NGU REPORT 2019.023

Geophysical and geological investigations for graphite on Senja and in Kvæfjord, Troms county, northern Norway

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REPORT

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Title:
Geophysical and geological investigations for graphite on Senja and in Kvæfjord, Troms county, Northern Norway.

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Summary:
As a part of the MINN project (Minerals in Northern Norway) helicopter-borne geophysical surveys were performed on Senja and in Kvæfjord. Electromagnetic data from these surveys showed up anomalies that could be caused by large graphite mineralisation. Geophysical and geological ground follow-up work were performed at seven locations on Senja and two in Kvæfjord.

Previously known graphite at Hesten, Vardfjellet and Bukken and new discoveries at Litjkollen (Bukken), Grunnvåg and Skarsvåg on Senja, were mapped in detail using ground based electric and electromagnetic geophysical methods. The length of the possible graphite mineralisation was from 1 to 2 km in all areas. The thickness perpendicular to strike and dip varies from a few metres to tens and even hundreds of metres. Geological mapping confirmed graphite of interesting quality in most of the areas. The area Skarsvåg had low total carbon content in surface exposures, and the sulphur content was relatively high. However, electric measurements indicate graphite of better quality deeper than 20 m. In all areas on Senja, analysis of thin sections shows flake graphite of same quality as mined at Trælen in western Senja, and as in Vesterålen where a beneficiation test was successful. All areas are intensively folded and some of them faulted. More detailed ground geophysics and deeper core drilling are recommended in the areas called Hesten, Vardfjellet, Bukken, Grunnvåg and Skarsvåg.

In Kvæfjord, the amount of graphite bearing rocks is large and the total carbon content relatively high. However, in this area, the grain size is much less than on Senja and the mineralisation is characterised as amorphous graphite which is sub-economic today. Based on this, further follow-up work is not recommended.

Deposit name and grid-reference (WGS 84 UTM 33).
Hesten: 609270 – 7702780. **Vardfjellet:** 607420 – 7705050. **Bukken**: 612200 – 7705100.
Grunnvåg: 617700 – 7702320. **Skarsvåg:** 617400 – 7790500.
Sørli (Kvæfjord): 556500 – 7635000. **Finngammen (Kvæfjord):** 550500 – 7618500.

Keywords:	Graphite	Geology
Geophysics	Electromagnetic	Electrical
Mapping	Analytical methods	Scientific report

EXECUTIVE SUMMARY

Purposes:

- To investigate and follow up previously known and possible new graphite mineralisation associated with airborne geophysical anomalies.
- To investigate with ground geophysical methods EM (EM31), CP/SP and ERT/IP), the mineralised areas.
- To sample outcropping graphite bearing rocks as representative as possible and describe the mineralogy of the graphite bearing units.
- To check the geological variation of the graphite bearing units with shallow drill holes.

Areas investigated:
The following main areas were investigated:

a) Hesten and Vardfjellet mountains, present work is a follow up of our 2016 results.
b) The Bukken area which again in this report is divided into the following subareas
    a. Bukkemoen, the area along Lysvatnet and immediate adjacent area
    b. Bukken, comprises the upper area of the Bukken mountain.
    c. Litjkollen area which comprises the easternmost extension of the Bukken area
c) The Grunnvåg area.
d) The Skarsvåg area which again comprises two anomaly areas.
e) Two deposits in the Kvæfjord area southwest of Harstad, divided into the sub-localities Finngammen and Sørli.

Results:

The localities on Senja occur in a high-grade metamorphic terrain, all the graphite occurrences are of flake graphite. The localities in Kvæfjord occur in a terrain with much lower metamorphic degree. The graphite schists in Kvæfjord comprises micro crystalline amorphous type of graphite. The Kvæfjord area is regarded as of less interest and further follow up work is not recommended.

The mineralised areas on Senja have approximately dimensions as follows:

Hesten: 2 x 0.3 km^2
Vardfjellet: 2 x 0.5 km^2
Bukkenmoen: Total extent 5.3 km x 0.6 km (included marine area in Sjøvatnet)

Bukkemoen	0.5 km x 0.5 km
Bukken	1.5 km x 0.4 km
Litjkollen	1.6 km x 0.35 km

Grunnvåg: 1.6 km x 0.2 km
Skarsvåg 2.2 km x 0.2 km

At all localities the graphite occurs in several mineralised zones of flake graphite that in the field are strongly polyphase folded. Individual graphite lenses can be followed outcropping continuously in width up to more than 100 metres. Geophysical measurements indicate the individual lenses to be electrically connected restricting the possibility to map the individual size (length and depth extend) of the graphite lenses over the whole anomaly area. Geophysical measurements also show that the outcropping and visible graphite schist most commonly only make up a small part of what is mapped out as a good conductor with geophysics. The complex deformation makes it difficult to get an exact overview of the total and individual thicknesses of the different graphite lenses. Drilling would be necessary to get a good understanding of grades and tonnages.

The table below shows the analytical results % TC (total carbon) from the different localities on Senja:

Variation in TC Area/Sub-area	No. of samples	Average (%)	Max (%)	Min (%)	StdDev (%)	Median (%)
Bukkemoen						
Bukkemoen	20	5.2	14.1	2.2	3.3	4.0
Bukken	27	6.5	19.7	0.6	4.5	5.0
Litjkollen	4	5.3	16.3	0.6	7.4	2.1
Grunnvåg						
Grunnvåg	37	5.2	14.9	0.5	2.8	4.9
Skarsvåg						
Skarsvåg	13	2.1	5.4	0.5	1.4	1.8
Vardfjellet-Hesten						
Hesten	21	5.8	12.8	1.7	3.0	5.5
Vardfjellet	37	9.2	40.3	1.1	7.5	6.9
GrandTotal	**159**	**6.2**	**40.0**	**0.5**	**5.1**	**5.1**

There is a large and mostly unsystematic spatial variation in the levels of graphitic carbon. In two of the areas, Grunnvåg and Skarsvåg, the total sulphur content is relatively high.

The mineralogy of the graphite bearing rock is similar to what is in production at Skaland and with all probability the rock can be beneficiated with similar good results.

Recommendations

Since we have documented that the mineralised zones at most localities have a much larger sub surface extent than what is visible from outcrops, it is natural that the next step of investigations would be a more systematic core drilling and >200 m long holes. This is particularly important for the localities Hesten, Vardfjellet, Bukkemoen, Bukken Litjkollen and Grunnvåg.

We believe that what we have done so far is close to what can be achieved with surface methods only and - as far as what is natural for NGU to do.

Sammendrag på norsk

Som en del av prosjektet Mineralressurser i Nord-Norge (MINN) ble det i 2012 – 2014 foretatt geofysiske målinger fra helikopter på den nordlige delen av Senja hvor potensialet for økonomiske grafittforekomster er stort. Det ble også foretatt tilsvarende målinger i Kvæfjord og også her ble det funnet grafitt senhøsten 2017. Disse målingene viste flere markerte elektromagnetiske anomalier, delvis knyttet til kjente forekomster av grafitt og delvis på mulige nye hittil ukjente forekomster. For å øke kunnskapen om de enkelte mineraliseringene foreslo NGU i 2016 et oppfølgingsprosjekt som ble gjennomført med støtte fra Troms fylkeskommune. Flere forekomster er fulgt opp med bakkegeofysikk, geologisk kartlegging og prøvetaking og kjerneboring med påfølgende analyser.

Ved fjellet **Hesten**, sentralt på Senja, er det påvist grafitt i en lengde på ca. 2 km og med en bredde på ca. 100 m til ca. 400 m. Det mineraliserte området består av flere soner og individuell tykkelse er målt til 3 - 4 m ved to plasser. Geofysiske målinger viser at de enkelte linsene er i elektrisk kontakt med hverandre og en vurdering av de individuelle størrelsene (lengde og dyptgående) er ikke mulig å tolke på grunnlag av geofysikk. Området er intenst foldet og delvis forkastet. Høy overdekningsgrad gjør det vanskelig med geologisk kartlegging. Grafitten opptrer som "flak-grafitt" og kornstørrelse på fra 50 til 2000 mikron. Gjennomsnittlig totalt karboninnhold på 21 fastfjells-prøver fra området er på 5,5 % med en maksimumsverdi på 12,8 %. Svovelinnholdet er mindre enn 1 %. NGU anbefaler videre undersøkelser i form av detaljerte elektromagnetiske målinger på bakken og oppfølgende boringer.

Ved fjellet **Vardfjellet,** ca. 2,5 km nord for Hesten er det også påvist elektrisk ledende strukturer i en lengde på ca. 2 km men med en bredde på ca. 100 til ca. 480 m. Grafitt er påvist ved flere lokaliteter innenfor dette området. Det mineraliserte området består av flere soner og individuell tykkelse observert til 7 m men er målt til ca. 100 m ved to plasser. Geofysiske målinger viser at de enkelte linsene er i elektrisk kontakt med hverandre og en vurdering av de individuelle størrelsene (lengde og dyptgående) er ikke mulig å tolke på grunnlag av geofysikk. Området er intenst foldet og forkastet, men godt blottet. Grafitten opptrer som "flak-grafitt" og kornstørrelse på fra 50 til 2000 mikron er påvist i tynnslipp. Analyser av 37 fastfjells-prøver fra området viser et gjennomsnittlig totalt karboninnhold på 9,2 % med en maksimumsverdi på 40,3 %. Svovelinnholdet på de samme prøvene er mindre enn 1,3 %. NGU anbefaler videre undersøkelser i form av detaljerte elektromagnetiske målinger på bakken og oppfølgende boringer.

Området **Bukken** nord for Lysvatnet, er delt inn i tre mindre områder; Bukkemoen, Bukken og Litjkollen. Ved Bukkemoen er det tidligere påvist grafitt i to strukturer med en total lengde på mer enn 1 km. De nye undersøkelsene viser en lengde på 1,25 km på en mineralisering. Ved de to områdene Bukkemoen og Bukken er det påvist grafitt sammenhengende i en lengde på 2 km og over en betydelig bredde. I tillegg er det påvist grafittførende gneis i en lengde av 1,6 km ved Litjkollen, øst for Bukken. Hvert område inneholder flere separate linser av grafitt, og mektigheten kan variere fra 2 m, via flere ti-talls meter til flere hundre meter. Områdene er intenst foldet og delvis forkastet. I gjennomsnitt viser analyser på i alt 51 prøver et totalt karboninnhold på 6,3 % med maksimumsverdier på ca. 20 % for all de tre delområdene. Gjennomsnittlig svovelinnhold er mindre enn 1 %. NGU anbefaler videre undersøkelser i form av detaljerte elektromagnetiske målinger på bakken og oppfølgende boringer i alle de tre områdene.

Ved **Grunnvåg**, innerst i Lysfjorden, er det påvist en elektromagnetisk anomali fra helikoptermålingen som er 1,6 km lang og opp til ca. 200 m bred. Ved en geologisk befaring her ble det høsten 2017 påvist og prøvetatt grafitt. Gjennomsnittlig innhold av grafittisk karbon (Cg) på fem fastfjells-prøver fra området er på 8,9 % med en maksimumsverdi på 14,8 %. Svovelinnholdet er høyere her, opptil 12,5 %. Området er fulgt opp med bakkegeofysikk, geologisk kartlegging med prøvetaking og en kort kjerneboring i 2018. Området er isoklinalt foldet, og mineraliseringen former ei lukket sløyfe av mer eller mindre sammenhengende grafitt i anomaliens totale lengde (1,6 km). Forkastninger er ikke påvist. I gjennomsnitt viser analyse av i alt 37 prøver fra området et totalt karboninnhold på 5,2 % med en maksimumsverdi på 14,9 %. Studier av ett tynnslipp viser at dette er i «flak-grafitt» hvor midlere kornstørrelse er 37 mikron og med en maksimumsverdi på 3477 mikron. Forekomsten inneholder i gjennomsnitt 2 % svovel. Kjerneboringen i nordenden av forekomsten viser sammenhengende grafittførende gneis i mer enn 35 m vinkelrett på strøk og fall. NGU mener forekomsten bør undersøkes nærmere med mer bakkegeofysikk og dypere kjerneboringer.

Ved **Skarsvåg** viser helikoptermålingene to ledende strukturer, begge med lengde ca. 2 km. Den østligste av disse fremstår som den mest interessante. Total bredde på denne anomalien er ca. 200 m. Områdene er dekt av relativt tykke løsmasser (4 – 8 m) og dette svekker anomaliene målt med instrumentet EM31 på bakken. I gjennomsnitt viser analyser på i alt 13 prøver et totalt karboninnhold på 2,1 % med maksimumsverdier på 5,4 %. Gjennomsnittlig svovelinnhold i de samme prøvene er på 1,9 %. Grafitten ved Skarsvåg fremstår som mindre interessant, og i utgangspunktet anbefales ikke videre oppfølging. Elektriske målinger viser imidlertid at kvaliteten kan være bedre 10 - 20 m under bakken, og dette bør undersøkes ved kjerneboring før området avskrives helt.

I **Kvæfjord**, vest for Harstad, ble en ny lokalitet på Kveøya prøvetatt for grafitt i 2016. Helikoptermålinger viser flere godt ledende strukturer i Kvæfjord, og feltarbeid i 2018 påviste grafitt / svartskifer ved ytterligere to lokaliteter; Finngammen i Melåmarka og Durmålshaugen / Middagshaugen sør for Sørli. Disse to ble deretter fulgt opp med bakkegeofysikk og supplerende prøvetaking seinere i 2018. Områdene Finngammen og Kveøya viser relativt høye karbonanalyser, gjennomsnittsverdi på henholdsvis 13,9 % og 17,1 %. Maksimumsverdiene er tilsvarende 25,8 % og 28,1 %. Dessverre er kornstørrelsen ved forekomstene i Kvæfjord jevnt over mindre, og denne type blir av industrien kalt amorf grafitt som ikke er økonomisk interessant i dag.

Felles for mineraliseringene på Senja er at grafitten er av meget god kvalitet og ligner grafitten det drives på ved Skaland grafittverk og den som er oppredningstestet med godt resultat fra Vesterålen. NGU mener den undersøkte grafitten fra Senja lett kan oppredes til konsentrat med høy konsentrasjon og med god gjenvinning. Ved forekomstene Hesten, Vardfjellet, Bukken (Bukkemoen, Bukken og Litjkollen) og Grunnvåg anbefales oppfølgende undersøkelser i form av detaljert bakkegeofysikk og kjerneboring, gjerne ned til ca. 200 m. Forekomsten Skarsvåg viser lavt innhold av grafitt i utgående men det indikeres bedre kvalitet fra ca. 20 meters dyp og det anbefales oppfølgende undersøkelser i form av kjerneboring også her. Dette for å klargjøre ressurspotensialet.

Undersøkelsene på Senja og i Kvæfjorden har løftet kunnskapen om grafitt-forekomstene til et nivå som er naturlig for NGU. Videre arbeid må utføres av industri-selskaper.

CONTENT:

APPENDIX:

1. INTRODUCTION

Norway has been a major producer of graphite for more than 100 years and in many places in the country, the geology favours the formation of flake graphite deposits. Graphite is a common mineral in Norwegian bedrock. However, it is rare to find it enriched in economically interesting amounts. There are more than 70 registered graphite occurrences in Norway, http://geo.ngu.no/kart/mineralressurser_mobil/. They are all located in four graphite provinces (Figure 1.1). All these provinces have a long history of graphite mining. Today only one deposit, the Trælen graphite mine on the island of Senja, is in operation (Skaland Graphite AS), producing approximately 10,000 tons of concentrate per year. However, the island of Senja has also numerous other graphite occurrences.

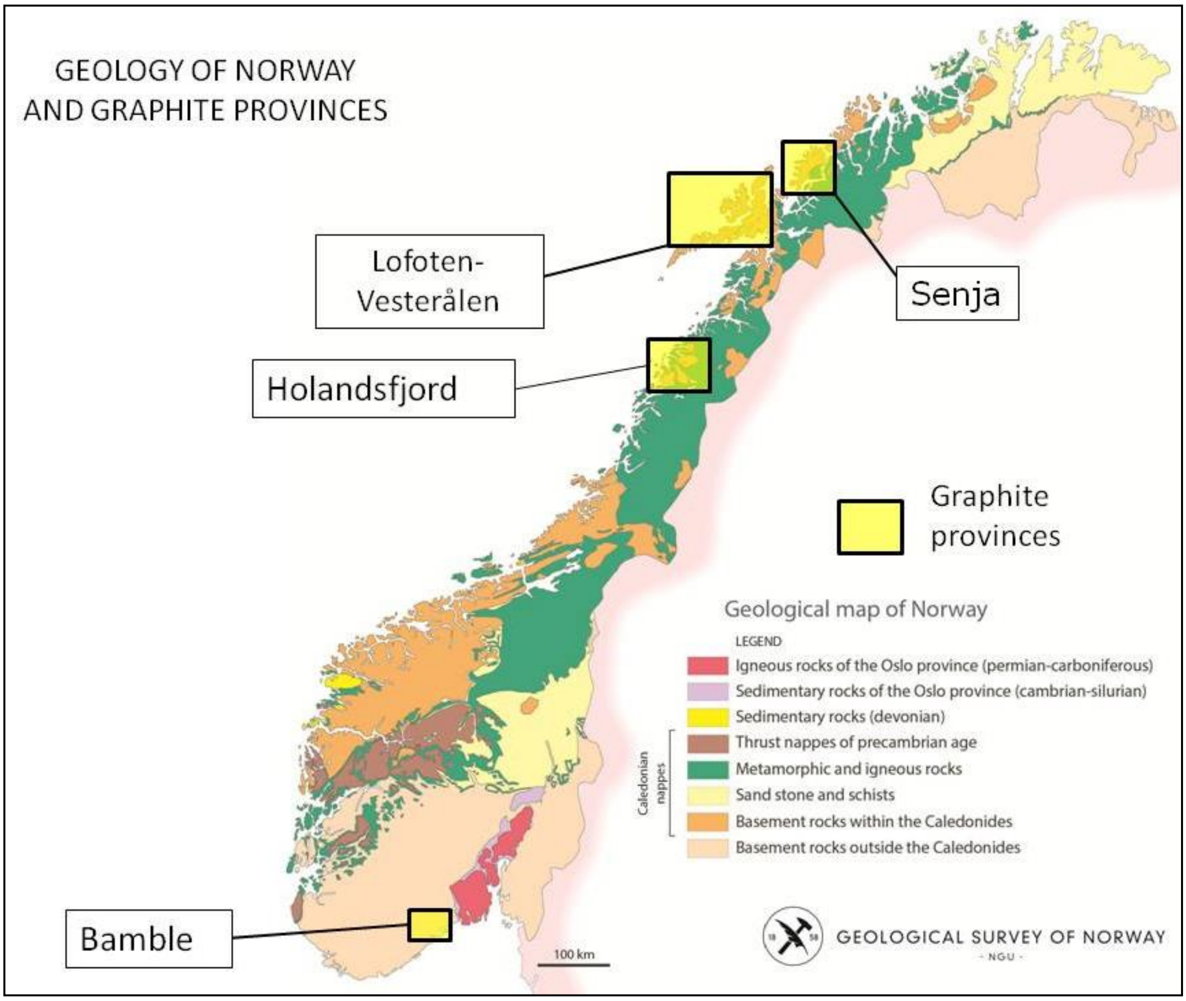

Figure 1.1: Geology of Norway and graphite provinces of Norway.

In this report we will present the data and results from recent graphite exploration on the largest graphite occurrences on Senja and in Kvæfjord. We will also give a brief review of the earlier work in the area. In every chapter we will limit our descriptions to what is regarded relevant for the graphite mineralisation. More academic type of studies of the general geology and metamorphic petrology are reported by others elsewhere.

During the work the following people have contributed with their different fields of expertise:

- Håvard Gautneb: Responsible field geologist, graphite geology, analysis and petrography, GIS and reporting.
- Iain Henderson: Structural geology on Senja.
- Janja Knežević: Graphite geology, sampling, core logging, petrography and GIS
- Børre Davidsen: Bedrock geology, mapping and sampling (Kvæfjord)
- Jomar Gellein: Ground geophysics, core drilling, Drill-hole logging
- Bjørn Eskil Larsen: Responsible field geophysicist, GIS
- Frode Ofstad: Airborne and ground geophysics, electronics
- NGU-lab: All chemical analysis
- Geir Viken: Core drilling
- Janusz Koziel: Instrumentation
- Jan Steinar Rønning: Responsible geophysicist, reporting, report editing and project leader.

The investigations are financially supported by Troms County Administration. The investigations were planned for two field seasons. In the first year (2016), the investigations were concentrated at Hesten, Vardfjellet and partly Grunnvåg (Rønning et al. 2017). In the second year (2018), investigations were performed mainly at Bukken, Grunnvåg, Skarsvåg on Senja and in the Kvæfjord area west of Harstad town. To make all results easier available, this report contains the work accomplished in 2016 and 2018.

1.1 Investigated areas on Senja and in Kvæfjord

As will be described later in this report, graphite has been known for more than 150 years on **Senja**. Several occurrences are known, and the company *Skaland Graphite AS* has been in operation almost continuous since 1917. As a part of the MINN project at the Geological Survey of Norway (NGU), helicopter-borne geophysical measurements were performed at the northern part of Senja from 2012 to 2014 (Rodionov et al. 2014). In Figure 1.2, previously known and recently discovered graphite deposits are shown on top of apparent resistivity calculated from helicopter-borne frequency electromagnetic measurements (FEM).

In 2012, as a part of the MINN project, helicopter-borne geophysical measurements were performed in **Kvæfjord** (Rodionov et al. 2012). In Figure 1.3, calculated apparent resistivity is shown together with two known graphite occurrences. The apparent resistivities show numerous low resistivity anomalies, and the cause of these were not known. However, graphite from a known locality at Kveøya were sampled in 2016, and subsequent reconnaissance work at two of these anomalies in 2018 discovered graphite / carbonaceous schists at Finngammen and south of Sørli, see Figure 1.3). Sørli and Finngammen were followed up with ground geophysics and additional sampling later in 2018.

Results of the graphite follow-up work on Senja and Kvæfjord will be reported in detail in chapters 6 to 11.

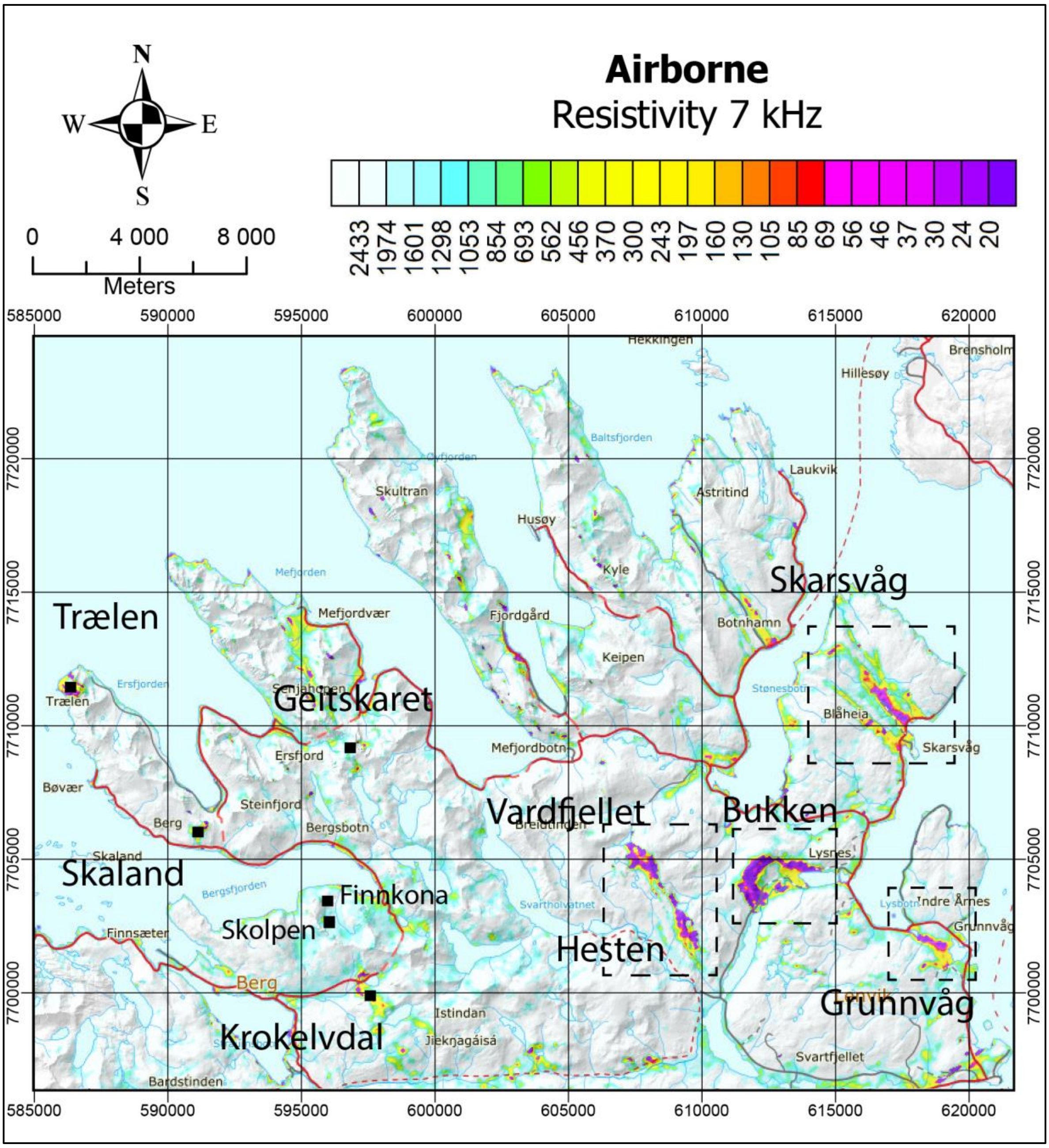

Figure 1.2: Graphite occurrences on Senja underlain by apparent resistivity from helicopter-borne 7 kHz coaxial coil configuration (Resistivity in Ωm). Follow-up work is performed at Hesten, Vardfjellet, Bukken, Grunnvåg and Skarsvåg.

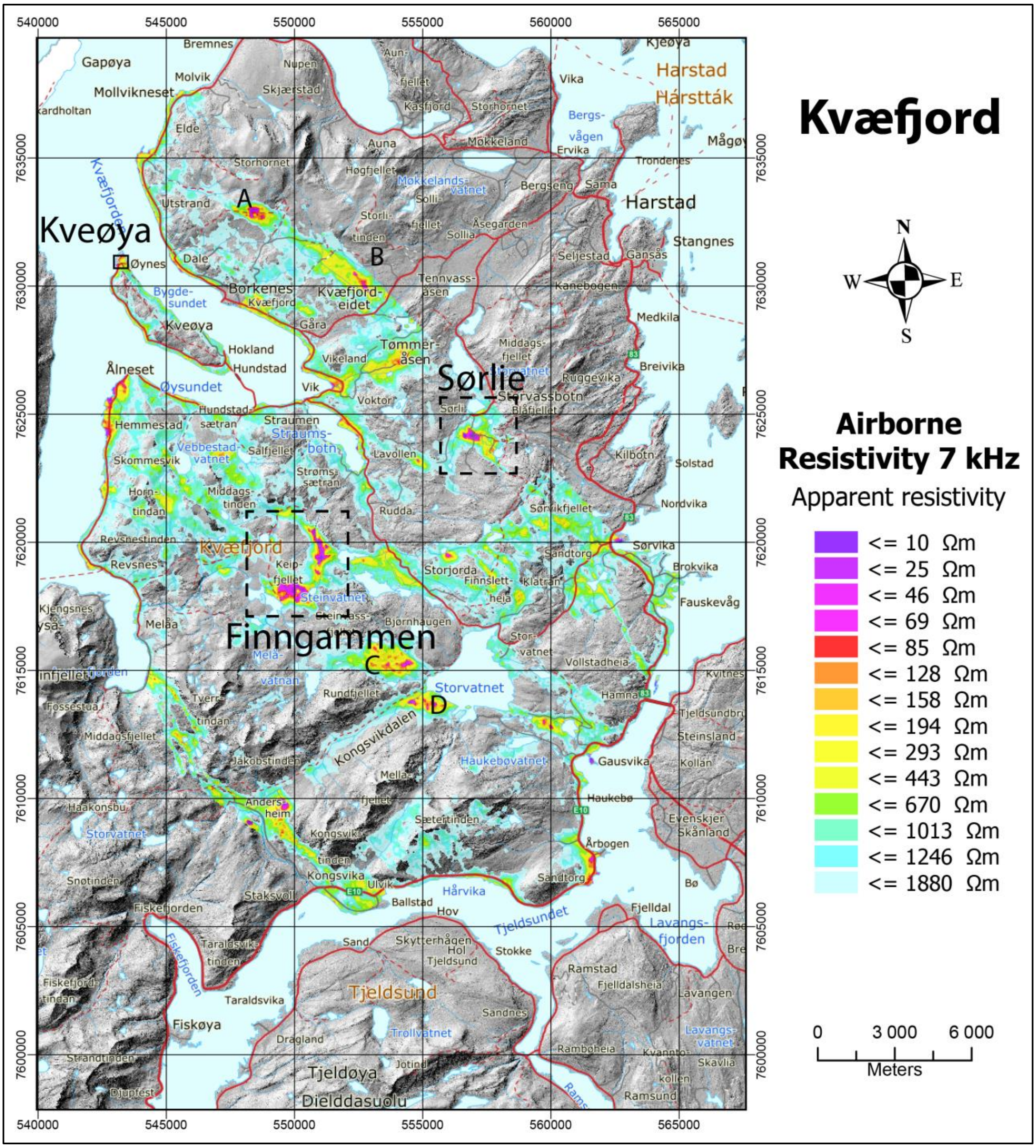

Figure 1.3: Graphite occurrences and resistivity anomalies in Kvæfjord area. Some follow-up work is performed at Kveøya, Sørli and Finngammen. Areas A, B, C and D are other potential graphite targets (see text).

1.2 Physiography and landownership

Senja.

Mount Hesten (The Horse) and Mount Vardfjellet (Cairn Mountain) are situated 2 - 4 km north of the Lysvatnet power station in the east-central part of the Senja island. Bukken (Mount Buck) is situated close to the eastern end of the lake Lysvatnet (Figure 1.2). The areas are most practically accessed with the use of four-wheel all-terrain vehicles (ATV). A permit for use of off-road vehicles is needed from the local municipality, Lenvik, located at Finnsnes. From Lysvatnet to the top of the Vardfjellet mountain is approximately a one-hour drive with ATV. From the lake Lysvatnet to the city of Finnsnes the drive is about 40 minutes on an all-weather road. The nearest quay is located at Gibostad about 20 minutes on an all-weather road from Lysbotn. Hesten and Vardfjellet mountains are totally uninhabited. The land is public and administrated by the state-owned enterprise Statskog (www.statskog.no).

The area called Bukken, divided in three sub-areas (Bukkemoen, Bukken and Litjkollen), can be easily accessed along the same road as for Hesten and Vardfjellet. Partly, the deposits at Bukkemoen are located along that road. The graphite at Bukken mountain located 400 - 500 m a.s.l., can be reached by a one hour walk in steep terrain or by a one-hour drive with an ATV. A permit for use of off-road vehicles is needed from the local municipality, Lenvik, located in Finnsnes. Distance to Finnsnes and the nearest quay is the same as for Hesten and Vardfjellet. Bukken mountain are totally uninhabited but at the lower part of Bukkemoen there are some cabins and one permanent settlement. Discussion with the private landowner before any activity is recommended.

The areas Grunnvåg and Skarsvåg are both located next to a county road (FV 861) and can be easily accessed. Distance to the nearest quay at Gilbostad is less than ten minutes by a car. Grunnvåg and Skarsvåg are mainly uninhabited but some settlements exist at the ends of the potential graphite bearing areas.

The cadastral map of the area can be accessed at www.seeiendom.no. During normal annual snow conditions, the areas Hesten, Vardfjellet and Bukken can be accessed from early July to the end of October. Snow can be expected at the mountain tops from mid-October. The areas Bukkemoen, Grunnvåg and Skarsvåg can be easily accessed from early May.

Prospectors interested in this area should visit the web sites of the Norwegian Directorate of Mining with the Commissioner of Mines at Svalbard (www.dirmin.no) for Norwegian mining regulations (webpages only in Norwegian).

Kvæfjord

The quality of graphite in Kvæfjord is sub-economical. Due to this, we do not recommend further activity, and no information on physiography and landownership is needed.

2. GEOLOGICAL SETTING

NGU has performed some follow-up work on Senja and in Kvæfjord.

2.1 Senja area

The investigated area is part of the West Troms Basement Complex that constitutes the coastal area of Troms (Figure 2.1). This region comprises Archean gneisses of variable origin, Archean and Paleoproterozoic greenstone belts and Svecofennian bimodal intrusions with an age of approximately 1.8 Ga. The geology of the West Troms Basement Complex is described by Myhre et al. (2013 and references therein). According to Myhre et al. (2013) the West Troms Basement Complex comprises three stages of Archean magmatism and one superimposed Neoarchean high grade metamorphic event. The three magmatic events are dated to 2.92-2.8 Ga, 2.75-2.70 Ga (main phase) and 2.70-2.67 Ga respectively. The Neoarchean metamorphic event involved stromatic migmatite formation and is dated to 2.70-2.67 Ga. These migmatites locally contain remnants of supracrustal rocks of volcanic and sedimentary origin. Their age is uncertain. The supracrustal rocks are today seen as marbles, hornblende biotite gneisses, graphite schist, quartzites and garnet mica schist.

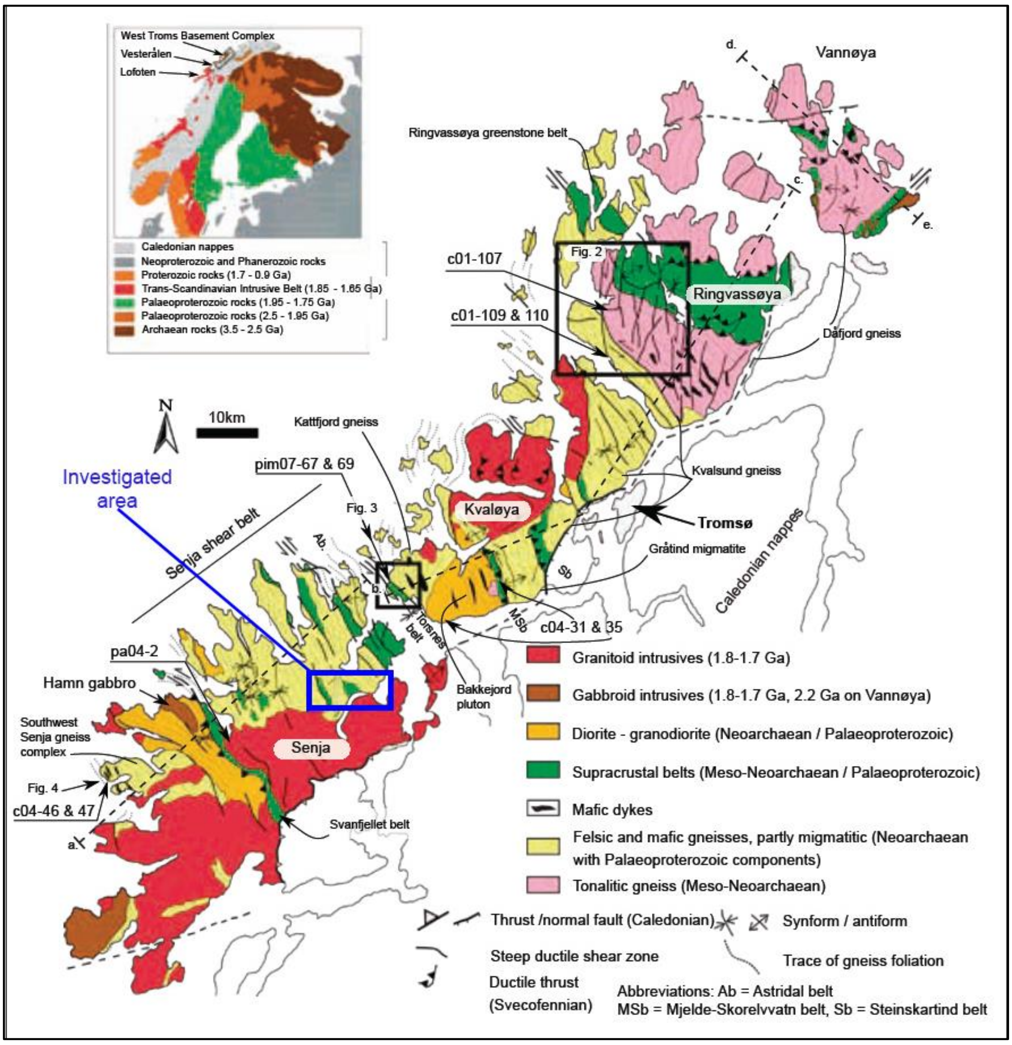

Figure 2.1: The geology of the West Troms Basement Complex and location of the investigated area (modified after Myhre et al. 2013).

During the Svecofennian orogeny (1.8-1.7 Ga) the West Troms Basement Complex was reworked, metamorphosed and intruded by mafic to felsic intrusions. A more specific description of the geology and structural controls of the graphite-bearing rocks are given in chapter 3.

2.2 Kvæfjord area

The exact geological setting for the different localities in the Kvæfjord area (Chapter 11) is not known in detail. On the geological map 1:250,000 Narvik (Gustavson 1974) these areas are situated within the Caledonian nappe sequence.

Resent reconnaissance work by NGU indicates that the graphite bearing rocks belongs to an early Proterozoic supracrustal sequence, metamorphosed to amphibolite facies. However, the Kvæfjord area is poorly mapped and the exact boundaries for the Caledonian domain is presently not known in detail. Bedrock mapping has now been initiated by NGU to solve these problems in the area. Recently (2019) additional helicopter-borne geophysical measurements were performed north of the area shown in Figure 1.3. Data from this survey will be available during the coming winter.

3. HISTORICAL BACKGROUND AND PREVIOUS INVESTIGATIONS

On Senja, graphite deposits have been known for more than 150 years and the Skaland deposit has been mined since 1917. In Kvæfjord no graphite occurrence was known before this project was established (2016).

3.1 Senja area

The graphite deposits on Senja were among the first that were described by geologists in Norway. Keilhau (1844) described the graphite occurrence at Trælen (Lyktgangen). This deposit had probably already been known for some time before that. The Skaland deposit was discovered around 1870. Mining started here in 1917. Modern mining started in 1932 and continues to the present day. In 2006, the reserves at Skaland were exhausted, and the mine moved to Trælen where operations today produce approximately 10,000 tons of graphite concentrate annually. Apart from unpublished (and confidential) reports, little is published about the graphite mineralisation on Senja.

A bedrock geological map in scale 1:50,000 is published by Zwaan & Fareth (2005).

3.1.1 <u>Structural geology of the graphite mineralisation and associated rocks</u>

Heldal & Lund (1987) were the first studying in detail the various graphite deposits on the island of Senja. The most comprehensive general study of the structural geology of the graphite mineralisation is published by Henderson & Kendrick (2003) which presents geological mapping and structural analysis of many graphite occurrences on Senja. This study includes detailed structural analysis of six of these graphite deposits. Detailed 1:5,000 structural mapping was undertaken for four of these deposits along with sample collection for graphite content analysis. Regional observations were also made to supplement the structural knowledge gained from the deposits and to put their geometries in a regional context.

Henderson & Kendrick (2003) characterised the complex structural episodes to have both created and modified the graphite deposits and found that the graphite is intimately associated with the development of F_2 folds, as graphite is best developed geographically in association with north-south striking F_2 fold hinges. However, the F_2 fold hinges are deformed by D_3 deformation on approximately E-W axes. This created complex interference geometries. The graphite is most geographically extensive where F_3 structures intersect graphite-bearing F_2 structures. The extent of graphite outcrop is also strongly affected by the presence of both F_2 and F_3 shear zone structures which locally (F_2) or regionally (F_3) 'shear-out' the graphite outcrops, thereby limiting the extent of the graphite deposits. Therefore, a good knowledge of the combination of the D_2 and D_3 structures will allow for a better understanding of the geometry of the graphite deposits.

At the Trælen and Finnkona deposits an additional deformation episode was identified (D_4). In many of the deposits both the F_2 and F_3 folding is highly non-cylindrical, demonstrating that using small-fold geometries to determine the large scale deposit geometry is highly problematic. It was summarized by Henderson & Kendrick (2003) that great care should be taken in further prospecting for graphite deposits on Senja.

3.1.2 Geophysical investigations

Detailed geophysical investigations have earlier been performed on the following graphite occurrences:

- Krokelvdalen and Geitskaret (Dalsegg 1985)
- Skaland (Dalsegg 1986, Rønning et al.2012)
- Bukkemoen (Lauritsen 1988).

In the period of 2012 to 2014, northern Senja was covered by helicopter-borne geophysics, including magnetic, electromagnetic and radiometric data (Rodionov et al. 2014). A more comprehensive description is given in chapter 4.

In cooperation with Troms County Administration, NGU performed follow-up work at Hesten and Vardfjellet in 2016 and minor work was performed at Grunnvåg (Rønning et al. 2017).

3.2 Kvæfjord area

In Kvæfjord, no graphite deposits were known before the helicopter-borne EM measurements were performed in 2012. The apparent resistivity maps from this survey (Rodionov et al. 2012) showed up several low resistivity areas that could be related to graphite or sulphides occurrences. Sulphides are known from the old Berg mine located at Borkenes in Kvæfjord municipality and 11 other showings in the area (Often 1982). Geological reconnaissance work by Børre Davidsen early in 2016 confirmed presence of graphite at Kveøya in Kvæfjord and later work in 2018 discovered graphite south of Sørli and at Finngammen west of Harstad.

4. GEOPHYSICAL AND GEOLOGICAL METHODS

The resolution of helicopter-borne electromagnetic measurements is low and detailed ground measurements are necessary to achieve a good knowledge of the graphite deposits. Here we describe the methods used in the graphite investigations in 2016 and 2018.

4.1 Geophysical methods

In the graphite investigations on Senja, we have used the following geophysical methods: Helicopter-borne electromagnetic (HEM), Charged Potential (CP), Self Potential (SP), 2D Resistivity (also called ERT) and Induced Polarisation (IP).

4.1.1 Helicopter-borne Electromagnetic Measurements

A helicopter-borne geophysical survey was performed in 2012, 2013 and 2014, with a total of 5,620 line-km covering 1,124 km^2 in the northern part of Senja. The full technical description, including details of processing of the data collected was reported by Rodionov et al. (2014). The survey included the instrumentation listed in Table. 4.1. A similar survey was performed in Kvæfjord in 2012 (Rodionov et al. 2012).

Table 4.1: Instrumentations used in helicopter-borne geophysical survey.

Instrument	Producer/Model	Accuracy	Sampling Frequency
Magnetometer	Scintrex Cs-2	0,002 nT	5 Hz
Base magnetometer	GEM GSM-19	0.1 nT	0.33 Hz
Electromagnetic	Geotech Hummingbird	1 – 2 ppm	10 Hz
Gamma spectrometer	Radiation Solutions RSX-5	1024 ch's, 16 litres down, 4 litres up	1 Hz
Radar altimeter	Bendix/King KRA 405B	± 3 % 0 – 500 feet ± 5 % 500 –2500 feet	1 Hz
Pressure/temperature	Honeywell PPT	± 0,03 % FS	1 Hz
Navigation	Topcon GPS-receiver	± 5 metres	1 Hz
Acquisition system	NGU in house software		

The Electromagnetic (EM) instrumentation, Geotech Hummingbird (Geotech 1997), is able to map variations in electric conductivity in the ground and is the most useful method in graphite exploration. Details about frequencies, coil orientations and coil separation are shown in Table 4.2.

Table 4.2: Configuration and frequencies of the Hummingbird EM equipment.

Coils:	Frequency	Orientation	Coil separation
A	7 kHz	Coaxial	6.20 m
B	6600 Hz	Coplanar	6.20 m
C	980 Hz	Coaxial	6.025 m
D	880 Hz	Coplanar	6.025 m
E	34000 Hz	Coplanar	4.87 m

The apparent resistivity for each frequency was calculated based on "In phase" and "Out of phase" components of the EM data, using a half-space model of the earth (HEM-module, Geosoft 1997). Data can also be presented as profile maps, on which "In Phase" and "Out of phase" components for each frequency are plotted along the flight path.

Figure 4.1: Equipment used in the helicopter-borne geophysical survey on Senja and in Kvæfjord.

Inverted resistivity sections can be produced based on the measured "In phase" and "Out of phase" components for all frequencies. Available software is EM1DFM (Electromagnetic 1D Frequency Measurements, UBC (Manual for EM1DFM., 2000)) and AarhusInv (formerly called em1Dinv, AarhusInv (2013)). These inversion codes create 2D images based on in principle 1D inversion and with vertical conducting structures, misleading images may be constructed. For this reason, inversions of EM data from Senja were performed but are not presented here. NGU are considering 2D or 3D inversion of EM data from Senja.

The main result from this geophysical survey was a large extension of the area with potential for new graphite mineralisation, and a better definition of the areal extent of known occurrences. This was the basis for defining new graphite targets to be followed up by ground investigations. Most of the occurrences described in this report were previously known, but the mineralised are is larger than previous known. Several new objects are derived from the interpretation of the new airborne geophysical data.

All the data from the helicopter survey can be downloaded from www.ngu.no as jpg-maps or geo-referenced data sets (geotiff-files).

4.1.2 Ground EM and magnetic methods (Modified EM31)

Electromagnetic measurements from helicopter in the Senja and Kvæfjord area (Rodionov et al. 2012 and 2014) show many anomalies that might be caused by graphite. Some of these coincided with known graphite showings, others did not. The area is largely covered by soil and vegetation, so detailed geophysical measurements were necessary to locate possible new graphite mineralisation. In the first attempt to map known and possibly unknown graphite deposits, a ground conductivity meter Geonics EM31 (Geonics 1984) was used. This instrument is calibrated such that it measures the apparent electric conductivity directly in mS/m down to 6 – 7 m. The instrument has normally horizontal coplanar coils separated by 3.8 m and working at a frequency of 9,800Hz.

NGU modified this instrument during the winter of 2017, including a GPS positioning system, magnetic sensor and a data logger. This has made measurements more effective and the quality of data are improved by continuous sampling and simultaneous registration of the magnetic field. Normal operation of the instrument produces one reading of apparent electric conductivity for each second. Measured apparent conductivity will be presented as colour coded dots where high electric conductivity is plotted on top of lower conductivities. In case of dense measurements, this may give an overrepresentation of high apparent conductivities and details can be hidden. To overcome this problem, EM31 data in selected areas is plotted as profile curves. Apparent resistivity can be calculated as the inverse value of apparent conductivity.

Figure 4.2: Geonics EM31 used in graphite investigations in Vesterålen.

The EM31 is a very effective instrument for locating unexposed graphite deposits: we experienced a success rate of almost 100 % when excavating targets indicated by the instrument. Trenches were excavated based on the EM31 data and the underlying graphite deposits were revealed. The instrument cannot discriminate between sulphides and graphite, and its penetration depth is a strong limitation where the graphite mineralisation exceeds a depth of 10 m.

Measurements with EM31 may, in some cases, show a negative apparent conductivity. This may happen when there is a vertical structure that is thinner than the coil separation of 3.8 m. In these cases, the apparent conductivity is read as -2 mS/m and given as black dots in the data presentation and labelled “Peak” in the legend.

4.1.3 Charged Potential and Self Potential methods

Charged Potential (CP) measurements are acquired by connecting a current electrode directly to the conductive body and locating the other remote electrode at a considerable distance to ensure that its effect is virtually non-existent in the survey area. The current can be injected through a surface outcrop or a Drill-hole if no outcrops are available. The potential between two non-polarizable electrodes is then measured on the surface around the conductive body in a sequence of connected measurement-points. As long as the electric conductivity of the mineralisation is more than 1000 times higher than that in the surrounding host rock, the electrical potential will, in practice, stay constant above the mineralisation, and then drop down when the measurements are outside the body (Figure 4.3). By measuring the potential around a known graphite body, the body's length, dip and size can be mapped. In addition, an outline of unknown bodies can be mapped.

