geological Survey of Finland	1940s–1980s
	Till geochemical surveys	Yes	Terra Mining	1990s
Airborne geophysical surveys	Low-altitude magnetic, electromagnetic and radiometric survey		Geological Survey of Finland	1991–2001
Ground geophysical surveys	Magnetic, IP, VLF, slingram surveys		Geological Survey of Finland	1940s–1980s
Drilling	Diamond and RC drilling	Yes	Terra Mining	1990s
	Diamond drilling	Yes	Geological Survey of Finland	1980s

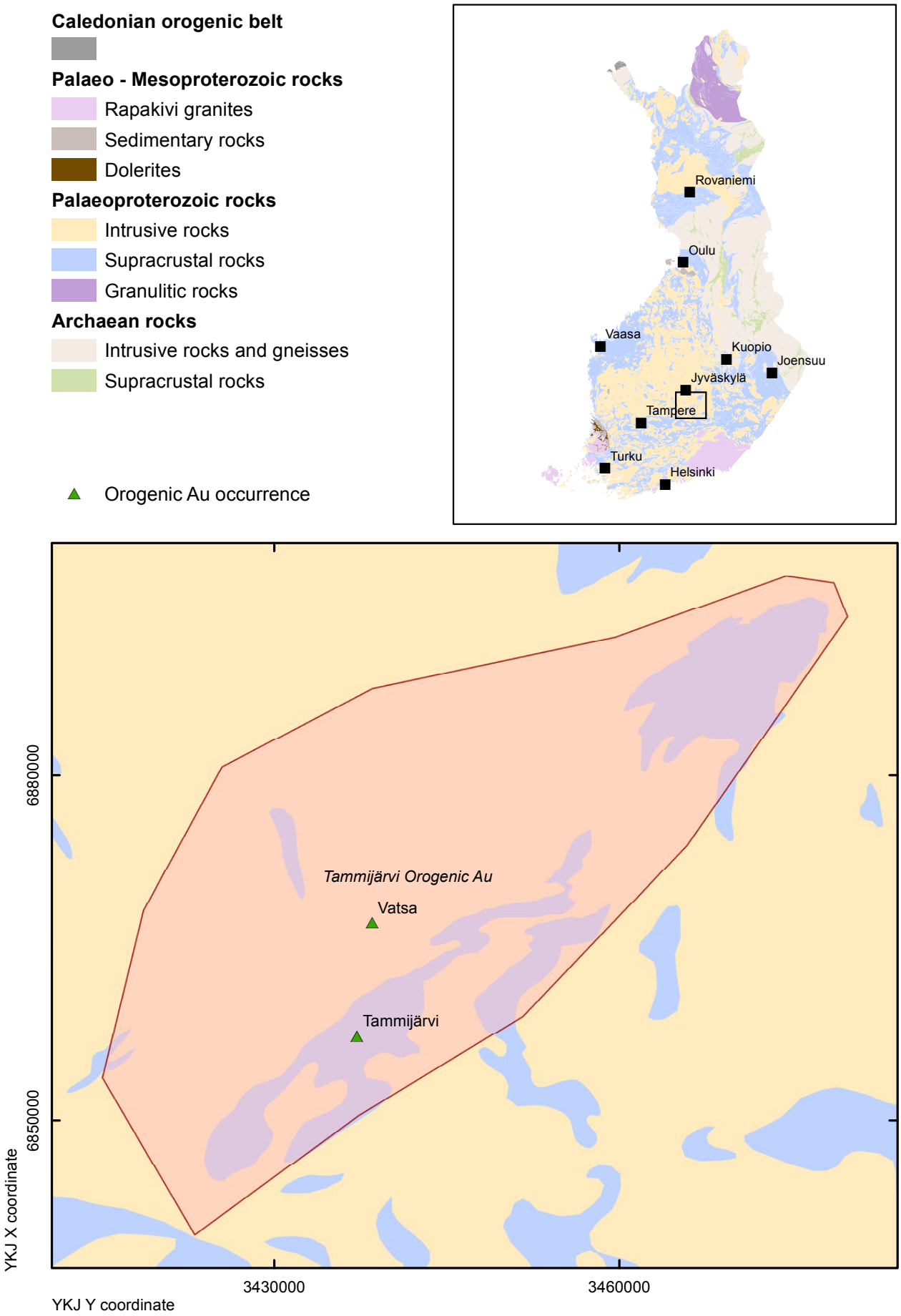

Fig. 1. Location of the Tammijärvi Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Tammijärvi Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Tammijärvi Orogenic Au permissive 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 gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Luukkonen et al. (1992), Luukkonen (1994), Poutiainen & Partamies (2003)
	Metallogenic assessments		Luukkonen et al. (1992), Luukkonen (1994), Kärkkäinen et al. (2003)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Luukkonen (1994), Kärkkäinen et al. (2003)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Lindmark (1988), Luukkonen et al. (1992), Kärkkäinen et al. (2003)
Exploration	Reports		Lindmark (1988), William Resources (1997), Kärkkäinen et al. (2003), Dragon Mining (2006)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Two partially explored possibly orogenic gold occurrences are known within the tract (Table 3). The existence of the two partially explored deposits, a few gold-mineralised outcrops and boulders with no indicated bedrock source, and two Au-anomalous locations in the bedrock geochemical database with no known bedrock source indicate the potential for undiscovered gold deposits for the tract. Exploration in the area has been rather scanty, however. The individual estimators considered the probability high that at least zero to one undiscovered economic deposits exist 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 Tammijärvi Orogenic Au 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	1	2			1.0	0.79	79	0	1	1720	0.00058

	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	0	1	2		
Individual 4	0	1	2		
Individual 5	0	1	2		
Individual 6	0	1	2		
Individual 7	1	1	3		
Mean	0	1	2		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Grönholm, Kärkkäinen, Kontoniemi, Niiranen, Sorjonen-Ward, Tiainen.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Tammijärvi Orogenic Au 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			
Au (t)	0	0	3.9	34	76	18	0.18	0.30
Rock (Mt)	0	0	1.5	20	47	12	0.14	0.30

t – metric tons; Mt – million metric tons.

