The Hietakero Co-Cu-Ni occurrence

PROSPECTUS

Contents

GTK Open File Work Report 4/2018

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Welcome to Finland

Finland, in the center of the Fennoscandian Shield, has similar geology and metallogeny to other Precambrian shields in Canada and Australia. The distinct pro-mining attitude, political and economic stability, and clear mining and environmental legislation in Finland create favorable conditions for the exploration and mining industry. The country also has highly developed infrastructure with good port facilities, an extensive high-voltage power grid, and a comprehensive road and airport network.

The Geological Survey of Finland (GTK) is a national geological organization operating under the Ministry of Employment and the Economy (http://en.gtk.fi/). One of the main duties of GTK as a national geoscientific information center is to promote and support mineral exploration and mining in Finland by providing high-quality data. GTK also actively identifies and evaluates areas with mineral potential, in order to encourage follow-up exploration and exploitation by the private sector.

GTK provides confidential and client-tailored services which include broad geoscientific and technical know-how. GTK offers also geological databases and other services and a wide range of expert services. For these reasons, Finland has been ranked as one of the most attractive country for mining and exploration in the annual surveys conducted by the Canadian Fraser Institute (Stedman & Green, 2017). The recent discoveries in Finland, such as Sakatti Cu-Ni-PGE (Anglo American Finland), Rompas Au (Mawson Resources Ltd.) and Aamurusko Au (Aurion Resources Ltd.) highlight the ore potential and unexplored nature of the country. For more information on these opportunities, please, visit the Mining Finland web site (http://www.miningfinland.com/opportunities).

Location, access and environmental statement

The Hietakero area is located in NW Finnish Lapland, around 17 km east of the river Lätäseno and 20 km north-east of Kaaresuvanto village (Figure 1). There are no public or maintained roads near the area. However, there is access to the area via tracks designed for all-terrain vehicles in summer and snowmobiles in winter. In this part of Finland, many areas belong to the Natura 2000 network and other types of conservation area that are protected by law.

The Hietakero area is mainly located in the Tarvantovaara and Käsivarsi wilderness areas of Natura 2000 network. The Hietakero area also includes mire reserves that are protected by law (http://www.metsa.fi/web/en/protected-areas). Moreover, it is important to recognize that this part of Finland is the Sámi homeland and therefore contains the reindeer herding territory of the Sámi people. In 2016, the Finnish Ministry of Employment and the Economy published a guide book on mineral exploration in protected areas, the Sámi homeland, and reindeer herding areas. This publication is available in digital form (http://www.tukes.fi/Tiedostot/kaivokset/TEM_Opas_MEKO_en.pdf).

It is recommended that exploration activities, such as drilling, are carried out in winter, when snow and frost protect sensitive nature. Most exploration activities in NW Lapland and Finland must be performed under a valid reservation access or exploration permit granted by the Finnish mining authority, TUKES (http://www.tukes.fi/en/Branches/Mining/). Any company or individual planning exploration work anywhere in Finland should seek guidance from this authority before starting operations.

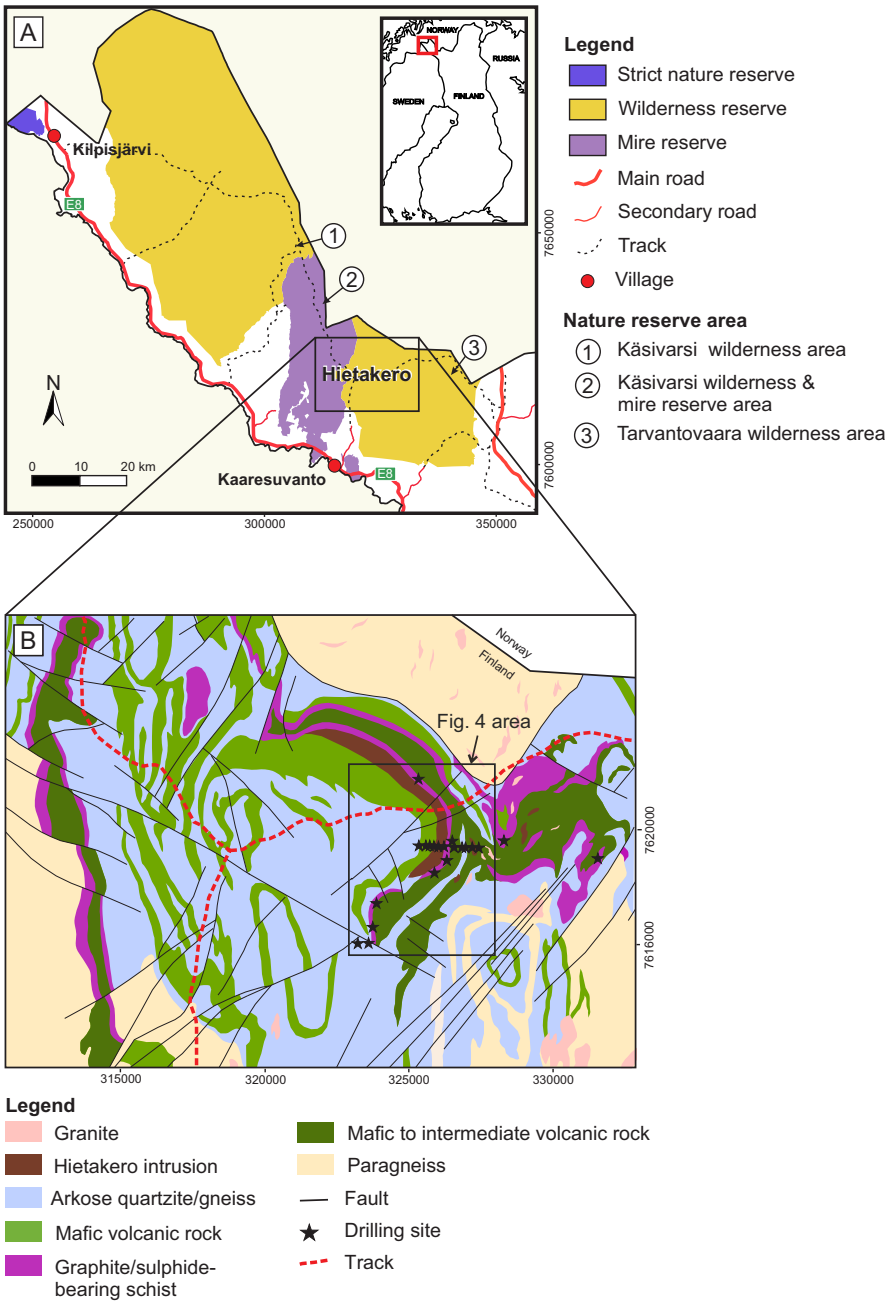


Figure 1. Location of the Hietakero area in NW Finland (A) and in a geological map (B).