A practical way of interpreting depth extend of nearly vertical electric conductive bodies from CP data is presented by Kihle & Eidsvig (Nye tolkninger for tolkning av CP-målinger, 1978).

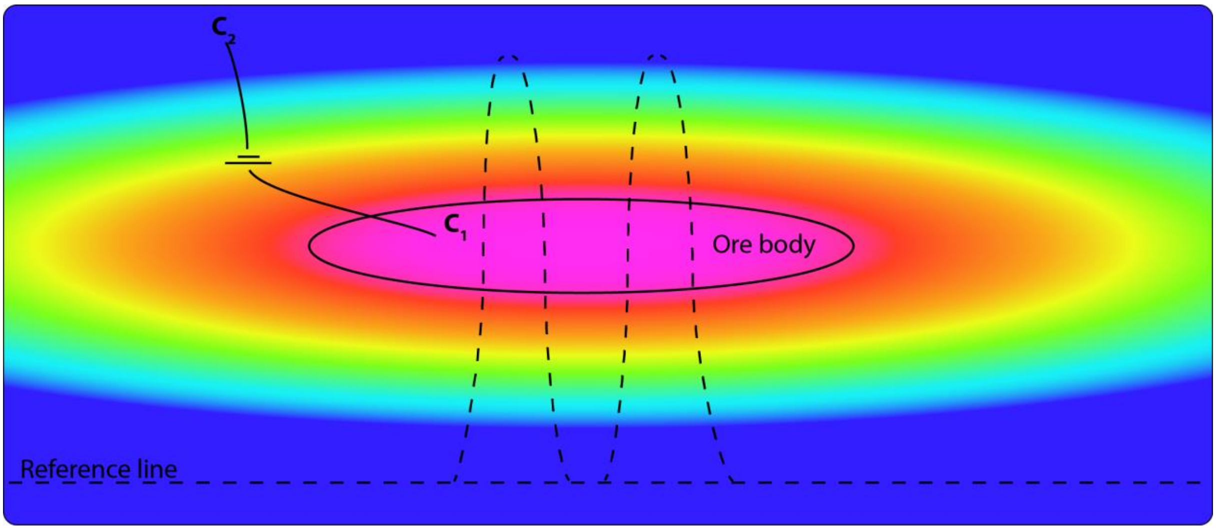

Figure 4.3: Conceptual illustration of the CP- method. The current electrode (C1) is connected to the ore body and the remote electrode (C2) is placed far outside the survey area. The colour indicates the strength of the charged potential above an ore-body. The dashed line shows the survey paths along which the entire body will eventually be covered.

Self Potential (SP) is measured simultaneously with CP. SP is a natural potential in the ground created by electrochemical processes in connection with electronically conducting minerals (graphite, sulphides and oxides, Sato & Mooney 1960). In order to separate data from the two methods, the transmitting and measuring sequence is controlled by GPS time. SP is measured just before a current pulse while both CP and SP are measured during a current pulse. SP is not dependant on exposed graphite for current injection and can be a very useful tool if there are several conductive bodies in the area of investigation.

SP may give negative potential values of 1000 mV or even more above graphite mineralisation. SP signals less than 100 mV are not regarded as anomalies in mineral prospecting.

The equipment used for **combined CP and SP** measurements was developed at NGU in 2014. It consists of an immobile current transmitter and a mobile receiver (Voltmeter). The transmitter sends current between the ore electrode (C_1 in Figure 4.3) and the remote electrode (C_2 in Figure 4.3) and charges the ore body. The current is transmitted in pulses of two seconds on and two seconds off. The pulses are synchronized through GPS-time enabling the receiver to "know" when the ore body is charged. SP is measured when the current is switched off and CP+SP is measured with the current on, and then, in order to get the pure CP, SP is subtracted from the CP+SP measurement. All of this is done automatically during the measuring procedure. Each measurement is the potential between the two mobile electrodes. This means that every measurement has to be added consecutively to a total potential sum.

The position of each measured point is given by a GPS recorder at the position of the receiver. The accuracy of the positioning is +/- 5 m.


Figure 4.4: Establishing CP ore grounding point and data acquisition in combined CP and SP measurements.

4.1.4 2D resistivity (ERT) and Induced Polarization (IP)

Detailed Electric Resistivity Traversing (ERT) and Induced Polarisation (IP) sections give valuable information in the evaluation of graphite mineralisation.

Data acquisition

The 2D resistivity and IP methods are carried out by injecting current into the ground with the use of two electrodes and by measuring the voltage between two separate electrodes. Based on measured resistance (measured voltage / injected current) and a geometrical factor dependent on the electrode positions, the apparent resistivity and IP effect can then be calculated.

The 2D ERT/IP measurements were performed using the Lund cable system (Dahlin 1993) and the instrument ABEM Terrameter LS (ABEM 2012) was used to acquire data. As seen in Figure 4.5, four multi-electrode cables can be used, and for the surveys presented in this report, a Multiple Gradient electrode configuration (Dahlin & Zhou 2006) was applied. Once the electrodes are connected to the ground and the measuring instrument, an automatic measuring procedure starts transmitting current at one electrode pair and measures electric potential at up to four electrode pairs simultaneously. Resistivity is measured when current is on, while IP-effect is measured shortly after current break. The electrode separation can be 2 m, 5 m and even 10 m. The penetration depths are ca. 20 m, ca. 60 m and ca. 120 m respectively. Penetration depth is however dependent on the resistivity in the ground. The resolution decreases with depth and deeper parts of the resistivity sections are, by experience, of low reliability.

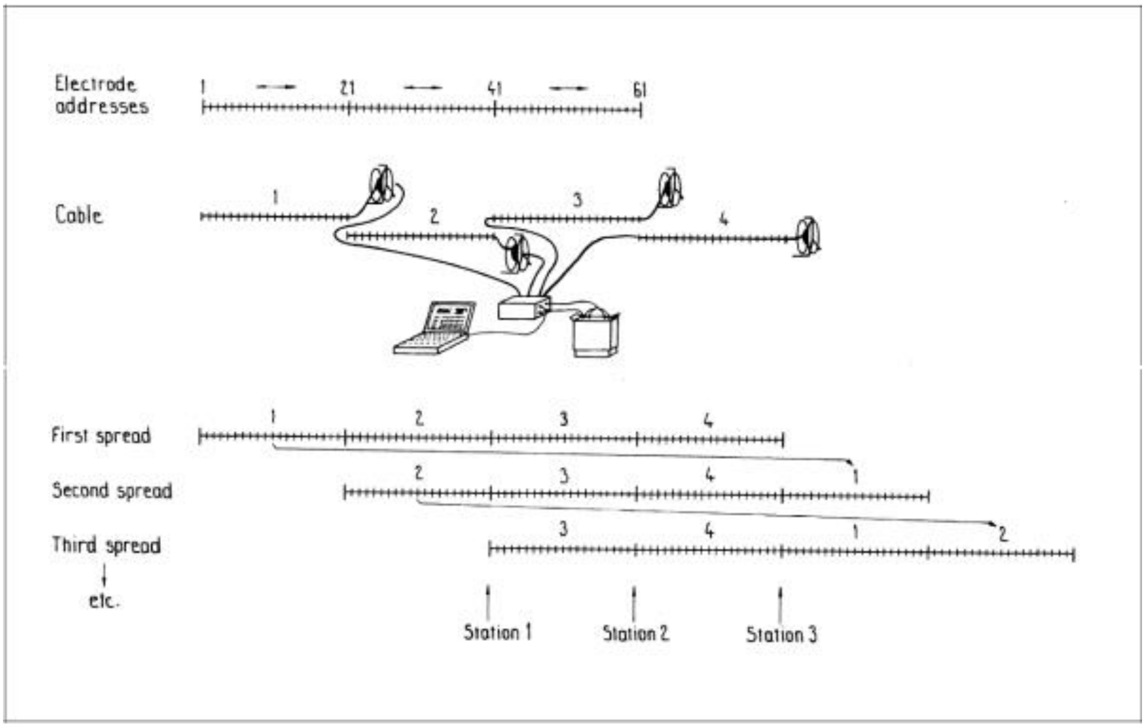

Figure 4.5: Diagram of measuring procedure illustrating the setup of the Lund System and the roll-along method for performing as many measurements as required. From (ABEM 2012).

Data inversion

Almost all resistivity and IP measurements give an apparent resistivity and IP value. The apparent values represent a weighted average resistivity which resulted from resistivity of each heterogeneous volume in the surroundings of the measurement points. The data are inverted in order to find the specific resistivity of each part of the heterogeneous investigated volume. This is done by dividing the profile into blocks each characterised by specific resistivity values; these are adjusted following an iterative procedure until a theoretical model fits the measured data.

Resistivity measurements were inverted using the computer program RES2DINV (Loke 2018) with robust data constraint.

Quality of the data

The quality of 2D ERT/IP data is dependent on current strength, resistivity in the ground and noise level in the area. Some data have a too high standard deviation during inversion according to the methods guidelines. These data points will be removed from the dataset before the inversion.

The data inversion quality can be evaluated by looking at the absolute error (Abs. Error) calculated as the difference between the measured data and a calculated response from the final inverted 2D resistivity section. Absolute error of less than 5 % is very good; 5 – 15 % is good and between 15 and 30 % of acceptable quality. Absolute error > 30 % is not acceptable inverted data.

Data interpretation

Graphite is an electronically conducting mineral, and the resistivity in massive graphite ore bodies is commonly less than 2 Ωm, or electric conductivity higher than 500 mS/m, (Dalsegg 1994, Rønning et al. 2012, Rønning et al. 2014). This can be used to distinguish between resistivity anomalies caused by graphite mineralisation and other ionic conducting geological materials such as porous rock filled with saline water, marine clay deposits and even sulphide deposits (resistivity less than 10 Ωm).

Induced Polarization (IP) responds to electronic conducting minerals which are not in electrical contact. This means that massive graphite deposits give no IP effect on massive graphite bodies. High IP effects are often seen in the contacts between graphite bodies and surrounding host rock where graphite grains are not connected (disseminated ore).

Unfortunately, 2D ERT/IP measurement may be disturbed by artificial conductivity effects interfering with responses from two or more sub-vertical conducting graphite structures (Rønning et al. 2014). The effect of this is a continuous image despite of having two or more vertical structures.

4.1.5 Resistivity drill-hole logging

The resistivity in drill-holes were logged using the ABEM SAS-LOG 200 equipment (ABEM 1993). Resistivity were measured each 25 cm with the Short Normal (SN) electrode configuration. This is a pole-pole configuration where distance between the drill-hole current and the drill-hole potential electrode is 40 cm. This configuration measures the apparent conductivity within a distance of ca. 20 cm into the surrounding rock.

4.2 Geological methods

In this section we define different definition of graphite, analytical methods and drilling equipment used.

4.2.1 Definitions of graphite types

There are some differences in the terminology between geologists and the industry regarding the use of the terms graphite, flake graphite, amorphous graphite and vein graphite that we will clarify here.

Graphite is a mineral with chemical composition C (pure carbon) where the carbon atoms are arranged in sheets where hexagonal rings of C atoms are bond together (Figure 4.6). These layers are again stacked in sheets that make up the graphite crystals. The industry distinguishes between flake, amorphous, and vein graphite, and we use the industrial definition when describing different graphite occurrences in this report.

Flake graphite is defined as graphite where the crystals occur in well-defined flakes with a silvery or steel like colour. Individual crystal size is usually from 0.1 mm up to several millimetres. Individual flakes are easily distinguished from each other with the eye only. Flake graphite usually occur in metasedimentary rocks of high metamorphic grade (granulite facies).

Amorphous graphite is a micro-crystalline graphite with a black colour and where the induvial graphite crystals are indistinguishable with the eye. Amorphous graphite occurs where metasedimentary rocks have been subjected to lower degree of metamorphism (green schist to amphibolitic facies) or in areas with contact metamorphism.

Vein graphite is a rare graphite type where the economic deposits only occur on Sri Lanka. They are formed were pure carbon is deposited from hydrothermal solutions. This type of graphite occurs as massive lumps of pure carbon. On small scale and as geological curiosities vein type graphite are probably not uncommon and described many places outside Sri Lanka.

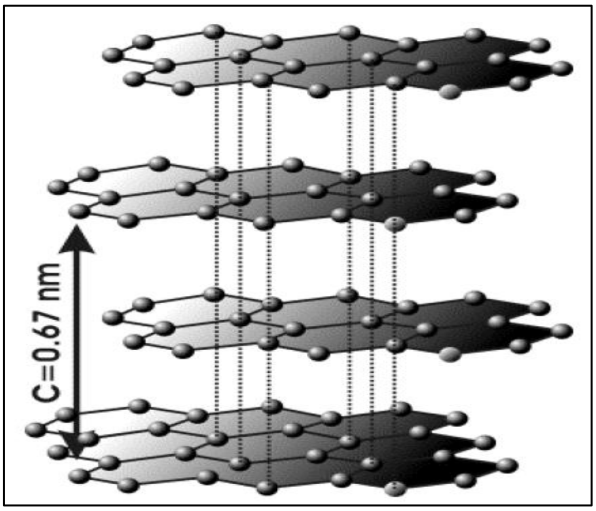

Figure 4.6: Crystalline structure of graphite with C atoms in a hexagonal sheet arrangement.

When we use the term "grade" we mean "content", not metamorphic grade (facies). Descriptions stating that the rock is a "medium grade graphite schist" means in this report a graphite schist with intermediate content of graphite based on visual inspection.

4.2.2 Analytical methods

The investigated area is partly soil covered, but there are numerous outcrops particularly on the mountain tops. We sampled the graphite schist when found in these area and coordinates for every sampling point were recorded, taking care to obtain as representative samples as possible and from as large an area as possible. Usual samples size was about 1-2 kg. The samples were analysed further at the NGU laboratory.

Samples from different outcrops were crushed using standard methods. The powders were analysed for total carbon (TC) and total sulphur (TS) using a Leco SC-632 analyser. The detection limits are 0.06 % and 0.02 % for carbon and sulphur respectively. The analytical uncertainty at 2 σ level is +/-15 % relative. The aggregate results for all samples are shown and are also reported under each area description in chapters 6 to 11.

The graphite industry uses the term "graphitic carbon" (Cg) when reporting graphite occurrences. This type of analysis is essentially the same as "total organic carbon" (TOC) but includes an extra step in which inorganic carbonate minerals and organic matter are removed using acid, and by roasting the sample before using a Leco carbon analyser. In rock types with little or no carbonate minerals and organic matter, analyses of total carbon (TC) would be similar or close to TOC and graphitic carbon (Cg) but the former is much cheaper and faster. The commercial laboratory procedures for TC, TOC and Cg analyses are described by, e.g. www.alsglobal.com

A number of standard thin sections were made from different occurrences. The modal content of graphite in the thin sections was measured using the *ZEN 2 pro* program from Zeiss. The measurement involves the following steps:

1) A micro-photo mosaic covering a whole standard thin section is collected.
2) Using image processing software, that involves several steps of colour segmentation, removal of noise and other adjustments and corrections, the total area percentage of graphite is calculated. In addition, the area, perimeter, diameter plus a number of other parameters are calculated for each individual graphite grain, in the measured thin sections. Complete data is available up on request.

When we use this method to describe the particle size, we use the "diameter" of individual grains, which is the diameter of a circle with the same area as the area of the measured individual particles (diameter = $2(\text{area of particle}/\pi)^{0.5}$.

The Image processing of micro photos to quantify the content and particle size of graphite in a thin section, have some shortcomings and errors. These are:

1) Individual particles that touch each other, will be regarded as one big grain, the same with mineral aggregates. To which degree this can be compensated for varies from thin section to thin section.
2) Minerals with the same colour as graphite will be regarded as graphite, this problem can be checked and to a certain degree compensated for.
3) Image processing cannot distinguish between flake and amorphous graphite, this is done by visual inspection of hand sample.
4) A thin section represents a 2x3cm large area and may not be representative for the hand sample or the locality
5) Grain size in situ in a rock cannot be directly used as a proxy for the grain size you get after ore dressing.

However, image processing methods are much more accurate than standard manual point counting methods or simple visual in section of a thin section. When one look at area % of graphite in relation to grain size distribution, it is always a few numbers of large grains that make up a large part of the total area % of graphite.

4.2.3 Core drilling, sampling and analyses

NGU has a truck mounted drilling rig as shown in Figure 4.7. When the 4x4 wheel drive truck can drive into an area, core drilling can be performed. The core diameter is 36 mm. The core length is limited to ca. 50 m.

Two localities were chosen for core drilling:

1) Bukkemoen, two drill-holes
2) Grunnvåg, one drill-hole.

The purpose of the drilling was as follows:

1) To obtain a continuous section through the graphite bearing units and their country rock.
2) To obtain information on the thickness and grade of graphite schists, on localities where there exists detailed ground geophysical information on the surface.

Figure 4.7: NGUs truck mounted drilling gear in operation.

The drilling undertaken is not detailed enough to estimate a meaningful resource tonnage. Drilling was limited to localities accessible with the truck and with a depth limitation of ca. 50 m.

The drill core was logged, described, sampled and analysed in the following manner:

a) Lithological logs and descriptions of cores (Chapters 8.3 and 9.3, Appendix 1). All drill cores were photographed dry and wet (Appendix 2)
b) Measurements with Portable XRF, one point per 0.25 meter (Appendix 4)
c) Splitting of core in 3 parts, one half and 2 quarter cuts of the core
d) At selected intervals, where visual logging shows the occurrence of graphite, sampling of 2 m intervals was made.
e) The most graphite rich intervals were analysed for TC and TS (Appendix 3)
f) Selected thin sections were made from representative intervals
g) Areas of high electric conductivity were identified using simple Drill-hole resistivity logging (ABEM 1993).

5. SELECTION OF FOLLOW-UP OBJECTS

Follow-up work on graphite is performed at Senja (five objects) and at two objects in Kvæfjord.

5.1 Senja area

Previously known and new graphite occurrences on Senja are located on calculated apparent resistivity from helicopter-borne 7 kHz frequency data (Rodionov et al. 2014) in Figure 5.1. The Trælen and Skaland deposits are well known especially from mining activities but also from follow-up work (Dalsegg 1986, Rønning et al. 2012). The two showings called Geitskaret and Krokelvdalen have previously been investigated with ground geophysics (Dalsegg 1985). The two reported occurrences Finnkona and Skolpan are hardly seen on the apparent resistivity map and seems to be of no economic interest. No follow-up work has been performed at these showings as a part of the cooperation project between NGU and Troms County Administration.

The most pronounced apparent resistivity anomalies from the helicopter-borne geophysics are at Hesten, Vardfjellet, Bukken, Grunnvåg and Skarsvåg. Graphite mineralisation were known at Hesten, Vardfjellet and Bukken long before helicopter-borne measurements were performed. However, the extend of these were not fully known. Grunnvåg, Skarsvåg and part of the Bukken area were discovered based on the helicopter-borne electromagnetic data.

Southern part of the Bukken showing has been investigated with ground geophysics before (Lauritsen 1988). In this area, two conductive structures, probably graphite, can be followed for ca. 1 km in the N-NE direction from Lysvatnet. Detailed studies showed that these could consist of several parallel graphite lenses.

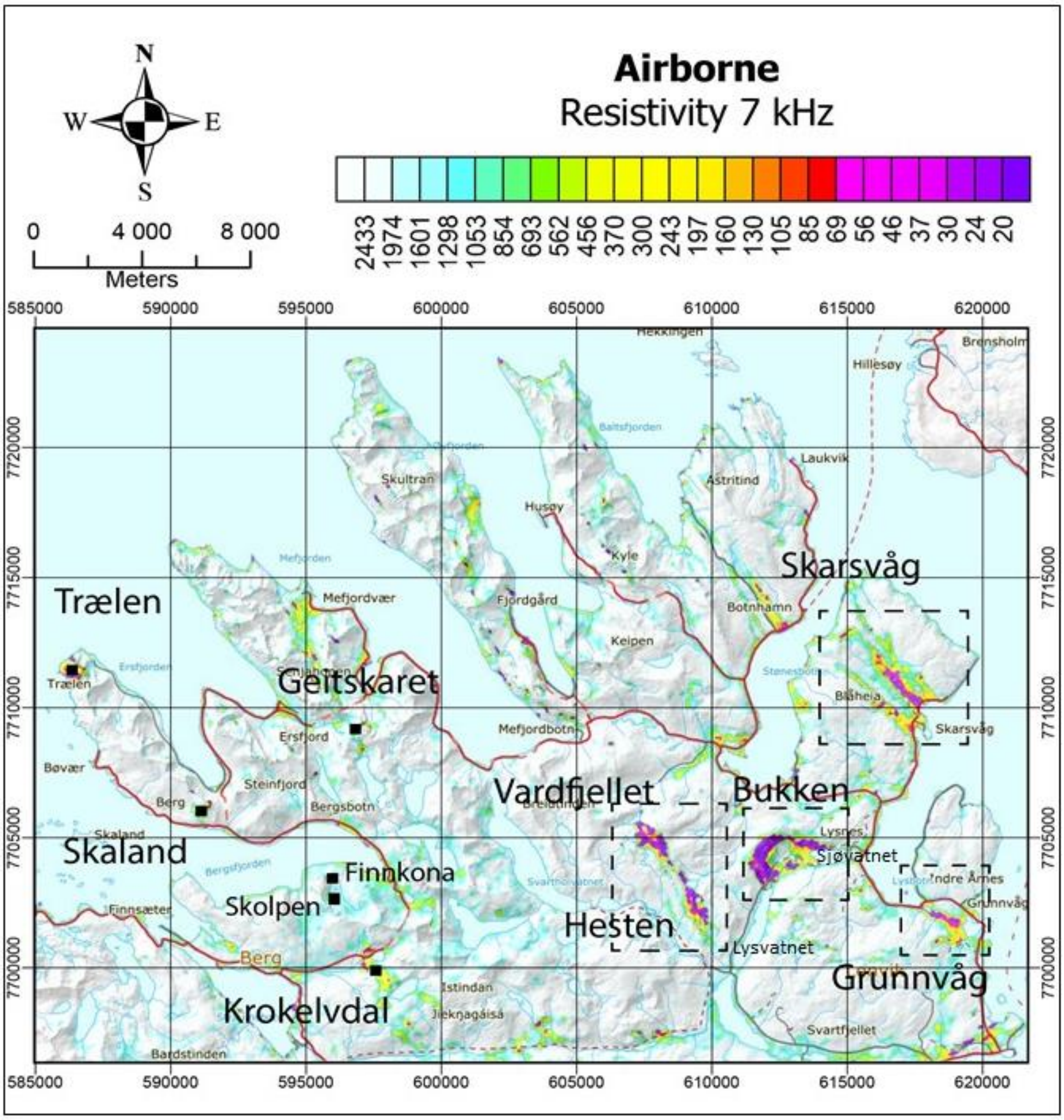

Figure 5.1: Apparent resistivity (7 kHz) and graphite mineralisation on Senja. The areas Hesten, Vardfjellet, Bukken, Grunnvåg and Skarsvåg were selected for follow-up work (resistivity in Ωm).

In the southern part of the area covered by helicopter-borne geophysics (Rodionov et al. 2014), south of the area presented in Figure 5.1, several low resistivity anomalies are shown. In this area, we observed a granitoid intrusive (see Figure 2.1) and therefore good quality graphite mineralisation are less likely.

The apparent resistivity calculated from helicopter-borne measurements has low resolution, and to be able to evaluate the quality and quantity of individual graphite mineralisation, ground follow-up investigations are necessary. Based on these discussions, the areas called Hesten, Vardfjellet, Bukken (Bukkemoen), Grunnvåg and Skarsvåg (see Figure 5.1) were selected for follow-up work in co-operation with the Troms County Administration.

5.2 Kvæfjord

Selection of follow-up objects in Kvæfjord is described in section 11.1.

6. GEOPHYSICAL AND GEOLOGICAL INVESTIGATIONS AT HESTEN

Ground geophysical and geological follow-up investigations were performed at Hesten in August 2016 and in August 2018. In this report, most of the results from 2016 are included.

6.1 Geophysical results, Hesten

The apparent resistivity anomaly from helicopter-borne EM measurements at Hesten is shown in Figure 6.1. The anomaly can be followed for ca. 2 km and the width is up to ca. 300 m. The apparent resistivity is less than 20 Ωm which may be caused by graphite. At Hesten, we performed Charged Potential (CP) in combination with Self Potential (SP) measurements and one profile of 2D resistivity in combination with Induced Polarisation (IP). In 2018, additional measurements with EM31 were performed.

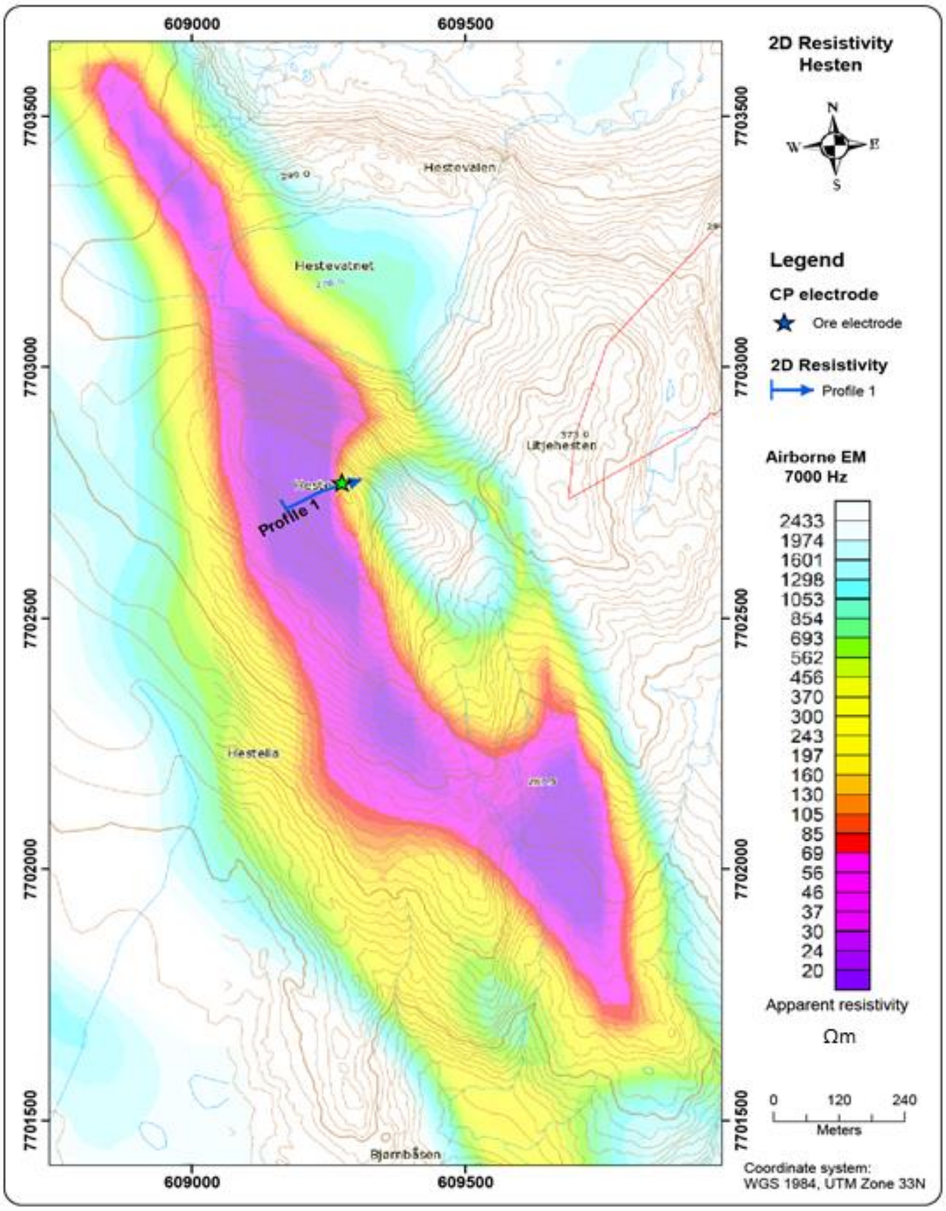

Figure 6.1: Apparent resistivity calculated from helicopter-borne 7 kHz coaxial coils at Hesten. Location of CP grounding point and 2D ERT/IP profile is given as a green star and a blue line respectively.

6.1.1 CP measurements at Hesten

In the Hesten area, CP measurements were performed with one ore grounding electrode. Technical details are given in table 6.1.

Table 6.1: Coordinates (WGS 84, UTM Zone 33), applied current and number of measured points used for CP measurements at Hesten.

Electrode	X-coordinate	Y-coordinate	Current (A)	No. of measurements
Ore	609274	7702770	1,0	123
Remote	610632	7703905		

During the measurements, two receivers were used. However, there appears to be an error on the CP data for one of these. An attempt was made to recover the data, but it was impossible to obtain reliable data. Therefore, only data from the working receiver are presented in Figure 6.2.

Red colours are characteristic at the grounding electrode for this CP contour map (electrode effect), a large area with constant potential shown in green and the blue area to the east. The electrode effect is standard and does always show up representing a potential drop immediately outside the ore electrode.

The green area is of interest. Inside this area the charged potential is at a constant level (ca. 28 mV). No potential drop indicates a good electrical contact between conducting structures within the area. The superimposed SP data indicate several conductors (see next section) but it is not possible to resolve the individual conductors with CP. From this it can be concluded that electrically connected graphite is present in a total length of more than 1 km and in a total width of at least 250 m. It is probable that graphite is in electrical contact within the entire helicopter-borne EM anomaly for a total length of ca. 2 km. It can also be concluded that despite the presence of several graphite exposures, CP grounding in these will give the same image.

The blue area in Figure 6.2 represents the host rock potential level. From the graphite mineralisation (green area) to this level there is a potential drop of ca. 28 mV. This potential drop could be used to interpret the depth extent of the graphite structure at Hesten (Kihle & Eidsvig 1978). Since full coverage of CP data over the entire mineralisation is not available, and that we were not able to find the host rock resistivity (see 2D ERT/IP interpretation), this calculation cannot be made. However, there are indications (the low potential drop of 28 mV) that the depth extent is in the order of several hundreds of metres.

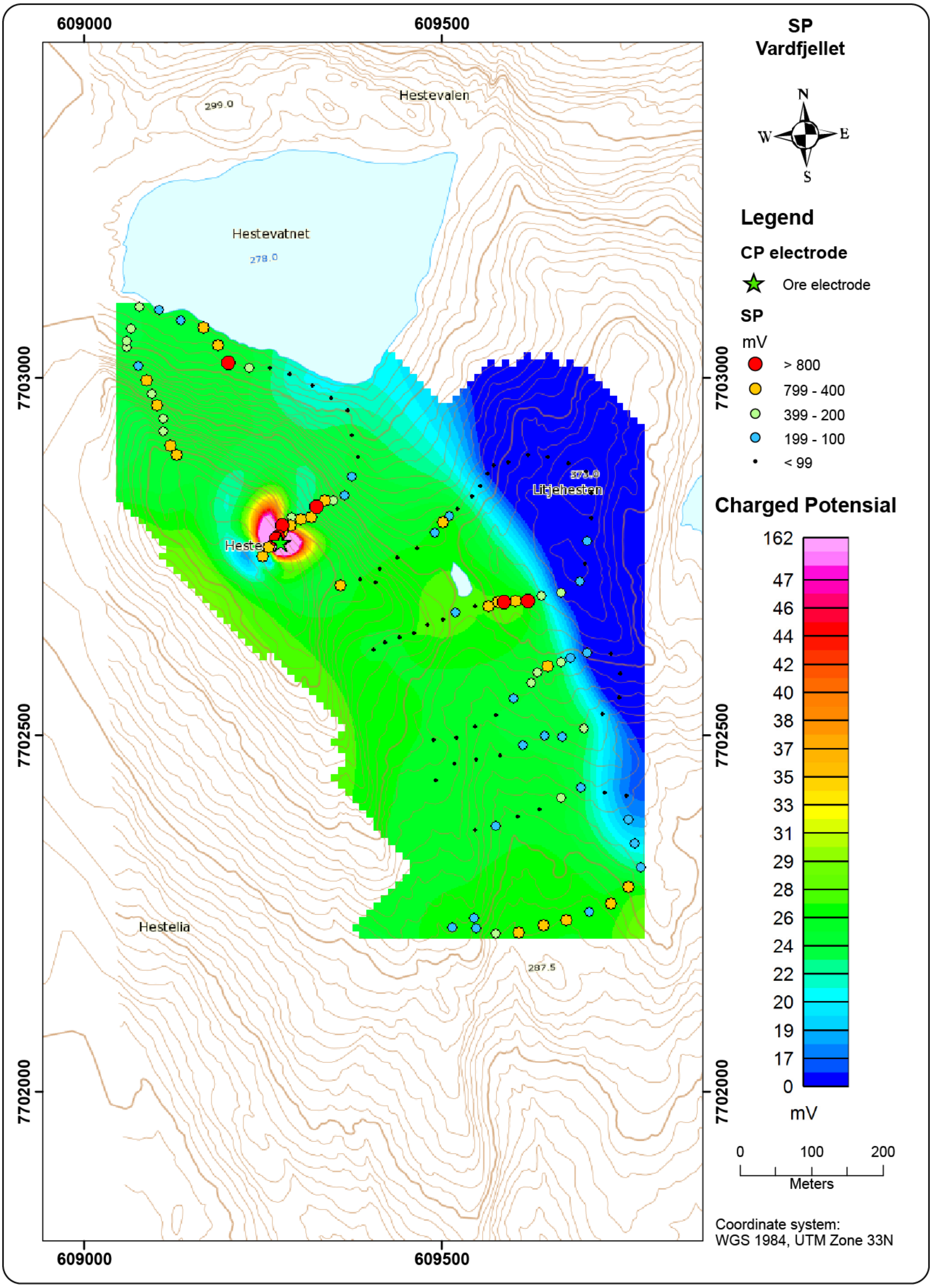

Figure 6.2: Results of CP measurements at Hesten with SP anomalies superimposed. The CP measuring points are the same as SP points.

6.1.2 SP measurements at Hesten

SP measurements at Hesten were performed simultaneously with CP measurements. All results are shown in Figure 6.3 (some in Figure 6.2).

An electrode separation of ca. 30 m was employed as standard. To obtain a better resolution, this was decreased to ca. 10 m in anomalous areas. Figure 6.3 shows numerous SP anomalies higher than 800 mV and some more moderate values. SP anomalies as high as 800 mV indicate graphite mineralisation. Lower anomalies can also be caused by the presence of graphite.

Most of the high SP anomalies represent individual graphite structures with less conducting material in between. This pattern indicates several parallel graphite horizons. All the high anomalies lie within the low apparent resistivity area from helicopter-borne EM measurements confirming the power of these ground-based methods to delineate graphite horizons.

Unfortunately, there is a lack of SP data in both extremities of the EM anomaly. However, it would be expected that graphite mineralisation would follow the helicopter-borne EM anomalies.

6.1.3 EM31 measurements at Hesten

The terrain at Hesten is very steep, making the execution of EM31 measurements challenging. As a result, only two profiles were measured, crossing the eastern part of the potential graphite mineralised area (Figure 6.4).

EM31 shows high apparent conductivity (> 200 mS/m) in the area where the apparent resistivity from helicopter-borne EM measurements is low. In addition, a ca. 100 m wide structure with apparent conductivity > 200 mS/m (apparent resistivity < 5 Ωm) show up in an area to the east where helicopter-borne EM show moderate resistivity (≈ 600 Ωm). Low grade graphite is found in this area. These differences between helicopter-borne and ground data demonstrate the need to undertake ground follow-up measurements. This graphite structure lies within the electric conducting part of the CP response (Figure 6.2).

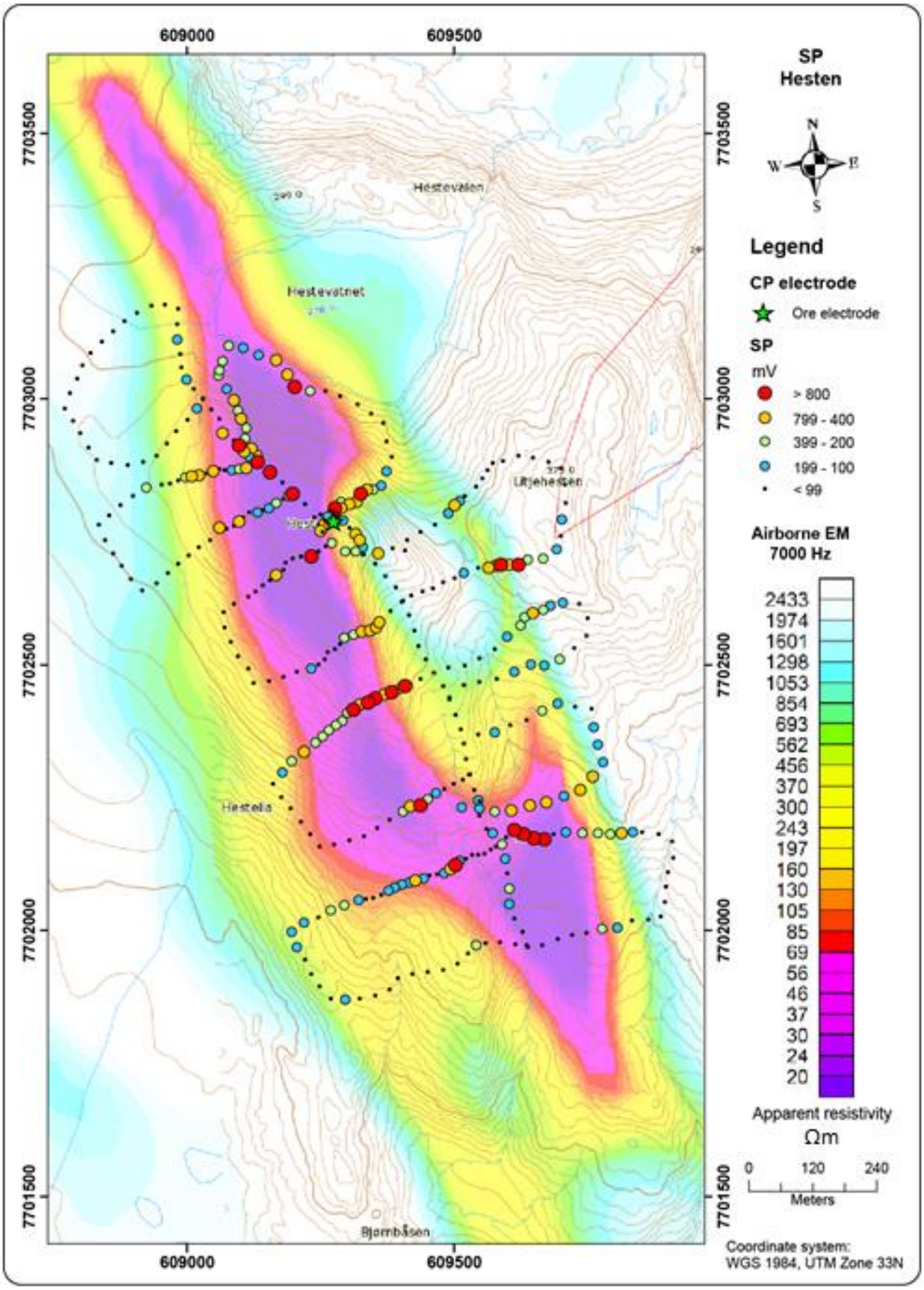

Figure 6.3: Results of SP measurements at Hesten on top of apparent resistivity from helicopter-borne EM measurements (7 kHz, from Rodionov et al. 2014).

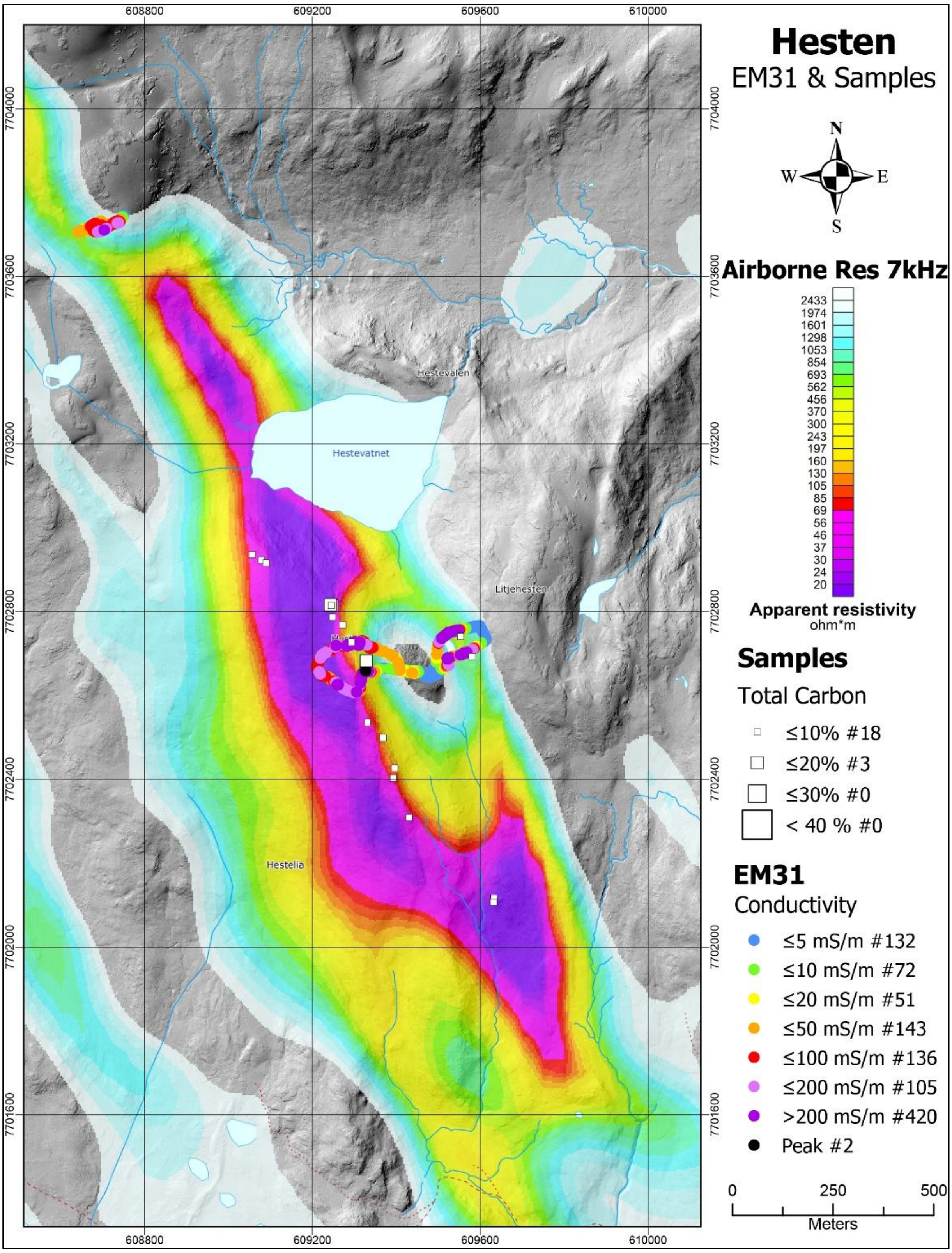

Figure 6.4: Results of EM31 measurements at Hesten on top of apparent resistivity from helicopter-borne EM measurements (7 kHz, from Rodionov et al. 2014). Location of graphite samples and their Total Carbon grade is given with white squares.

6.1.4 2D ERT/IP at Hesten

At Hesten, one 2D ERT/IP profile was measured just south of Hestevatnet (see Figure 6.1). Electrode separation was 2 m and the other technical data is as described in chapter 4.1.4.

Quality parameters are shown in Table 6.2. Absolute error for the resistivity inversion is good (< 15%) while the quality of the inverted IP section is not acceptable. The reason for the latter is probably a very heterogeneous section with many structures giving an IP effect which is difficult to reconstruct by the inversion. The inverted sections are shown in Figure 6.5.

Table 6.2: Quality of 2D ERT/IP at Hesten. Number of measured, removed and remaining data points for inversion, and observed Absolute error from the inversion of resistivity and IP data.

Name	Location	Measured data points	Removed data points	Final data points	Abs. error Resistivity (%)	Abs. Error IP (%)
Profile 1	Hesten	1168	226	942	14.4	56.7

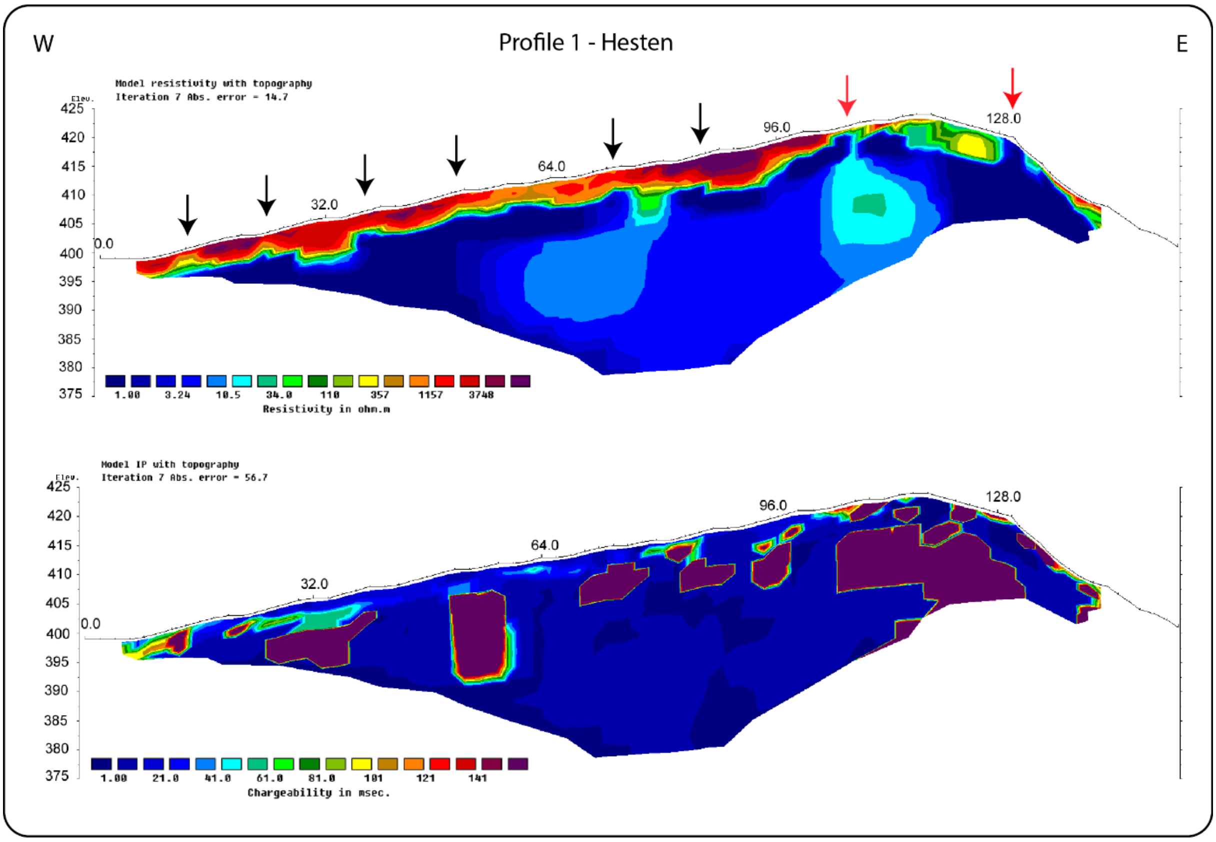

Figure 6.5: 2D resistivity (top) and IP (bottom) results along profile 1 at Hesten. Known graphite outcrops are indicated with red arrows, possible (interpreted) graphite zones with black arrow.

