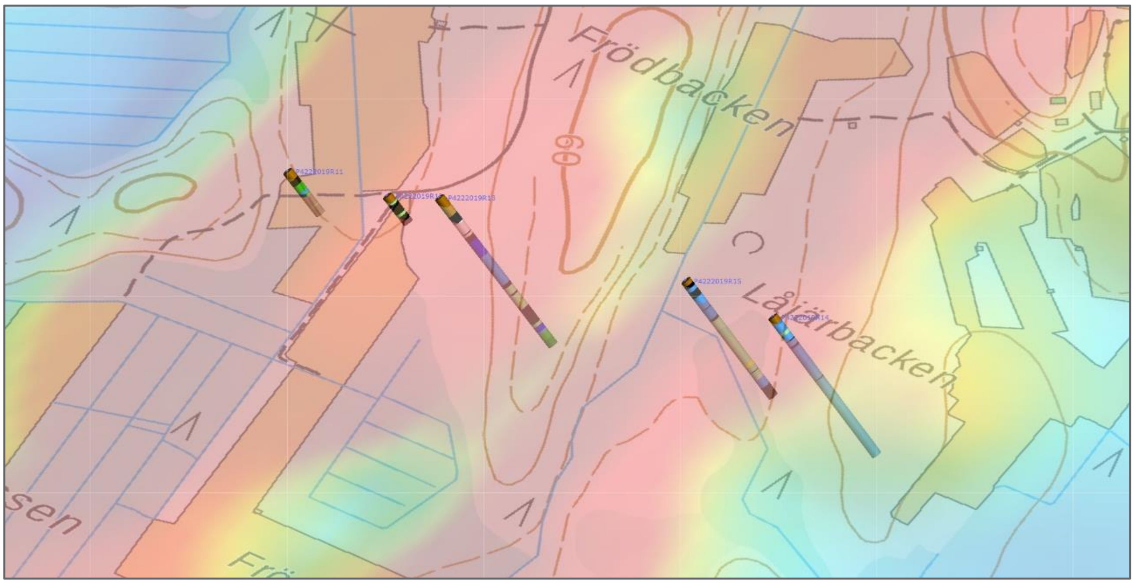
Geological Survey of Finland
Mineral Economy Solutions
Espoo

21.12.2021

Open File Work Report
69/2021



The investigation of the Kaitåsen metavolcanic rocks in Kruunupyy, Western Finland

Henrik Nygård, Janne Kuusela, Hanna Leväniemi, Jukka-Pekka Kujasalo

GEOLOGICAL SURVEY OF FINLAND **DOCUMENTATION PAGE**

Authors
Henrik Nygård, Janne Kuusela, Hanna Leväniemi, Jukka-Pekka Kujasalo

Type of report
Open File Work Report

Commission by
GTK

Title of report
The investigation of the Kaitåsen metavolcanic rocks in Kruunupyy, Western Finland

Abstract
The Kaitåsen area was investigated as part of the Geological survey of Finland's battery mineral project that begun in 2019. The area was selected because of cobalt-bearing layman samples found downrange in the transport direction of the glacial till. A drilling campaign of five holes covering 618.60 meters intersected the volcanic rocks and black schists of the area. The drill cores were logged, and 111 core samples analyzed. A small-scale geophysical ground survey as well as drillhole survey was conducted. The drilling intersected graphitic black schist layers of a maximum of 20 meters wide, containing a median of 4.4 % graphitic C. The maximum reaching 11.4 % C per meter. A few hydrothermally altered zones was intersected with elevated values of Co, Ni, and REE elements among others. However, no significant mineralization was intersected in the drillings.

Keywords
Cobalt, Graphite, Battery minerals, Metavolcanic rocks, Black schist, Diamond drilling, Geophysics, Ostrobothnia, Kruunupyy

Geographical area
Ostrobothnia, Kruunupyy, Kaitåsen

Map sheet
P4222H2

Other information
-

Report serial
GTK Open File Work Report

Archive code
69/2021

Total pages
17

Language
English

Price
-

Confidentiality
Public

Unit
Mineral Economy Solutions

Project code
50402-20108212

Signature/name
Henrik Nygård

Signature/name
Aleksi Salo

Contents

1 INTRODUCTION

The Kaitåsen drill area was part of the GTK’s battery mineral project. This project aimed to expand the knowledge of battery mineral potential at several locations in Finland. The main minerals of focus were lithium, cobalt, nickel and graphite. At the Raisjoki investigation area several drill targets were chosen to investigate the north-south striking volcanic belts in the area. This includes the Kaitåsen drill location. Historically some cobalt-bearing (up to 1500 ppm) layman boulders had been discovered in the area (Lindmark 1978, GTK internal data).

The area in general where the volcanic belts occur, has also been investigated for tungsten bearing scheelite at Fröidömossen 6 km north of Kaitåsen (Lindmark 1977). The Raisjoki-river (same placename as the project name) 13 km southeast was investigated for Co-bearing layman samples in the 1970s (Lindmark 1978). At Ahvenjärvet, 7 km to the east, a Cu-Zn-Au target was extensively investigated and drilled during the 1970s (Lindmark 1979). At several more places sulphidic boulders and bedrock has been found and investigated (Järnefelt 1936).

The glacial transportation of the Co-bearing boulders was likely originating from the volcanic belts, which have magnetic and electromagnetic geophysical anomalies. Furthermore, the volcanic belts, especially the westernmost one, had been poorly investigated by drilling in the past. One reason being the extensive till cover of the glacial drumline landscape providing few outcrops of bedrock.

GTK applied for and where granted a reservation notification for an exploration permit. This covered the Kaitåsen area where the geophysical survey and the drilling was conducted.

The Northern part of the volcanic belt at Dragbacken, the Southern part at Emas, Kedonkangas as well as the similar belt to the east at the river Raisjoki are investigated in separate GTK reports.

2 REGIONAL GEOLOGY

The investigated Kaitåsen area (Fig. 1) are part of a North-South striking metavolcanic belt with lithologies of mafic volcanite, amphibolite, basalts, pillow lavas, volcanic tuff and graphitic black schist. This belt is surrounded by metasedimentary rocks (grauwacke and mica schists). These rocks where originally deposited on the oceanic floor. The volcanic belt is thought to represent a mid-ocean ridge basalt (MORB) or within-plate lava (WPL) environment (Vaarma & Pipping 1997).

The bedrock was strongly deformed during the 1860 Ma orogeneses of the Svecofennian bedrock being thrusted into the Central Finland Granitoid Complex. The North-South volcanic belt together with the black schists acted as a regional overthrust and slip/fault zone. The black schists are fine-grained pelitic sulfidic graphite schists. The graphite content varies between 3-12 %. At some places the black schist sequences may contain tremolite skarn pods and a few meter wide volcanic tuff interlayers (Vaarma & Pipping 1997). The metamorphic grade is at the lower amphibolite facies.

The investigated metavolcanic belt is in the north cut by post-orogenic S-type pegmatite granite intrusion and in the south by a couple of granitoid intrusions. Although the area is generally heavily intruded with pegmatite veins (GTK field mapping 2019 and 2020), no pegmatitic veins was observed in the Kaitåsen drillholes.