Mineral systems

GTK has evaluated the geology and mineral potential of NW Finnish Lapland, because this area has good potential to contain several mineral systems and is also one of the least explored districts in the country. The following mineral systems have been detected:

- Ni-Cu-Co-PGE related to the 2.45-2.50 Ga layered intrusions
- Co-Cu-Ni related to the Paleoproterozoic mafic magmatism such as the Hietakero area
- Cu-(±Au-Fe) related to the highly altered Paleoproterozoic greenstone belts
- Ni-Cu-PGE related to the Archean komatiitic rocks
- Mo showings associated with altered granitoids and aplites
- Intensively altered Archean supracrustal rocks with potential for Au-Cu occurrences.

Mined Cu-Au deposits in geologically similar environments to the north and south, in Bidjovagge in Norway and Viscaria in Sweden, respectively, indicate the mineral potential of the region.

In Finland, known deposits, metallogenic areas, and permissive areas for mineral deposits are mapped in GTK's mineral deposits and exploration online map service (http://gtkdata.gtk.fi/MDaE/).

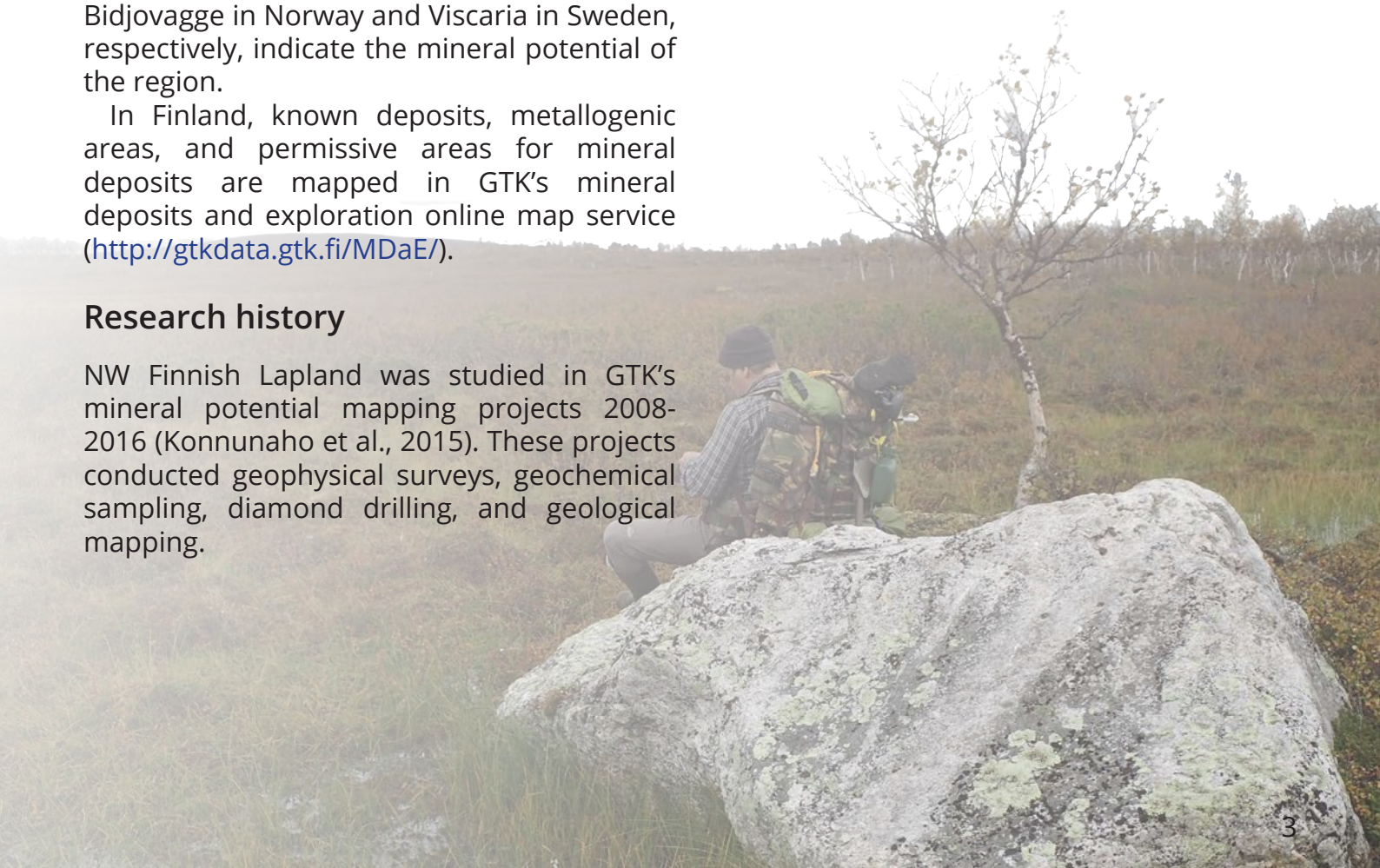
Research history

NW Finnish Lapland was studied in GTK's mineral potential mapping projects 2008-2016 (Konnunaho et al., 2015). These projects conducted geophysical surveys, geochemical sampling, diamond drilling, and geological mapping.

Geophysical surveys

The Hietakero Co-Cu-Ni occurrence and surrounding areas have been covered by a high-resolution, low-altitude airborne geophysical survey within GTK's national airborne geophysical program. The survey in the Hietakero area was performed in 1983, at flight altitude 30 to 40 meters, line spacing 200 meters, and line direction E-W. The survey included magnetic, electromagnetic, and radiometric components.

In 2012, during GTK's mineral potential mapping project, a time-domain electromagnetic airborne survey was carried out in the Hietakero area. This survey, performed by the Danish contractor SkyTEM Surveys ApS, included magnetic measurement. The total size of the flight area was 104.5 km^2, the flight direction was E-W, and the line spacing was 200 meters. SkyTEM survey data have been utilized in mapping conductivity structures of the area down to a depth of 500 meters.



During the 1980s, 2011-2012, and 2016, a total of around 3500 regional gravity points were measured in NW Finnish Lapland, covering an area of 1085 km^2. In the Hietakero area, the measurements were performed in 2011 and 2016 with station density 4 p/km^2. In addition, several ground geophysical magnetic, VLF-R, and gravity profiles were determined in 2011 and 2012 for drilling targeting purposes. In 2017, a systematic magnetic survey was conducted in a 3.3 km^2 sub-area using 50 meter line spacing and 1-2 meter point spacing. This survey investigated the continuation of lithology and structures related to the Co-Cu-Ni occurrence at Hietakero.

The locations of the geophysical surveys are shown in Figure 2. Furthermore, petrophysical laboratory measurements of density, susceptibility, and remanence have been made, with 1 m average sampling interval, from diamond drill cores V4222012R5-R11 and V422212R14-R17. All the data are available in GTK's digital databases and files.