Along this line, graphite could be observed at two locations (red arrows in Figure 6.5). Low resistivity (< 3 Ωm) can be observed along the entire profile. This may be an indication of continuous graphite. However, modelling has shown that several individual graphite zones might explain such a pattern (Rønning et al. 2014). Based on the near surface resistivity pattern, a number of conducting zones can be interpreted that are most likely graphite. Due to the mixed responses, it is impossible to interpret the thickness of the individual zones except for the two outcropping zones that appear to be 3-4 m thick. Along most of the line the interpreted graphite is covered by three to five metres thick high resistive material, probably bolder rich soil.

Very high IP anomalies confirm that disseminated graphite mineralisation can occur along the entire profile, but it is not possible to say more about this due to the quality of the inverted IP data.

Based on the ERT/IP measurements we can conclude that graphite zones with a thickness of more than 160 m (total length of the profile) are more than likely present. Unfortunately, this can be made up of several thinner zones. The thickness of two of these zones appears to be 3 - 4 m. The potential for valuable graphite is therefore quite large in the Hesten area.

6.2 Geological results, Hesten

In 2018 no new sampling was performed at Hesten, and the results presented here are the same as those presented previously (Rønning et al. 2017). In this follow up, the main activity was to undertake EM31 measurements and detailed mapping to upgrade previous geological mapping (Henderson & Kendrick, 2003).

6.2.1 Geological and structural mapping

The existing geological mapping covering both Hesten and Vardfjellet is shown in Appendix 6. This shows that the graphite schist on the surface consists of several apparently isolated lenses that are isoclinally folded and refolded (Henderson & Kendrick 2003).

The mapping of Henderson and Kendrick (2003) is now considered as being outdated as a large and unsystematic error was detected in the original handheld GPS measurements for all observation localities. In addition, further mapping has been carried out in this study, underpinned by the helicopter EM data from 2014 (Rodionov et al. 2014) and the detailed ground based EM31 results. This allows for a new interpretation shown in Figure 6.6. There is overall remarkably good correlation between the graphite outcrops observed in the field and the EM31 results (also shown in Figure 6.6) and an overall similar geometric pattern to that described previously by Henderson & Kendrick (2003).

Based on EM31 results, the individual graphite structures seem to be thicker than indicated at surface exposures. Especially the two zones at the eastern flank acts as one in the EM31 data, and graphite is indicated in a total width of ca. 100 m. Also, in the western part, several structures appear to merge in the EM31 data and the total thickness along the measured lines is several tens of metres.

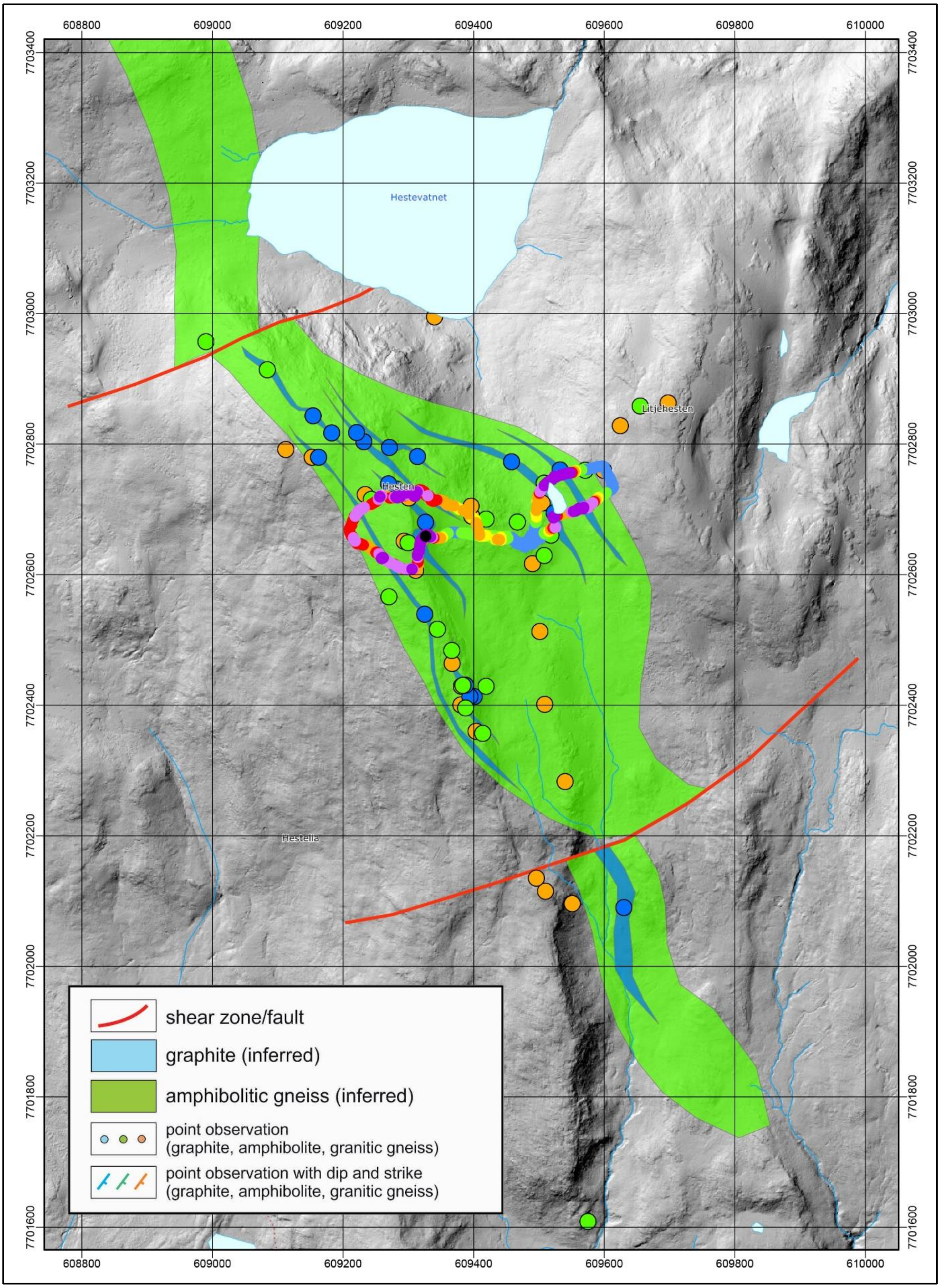

Figure 6.6: Geological map of the Hesten deposit based on earlier mapping of Henderson & Kendrick (2003), new geological mapping in this study, helicopter-borne EM data and ground based EM31. Data from EM31 are superimposed (colour scale in Figure 6.4).

6.2.2 Geological observations, sampling and analysis at Hesten

On the upper part of the Hesten, outcrops of graphite schist can be found over a distance of approximately 1 km. The graphite occurs in a strongly foliated rusty, weathered graphite schist. The graphite appears partly enriched in individual layers and partly evenly distributed in the rock. The contact relationship between the graphite schist and the host rocks was not observed at the Hesten deposit. The mineralised zone has a variable and unknown width. However, from scattered outcrops, it is observed that along certain profiles the minimum width perpendicular to the strike can be up to 150 metres.

Samples were collected on the exposed outcrops, in order to obtain as even a distribution as possible. The samples were analysed at NGU lab and the samples points and approximate grade are shown in Figure 6.4. Individual analyses of 21 samples collected at the mountain of Hesten are presented in Appendix 5, average values in Table 6.3.

Table 6.3: Total Carbon (TC) data from 21 surface samples from the Hesten area.

Locality	N	Average TC (%)	Max TC (%)	Min TC (%)	STdv TC (%)	Median (%)
Hesten	21	5.8	12.8	1.7	3.0	5.5

The average Cg content is 5.8 % with a maximum and minimum of 12.8 % and 1.7 %. The standard deviation is 3.0 %. This graphitic carbon content is comparable with content in deposits under development in Canada and Mozambique. In comparison with Vardfjellet (Chapter 7) a narrower range in content of Cg is observed. The average sulphur content in these samples from Hesten is 0.2 % with a maximum and minimum value of 0.9 % and 0.01 %.

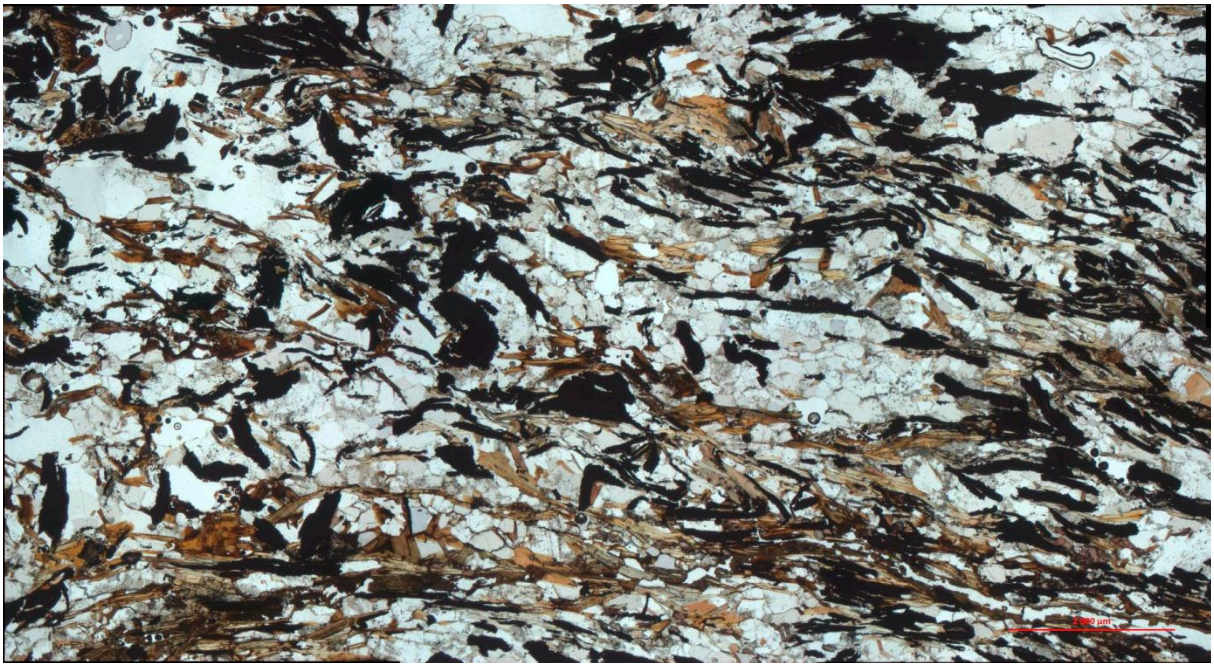

Figure 6.7: Example of thin section from Hesten (Sample HG39-16), with typical flake graphite flake size from about 0.01 mm up to about 0.5 cm

Table 6.4 shows the results of image processing (calculated diameter of graphite crystal) using the method described in section 4.2.2 for sample HG39-16).

Table 6.4: Example of analysed grain size of graphite minerals at Hesten (sample HG39-16).

Locality	Average size (µm)	Max size (µm)	STdv TC (µm)	Median (µm)
Hesten	61	1115	99	18

The calculated diameter of graphite crystals in this thin section shows that the flake size is within the size range *in situ* that can give coarse grained flake size of economic value in a final processed product. However, such measurements have only limited relevance from an industrial point of view, since it is the grain size after crushing, screening and flotation, that determines the quality of the finished product.

7. GEOPHYSICAL AND GEOLOGICAL INVESTIGATIONS AT VARDFJELLET

Ground geophysical and geological follow-up investigations were performed at Vardfjellet in August 2016 and in August 2018.

7.1 Geophysical results, Vardfjellet

The apparent resistivity anomaly from helicopter-borne EM measurements with frequency 7 kHz at Vardfjellet is shown in Figure 7.1 (From Rodionov et al. 2014). The anomaly can be followed for ca. 2 km and the width is up to ca. 480 m. The apparent resistivity is partly less than 20 Ωm and this low resistivity might be an indication of graphite.

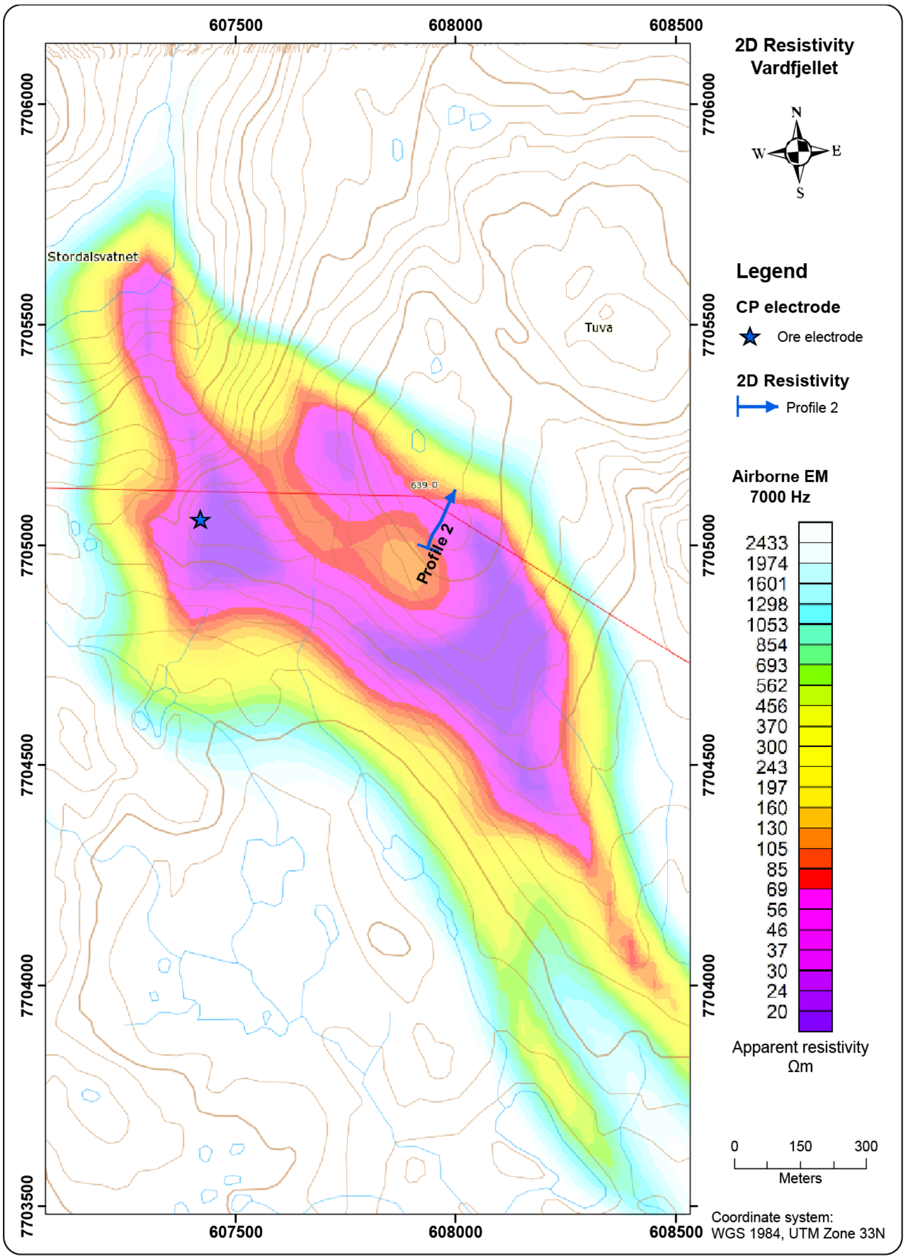

Figure 7.1: Apparent resistivity calculated from 7 kHz coaxial coils at Vardfjellet. Location of CP grounding point and 2D ERT/IP profile is given as green star and blue line.

At Vardfjellet Charged Potential (CP) in combination with Self Potential (SP) measurements were undertaken and one profile of 2D resistivity in combination with Induced Polarisation (IP). The location of CP grounding and the resistivity/IP profile are shown in Figure 6.1. In 2018, some EM31 profiling was performed.

7.1.1 CP measurements at Vardfjellet

Technical details of the CP measurements are given in table 7.1.

Table 7.1: Coordinates (WGS 84, UTM Zone 33), applied current and no. of measured points used for CP measurements at Vardfjellet. R2 is the remote electrode.

Electrode	X-coordinate	Y-coordinate	Current (A)	No. of measurements
Ore	607421	7705059	1,0	267 + 160
Remote	606274	7704738		

Due to bad weather, which caused instrumental problems, the quality of the CP data at Vardfjellet was not trustworthy, and hence no data are presented here. However, the measured data indicate electrical contact between the different graphite horizons, and it is impractical to delineate the form of individual graphite bodies.

7.1.2 SP measurements at Vardfjellet

SP measurements at Vardfjellet were performed simultaneously with the CP measurements. The results are shown in Figure 7.2.

As a standard, an electrode separation of ca. 30 m was used. To obtain a better resolution, this was decreased to ca. 10 m in anomalous areas. Figure 7.2 shows numerous SP anomalies higher than 800 mV and some more moderate values. SP anomalies as high as 800 mV indicate graphite mineralisation. Graphite is also observed outcropping at several locations in the area (see Figure 7.3). Lower anomalies can also be caused by the presence of graphite.

Most of the high SP anomalies represent individual graphite structures with less conducting material in between. This pattern indicates several parallel graphite horizons at Vardfjellet. All the high anomalies lie within the low apparent resistivity area from helicopter-borne EM measurements, confirming again the power of these ground-based methods to delineate graphite horizons.

Unfortunately, there is a lack of SP data in both extremities of the EM anomaly. However, graphite mineralisation is expected to follow the helicopter-borne EM anomalies.

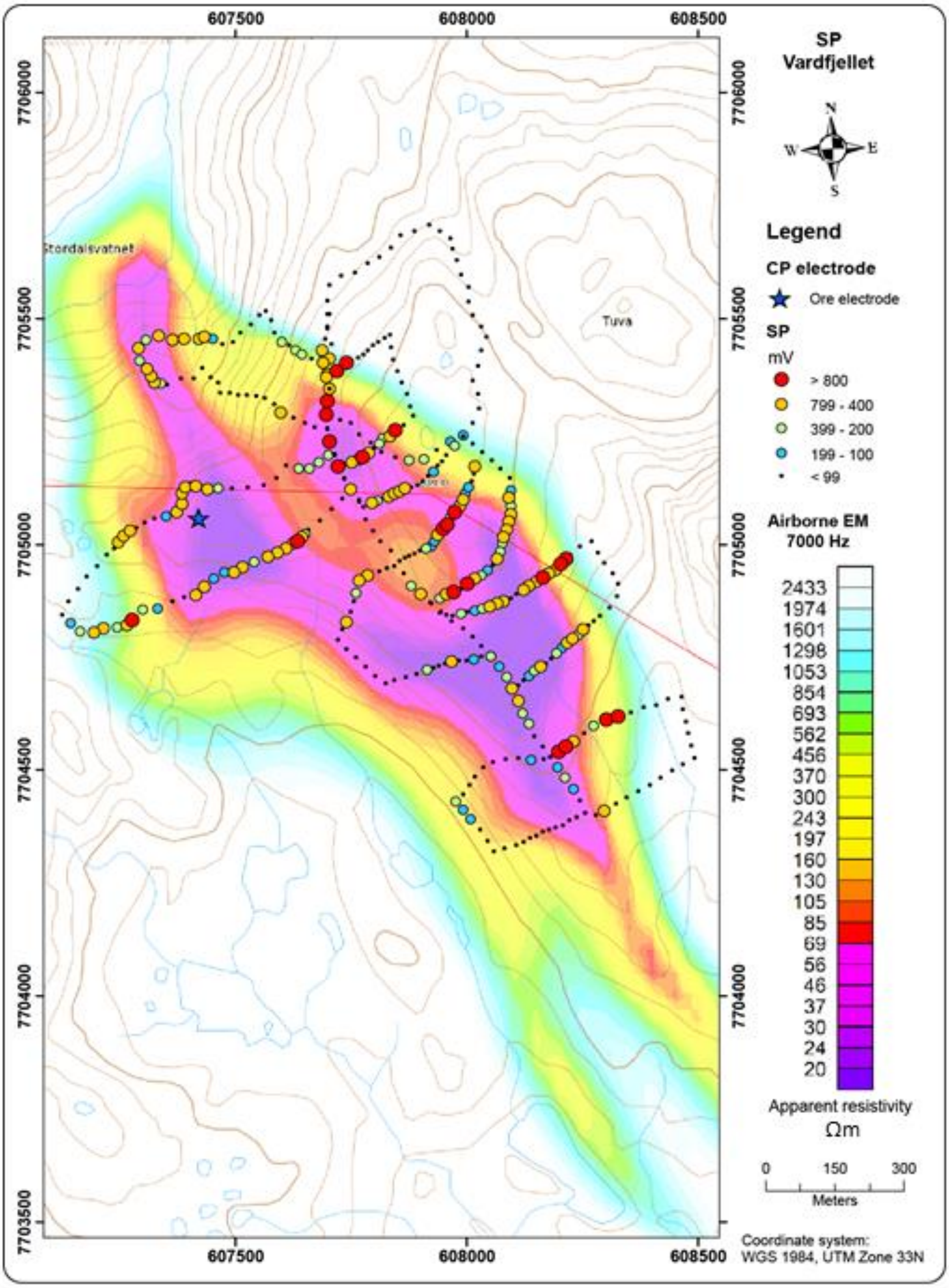

Figure 7.2: Results of SP measurements at Vardfjellet superimposed on apparent resistivity (7 kHz, from Rodionov et al. 2014).

7.1.3 EM31 measurements at Vardfjellet

The terrain at Vardfjellet is very steep and the execution of EM31 measurements were therefore challenging. Due to this, only the eastern half of the interesting area at Vardfjellet is covered with EM31 measurements.

The EM 31 measurements seems to confirm the helicopter-borne electromagnetic data (Figure 7.3). All the high apparent electric conductivity values measured with EM31 are inside the anomalous apparent resistivity from helicopter data (yellow, red to violet colours). Relatively thin structures can be identified, but also wider parts where width of continuous good conducting material can be up to 100 m.

The way in which the EM31 data are presented can overestimate the amount of good graphite bearing rocks. To see the details in the continuous EM31 readings, selected profiles are presents as plotted curves in Figure 7.4. Table 7.2 shows the coordinates and the width of the conducting structures, which are most likely graphite mineralisation. The estimated width of these potential graphite structures are areas where apparent conductivity is > 100 mS/m (apparent resistivity < 10 Ωm).

The selected lines presented in Figure 7.4 indicate numerous individual heterogenous graphite structures. The thickness of these varies from 4 m to more than 100 m. The thickest structures most likely consist of several graphite horizons and there can be country rock layers in between. The anomalous apparent conductivity varies from less than 100 mS/m to a maximum value of ca. 600 mS/m. This can be an effect of the quality of the graphite, but also of variations in the overburden thickness. The quality of the graphite will be discussed later in section 7.2.2.

Table 7.2: Description of anomalous conductivity zones measured with EM31 at Vardfjellet.

EM31 anomaly	Position at the line	Start UTM X	Start UTM Y	End UTM X	End UTM Y	Estimated width (m)	Comment
1A	0 - 20	607919	7704876	607931	7704879	20	Partly < 100 mS/m
1B	48 - 54	607958	7704880	607964	7704882	4	
1C	95 - 101	608000	7704895	608007	7704897	6	
1D	147 - 153	608043	7704925	608047	7704926	6	
1E	200 - 208	608080	7704962	608086	7704966	8	
1F	224 - 270	608097	7704977	608119	7705014	46	Same as 1G?
1G	275 - 317	608124	7705019	608146	7705051	47	Same as 1F?
2A	4 - 30	608044	7704654	608063	7704662	26	Partly < 100 mS/m
2B	50 - 82	608078	7704672	608105	7704667	32	
2C	126 - 134	608130	7704700	608133	7704705	8	Thin structure
2D	222 - 235	608146	7704722	608158	7704742	13	
2E	243 - 290	608183	7704775	608222	7704826	57	
3A	20 - 136	607564	7704942	607631	7705023	116	3 structures
3B	322 - 420	607772	7705131	607838	7705132	98	2 structures
3C	488 - 495	607881	7705175	607886	7705179	7	Thin structure
3D	518 - 528	607906	7705187	607914	7705192	10	2 thin structures

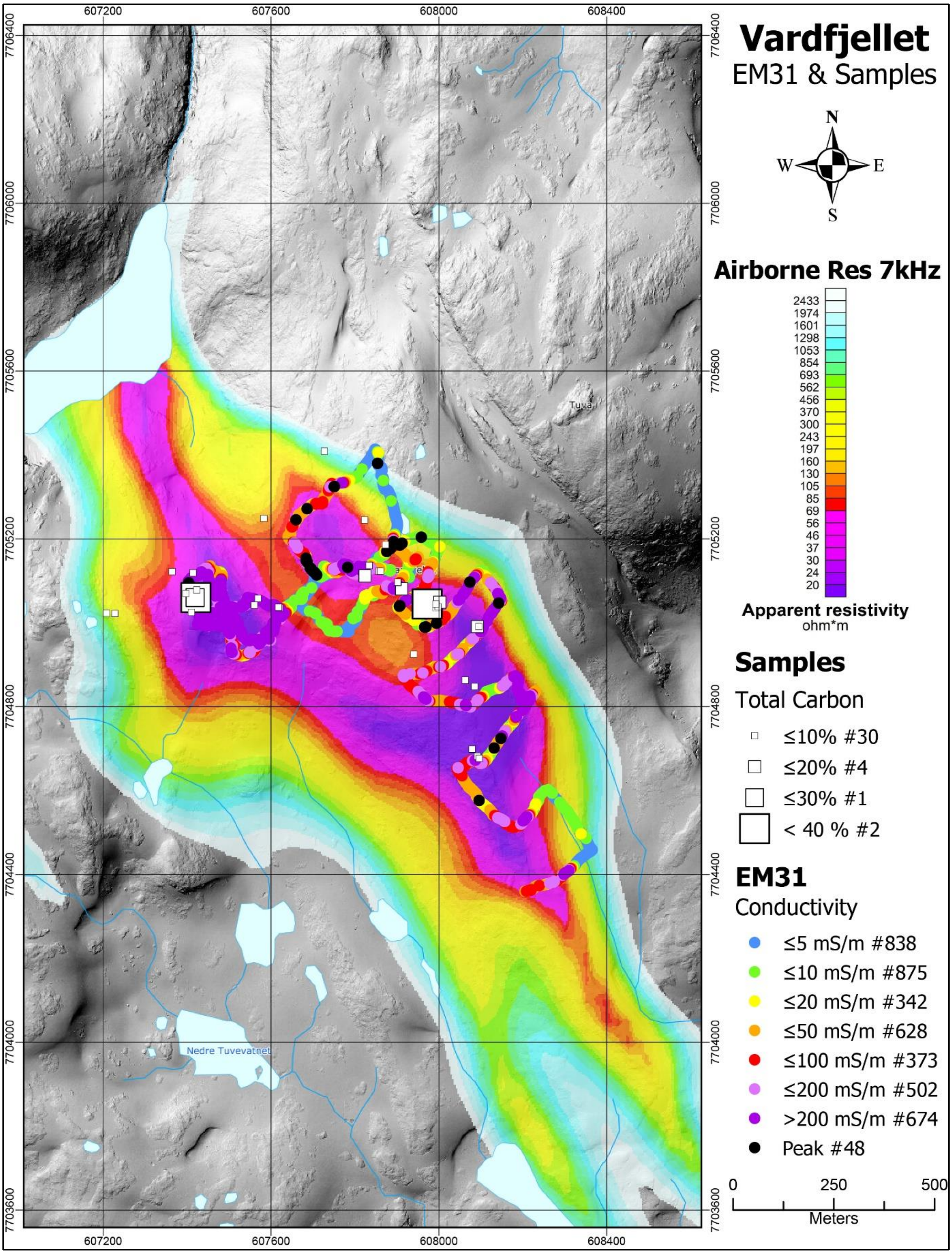

Figure 7.3: Results of EM31 measurements at Vardfjellet superimposed on apparent resistivity (7 kHz, from Rodionov et al. 2014). Location of graphite samples and their Total Carbon grade is given with white squares.

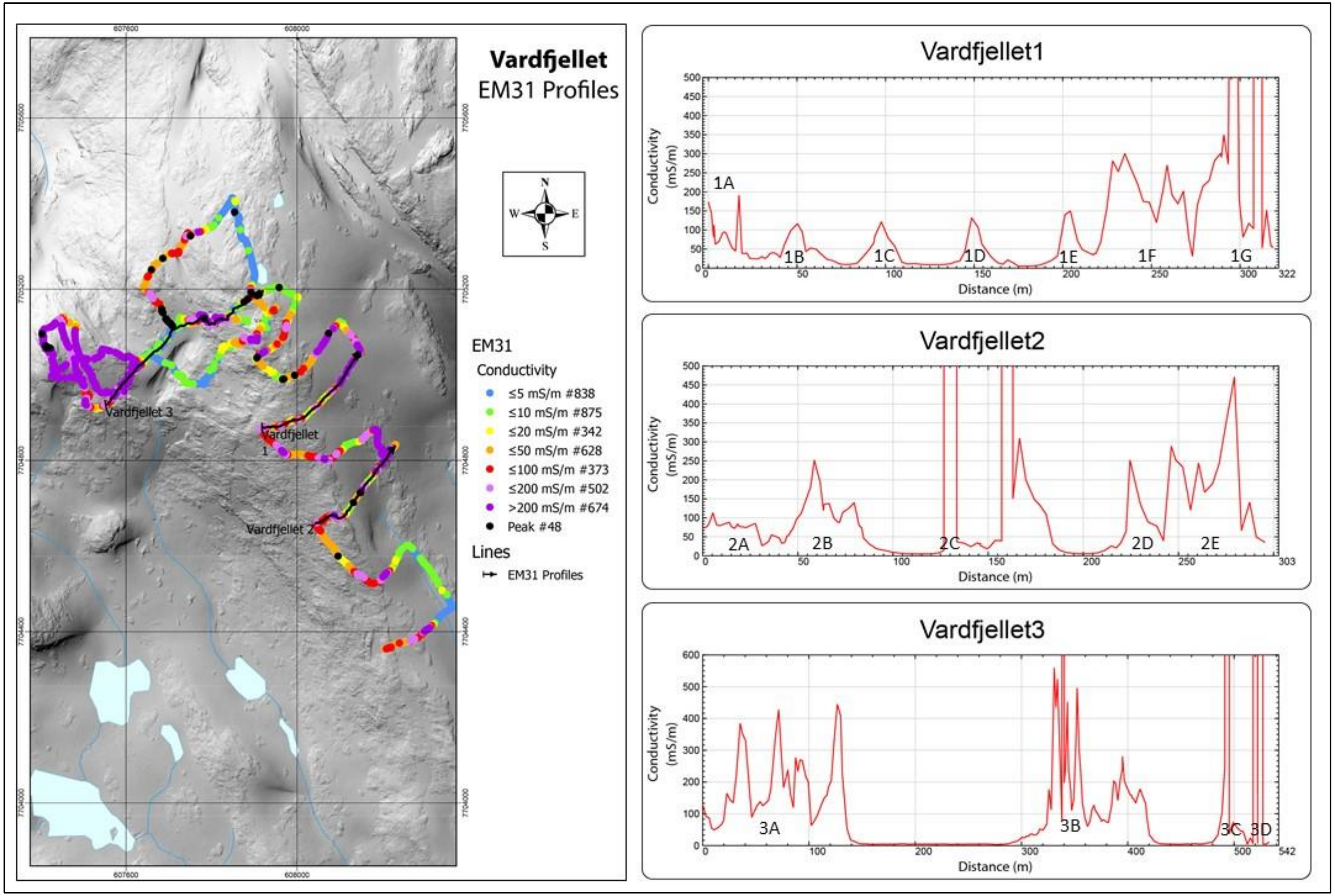

Figure 7.4: Results of EM31 measurements at Vardfjellet. Selected profiles for detailed studies.

7.1.4 2D ERT/IP at Vardfjellet

At Vardfjellet, one 2D ERT/IP profile was measured just S of the Vardfjellet 639 summit (see Figure 7.1). Electrode separation was 2 m and the other technical data is as described in chapter 4.1.4.

Quality parametres are shown in Table 7.3. Absolute error for the resistivity inversion is good (> 15%) while the quality of the inverted IP section is not acceptable (> 30 %). The reason for the latter is probably a very inhomogeneous section with a many structures giving an IP effect which is difficult to reconstruct by the inversion. The inverted sections are shown in Figure 7.5.

Table 7.3: Quality of 2D resistivity and IP at Vardfjellet. Number of measured, removed and remaining data points for inversion, and observed "Absolute error" from the inversion of resistivity and IP data.

Name	Location	Measured data points	Removed data points	Final data points	Abs. error Resistivity	Abs. Error IP
Profile 2	Vardfjellet	1168	301	867	14.8	36.8

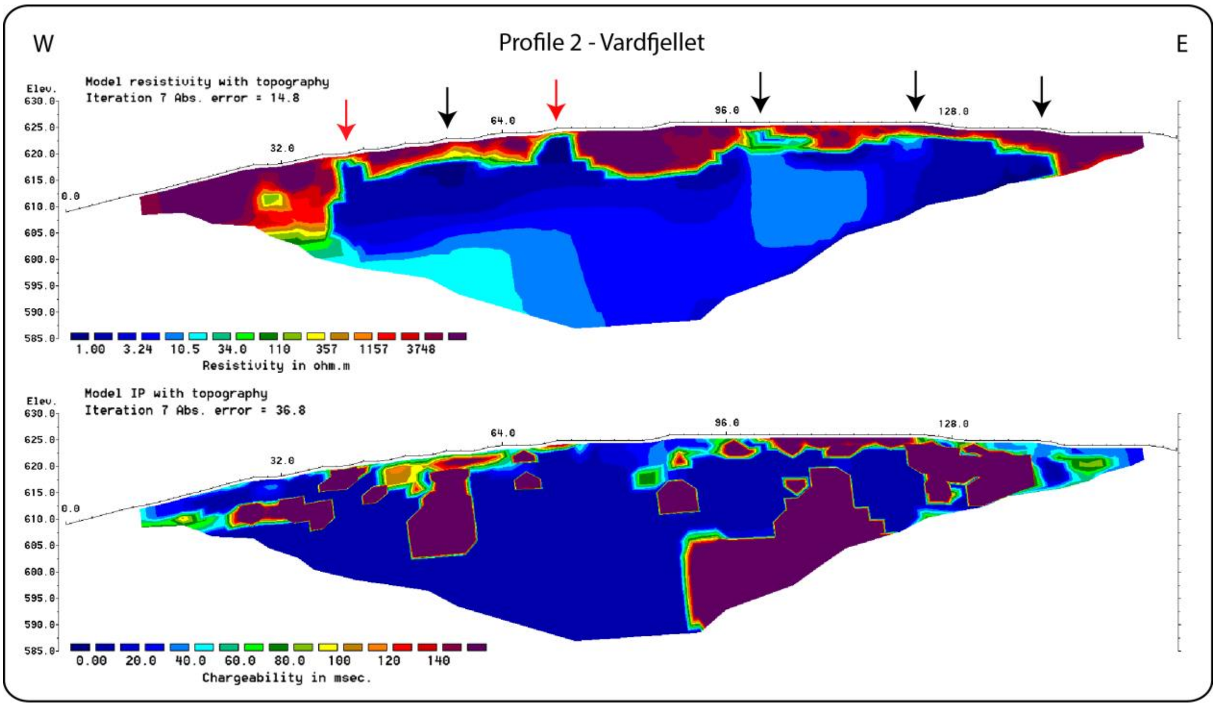

Figure 7.5: 2D resistivity (top) and IP (bottom) results along profile 1 at Vardfjellet. Known graphite outcrops are indicated with red arrows and possible (interpreted) graphite zones are shown with a black arrow.

Graphite could also be observed outcropping along this line at two locations (red arrows in Figure 7.5). Partly low resistivity (< 3 Ωm) can be observed at a length of ca. 100 m along the profile, indicating graphite. Along most of the line the interpreted graphite is covered by two to five metres thick high resistive material, probably bolder rich soil. High resistivity (> 5000 Ωm) in both ends of the profile represents the granitic host rock. However, modelling has shown that the resistivity pattern in the central part of the profile is typical for individual (sub-) vertical graphite zones (Rønning et al. 2014). Based on the near surface resistivity pattern, a number of conducting zones can be interpreted (black arrows in Figure 7.5) that are probably caused by the presence of graphite. Due to the nature of the responses, it is impossible to interpret the thickness of the individual zones except for the two outcropping zones that appear to be 3-5 m thick. As can be seen in Figure 7.1, this 2D ERT/IP profile covers less than half of the helicopter-borne EM anomaly, and the potential for valuable graphite is quite large in the area.

Very high IP anomalies confirm that graphite mineralisation is present along a large part of the profile, but it is not possible to say more about this due to the quality of the inverted IP data.

Based on the resistivity/IP measurements we can conclude that graphite zones are most likely present in a total horizontal thickness of ca. 100 m, but this line covers less than half of the helicopter-borne EM anomaly (see Figure 7.1). Unfortunately, this can be several smaller graphite zones. Thicknesses of two of these appear to be 3 -5 m. The potential for valuable graphite is quite large in the Vardfjellet area.

7.2 Geological results, Vardfjellet

Geological investigations were performed at Vardfjellet in August 2016. EM31 measurements and some additional geological work were performed in August 2018. In this chapter the results of all geological mapping, sampling, chemical analysis, petrography and modal analyses of graphite are presented.

7.2.1 Geological and structural mapping, Vardfjellet

The earlier geological mapping of Henderson & Kendrick (2003) is shown in Appendix 6 which covers both Hesten and Vardfjellet. Surface outcropping graphite schist consists of several apparently isolated lenses that are isoclinally folded and refolded. However, the mapping carried out on the Vardfjellet deposit by Henderson and Kendrick (2003) is also now considered as being outdated in the same way as the Hesten deposit as a large and unsystematic error was also detected in the original handheld GPS measurements for all observation localities. In addition, further mapping has been carried out in this study, underpinned by the helicopter EM data and the detailed ground based EM31 results. This allows for a new interpretation shown in Figure 7.6.

This succession is part of rock association that comprises amphibolitic- and granitic (granodioritic) gneisses, that are intruded by several generations of granitic and pegmatitic dykes. The Vardfjellet deposit consists of a number of very isolated and attenuated lenses of graphite schist that are isoclinally folded along NNW-SSE trending F_2 fold hinges (Henderson & Kendrick, 2003) and are refolded and dissected by a number of minor faults (Figure 7.6). The whole northern part of the deposit is folded around a NE-SW trending F_3 fold hinge (Henderson & Kendrick, 2003) and extensively sheared and faulted on N-S striking dislocations. The attenuation of the folds and the subsequent shearing and faulting has resulted in a very complex geometrical pattern in the deposit.

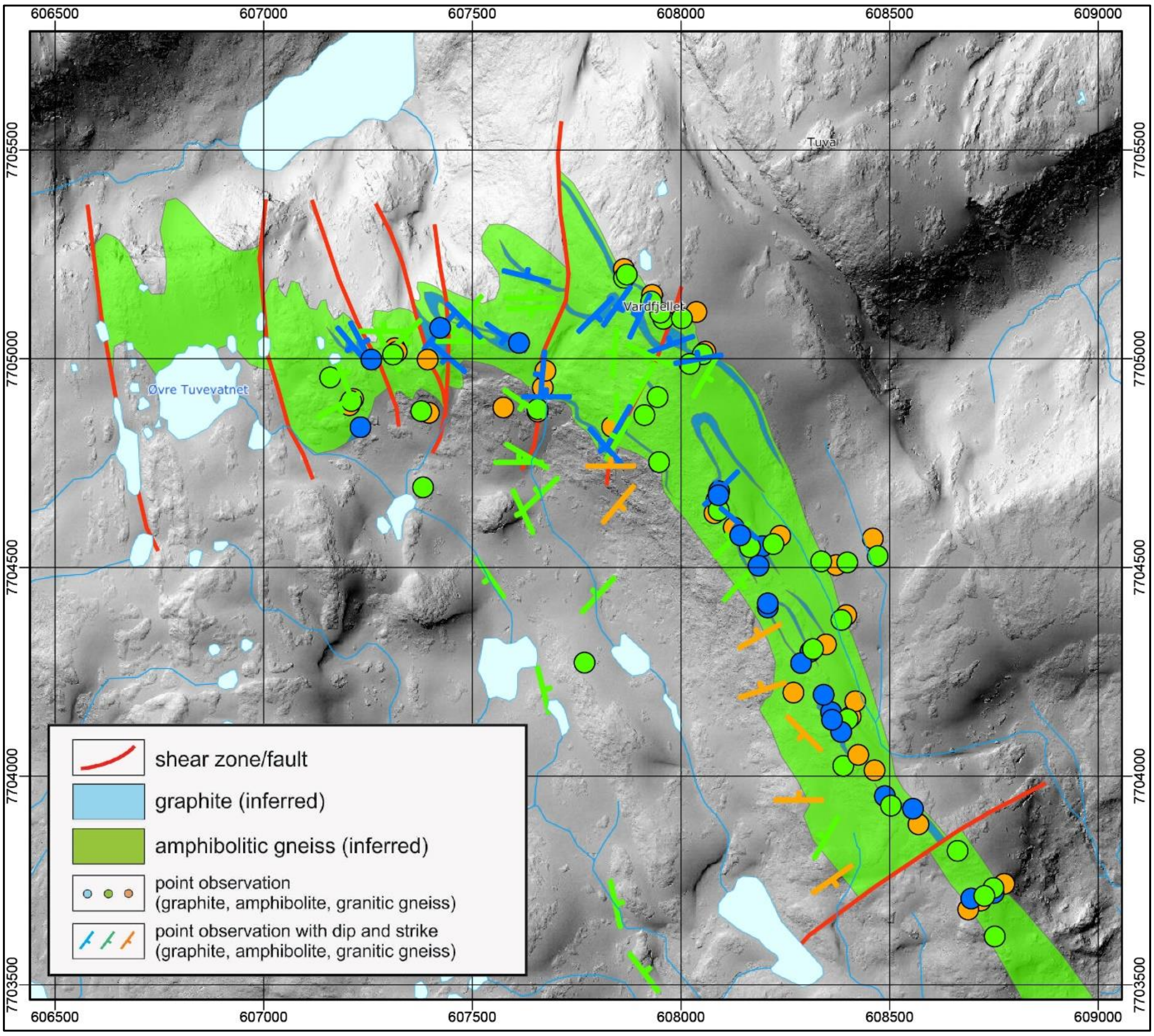

Figure 7.6: Geological map of the Vardfjellet deposit based on earlier mapping of Henderson & Kendrick (2003), new geological mapping in this study, helicopter-borne EM data and ground based EM31.

In Figure 7.7, the EM31 data are superimposed on the new geological map. EM31 anomalies coincide with the exposed graphite but seems to be more continuous than shown in the geological map. Most likely, graphite is hidden immediately underneath a thin soil/bedrock cover.

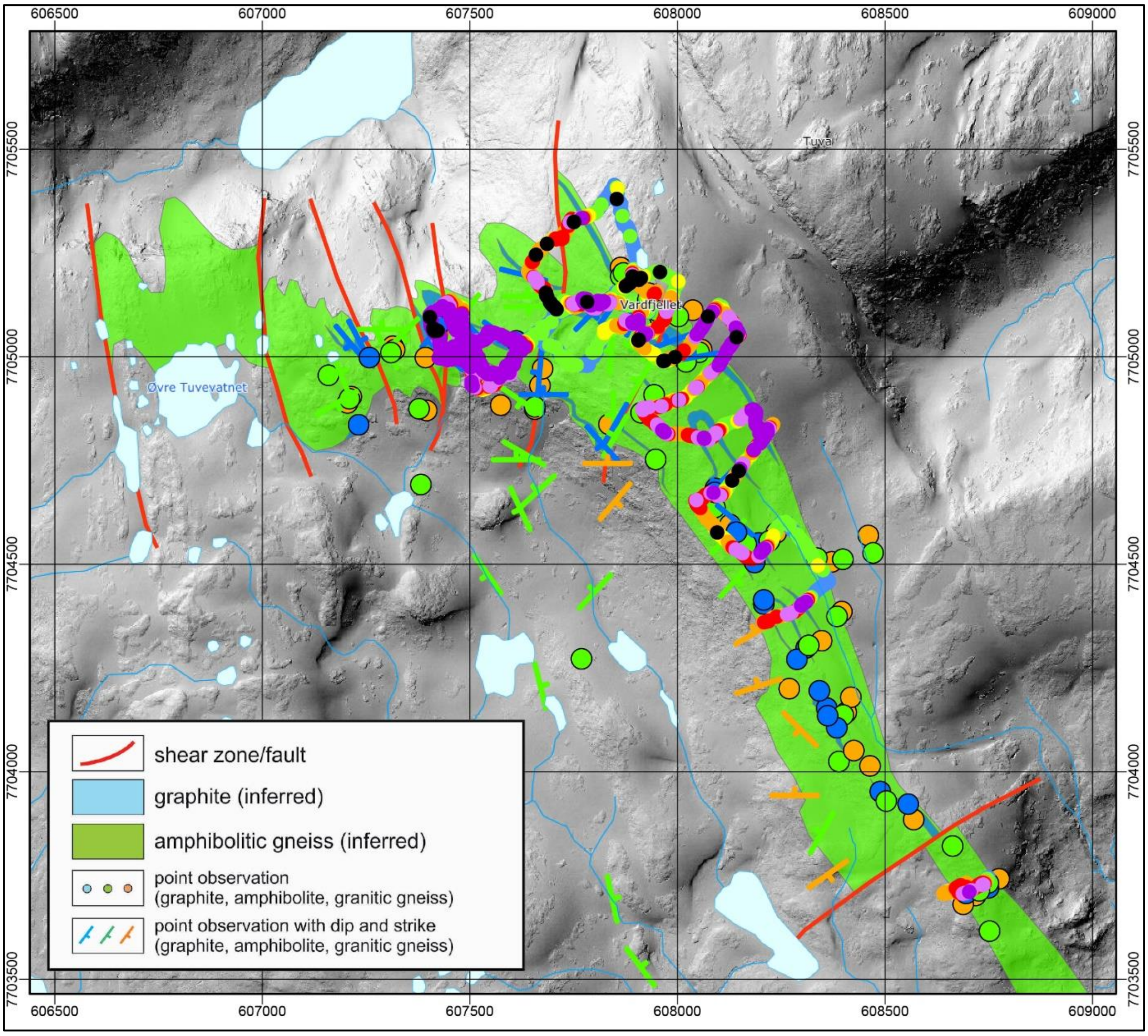

Figure 7.7: Geological map of the Vardfjellet deposit based on earlier mapping of Henderson & Kendrick (2003), new geological mapping in this study, helicopter-borne EM data and ground based EM31. Data from EM31 are superimposed (colour scale in Figure 7.3).

7.2.2 <u>Geological observations, sampling and analysis at Vardfjellet</u>

The Vardfjellet mountain is much better exposed than Hesten and graphite schist can be found outcropping over an area of 1.7 km in length and up to 350 metres in width. However, the helicopter-borne EM anomaly indicates graphite in a total length of ca. 2 km (Figure 7.3). From the outcrops it is evident that there are a number of apparently isolated minor outcrops that occur in the 1.7 km long mineralised zone.

The exposures of graphite schist occur mainly on the northern and western side of the mountain where scattered outcrops are found (see Figure 7.8). It is very rare to see contact relationships with the country rock except at some few localities. The graphite schist is part of a succession that comprises sulphide bearing quartz and feldspar rich rocks. At some localities, quartz is the dominating mineral and the rock would be classified as (sulphide and graphite bearing) quartzites.