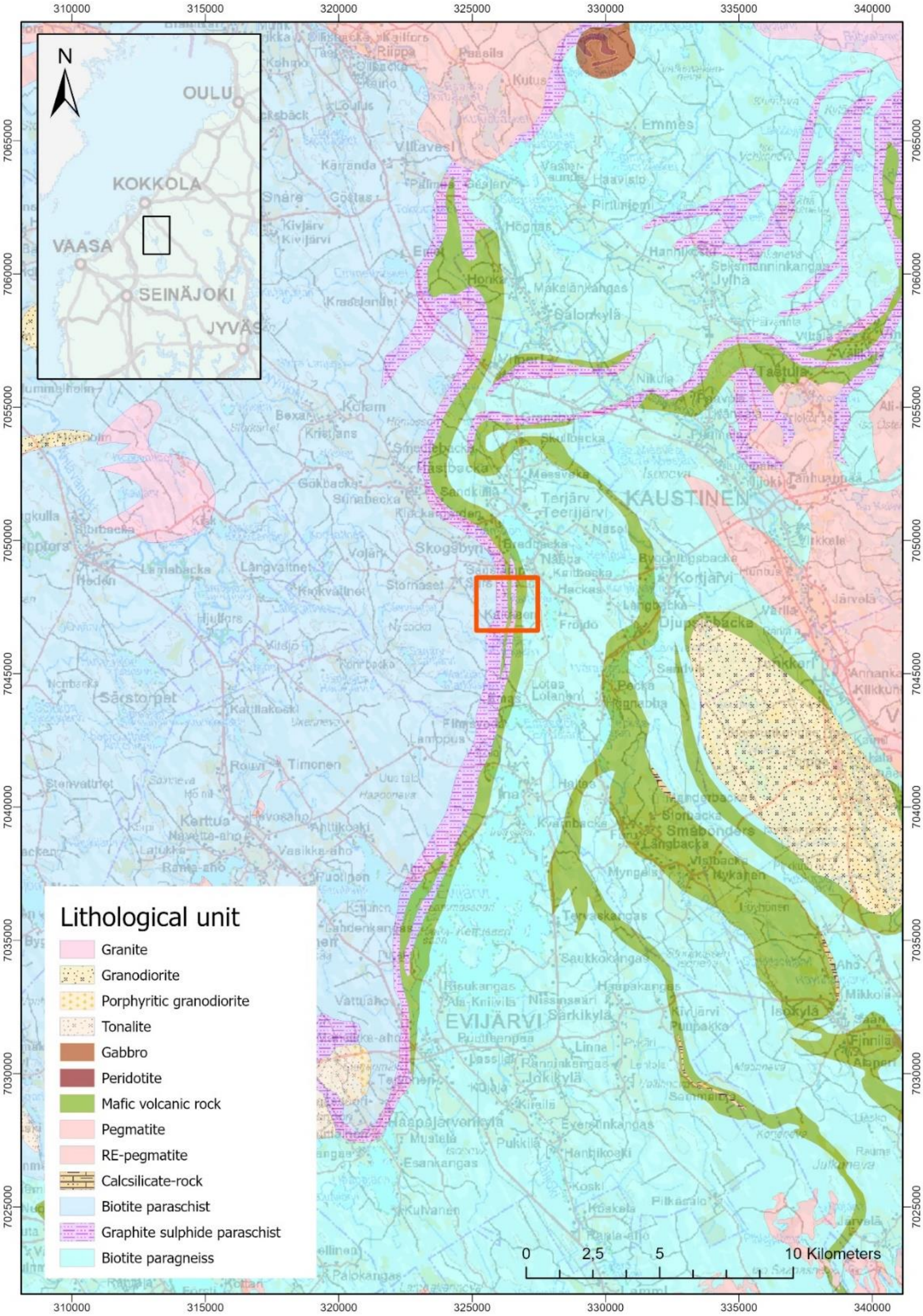


Fig. 1. Regional geology map. The investigated Kaitåsen area is framed with a red square.

3 GEOPHYSICAL DATA

GTK's national aerogeophysical dataset (Hautaniemi et al. 2005) covers the area. The flight was conducted in 2001 (flight area 275) with 200 m line spacing (EW) and 30 m nominal altitude. The dataset consists of magnetic, frequency-domain electromagnetic (EM) and radiometric measurements.

Four EW ground profiles were measured with magnetic and multi-frequency EM (MaxMin) methods across the anomalies detected in the airborne data (Fig. 2). Both airborne and ground surveys indicate strong magnetic and conductive anomalies. From the ground profiles it can been seen that two north-south anomalies from airborne data actually consist of multiple separate anomalies.

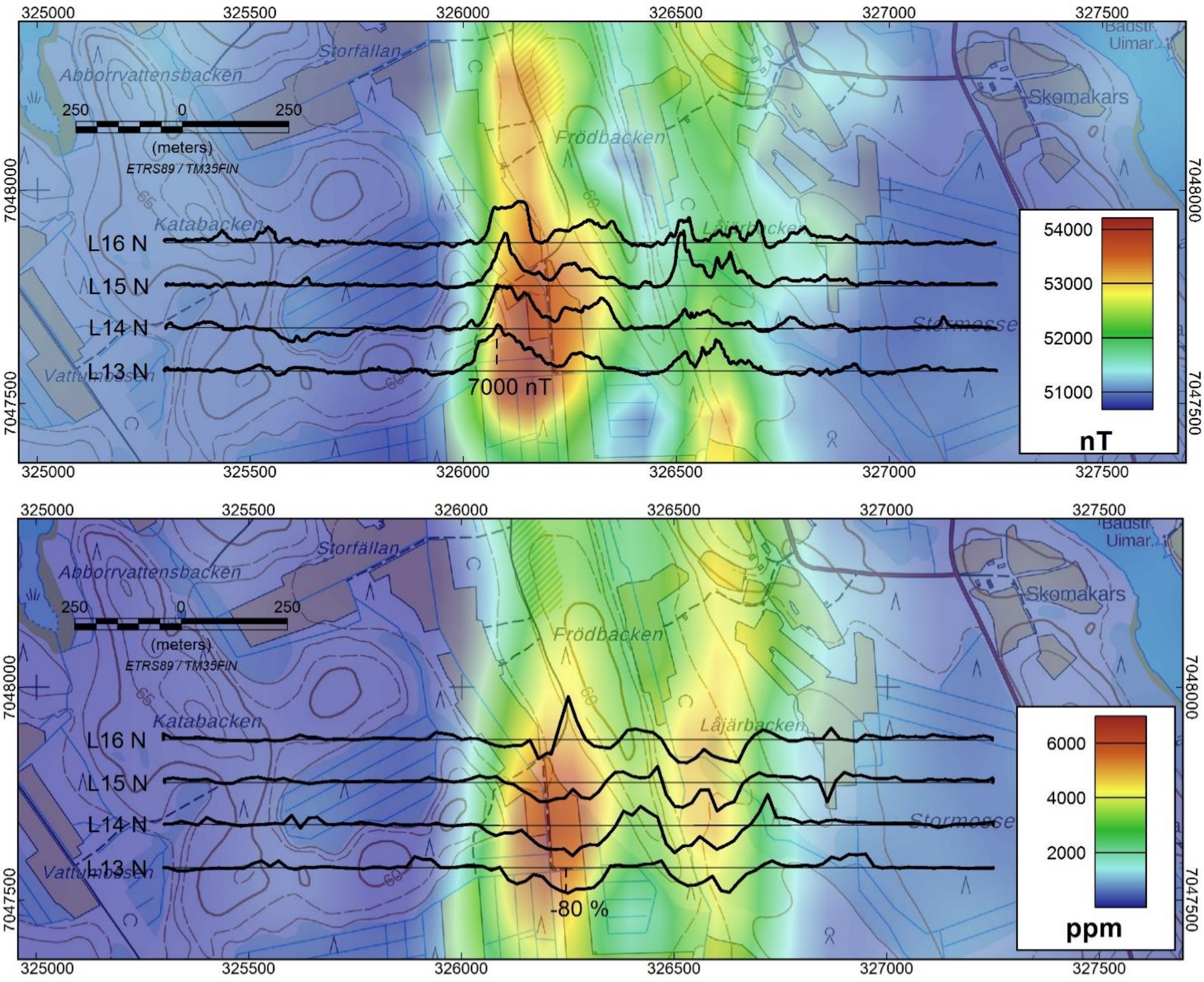


Fig. 2. On top: airborne magnetic data and ground magnetic profiles. On bottom: airborne EM 3 kHz in-phase component and MaxMin 3.5 kHz in-phase component profiles.