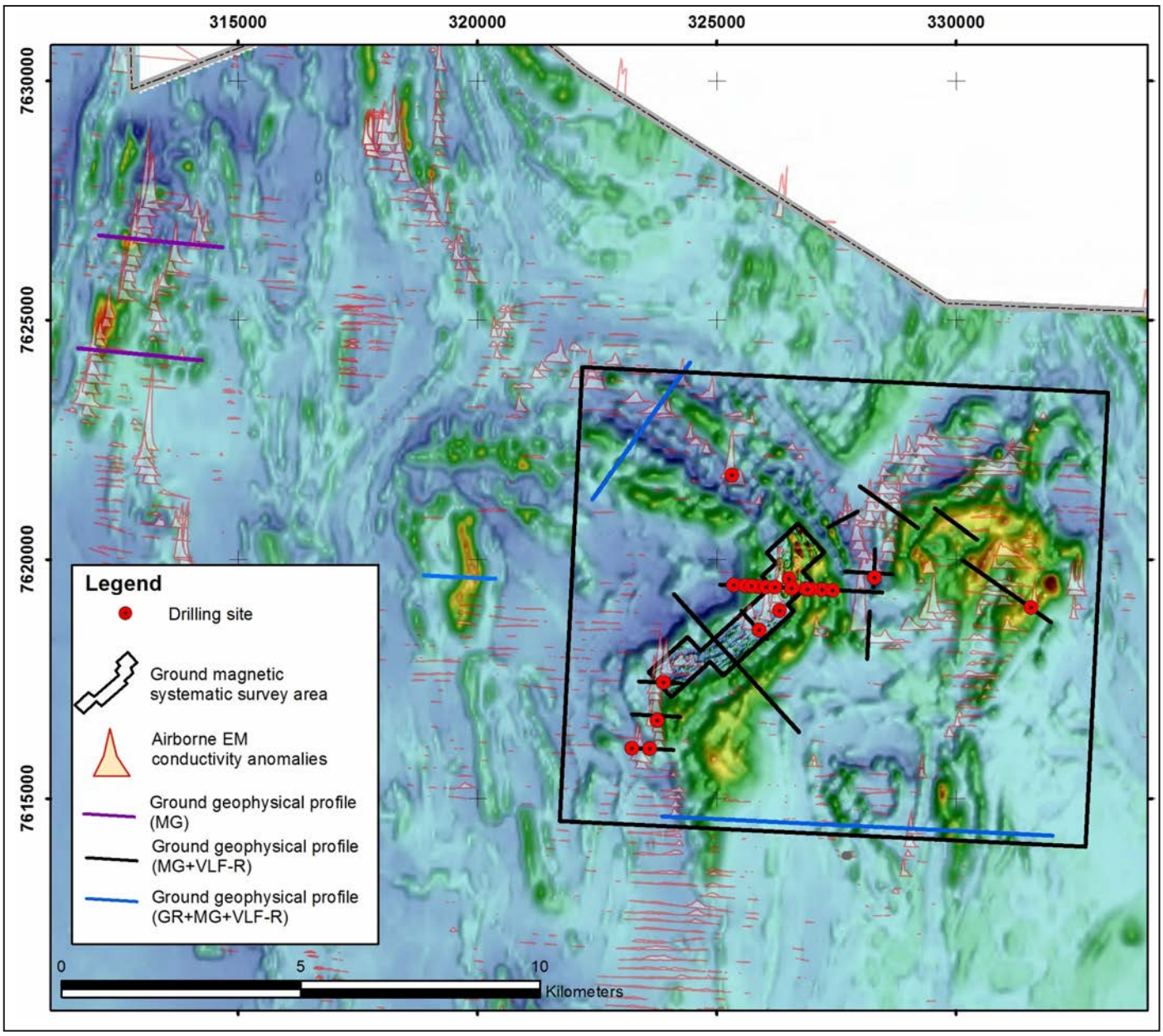


Figure 2. Aeromagnetic map of the Hietakero area showing the coverage of the SkyTEM survey in 2012 and the locations of the systematic ground magnetic survey area and separate ground geophysical profiles (MG = magnetic, GR = gravity, VLF-R = VLF-R method). Locations of electromagnetic conductivity anomalies over 80 ppm are plotted along flight profiles (GTK survey 1983).

Geochemical studies

GTK's regional till geochemical mapping survey covers the entire area of Finland. The samples were collected during 1982-1994 with sampling density of 1 sample per 4 km^2 (Salminen, 1995). One sample is a composite of 3-5 subsamples taken at a depth of approximately 1.5 m from the C-horizon and the sample material is till.

The fine fraction (<0.06 mm) was analyzed after hot aqua regia digestion with ICP-AES. The Hietakero area includes 71 regional till sampling points (Figure 3B). During GTK's mineral potential mapping project (Konnunaho et al., 2015), two systematic percussion drilling programs were performed in the Hietakero area in 2011 (Figure 3A).

The northern percussion drilling area (~3.4 km^2) consists of 73 sample sites with 73 till samples and 48 weathered bedrock samples. The southern area (~4.8 km^2) includes 200 sample sites with 186 till samples and 102 weathered bedrock samples. The line and sampling site spacing in both targets is 150-200 m.