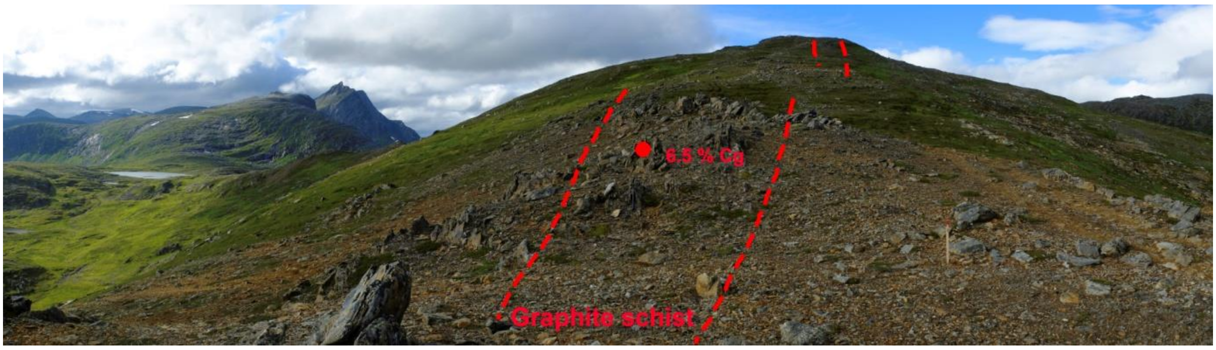

Figure 7.8: The southern side of Vardfjellet with some of the graphite lenses and sample point and analyses indicated. The total with of the graphite schist is ca. 7 m.

Figure 7.9: Rock face (about 150 m long) on the western side of Vardfjellet comprising a mixture of graphite schist and sulphide bearing quartz and feldspar rich rock. (sample points and analyses are indicated).

Samples were collected on the exposed outcrop, in order to get a distribution as even as possible. The samples were analysed at NGU lab and the sample locations are shown in Figure 7.3.

Table 7.4: Total Carbon (TC) data from 37 surface samples from the Vardfjellet area.

Locality	N	Average TC (%)	Max TC (%)	Min TC (%)	STdv TC (%)	Median (%)
Vardfjellet	37	9.2	40.3	1.1	7.5	6.9

Individual analyses of 37 samples collected at Vardfjellet are presented in Appendix 5. The average Cg content is 9.2 % with a maximum and minimum of 40.3 % and 1.1 %. The standard deviation is 7.5 %. This graphitic carbon content is comparable with content in deposits under development in Canada and Mozambique. The average Sulphur content in these samples is 0.3 % with a maximum and minimum value of 1.3 % and 0.02 %.

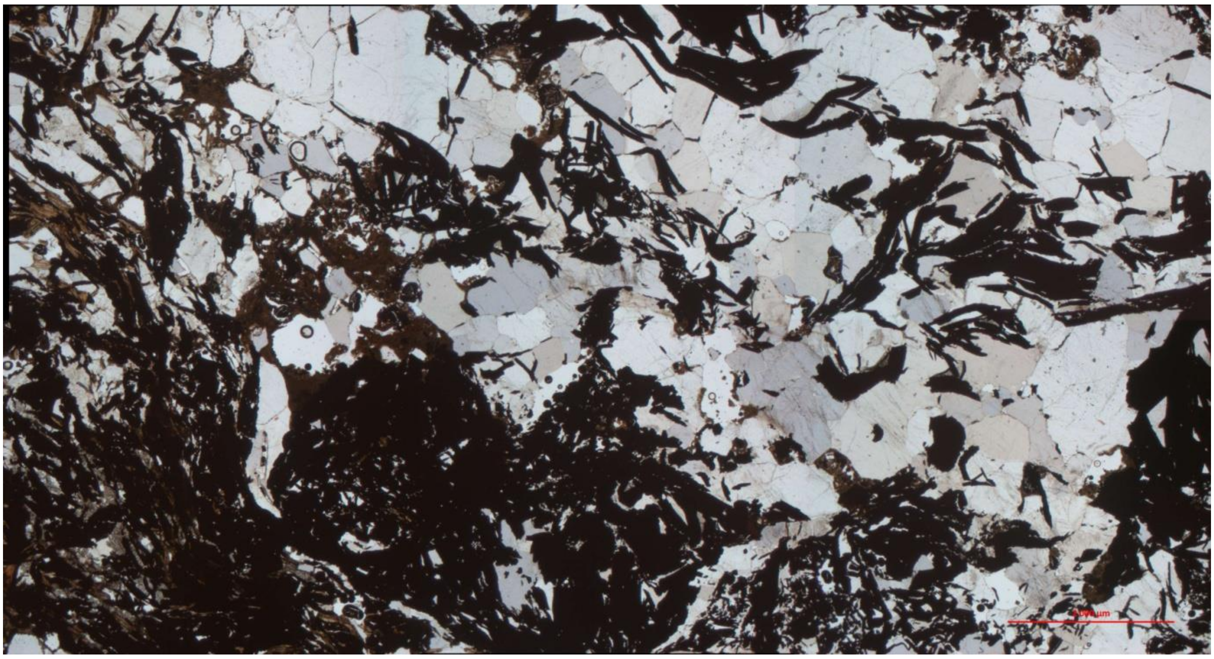

Figure 7.10: Example of thin section from Vardfjellet (Sample HG45-16), showing aggregates of flake graphite crystals as well as individual graphite crystals.

Table 7.5 shows the results of image processing (calculated diameter of graphite crystal) using the method described in section 4.2.2 for sample HG39-16).

Table 7.5: Example of analysed grain size of graphite minerals at Hesten (sample HG39-16).

Locality	Average size (µm)	Max size (µm)	STdv TC (µm)	Median (µm)
Vardfjellet	51	5780	173	28

The calculated diameter of graphite crystals in this thin section shows that the flake size is slightly bigger than at Hesten. Ore dressing experiments has shown that this grain size can result in a valuable product after processing (Gautneb et al. 2017). However, such measurements have only limited relevance from an industrial point of view, since it is the grain size after crushing, screening and flotation, that determines the quality of the final product.

8. GEOPHYSICAL AND GEOLOGICAL INVESTIGATIONS, BUKKEN AREA

Ground geophysical and geological follow-up investigations were performed in the Bukken area in May, June and August 2018. For convenience, the Bukken area is presented in three separate areas: Bukkemoen in the south, Bukken in the north (the high mountain area) and Litjkollen to the east. To make the report complete, results from a survey in 1988 are included.

8.1 Geophysical measurements

In 1988, NGU performed a geophysical survey in the Bukkemoen area (Lauritsen 1988). In 2018, EM31 measurements were performed, and in challenging terrain, these were replaced by SP measurements.

8.1.1 <u>Earlier geophysical investigations</u>

In 1988, NGU performed CP and SP measurements in combination with VLF measurements at Bukkemoen (Lauritsen 1988). VLF is an electromagnetic method where shallow conducting structures in the ground can be located by measuring the dip angle in the ellipse of polarisation (Reynolds 2011). In Figure 8.1, the results from the 1988 survey are summarised on top of apparent resistivity calculated from 7 kHz coaxial coil measurements.

Three grounding points for the CP measurements were tested. Two of them (E1 and E2, Figure 8.1) indicated small graphite structures and the results were not presented. Grounding point E3, indicates an at least 1000 m long graphite structure dipping to the WSW. The structure is open at both ends and appears to consist of several parallel mineralisation indicated by VLF and SP measurements. The greatest thickness is in the north-western part of the structure. Based on the helicopter-borne resistivity results, the total length of this mineralisation is interpreted to be ca. 1250 m.

From the conducting structure indicated with grounding E3, there is a potential difference of 700 mV to another conducting horizon towards the east. Most of the conducting structures indicated by SP and VLF in this area, have a constant electrical potential (see Lauritsen 1988), and appear to stay in electrical contact to each other.

The electrical conducting structures indicated by SP and VLF data from 1988, correlate well with the EM31 measurements along the road from Krokelvbukta in Lysevatnet in the south to Bukkemoen in the north (see Figure 8.1 and Figure 8.3). In the northern end of this EM31 profile, at coordinate ca. 612280 – 7703700, a new conductive structure occurs. This is probably also graphite.

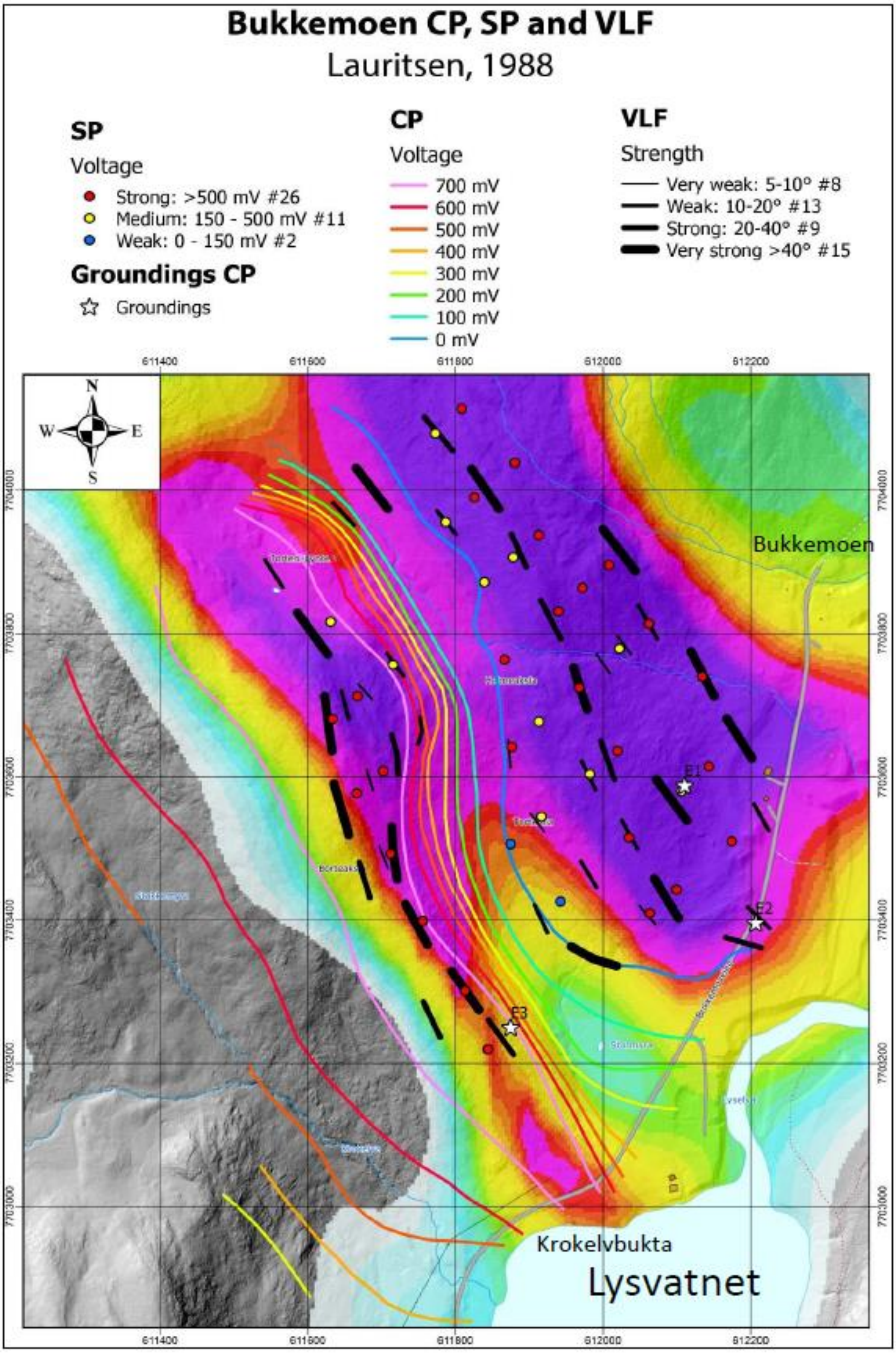

Figure 8.1: Synthesis of the 1988 CP, SP and VLF results at Bukkemoen superimposed on apparent resistivity (7 kHz, from Rodionov et al. 2014, see colour scale in Figure 8.3).

8.1.2 EM31 and SP measurements

EM31 and SP results from the entire **Bukken** area are presented in Figure 8.2. To give a better resolution, the same data are plotted in two areas, Bukkemoen/Bukken and Litjkollen in Figures 8.3 and 8.4.

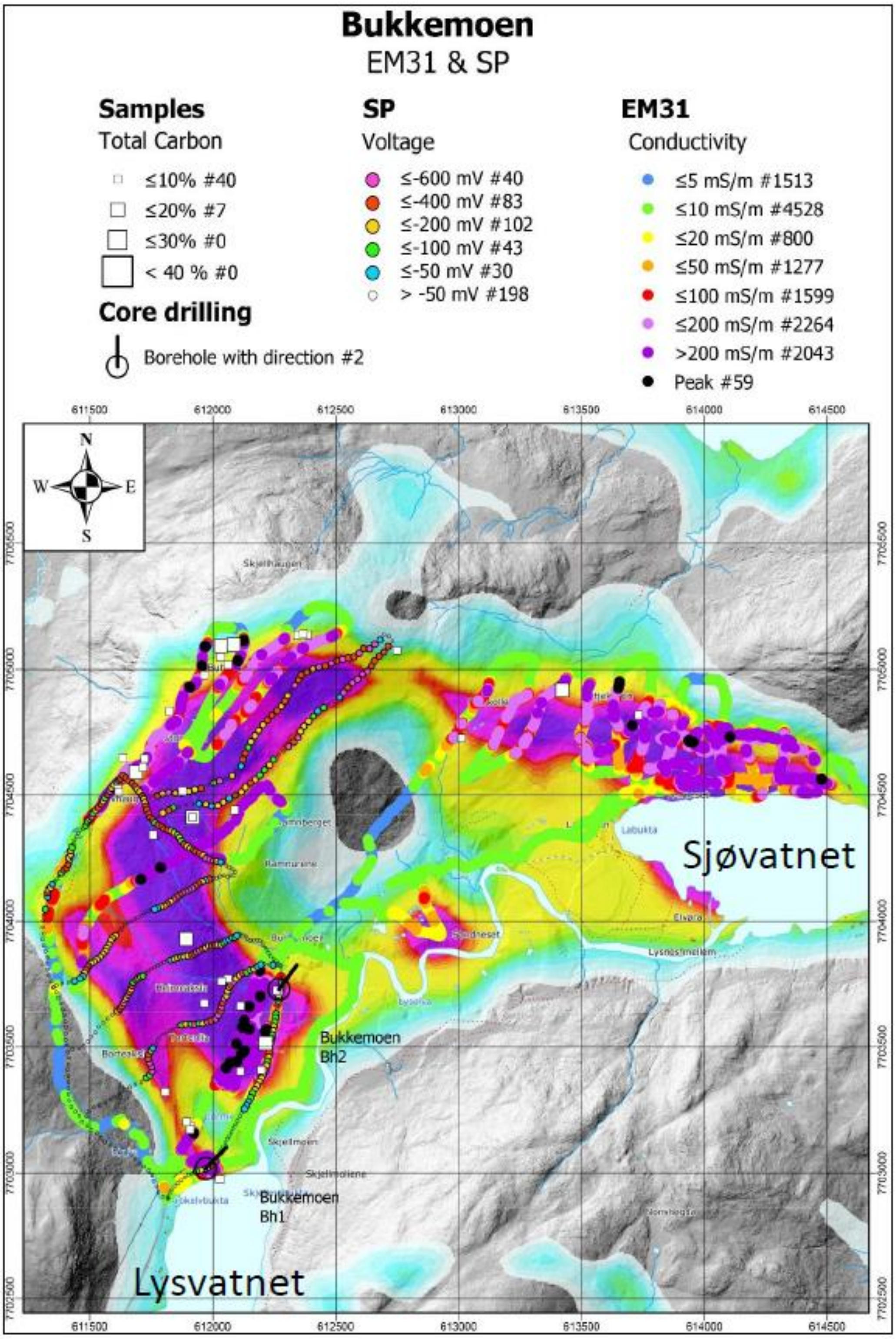

Figure 8.2: Overview map at the Bukken area. SP, EM31, Drill-hole locations and total carbon (TC) analyses on samples superimposed on apparent resistivity (7 kHz, Rodionov et al. 2014 see colour scale in Figure 8.3).

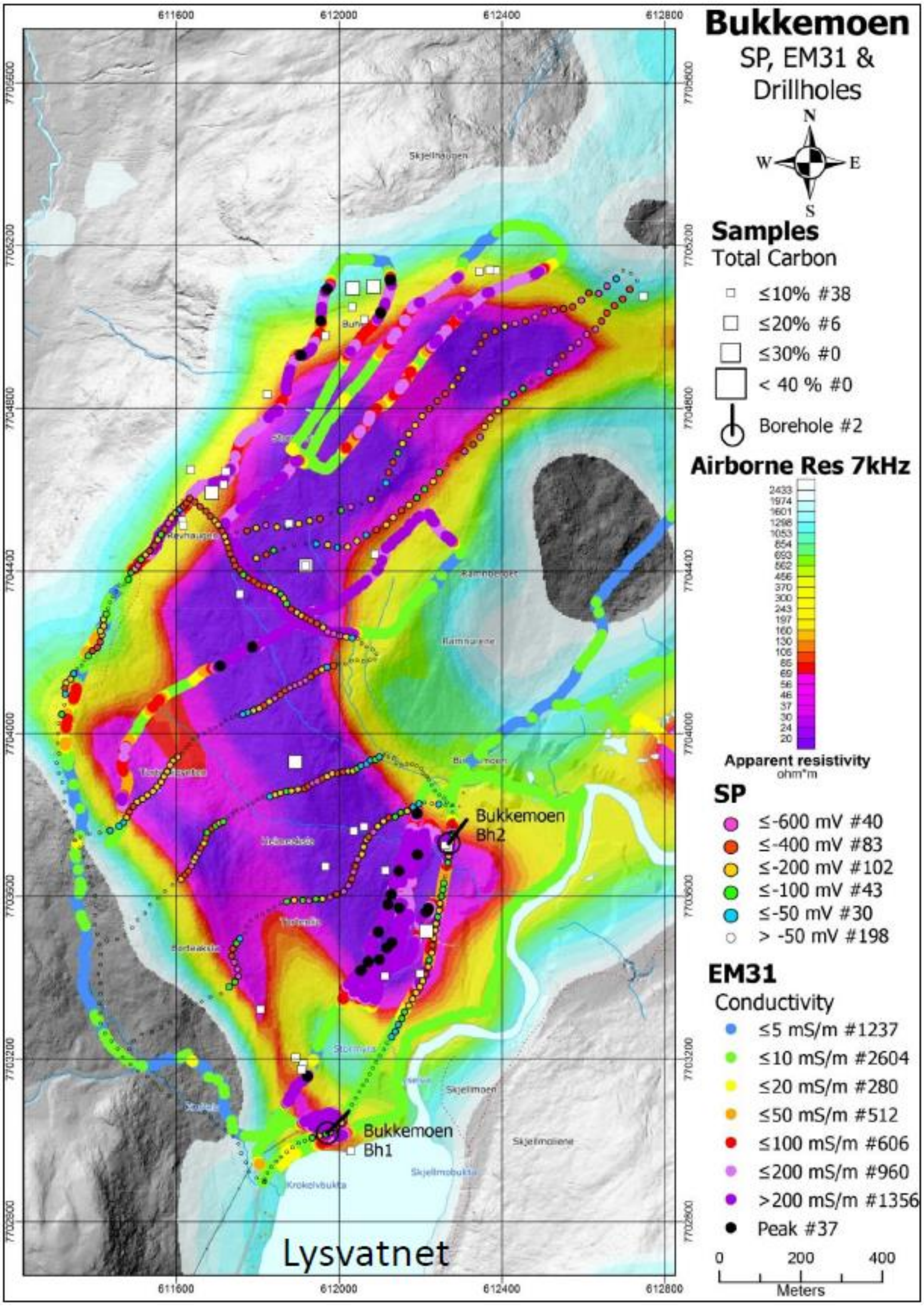

Figure 8.3: Bukkemoen (south) and Bukken (north) area. SP, EM31, Drill-hole locations and total carbon (TC) analyses on samples superimposed on apparent resistivity (7 kHz, from Rodionov et al. 2014). Location of graphite samples and their Total Carbon grade is given with white squares.

The Bukkemoen/Bukken area.

As described in section 8.1.1, the Bukkemoen graphite mineralisation can be separated into two different electrically conducting structures. The western structure was interpreted to be ca. 1250 m long and can consist of several individual structures. North and east of this, a new boomerang shaped structure appears, and this can be followed for a total length of ca. 2 km (see Figure 8.3). The total width of this structure is up to ca. 400 m.

In general, the ground EM31 and SP data (Figure 8.3) fits well with the helicopter-borne low resistivity data at Bukkemoen. However, some of the EM31 and SP anomalies are located just outside the anomalous area from helicopter-borne resistivity measurements. This occurs on both sides of the low resistivity area measured from helicopter. This can be an effect of the steep terrain and difficulties to drape the terrain during helicopter measurements but may also be due to the line spacing (200 m).

The SP and EM31 data shown in Figure 8.3, indicate four individual structures along the road between the two Drill-holes Dh1 and Dh2. Three of these are known from the 1988 investigations (see Figure 8.1). In the hillside west of the road and all the way to the northern end of anomalous resistivity area from helicopter-borne measurements, it appears that the three northernmost of these structures merge into one good conducting structure. This correspond with the CP-results from 1988 (Lauritsen 1988) also shown in Figure 8.1. Geological sampling (section 8.2.2) demonstrates that graphite mineralisation is scattered in the whole area (Figure 8.2).

From the EM31 data, it appears that continuous sections with high electric conductivity are found in several places. This can be an effect of the way the data are presented. Sampling distance can be less than one meter in some places, and when the data are plotted, higher electric conductivity is always plotted above lower conductivity. With the utilised point size, lower electric conductivity points may be hidden underneath the violet dots showing good electric conductivity.

To obtain a better resolution on the variations in electric conductivity, apparent conductivity along selected sections is presented as profile plots in Figure 8.4. Table 8.1 shows the coordinates and the width of the conducting structures, most likely graphite mineralisation. The estimated width of these possible graphite structures are areas where apparent conductivity is > 100 mS/m (apparent resistivity < 10 Ωm).

The selected lines presented in Figure 8.4 indicate numerous individual heterogenous graphite structures. The thickness of these varies from 10 m to several hundred metres (structures 1E and 2D). The thickest structures most likely consists of several graphite horizons and there can be country rock layers in between. The anomalous apparent conductivity varies from less than 100 mS/m to a maximum value of ca. 600 mS/m. This can be an effect of the quality of the graphite, but also of variations in the overburden thickness. Structure 2D (Figure 8.4) shows high electric conductivity (200 – 300 mS/m) in a total length of 700 m along profile Bukkemoen2. According to the helicopter-borne EM data (Figure 8.3) this is partly perpendicular to the main strike direction and partly along the strike. However, this is an indication of extensive amounts of graphite bearing rocks in the area.

The quality of the graphite will be discussed in section 8.2.2.

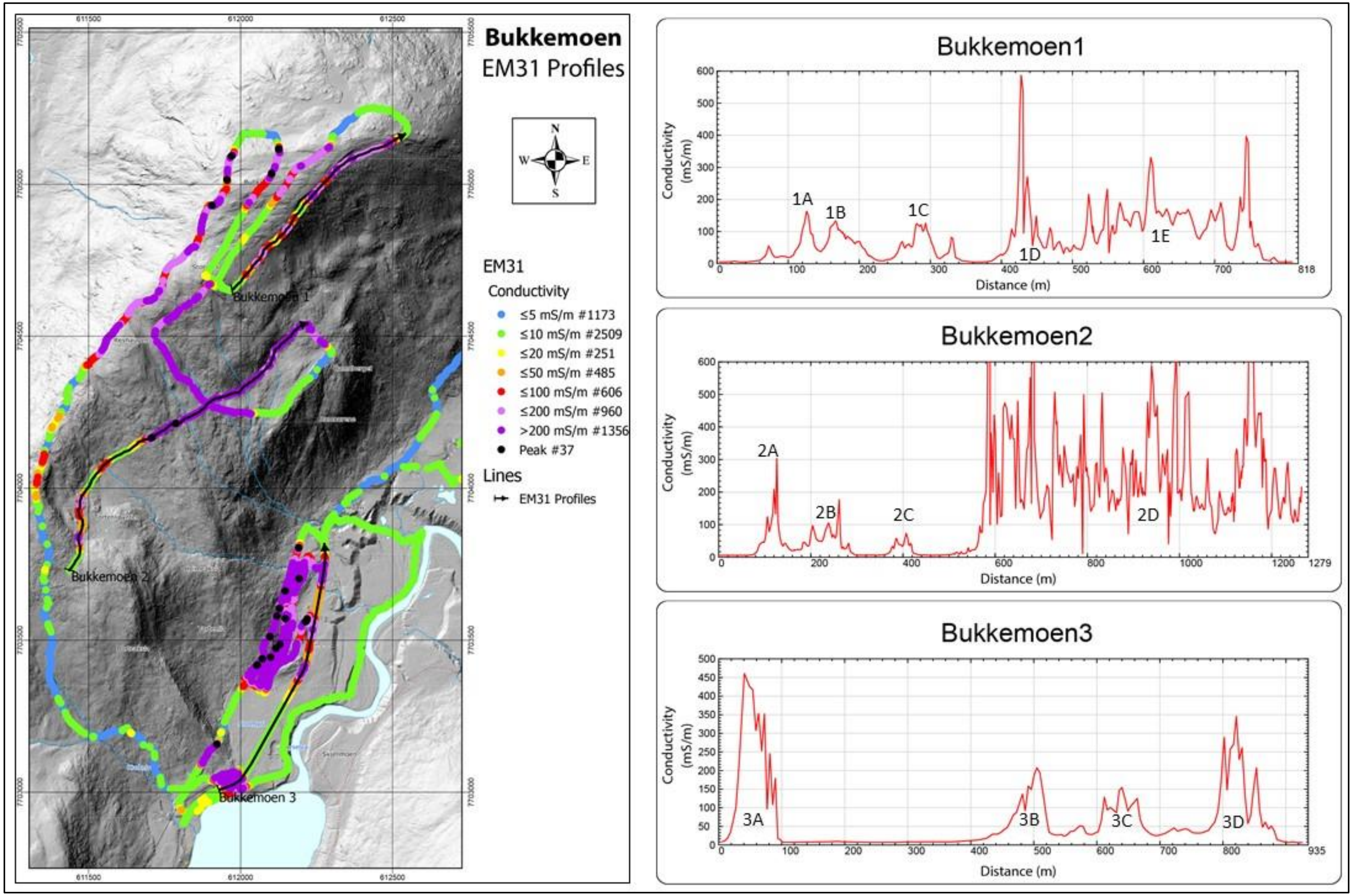

Figure 8.4: Results of EM31 measurements at Bukkemoen and Bukken. Selected profiles for detailed studies.

Table 8.1: Description of anomalous conductivity zones measured with EM31 at Bukkemoen/Bukken.

EM31 anomaly	Position at the line	Start UTM X	Start UTM Y	End UTM X	End UTM Y	Width (m)	Comment
1A	120 -132	612047	7704739	612055	7704748	12	
1B	160 - 170	612072	7704770	612076	7704784	10	
1C	278 - 298	612148	7704846	612160	7704861	20	
1D	414 - 456	612228	7704953	612497	7705139	42	3 lenses
1E	520 - 755	612228	7704953	612497	7705139	235	8 lenses or more
2A	102 - 134	611468	7703822	611468	7703845	32	
2B	200 - 264	611469	7703912	611475	7703966	64	
2C	380 - 420	611542	7704065	611564	7704087	40	< 100 mS/m
2D	580-1280	611689	7704161	612222	7704538	700	> 30 lenses
3A	30 - 90	611952	7703015	612008	7703050	60	> 3 lenses
3B	475 - 520	612196	7703383	612215	7703421	45	2 lenses
3C	610 - 665	612234	7703511	612245	7703566	55	3 lenses
3D	794 - 860	612267	7703688	612277	7703753	66	> 3 lenses

Litjkollen area.

EM31 data from the area called Litjkollen (east of Bukken), is presented in Figure 8.5. Conducting structures were mapped in a total length of ca. 1.6 km, and it appears that the structure is continuing underneath the water in Sjøvatnet. Due to the possible effect of the salt content of this water, all resistivity data from the helicopter-borne resistivity measurements were removed. The total thickness of the conducting structure is large, in parts more than 200 m, and graphite is found at four locations scattered throughout the area. The EM31 data indicate that the continuous low apparent resistivity from helicopter measurements can be delineated into several graphite structures.

At the south-western corner of Figure 8.5, a small circular resistivity anomaly appears. EM31 give almost no response in this area. This is probably caused by a thick layer of soil (< 10 m) which exceeds the penetration depth of the instrument. However, this anomaly seems to be too small to be of economic interest.

The presentation method of the EM31 data can overestimate the amount of good graphite bearing rocks. To see the details in the continuous EM31 readings, selected profiles are presented as plotted curves in Figure 8.6. Table 8.2 shows the coordinates and the width of the conducting structures, which are most likely graphite mineralisation. The estimated width of these possible graphite structures are areas where apparent conductivity is mostly > 100 mS/m (apparent resistivity < 10 Ωm).

The anomalous apparent conductivity varies from ca. 50 mS/m (resistivity to a maximum value of ca. 900 mS/m (see Figure 8.6). This can be an effect of the quality of the graphite, but also of variations in the overburden thickness.

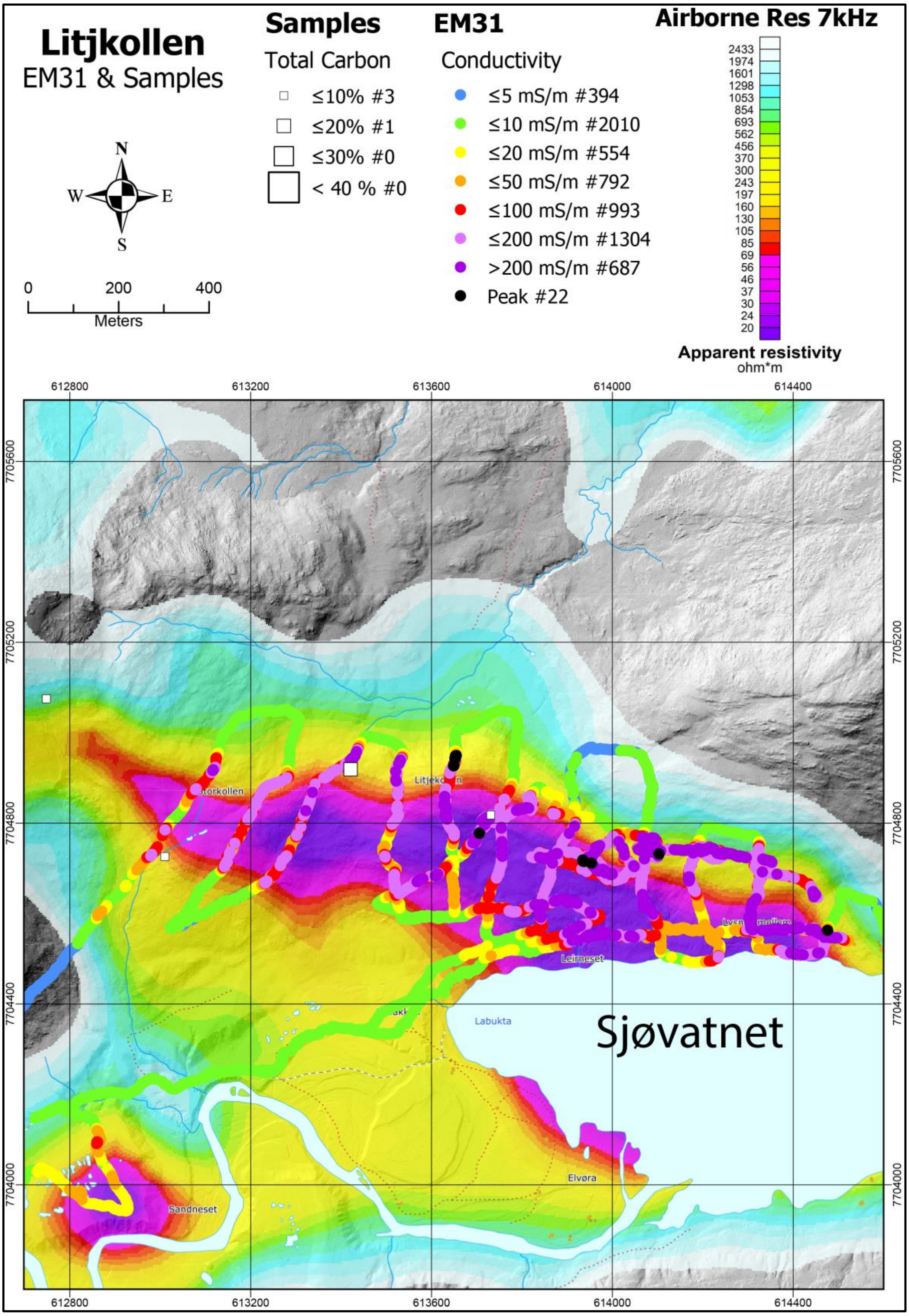

Figure 8.5: EM31 and total carbon (TC) analyses on samples from Litjkollen east of the Bukken mountain superimposed on apparent resistivity (7 kHz, from Rodionov et al. 2014). Location of graphite samples and their Total Carbon grade is given with white squares.

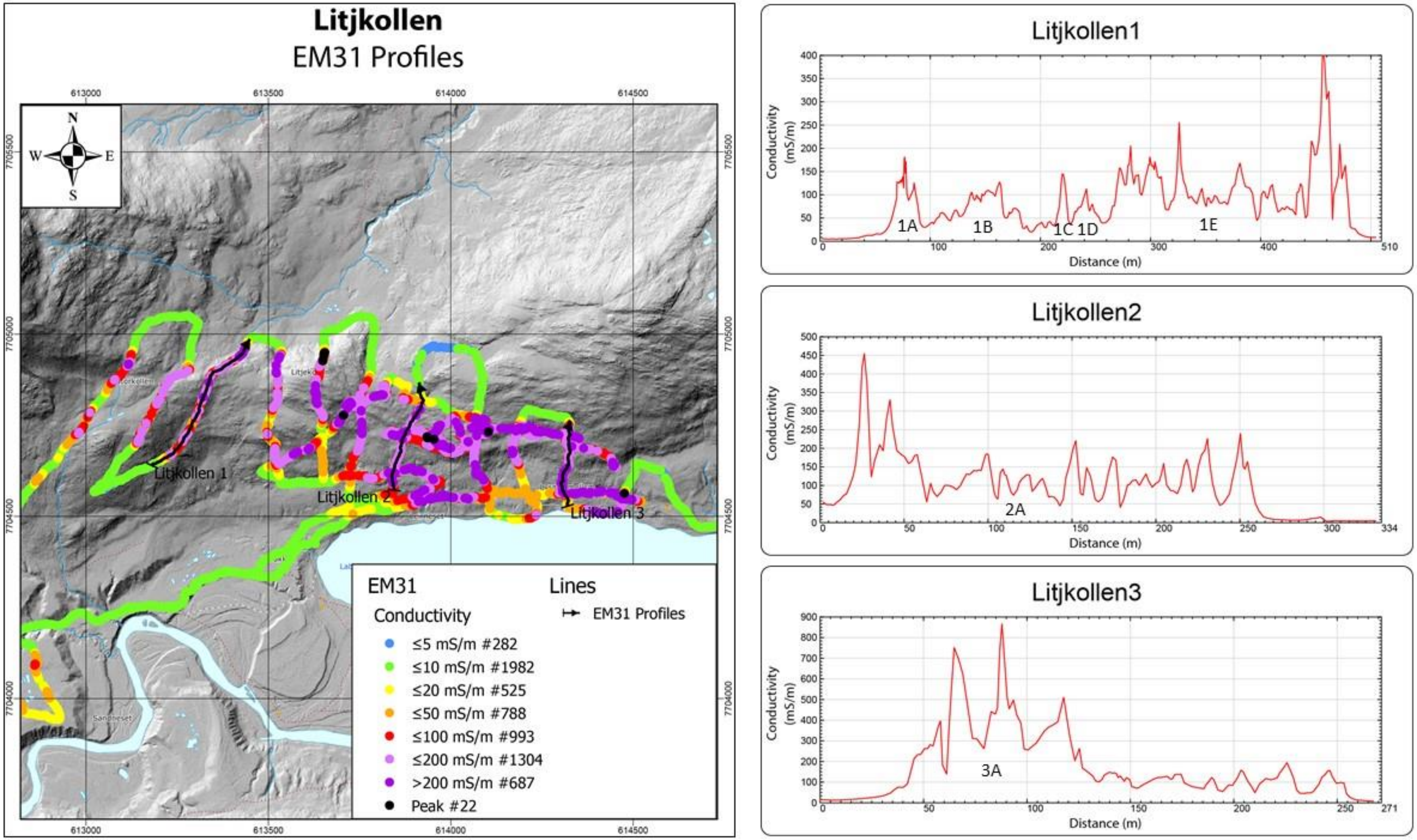

Figure 8.6: Results of EM31 measurements at Litjkollen. Selected profiles for detailed studies.

The selected lines presented in Figure 8.6 indicate numerous individual heterogenous graphite structures. The thickness of these varies from 2 m to more than 200 m. The thickest structures most likely consists of several graphite horizons and there can be country rock layers in between. The anomalous apparent conductivity varies from less than 100 mS/m to a maximum value of ca. 900 mS/m. This can be an effect of the quality of the graphite, but also of variations in the overburden thickness. The quality of the graphite will be discussed later in section 8.2.2.

Table 8.2: Description of anomalous conductivity zones measured with EM31 at Litjkollen.

EM31 anomaly	Position at the line	Start UTM X	Start UTM Y	End UTM X	End UTM Y	Estimated width (m)	Comment
1A	68 -88	613231	7704669	613236	7704672	20	Partly < 100 mS/m
1B	138 - 164	613266	7704706	613280	7704729	28	
1C	218 - 222	613302	7704773	613303	7704777	4	
1D	240 - 142	613310	7704790	613311	7704794	2	
1E	268 - 480	613317	7704817	613437	7704965	212	> 10 lenses Partly < 100 mS/m
2A	18 - 258	613842	7704587	613918	7704800	240	> 10 lenses Partly < 100 mS/m
3A	42 - 256	614323	7704748	614311	7704564	214	> 10 lenses Partly < 100 mS/m

8.2 Geological investigations

The geological investigations in the Bukken area consist of geological mapping, structural mapping, observations, sampling, analysis and thin section studies.

8.2.1 Geological and structural mapping, Bukken area

Appendix 7 shows the mapping of Henderson & Kendrick (2003) from the northern part of the Bukken deposit. This part of the deposit consists of an F_2 fold closure in the southern part where graphite appears to have been re-mobilised and forms a thick pod in the fold closure. In the northern part of this sub-deposit several thin bands of graphite schist are contained within an ENE-WSW envelope of amphibolitic schist. The F_2 isoclinal folds are extensively folded by NE-SW trending F_3 folds. This deposit is the most affected by F_3 folding in the whole of the Senja area.

Figure 8.7 shows the updated geological map with new interpretation from the present study based on further mapping underpinned by the helicopter EM data and the detailed ground based EM31 results. The new interpretation is remarkably similar to Henderson & Kendrick (2003) with the addition of a much more extensive graphite presence in the southern F_2 fold closure and an extension of the thin bands in the northern deposit eastwards towards Litjkollen (see Figures 8.9 and 8.11).

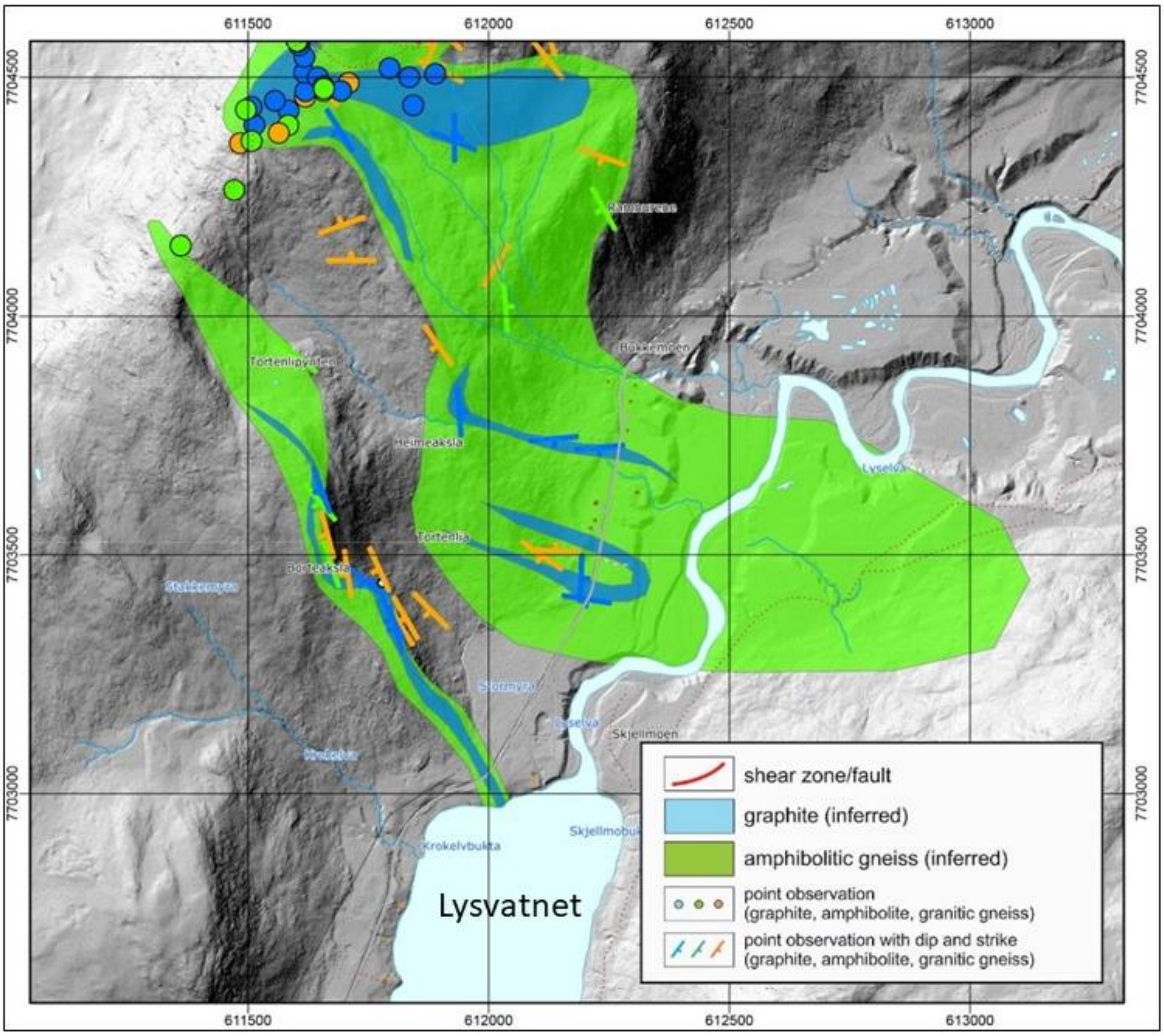

Figure 8.7: Geological map of the southern part of the Bukkmoen deposit (partly Bukken) based on earlier mapping of Henderson & Kendrick (2003), new geological mapping in this study, helicopter-borne EM data and ground based EM31.

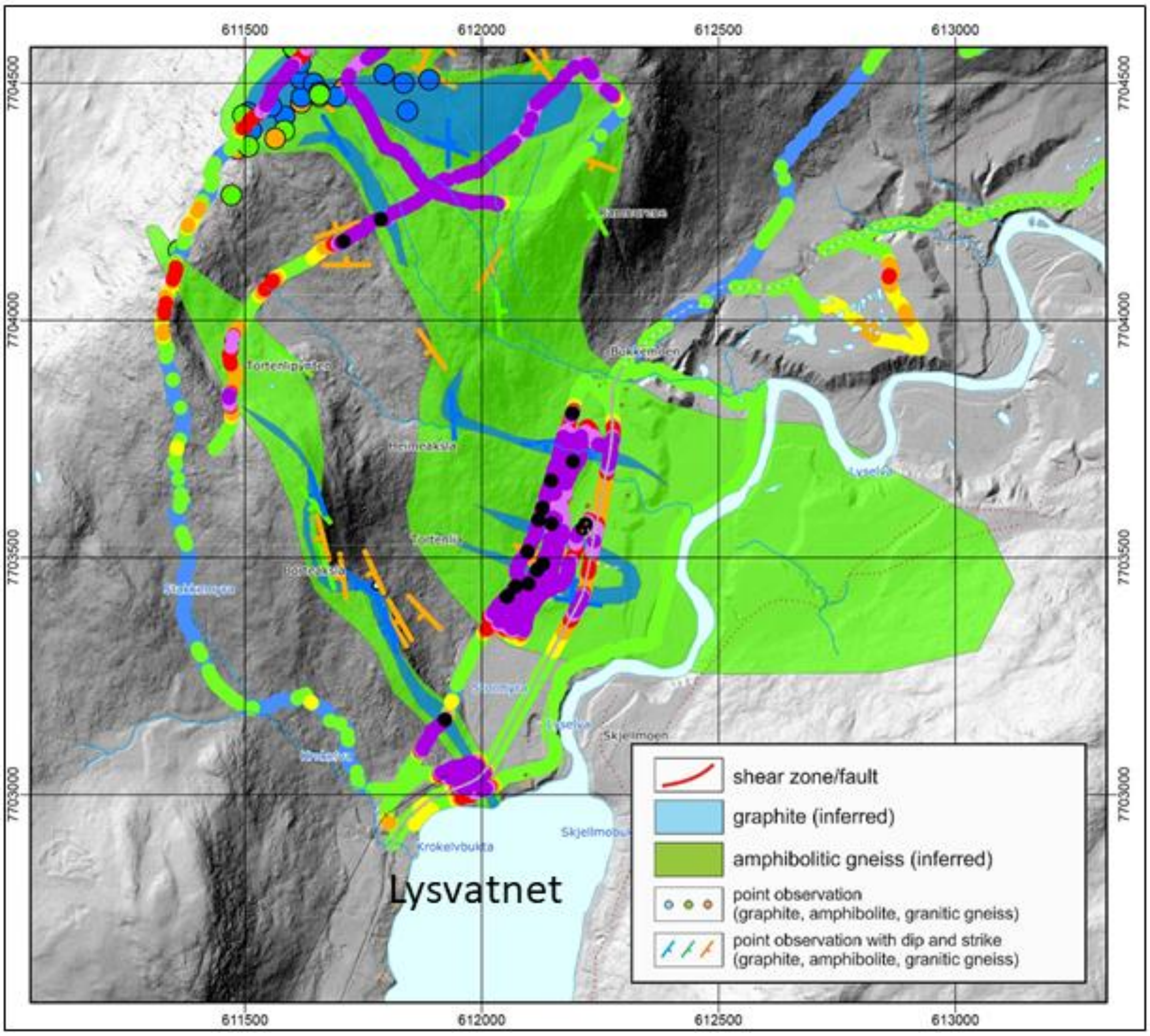

Figure 8.8: Geological map of the southern part of the Bukken deposit based on earlier mapping of Henderson & Kendrick (2003), new geological mapping in this study, helicopter-borne EM data and ground based EM31. Data from EM31 are superimposed (colour scale in Figure 8.2).

If we compare the geologically mapped graphite structures with apparent conductivity from EM31 measurements (Figure 8.8), it appears that there is much more graphite in the area than documented from surface mapping. Along the road from Krokelvbukta in lake Lysvatnet to Bukkemoen further to the north, the same four structures are observed but they are substantially thicker in the EM31 data. Approximately 100 m west of the road graphite is indicated in a total thickness of ca. 500 m. As discussed in section 8.1.2, also further to the north, in the Bukken area, graphite is appearing in extensive amounts along the EM31 lines. The discrepancy may be an effect of thin soil or bedrock cover and therefore limited number of exposures.