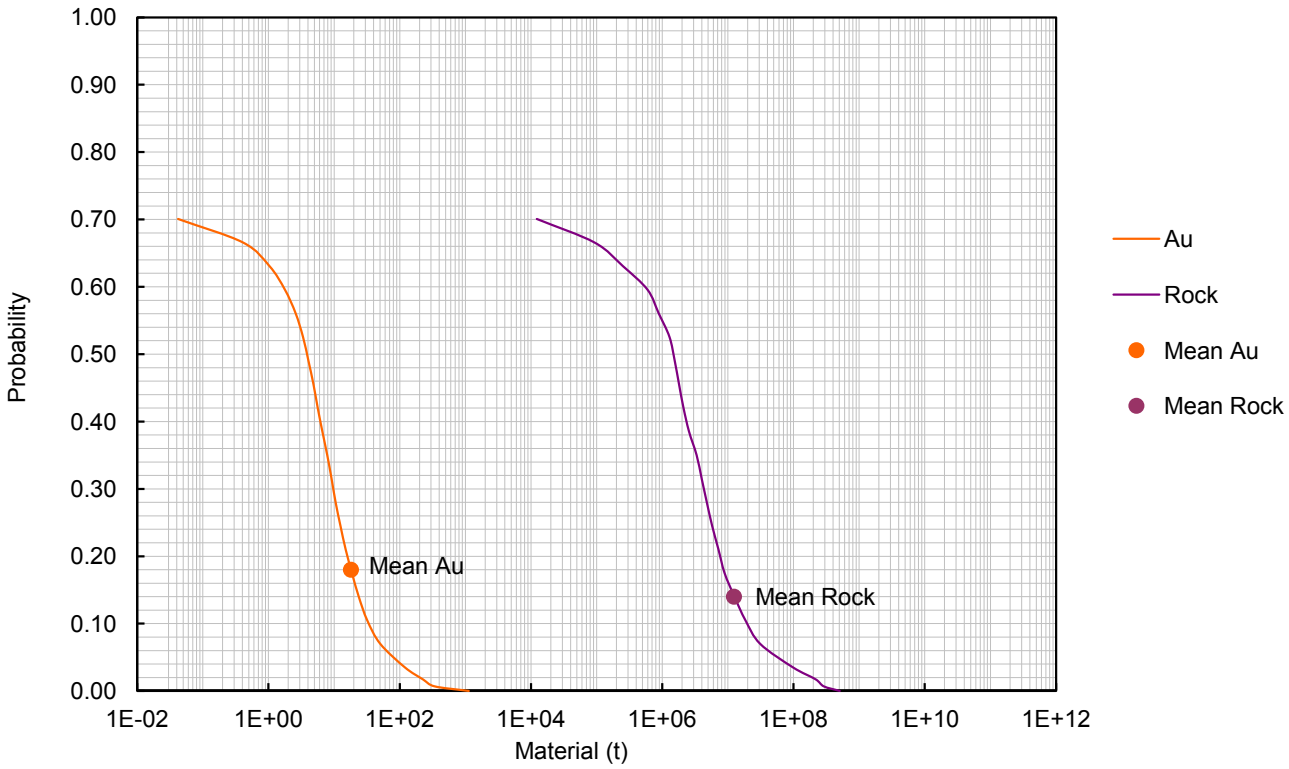

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Tammijärvi Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT TANA–LOKKA OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Tana–Lokka Orogenic Au permissive tract is located in northern Finland in the Inari, Kittilä, Savukoski, Sodankylä and Utsjoki municipalities, about 170 km N to NE of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 2833, 2834, 2843, 3712, 3714, 3721, 3722, 3723, 3724, 3732, 3734, 3741, 3742, 3743, 3744, 3811, 3812, 3813, 3821, 3822, 3823, 4721, 4722 and 4724. The UTM map sheets containing the tract are U443, U444, U521, U522, U524, V431, V432, V433, V434, V441, V442, V443, V444, V511, V512, V513, V514, V531, W431, W432, W433, W434 and W441. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Tana–Lokka Orogenic Au 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)
17/1/2012	1	7260	Au 0	Au 39	Au 14

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract has an arched form opening to the NE, and is defined by the known extent of Palaeoproterozoic supracrustal Salla, Kuusamo, Sodankylä and Savukoski Group rocks in northern Finland. To the NE, the tract is bounded by the Granulite Belt Orogenic Au tract, to the SW by the Kittilä, to the south by the Sattanen–Kolari and Sodankylä–Savukoski, and to the SE by the Tulppio–Tuntsa Orogenic Au tracts. Archaean TTG inliers, the Koitelainen layered intrusion and Nattanen granites form holes in the tract, as they are regarded barren for orogenic gold. Low-altitude airborne magnetic data were extensively used to define the extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to 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 orogenic Au deposits within the 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 orogenic Au deposits in the Tana–Lokka Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are four partially explored orogenic Au occurrences within the permissive tract (Table 3). There also are two gold-enriched magnetite-quartz± haematite±baryte±carbonate±chalcopyrite vein occurrences of possibly IOCG type or more directly related to post-orogenic granitoids (Palokiimaselkä and Mäkärärova).

Table 3. Significant orogenic Au occurrences in the Tana–Lokka Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Kirakka-aapa	7548500	3473910		2 m @ 3.1–5 g/t Au, enriched in Ni	Pulkkinen et al. (2007a)
Lohisarriot	7548000	3495000		1 m @ 0.12–2.0 g/t Au; core recovery poor due to deep weathering; also Ag and Cu enriched	Pulkkinen et al. (2008b)
Petäjälehto	7566000	3481000		Distinct Au anomaly and abundant micro nuggets in till; best drill section <0.1 g/t Au	Pulkkinen et al. (2008a)
Ruosselkä (Sakiatieva)	7539800	3506850		7 m @ 13.7 g/t Au; 8 m @ 6 g/t Au	Rantala (2003), Pulkkinen et al. (2005)

Ga – billion years.

Exploration history

Exploration activities for gold within the tract are listed in Table 4. Most of the exploration in the region has targeted nickel, PGE and Cr.

Table 4. Exploration history for the Tana–Lokka Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	Partly	Geological Survey of Finland	1950–
	Outcrop observations and boulder survey	?	Outokumpu	1960s–1990s
	Outcrop observations	No	University of Turku	1970s
	Outcrop observations	No	University of Helsinki	1980s
Geochemical surveys	Nationwide till survey, systematic, 1598 points	Yes	Geological Survey of Finland	1970s–1990s
	Till and regolith geochemical surveys, line till profiles: systematic profiles 2378.5 km^2, additional sampling 4835 points	No	Geological Survey of Finland	1971–1980
	Stream sediment surveys, organic sampling, total 4017 points	No	Geological Survey of Finland	1970s
	Stream sediment surveys, inorganic sampling, total 6064 points	No	Geological Survey of Finland	1970s
	Targeted till and regolith geochemical surveys, grid total 0.06 km^2, profile total 222.5 km, scattered sampling 2117 points	No	Geological Survey of Finland	1970s–1980s
	Targeted till and regolith geochemical surveys, grid total 46.9 km^2, profile total 91.7 km, scattered sampling 1155 points	Yes	Geological Survey of Finland	1970s–2000s
	Targeted till and regolith geochemical surveys, profile total 19.8 km	Yes	Outokumpu	1980s–1990s
	Targeted till and regolith geochemical surveys, profile total 42.7 km	No	Outokumpu	1980s–1990s
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1975–2004
Ground geophysical surveys	Magnetic surveys, grid total 316.2 km^2, profile total 310.0 km		Geological Survey of Finland	1970s–2000s
	Gravimetric surveys, grid total 72.0 km^2, profile total 189.6 km		Geological Survey of Finland	1970s–1980s
	IP surveys, grid total 0.8 km^2, profile total 15.3 km		Geological Survey of Finland	2000s
	Slingram multifrequency surveys, grid total 1.6 km^2		Geological Survey of Finland	1988

Table 4. Cont.

Theme	Type of work	Au analysed	Organisation	When carried out
	Slingram one frequency surveys, grid total 206.0 km^2, profile total 26.7 km		Geological Survey of Finland	1970s–1990s
	VLF surveys, profile total 4.8 km		Geological Survey of Finland	1985
	VLF-R surveys, grid total 72.4 km^2, profile total 76.8 km		Geological Survey of Finland	1980s–2000s
	Self potential surveys, grid total 0.4 km^2, profile total 8.0 km		Geological Survey of Finland	1994, 2000
	Reflection seismic, FIRE 4a, profile total 30.5 km		Geological Survey of Finland, University of Helsinki, University of Oulu	2001–2005
	Reflection seismics, HIRE Kevitsa E2-E5, profile total 6.3 km		Geological Survey of Finland, University of Helsinki	2007–2008
	Magnetic surveys (proton), grid total 0.4 km^2, profile total 0.4 km		Outokumpu	1986, 1996
	Slingram surveys, grid total 0.4 km^2, profile total 0.4 km		Outokumpu	1986, 1996
Drilling	Diamond drilling, 873 DDH, total 65,084.20 m	Yes, from 1975 onwards	Geological Survey of Finland	1952, 1970s–2010s
	Diamond drilling, 77 DDH, total 6192.30 m	No	Outokumpu	1960s–2000s
	Diamond drilling, 38 DDH, total 874.75 m	No	Kemijoki Oy	1960s–1970s
	Diamond drilling, 21 DDH, total 435.95 m	No	Suomen Malmi Oy	1966–1967
	Diamond drilling, 5 DDH, total 1004.80 m	No	University of Turku	1978
	Diamond drilling, 3 DDH, total 131.15 m	?	Rio Tinto Zinc, Mining and Exploration	1995