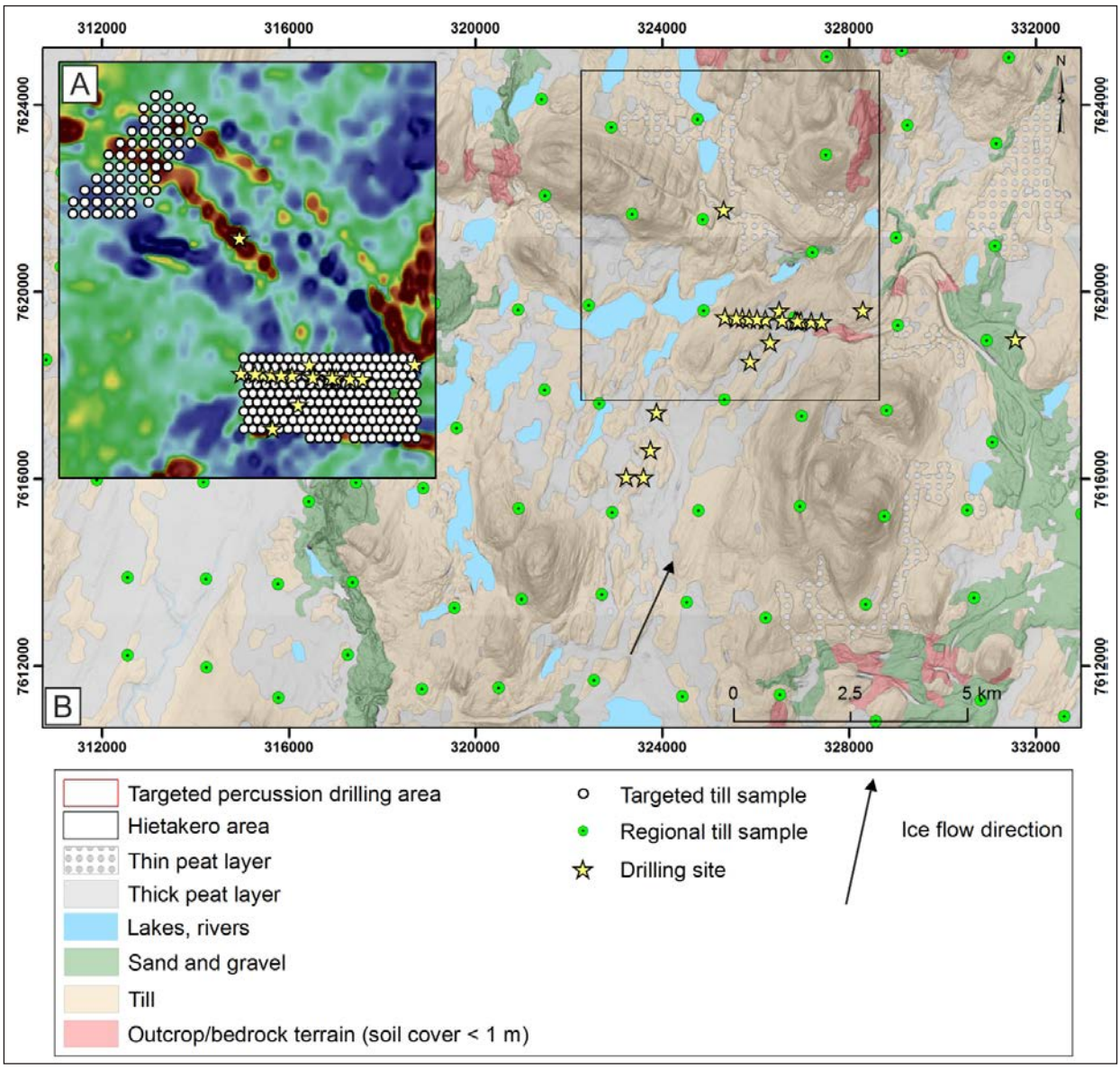


Figure 3. A) Targeted percussion drilling areas on the aeroelectromagnetic map (real component: red = high, yellow = moderate, green = low, blue = very low). B) Surficial geology map of the Hietakero area on the digital elevation model (DEM). The rectangle in Figure 3B indicates the area in Figure 3A. Basemaps © National Land Survey of Finland.

Table 1. Statistics on selected elements in the till samples collected from the Hietakero systematic percussion drilling areas. All concentrations are in ppm.

	Northern percussion drilling area						Southern percussion drilling area					
	Au	Co	Cu	Ni	Zn	S	Au	Co	Cu	Ni	Zn	S
N	69	69	69	69	69	69	177	177	177	177	177	177
Min	0.001	9	14	14	11	10	0.000	2	6	5	5	10
Max	0.010	43	378	135	78	1000	0.045	49	331	123	214	17600
Median	0.002	14	34	25	22	10	0.001	14	44	34	24	21
SD	0.002	6	53	17	10	124	0.005	7	42	19	18	1332
25 percentile	0.002	11	27	20	19	10	0.000	11	32	26	18	10
75 percentile	0.003	16	55	31	25	27	0.002	19	73	48	33	44
99 percentile	0.010	43	378	135	78	1000	0.044	46	249	113	104	5658

The till samples were sieved to <0.06 mm size fraction and 39 elements (including Au and Pd) were analyzed by ICP-MS/OES. In addition, Au, Pd and Te were analyzed using the GFAAS technique. The weathered bedrock samples were crushed, pulverized, and analyzed by ICP-MS/OES (38 elements including Au and Pd) and the GFAAS technique (Au, Pd, Te). Statistics on Au, Co, Cu, Ni, Zn, and S concentrations in the till samples from these areas are presented in Table 1.

In addition, analytical data on regional stream sediment geochemistry (both organic and inorganic sampling media) are available. These samples were collected during 1971-1985, with sampling site spacing of 50-300 m along streams and ~500 m along lake shorelines. The geochemical data are available on the GTK website (https://hakku.gtk.fi/en/locations/search).

Regional geology

The landscape of the Hietakero area and its surroundings reveals that the latest ice flow direction in the area was almost directly south to north. This is clearly visible in the digital elevation model (DEM) depicted in the map in Figure 3. Based on the DEM, ice transport can be hundreds of meters but was probably markedly shorter on the lee side of hills. An N-S trending esker splits the landscape on the western side of the Hietakero area. In the eastern part there are also sorted sediments in glacial meltwater eruption channels, formed during deglaciation.

The bedrock is poorly exposed and it is mostly covered by a thick layer of till and peat. Percussion drilling has revealed that the thickness of the overburden is up to 10 m in the northern and 15 m in the southern targeted area. It is thickest in lowland areas and in gorges, and thinnest on the sides and tops of hills and in meltwater eruption channels. The overburden thicknesses recorded during diamond drilling in the southern target area confirm that the overburden is generally less than 15 m thick (Table 2).

The Hietakero area (Figure 1B) is part of the Lätäseno Schist Belt (LSB), which consists of Archaean to Paleoproterozoic supracrustal rocks running approximately N-S. The supracrustal rocks of the area belong to the Paleoproterozoic part of LSB. Mafic volcanic rocks are the most voluminous rocks in the area. In addition, there are amfibolites of unknown origin, but they may be related to the mafic volcanic rocks. Minor amounts of felsic to intermediate volcanic rocks occur as thin, semi-continuous layers in the area, whereas graphite-sulfide bearing schists, clearly visible in electromagnetic maps, form more continuous units. The paragneisses that border the area to the north belong to the Paleoproterozoic Raiseatnu Suite and elsewhere the gneisses belong to the Archaean Muonio Complex.

The Hietakero area has been multiply folded, as indicated by the complex interference pattern. The fold axes are orthogonally located, indicating N- and E-trending shortening. The supracrustal rocks are pervasively scapolitized and albitized, like many other Paleoproterozoic greenstone belts in Finnish Lapland.

The area also includes mafic-ultramafic intrusive rocks, of which the Hietakero intrusion has an extension of about 1 x 9 km at the surface. It is likely that the magma from which the intrusion crystallized intruded in several pulses into the country rocks and that the Co-Cu-Ni occurrence was formed during the intrusion stage(s). According to geophysical data, the mineralization is located in a conductive zone referred to as the Critical Zone. Drill cores indicate that this zone includes mineralized hybrid rocks, felsic volcanic rocks, and pyroxenites. The mineralized rocks are sandwiched between gabbroic cumulates. The intrusion can be detected in the aeromagnetic map (Figure 4) by its relatively lower magnetic anomaly compared with the surrounding country rocks (amfibolites