Three drill holes out of five (P4222019R13, P4222019R14 and P4222019R15) could be measured with GTK's petrophysical drill hole logging system. The measurements included magnetic susceptibility, electrical conductivity, natural gamma radiation and density. Measurement results together with lithological logging are shown in Fig 3. Drillhole R13 is located on the eastern side of the stronger aeromagnetic/aero-EM anomaly and the drill hole contains graphite, pyrite and pyrrhotite up to drill hole depth 175 m. Magnetic susceptibility and magnetic anomaly is related to the pyrrhotite, which may also carry remanent magnetization (not determined). The conductivity response is likely a combination of the graphite and sulphide minerals. Drill holes R14 and R15 are oriented across the eastern magnetic/conductivity zone, but the magnetic response in their location is lower in comparison to the northern and southern continuation of the zone (Fig 2, Fig 3). These drill holes also contain plenty of graphite and iron sulphides, which can be seen as magnetic susceptibility (pyrrhotite) and conductivity responses in the petrophysical drill hole measurements. Variation in the natural gamma radiation occurs in sediments and gneisses and reflects some variation in the mineralogy of these rocks. A density contrast is seen between these rocks and the basalts and volcanic rocks; the latter will show in gravity measurements as positive anomalies. Difference in the density and natural gamma ranges in volcanic rocks in R13 and R15 may be explained by a higher amount of e.g., black schist in R13 volcanic rock, or by a compositional difference (more mafic in R15 than in R13).

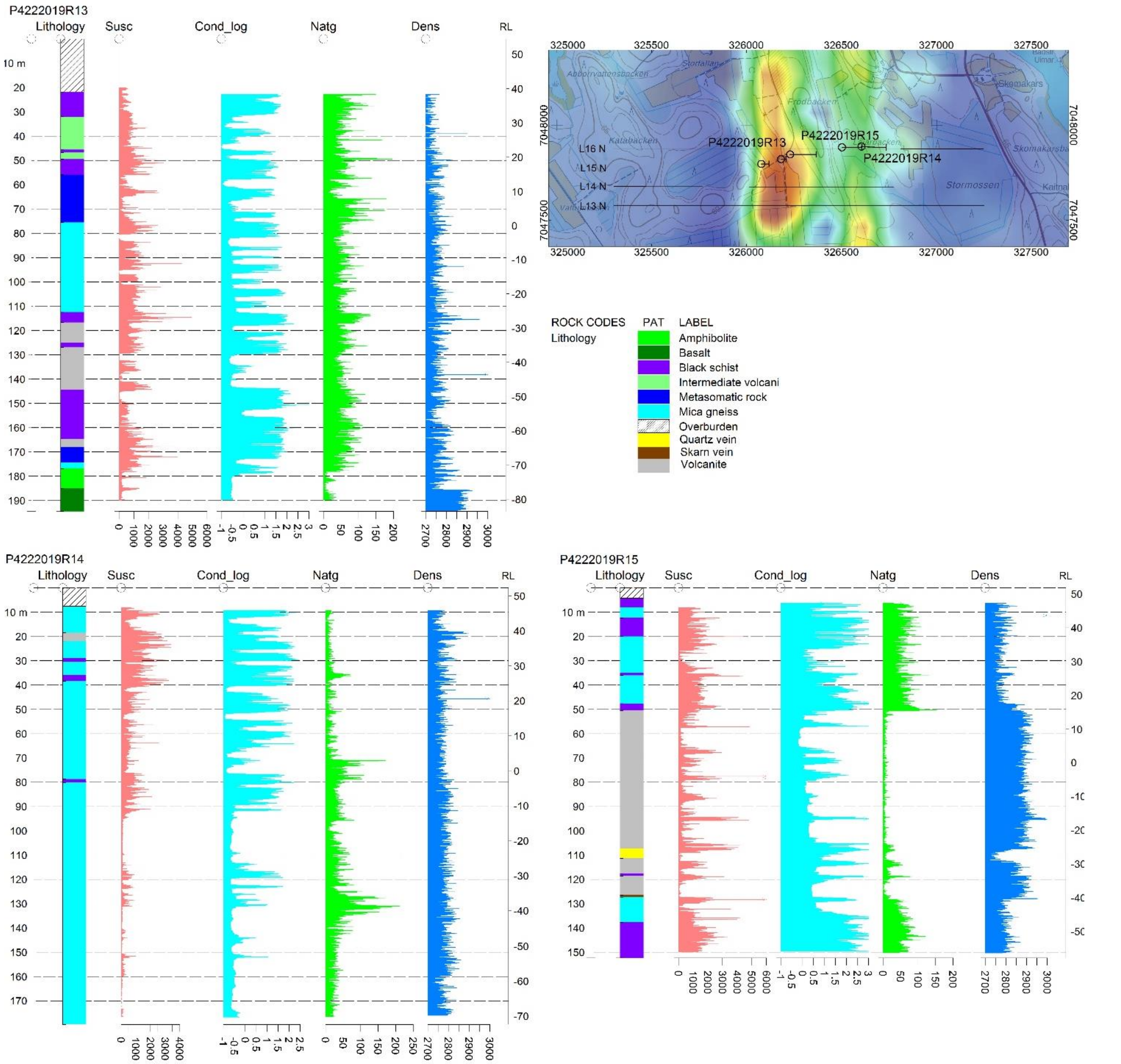


Fig. 3. Drill hole loggings from holes P4222019R13, P4222019R14 and P4222019R15. Susc = magnetic susceptibility (uncalibrated units), Cond_log = apparent electrical conductivity (mS/m, log scale), Natg = natural gamma radiation (counts/sec) and Dens = density (uncalibrated units). Top right, drill hole locations on aeromagnetic map.