DDH – Diamond drill hole

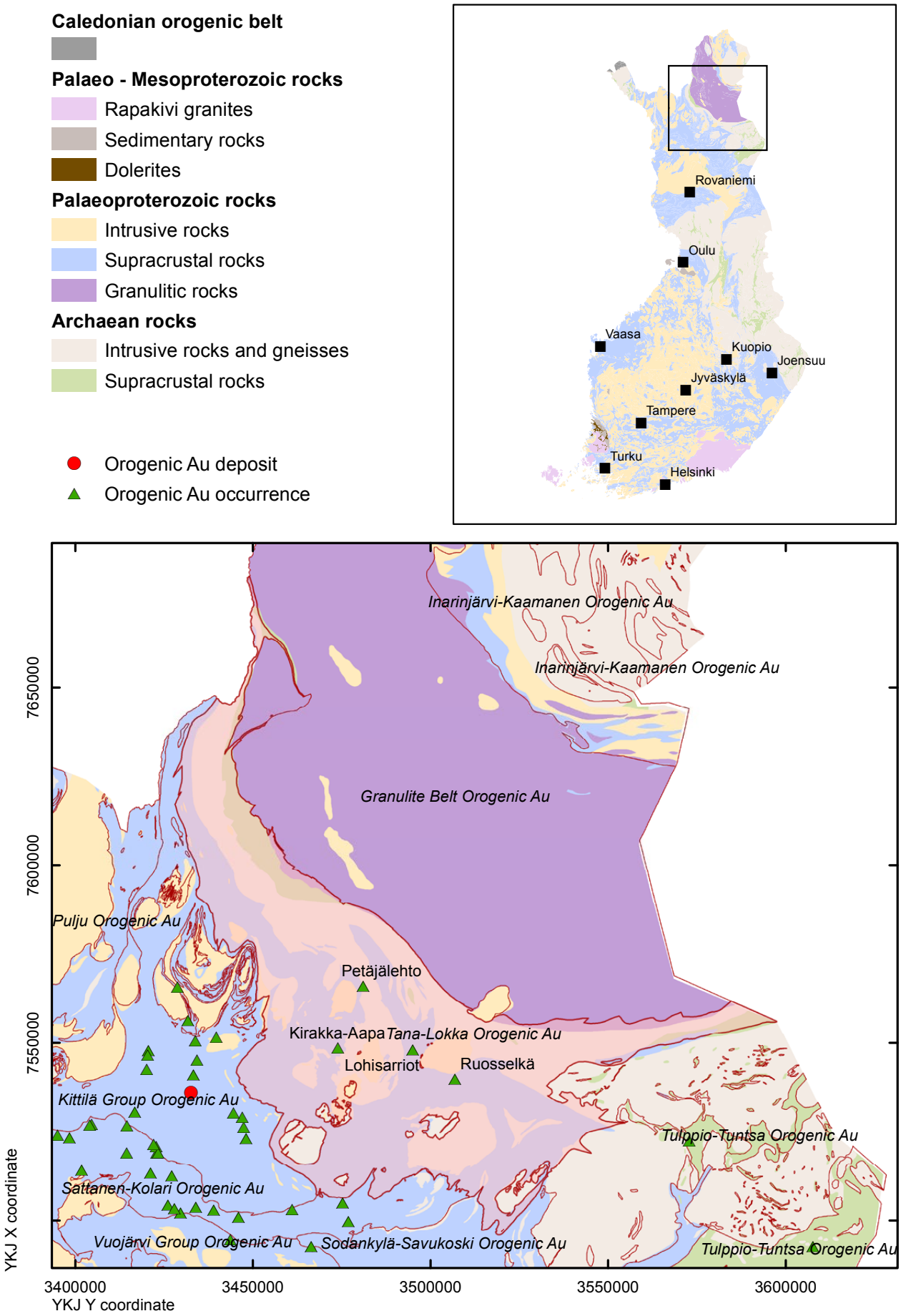

Fig. 1. Location of the Tana–Lokka Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Tana–Lokka Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Tana–Lokka Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:300,000	Lehtonen et al. (1998)
	Geological maps	1:100,000	Kujansuu (1969), Tyrväinen (1980, 1983), Pihlaja & Manninen (1993), Kujansuu & Hyyppä (1995), Manninen (2003)
	Thematic geology reports		Lehtonen et al. (1998), Manninen et al. (2001), Korkalo (2006), Airo (2007), Eilu et al. (2007), Hölttä et al. (2007), Patison (2007), Sarapää et al. (2008), Pulkkinen & Sarala (2009), Eilu et al. (2012)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Kinnunen (1980), Rantala (2003), Pulkkinen et al. (2005, 2007a, 2008a,b), Niska (2006), Eilu et al. (2007), Keinänen et al. (2007), Al-Ani et al. (2008), Hartikainen et al. (2008), Pulkkinen & Salmirinne (2008), Sarapää et al. (2008)
	Metallogenic assessment		Nykänen & Salmirinne (2007), Patison et al. (2008), Nykänen (2010)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Lestinen (1980), Äyräs (1982), Pulkkinen (1983), Äyräs & Koivisto (1984), Rantala (2003), Niska (2006), Pulkkinen et al. (2005, 2008a,b, 2009), Al-Ani et al. (2008), Hartikainen et al. (2008), Pulkkinen & Puljujärvi (2008), Sarapää et al. (2008), Pulkkinen & Sarala (2009), Sarala et al. (2009), Valkama & Sarala (2009), Lehmuspelto et al. (2009), Lehmuspelto & Pohjola (2010), Sarapää & Sarala (2011)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Pulkkinen et al. (2005, 2007a, 2008a,b), Pulkkinen & Salmirinne (2006), Airo (2007), Keinänen et al. (2007), Sarapää et al. (2008)
Exploration	Reports		Mutanen (1979), Kinnunen (1980), Rahkola (1982), Härkönen (1987), Pulkkinen et al. (2005, 2007a,b, 2008a,b, 2009), Pulkkinen & Salmirinne (2006, 2008), Keinänen et al. (2007), Al-Ani et al. (2008), Pulkkinen & Puljujärvi (2008), Sarapää et al. (2008), Pulkkinen & Sarala (2009), Valkama & Sarala (2009)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Four partially explored orogenic gold occurrences are known within the tract (Table 3). These occurrences were regarded modest. The known gold occurrences and the numerous geochemical gold and micro-nugget anomalies in till were considered to indicate a good potential for orogenic gold deposits in the tract. No auriferous boulders have been detected in the tract, nor mineralised boulders of any other metal. The extent and intensity of exploration within the tract have been low, and most of the exploration has been for nickel. This is a large tract with abundant supracrustal rocks deformed and metamorphosed at lower to mid-amphibolite facies conditions. The NNE-trending fault and shear zones, which in the Kittilä Group Orogenic Au tract contain orogenic gold deposits, extend to the Tana–Lokka tract. Hence, the tract may well contain orogenic gold deposits with no known indications. The individual estimators considered the probability high that at least zero to one undiscovered economic deposits exist 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 Tana–Lokka Orogenic Au 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	7260	0.00030

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Keinänen, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Tana–Lokka Orogenic Au 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			
Au (t)	0	0.71	14	89	190	39	0.22	0.06
Rock (Mt)	0	0.18	6.0	56	190	27	0.18	0.06

t – metric tons; Mt – million metric tons.

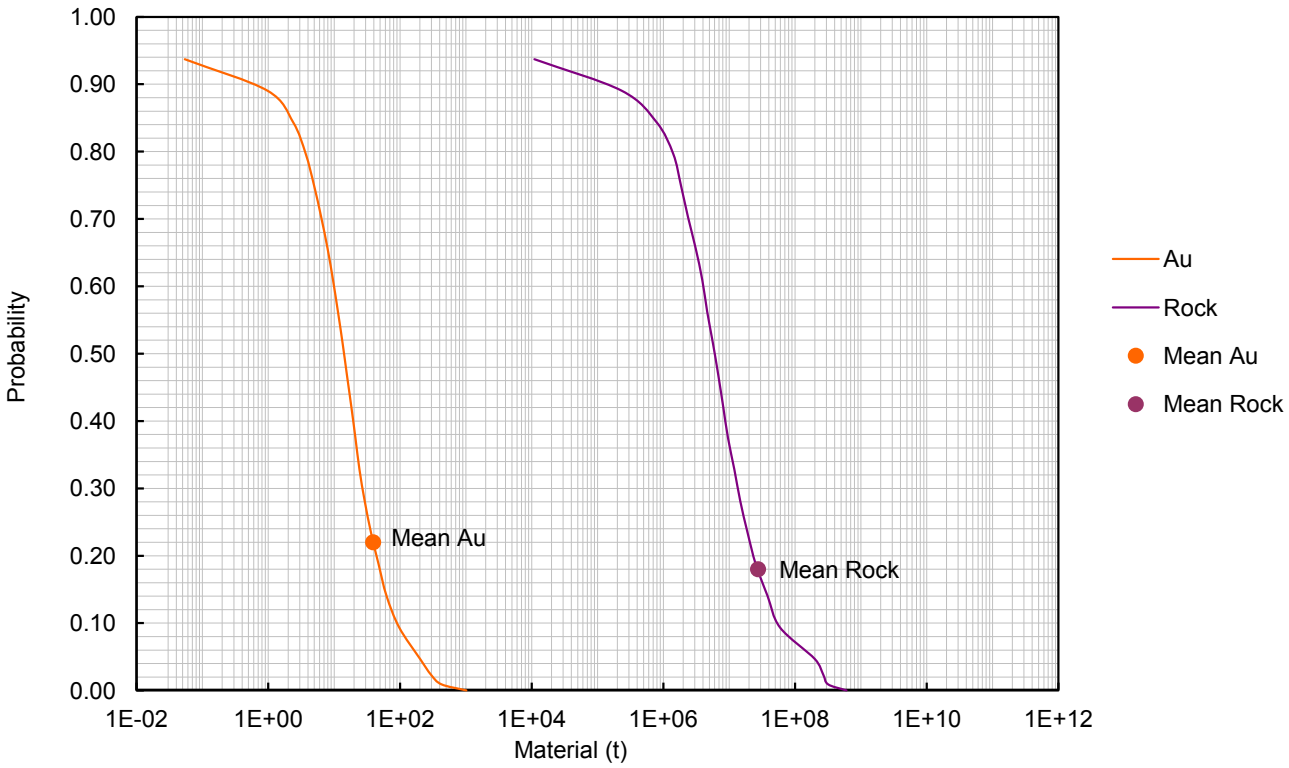

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Tana–Lokka Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT TULPPIO–TUNTSA OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Tulppio–Tuntsa Orogenic Au permissive tract is located in northeastern Finland in the Salla, Savukoski and Sodankylä municipalities, 150–225 km to the NE of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 3731, 3732, 3733, 3734, 3741, 3743, 4711, 4712, 4713, 4714, 4721 and 4723. The UTM map sheets containing the tract are U512, U513, U514, U521, U523, U524, U532, U541, U542, V511, V513 and V531. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Tulppio–Tuntsa Orogenic Au 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)
17/1/2012	1	1895	Au 0	Au 30	Au 9.0