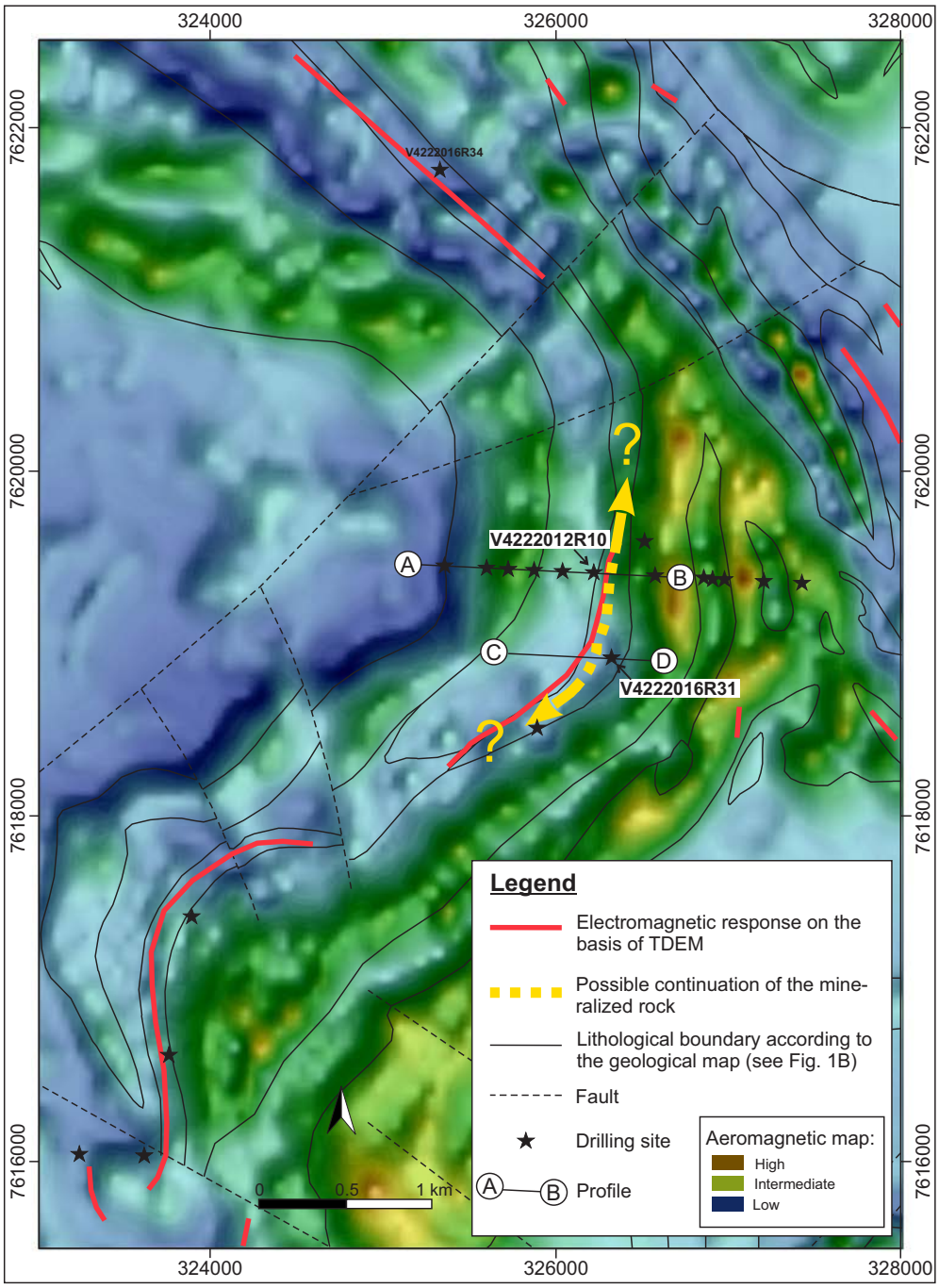


Figure 4. Aeromagnetic map of the Hietakero area showing diamond drilling sites and the probable continuation of the Co-Cu-Ni-mineralized zone. In general, the bedrock geology of the area is poorly understood due to glacial overburden, sparse outcrops, and very few drill cores. For this reason, wide areas of inferred map units are based largely on interpretation of geophysical data.

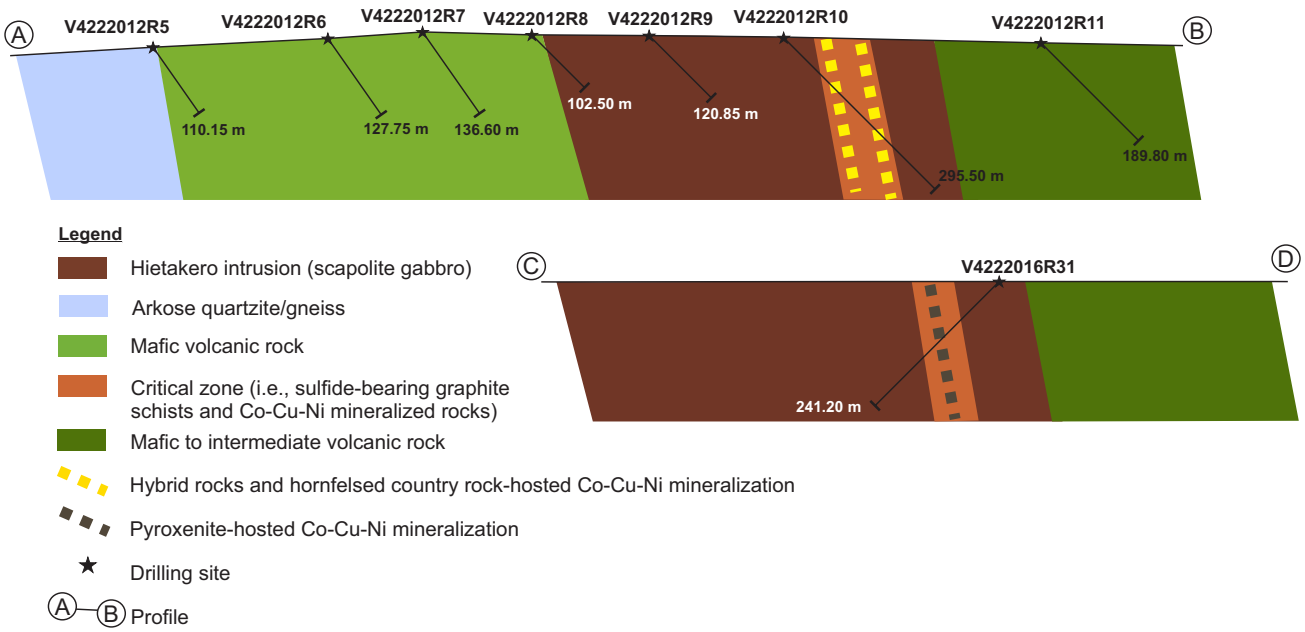


Figure 5. Simplified geological cross-sections along the drilling profiles (see Figure 4).

and mafic volcanic rocks). According to geophysical inversion models of susceptibility and EM data from aerial surveys, the intrusion is located along an N- trending synform and is mostly eastward dipping. Figure 5 illustrates geological cross-sections along the profiles shown in Figure 4.

Hietakero Co-Cu-Ni occurrence

Altogether, 3373.5 m of core have been drilled in the Hietakero area, in two campaigns (2012 and 2016). Details of these campaigns are presented in Table 2. The Co-Cu-Ni mineralized rocks are distinct in two diamond drill holes (Figure 6). In the discovery hole V4222012R10 (hole R10), which was drilled in 2012, the sulfides are located in a hybrid of intrusion rocks and hornfelsed country rocks (felsic to intermediate volcanic rock). This mineralized zone includes on average 0.2 wt% Ni, 0.1 wt% Co, and 0.35 wt% Cu in 173.80-178.80 m and 0.23 wt% Ni, 0.1 wt% Co, and 0.31 wt% Cu in 194.80-208.80 m down-hole depth. Furthermore, there is an area in the lower part of the hole (outside the main mineralization) in which the PGE content is elevated in a sulfide-poor gabbroic sequence, up to 350 ppb Au+Pt+Pd between 282.35 and 288.35 m down-hole depth.