4 DIAMOND DRILLING

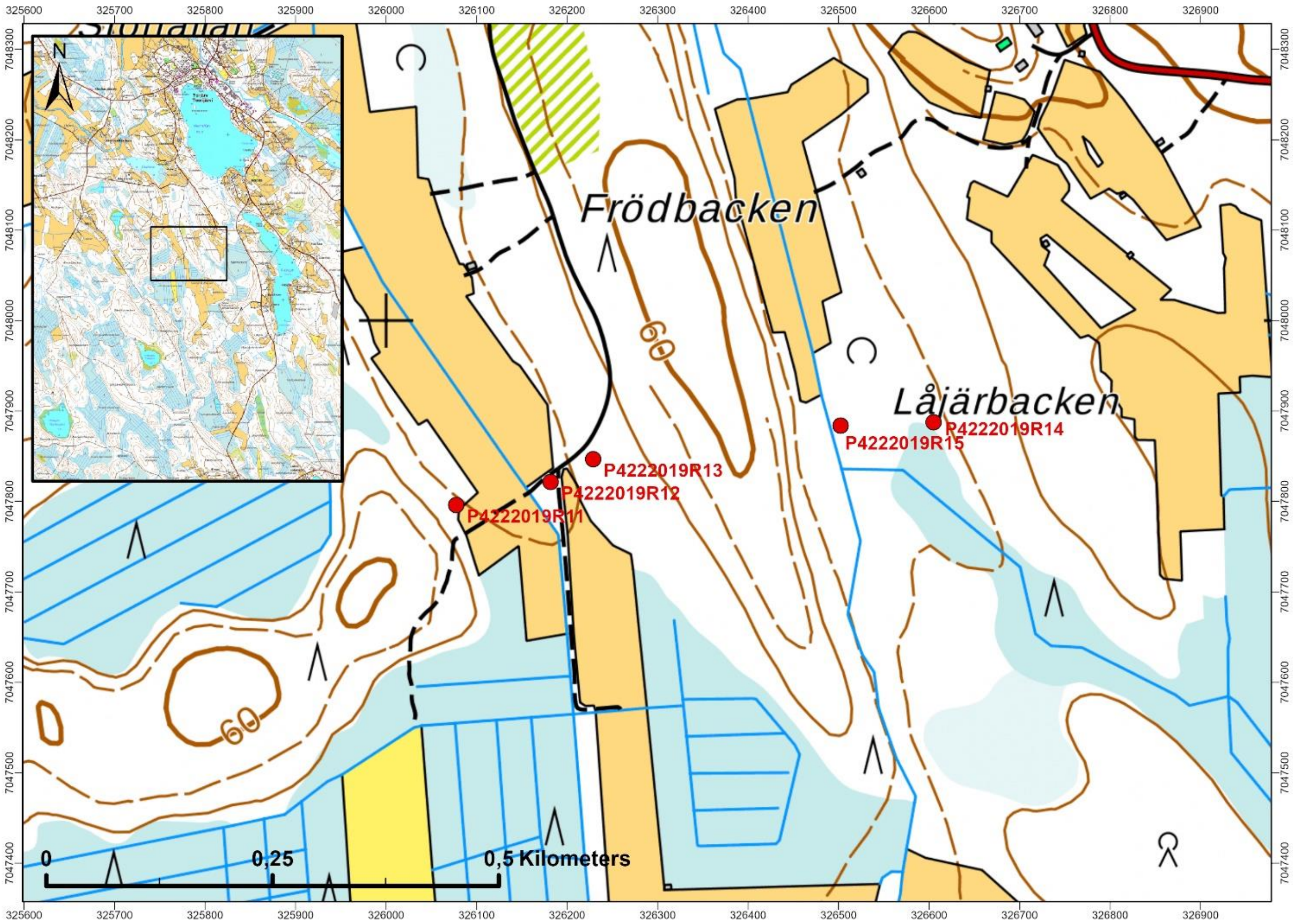


Fig 4. The locations of the Kaitåsen drillholes on the topological map.

Five diamond drill holes (R11 to R15, Fig. 4) were drilled to intersect selected geophysical anomalies. A total of 618.60 meters were drilled, approximately 90 degrees to the east and with a dip of ca 45 degrees. The drillholes R11 and R12 ended shorter than planned due to technical difficulties when the drill piping got stuck at depth. This was probably due to intersecting a major brittle fault zone. The drill collars technical data are listed in table 1.

Table 1. Kaitåsen collar technical data. The core size is NQ.

HOLE ID	N-TM35FIN	E-TM35FIN	AZIMUTH	DIP	OVERBURDEN (m)	LENGTH (m)
P4222019R11	7047796	326077	Approx. 90	44.90	9.80	56.60
P4222019R12	7047821	326181	Approx. 90	44.50	7.80	35.50
P4222019R13	7047846	326228	90.08	45.22	21.00	194.50
P4222019R14	7047887	326604	92.52	43.97	7.60	179.70
P4222019R15	7047883	326502	90.00	46.07	4.30	152.30

5 LOCAL GEOLOGY

The major lithologies in the N-S volcanic belt are a mix of volcanogenic (volcanite, amphibolite, basalt and tuff) and sedimentary (mica schist, black schist) rocks. The lithologies are generally steeply dipping westwards. In a few places these have been hydrothermally altered. The lithologies are individually presented below in section 5.1 along with core pictures. The lithological loggings are presented as drillhole profiles in Fig. 5 and Fig. 6. The westernmost drillhole R11 stared in a surface lithology of black schist. The easternmost drillhole R14 was drilled eastwards out of the volcanic belt and into the mica schist.

Oriented drill core measurements show steep dipping lithologies. These measurements are presented in the stereonet plot in Fig 7. The dots are the measured alpha and beta angles from the drill cores. Bingham statistical analysis shows a mean plane strike of 171.8 and a dip of 77.9 degrees. This is the average local bedrock strike and dip for all the drilled lithologies in Kaitåsen. Measurements were taken from the core wherever possible after every drill run of 3 meters. It is worthwhile to note that local folds might get unnoticed since the measurement are not continuous along the core. Bedrock folds, especially in the black schist, often coincidence with brittle shear zones (Fig. 8) where the drillers cannot get reliable measurements.

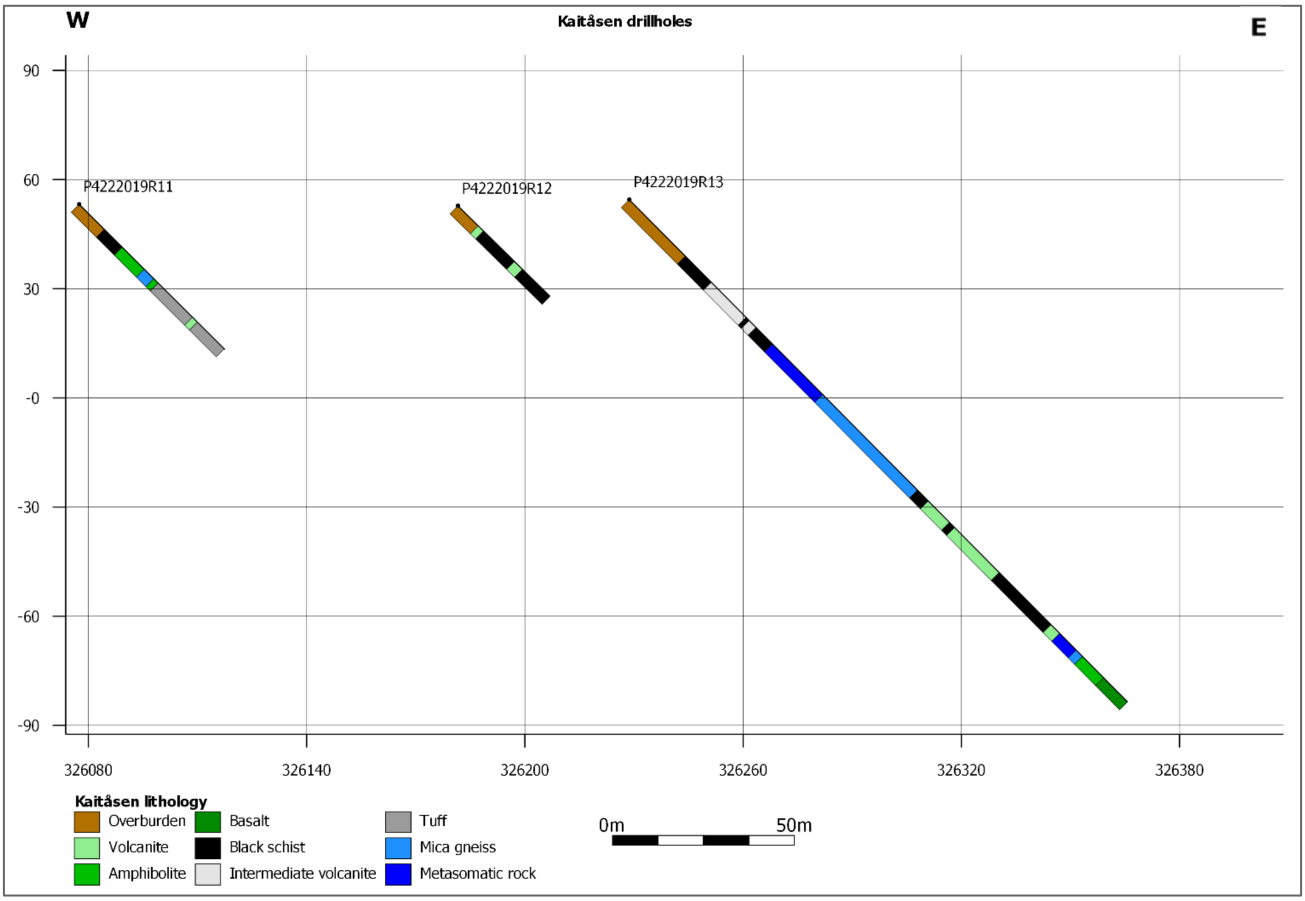


Fig. 5. Drillholes R11, R12 and R13 with lithologies.