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract covers Archaean and Proterozoic supracrustal rocks in NE Lapland, defined by the known extent of Tuntsa and Tulppio Suite rocks and Kemihaara and Ahmatunturi Complex rocks. To the east, the tract is bounded by the Finnish–Russian border, to the N and NW by the Tana–Lokka and to the SW by the Sodankylä–Savukoski Orogenic Au tracts and Palaeoproterozoic rocks, and to the SE by Archaean TTG terrain. The Archaean TTGs also form extensive, irregular inliers within the tract, as they are regarded as barren for orogenic gold, except where close to the greenstone belts. Conversely, there are many small inliers of the greenstones within the TTG terrain defining tract outliers in the region. Low-altitude airborne magnetic data were extensively used to define the extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to 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 orogenic Au deposits within the 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 orogenic Au deposits in the Tulppio–Tuntsa Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are three partially explored Au occurrences of a possibly orogenic type within the permissive tract (Table 3). Auermavaara may be an orogenic or a metamorphosed epithermal occurrence. Mineral assemblages as well as enriched and depleted elements are consistent with a syngenetic (epithermal?) mineralisation style, but not enough is known to be sure of the genesis of the occurrence. There also are small tungsten and stratiform iron and base-metal occurrences within the tract and its immediate vicinity.

Table 3. Significant orogenic Au occurrences in the Tulppio–Tuntsa Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Auermavaara	7492608	3607644	?	2 m @ 2.6 g/t Au	Inkinen (1990a), Mutanen (2002)
Patonenäkkeenselkä	7471380	3559380	?	2.5 m @ 2 g/t Au; 0.6 m @ 5.24 g/t Au	Juopperi & Karvinen (2002)
Rovaukonselkä	7522359	3572809	?	2.05 m @ 2.25 g/t Au	Inkinen (1990b)

Ga – billion years.

Exploration history

Exploration activities for gold within the tract are listed in Table 4. The tract area has also been explored for nickel, tungsten, iron, copper and zinc, but very little has been drilled for any commodity.

Table 4. Exploration history for the Tulppio–Tuntsa Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	Partly yes	Geological Survey of Finland	1970s–2010s
	Outcrop observations and boulder survey	Partly yes	Outokumpu	1960s–1990s
Geochemical surveys	Nationwide till survey, systematic, 437 points	Yes	Geological Survey of Finland	1980s
	Line till geochemistry, total 4409 points	No	Geological Survey of Finland	1970s
	Organic deposit sampling, total 1345 points	No	Geological Survey of Finland	1980s–1990s
	Inorganic deposit sampling, total 1323 points	No	Geological Survey of Finland	1980s–1990s
	Targeting survey, 6573 points	No	Outokumpu	1970s–1990s
Airborne geophysical surveys	Low-altitude airborne magnetic, electromagnetic and radiometric surveys		Geological Survey of Finland	1970s–2000s
Ground geophysical surveys	Magnetic surveys		Outokumpu	1970s–1980s
	Slingram survey, profile surveys total 18.4 km		Outokumpu	1970s–1980s
	Slingram regional survey, systematic surveys total 25.4 km^2		Outokumpu	1970s–1990s
	Proton regional survey, systematic surveys total 25.4 km^2		Outokumpu	1970s–1990s
	Proton survey, profile surveys total 18.4 km		Outokumpu	1980s
	Ground gravimetric survey, profile surveys total 16.4 km		Outokumpu	1970s
	VLF regional surveys, systematic, total 0.5 km^2		Outokumpu	1970s
	Jalander survey, profile surveys total 17.9 km		Outokumpu	1970s–1980s
	Jalander regional survey, systematic surveys total 19.1 km^2		Outokumpu	1970s–1980s
Drilling	Diamond drilling 212 DDH, total 18,917.25 m	Yes	Geological Survey of Finland	1980s–2010s
	Diamond drilling 87 DDH, total 6442.15 m	Yes	Outokumpu	1970s–1990s

DDH – Diamond drill hole

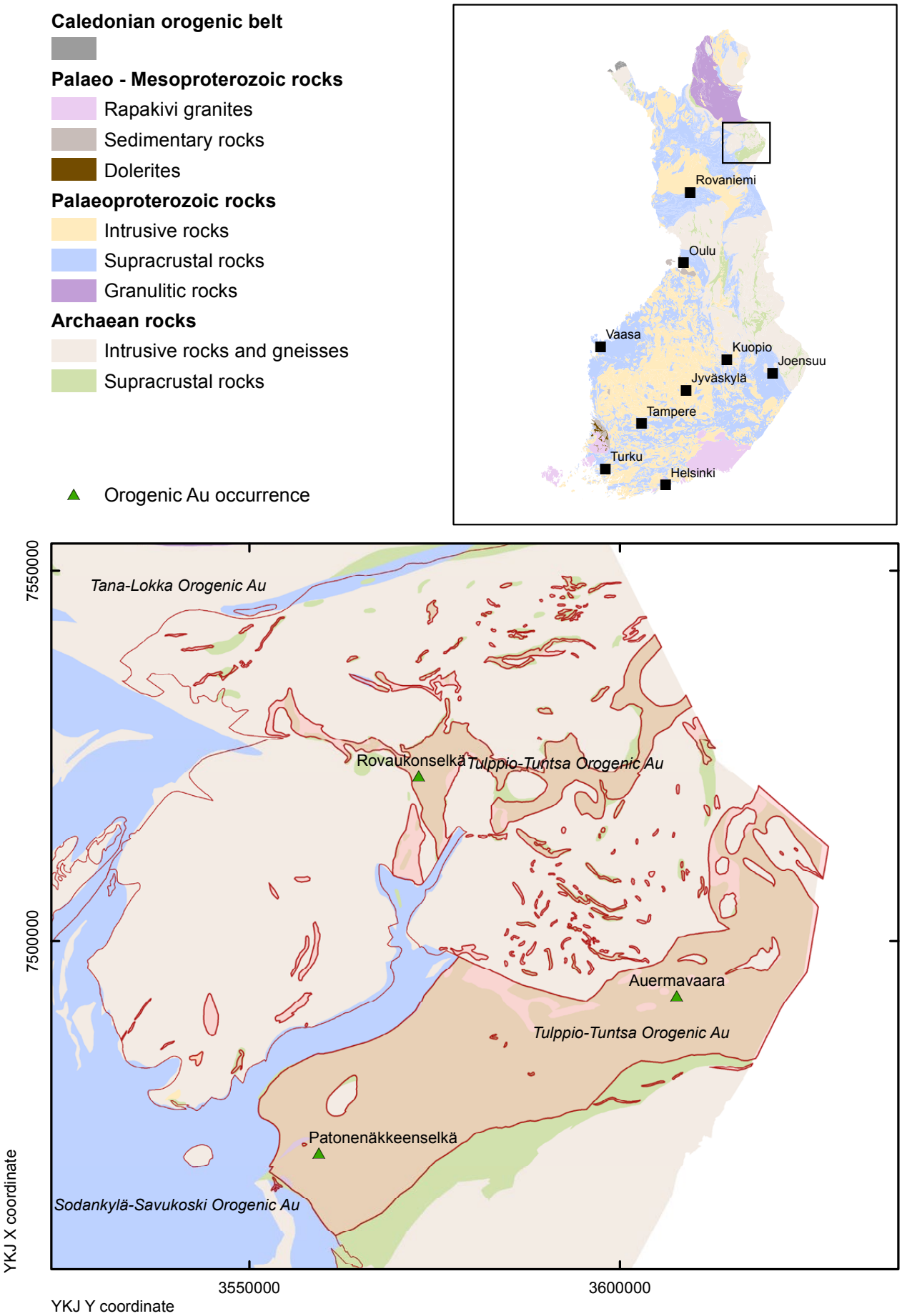

Fig. 1. Location of the Tulppio–Tuntsa Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Tulppio–Tuntsa Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Tulppio–Tuntsa Orogenic Au permissive tract.