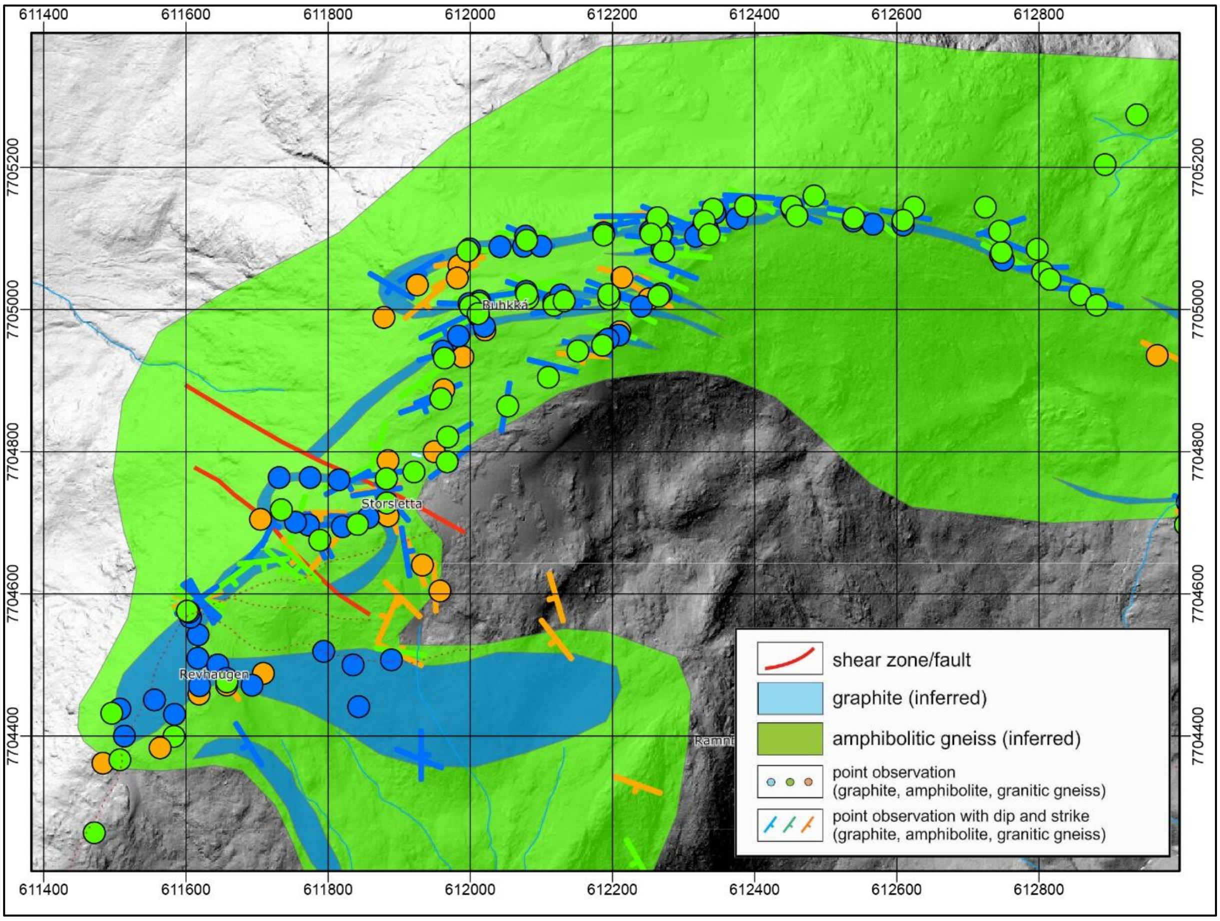

Figure 8.9: Geological map of the northern part of the Bukken deposit based on earlier mapping of Henderson & Kendrick (2003), new geological mapping in this study, helicopter-borne EM data and ground based EM31.

Figure 8.9 shows the result of the geological mapping in the Bukken area. Graphite structures are folded and faulted. The folding history is described earlier in this section. Also, in the Bukken area, there seems to be more graphite indicated by the EM31 measurements than is documented in the surface mapping (Figure 8.10).

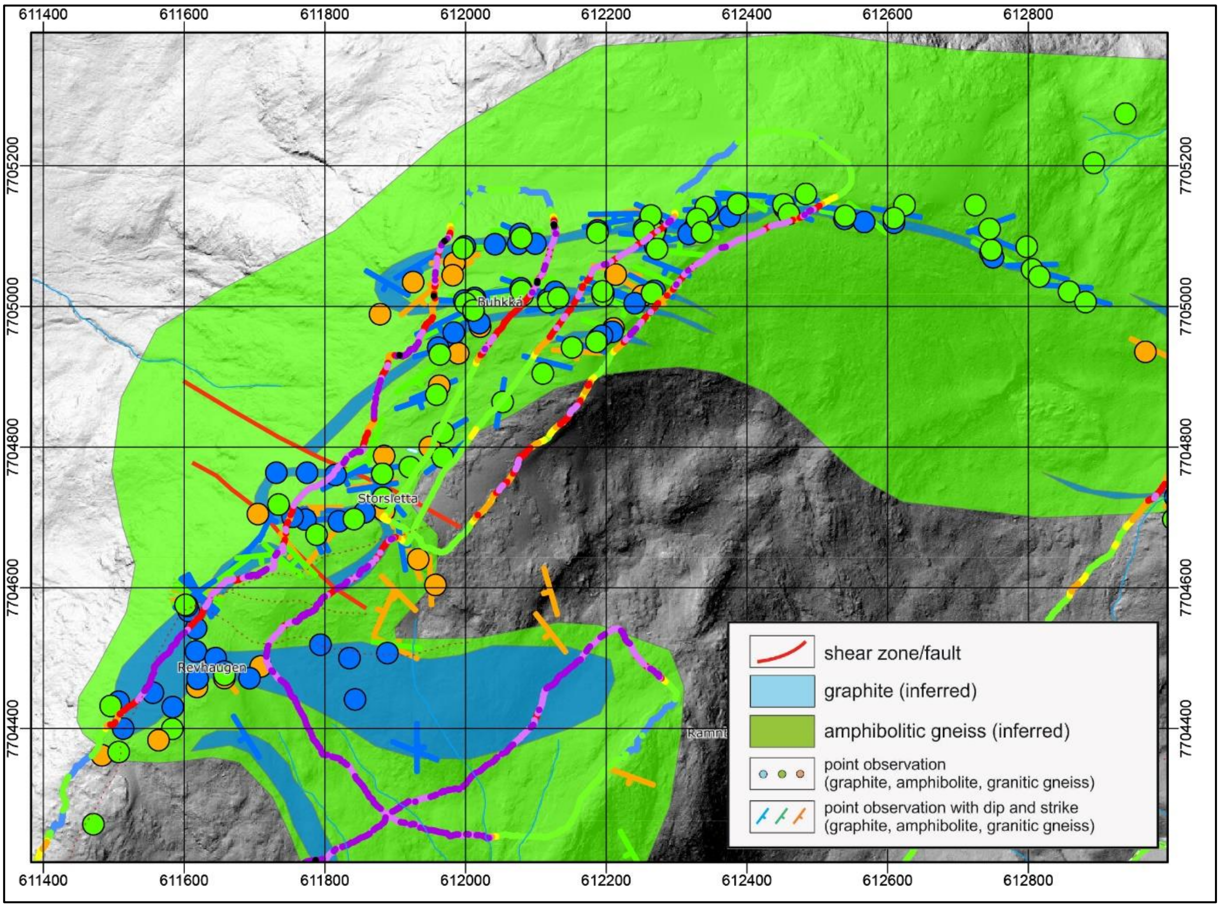

Figure 8.10: Geological map of the northern part of the Bukken deposit based on earlier mapping of Henderson & Kendrick (2003), new geological mapping in this study, helicopter-borne EM data and ground based EM31. Data from EM31 are superimposed (colour scale in Figure 8.2).

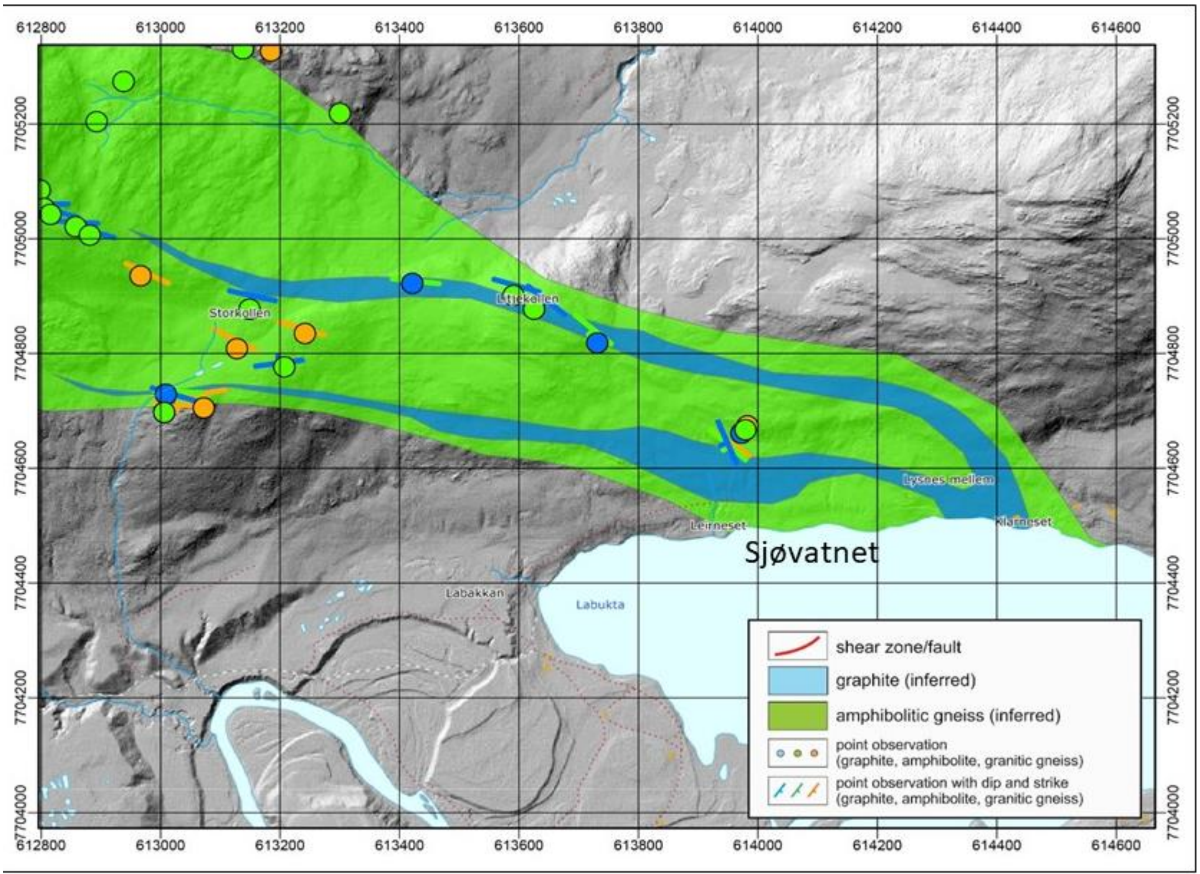

Figure 8.11: Geological map of the Litjkollen deposit based on earlier mapping of Henderson & Kendrick (2003), new geological mapping in this study, helicopter-borne EM data and ground based EM31.

According to Henderson & Kendrick (2003) the graphite layers in the eastern part of the Bukken deposit were thought to attenuate and die out eastwards. However, a geophysical anomaly was found in the area of Litjkollen (Figure 8.5) from the helicopter geophysics (Rodinov et al. 2014). This anomaly has a clear WNW-ESE trend extending for several km eastwards to the coastline at Sjøvatnet as a direct continuation of the Bukken deposit. The nature of this anomaly was unknown before the field campaign in 2018 where both detailed ground based EM31 data were collected and geological observations were made simultaneously. Although the bedrock in the area is hardly exposed, several interesting outcrops were found with the regional strike trending parallel to the EM anomaly shown in Figure 8.5 where outcrops of graphite-bearing rocks were discovered.

Figure 8.11 shows the integrated geological map based on the geological observations and the EM data. An eastward closing isoclinally folded (F_2 from Henderson & Kendrick, 2003) thin graphite layer is interpreted. The thickness of this layer is difficult to determine as the outcrops were very poor, but the thickness may be up to several metres. The fold closure of the F_2 fold has been further folded on a NE-SW F_3 fold hinge.

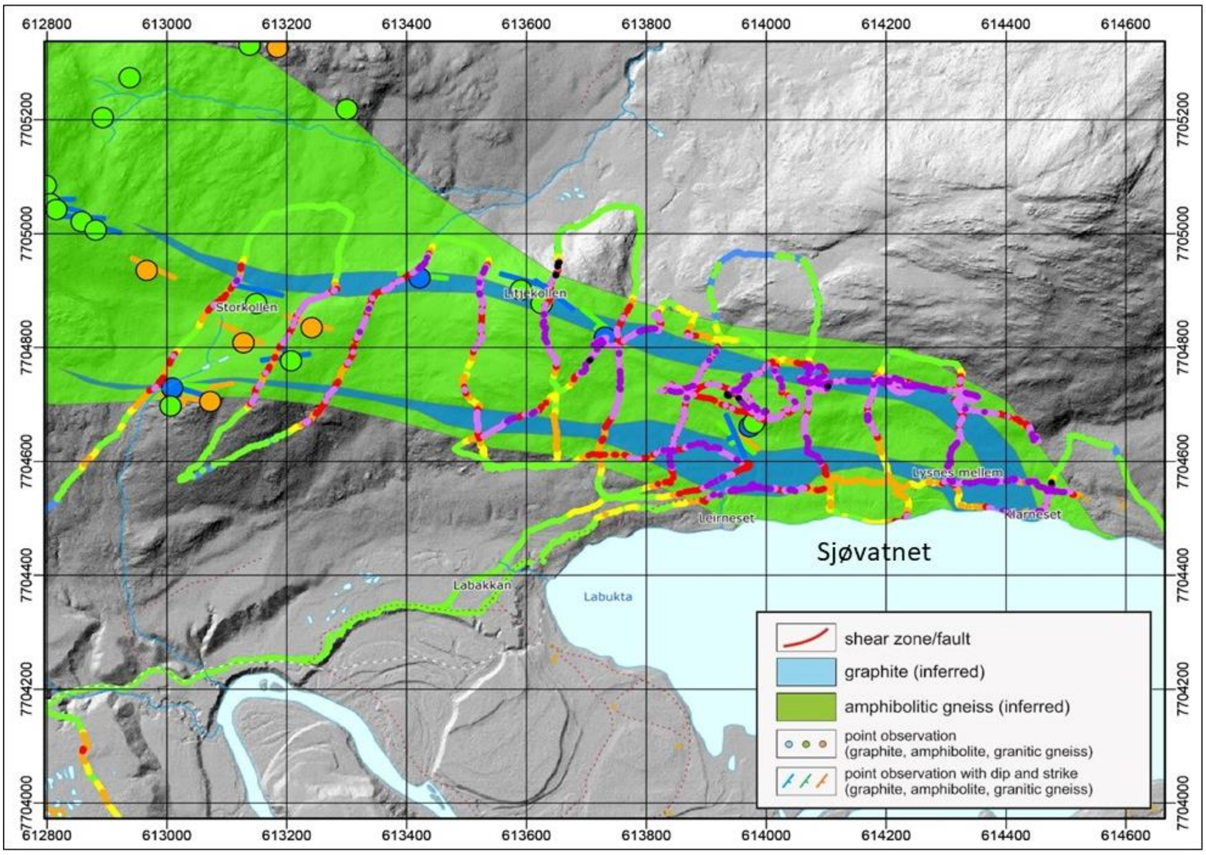

Figure 8.12: Geological map of the Litjkollen deposit based on earlier mapping of Henderson & Kendrick (2003), new geological mapping in this study, helicopter-borne EM data and ground based EM31. Data from EM31 are superimposed (colour scale in Figure 8.2).

In Figure 8.12, the upgraded geological map from Litjkollen has the EM31 data superimposed. In general, the EM31 data correlates well with the interpreted graphite structures in the area. However, the EM31 data show high electric conductivity in a much wider area than indicated by the geological mapping. Detailed analysis along four selected profiles (Figure 8.6) shows that this is not an artificial effect of the way the EM31 data are presented. Therefore, we conclude that the area contains more graphite than is documented in the surface mapping. Based on EM31 data only we are not able to determine the total carbon content and sampling and analysis are necessary.

8.2.2 Geological observations, sampling and analysis at Bukken area

The location of the Bukkemoen area is shown in Figures 1.2, 5.1 and 8.2. It comprises the largest continuous geophysical helicopter-borne anomaly known to be associated with graphite in Norway and in Fennoscandia. The geophysical anomaly is divided into three parts: Bukkemoen to the south, Bukken to the north and Litjkollen to the east. The eastern part extends into the sea inlet of Sjøvatnet and may continue underneath the salt/saline brackish water. This chapter gives a brief overview of the outcrops of graphite schist in this area.

The area is to a large degree covered by soil, but scattered outcrops can be found. On top of the mount Bukken, graphite schist is continuously exposed over several hundreds of metres.

Bukkemoen area

Apart from scattered outcrops, the Bukkemoen areas is almost entirely soil covered. The best exposures are found along several small road sections and along some scattered outcrops on the northern side of Lysvatnet. Two short drill-holes were placed in this area and their description is given in Section 8.3. Where exposed, the graphite schist can be observed as a medium grade graphite.

Figure 8.13: Weathered graphite schist from Bukkemoen (Road section along Lysvatnet).

Bukken area

Along the western uppermost slopes and the flat, upper ridge area, graphite schist is exposed in several, more than 100 metres long outcrops (Figures 8.14 and 8.15). The graphite schist is always strongly weathered and clearly occurs in several isolated lenses. On the flat uppermost area of mount Bukken, at least three sub-parallel lenses of graphite are visible. The detailed EM31 data from the area (Figure 8.3 and 8.4) shows that along selected profiles in this area several different bands of graphite schist occur.


Figure 8.14: The floats of weathered graphite schist on the western slope of mount Bukken.

Litjkollen area

The easternmost extension of the airborne geophysical anomaly is almost completely soil covered. Only four outcrops with graphite schist have been found in this area (Figure 8.5). However, the Litjkollen area was extensively traversed with EM31 and several graphite bearing structures are apparent (see section 8.1.2)

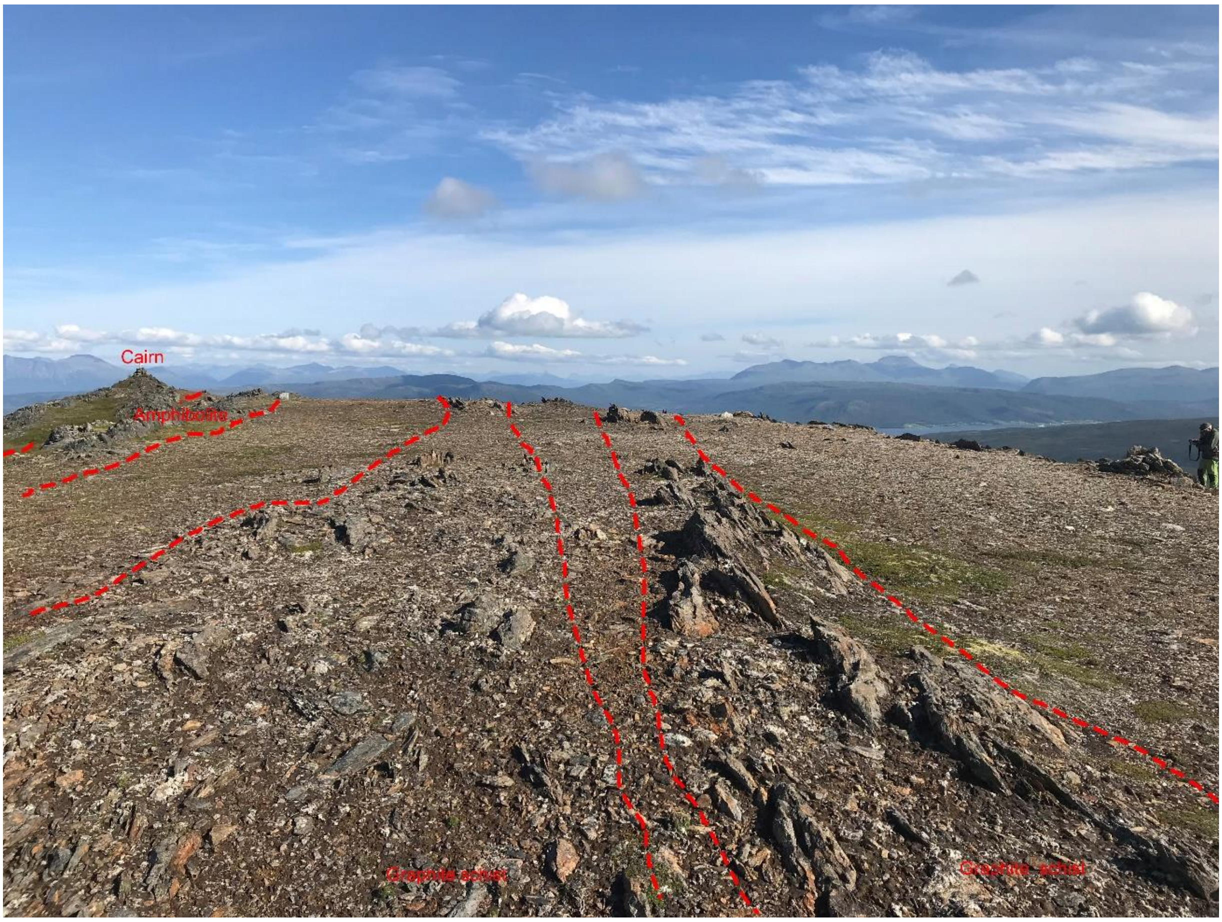

Figure 8.15: The top area of mount Bukken with some selected lenses of graphite schist and country rock indicated.

Variation in TC in the Bukken area.

Sampled locations of graphite in the Bukken area are shown in Figures 8.2, 8.3, 8.5 and Figure 8.16). Individual coordinates and analysed values of Total Carbon (TC) and Total Sulphur (TS) are listed in Appendix 5. Average TC for the three areas is listed in Table 8.3. Here, country rock (samples of country rock typically have TC< 0,5%) are removed from the data.

Table 8.3: Total carbon (TC) in the samples set from the three sub localities in the Bukken area.

Sub locality	N	Average (%)	Max (%)	Min (%)	StdDev (%)	Median (%)
Bukkemoen	20	5.2	14.1	2.2	3.3	4.0
Bukken	27	6.5	19.7	0.6	4.5	5.0
Litjkollen	4	5.3	16.3	0.6	7.4	2.1

An average carbon content of 6.2 % TC is significantly lower than production grades at the Skaland Graphite Mine but are normal values when the geographically large area is taken into account. Maximum values from ca. 14 % to ca. 20 % show that there are interesting TC concentrations in the area.

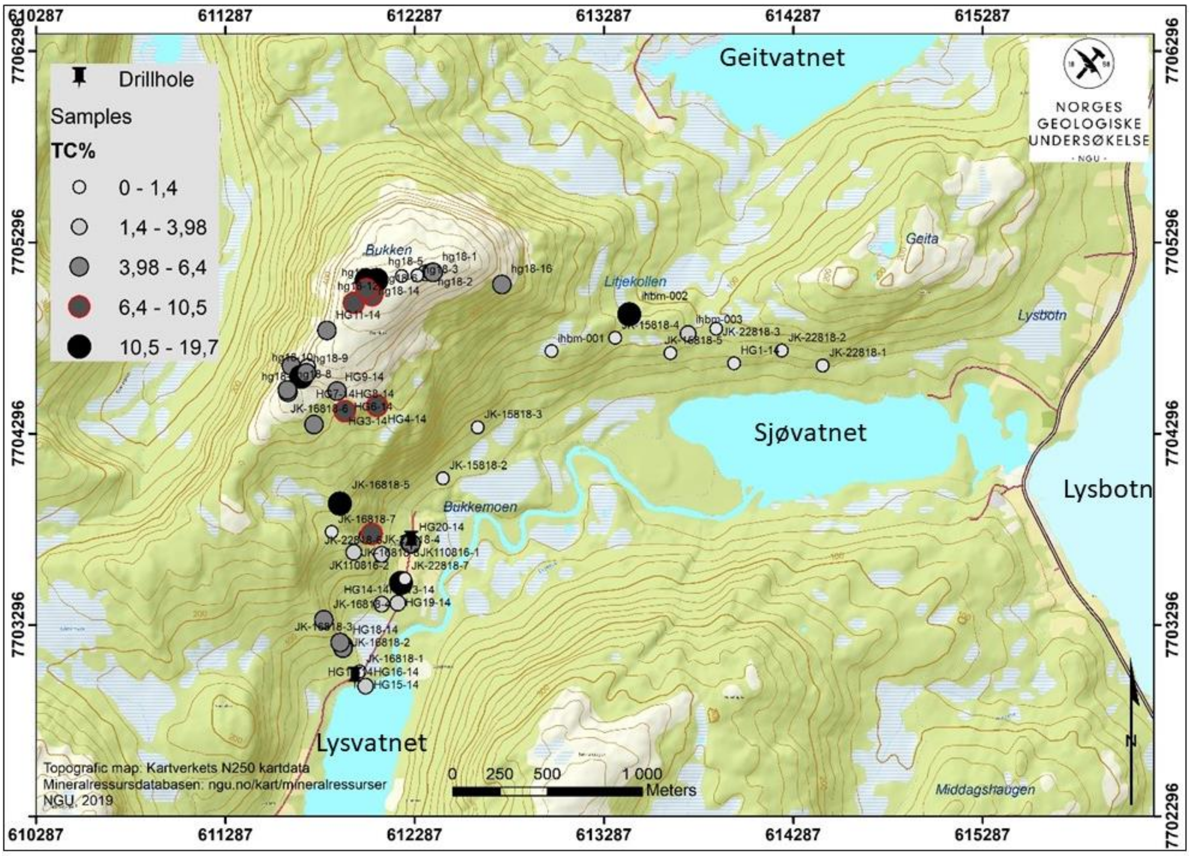

Figure 8.16: Distribution of graphite samples and analysed Total Carbon (%) at Bukken.

8.2.3 Petrography of graphite ore from the Bukken area.

In thin section, the graphite schist from the Bukken area is a quite inhomogeneous rock with a rather simple mineralogy that has undergone a high grade of granulite facies metamorphism. This is typical for carbon rich rocks of sedimentary origin. A typical graphite schist from this area is a medium grained rock where the dominant silicate minerals are quartz and feldspar and, with less amount of biotite, muscovite and clino zoisite. Accessory minerals are titanite and zircon (Figures 8.17 and 8.18).

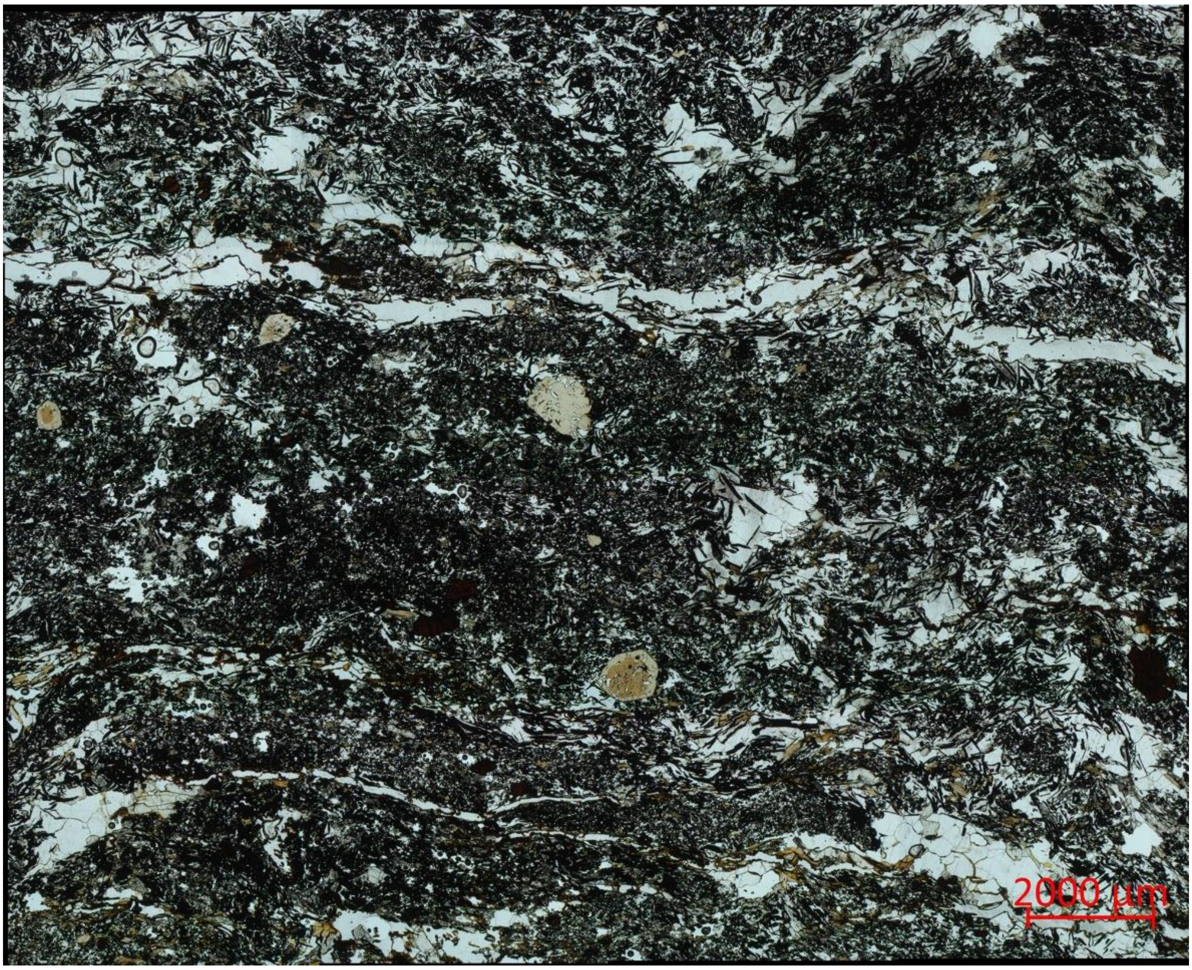

Figure 8.17: Micro-photo of graphite schist from the Bukken area (sample HG18-9). This sample contain 25.3 vol % of graphite.

In reflected light the main sulphide mineral is pyrrhotite (Figure 8.19).

Table 8.4 shows the results of image processing (calculated diameter of graphite crystal) using the method described in section 4.2.2 for sample HG18-9).

Table 8.4: Example of analysed grain size of graphite minerals at Bukken (sample HG18-9).

Locality	Average size (µm)	Max size (µm)	STdv (µm)	Median (µm)
Bukken	25	1807	36	13

The calculated diameter of graphite crystals in this thin section shows that the flake size is slightly less than at Hesten/Vardfjellet but within the size range *in situ* that can give coarse grained flake size of economic value in the finished product. However, such measurements have only limit relevance from an industrial point of view, since it is the grain size after crushing, screening and flotation, that determines the quality of the finished product.

The graphite crystals occur partly as individual plate-like crystals (flake graphite) often enriched in vein-like areas in the rock and as structureless masses that represent aggregates of many individual crystals. It is also common to find graphite crystals as inclusions in the silicate minerals.

With reference to earlier tests, the mineralogy of graphite schist from Bukkemoen and adjacent localities, should have a simple mineralogy with respect to ore beneficiation and production of a graphite concentrate (Gautneb et al. 2017).

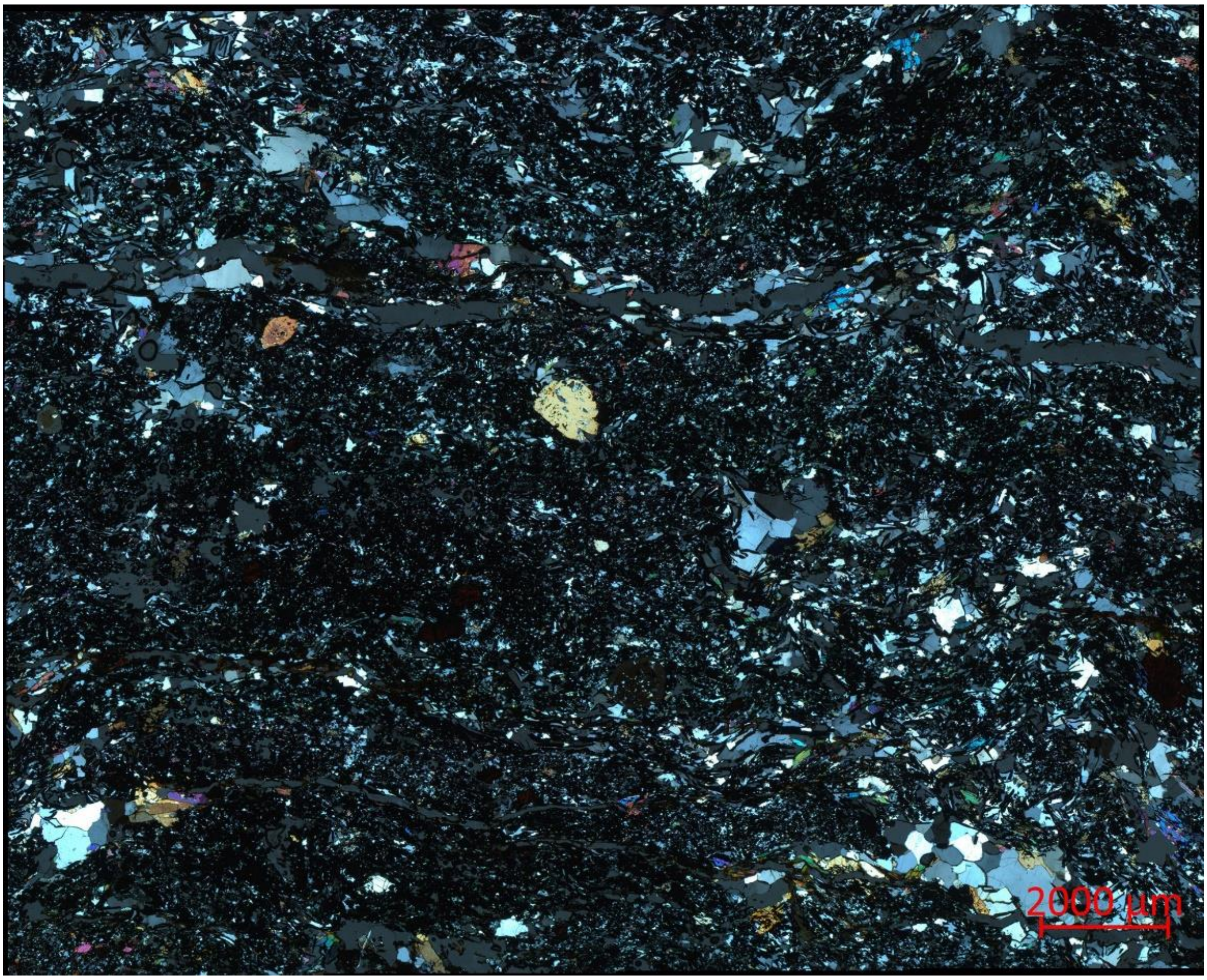

Figure 8.18: Micro-photo in cross polarized light, same area as Figure 8.17 above.

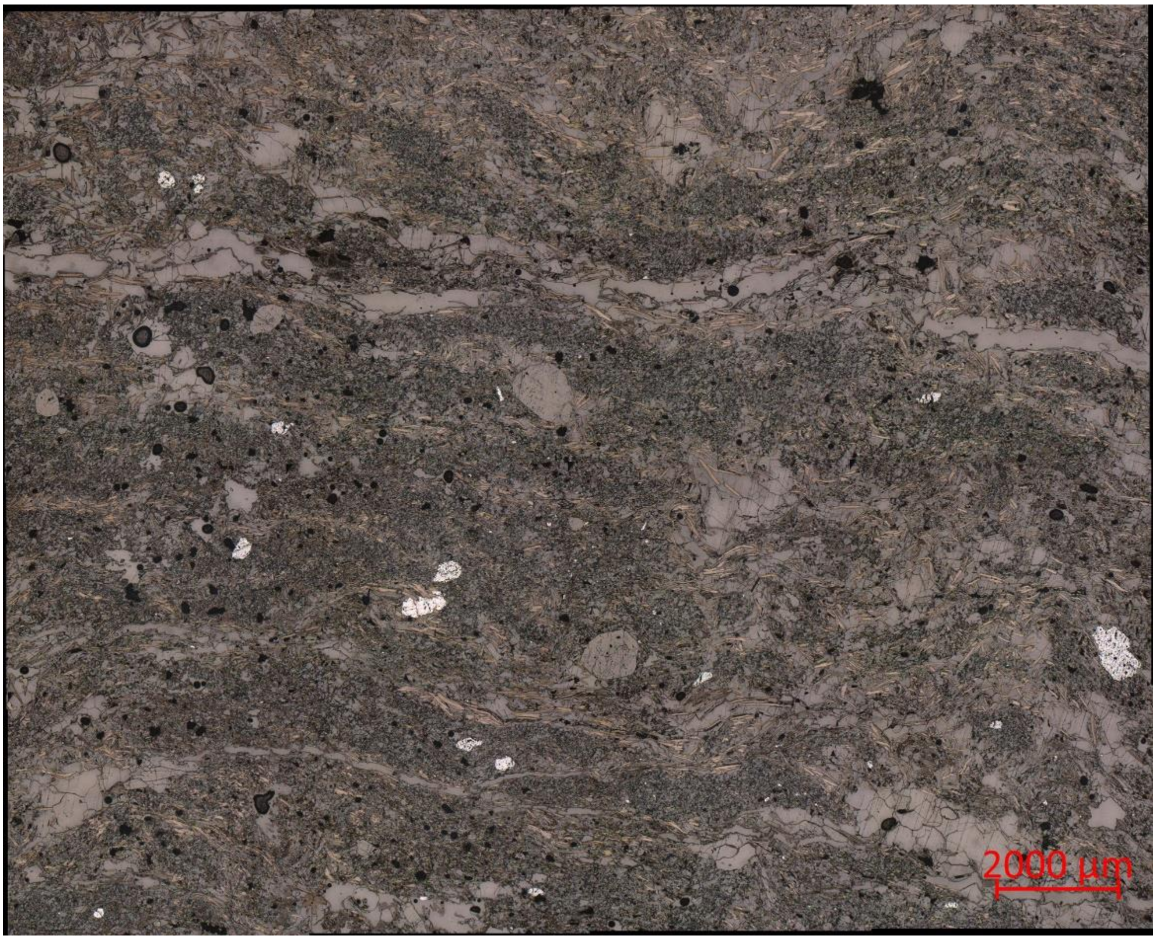

Figure 8.19: Micro-photo in reflected light, same area as Figures 8.17 and 8.18 above,

8.3 Core drilling

At Bukkemoen, two short core drillings were performed. The location of the drill-holes is shown in Figure 8.3 and technical data for these are given in Table 8.4. According to our structural observations, the drilling cuts the graphite horizons almost perpendicular to their strike and dip. The electric conductivity is logged in the drill-hole using the ABEM equipment described in section 4.1.5.

Table 8.4: Technical data, core drilling at Bukkemoen. Coordinates in UTM WGS84 Sone 33.

Area	Drill-hole	UTM X	UTM Y	Direction (o)	Dip (o)	Length (m)
Bukkemoen	Dh1	611971	7703018	045	45	41.45
Bukkemoen	Dh2	612269	7703730	037	50	37.52

The short drill-holes along the Lysvatnet road were drilled to penetrate and check the nature of the rocks in the western and smaller south eastern lobe of the EM anomaly area along the Lysvatnet lake. The core samples were analysed with portable XRF and resistivity was measured *in situ*. The drill-holes were sampled every two metres and analysed for TC and TS. All data are shown in Figure 8.19 (Dh1) and Figure 8.20 (Dh2).

Detailed geological logs are presented in Appendix 1. Pictures of the cores are shown in Appendix 2 and analytical data (chemical analysis) are presented in Appendix 3.

8.3.1 Drill-hole Bukkemoen Dh1-18

This drill-hole is located at the south side of the main lobe of the helicopter EM anomaly. The location shown in Figure 8.3, was selected based on detailed EM31 measurements and outcropping graphite schist. The well's total depth is 41.5 metres and is almost perpendicular to the strike and dip of the graphite horizon. All data are presented in Figure 8.20.

Drill-hole Dh1 (Bukkemoen Dh1-18) penetrates the upper 38 metres of a very heterogenous coarse grained rock which we classify as a graphite bearing biotite feldspar gneiss (Figure 8.19). This unit also contain scattered thin veins and bands of pyrrhotite and other sulphides. In parts, the graphite occurs in up to 5 cm large "megablasts". Over the sampled intervals, this rock unit is nevertheless quite homogenous with respect to content of Total Carbon which range from 3 to 4.5 %. Total Sulphur shows a similar relatively uniform distribution, in some parts the % TS is higher than TC reaching levels up to about 6.5 %. In most cases there is a co-occurrence of Fe, S and Ni, indicating that pyrrhotite is the main sulphide mineral.

The lowermost 4.5 metres of the core consists of a medium to coarse grained biotite amphibole rich gneissic rock with traces of sulphides and thin scattered bands of calcite veins.

The electric conductivity from borehole logging shows variable increased values for the entire graphite sequence. However, it appears that there is no direct correlation between electric conductivity and Total Carbon (and Total sulphur) but increased electric conductivity suggests the presence of graphite and/or sulphides. Therefore, based on the electric conductivity, we can assume graphite mineralisation is also present in the parts of the drill-cores which were not analysed.

In the graphite bearing sequence, the electrical conductivity varies from 0.5 to 1.0 mS/m (resistivity from 5 to 1.0 kΩm). Normally, the graphite schist is more conductive (conductivity > 100 mS/m, resistivity < 10 Ωm). Moderate electric conductivity can be explained by layered graphite horizons giving anisotropic effects. In the biotite amphibole-rich gneiss below the graphite bearing sequence, the electric conductivity is from 0.03 to 0.08 mS/m (resistivity 13 – 30 kΩm) which is normal for non-mineralised gneisses.

8.3.2 Drill-hole Bukkemoen Dh2-18

This drill-hole is located on the northern side of the main lobe of the helicopter EM anomaly. The location was selected based on detailed EM31 measurements and outcropping graphite schist (Figure 8.3). The total depth was 37.5 metres perpendicular to the strike and dip of the graphite horizon. All data are presented in Figure 8.21.

The first 24 metres consist of a heterogenous graphite bearing biotite feldspar gneiss, most likely the same rock type as in the upper part of drill-hole 1. However, in drill-hole 2 this rock shows greater variability with respect to the types of different sulphide minerals, the presence of thin quartz-felspar felsic veins, and quite abundant phenocrystals of feldspar.

The variation in TC is quite similar to drill-hole 1, varying from about 3 to 5% TC and is also similar for TS.

From 24 m to the end of the core (37.5 m) the rock is a grey-greenish amphibolitic rock, with abundant felsic veins and some scattered sulphide enrichments and calcite veins.

In drill-hole Bukkemoen Dh2-18, there is a clearer correlation between "high" conductivity and "high" TC. This shows that the graphite occurs in selected bands. Based on the electric conductivity, it can be assumed that graphite mineralisation also exists in the parts of the drill-cores which were not analysed. In the graphite bearing sequence, the electric conductivity varies from 0.6 to 1.6 mS/m (resistivity from ca. 620 Ωm to 1.0 kΩm). Normally, the graphite schist is more conductive (conductivity > 100 mS/m, resistivity < 10 Ωm). Moderate electrical conductivity can be explained by layered graphite horizons giving anisotropic effects. In the biotite amphibole rich gneiss below the graphite bearing sequence, the electric conductivity is from 0.09 to 0.26 mS/m (resistivity 3 – 11 kΩm) which agrees with the low levels of TC in this section.

8.3.3 Commonality for the two drill-holes

In these two drill-holes, high-grade graphite rich zones were not found. It is possible that the south eastern lobe consists of a low grade and relatively homogenous rock (with respect to TC). Nevertheless, the EM31 profiling shows numerous places with high electrical conductivity. It is therefore clear that such short drill-holes is not ideal to gain a representative impression of the variation in TC and distribution of areas with higher levels of TC. Drill-hole to at least 200 metres depth would be necessary to gain a representative impression of the variability of the graphite mineralisation.

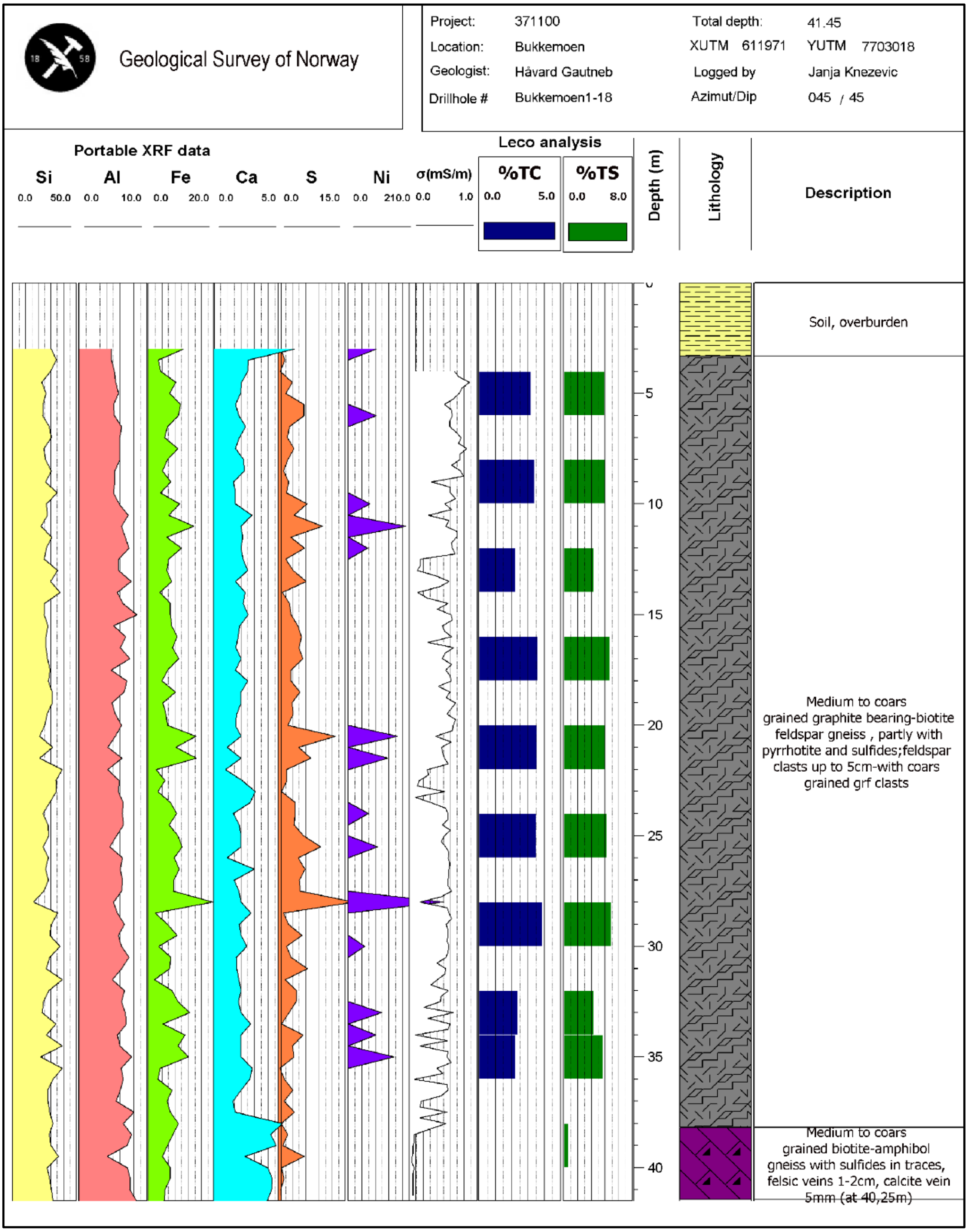

Figure 8.19: Results from the Bukkemoen Dh1-18 drill-hole: Portable XRF analyses (Si, Al, Fe, Ca, and S in %, Ni in ppm) at the cores, downhole electric conductivity log (σ), selected Leco analyses of Total Carbon (TC) and Total Sulphides (TS), lithological log and core description.