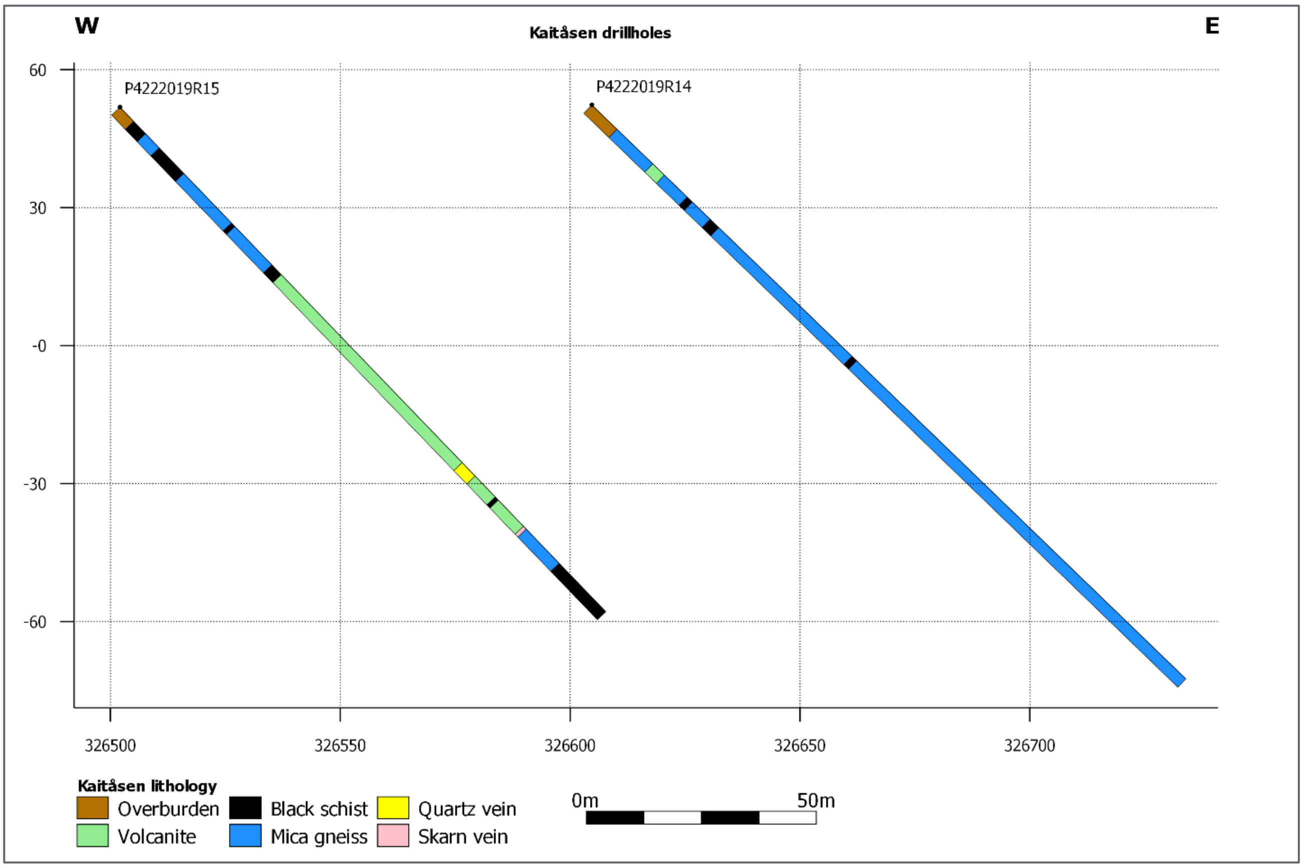


Fig. 6. Drillholes R14 and R15 with lithologies.

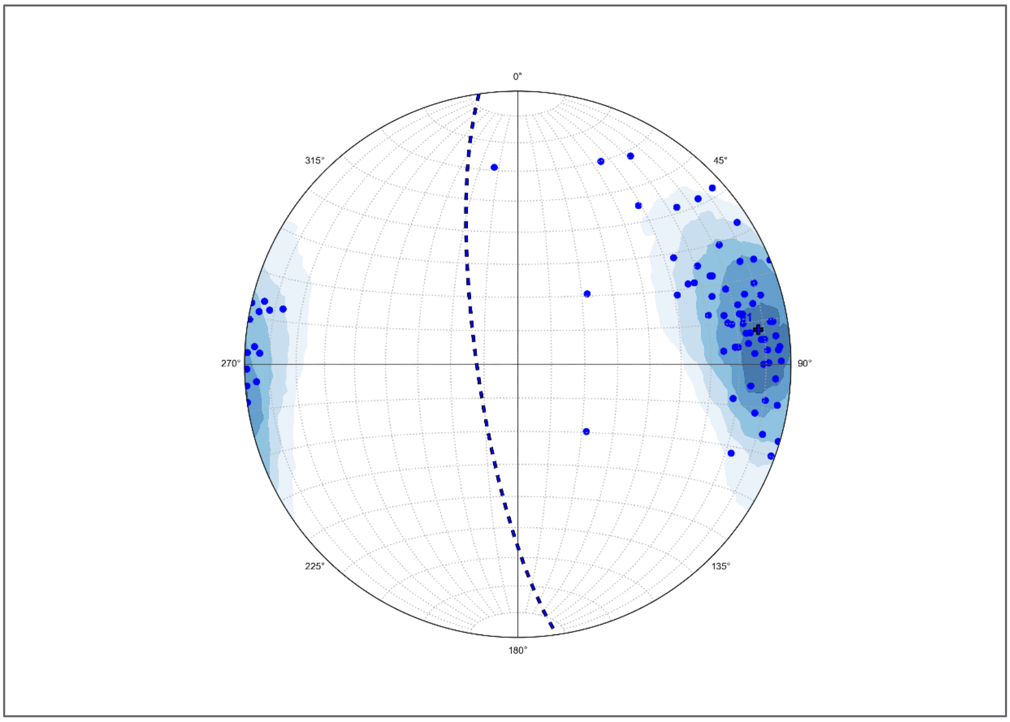


Fig. 7. Equatorial stereonet plot of the Kaitåsen drillholes.

Fig. 8. A brittle shear zone in black schist at R13 144-149 m.

5.1 Volcanite

The volcanites (Fig. 9) are fine and even grained greenish gray intrusive rock. In some places it is intruded into the sedimentary rock units. It is usually quite even textured, but in places there are fragmented clasts.

Fig. 9. Volcanite R15 74.50-77 m.

5.2 Intermediate volcanite

A massive gray rock, sometimes with volcanic fragments (Fig. 10). It is similar to the greenish volcanites, but with a more intermediate magma composition.

Fig. 10. Intermediate volcanite at R13 47-49 m.