Theme	Type of source	Scale	Reference
Geology	Geological Survey of Finland in-house Bedrock Map Database DigiKP Finland		
	Geological maps	1:400,000	Mikkola (1936, 1941)
	Geological maps	1:100,000	Juopperi (1986)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Inkinen (1990a,b), Juopperi & Karvinen (2002), Mutanen (2002)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Outokumpu Oy malminetsintä (1986), Juopperi & Karvinen (2002), Mutanen (2002), Hartikainen et al. (2008), Sarapää et al. (2008), Heikura et al. (2009), Lehmuspelto et al. (2009)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Inkinen (1990b), Juopperi & Karvinen (2002), Mutanen (2002), Sarapää et al. (2008), Heikura et al. (2009)
Exploration	Reports		Inkinen (1988, 1990a,b), Juopperi & Karvinen (2002), Mutanen (2002), Sarapää et al. (2008), Heikura et al. (2009)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Two or three partially explored orogenic gold occurrences are known within the tract (Table 3). These occurrences were regarded as modest. The following were considered to indicate a good potential for orogenic gold deposits in the tract: 1) the Neoarchaean age of the greenstones, 2) the detected gold occurrences, 3) scattered geochemical gold and micro nugget anomalies in till and 4) the proven placer gold in the tract area. The extent and intensity of exploration within the tract is low, and most of the exploration has been for other metals than gold. Negative factors for orogenic gold include the high metamorphic grade (dominantly mid-amphibolite to lower-granulite facies) and the dominantly subhorizontal structures with few subvertical faults and shear zones so far detected. The individual estimators considered the probability high that at least zero to one undiscovered economic deposits exist 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 Tulppio–Tuntsa Orogenic Au 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	2	3			1.7	1.1	63	0	1.7	1895	0.0090

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Karvinen, Keinänen, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Tulppio–Tuntsa Orogenic Au 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			
Au (t)	0	0	9.0	65	150	30	0.21	0.21
Rock (Mt)	0	0	3.7	43	140	20	0.17	0.21

t – metric tons; Mt – million metric tons.

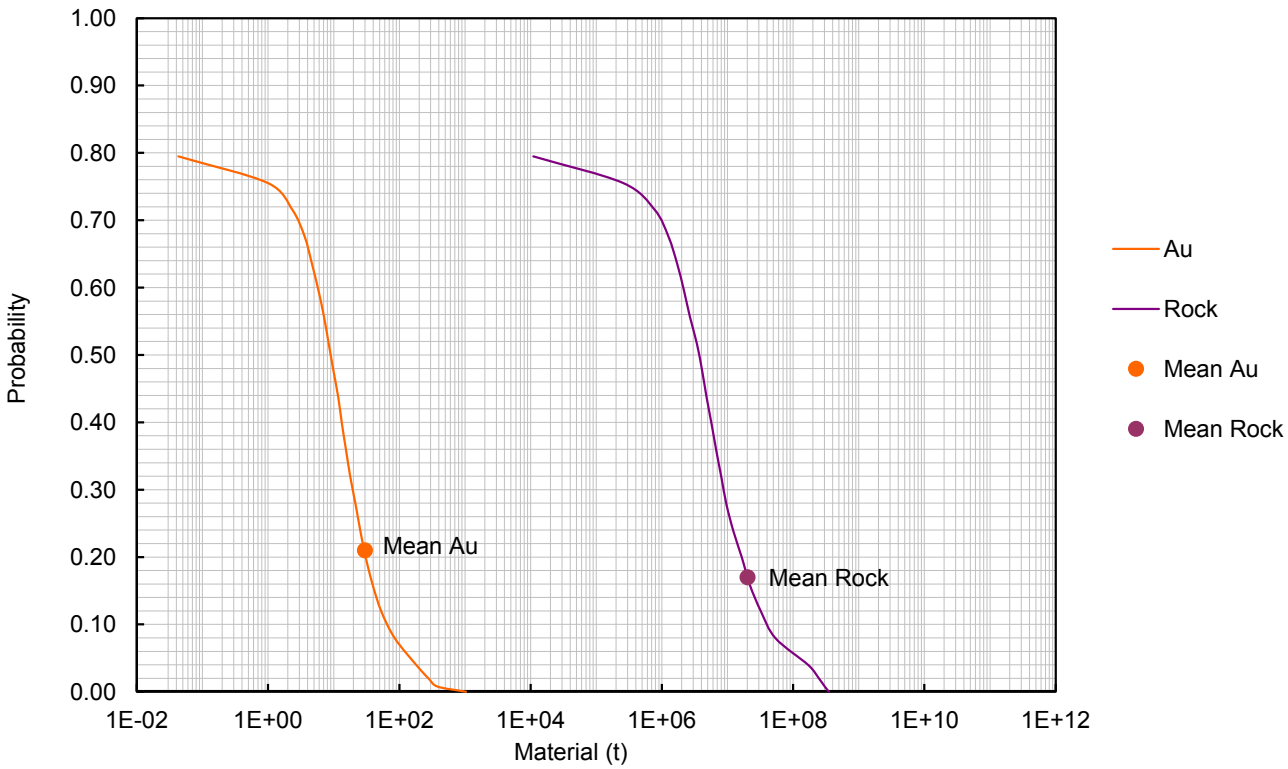

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Tulppio–Tuntsa Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT TURKU OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The NW-trending Turku Orogenic Au permissive tract is located in southwestern Finland in the municipalities of Aura, Hyvinkää, Kaarina, Kustavi, Länsi-Turunmaa, Lieto, Lohja, Marttila, Masku, Mynämäki, Mäntsälä, Naantali, Nurmijärvi, Paimio, Pukkila, Raisio, Salo, Somero, Taivassalo, Tarvasjoki and Turku. The tract consists of three parts. The main part extends for about 90 km to the east and 65 km to the west of the city of Turku (Fig. 1). Its N–S width is 20 km at the western part, and it diminishes to approximately three kilometres at the eastern end. Another 50-km-long and 1–5-km-wide part of the tract is located 37 km to the west of the main part. The third part, 22 km * 4 km, is located 30 km NNW of Turku. The 1:100,000 KKJ map sheets are 1041, 1042, 1043, 1044, 1133, 2021, 2022, 2023, 2024, 2042, 2044 and 3022. The UTM map sheets containing the tract are L314, L323, L332, L334, L341, L3442, L343, L412, L421, L423 and L441.The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Turku Orogenic Au 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)
4/3/2013	1	2835	Au 0	Au 39	Au 14

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geologic criteria

The permissive tract covers Palaeoproterozoic Svecofennian sedimentary, volcanic and subvolcanic rocks and syntectonic (1.89–1.87 Ga) granitoids. The western parts of the tract contain upper amphibolite and granulite grade rocks in the western parts of the Häme migmatite and Southern Finland granite suites. The easternmost part of the tract covers a block of mid-amphibolite facies rocks surrounded by higher-grade rocks in the southeastern part of the Häme migmatite suite. To the west, the tract is bounded by the Kihti shear or fault zone. The delineation is based on the extent of rocks mentioned above, suitable second- and third-order shear structures, and the presence of known gold occurrences and indications. Low-altitude aeromagnetic data of the Geological Survey of Finland (GTK) were used to define the margins of the tract. The tract extends down to 1000 m depth. The sources of information used in the delineation of the tract are summarised in Table 5.

Known deposits

No well-explored orogenic Au deposits are known within the 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 orogenic Au deposits in the Turku Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

Three partially explored, possibly orogenic Au occurrences are known within the permissive tract (Table 3).

Table 3. Possible orogenic Au occurrences in the Turku Orogenic Au permissive tract. The Kultanummi and Teersalo occurrences have features that may indicate a metamorphosed epithermal gold mineralisation; as the metamorphic grade is very high, their genetic type is difficult to define.

Name	X coord	Y coord	Age (Ga)	Comments	Reference
Korvenala	6716632	3269949		5.5 m @ 1 g/t Au; 5.5 m @ 0.8 g/t Au	Rosenberg (2000), Grönholm et al. (2012)
Kultanummi	6713335	3276359		1–6 m sections @ 0.5–10 g/t Au	Grönholm et al. (2005, 2012)
Velkua	6718629	3209288		6 m @ 5.5 g/t Au	Kärkkäinen et al. (2012)

Ga – billion years.

Exploration history

Little exploration for any metal has been performed within the tract area. Most of the work has been targeted at copper, zinc, lithium and feldspars. Before the 1980s, gold was rarely analysed from a sample taken, and exploration targeting gold has only taken place since the 1990s. Exploration activities for gold within the tract are listed in Table 4.