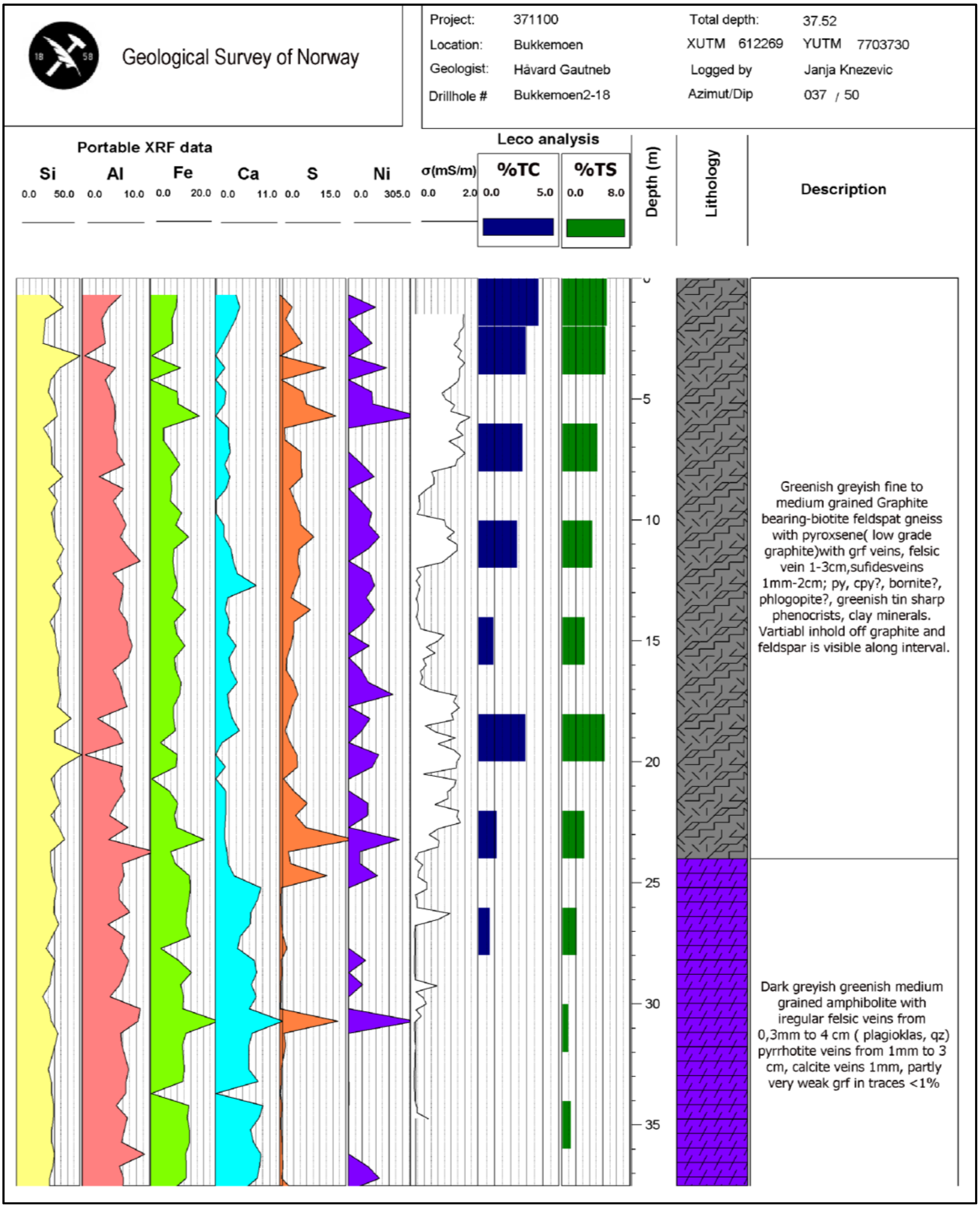

Figure 8.20: Results from the Bukkemoen drill-hole Dh2-18 drill-hole: Portable XRF analyses (Si, Al, Fe, Ca, and S in %, Ni in ppm) at the cores, downhole electric conductivity log (σ), selected Leco analyses of Total Carbon (TC) and Total Sulphides (TS), lithological log and core description.

9. GEOPHYSICAL AND GEOLOGICAL INVESTIGATIONS AT GRUNNVÅG

Ground geological follow-up investigations were performed at Grunnvåg in August 2016 (Rønning et al. 2017) and in May, June and August 2018 (geophysics, geology and core drilling). The apparent resistivity calculated from helicopter-borne 7kHz coaxial coil configuration is presented together with the location of the drill-hole in Figure 9.1. Anomalous resistivity shows up in a length of 1.5 km. The graphite may continue underneath the seawater in Lysebotn to the west.

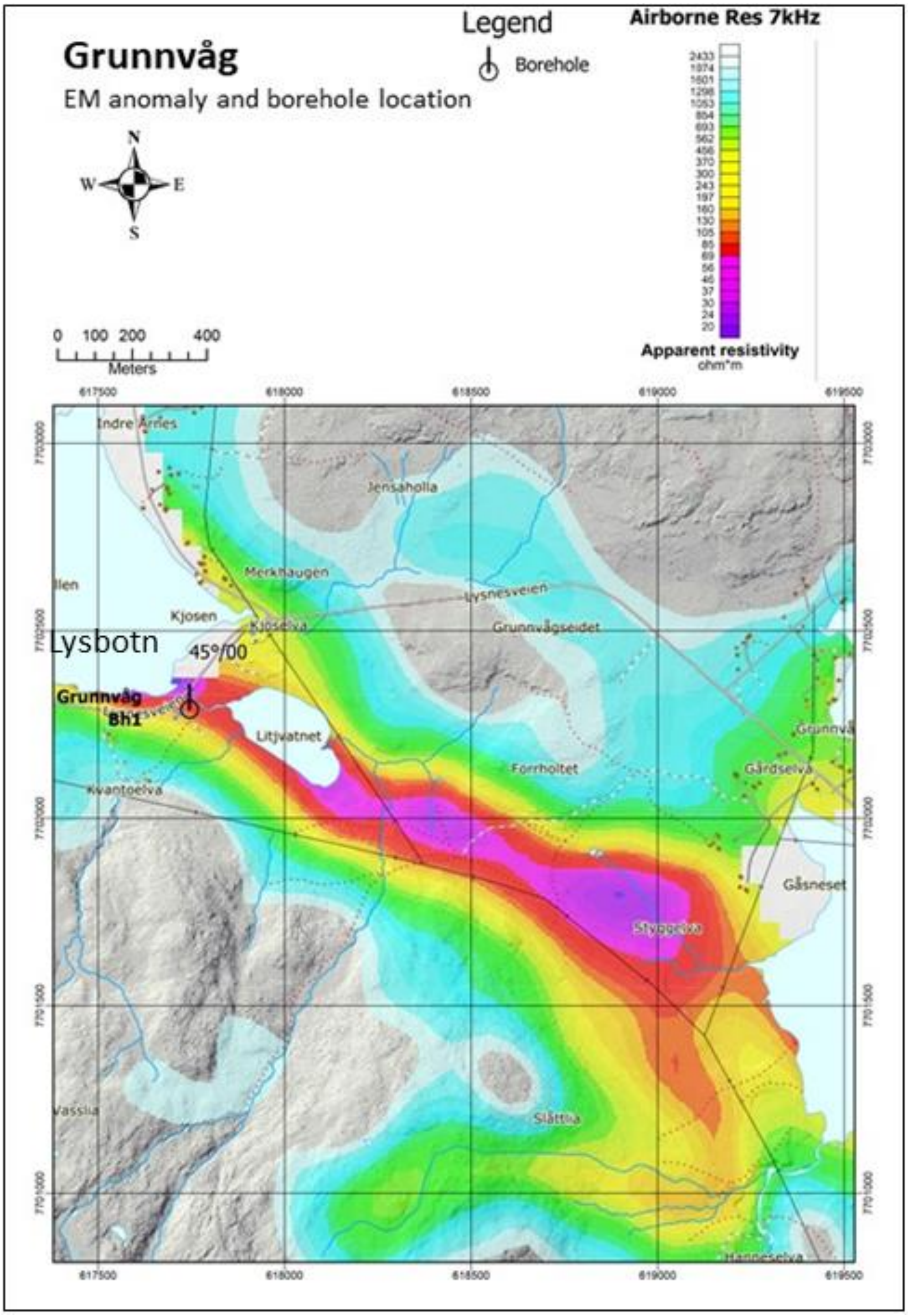

Figure 9.1: Grunnvåg. Apparent resistivity calculated from helicopter-borne 7 kHz coaxial coil configuration and location of the short core drilling. (Resistivity from Rodionov et al. 2014).

9.1 Geophysical measurements

The terrain at Grunnvåg is relatively flat and easily accessible, and the anomalous resistivity area is covered with very detailed EM31 traversing (Figure 9.2). The EM31 results confirm the results from helicopter-borne apparent resistivity. Within the anomalous area from helicopter-borne EM measurements, thick structures of high conducting material are mapped. Subsequent geological mapping has confirmed graphite schist, which explains the anomaly. Follow-up EM31 measurements confirm possible graphite in a total length of 1.6 km.

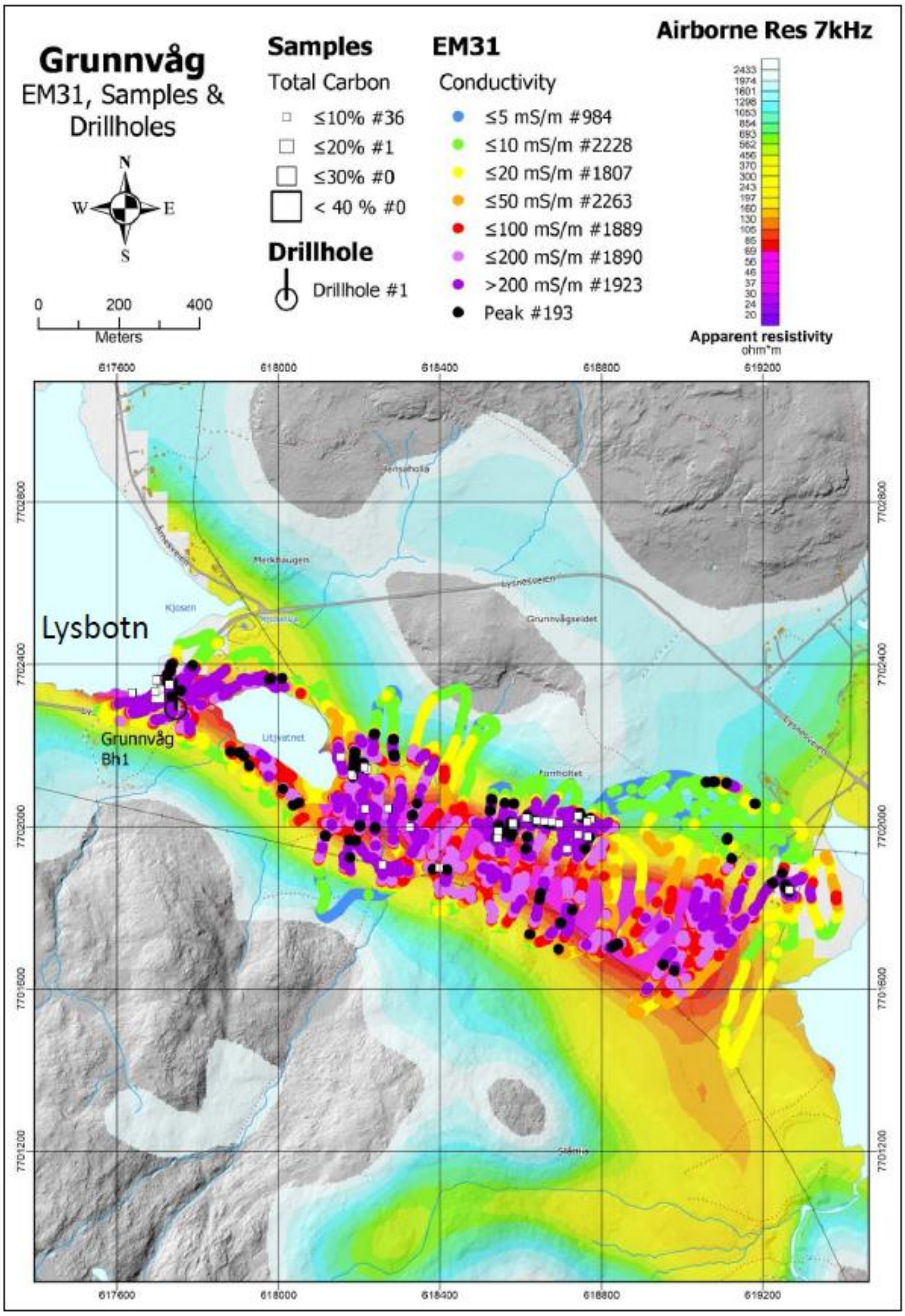

Figure 9.2: EM31 and total carbon (TC) analyses on samples from Grunnvåg superimposed on apparent resistivity (7 kHz, from Rodionov et al. 2014). Location of graphite samples and their Total Carbon grade is given with white squares.

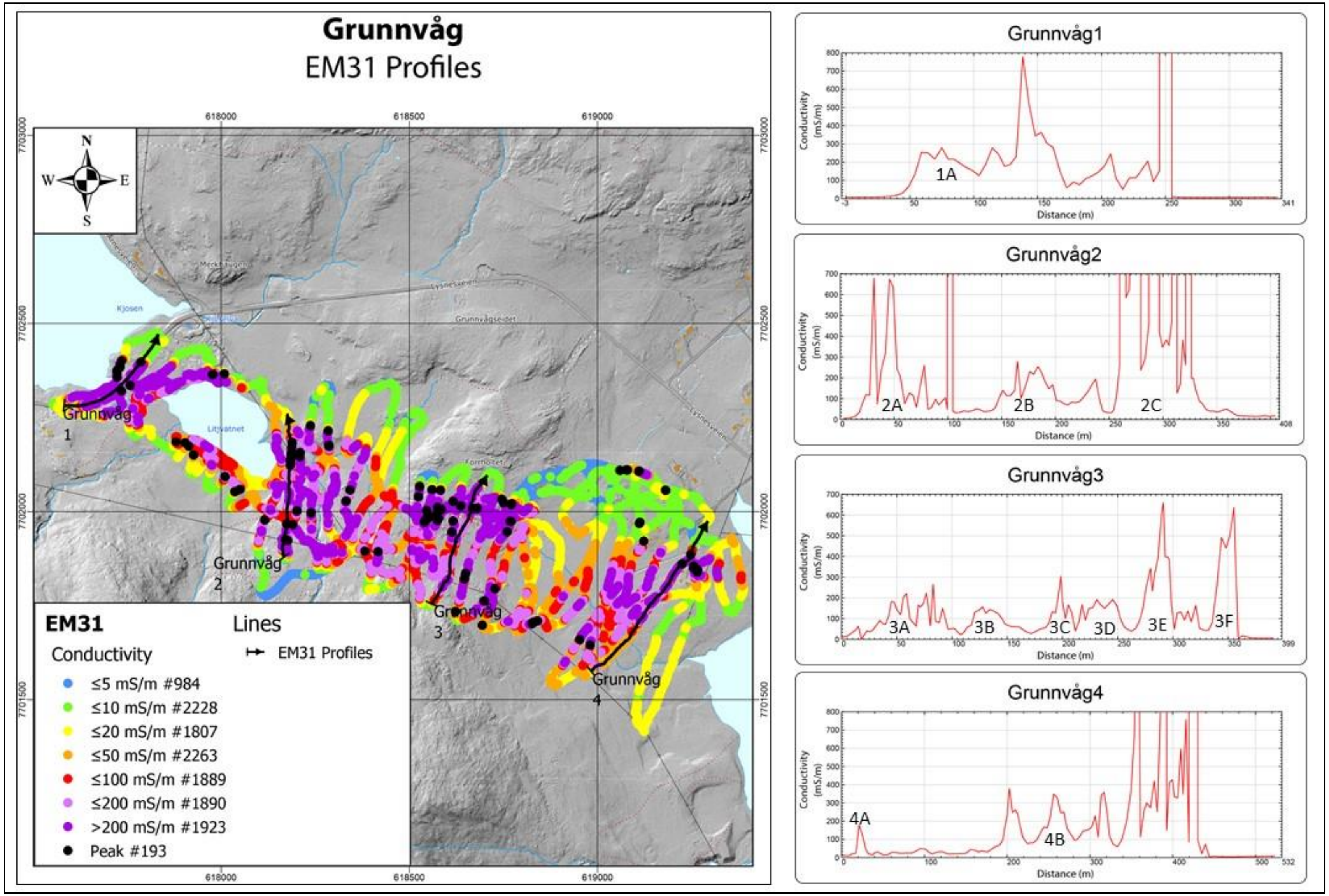

Figure 9.3: Results of EM31 measurements at Grunnvåg. Selected profiles for detailed studies.

The presentation method of the EM31 data shown in Figure 9.2 can overestimate the amount of good graphite bearing rocks. To see the details in the continuous EM31 readings, selected profiles are presented as plotted curves in Figure 9.3. Table 9.1 shows the coordinates and the width of the conducting structures, which are most likely graphite mineralisation. The estimated width of these potential graphite structures are areas where apparent conductivity is > 100 mS/m (apparent resistivity < 10 Ωm).

Table 9.1: Grunnvåg. Description of zones with anomalous conductivity measured with EM31.

EM31 anomaly	Position at the line	Start UTM X	Start UTM Y	End UTM X	End UTM Y	Estimated width (m)	Comment
1A	50 - 255	617635	7702283	617789	7702402	205	No. of lenses Partly < 100 mS/m
2A	22 - 105	618163	7701901	618174	7701971	83	> 5 lenses Partly < 100 mS/m
2B	147 - 240	618176	618176	618180	7702065	93	> 3 lenses
2C	255 - 333	618184	7702119	618186	7702193	78	High conductivity Several lenses
3A	42 - 94	618581	7701789	618604	7701828	52	5 lenses Partly < 100 mS/m
3B	118 - 145	618607	7701854	618609	7701878	27	
3C	188 - 208	618623	7701922	618631	7701937	20	
3D	215 - 252	618635	7701942	618653	7701974	37	Partly < 100 mS/m
3E	270 - 322	618658	7701990	618669	7702035	52	> 5 lenses Partly < 100 mS/m
3F	335 - 358	618673	7702050	618684	7702066	23	High conductivity
4A	20 - 25	618996	7701589	618999	7701591	5	
4B	194 - 434	619111	7701709	619250	7701890	240	> 5 lenses Partly < 100 mS/m

The selected lines presented in Figure 9.3 indicate numerous individual heterogenous graphite structures. The thickness of these varies from 5 m to more than 200 m (1A and 4B), and these values are mostly perpendicular to the main strike direction. The thickest structures most likely consists of several graphite horizons and there can be thin country rock layers in between. The anomalous apparent conductivity varies from less than 100 mS/m to a maximum value of ca. 800 mS/m. This can be an effect of the quality of the graphite but can also be due to variations in the overburden thickness. The quality of the graphite will be discussed later in section 9.2.2.

9.2 Geological investigations, sampling and analyses

In the Grunnvåg area bedrock/structural mapping, geological observations, sampling/analysis have been undertaken, as well as and one short core drilling.

9.2.1 Geological and structural mapping, Grunnvåg

The geophysical anomaly visible at the south eastern part of Lysbotn towards Grunnvåg (Figure 9.1) was unknown until the helicopter geophysics was collected (Rodinov et al. 2014). The nature of this anomaly was also unknown until outcrops of graphite-bearing rocks were discovered along the shore of the inner part of Lysbotn during this study. Detailed ground based EM31 has been carried out over this helicopter anomaly revealing an extensive graphite deposit.

The area is almost 100 % soil covered, but graphite schist occurs in small exposures along the shoreline in the innermost part of Lysbotn, and at scattered locations within the anomalous area (See Figures 9.2 and 9.4). These are dissected and intruded by mafic and granitic rocks.

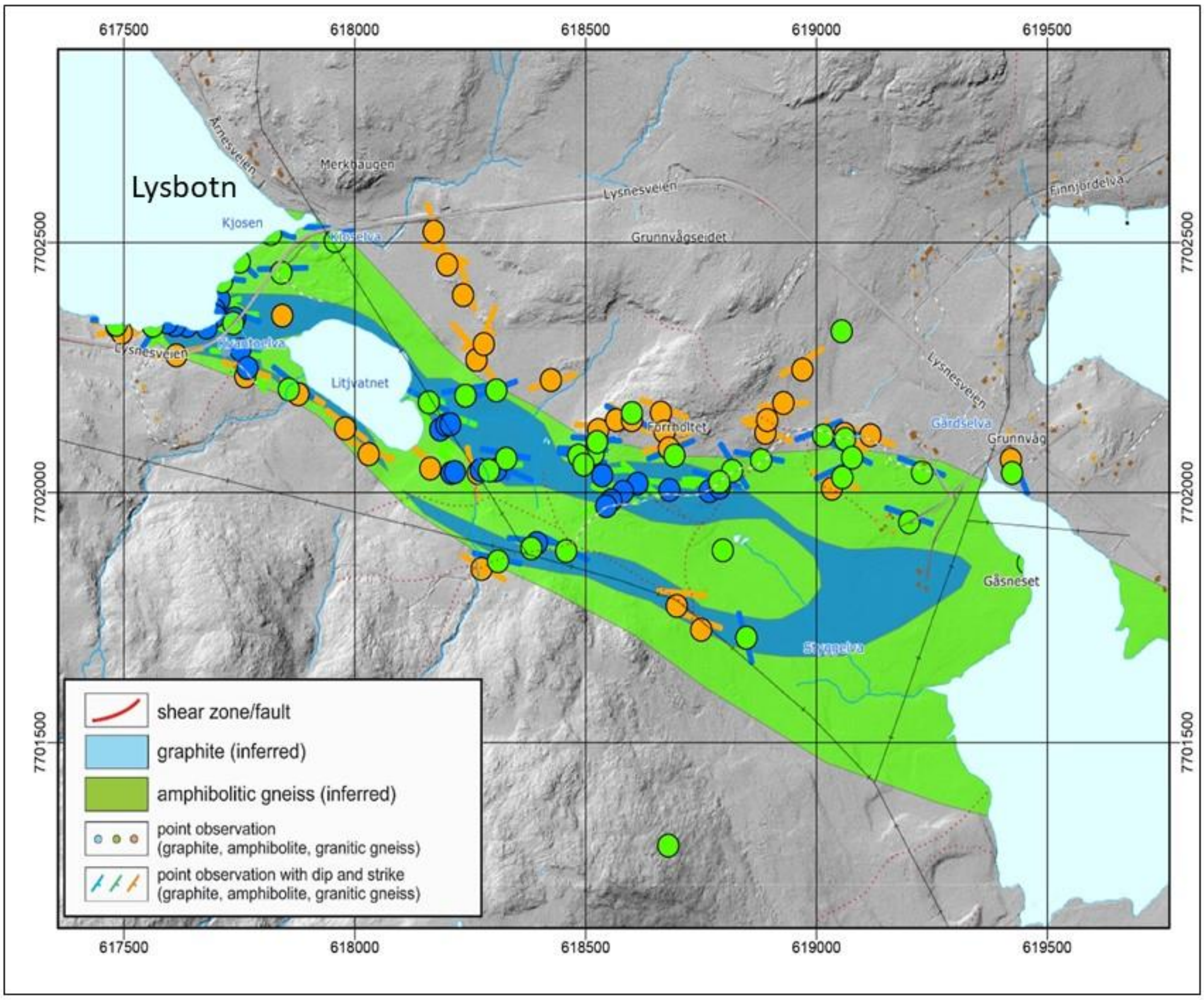

Figure 9.4: Geological map of the Grunnvåg deposit based on new geological mapping in this study, helicopter-borne EM data and ground based EM31.

Detailed mapping of the Grunnvåg deposit was carried out in 2018 and has been integrated with the ground EM31 data collected in the same field campaign. The integrated interpretation is shown in Figure 9.4. The graphite is enclosed within a thin amphibolitic gneiss pod with an elongated, WNW-ESE strike, extending from Lysbotn in the western extremity to east of Grunnvågvatnet in the east. The graphite occurs as a relatively thin, but up to several metres thick band which has been isoclinally folded along WNW-ESE F_2 fold hinges (see Henderson & Kendrick 2003) and refolded along a NE-SW F_3 fold hinge creating a double closing graphite isocline in both the western and eastern parts of the deposit. The southern graphite band has been more attenuated than the northern part. Axial planar faulting, dissecting and attenuated the geometrical signature including extensive F_3 fold development of the other graphite deposits is not observed in the Grunnvåg deposit.

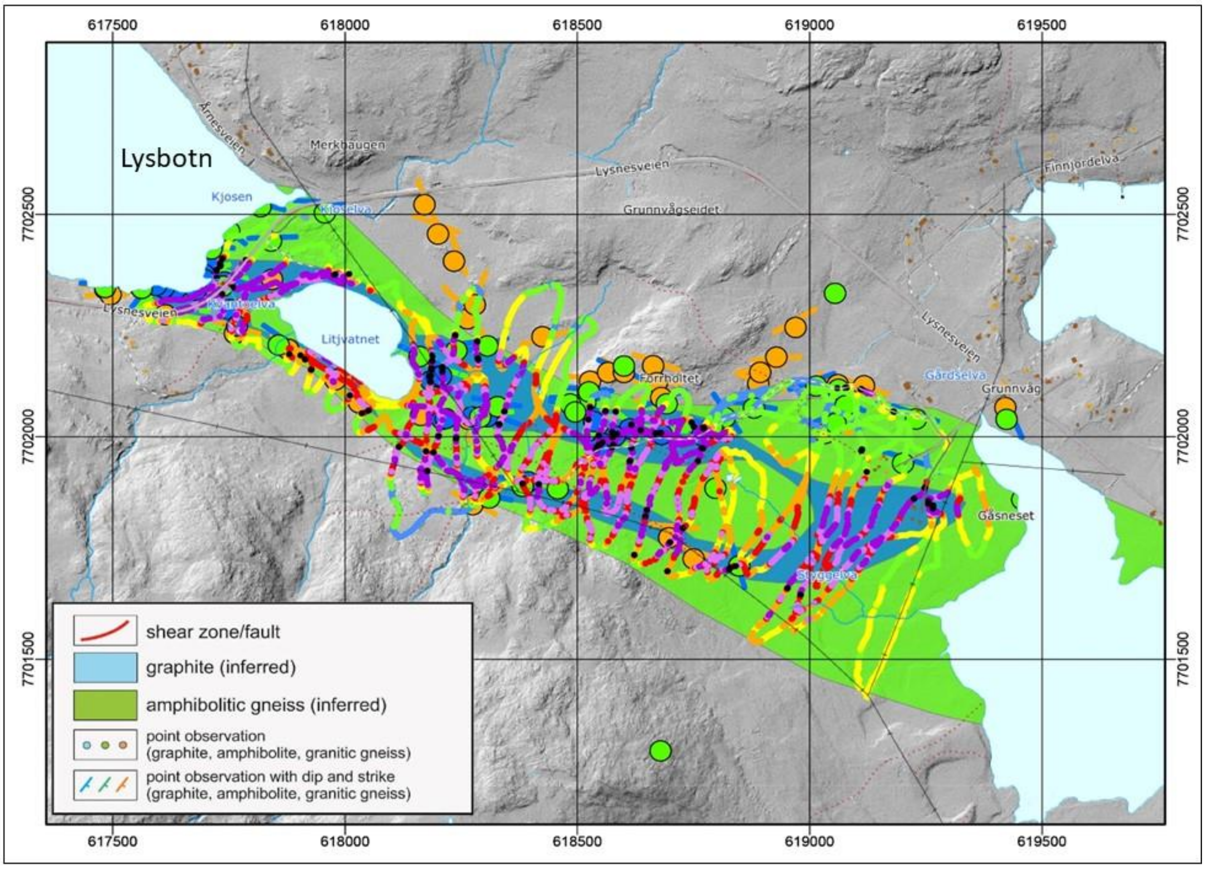

Figure 9.5: Geological map of the Grunnvåg deposit based on new geological mapping in this study, helicopter-borne EM data and ground based EM31. Data from EM31 are superimposed (colour scale in Figure 9.2).

In Figure 9.5, the data from the EM31 measurements area is superimposed on the new geological map. The outline of the graphite structures fits well with the EM31 data. The graphite is steeply dipping and based on the detailed EM31 thickness analyses (Table 9.1) and a total length along the strike, the volume of graphite bearing rock appears to be substantial.

9.2.2 Geological observations, sampling and analysis at Grunnvåg

The Grunnvåg graphite deposit was identified for the first time during the field season of 2016 (Rønning et al. 2017). Five samples were collected and analysed. The samples were analysed for total carbon (TC) and total sulphur (TS) using a Leco SC-632 analyser. The detection limits are 0.06 % and 0.02 % for carbon and sulphur respectively. The average graphite and sulphur content of the five samples was 8.9 TC %, 4.9 TS %, and with the highest content of 14,9 TC %. Samples were taken during the investigation on the easternmost part of the apparent resistivity anomalies measured by a helicopter-borne geophysical survey during the MINN project (Minerals in Northern Norway) from 2012-2014. This study indicated possible graphite occurrences along apparent resistivity anomalies, taking into account that graphite is a good conductor.

In 2018, the investigations were continued along the apparent resistivity anomaly which is approximately 1600 m long in an WNW-ESE trend. It was found to be the longest and best exposed graphite outcrop in Norway until now, with an approximate length of 265 m and width of 55-90 m, also demonstrated by sampling and EM31 measurements. The average value of TC in the Grunnvåg deposit is 5.2 TC % with a maximum value of 14,9 TC% (Figure 9.6, Table 9.2), Samples taken in the eastern part of the anomaly are richer in sulphides, with an average TS % of 4.2 % and a maximum value of 12.5 % TS.

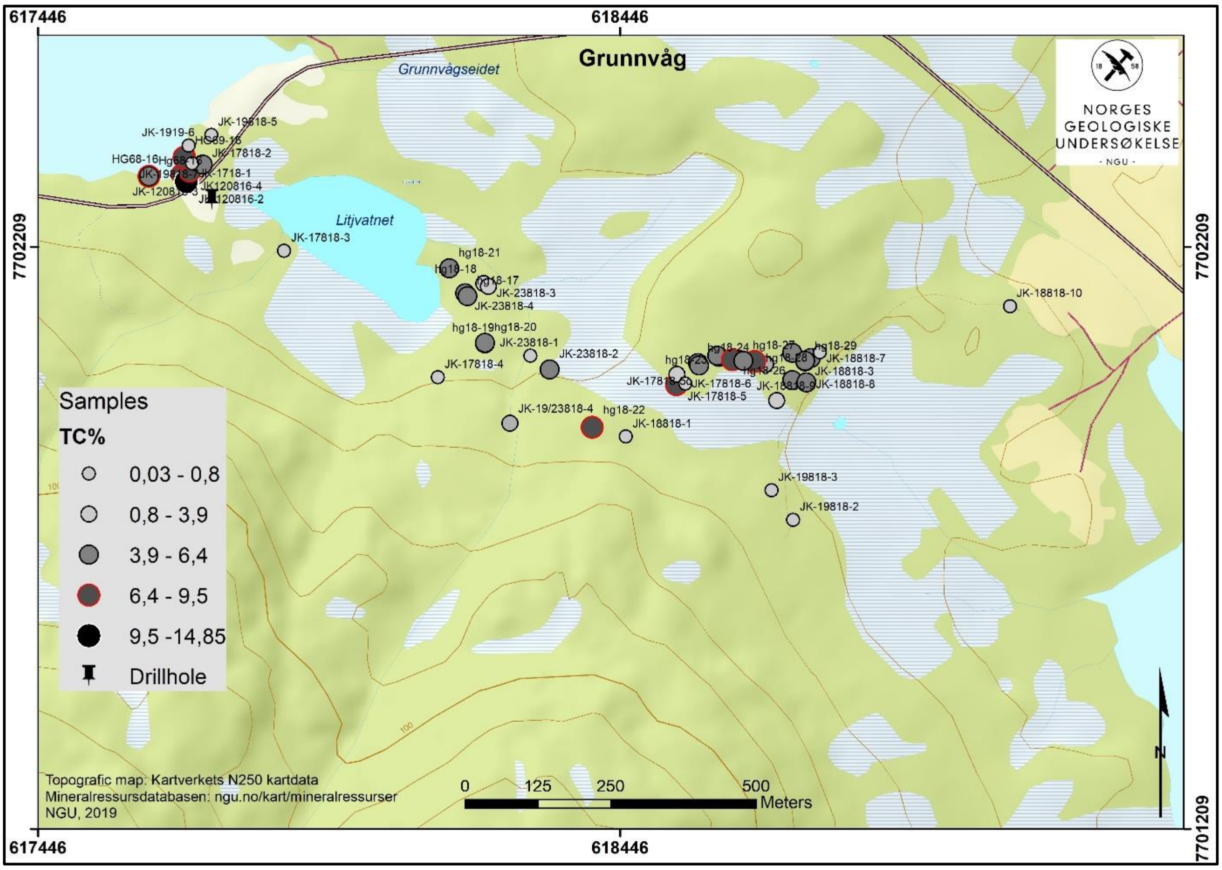

Figure 9.6: Distribution of graphite samples and analysed Total Carbon (%) at Grunnvåg.

Table 9.2: Total Carbon (TC) data from 21 surface samples from the Grunnvåg area.

Locality	N	Average TC (%)	Max TC (%)	Min TC (%)	STdv TC (%)	Median (%)
Grunnvåg	37	5.2	14.9	0.5	2.8	4.9

The average total carbon content (5.2 %) is somewhat lower than at the Vardfjellet deposit (9.9 %) but is similar to that of the Bukkemoen deposit (5.2 %).

Site observations.

Figure 9.7: Well exposed Graphite schist outcrop along the tractor road (grf + felsic vein).

Figure 9.8: Sulphide rich graphite schist, Grunnvåg (innermost part of Lysbotn).

Figure 9.9: Graphite schist along the stream, sample JK-17818-2, 6.05 TC %.

In the Grunnvåg area weathered graphite schist is covered by vegetation and soil (Figure 9.10). The EM31 instrument located anomalies under the soil, which were proven to be graphite by excavations.

Figure 9.10: Graphite schist outcrops covered by vegetation and soil.

Figure 9.11: Folded graphite schist.

Figure 9.12: Weathered graphite schist.

Figure 9.13: Amphibolite with felsic veins.

Petrography.

The host rock comprises quartz, alkali feldspar (mainly K- feldspar), plagioclase, biotite, amphibole, mica minerals, variable amount of graphite, mainly in strongly deformed layers together with biotite and small crystals of quartz and feldspar (Figure 9.14). The accessory minerals observed are pyroxene, titanite, epidote, magnetite, pyrite, hematite, chalcopyrite, actinolite/tremolite (Figure 9.15). Biotite feldspar quartz gneiss is enriched in Ba, V and Sr.

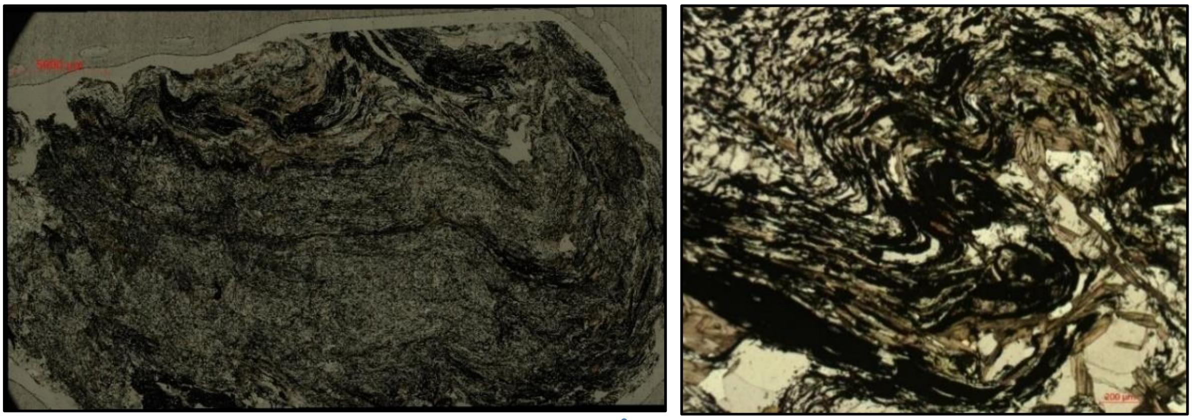

Figure 9.14: Thin section of sample from Grunnvåg.

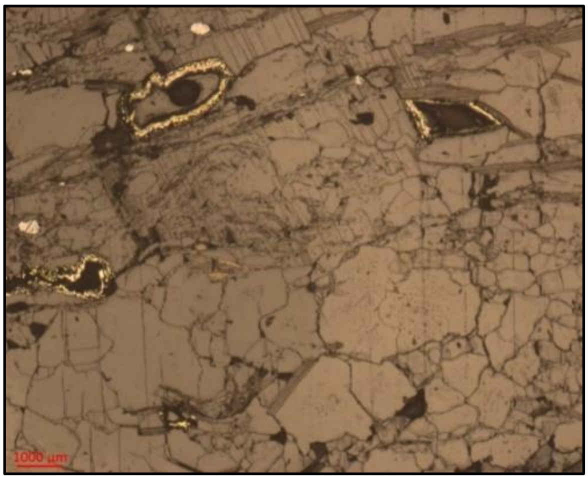

Figure 9.15: Thin section photo of graphite bearing biotite feldspar quartz gneiss with hematite, pyrite and magnetite, (chp?).

Table 9.3 shows the results of image processing (calculated diameter of graphite crystal) using the method described in section 4.2.2 for sample HG18-28).

Table 9.3: Example of analysed grain size of graphite minerals at Grunnvåg (sample HG18-28).

Locality	Average size (µm)	Max size (µm)	STdv TC (µm)	Median (µm)
Grunnvåg	37	3477	59	24

The calculated diameter of graphite crystals in this thin section shows that the flake size is about the same distribution as that for the Bukken deposit and within the size range *in situ* that can give coarse grained flake size of economic value in the final product. However, such measurements have only limited relevance from an industrial point of view, since it is the grain size after crushing, screening and flotation, that determines the quality of the finished product.

9.3 Core drilling, Grunnvåg

At Grunnvåg, one short core drilling was performed. The location of the drill-hole is shown in Figure 9.1 and technical data for this are given in Table 9.3. The electrical conductivity was logged in the drill-hole using the ABEM equipment described in section 4.1.5. Results from core analyses and resistivity downhole logging are given in Figure 9.16. A detailed geological log is presented in Appendix 1, the pictures of the cores are shown in Appendix 2 and analytical data (chemical analysis) are presented in Appendix 3.

Table 9.3: Technical data, core drilling at Grunnvåg. Coordinates in UTM 84 Sone 34.

Area	Drill-hole	UTM X	UTM Y	Direction (°)	Dip (°)	Length (m)
Grunnvåg	Dh1	382270	7702290	000	45	39.33

The location of the drill-hole was selected based on the EM31 measurements. The purpose was to check if it was possible to penetrate the graphite bearing zones known to exist near the stream running down to Grunnvåg. Along the entire core, the rock is a very inhomogeneous grey medium grained biotite feldspar gneiss. Graphite is enriched in bands from 1 mm to 30 cm thick that are unevenly distributed throughout the core. The rock shows quite abundant pyrrhotite and pyrite in parts and some parts are richer in muscovite and chlorite. There is a thin massive graphite layer 13 cm thick at 37.5 m.

The content of TC and TS show some small variation. The highest % TC of about 8 % is found from 14 to 18 metres. TS varies from about 2 to 5 %.

There is a good correlation between high electrical conductivity and high graphite content. This means the EM31 is well suited to map shallow buried graphite mineralisation. We interpret the graphite as most likely quite unevenly distributed in the upper < 100 m and that a several significant longer drill-holes are required to determine the graphite distribution.

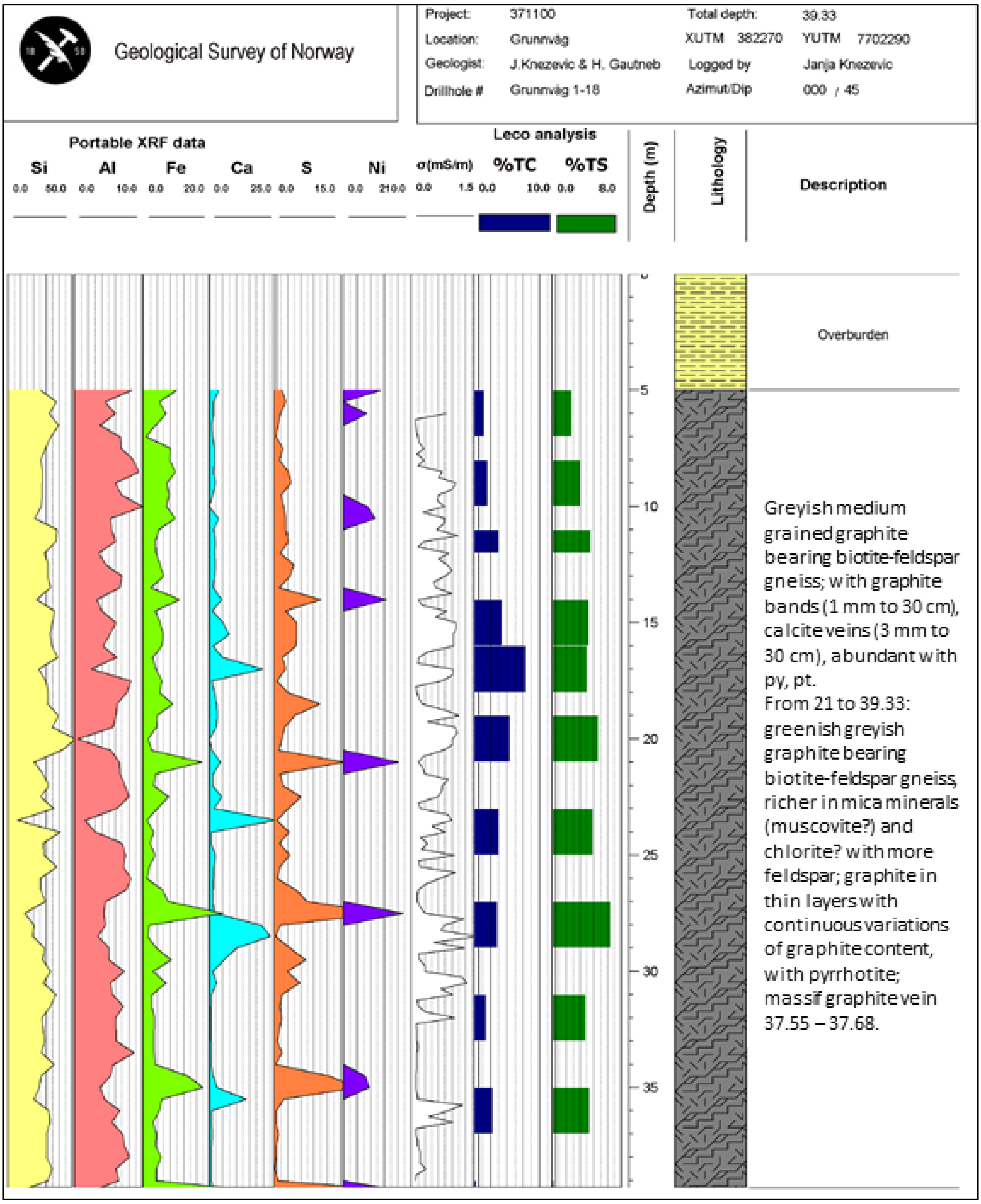

Figure 9.16: Results from the Grunnvåg Dh1-18 Drill-hole: Portable XRF analyses at the cores, downhole electric conductivity log (σ), selected Leco analyses of Total Carbon (TC) and Total Sulphides (TS), lithological log and core description.

10. GEOPHYSICAL AND GEOLOGICAL INVESTIGATIONS AT SKARSVÅG

Ground geophysical and geological follow-up investigations were performed at Skarsvåg in May and August 2018.

10.1 Geophysical measurements

At Skarsvåg, two locations are investigated with EM31 profiling, and 2D ERT/IP.

10.1.1 EM31 measurements

The helicopter-borne apparent resistivity indicates two ca. 2 km long and more the 200 m wide anomalous areas at Skarsvåg. The north-eastern anomaly is much more pronounced than that in the SW. Electrical conductivity data measured with EM31 at both locations are shown in Figure 10.1 superimposed on apparent resistivity measured with 7kHz coaxial coils from helicopter.

In the north-eastern area, the apparent electric conductivity is mostly less than 50 mS/m (apparent resistivity > 20 Ωm) represented by blue, green, yellow and orange dots. In some areas the apparent electrical conductivity is higher than 100 mS/m (resistivity less than 10 Ωm) represented by red and violet dots. The latter is interpreted to be caused by graphite, and graphite bearing rocks are found in several locations. High conducting areas are located mostly in the bottom of valleys eroded by a river. The soil thickness next to the valleys is from 4 to 8 metres, and this soil cover is probably the reason for not having continuous high conducting graphite structures. The EM31 equipment has limited penetration depth (70 % of the response derives from the upper 6 metres) and in most of the areas, the soil cover allows limited coupling to potential graphite structures. This means that there can be more graphite in the Skarsvåg area than indicated by the EM31 measurements.

In the south-western area, the apparent resistivity from helicopter-borne measurements are much less pronounced, and the EM31 ground measurements show even lower apparent conductivity. However, apparent conductivity higher than 200 mS/m (resistivity < 5 Ωm) are seen indicating graphite mineralisation. Graphite exposures were found also in this area. Based on the total EM response, less graphite is expected in this area than in the north-eastern area.