5.3 Amphibolite

The amphibolite is a dark green rock (Fig. 11). The lithology logged as amphibolite is seldom a pure amphibolite but often contains carbon veining. Skarn alteration occurs e.g., at R11 16 m to 25 m together with carbon veining.

The only representative analyzed amphibolite section is R13 182-183 m. Its chemistry represents a very mafic rock, with high contents of Mg, Fe, Cr, Ni, Ti and low Al, K, Na. Incompatible elements Ba, Rb, U and La are very low. This could indicate a similarity with the downhole basalt lithology from R13 185.1-194.5 m.

Fig. 11. Amphibolite at R13 ca 183 m.

5.4 Basalt

The basalt (Fig. 12) is fine grained, dark gray green with sharp wall rock contacts and occurs only at the end of the drillhole R13 185.1-194.5 m. It is massive in nature with slight foliation and only sporadic, thin carbon veining. There are no analytical results from this lithology.

Fig. 12. Basalt R13 ca 191.50 m.

5.5 Tuff

Volcanic tuff with angular to rounded fragments (Fig 13). Some flow textures occurs and in places it is mixed in with black schist.

Fig. 13. Volcanic tuff at R11 46.50-49.50 m.

5.6 Black schist

The black schist (Fig. 14 and 15) is in many places intermingled with the mica schist or occurs as layers in the mica schist. It can be strongly deformed and folded with shear textures due to tectonic movements. Pyrite and pyrrhotite occurs usually disseminated and in thin stringers. Locally the pyrrhotite can be patchy. The graphite content varies a lot, from 1.4 % to 11.4 %, the median being 4.4 %. Some of the sections with lower graphite content can be explained with intermingled other lithologies. Brittle shear zones are usually associated with the black schists. E.g., drillhole R13 at 144 m to 156 m with a very fractured rock. Due to the lower amphibolite facies metamorphic grade, the graphite is assumed to be of very small grainsize.

Fig. 14. Drillhole R15. 10.4 % graphite at 49-50 m.

Fig. 15. The upper core shows black schist at R13 159-160 m.

5.7 Mica schist

The mica schist or gneiss is a foliated gray rock (Fig. 16). It is at places mixed or mingled with black schist. At places it can be very mixed, which could indicate disturbance and mass flow in the sedimentary basin. The mica schist in R14 shows at a few places metamorphic porphyroblasts.

Fig. 16. Mica schist with porphyroblasts at R14 94-96 m.

5.8 Metasomatic rock

This rock is hydrothermally altered and in places silicified with white-grayish quartz veins (Fig. 17). In places it contains brownish biotite mass or alteration. The rock is brecciated and have flow texture and is folded in places. Disseminated and patchy pyrite and pyrrhotite may occur, in some places with fuchsite-bearing veining (Cr). The metasomatic rock's protolith is probably a mix of metasediment, mixed with black schist layers where hydrothermal fluids flowed through the rock. The analysis shows at places a few percent graphite.

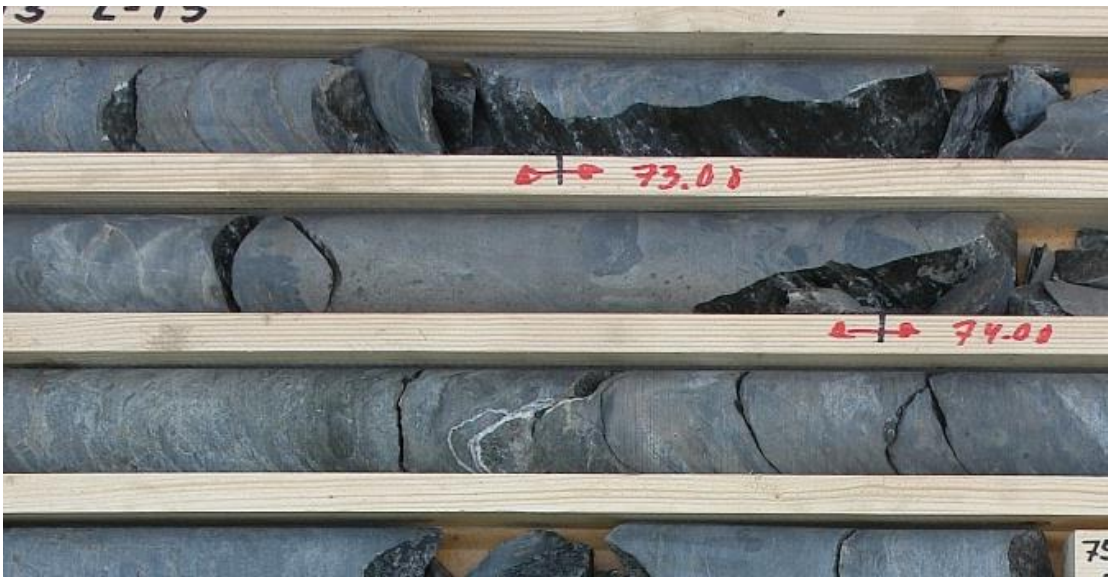


Fig. 17. Drillhole R13. Hydrothermal alteration zone and chrome-bearing fuchsite (light green veining e.g., at 73.90 m).

6 GEOCHEMICAL ANALYSES

A batch of 111 samples were analyzed at Labtium Oy with methods 306M, 306P and for Au, Pt and Pd with method 705P. 48 samples of black schist were selected for total non-carbon C analysis with method 811L. Some selected samples were also analyzed for In, Sn and W (Fig. 18).

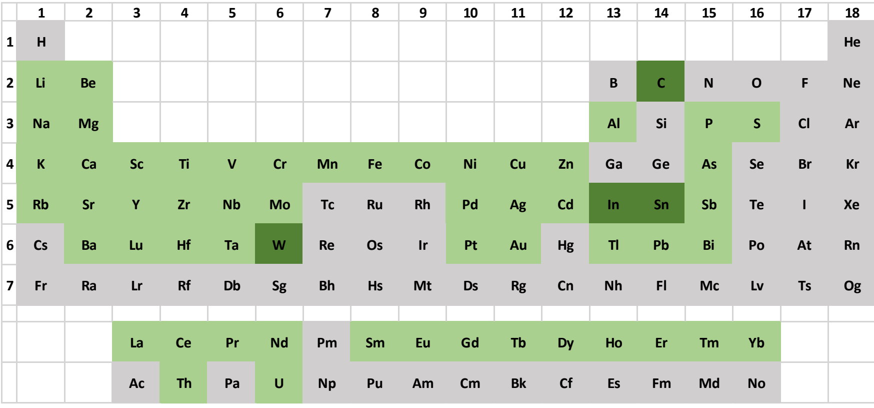


Fig. 18. Simplified periodic table with the analyzed elements in light green. Limited number of analyses for elements in dark green.

In table 2 is a list of some selected elements usually associated with cobalt-bearing mineralization from the variety of the logged drill core lithologies. The table shows the elemental difference between the lithologies in median and maximum values. The metasomatic rock shows elevated values of REE-elements, Co, Ni, As, Cr and P. The metasomatic rocks have a graphite content of median 1.9 %. Graphitic carbon in the black schists have a maximum value of 11.4 % with a median of 4.4 %. Figures 19 to 22 shows downhole plots for C, Co, Cr and total REE for each analyzed section of drill core.

Table 2. Combined analyzis of selected elements with median and maximum values.