During the second drilling program in 2016, designed to outline the mineralized rocks, a sulfide-bearing zone was intersected by the diamond drill core V4222016R31 (hole R31), located about 600 m south of the discovery hole. At this site, however, the most mineralized part is a sulfide-bearing pyroxenite which contains up to 0.24 wt% Ni, 0.08 wt% Co, and 0.60 wt.% Cu in a 2.5 m thick interval in between 146.30 and 148.80 m in the core.

The southward and northward continuation of the mineralized rock in the Hietakero intrusion is as yet unknown, as shown in Figure 4. Thus, on the basis of the limited amount of the drilling, the occurrence is considered poorly investigated and a mineral resource cannot be estimated.

The concentrations of Ni and Co in the samples collected from the drill core show a strong positive correlation with sulfur content, indicating that these elements are concentrated in the sulfides. The rocks in hole R31 appear to be slightly richer in Ni at a given S content than those in hole R10, which indicates somewhat different sulfide mineralogy in the cores.

The concentration of Cu does not show a distinct correlation with S in either core, a feature which is likely due to late magmatic mobilization (Figure 7). Further evidence of this is provided by the notable occurrence of chalcopyrite in fractures in the hybrid rocks observed especially in hole R10.

The distribution of Cu, Co, and Ni in different sulfide-bearing rocks in drill cores R10 and R31 is illustrated in the molar ternary Cu-Co-Ni diagram in Figure 8. The diagram also includes microprobe data on the sulfide minerals that control the chalcophile element distribution of the occurrence. These sulfide minerals are chalcopyrite, pyrite, Co-pentlandite, pyrrhotite, and linnaeite-polydymite. It is clear from the diagram that the chalcophile element distribution of the prospect is bimodal, controlled by the mode of Cu-rich and Co-Ni-bearing phases. Another distinct feature is that there appears to be variation in the amount of Cu-rich and Co-Ni-rich phases between different rock types. The felsic rocks and hybrids (mostly in R10) are slightly more Cu-rich than the pyroxenites and gabbros (mostly in R31). In mineralized rocks, the Ni/Co is approximately 1.9 to 3.

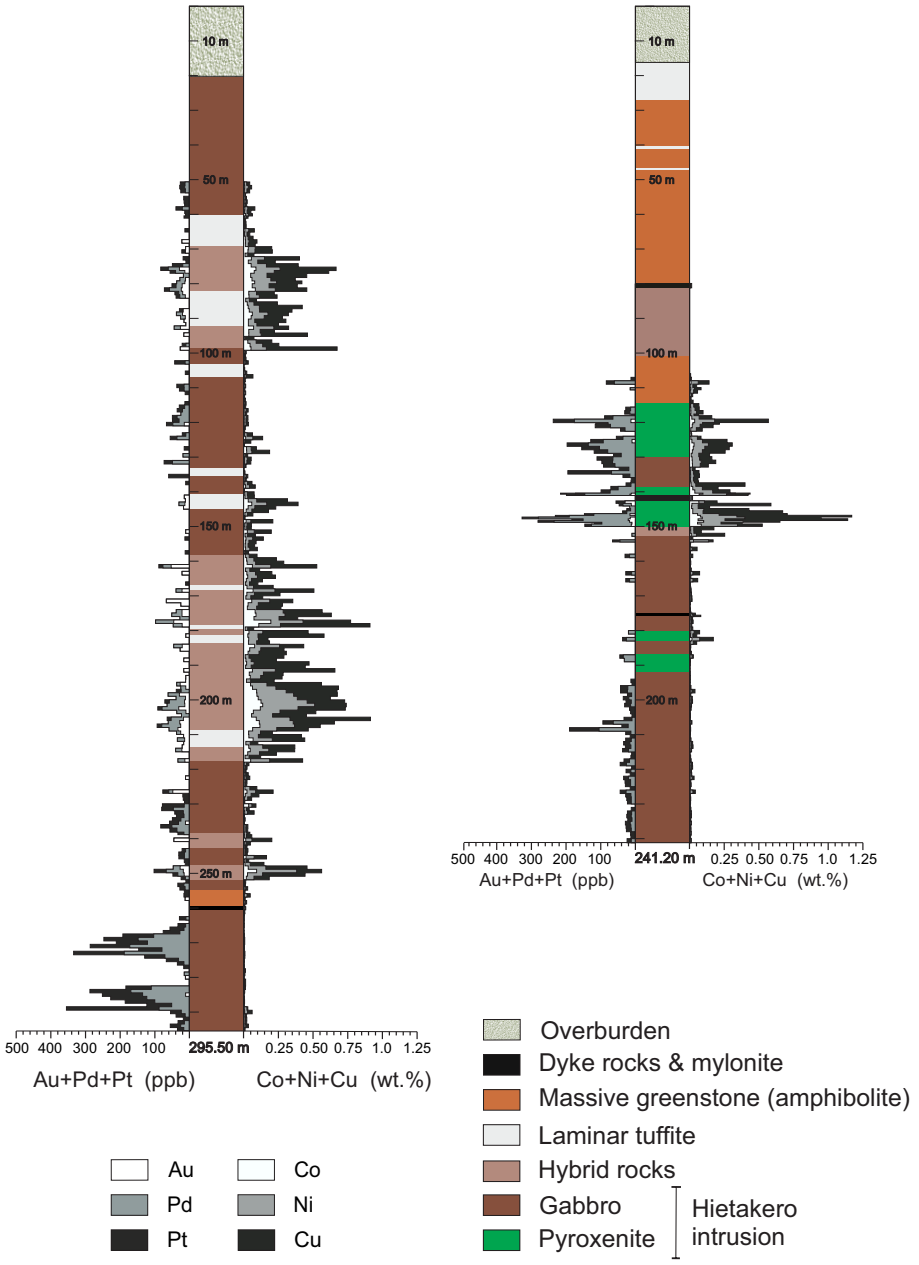


Figure 6. Concentrations of (left) Au, Pd, and Pt and (right) Co, Ni, and Cu in the diamond drill cores R10 (V4222012R10 analyzed from 50.45 to 295.35 m) and R31 (V4222016R31 analyzed from 79.97 to 81.22 m and from 106.00 to 241.20 m).

Co-Cu-Ni mineralized sample from core R10.

Table 2. Details of the diamond drilling performed in the Hietakero area in 2012 and 2016.
(X = longitudinal location in Finnish coordinate system (ETRS-TM35FIN), Y= latitudinal location in Finnish coordinate system (ETRS-TM35FIN), Z (m) = altitude a.s.l.).