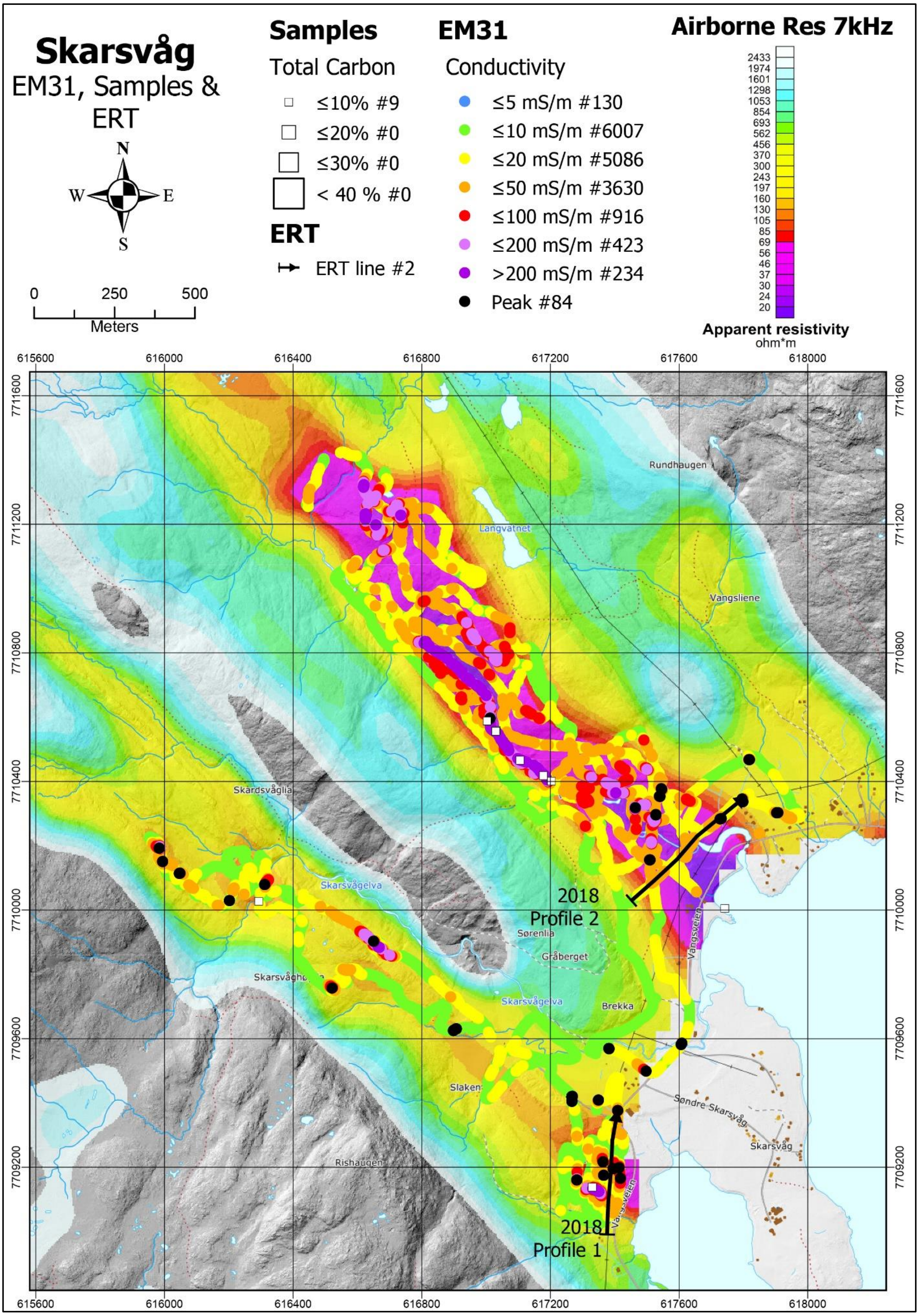

Figure 10.1: Results of EM31 measurements at Skarsvåg superimposed on apparent resistivity (7 kHz, from Rodionov et al. 2014). Location of graphite samples and their Total Carbon grade is given with white squares.

10.1.2 2D ERT/IP measurements

At Skarsvåg, two 2D ERT/IP profile were measured (for location, see Figure 10.1). Electrode separation was 5 m and the other technical data as described in chapter 4.1.4. Profile 1 is 400 m long while profile 2 is 500 m long.

Quality parameter are shown in Table 10.1. Absolute error for the resistivity and IP inversion is good (> 15 %). The inverted sections are shown in Figure 10.2.

Table 10.1: Quality of 2D resistivity and IP data at Skarsvåg. Number of measured, removed and remaining data points for inversion, and observed "Absolute error" from the inversion of resistivity and IP data.

Name	Location	Measured data points	Removed points	Final data points	Abs. error Resistivity (%)	Abs. Error IP (%)
Profile 1	Skarsvåg	1107	0	1107	10.0	7.1
Profile 2	Skarsvåg	1616	0	1616	9.4	9.2

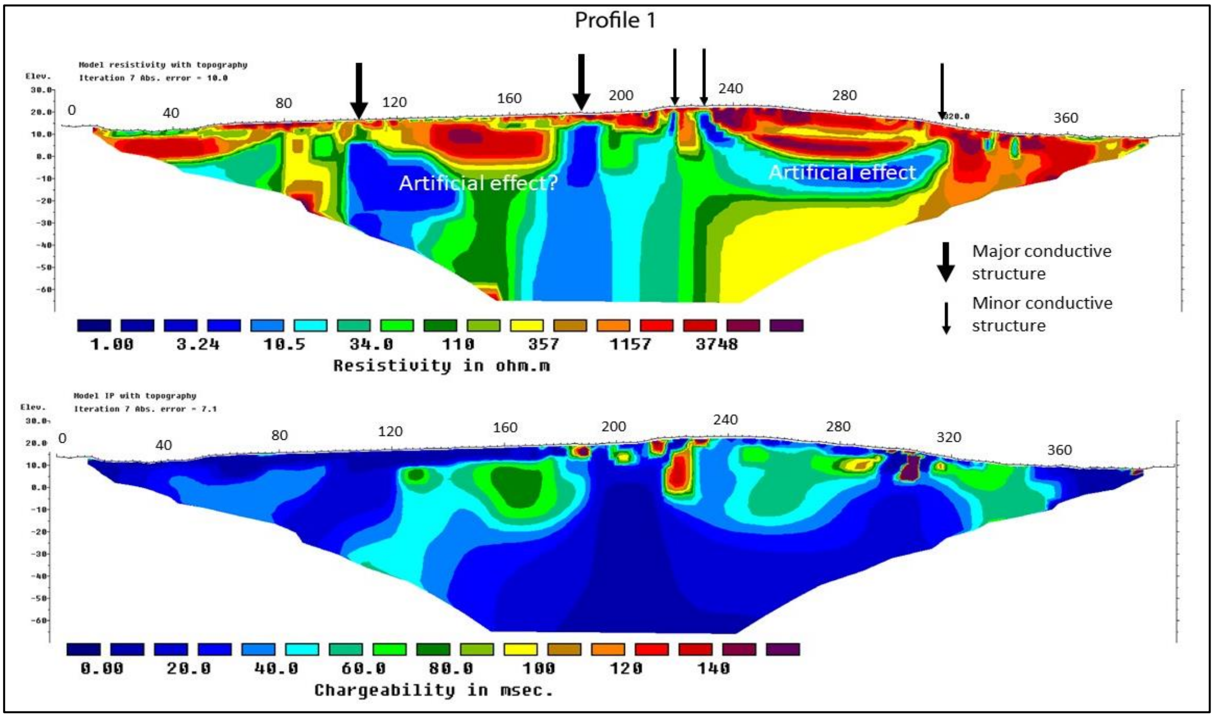

Figure 10.2: 2D resistivity (top) and IP (bottom) results along profile 1 at Skarsvåg.

Resistivity profile 1 at Skarsvåg (Figure 10.2) indicate five potential graphite structures. Three of these appear to be minor which means relatively thin (< 5 m) and two of them may have a total thickness of five to ten metres (Major structures). From position 105 to 180 and from 230 to 310 the resistivity section probably shows artificial effects. Vertical good conducting structures as seen in the section (resistivity < 5 Ωm) may shortcut the current giving an effect of horizontal conductivity at a certain depth (Rønning et al. 2014). Based on this, five potential graphite near vertical structures are interpreted.

Induced Polarisation (IP) show moderate anomalies next to the conducting structures indicating electronic conducting minerals, graphite or sulphides.

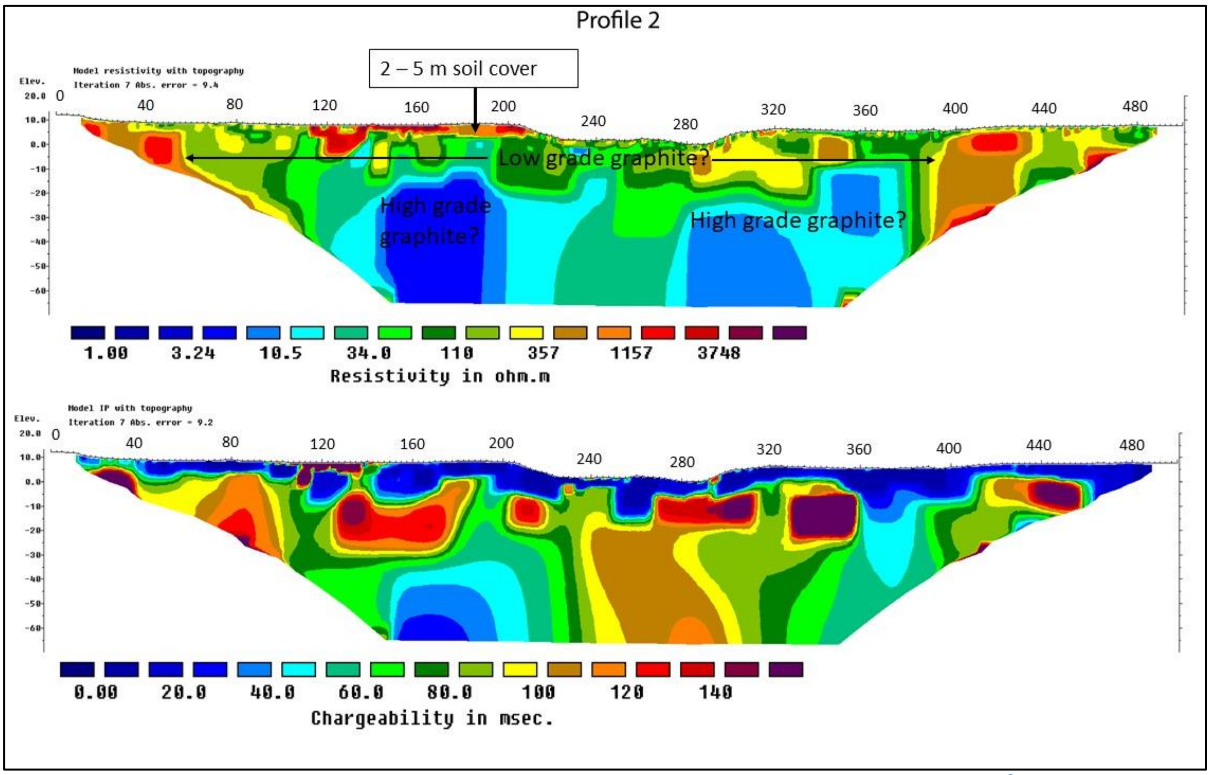

Figure 10.3: 2D resistivity (top) and IP (bottom) results along profile 2 at Skarsvåg.

Resistivity profile 2 at Skarsvåg (Figure 10.3) shows some interesting features. On top from ca. position 100 to position 215 the resistivity is higher than 400 Ωm. This can be interpreted as three to five metres of thick soil overburden. Underneath the soil layer, reduced resistivity in bedrock (< 200 Ωm) appears all the way from position 50 to position 390. This fits well with the resistivity anomaly calculated from helicopter-borne electromagnetic measurements (Figure 10.1). Inside this interval, two structures from position 150 to 190 and from position 280 to 370 appear with resistivity partly less than 5 Ωm. High IP anomalies along the entire profile indicate graphite, sulphides or a combination of these.

The moderate low resistive material (resistivity between 200 and 10 Ωm) can be low grade disseminated mineralisation while material where resistivity is less than 10 Ωm can be interpreted as massive mineralisation. This model indicates that the best part of the mineralisation can lie below a 20 to 25 metres thick layer of low-grade graphite/sulphite. To confirm this, deep core drilling (100m) is necessary.

10.2 Geological investigations

In the Skarsvåg area bedrock/structural mapping, geological observations and sampling/analysis have been undertaken.

10.2.1 Geological and structural mapping, Skarsvåg

A geophysical anomaly (Figure 10.1) was found in the Skarsvåg area from the helicopter geophysics (Rodinov et al. 2014). This anomaly has a clear NW-SE trend extending from the eastern coastline of Senja from the village of Skarsvåg ca. two km inland. The nature of this anomaly was unknown before the field campaign in 2018.

Although the bedrock in the area is poorly exposed, several interesting outcrops were found in a stream running parallel to the EM anomaly as shown in Figure 10.1 where outcrops of graphite-bearing rocks were discovered (see also Figure 10.6). Detailed ground based EM31 was simultaneously carried out over the helicopter anomaly (Figure 10.1). The combined geological, geophysical interpretation is presented in Figure 10.4. The northern most area was the most promising in terms of the ground based EM31 survey. Here, there is a clear anomaly that correlates with the helicopter anomaly (Rodinov et al. 2014). Several thin bands, up to a maximum of several metres, of isoclinally folded graphitic schist are present which are isoclinally folded around WNW-ESE trending F_2 fold hinges (Henderson & Kendrick, 2003). These may have at some time been a single layer that have been folded and attenuated through progressive deformation. The southern EM31 area displays a much less prominent anomaly than the northern profile. More detailed investigations of this anomaly were not carried out so far due to budget limitations in this project, but we recommend follow up work in this area as well.

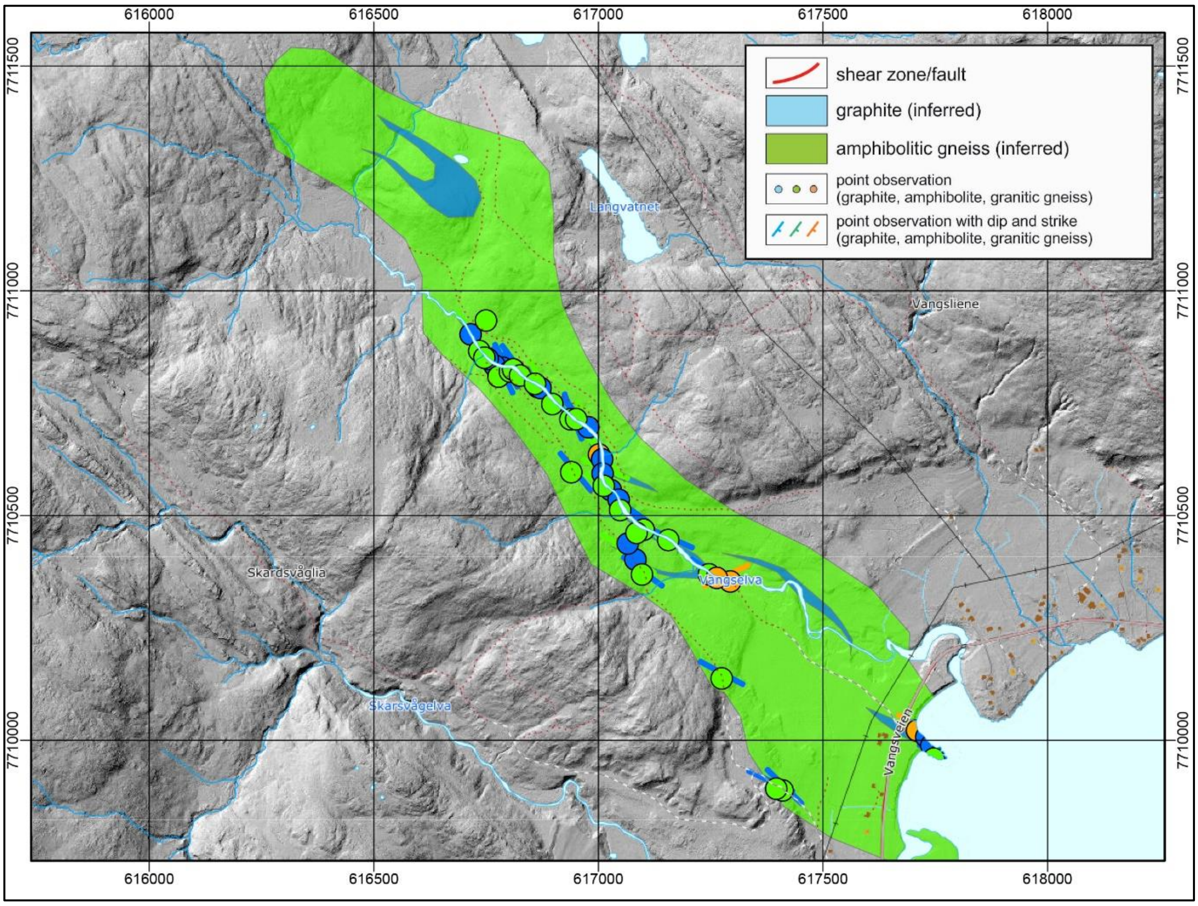

Figure 10.4: Geological map of the Skarsvåg deposit based on new geological mapping in this study, helicopter-borne EM data and ground based EM31.

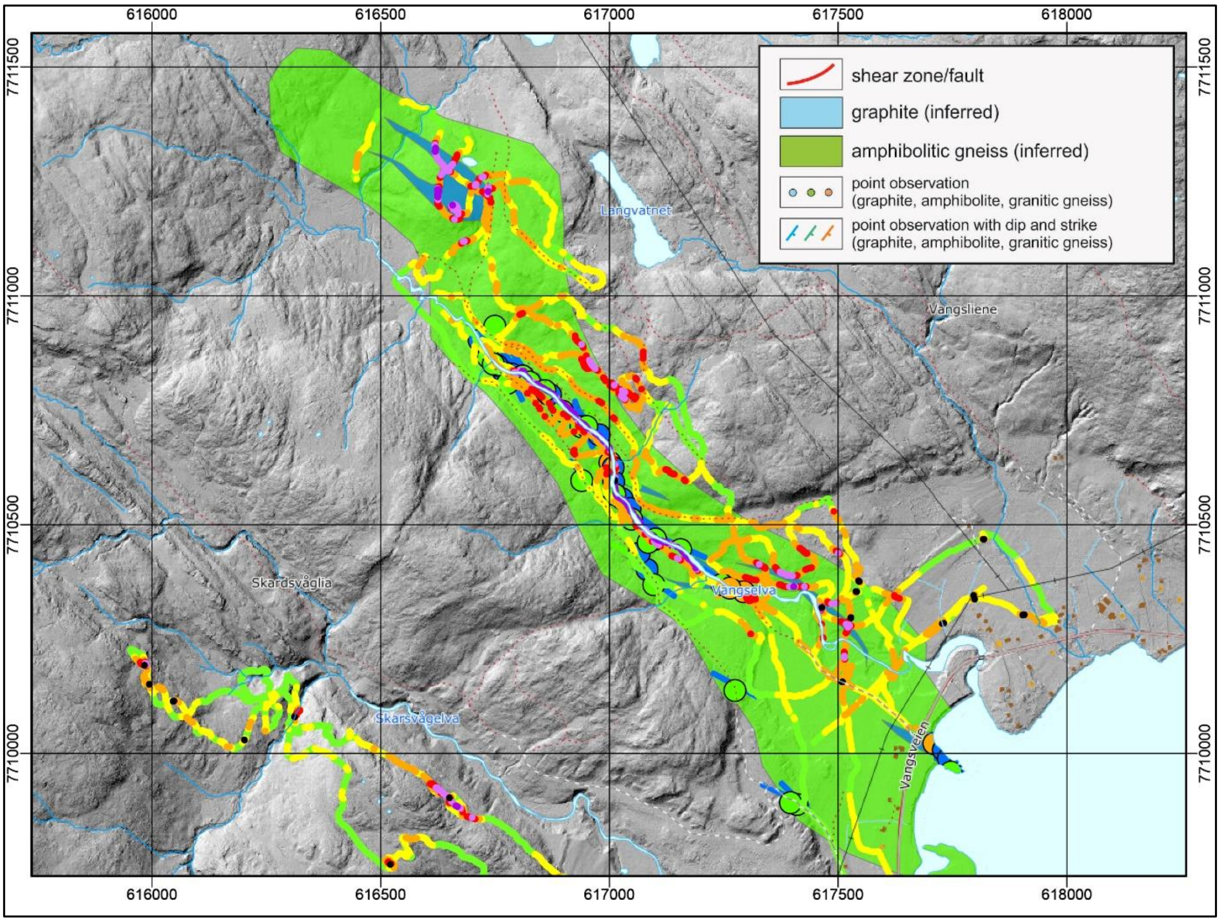

Figure 10.5: Geological map of the Skarsvåg deposit based on new geological mapping in this study, helicopter-borne EM data and ground based EM31. Data from EM31 are superimposed (colour scale in Figure 10.1).

The EM31 data superimposed on the geological map (Figure 10.5) coincides with the exposed graphite. In addition, graphite is indicated north-west of the exposed graphite structure in the "Vangselva" river. It appears that more graphite is present at depth than can be documented at the surface. The reason for this is the soil cover in the valley bottom.

10.2.2 Geological observations, sampling and analysis, Skarsvåg

The Skarsvåg area is dominated by two EM anomalies (Figure 10.1). Both follow topographic depressions in the area, where the north eastern and largest anomaly follows along the Vangselva river, and the south western anomaly follows along the Skarselva river. This latter anomaly is almost completely soil covered and only two outcrops were found. The north eastern anomaly shows numerous outcrops along the Vangselva river as well as on a small peninsula a few metres south of the Vangselva river outlet.

Along the path of Vangselva, small outcrops of a rusty weathered sulphide and graphite bearing rock occurs (Figures 10.1 and 10.6). Some of these were sampled for chemical analysis.

Figure 10.6: Outcrops along Vangselva river at Skarsvåg.

The graphite flakes are clearly visible in the rock but occur in relatively small amounts. Analysis of 30 samples from this area with showed an average TC of 1.0 %. If samples with TC > 0.5 % only are used, the number of samples goes down to 13 with an average of 2.1 % TC (Table 10.2). The distribution of the samples at Skarsvåg is shown in Figure 10.7.

Based on the composition of the surface samples Skarsvåg is a low-grade graphite deposit, and probably of less industrial interest as a graphite occurrence when compared to the other occurrences on Senja documented here.

Table 10.2: Total Carbon (TC) data from surface samples from the Skarsvåg area.

Locality	N	Average (%)	Max (%)	Min (%)	Stdev (%)	Median (%)
Skarsvåg all	30	1.0	5.4	0.03	1.3	0.4
Skarsvåg TC >0.5 only	13	2.1	5.4	0.5	1.4	1.8

Due to the low quality of the samples and the low TC content, no thin sections were produced from the samples at Skarsvåg. Hence, the petrography is not described in this area.

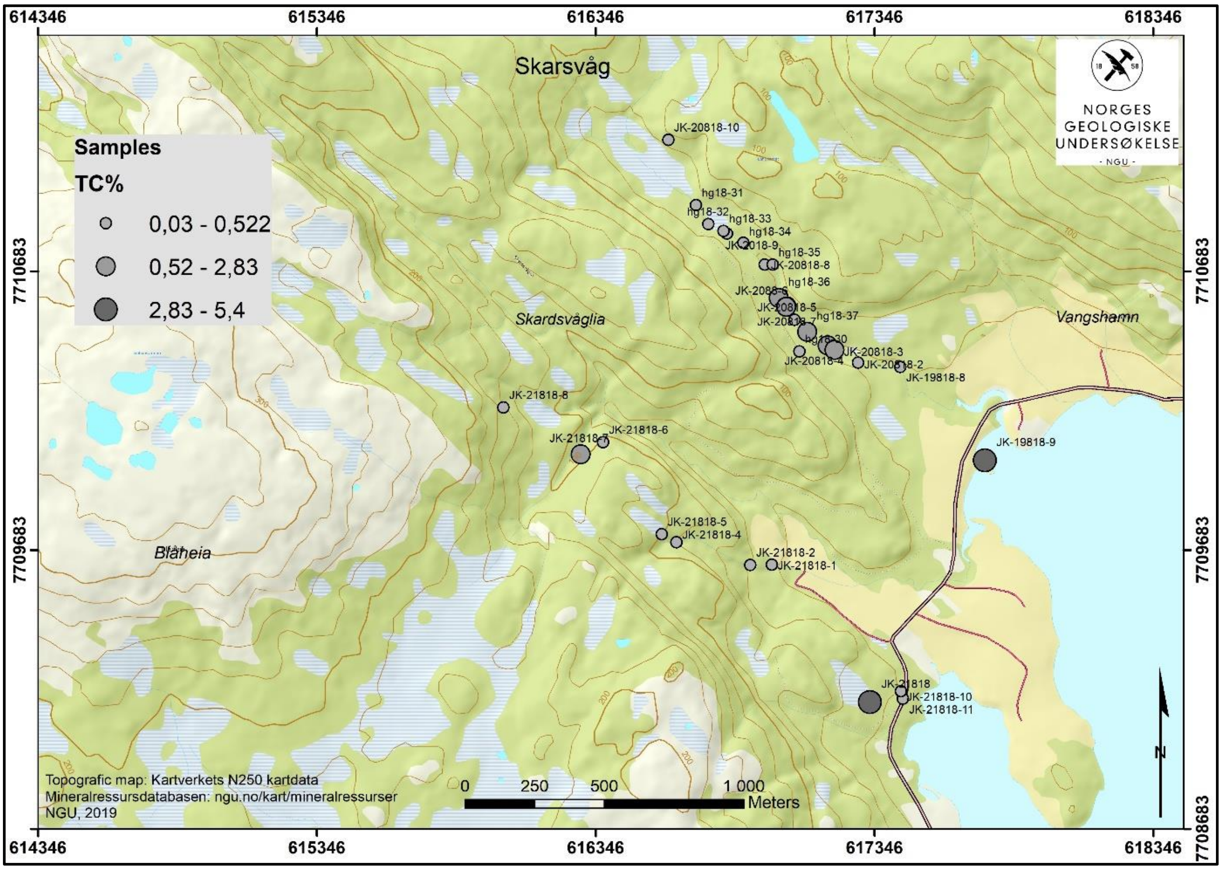

Figure 10.7: Distribution of graphite samples and analysed Total Carbon (%) at Skarsvåg.

11. GEOPHYSICAL AND GEOLOGICAL INVESTIGATIONS IN KVÆFJORD

Ground geophysical EM31 traversing and geological sampling for TC analysis were performed at two areas in Kvæfjord in August 2018.

11.1 Selection of follow-up objects in Kvæfjord

Apparent resistivity calculated from helicopter-borne 7 kHz frequency data (Rodionov et al. 2012) is shown in Figure 11.1. West and south-west of Harstad, numerous resistivity anomalies are clearly visible. A graphite occurrence was discovered by geologists from Harstad (Peter Midbøe and Jon Erik Eriksen) at Øynes, Kveøya (black box), and sampled by NGU in 2016. In June 2018, field reconnaissance showed that several of the resistivity anomalies in the Kvæfjord area also were caused by black schists, and a follow-up with ground geophysics and additional sampling were conducted at Finngammen and Sørli in August 2018 (dashed black boxes in Figure 11.1).

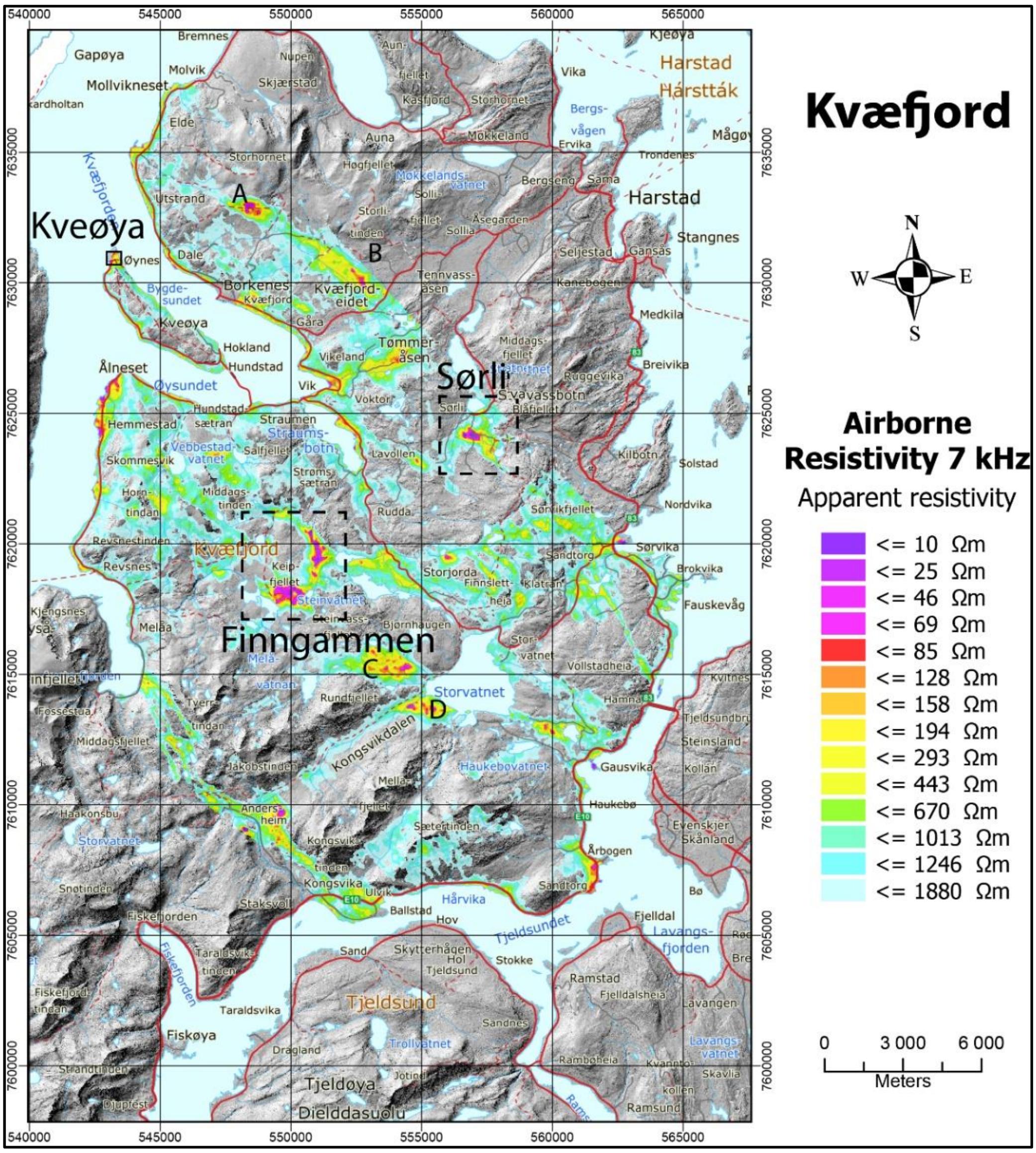

Figure 11.1: Apparent resistivity anomalies and potential graphite showings in Kvæfjord. The areas Finngammen and Sørli were selected for follow-up work.

Several of the resistivity anomalies (A, B, C and D in Figure 11.1) could be a target for follow-up work, but the largest and most accessible anomalies were selected; Finngammen in Melåmarka and Durmålshaugen / Middagshaugen south of Sørli. After initial field reconnaissance and sampling, these two areas were then investigated with EM31 profiling and additional sampling.

11.2 Finngammen area

The Finngammen area is situated about 17 km SW of Harstad and is accessable via forest roads and walking from Oldervika in the innermost part of Straumsbotn. The area consists of two individual geophysical anomalies: Finngammen North and Finngammen West.

At the **Finngammen North** (Figure 11.2), the apparent resistivity measured from helicopter shows a ca. 1.5 km long NS trending continuous low resistivity area. Follow-up work with EM31 confirms this anomaly and indicates near outcropping conductive material along the entire anomaly. The apparent conductivity is often higher than 200 mS/m (apparent resistivity < 5 Ωm) which may suggest graphite mineralisation.

At **Finngammen West** (Figure 11.2), the helicopter-borne apparent resistivity indicates a potential graphite mineralised area of ca. 1 km x 0,5 km, but with varying apparent resistivity. EM31 follow-up work shows partly apparent conductivity higher than 200 mS/m, indicating graphite, but also areas with less apparent conductivity. The latter can be caused by inhomogeneous mineralisation or variations in the soil thickness.

The two Finngammen areas are both soil covered with but outcrops can be found in stream sections and other scattered locations. The rock type is always a metamorphic black shale containing amorphous graphite only. Crystalline flake graphite, as described from Senja (Chapters 6 to 10, this report), is not observed in this area. Most commonly the black shale appears as a schistose shale and is locally strongly deformed (Figure 11.3). Apart from later quartz-rich veins, the shale appears to be relatively homogenous.

However, carbon analysis show that the total carbon content (TC) can be high and in some samples, more that 25 % TC are found. At Finngammen North, three locations of amorphous graphite were observed and in Finngammen West five locations (Figure 11.2). Average Total Carbon content is given in Table 11.1. Summary of modal content of graphite is given in section 11.5.

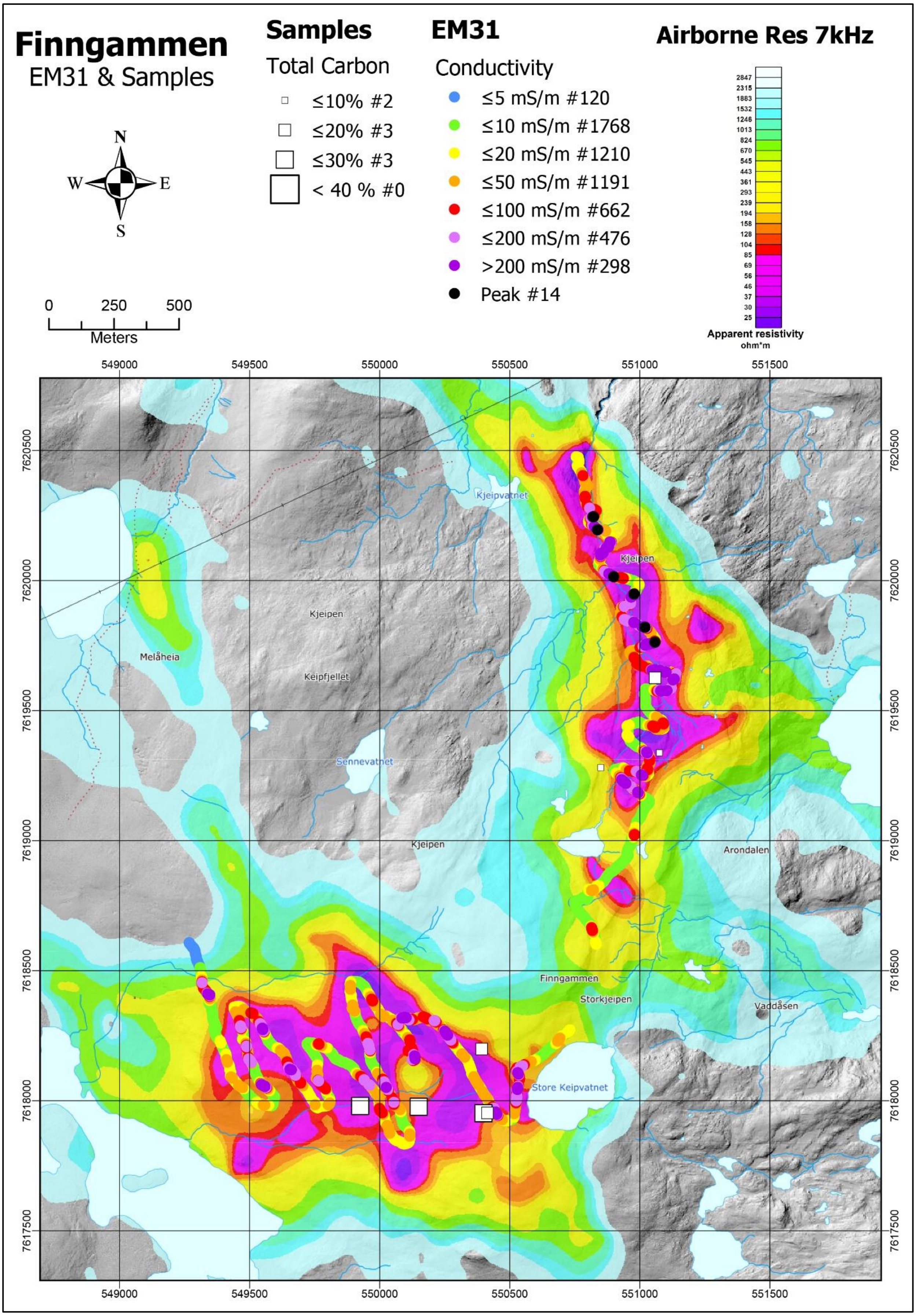

Figure 11.2: Results of EM31 measurements at Finngammen West and North superimposed on apparent resistivity (7 kHz, from Rodionov et al. 2012). Location of graphite samples and their Total Carbon grade is given with white squares.


Figure 11.3: Outcrop of black schist in the Finngammen area.

11.3 Sørli area

The Durmålshaugen and Middagshaugen localities in the Sørli area is situated about 10 km SE of Harstad. The whole anomaly area is located within a military exercise area with restricted access. Permission from the army is needed to visit the area. With a permit, the area is easily accessed via several dirt roads.

South of Sørli, the apparent resistivity calculated from helicopter-borne EM measurements, identifies a 200 m x 600 m anomalous area with low resistivity (Figure 11.4). Apparent resistivity is partly less than 25 Ωm which can indicate graphite. The EM31 follow-up profiling shows only sporadic apparent conductivity that can be associated with graphite. This can be caused by inhomogeneous mineralisation or variations in the soil thickness.

Black schist of similar type as in the Finngammen area, is exposed in numerous small road sections (Figure 11.5). The rock appears as a schistose, rusty, strongly weathered and sulphide rich black schist. As for the Finngammen area, coarse grained crystalline flake graphite is not found.

At Sørli, seven samples of sulphide rich black schist were collected. The locations are shown in Figure 11.4 and coordinates in Appendix 5. Average Total Carbon content is given in Table 11.1. In addition to being amorphous graphite, the average TC is low.

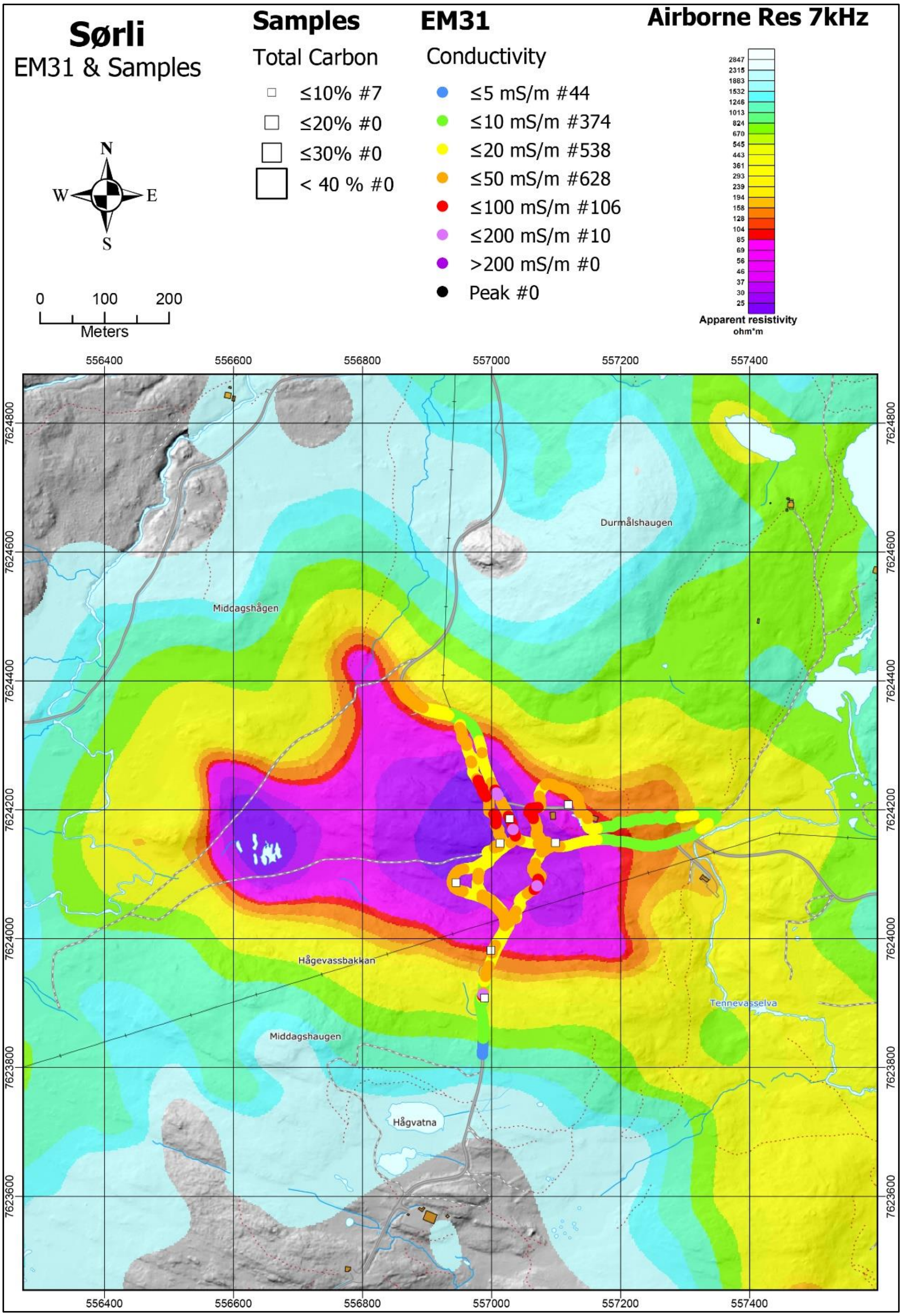

Figure 11.4: Results of EM31 measurements at Sørli superimposed on apparent resistivity (7 kHz, from Rodionov et al. 2012). Location of graphite samples and their Total Carbon grade is given with white squares.

Figure 11.5: Road section south of Sørli showing the brown rusty graphite and sulphide bearing black schist.

11.4 Kveøya and other mineralisation

At Øynes, the northernmost end of the Kveøy island (Figure 11.1), graphite schist of the low metamorphic grade was confirmed in 2016. The associated geophysical anomaly is of small size and partly blanked out by the sea. The black shale has a high carbon content with values up to 28 % TC. However, the graphite is microcrystalline and belongs to the amorphous type, and we believe that this occurrence also is of limited economic significance.

Elsewhere in Kvæfjord, north-west of Sørli and south-east of the Finngammen area, four other anomalies from helicopter-borne electromagnetic measurements displays similar geophysical signatures as those visited south of Sørli and the Finngammen area (A, B, C and D in Figure 11.1). These anomalies have not been visited, but are believed to be caused by black schists, as well. We assume that the Kvæfjord area does not contain graphite of the same good quality type (coarse grained flake graphite) as on Senja or in Vesterålen (Rønning et al. 2017 and 2018).

Table 11.1: Total Carbon (TC) data from 25 surface samples from the Kvæfjord area.

Kvæfjord	N	Average (%)	Max (%)	Min (%)	Stdev (%)	Median (%)
Finngammen	13	13.9	25.8	2.3	8.1	15.1
Sørli	10	2.8	3.7	2.2	0.4	2.7
Kveøy	4	17.1	28.1	3.0	17.7	15.6

All the investigated geophysical anomalies and probably most other geophysical EM anomalies are associated with metamorphic black schists containing microcrystalline (amorphous) graphite only (Figure 11.6, 11.7 and 11.8). The carbon content can be high at selected localities. However, by all probability the graphite bearing rocks of the Kvæfjord area are of limited interest to the graphite industry due to the absence of flake graphite.

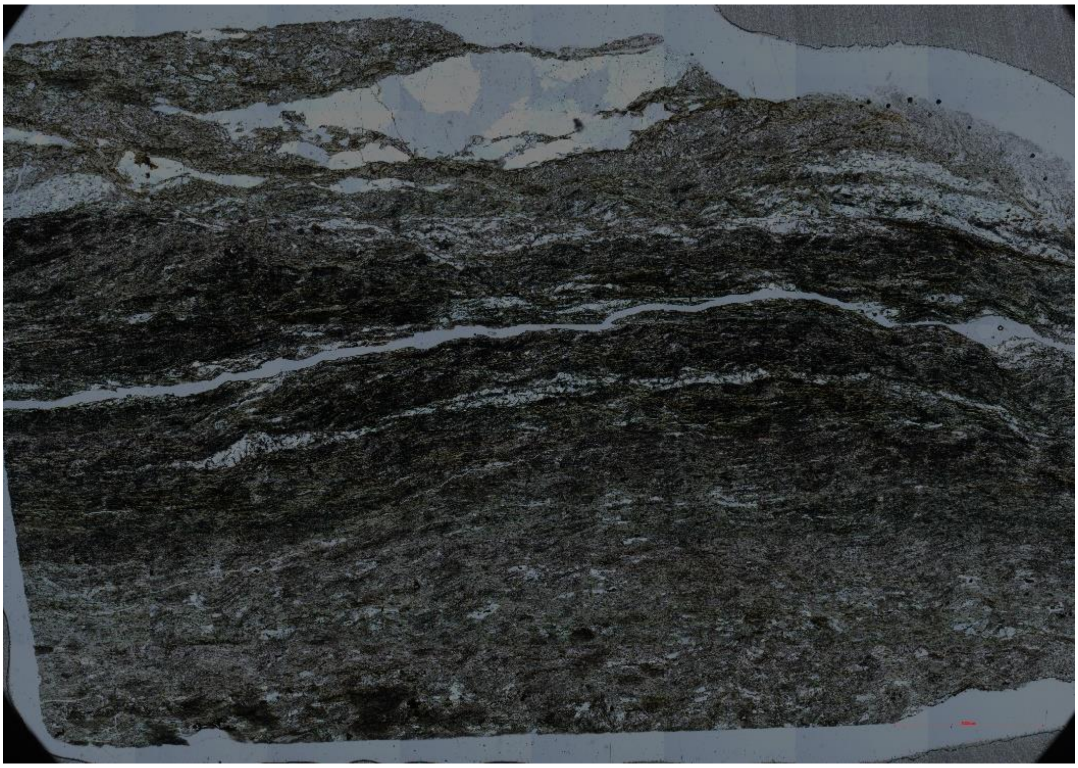

Figure 11.6: Micro-photo of thin section from Finngammen, Kvæfjord (HG18-44), showing the fine-grained nature of the graphite flakes, typical for graphite that the industry classifies as amorphous.

Table 11.2: Example of analysed grain size of graphite minerals at Kvæfjord (sample HG18-44).

Locality	Average size (µm)	Max size (µm)	STdv (µm)	Median (µm)
Kvæfjord	52	1095	41	40

The calculated diameter of graphite crystals indicate that the average grain size is in the same order of magnitude as on Senja, but the maximum grain size is somewhat smaller. The Kvæfjord samples are relatively carbon rich (Table 11.1), but the grain size distribution of graphite flakes has a higher proportion of smaller grains compared to most localities on Senja. This demonstrates that the method for grain size calculations described in section 4.2.2 can be misleading.

Two other micro-photos of thin sections are shown in Figures 11.7 and 11.8. These show a typical grain size of 10 – 20 microns (0.01 – 0.02 mm) and between 5 and 10 microns (0.005 – 0.01 mm) respectively and can be characterized as microcrystalline (amorphous) graphite.

Figure 11.7: Micro-photo of thin section from Finngammen (BD Kvæ1813, 21.1 % TC, 21.0% TOC), show the fine-grained nature of the graphite flakes, typical for graphite that the industry classifies as amorphous.

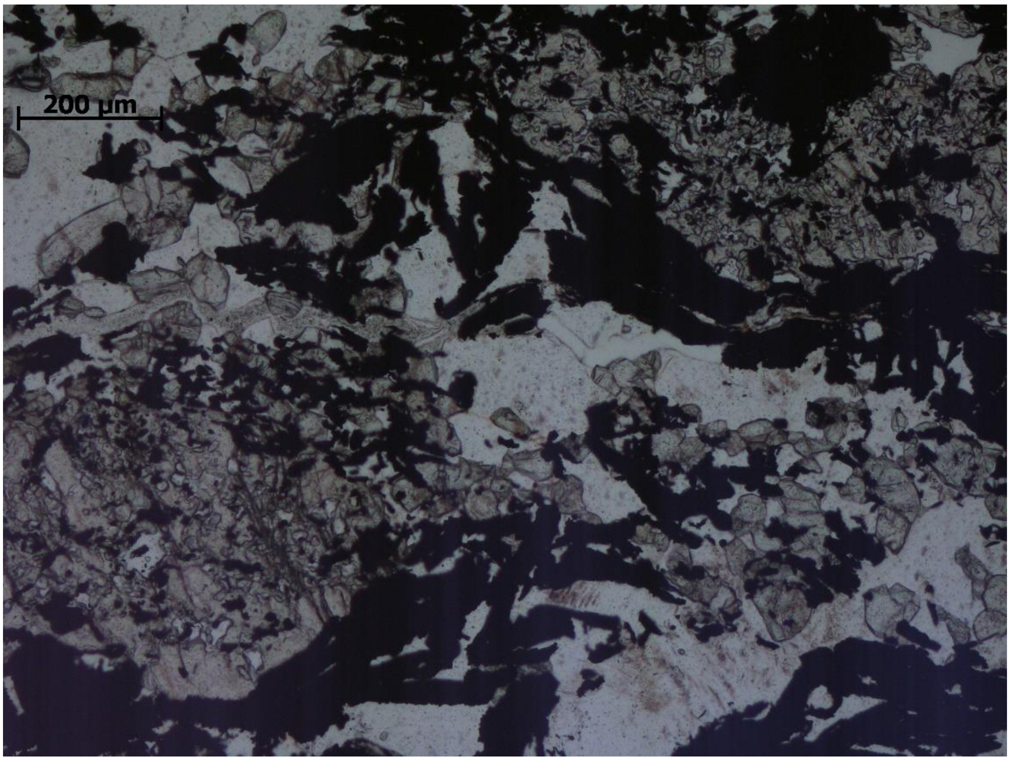

Figure 11.8: Micro-photo of thin section from Kveøya (BD Kvæ1602B, 20.6% TC, 20.4 % TOC) showing the fine-grained nature of the graphite flakes, typical for graphite that the industry classifies as amorphous.