Samples	Value	Lithology	As ppm	U ppm	Co ppm	Cr ppm	Cu ppm	Ni ppm	P ppm	Zn ppm	C non carb %	Total REE
7	Median	Mica gneiss	2	5	14	82	130	250	614	462		179
5	Median	Amphibolite	32	2	63	717	121	368	1080	197		177
13	Median	Volcanite	3	4	15	85	109	80	622	142		187
57	Median	Black schist	6	11	21	129	207	253	594	524	4.4	181
24	Median	Metasomatic rock	7	8	58	487	201	434	1315	169	1.9	252

Samples	Value	Lithology	As ppm	U ppm	Co ppm	Cr ppm	Cu ppm	Ni ppm	P ppm	Zn ppm	C non carb %	Total REE
7	Max	Mica gneiss	18	10	25	100	318	432	734	1200		199
5	Max	Amphibolite	167	4	82	1260	135	852	1890	228		309
13	Max	Volcanite	31	7	47	151	315	201	761	425		207
57	Max	Black schist	88	30	105	608	524	1080	1500	3030	11.4	306
24	Max	Metasomatic rock	1250	25	268	2660	372	1630	2640	1130	3.8	381

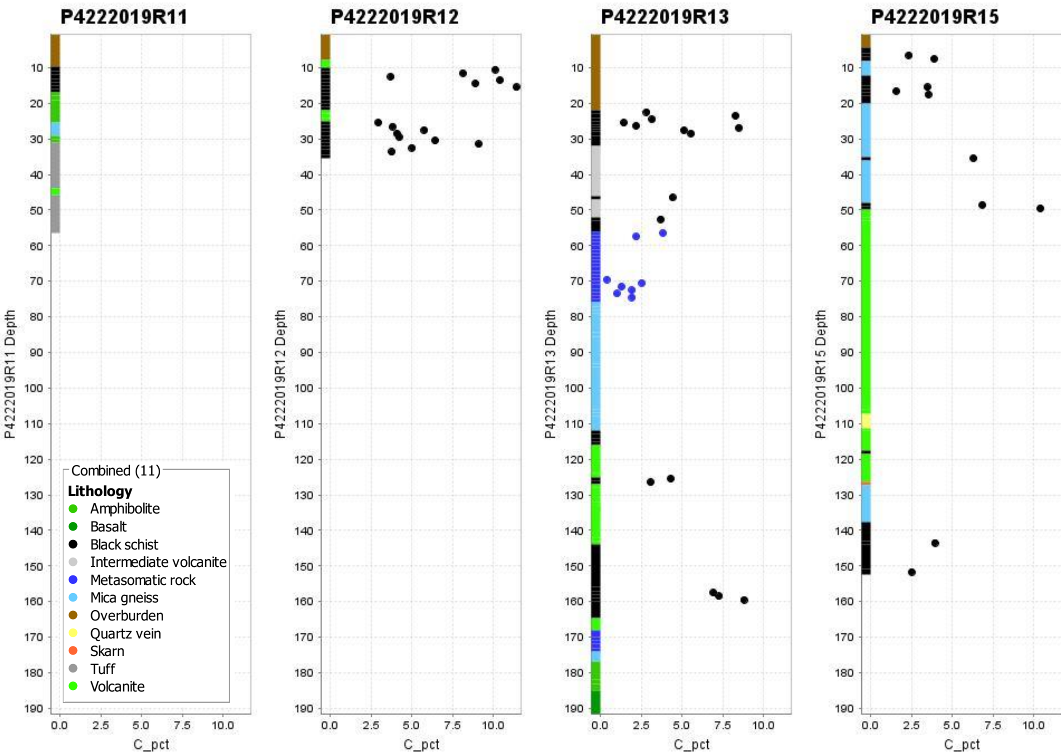


Fig. 19. Graphite (%) in drillholes. The colors represent different rock types according to the legend. Note that there are no analytical data from drillhole R11.

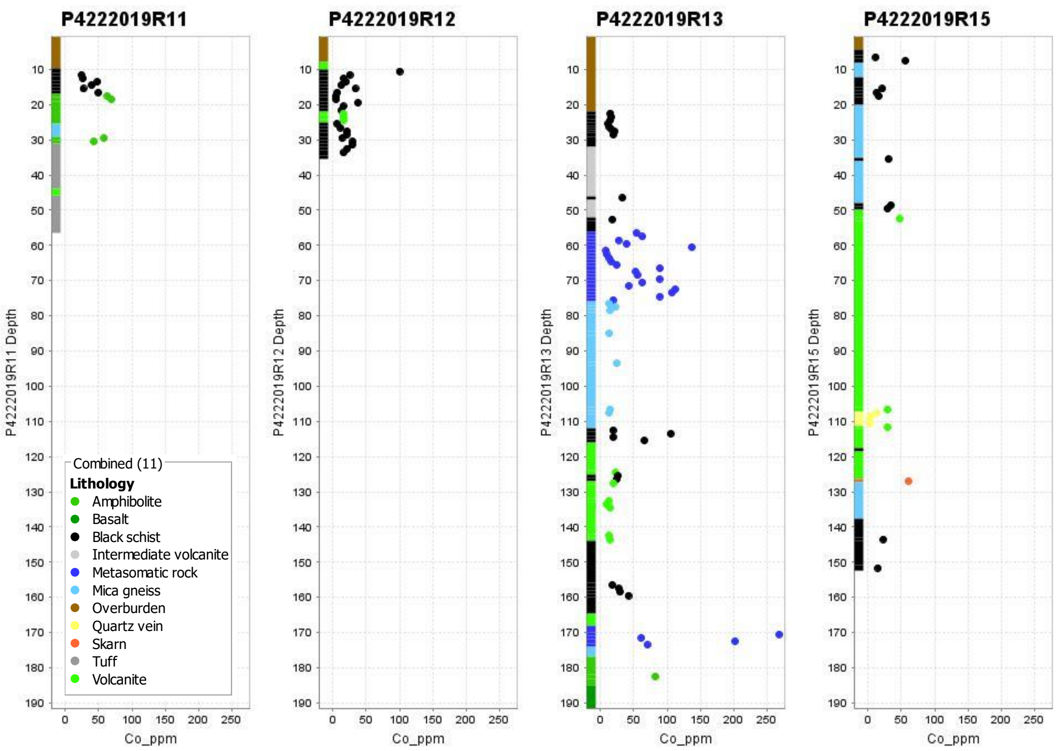


Fig. 20. Cobalt in drillholes. The colors represent different rock types according to the legend.

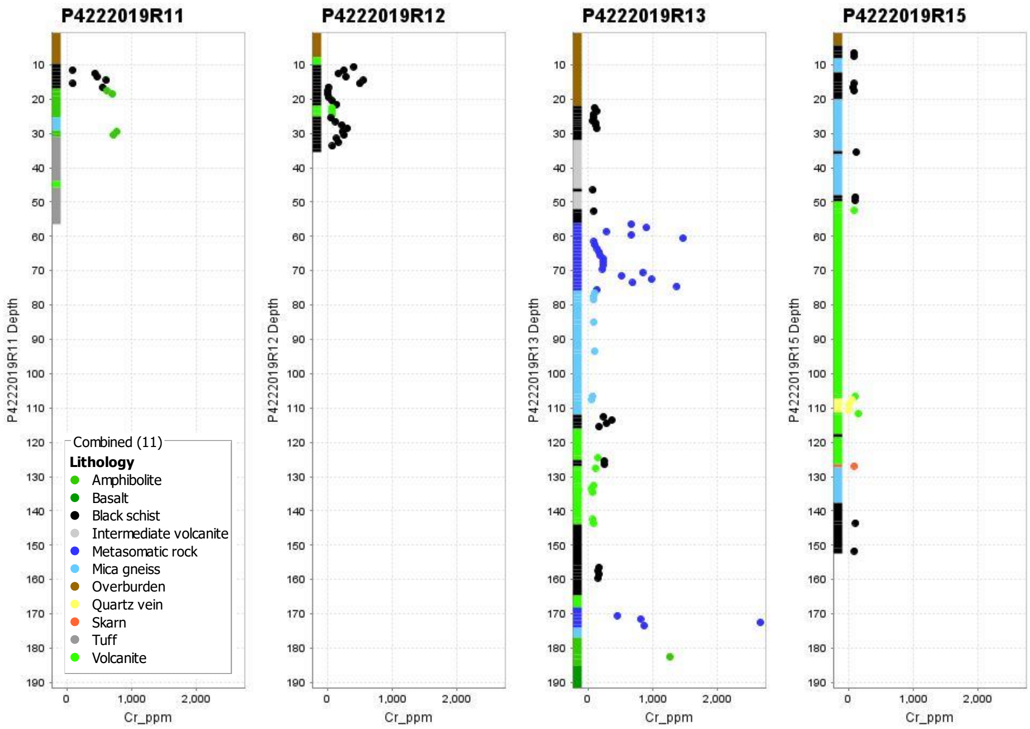


Fig. 21. Chromium in drillholes. The colors represent different rock types according to the legend.