DDH	Year	X	Y	Z (m)	Azimuth	Dip	Length (m)	Overburden (m)
V4222012R5	2012	325354	7619457	448	90	55	110	9.00
V4222012R6	2012	325594	7619446	460	90	55	128	5.65
V4222012R7	2012	325724	7619439	469	90	55	137	4.90
V4222012R8	2012	325874	7619432	465	90	45	103	16.80
V4222012R9	2012	326035	7619423	464	90	45	121	17.00
V4222012R10	2012	326218	7619419	462	90	45	296	20.20
V4222012R11	2012	326572	7619399	454	90	45	190	16.70
V4222012R12	2012	326972	7619379	455	270	45	42	42.00
V4222012R13	2012	326902	7619379	455	270	60	15	15.00
V4222012R14	2012	326853	7619387	452	270	60	98	17.00
V4222012R15	2012	327201	7619366	448	270	55	103	10.80
V4222012R16	2012	327421	7619356	448	90	45	187	21.55
V4222012R17	2012	328300	7619611	452	360	55	144	9.00
V4222016R26	2016	323234	7616048	435	90	45	229	15.70
V4222016R27	2016	323610	7616040	429	90	45	155	10.90
V4222016R28	2016	323754	7616623	432	270	45	55	11.15
V4222016R29	2016	323887	7617426	432	270	45	201	7.20
V4222016R30	2016	325891	7618517	450	315	45	205	5.90
V4222016R31	2016	326320	7618923	451	290	45	241	16.20
V4222016R32	2016	326515	7619598	460	270	50	220	19.80
V4222016R33	2016	331565	7618988	414	125	45	204	21.20
V4222016R34	2016	325326	7621750	461	225	45	191	5.90

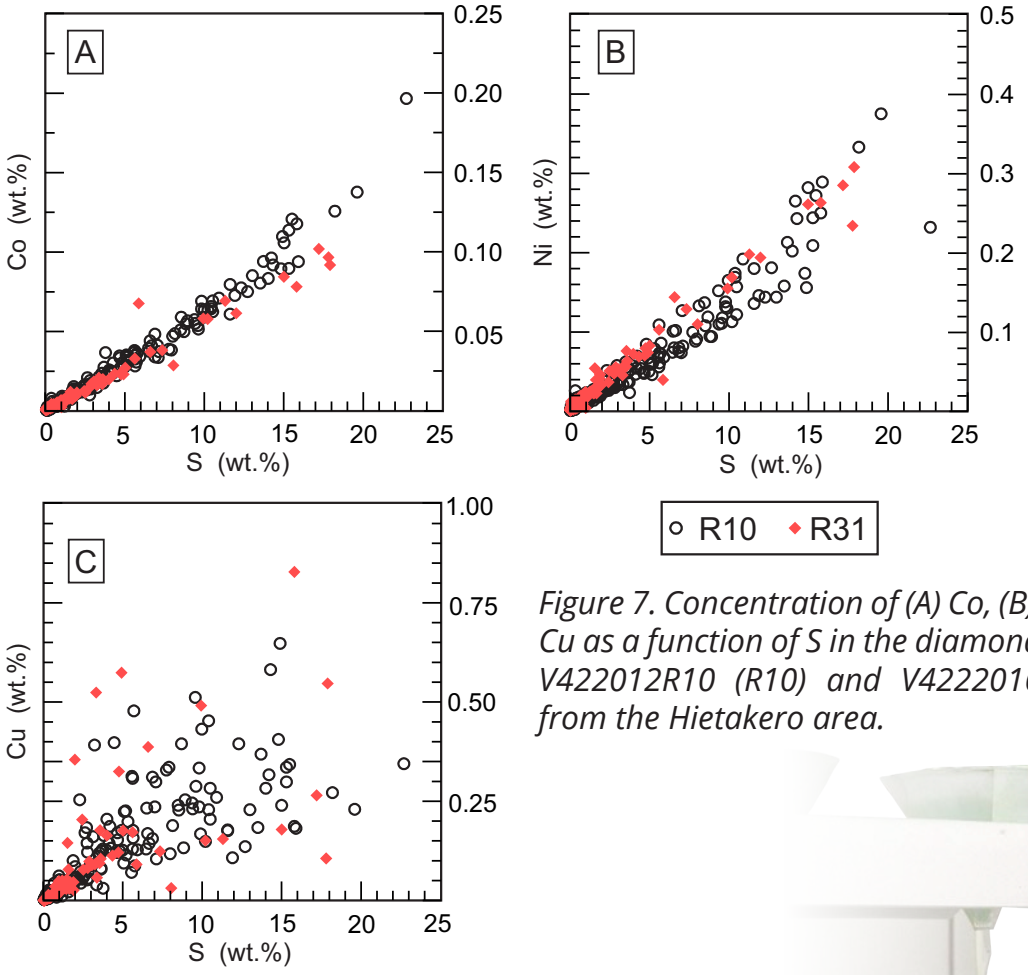


Figure 7. Concentration of (A) Co, (B) Ni, and (C) Cu as a function of S in the diamond drill cores V422012R10 (R10) and V4222016R31 (R31) from the Hietakero area.

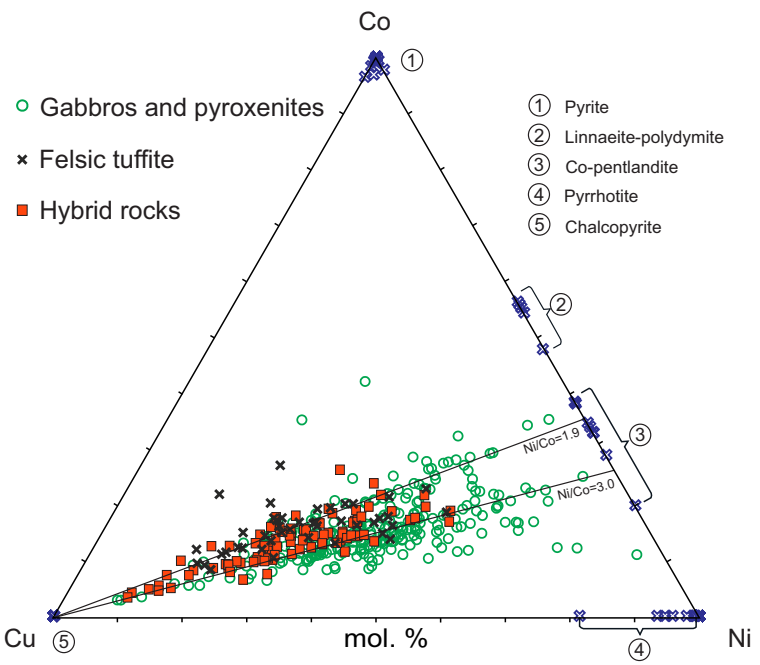


Figure 8. Molar ternary Co-Cu-Ni diagram illustrating the chalcophile element distribution in the mineralized rock types of drill cores R10 and R31.

Mineral potential and recommendations

Hietakero Co-Cu-Ni occurrence

- The continuation of Co-Cu-Ni mineralized rock along the strike and down-dip of the Hietakero intrusion is as yet unknown. It is possible that the occurrence is connected along the strike of the intrusion between drill holes R10 and R31, in which case the mineralized rocks extend for at least 600 m (see Figure 4).
- On the basis of continuation of the Critical Zone in the other drill cores of GTK diamond drilling, the potential zone could extend towards the north and south.