Table 4. Exploration history for the Turku Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Bedrock mapping, boulder tracing	Yes	GTK	1900s–2010s
Geochemical surveys	Regional till geochemistry	Yes	GTK	1980s
	Till geochemical and heavy mineral surveys	Yes	GTK	1960s–2010s
Airborne geophysical surveys	Low-altitude magnetic, electromagnetic and radiometric survey		GTK	1978–2002
Ground geophysical surveys	Magnetic, IP, slingram		GTK	1990s–2010s
Drilling	Diamond and percussion drilling	Yes	GTK	1990s–2010s

Sources of information

Principal sources of information used by the assessment team for the delineation of the Turku Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Turku Orogenic Au permissive 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 gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Rosenberg (2000), Kärkkäinen et al. (2003, 2012), Kärkkäinen & Lehto (2004), Grönholm & Kärkkäinen (2006), Grönholm et al. (2005, 2012)
	Regional metallogenic assessments		Kärkkäinen et al. (2003), Saalmann et al. (2009), Eilu (2012)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Rosenberg (2000), Kärkkäinen et al. (2003, 2012), Grönholm & Kärkkäinen (2006), Huhta et al. (2012)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Rosenberg (2000), Kärkkäinen et al. (2003, 2012), Grönholm & Kärkkäinen (2006), Airo & Leväniemi (2012), Grönholm et al. (2012), Lohva & Jokinen (2012)
Exploration	Reports		Rosenberg (2000), Kärkkäinen et al. (2003, 2012), Kärkkäinen & Lehto (2004), Grönholm & Kärkkäinen (2006), Grönholm et al. (2012)
	Geological Survey of Finland in-house drill-core database		

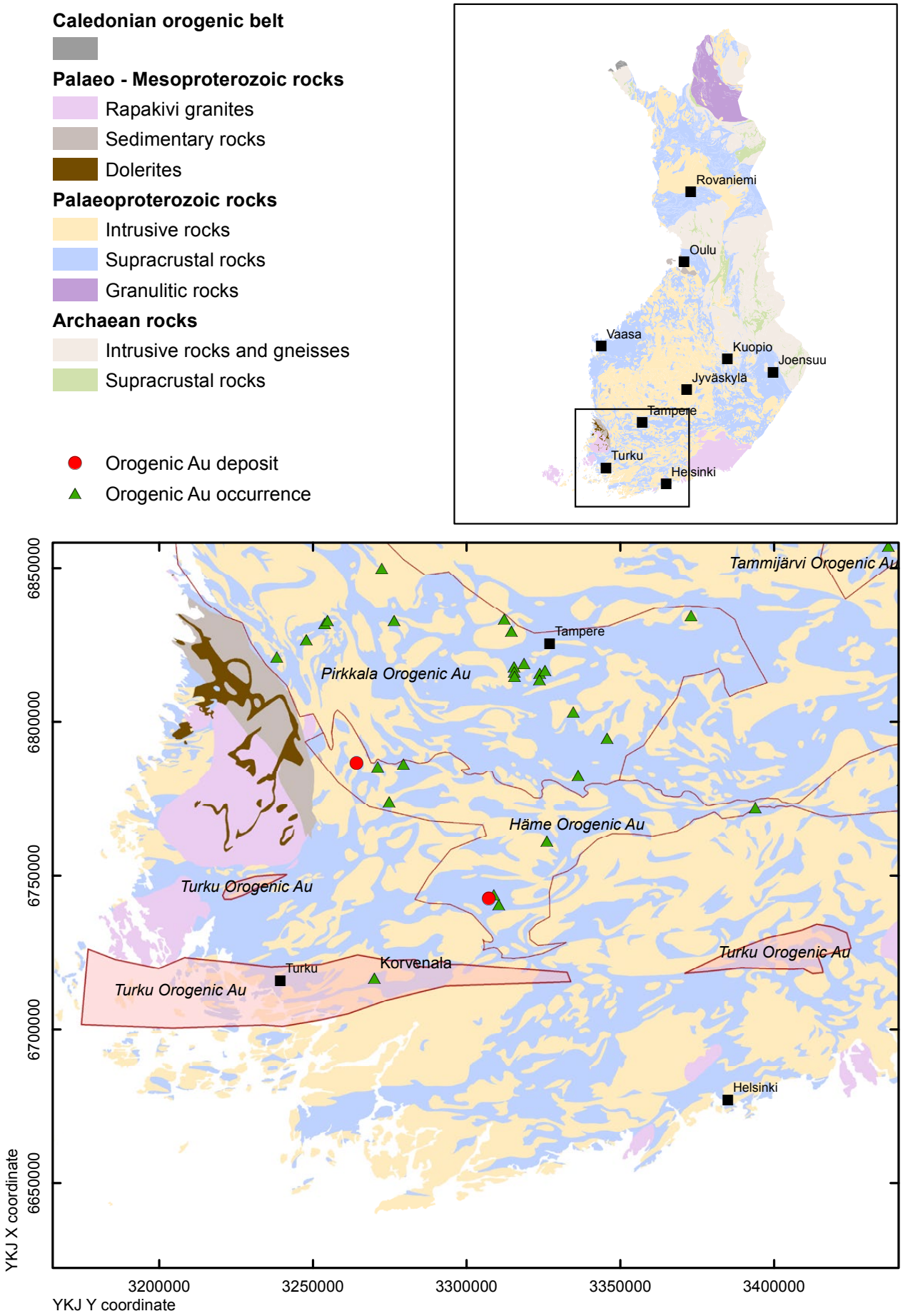

Fig. 1. Location of the Turku Orogenic Au permissive tract.

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Three partially explored possibly orogenic gold occurrences are known within the tract (Table 3). The existence of three partially explored occurrences, undrilled gold-mineralised outcrops, mineralised boulders with no indicated bedrock source, and numerous gold-anomalous locations in till indicate the potential for undiscovered gold deposits for the tract. This is mostly an upper amphibolite to lower granulite facies tract, and hence, according to the deposit model, it does not have a good potential for orogenic gold. The present high metamorphic grade also makes it difficult to decide whether the known gold occurrences and indications are orogenic or syngenetic. It is very difficult to verify whether the area has suffered a lower degree regional metamorphism associated with an earlier orogenic stage at ca. 1.89–1.86 Ga. In the latter case, the potential for orogenic gold would be much higher – presuming mineralisation took place pre-1.85 Ga. The individual estimators considered the probability high that at least one to two undiscovered economic deposits exist 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 Turku Orogenic Au 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	2835	0.00078

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

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Grönholm, Kärkkäinen, Kontoniemi, Niiranen, Sorjonen-Ward, Tiainen.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Turku Orogenic Au 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			
Au (t)	0	0.71	14	94	190	39	0.22	0.07
Rock (Mt)	0	0.16	6	58	180	27	0.18	0.07

t – metric tons; Mt – million metric tons.

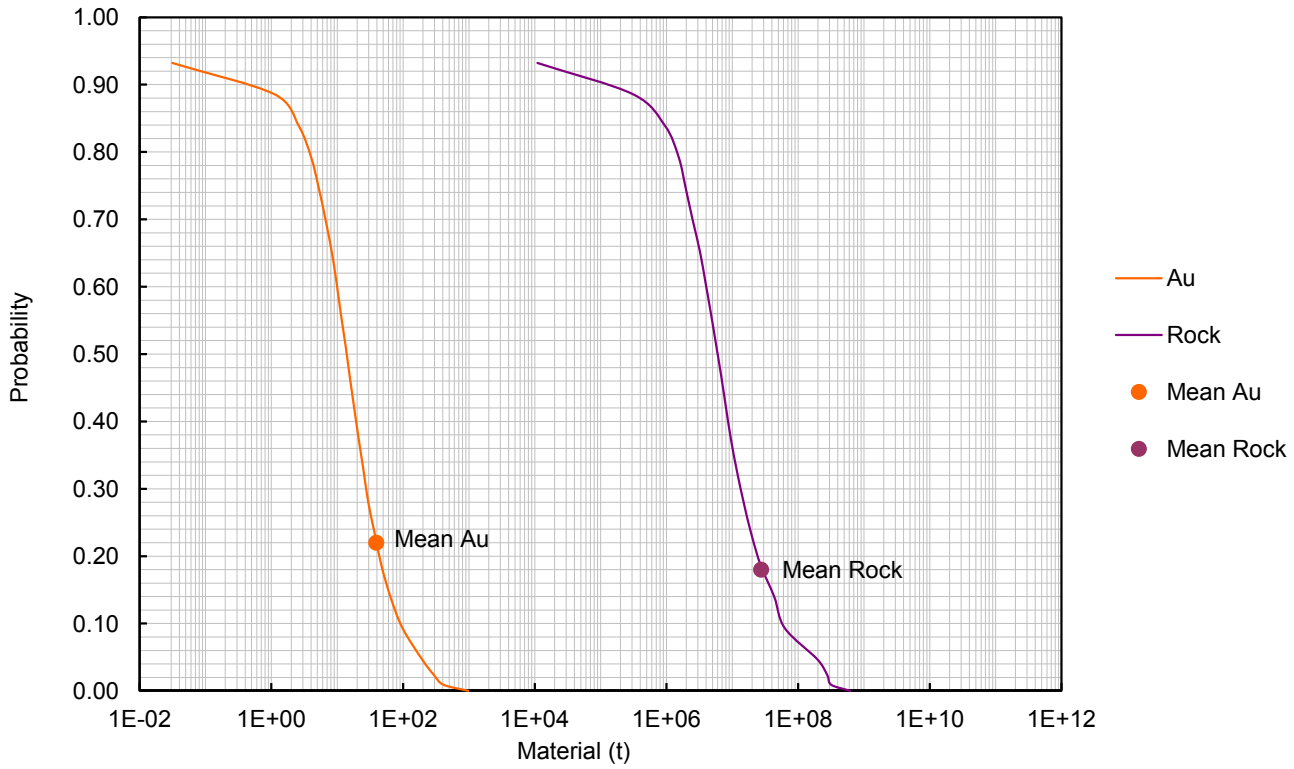

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Turku Orogenic Au permissive tract. Labelled dots indicate mean values.