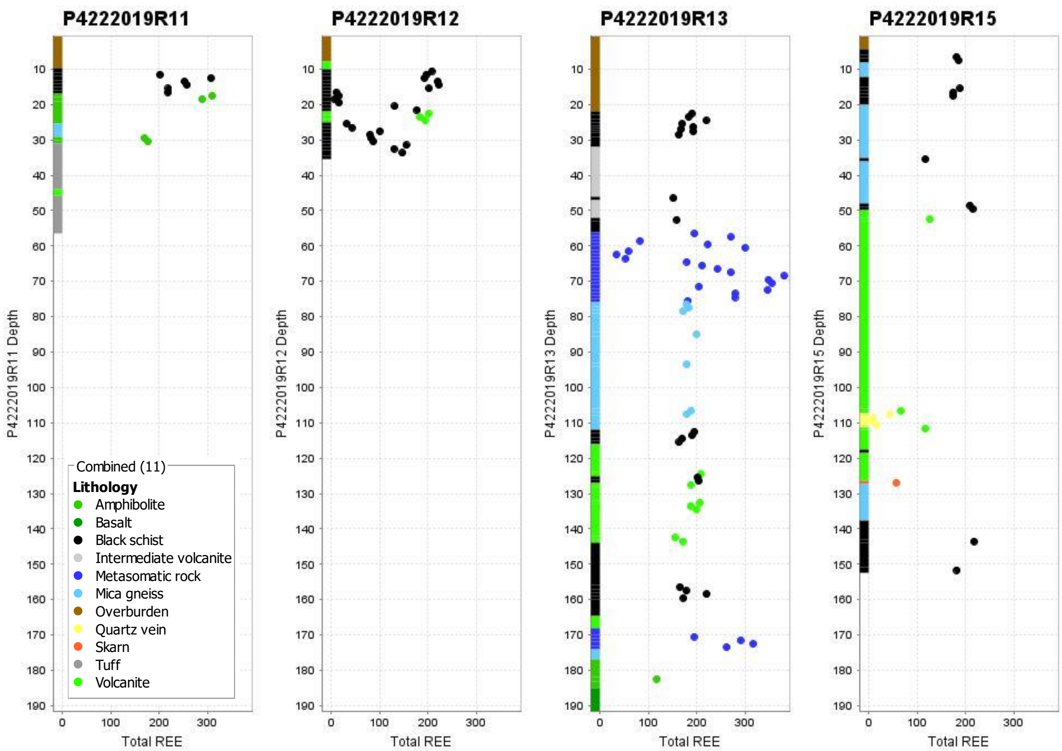


Fig. 22. Total REE in drillholes. The colors represent different rock types according to the legend.

7 CONCLUSIONS

The main purpose of the drilling campaign was to determine the origin of the cobalt-bearing layman sample boulders, as well as to gain lithological knowledge of the poorly exposed volcanic belt. Elevated values of Co, Ni, As, Cr, P and REE-elements, was discovered in metasomatic rocks. However, no significant mineralization was found. These elevated elements could indicate a mafic rock source for the hydrothermal fluids. The metasomatic rocks have a graphite content of median 1.9 % indicating that the protolith rock is likely to partly be a black schist.

The black schists have a median of 4.4 % graphite, reaching a maximum of 11.4 % over a meter wide sample. Not all the samples from the black schist were analyzed for graphite. The widest black schist section was ca 20 m wide indicating a potential for economic scale of graphite content along the volcanic belt.

In a report about Kaustinen and Kruunupyy (Teerijärvi) carbon-rich schists Lonka (1981) found the Teerijärvi black schists to be richer in sulphides. Hence also the base metal content is higher. The average values for Kaustinen are Cu 107 ppm, Ni 171 ppm, Co 24 ppm, Zn 276 ppm and for Teerijärvi Cu 408 ppm, Ni 269 ppm, Co 66 ppm, Zn 1468 ppm. Teerijärvi is geographically closer to Kaitåsen. These values are in line with the median values from the Kaitåsen black schists, being Cu 207 ppm, Ni 253 ppm, Co 21 ppm and Zn 524 ppm.

A GTK drilling campaign at Raisjoki (Kuusela et al. 2020) shows similar median values for the black schist: C 4.93 % (max 11.9 %), Cu 333.5 ppm, Ni 378.5 ppm, Co 42 ppm, Zn 799 ppm.

The volcanic (volcanite, amphibolite, basalt) lithologies can clearly be distinguished from the other lithologies based on geophysical downhole data. These have low electrical conductivity, low gamma radiation and a high density. The black schists in contrast have high conductivity and higher magnetic susceptibility. The metasomatized rock does not stand out in the geophysics as a different unit.

Suggestions for possible further investigations is to have a closer look at the type of hydrothermal alteration (thin section study). Trace element study of the different volcanic rocks could better determine the formation environment of the rocks. The quality of the graphite could be investigated as well as a lithology comparison with the other drill sites in the region.

As a summary the evidence of hydrothermal fluid activity in the volcanic-black schist environment holds the potential for base metal (including Co) mineralization along the volcanic belt. The black schists also hold potential for economical grades of graphite.

8 REFERENCES

Hautaniemi, H., Kurimo, M., Multala, J., Leväniemi, H. and Vironmäki, J. 2005. The ‘three in one’ aerogeophysical concept of GTK in 2004. In: Airo, M.-L. (ed.) Aerogeophysics in Finland 1972-2004: Methods, System Characteristics and Applications, Geological Survey of Finland, Special Paper 39, 21-74.

Järnefelt, O. 1926. Lohkaretutkimukset Teerijärvellä kesällä v. 1936. Geological Survey of Finland, Dc N:o 22, 5 p.

Kuusela, J., Nygård, H., Leväniemi, H., Al-Ani, T. 2020. The investigations of the Raisjoki metavolcanic rocks in Evijärvi, Western Finland. Geological Survey of Finland, open file work report 57/2020.

Lindmark, B. 1977. Geologisen tutkimuslaitoksen scheeliittitutkimukset Kruunupyyn ja Kaustisen alueella vuosina 1967–1977. 75 p. M19/2323/77/2/10.

Lindmark, B. 1978. Raisjoen mustaliuskevyöhyke. Geological Survey of Finland, report M19/2314/78/1/10. 15 p.

Lindmark, B. 1979. Geologisen tutkimuslaitoksen malmitutkimukset Kaustisen Ahvenjärvellä vuosina 1970–1978. 27 p. M19/2323/79/2/10

Lonka, A 1981. Eräistä hiilipitoisista liuskeista Kaustisen kallioperäkarttalehdellä, report M 19/2323/-81/1/81

Vaarma, M., Pipping, F. 1997. Alajärven ja Evijärven kartta-alueiden kallioperä. Geological Survey of Finland.