Surrounding areas

- Diamond drilling has revealed that the mafic-ultramafic magmatism extends over a wider area. These igneous rocks are in places adjacent to similar conductive zones, as is the case for the Co-Cu-Ni-enriched zone of the Hietakero intrusion. These analogous targets are marked 1 and 2 in the map in Figure 9B.
- The geological and geophysical data indicate at least two distinct areas of possible mafic–ultramafic intrusion. These targets are numbered as 3 and 4 in the map of Fig. 9B. The area 3 includes a positive gravity anomaly and the area 4 includes a strong conductive zone around a gravity anomaly.

In general

- In a wider view, the relatively strongly scapolite-albite-biotite altered rocks are potential host rocks of Au-Cu deposits in Paleoproterozoic greenstone belts, as is the case e.g., at Bidjovagge (Norway) and Saattopora (Finland).
- Extensive geophysical surveys (magnetic-electromagnetic-gravity) have identified several targets for future exploration in Hietakero and surrounding areas. These existing survey data can reduce the exploration costs significantly.

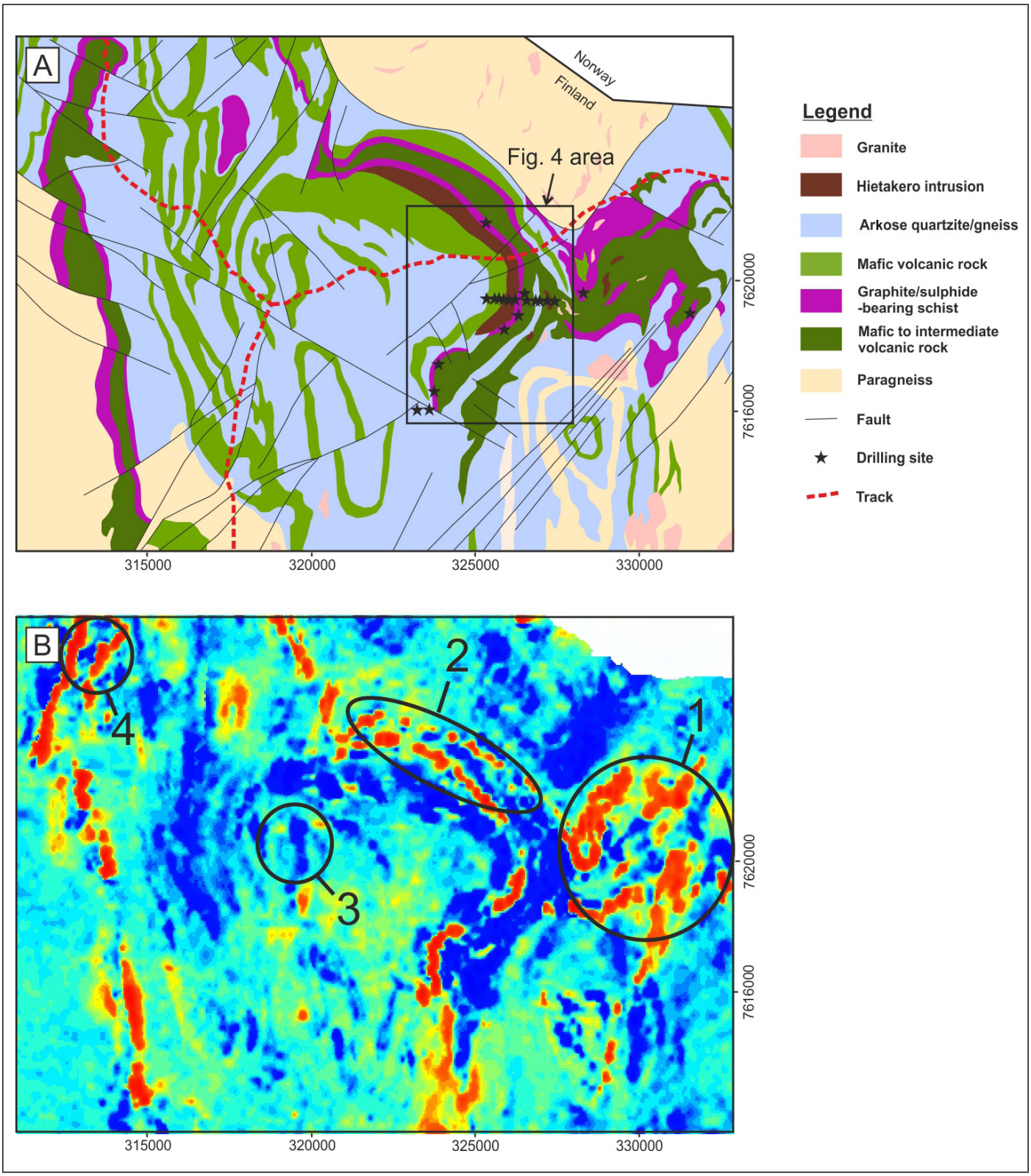


Figure 9. (A) Geological and (B) electromagnetic map of the Hietakero area. The red-yellow areas in the electromagnetic map are conductive zones. Additional exploration targets in the area are indicated by circles 1 to 4.

GTK services for exploration and mining industry

GTK is national geoscientific information center which actively participates in development of the exploration and mining sector in Finland. GTK produces and disseminates geological information for the industry and society, in order to promote systematic and sustainable use of mineral resources. It offers a wide spectrum of transferable technical knowledge and expert services in order to support partners in achieving their specific goals. GTK staff are highly qualified in various aspects of geology, including geochemistry, mineralogy, geophysics, satellite imagery interpretation, GIS-aided data processing, and 3D modelling. Some GTK experts hold Qualified Person status in different geo-sectors. For the exploration and mining industry, the services include:

Ore potential evaluation

- **Regional evaluation of potential ore**
  - Mineral prospectivity maps
  - Maps and interpretation of aerogeophysical data
  - Maps and interpretation of bedrock and soil geochemical data
  - Mineral system modeling
  - Survey planning
- **Location-specific ore potential evaluation**
  - Ground geophysical surveys and interpretation
  - Geochemical surveys and interpretation
  - Mineral system modeling
  - Mineralogical surveys
  - Survey planning

Ore deposit modelling and mineral resource evaluation

- Compilation of research data into digital format
- 3D modeling (solids, surfaces, block modeling)
- Mineral resource evaluation according to current industrial standards
- Software, such as Gemcom Surpac, Gemcom GEMS, and ArcGIS
- Qualified Person-level research and reporting

Geophysical services

- **Ground geophysical surveys**
- **Borehole surveys and logging**
- **Special surveys**
- **Geophysical laboratory measurements**
- **Exploration geophysics of natural resources**

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https://hakku.gtk.fi/en/reports (GTK online report service)
https://hakku.gtk.fi/en/locations/search (GTK spatial data products and data extraction)
http://www.tukes.fi/en/Branches/Mining (TUKES, mining authority in Finland)

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