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OROGENIC Au ASSESSMENT FOR THE TRACT VUOJÄRVI GROUP OROGENIC Au, FINLAND

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DEPOSIT TYPE ASSESSED

Deposit type: Orogenic Au
Descriptive model: Orogenic Au (Appendix 1)
Grade-tonnage model: Orogenic Au (Appendix 2)

LOCATION AND RESOURCE SUMMARY

The Vuojärvi Grop Orogenic Au permissive tract is located in northern Finland in the Kemijärvi, Kittilä, Kolari, Pelkosenniemi, Pello, Salla and Sodankylä municipalities. It is a relatively narrow, curved domain expanding almost the full width of central Finnish Lapland, 75–135 km N, NW and E of the city of Rovaniemi (Fig. 1). The 1:100,000 KKJ map sheets are 3623, 2624, 2641, 2642, 2644, 2713, 2731, 2732, 2733, 2734, 2623, 3624, 3632, 3634, 3641, 3642, 3643, 3644, 3711, 3712, 3713, 3714, 4621 and 4622. The UTM map sheets containing the tract are T424, T444, T512, T521, T522, T523, T524, U411, U412, U413, U414, U423, U424, U431, U432, U433, U434, U441, U42, U443 and U511. The Au resource assessment carried out for this tract is summarised in Table 1.

Table 1. Summary of selected resource assessment results for the Vuojärvi Group Orogenic Au 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)	
17/1/2012	1	4505	Au	0	Au	65	Au	27

t – metric tons.

DELINEATION OF THE PERMISSIVE TRACT

Geological criteria

The permissive tract is defined by the known extent of the Palaeoproterozoic Vuojärvi Group rocks and the 2.2–2.0 Ga and 1.91–1.86 Ga intrusions within the Vuojärvi Group domain. To the south, the tract is bounded by the migmatites and granitic intrusions of the Central Lapland Granitoid Complex (CLGC), to the north and east by the Kuusamo, Savukoski, Sodankylä, and Kumpu Group rocks, and to the west by the Finnish–Swedish border. Low-altitude airborne magnetic data were extensively used to define the extent of the tract rocks. The extension of the tract to the depth of 1 km is based on the assumption that the tract rocks continue downwards to 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 orogenic Au deposits within the 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 orogenic Au deposits in the Vuojärvi Group Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Tonnage (Mt)	Au grade (g/t)	Contained Au (t)	Reference
None							

Ga – billion years; Mt – million metric tons; t – metric ton.

Prospects, mineral occurrences and related deposit types

There are two partially explored orogenic Au occurrences within the Vuojärvi Group Orogenic Au permissive tract (Table 3).

Table 3. Significant orogenic Au occurrences in the Vuojärvi Group Orogenic Au permissive tract.

Name	X coordinate	Y coordinate	Age (Ga)	Comments	Reference
Kiekerömaa	7494600	3443600	?	5.0 m @ 5.8 g/t Au, several 1-5 m sections @ 1.0-8.9 g/t Au	Korkalo (2006)
Pahkavaara	7404100	3563300	1.84–1.77?	2.0 m @ 1.85 Au; 2 m @ 1.4 g/t Au	Pankka (2000), Laivola (2002)

Ga – billion years.

Exploration history

Exploration activities for orogenic Au deposits within the Vuojärvi Group Orogenic Au permissive tract are listed in Table 4.

Table 4. Exploration history for the Vuojärvi Group Orogenic Au permissive tract.

Theme	Type of work	Au analysed	Organisation	When carried out
Mapping	Outcrop observations and boulder survey	?	Outokumpu	1960s–1980s
	Outcrop observations and boulder survey	Partly yes	Geological Survey of Finland	1960s–2010s
Geochemical surveys	Nationwide till survey, systematic, 1106 points	Yes	Geological Survey of Finland	1986–1995
	Line till geochemistry, systematic, total 16,487 points	No	Geological Survey of Finland	1972–1983
	Targeting geochemistry, profile surveys, total 3772 points	Partly yes	Geological Survey of Finland	1978–2008
Airborne geophysical surveys	Regional low-altitude airborne magnetic, electromagnetic and radiometric survey		Geological Survey of Finland	1976–2002
Ground geophysical surveys	VLF survey, profile surveys, total 120 km		Geological Survey of Finland	1995
	VLF-R survey, profile surveys, total 535 km		Geological Survey of Finland	1985–2004
	Slingram survey multifrequency, profile surveys total 77 km		Geological Survey of Finland	1990
	Slingram survey one frequency, profile surveys, total 1004 km		Geological Survey of Finland	1972–1999
	Gravimetric survey, profile surveys, total 319 km		Geological Survey of Finland	1970s–2000s
	Magnetic surveys, profile surveys, total 1225 km		Geological Survey of Finland	1970s–2000s
	Self potential survey, profile surveys, total 5.3 km		Geological Survey of Finland	1996
	Slingram regional, systematic surveys, total 8 km^2		Outokumpu	1990–1991
	Protem regional survey, systematic survey, total 14 km^2		Outokumpu	1989–1990
Drilling	Diamond drilling, 244 DDH, total 20,834 m	Partly yes	Geological Survey of Finland	1992–2012
	Diamond drilling, 13 DDH, total 1617 m	Partly yes	Outokumpu	1964–1990

DDH – Diamond drill hole

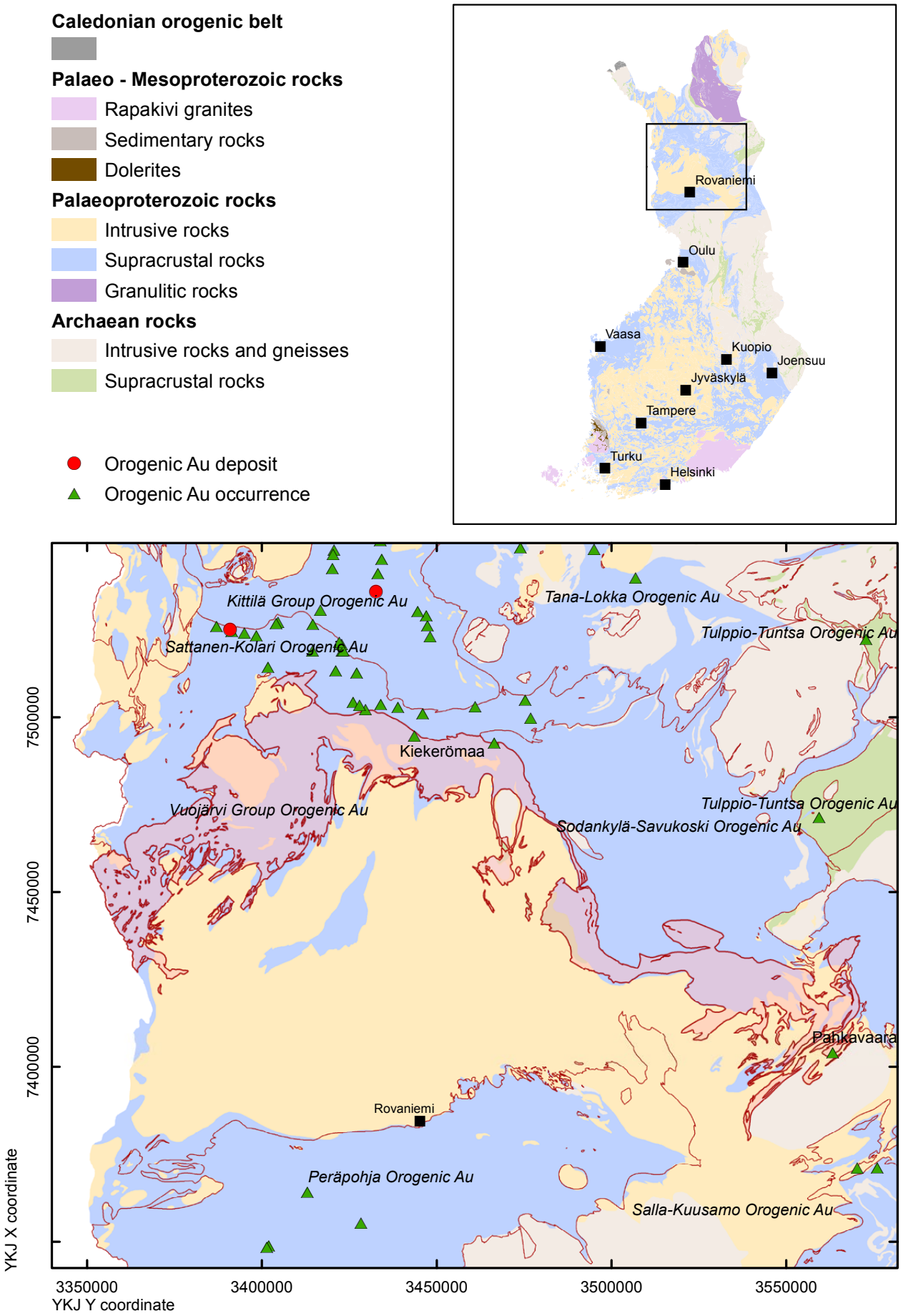

Fig. 1. Location of the Vuojärvi Group Orogenic Au permissive tract.

Sources of information

Principal sources of information used by the assessment team for the delineation of the Vuojärvi Group Orogenic Au permissive tract are listed in Table 5.

Table 5. Principal sources of information used by the assessment team for the Vuojärvi Group Orogenic Au permissive 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 (1959)
	Geological maps	1:100,000	Lauerma (1967a,b,1995), Mielikäinen (1979), Tyrväinen (1979, 1980, 1983), Räsänen (1983), Rastas (1984), Väänänen (1984, 1988, 1992, 2004, 2006), Väänänen & Leppinen (2001), Hanski (2003)
	Thematic geology reports		Lehtonen et al. (1998), Väisänen (2002), Korkalo (2006), Eilu et al. (2007), Hölttä et al. (2007), Patison (2007)
Mineral occurrences	Geological Survey of Finland gold deposit database		Eilu & Pankka (2009)
	Deposit descriptions		Pankka (2000), Laivola (2002), Korkalo (2006)
Geochemistry	Geological Survey of Finland in-house database		
	Reports		Lehmuspelto (1978), Pulkkinen (1983), Hartikainen et al. (2008), Lehmuspelto et al. (2009), Pulkkinen & Sarala (2009), Lauri et al. (2013)
Geophysics	Geological Survey of Finland in-house database		
	Reports		Lauri et al. (2013)
Exploration	Reports		Hartikainen et al. (2008), Pankka (2000), Lauri et al. (2013)
	Geological Survey of Finland in-house drill-core database		

ESTIMATE OF THE NUMBER OF UNDISCOVERED DEPOSITS

Rationale for the estimate

Two partially explored orogenic Au occurrences are known within the Vuojärvi Group Orogenic Au tract (Table 3). These occurrences are rather modest. The following were considered to support the orogenic gold potential of the Vuojärvi Group Orogenic Au tract: 1) the presence of two drilling-indicated orogenic gold occurrences, 2) a major transcrustal thrust zone (the W-trending, S-dipping Venejoki Shear Zone) cutting across the tract in its northern part and 3) the favourably low mid-greenschist facies regional metamorphic grade in the northern part of the tract. Much less exploration for gold has been carried out within the Vuojärvi Group tract than in the adjacent tracts to the north. Practically no exploration for any commodity has taken place in the eastern half and the SW part of the tract area. The individual estimators considered the probability high that at least one to four undiscovered economic deposits exist 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 Vuojärvi Group Orogenic Au 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}		
2	3	6			3.5	1.6	47	0	3.5	4505	0.00078

	Estimated number of undiscovered deposits				
Estimator	N_{90}	N_{50}	N_{10}	N_{05}	N_{01}
Individual 1	1	3	5		
Individual 2	1	2	5		
Individual 3	2	3	5		
Individual 4	1	2	4		
Individual 5	4	5	8		
Individual 6	1	3	6		
Mean	2	3	6		

N_{xx} – Estimated number of deposits associated with the xxth 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): Eilu, Karvinen, Keinänen, Niiranen, Nykänen, Sorjonen-Ward.

QUANTITATIVE ASSESSMENT SIMULATION RESULTS

Undiscovered resources for the tract were calculated by combining the undiscovered deposit estimates with the global orogenic gold 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 (Figure 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 Vuojärvi Group Orogenic Au 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			
Au (t)	1.0	4.6	27	180	290	65	0.25	0.04
Rock (Mt)	0.25	1.7	13	150	270	45	0.21	0.04

t – metric tons; Mt – million metric tons.

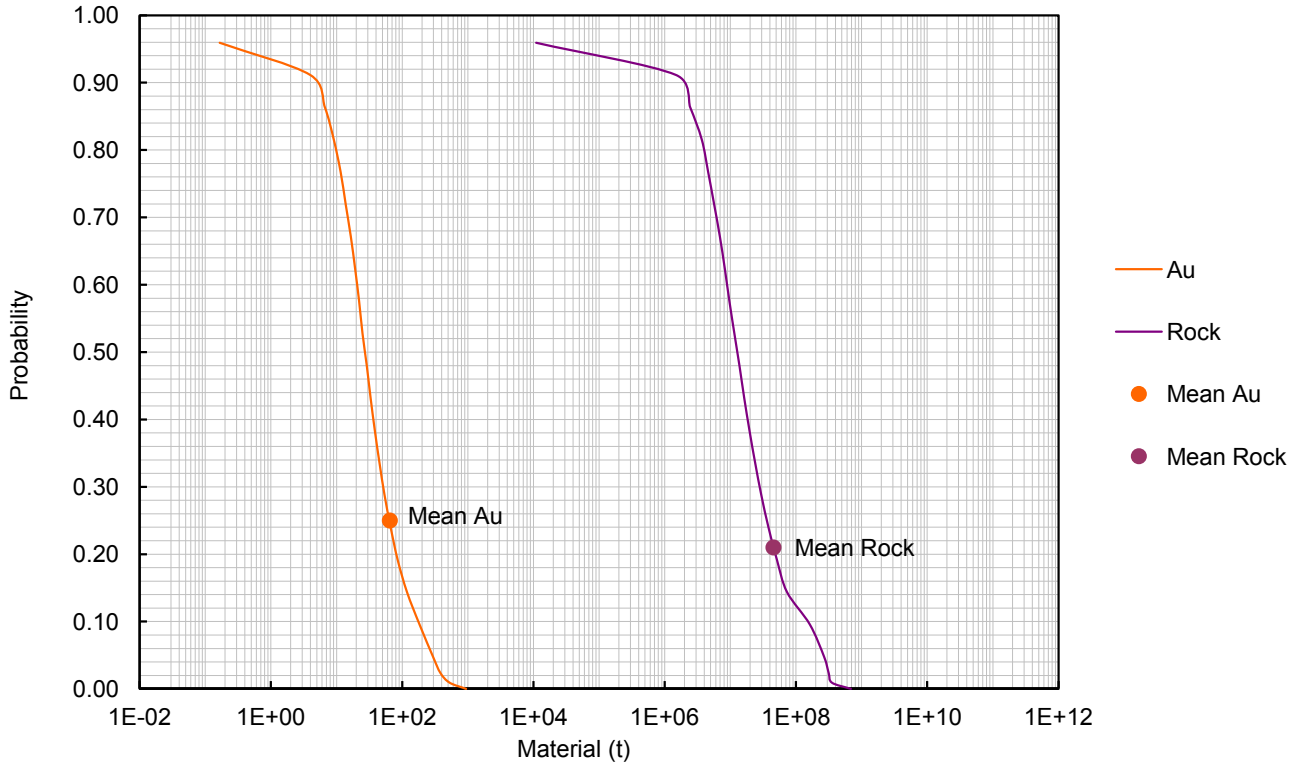

Fig. 2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in the Vuojärvi Group Orogenic Au permissive tract. Labelled dots indicate mean values.

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The present work uses statistical and expert assessment methods to estimate undiscovered resources in orogenic gold deposits in the uppermost one kilometre of the bedrock in Finland. It provides numerical estimates for the expected endowment of gold in undiscovered, but potentially exploitable deposits in Finland.

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