12. OTHER RESULTS

In addition to our site investigations, the modal content of graphite in thin sections has been examined. This chapter provides a summary of total carbon and total sulphur analysis.

12.1 Modal analysis of graphite content

On selected samples, we measured the modal content of graphite using image processing. The data are compared to the corresponding Leco analyses of TC (Table 12.1). The data from 2016 and 2018 are aggregated.

Table 12.1: Modal % of graphite and weight percent of graphitic carbon (Cg) in some selected samples from Hesten, Vardfjellet, Bukken, Bukkemoen Grunnvåg, and Kvæfjord (Sørli and Finngammen).

Sample	Locality	Vol % graphite	% TC
jk110816-1	Bukkemoen	6.1	5.1
hg18-9	Bukken	33.5	19.7
hg18-11	Bukken	6.6	1.8
hg18-14	Bukken	18.3	17.2
hg18-15	Bukken	9.0	3.3
Bukken average		16.8	10.5
hg18-45	Finngammen	8.5	8.7
hg18-44	Finngammen	3.5	5.6
Finngammen average		6.0	7.2
JK120816-2	Grunnvåg	26.8	14.9
JK120816-3	Grunnvåg	34.8	6.7
hg18-25	Grunnvåg	11.1	4.6
hg18-28	Grunnvåg	23.3	9.5
hg18-29	Grunnvåg	31.1	4.5
Grunnvåg average		25.5	8.0
hg39-16	Hesten	22.2	12.8
hg24-14	Hesten	12.6	4.0
hg30-14	Hesten	4.6	5.5
Hesten average		13.1	9.6
hg18-50	Sørli	19.0	3.5
hg18-48	Sørli	10.1	2.7
Sørli average		14.5	3.1
jk4-020816	Vardfjellet	21.2	6.7
hg45-16	Vardfjellet	30.9	23.6
Vardfjellet average		26.1	15.6

The modal or volume % of graphite should always be larger than the weight % (% TC) in a rock (by a factor of 2.266). However, this relationship is never straight forward since a thin section only represents about 3 cm^2 and a chemical analysis represents a hand size (or larger) sample. Sample heterogeneity will therefore strongly affect the modal measurements of graphite.

Our image processing measurements also gave information of grain size variation for the graphite crystals. However, measurements of grain size from thin section image processing will give results that are very different from what might be expected after crushing and ore beneficiation. It is therefore not relevant to present these data.

12.2 Summary of sulphide and carbon analysis

After the investigations of 2018, a data set comprising 159 surface samples has been collected of graphite schist (63 samples from 2016). These samples have been grouped in the same sub-areas as used in the descriptions above. Our complete database (Appendix 5) also contains some samples that are characterised as country rocks (amphibolite and different type of gneisses which contain TC usually < 0.5 %). When these samples are excluded from the dataset, the following table can be constructed (Table 12.1) to show the variation in graphite content between the different sub-areas.

Table 12.2: Variation in the graphite content in the investigated areas and sub-areas.

Variation in TC Area/Sub-area	N	Average (%)	Maximum (%)	Minimum (%)	StdDev (%)	Median (%)
Bukkemoen						
Bukkemoen	20	5.16	14.13	2.21	3.33	4.03
Bukken	27	6.54	19.70	0.58	4.51	5.01
Litjkollen	4	5.30	16.30	0.64	7.39	2.13
Grunnvåg						
Grunnvåg	37	5.23	14.85	0.54	2.75	4.88
Skarsvåg						
Skarsvåg	13	2.05	5.41	0.51	1.43	1.76
Vardfjellet-Hesten						
Hesten	21	5.77	12.81	1.72	3.02	5.48
Vardfjellet	37	9.19	40.30	1.12	7.49	6.86
GrandTotal	**159**	**6.18**	**40.30**	**0.51**	**5.05**	**5.09**

The investigated graphite occurrences on Senja show certain common characteristics. Except for the Vardfjellet and Skarsvåg areas, other occurrences have about the same average TC values which is approximately 5 to 6 % TC. For these deposits, the median value is close to or a little less than the average. For Vardfjellet and Skarsvåg the average TC is approximately 9 % and 2 % respectively. For Vardfjellet, the median value is 6 % TC showing that the high average of 9 % is dominated by some very graphite rich samples (max TC of 40.3 % TC) in the dataset. For Skarsvåg the average and median are close to the mean value.

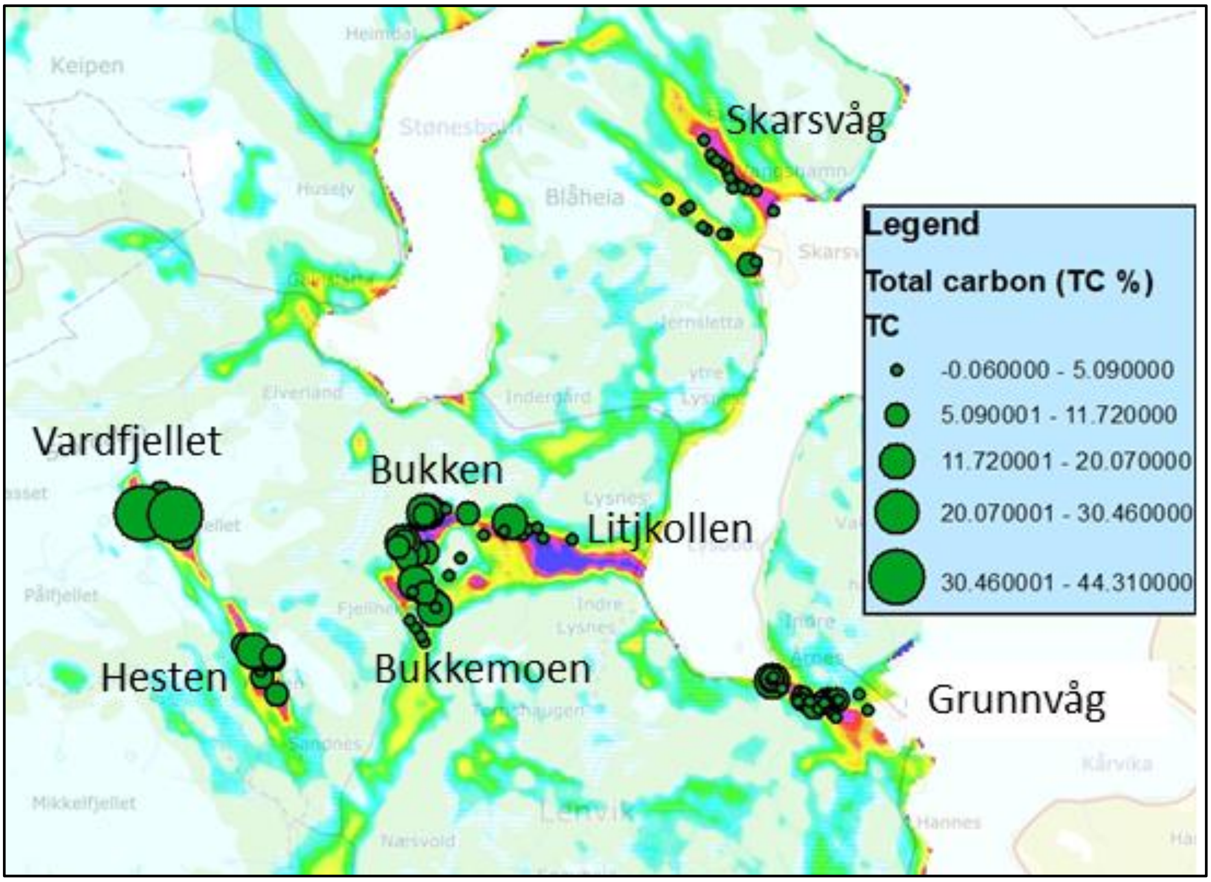

Figure 12.1: A visual image of the Total Carbon content at locations on Senja.

The same analysis can be done for total sulphur (Table 12.3 and Figure 12.2).

Table 12.3: Variation in the sulphur content in the investigated areas and sub-areas.

Variation of TS Area/Sub-area	N	Average (%)	Max (%)	Min (%)	StdDev (%)	Median (%)
Bukkemoen						
Bukkemoen	20	0.71	4.09	0.05	1.00	0.32
Bukken	27	0.98	11.90	0.02	2.61	0.14
Litjkollen	4	0.08	0.14	0.01	0.06	0.07
Grunnvåg						
Grunnvåg	37	1.98	12.50	0.11	2.43	1.15
Skarsvåg						
Skarsvåg	13	1.88	3.55	0.10	1.07	1.90
Vardfjellet Hesten						
Hesten	21	0.22	0.85	0.01	0.23	0.12
Vardfjellet	37	0.29	1.32	0.02	0.24	0.24
Grand Total	**159**	**0.97**	**12.50**	**0.01**	**1.79**	**0.32**

The total sulphur (TS) is low with average values less than 1% for all deposits except for at Bukken, Skarsvåg and Grunnvåg.

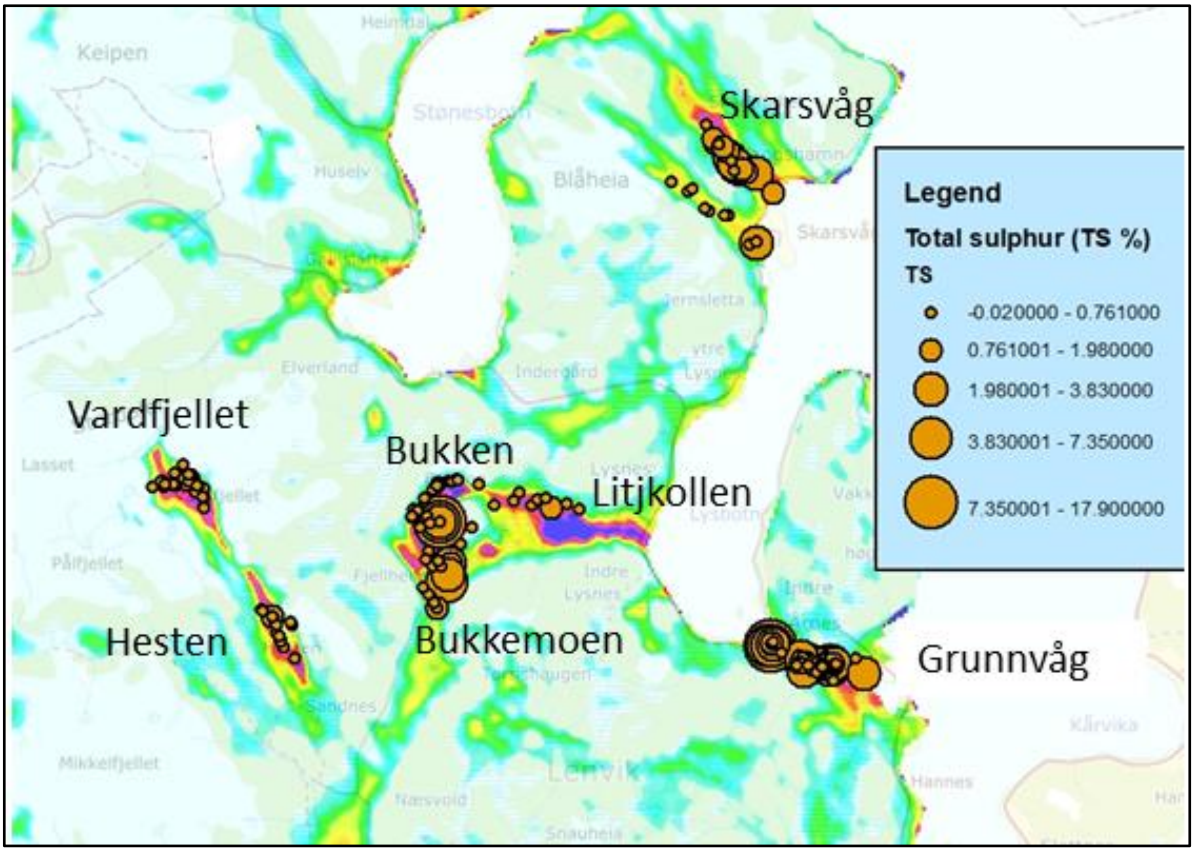

Figure 12.2: A visual image of the Total Sulphur content at locations on Senja.

To conclude, we believe that the present dataset gives an optimum overview of the graphite content variation from surface sampling on Senja.

12.3 Beneficiation test

The mineralogy of the graphite schist on Senja is essentially the same as in the Vesterålen area. Gautneb et al. (2017) reported results from bench scale beneficiation tests of Vesterålen graphite schists. The results were successful and using standard methods it is possible to obtain a final graphite concentrate with more than 95% graphite carbon and a good recovery (see Gautneb et al. 2017 for details). Most likely, such results will also be possible with rocks from Vardfjellet and Hesten.

13. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

In this chapter we give a summary of our investigations, we conclude and give recommendations for further work.

13.1 Summary, conclusions and recommendations, Hesten

At Hesten, outcropping graphite mineralisation is mapped for a total length of ca. 1 km. The graphite is partly soil covered, and geophysical mapping indicates graphite with a total length of ca. 2 km. The total width of the mineralised zone is from ca. 100 up to ca. 400 m. There is clear evidence that several graphite zones are present, with a possibility of up to 8 – 10 individual zones. The thickness of these is measured to 3 – 4 m at two locations. However, we have no data for all the individual zones, and the actual thicknesses could be more. The outcropping graphite layers dip steeply (ca. 70º) to the west at the surface. Charged Potential measurements (CP) indicate that graphite bodies are electrically connected, and the size (length along strike and depth extend) of individual lenses is not possible to map using the CP method in this area.

The graphite appears partly enriched in individual layers and partly evenly distributed in the rock. The dominating minerals are quartz, feldspar (mainly orthoclase), biotite and graphite. In general, there is a very limited sulphide occurrence. The individual graphite crystals size in the rock varies from approximately 50 to 2000 microns. Some samples have high carbon content where the crystal size can reach several centimetres. The mineralisation appears as flake graphite and can be of economic value.

Bedrock and structural investigations have previously been performed by Henderson & Kendrick (2003) and show that the graphite schist on the surface consists of several apparently isolated lenses that are isoclinally folded and refolded. Complex structural episodes have both created and modified the graphite deposits and the graphite is intimately associated with the development of F_2 folds, as graphite is best developed geographically in association with north-south striking F_2 fold hinges. In addition to the folding, several deformation sequences have influenced the graphite structures.

In total 21 samples from the Hesten area were analysed for total carbon (TC) and total sulphur content (TS). Individual sampling points and analysis are presented. The average TC content is 5.8 % with a maximum and minimum of 12.8 % and 1.7 %. The standard deviation is 7.5 %. The average sulphur content in samples from Hesten is 0.2 % with a maximum value of 0.9 %.

Despite the relatively low graphitic content in the Hesten mineralisation (average 5.8 %), the total area of graphite is quite large and the potential for economic mineralisation is high. This graphitic carbon content is comparable with content in deposits under development in Canada and Mozambique. NGU recommends further investigation with detailed ground electromagnetic measurements prior to core drilling. This activity is outside of the scope of studies for NGU and must be financed by a prospecting company.

13.2 Summary, conclusions and recommendations, Vardfjellet.

At Vardfjellet, the graphite mineralisation is better exposed at the surface than at Hesten, and graphite can be found over an area of 1.7 km in length and up to 350 m in width. Geophysical mapping indicates graphite with a total length of ca. 2 km. The total width of the graphite mineralised zone based on detailed EM31 measurements is from ca. 4 m up to more than 100 m. The graphite quality within these zones can vary, and there can be thin zones of low graphite content within the individual zones. The observed individual thickness of these is 7 m at one location and measured to 3 – 5 m at two other locations. Due to the intense folding observed at Vardfjellet, the dip of the graphite zones varies but the graphite dips mostly steeply towards the west. Charged Potential measurements (CP) indicate that the graphite bodies are electrically connected, and the size (length along strike and depth extend) of individual lenses is not possible to map using the CP method.

The graphite appears partly enriched in individual layers and locally evenly distributed in the rock. The dominating minerals are quartz, feldspar (mainly orthoclase), biotite and graphite. In general, there is a low sulphide content. The mineralisation appears as flake graphite. The individual graphite crystals size in the rock varies from approximately 50 to 2000 microns, with some samples with high carbon content where the crystal size can reach several centimetres. This is a size range *in situ* that can give coarse grained flake size of economic value in the final product.

In total 37 samples from the Vardfjellet area were analysed for total carbon (TC) and total sulphur content (TS). Individual sampling points and analyses are presented. The average TC content is 9.2 % with a maximum and minimum of 40.3 % and 1.1 %. The standard deviation is 7.5 %. Total sulphur (TS) content at Vardfjellet is slightly higher than at Hesten but still low. Average TS value is 0.3 % with a maximum value of 1.3 %.

As for Hesten, bedrock and structural investigations have previously been performed by Henderson & Kendrick (2003) and show that the graphite schist on the surface consists of several apparently isolated lenses that are isoclinally folded and refolded. Complex structural events have both created and modified the graphite deposits and the graphite is intimately associated with the development of F_2 folds, as graphite is best developed geographically in association with north-south striking F_2 fold hinges. In addition to the folding, several deformation episodes have influenced the graphite structures.

Despite the relatively low graphitic content in the Vardfjellet mineralisation (average 9.2 %), the total area of graphite is quite large, and the potential for economic mineralisation is high. This graphitic carbon content is comparable with content in deposits under development in Canada and Mozambique. To get a better understanding of how high-grade graphite occurs at Vardfjellet, NGU recommends further investigation with ground electromagnetic measurements prior to core drilling. This activity is outside of the scope of studies by NGU and must to be financed by a prospecting company.

13.3 Summary, conclusions and recommendations, Bukken

The Bukken deposit is divided into three sub-areas: Bukkemoen (southern part), Bukken (northern part) and Litjkollen (eastern part). The Bukken area is located north of Lysvatnet in the north-eastern part of Senja.

In 1988, NGU performed a detailed study of the **Bukkemoen** area. Here, two electric conductive structures were observed (Lauritsen 1988). Detailed studies indicated that these consist of several graphite lenses in electrical contact to each other. The total length was estimated to be more than 1 km. Helicopter-borne EM measurements and ground EM31 follow-up measurements confirmed a total length of 1.25 km. Detailed EM31 studies indicated individual widths from 10 m to approximately 700 m. The graphite quality within these zones is variable, and there can be thin zones with low graphite content.

The **Bukken** area is located to the north of Bukkemoen, in the high mountain area. These two locations form a boomerang shaped conductive structure in the helicopter-borne electromagnetic data. The total length of this structure is more than 2 km. EM31 follow-up work indicates graphite bearing structures with widths from 10 m and up to 700 m width, mostly perpendicular to the strike direction. The quality within these structures can vary, and there can be low graphite content within individual zones. The graphite lenses are steeply dipping towards the west, and there appears to be a huge volume of graphite bearing rocks in this area.

The **Litjkollen** area is situated east of Bukken, between the Bukken mountain and the lake “Sjøvatnet” at sea-level. In this area a 1.6 km long EM anomaly from helicopter-borne measurements was confirmed by EM31 ground follow-up work. The anomaly may continue underneath the lake Sjøvatnet. Several conducting structures are indicated, and the total thickness varies from 2 m up to more than 200 m. The thickest structures seem to consist of several individual lenses of graphite. The deposit is intensively folded and faulted with an isoclinally fold closing in the east. The area is almost 100 % soil covered, and only four exposures with graphite were observed.

The total carbon content (TC) is relatively homogenous in the three areas of Bukken, Bukkemoen and Litjkollen. In total, 51 samples were analysed, and the average TC content is 6.2 %. Maximum TC values from the three areas are approximately 20 %. Total Sulphur (TS) concentrations are mostly less than 1 %, but in some samples, values higher than 10 % are observed. The graphite crystals size in one thin section shows an average value of 25 microns and a maximum value of 1807 micron. In some samples with high carbon content, the crystal size can reach several centimetres. This is a size range *in situ* that can give coarse grained flake size of economic value in the final graphite product.

NGU has made two short core drillings almost perpendicular to the dip in the Bukkemoen area. Graphite bearing rocks are confirmed over a length of 35 m and 29 m in the two drill-holes. The latter can be even thicker since drilling started within the structure. The Total Carbon (TC) in drill cores are relatively low, varying between 2 and 5 %. The Total Sulphur varies between 4 and 8 %.

The Bukken area contains extensive amounts of graphite bearing rocks. The grain size is of an economically interesting size, but the presently documented content of graphite is not economically viable. This area should be explored further, and detailed ground geophysics and deeper core drilling is recommended in all three areas.

13.4 Summary, conclusions and recommendations, Grunnvåg

At Grunnvåg, an approximately 1.5 km long and ca.100 m wide apparent resistivity anomaly from helicopter-borne electromagnetic measurements was observed. Reconnaissance work performed in 2016 discovered graphite mineralisation in the northern part of the anomaly.

Follow-up work with EM31 confirmed the anomaly from helicopter-borne measurements. Detailed studies indicated several conductive structures where thicknesses vary from 5 m, to several tens of metres and even up to more than 200 m. All values were measured perpendicular to the main strike direction. Despite a high level of soil cover, geological mapping confirmed the presence of graphite distributed almost all over the area. In the central part of the area, graphite is exposed continuously with a total length of 265 m and with a width ranging from 55 to 90 m.

The graphite occurs as bands which have been isoclinally folded, creating a double-closing graphite isocline in both the western and eastern parts of the deposit. The axial planar faulting, dissecting and complicating the geometrical signature of the graphite observed in other deposits, is not observed in the Grunnvåg deposit.

Analysis of 37 samples from the Grunnvåg area shows an average Total Carbon (TC) content equal 5.2 % and a maximum value of 14.9 %. The average Total Sulphur (TS) is ca. 2 % with a maximum value of 12.5 %. This is slightly higher than in the Bukken and Vardfjellet/Hesten deposits. The graphite crystal size in one thin section shows an average value of 37 microns and a maximum value of 3477 micron. This is almost the same as in the other areas on Senja, and a size range *in situ* that can give coarse grained flake size of economic value in the final product.

NGU has made one short core drilling almost perpendicular to the dip direction in the north-western part of the Grunnvåg area. Graphite bearing rocks are confirmed over a length of ca. 35 m. The thickness can be even more than this since drilling started within the structure. The Total Carbon (TC) in drill cores is relatively low, varying from 2 to 5 %. The maximum TC is 8 % with a total length of 4 m. The Total Sulphur varies between 4 and 7 % which fits with the TS content at surface samples.

The Grunnvåg area contains extensive amounts of graphite-bearing rocks. The grain size is economically interesting, but the content of graphite is not economically viable. This area should be explored further, and detailed ground geophysics and deeper core drilling is recommended.

13.5 Summary, conclusions and recommendations, Skarsvåg

At Skarsvåg, two structures with anomalous electrical conductivity were documented from the helicopter-borne electromagnetic measurement (EM) in 2014. The length of both anomalies is ca. 2 km, and the width of the largest is ca. 200 m. Ground based EM31 measurements confirm the helicopter-borne EM anomalies. However, both areas are covered by relatively thick soil (4 - 8 m in some areas) and this resulted in lower apparent conductivity values. Based on EM data, the north-eastern structure is the most interesting.

In both areas, 2D electric resistivity traversing (ERT) was performed in combination with induced polarisation (IP). Results from these measurements indicate graphite or sulphide mineralisation.

Despite a thick soil cover, exposed graphite was found at some locations in both areas. Analysis of 30 graphite-bearing surface samples shows an average TC content of 1.0 % and a maximum value of 5.4 %. If all samples with a TC< 0.5 % are filtered out, 13 samples give an average TC content of 2.1 %. The total sulphur content of these 13 samples was 1.9 % with a maximum value of 3.6 %. Based on this, the Skarsvåg deposit is regarded as a low-grade sulphide-bearing graphite schist.

However, the combined 2D ERT/IP measurements in both areas show a moderate resistivity that can represent low quality graphite in bedrock underneath the soil cover but at a depth of 10 to 20 m, the resistivity decreases in some structures (resistivity < 5 Ωm, conductivity > 200 mS/m). This can indicate graphite of a better quality. Follow up work should be undertaken on this anomaly.

Based on the surface data, the content of TC is so low that the Skarsvåg area is regarded as of limited economic interest. However, the possibility of the presence of a higher quality graphite at moderate depth should be investigated with core drilling.

13.6 Summary, conclusions and recommendations, Kvæfjord

Helicopter-borne EM measurements in Kvæfjord west of Harstad, show several low resistivity anomalies that could be caused by mineralisation of economic interest. The abandoned Berg copper mine at Borkenes is an example of such mineralisation. Reconnaissance work in 2016 and 2018 discovered graphite mineralisation at three locations; Kveøya, Finngammen and south of Sørli. The Kveøya occurrence has a limited extension and appears as non-economic. Some follow-up work with EM31 and sampling were performed at Finngammen and Sørli.

The Finngammen area is divided into two structures. Finngammen North is ca. 1.5 km along the strike while Finngammen West is ca 1.0 km. In both areas, the EM31 measurements confirmed the helicopter-borne EM anomalies. The areas are soil covered, but graphite was found in a few exposures. In all, 13 samples of graphite bearing rock were analysed giving an average TC content of 13.9 % and a maximum value of 25.8 %.

The location called Sørli appears from helicopter-borne EM data as a 600 m x 200 m anomalous area. This is also soil covered, but graphite was found in seven exposures. Average TC content of ten samples was 2.8 % with a maximum value of 3.7 %.

Analyses of the samples and numerous thin sections from the Kvæfjord area shows that the graphite is very fine grained (microcrystalline) and to be classified as amorphous graphite with limited economic value. Based on this, no follow-up work is recommended.

14. REFERENCES

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Appendix 1: Drill-core geology, log descriptions

The collar data for the drill holes is given below:

Locality	Hole no.	UTM X	UTM Y	EOH (m)	AZIMUTH (º)	DIP (º)
Grunnvåg	Dh1	617745	7702291	39.33	0	45
Bukkemoen	Dh1	611971	7703018	41.45	45	45
Bukkemoen	Dh2	612269	7703730	45	37	50

Geological logs:

Drill-hole No.	From	To	Description
Bukkemoen 1-18	0	3.3	Soil, overburden
Bukkemoen 1-18	3.3	38.17	Medium to coarse grained graphite bearing biotite-feldspar gneiss, partly with pyrrhotite and sulphides, feldspar clasts up to 5 cm-with coarse grained graphite clasts
Bukkemoen 1-18	38.2	41.45	Medium to coarse grained biotite-amphibole gneiss with sulphides in traces, felsic veins 1-2 cm, calcite vein 5 mm (at 40,25m)
Bukkemoen 2-18	0	24	Greenish greyish fine to medium grained Graphite bearing-biotite feldspar gneiss with pyroxene (low grade graphite) with graphite veins, felsic vein 1-3cm, sulphide veins 1 mm-2 cm; py, cpy? bornite? phlogopite? greenish thin sharp phenocrystals, clay minerals. Variable content of graphite and feldspar is visible along interval.
	24	37.52	Dark greyish greenish medium grained amphibolite with irregular felsic veins from 0.3 mm to 4 cm (plagioclase, qz) pyrrhotite veins from 1mm to 3 cm, calcite veins 1mm, partly very weak graphite in traces & lt;1%
Grunnvåg	0	5	Overburden
Grunnvåg	5	39.33	Greyish medium grain graphite bearing biotite-feldspar gneiss; with graphite bands (1mm to 30 cm), felsic bands (2 mm to 30 cm), calcite veins (3 mm to 1cm), abundant within pyrite, pyrrhotite. Frequent repetition of mm graphite, felsic, calcite rich bands. 15-21 zones richer in graphite. From 21 to 39.33 greenish greyish graphite bearing-biotite feldspar gneiss richer in mica minerals (muscovite?), and chlorite? with more feldspar; graphite in thin layers, a thin massive graphite vein 37,55-37,68 = 13cm.

Appendix 2: Drill-core pictures

Pictures of drill cores, Bukkemoen and Grunnvåg.

The collar data for the drill holes is given below:

Locality	Hole no.	UTM X	UTM Y	EOH (m)	AZIMUTH (°)	DIP (°)
Grunnvåg	Dh1	617745	7702291	39.33	0	45
Bukkemoen	Dh1	611971	7703018	41.45	45	45
Bukkemoen	Dh2	612269	7703730	37.52	37	50

Bukkemoen DH 1: BOX 1, 3 – 10 m.

BUKKEMOEN DH1: BOX 2, 10 – 20 m.

BUKKEMOEN DH1: BOX 3, 20 – 30 m.

BUKKEMOEN DH1: BOX 4, 30 – 40 m.

BUKKEMOEN DH1-18: BOX 5, 40 – 41,45 m.

BUKKEMOEN DH 2-18: BOX 1, 0 – 9.9 m.

BUKKEMOEN DH 2-18: BOX 2, 9.9 – 19.8 m.

BUKKEMOEN DH 2-18: BOX 3, 19.8 – 29.75 m. Note: Wrong numbering at drill-cores.

BUKKEMOEN DH 2-18: BOX 4, 29.75 – 37.52 m. Note: Wrong numbering at drill-cores.

GRUNNVÅG Dh 1-18: BOX1, 5 -10 m.

GRUNNVÅG Dh 1-18: BOX2: 10 -19.8 m.

GRUNNVÅG Dh 1-18: BOX3, 19.8 – 28.75 m.

GRUNNVÅG Dh 1-18: BOX4, 28.75 – 39.33m.

Appendix 3: TS and TC drill-core chemical analysis

The collar data for the drill holes is given below:

Locality	Hole no.	UTM X	UTM Y	EOH (m)	AZIMUTH (°)	DIP (°)
Grunnvåg	Dh1	617745	7702291	39.33	0	45
Bukkemoen	Dh1	611971	7703018	41.45	45	45
Bukkemoen	Dh2	612269	7703730	37.52	37	50

In general, each core was sampled, crushed, homogenised and analysed for every second meter. The results are listed below.

NGU Lab no.	Drill hole no.	Sample no.	Depth from (m)	Depth To (m)	%TS	%TC
195001	Bukkemoen1	Bukkem1 (4-6)	4	6	4.79	3.20
195002	Bukkemoen1	Bukkem1 (8-10)	8	10	4.82	3.40
195003	Bukkemoen1	Bukkem1 (12-14)	12	14	3.51	2.26
195004	Bukkemoen1	Bukkem1 (16-18)	16	18	5.38	3.62
195005	Bukkemoen1	Bukkem1 (20-22)	20	22	4.85	3.56
195006	Bukkemoen1	Bukkem1 (24-26)	24	26	5.04	3.51
195007	Bukkemoen1	Bukkem1 (28-30)	28	30	5.56	3.90
195008	Bukkemoen1	Bukkem1 (32-34)	32	34	3.50	2.39
195009	Bukkemoen1	Bukkem1 (34-36)	34	36	4.59	2.26
195010	Bukkemoen1	Bukkem1 (38-40)	38	40	0.57	< 0.06
195011	Bukkemoen2	Bukkem2 (0-2)	0	2	5.32	3.77
195012	Bukkemoen2	Bukkem2 (2-4)	2	4	5.18	2.98
195013	Bukkemoen2	Bukkem2 (6-8)	6	8	4.20	2.77
195014	Bukkemoen2	Bukkem2 (10-12)	10	12	3.61	2.44
195015	Bukkemoen2	Bukkem2 (14-16)	14	16	2.73	0.965
195016	Bukkemoen2	Bukkem2 (18-20)	18	20	5.07	2.95
195017	Bukkemoen2	Bukkem2 (22-24)	22	24	2.70	1.17
195018	Bukkemoen2	Bukkem2 (26-28)	26	28	1.75	0.749
195019	Bukkemoen2	Bukkem2 (30-32)	30	32	0.795	0.03
195020	Bukkemoen2	Bukkem2 (34-36)	34	36	1.08	0.03
195021	Grunnvåg	Grunnv (5-7)	5	7	2.27	1.28
195022	Grunnvåg	Grunnv (8-10)	8	10	3.27	1.68
195023	Grunnvåg	Grunnv (11-12)	11	12	4.51	3.04
195024	Grunnvåg	Grunnv (14-16)	14	16	4.26	3.45
195025	Grunnvåg	Grunnv (16-18)	16	18	4.08	6.31
195026	Grunnvåg	Grunnv (19-21)	19	21	5.32	4.39
195027	Grunnvåg	Grunnv (23-25)	23	25	4.70	3.03
195028	Grunnvåg	Grunnv (27-29)	27	29	6.77	2.86
195029	Grunnvåg	Grunnv (31-33)	31	33	3.87	1.51
195030	Grunnvåg	Grunnv (35-37)	35	37	4.35	2.30
195031	Grunnvåg	Grunnv (39-39.3)	39	39.3	0.246	0.265

Appendix 4: Portable XRF analysis of drill-cores

Data given in %.

Drill-hole no	Depth	Si (%)	Al (%)	Fe (%)	Ca (%)	Ni (ppm)	S (%)
Bukkemoen 1	3	30.12	4.73	10.48	5.97	86.90	0.40
Bukkemoen 1	3.5	34.14	4.76	2.90	2.55	-	1.28
Bukkemoen 1	4	29.49	5.22	3.70	2.50	-	0.29
Bukkemoen 1	4.5	22.75	5.36	8.24	2.05	-	3.05
Bukkemoen 1	5	25.98	5.81	6.37	1.98	-	1.54
Bukkemoen 1	5.5	23.59	5.06	9.61	1.61	-	5.56
Bukkemoen 1	6	23.48	5.18	9.01	1.87	86.63	5.64
Bukkemoen 1	6.5	28.57	6.26	5.69	2.35	-	2.34
Bukkemoen 1	7	30.32	5.96	4.83	1.89	-	1.91
Bukkemoen 1	7.5	24.20	5.98	8.86	1.60	-	3.42
Bukkemoen 1	8	25.78	6.01	5.69	2.18	-	1.96
Bukkemoen 1	8.5	30.21	5.22	4.18	2.24	-	1.06
Bukkemoen 1	9	25.54	5.23	6.72	1.46	-	2.15
Bukkemoen 1	9.5	34.70	5.08	3.57	1.60	-	1.66
Bukkemoen 1	10	26.29	5.87	9.32	1.59	67.53	6.31
Bukkemoen 1	10.5	27.22	7.25	6.09	2.82	-	3.36
Bukkemoen 1	11	22.10	6.23	13.69	1.99	178.44	9.78
Bukkemoen 1	11.5	30.70	6.80	5.49	2.12	-	2.63
Bukkemoen 1	12	26.31	7.38	9.93	2.00	60.08	5.77
Bukkemoen 1	12.5	24.69	5.80	6.03	2.15	-	1.51
Bukkemoen 1	13	35.12	5.82	5.47	2.50	-	3.25
Bukkemoen 1	13.5	29.46	7.63	6.91	1.60	-	6.11
Bukkemoen 1	14	37.01	5.61	3.45	2.31	-	0.76
Bukkemoen 1	14.5	25.08	6.43	6.53	2.16	-	2.36
Bukkemoen 1	15	24.70	8.55	6.63	2.53	-	2.77
Bukkemoen 1	15.5	27.58	5.06	6.99	1.92	-	4.20
Bukkemoen 1	16	26.04	6.87	8.58	1.78	-	5.13
Bukkemoen 1	16.5	26.01	6.03	7.22	1.63	-	4.51
Bukkemoen 1	17	27.29	7.49	9.06	2.00	-	5.36
Bukkemoen 1	17.5	29.41	4.71	5.65	1.61	-	2.76
Bukkemoen 1	18	27.81	7.05	4.08	2.50	-	2.75
Bukkemoen 1	18.5	30.87	6.59	8.07	2.00	-	4.75
Bukkemoen 1	19	31.00	4.84	4.31	2.00	-	2.91
Bukkemoen 1	19.5	27.07	5.32	5.21	1.71	-	3.25
Bukkemoen 1	20	25.10	6.24	5.72	1.60	-	1.98
Bukkemoen 1	20.5	21.02	5.34	14.32	2.00	153.07	12.76
Bukkemoen 1	21	31.30	4.19	8.21	1.00	-	4.47
Bukkemoen 1	21.5	21.15	6.27	14.45	2.00	121.99	7.15
Bukkemoen 1	22	38.82	4.20	2.25	0.85	-	1.66
Bukkemoen 1	22.5	33.77	5.88	4.89	2.09	-	1.79
Bukkemoen 1	23	34.37	5.77	2.83	3.05	-	0.60

Drill-hole no	Depth	Si (%)	Al (%)	Fe (%)	Ca (%)	Ni (ppm)	S (%)
Bukkemoen 1	23.5	29.10	6.50	6.58	2.67	-	3.64
Bukkemoen 1	24	23.70	6.36	8.54	1.44	61.76	3.63
Bukkemoen 1	24.5	27.69	6.53	6.26	1.89	-	3.38
Bukkemoen 1	25	28.20	5.50	8.83	2.00	-	5.57
Bukkemoen 1	25.5	23.62	4.51	10.08	2.00	90.33	9.46
Bukkemoen 1	26	27.94	6.38	7.78	1.00	-	4.35
Bukkemoen 1	26.5	25.68	6.04	9.27	3.00	-	5.85
Bukkemoen 1	27	27.89	6.38	7.61	1.52	-	4.58
Bukkemoen 1	27.5	24.29	6.26	7.45	1.86	-	4.80
Bukkemoen 1	28	16.18	5.08	19.35	2.00	294.32	16.90
Bukkemoen 1	28.5	35.10	5.60	2.01	2.75	-	1.06
Bukkemoen 1	29	30.30	6.68	5.69	1.89	-	2.19
Bukkemoen 1	29.5	29.01	5.75	8.59	2.00	-	5.20
Bukkemoen 1	30	37.30	6.21	3.06	2.44	50.09	1.69
Bukkemoen 1	30.5	28.90	7.37	6.70	1.67	-	2.73
Bukkemoen 1	31	26.27	6.24	6.36	1.68	-	6.41
Bukkemoen 1	31.5	38.85	4.87	1.78	1.85	-	1.37
Bukkemoen 1	32	28.39	6.67	7.11	2.00	-	3.92
Bukkemoen 1	32.5	23.85	6.27	8.80	1.82	-	3.85
Bukkemoen 1	33	22.89	6.81	12.41	2.00	103.82	2.30
Bukkemoen 1	33.5	34.01	6.99	4.30	2.71	-	0.59
Bukkemoen 1	34	26.18	5.65	11.06	2.00	85.14	5.46
Bukkemoen 1	34.5	38.68	5.97	8.88	2.00	-	3.06
Bukkemoen 1	35	21.82	7.72	12.08	2.00	140.88	3.44
Bukkemoen 1	35.5	38.96	6.20	3.49	2.85	-	0.22
Bukkemoen 1	36	31.65	6.47	2.77	2.66	-	1.19
Bukkemoen 1	36.5	27.19	6.03	7.03	1.99	-	3.08
Bukkemoen 1	37	27.48	5.42	5.56	1.41	-	1.11
Bukkemoen 1	37.5	28.97	8.07	6.58	1.57	-	3.50
Bukkemoen 1	38	31.54	6.47	9.00	5.05	-	0.44
Bukkemoen 1	38.5	28.63	7.70	7.40	4.19	-	2.00
Bukkemoen 1	39	29.83	7.05	5.67	4.59	-	0.89
Bukkemoen 1	39.5	35.87	4.14	4.12	2.33	-	5.67
Bukkemoen 1	40	26.88	7.11	6.53	3.99	-	0.56
Bukkemoen 1	40.5	28.92	7.55	6.44	4.31	-	1.16
Bukkemoen 1	41	30.12	7.46	4.93	4.26	-	0.36
Bukkemoen 1	41.5	31.57	8.43	4.62	3.95	-	0.56
Bukkemoen 1	42	31.57	8.43	4.62	3.95	-	0.56
Bukkemoen 2	0.7	26.12	5.75	7.92	3.35	-	-
Bukkemoen 2	1.2	37.00	3.89	7.64	3.94	119.94	2.69
Bukkemoen 2	1.7	22.73	2.86	6.31	3.27	-	1.26
Bukkemoen 2	2.7	20.68	3.41	6.61	1.19	105.08	4.97
Bukkemoen 2	3.2	50.28	0.31	0.08	-	-	-
Bukkemoen 2	3.7	34.32	4.86	8.98	1.51	170.60	10.35

Drill-hole no	Depth	Si (%)	Al (%)	Fe (%)	Ca (%)	Ni (ppm)	S (%)
Bukkemoen 2	4.2	26.97	3.36	-	-	-	0.31
Bukkemoen 2	4.7	25.01	4.13	7.98	1.71	103.49	5.23
Bukkemoen 2	5.2	29.96	4.73	8.26	1.46	109.33	5.93
Bukkemoen 2	5.7	32.16	4.91	14.62	-	317.13	12.68
Bukkemoen 2	6.2	21.16	4.62	3.78	2.13	-	0.94
Bukkemoen 2	6.7	27.05	5.18	3.61	2.09	-	1.16
Bukkemoen 2	7.2	27.63	5.11	6.36	2.40	-	4.79
Bukkemoen 2	7.7	27.93	6.22	8.74	1.50	61.02	4.72
Bukkemoen 2	8.2	36.63	2.49	5.94	2.30	114.53	4.95
Bukkemoen 2	8.7	25.40	6.10	6.30	1.73	-	2.18
Bukkemoen 2	9.2	32.12	4.54	5.78	-	53.74	3.32
Bukkemoen 2	9.7	27.55	5.63	9.22	-	102.62	4.39
Bukkemoen 2	10.2	29.34	6.46	7.46	1.29	89.61	4.76
Bukkemoen 2	10.7	30.99	5.60	11.35	1.34	140.00	7.63
Bukkemoen 2	11.2	37.33	7.00	6.90	2.54	86.27	4.33
Bukkemoen 2	11.7	31.75	8.60	6.64	2.88	-	3.96
Bukkemoen 2	12.2	36.11	4.50	7.08	3.50	96.84	4.56
Bukkemoen 2	12.7	28.37	6.14	7.94	6.63	116.06	3.50
Bukkemoen 2	13.2	34.78	5.83	6.48	1.97	78.51	2.43
Bukkemoen 2	13.7	32.90	5.42	10.54	1.59	117.21	6.88
Bukkemoen 2	14.2	26.26	6.62	7.07	2.26	71.05	3.08
Bukkemoen 2	14.7	30.39	6.76	7.68	1.89	-	3.02
Bukkemoen 2	15.2	31.23	7.41	10.25	3.33	93.02	2.43
Bukkemoen 2	15.7	33.87	6.81	7.06	2.18	-	1.54
Bukkemoen 2	16.2	32.60	4.53	7.46	2.53	55.94	1.36
Bukkemoen 2	16.7	33.30	5.54	9.12	3.55	89.36	3.11
Bukkemoen 2	17.2	34.57	5.97	8.69	1.90	200.31	4.07
Bukkemoen 2	17.7	32.21	6.62	6.79	2.18	-	2.74
Bukkemoen 2	18.2	43.23	2.25	6.82	2.69	95.42	2.06
Bukkemoen 2	18.7	30.07	5.17	7.37	3.84	58.32	1.13
Bukkemoen 2	19.2	30.29	6.14	2.75	1.02	-	2.26
Bukkemoen 2	19.7	51.24	0.36	7.92	-	135.85	3.74
Bukkemoen 2	20.2	35.12	6.00	7.51	1.59	107.23	3.98
Bukkemoen 2	20.7	27.17	5.64	0.11	-	-	0.74
Bukkemoen 2	21.2	30.59	6.31	5.41	1.64	-	3.03
Bukkemoen 2	21.7	34.07	5.03	8.05	1.68	86.91	6.16
Bukkemoen 2	22.2	26.96	4.02	7.05	1.65	84.28	3.51
Bukkemoen 2	22.7	33.19	6.72	7.91	1.46	-	5.89
Bukkemoen 2	23.2	37.92	3.90	16.16	1.50	228.90	16.88
Bukkemoen 2	23.7	26.65	10.69	6.01	1.81	50.29	1.91
Bukkemoen 2	24.2	26.95	5.94	7.32	2.04	51.39	2.39
Bukkemoen 2	24.7	28.15	6.18	11.66	2.96	130.35	10.68
Bukkemoen 2	25.2	31.51	5.36	11.97	7.38	-	0.31
Bukkemoen 2	25.7	29.77	5.50	11.55	6.88	-	0.12
Bukkemoen 2	26.2	29.19	7.06	10.88	5.76	-	0.32

Drill-hole no	Depth	Si (%)	Al (%)	Fe (%)	Ca (%)	Ni (ppm)	S (%)
Bukkemoen 2	26.7	33.37	3.74	10.62	5.63	-	0.25
Bukkemoen 2	27.2	27.95	6.23	11.85	4.03	-	0.67
Bukkemoen 2	27.7	23.36	5.69	2.91	3.60	-	1.52
Bukkemoen 2	28.2	30.11	6.85	8.33	6.29	75.95	0.18
Bukkemoen 2	28.7	27.75	6.28	12.33	6.74	-	0.39
Bukkemoen 2	29.2	26.44	5.54	8.98	5.87	61.58	0.05
Bukkemoen 2	29.7	20.39	4.06	9.85	6.62	-	0.16
Bukkemoen 2	30.2	25.52	8.56	9.61	5.50	-	-
Bukkemoen 2	30.7	27.36	8.26	20.48	10.98	302.27	13.08
Bukkemoen 2	31.2	32.66	5.65	10.70	5.98	-	0.89
Bukkemoen 2	31.7	30.17	5.84	9.47	5.42	-	1.22
Bukkemoen 2	32.7	25.16	6.86	10.06	5.42	-	0.19
Bukkemoen 2	33.2	27.37	6.47	9.60	6.94	-	0.32
Bukkemoen 2	33.7	27.52	6.41	0.00	-	1.00	-
Bukkemoen 2	34.2	29.25	5.00	11.55	7.77	-	0.33
Bukkemoen 2	34.7	28.79	6.65	10.95	7.11	-	0.19
Bukkemoen 2	35.2	27.64	6.23	11.67	5.71	-	0.21
Bukkemoen 2	35.7	27.69	5.79	11.82	6.16	-	0.33
Bukkemoen 2	36.2	29.94	9.24	10.47	7.39	-	0.45
Bukkemoen 2	36.7	28.70	5.50	10.70	7.17	84.92	0.66
Bukkemoen 2	37.2	25.97	6.13	10.67	6.82	139.44	0.28
Bukkemoen 2	37.7	25.57	5.97	6.27	4.42	-	2.97
Bukkemoen 2	38.2	27.18	4.27	10.57	5.82	-	0.40
Bukkemoen 2	38.7	25.38	4.49	13.65	5.80	-	0.68
Grunnvåg	5	25.57	8.46	9.91	3.51	115.58	1.75
Grunnvåg	5.5	37.77	4.53	4.64	1.75	-	2.68
Grunnvåg	6	32.38	6.02	6.72	1.67	72.10	1.42
Grunnvåg	6.5	39.69	3.74	3.58	1.08	-	0.81
Grunnvåg	7	33.68	6.76	0.59	1.36	-	0.35
Grunnvåg	7.5	29.27	6.88	8.11	2.04	-	2.01
Grunnvåg	8	25.54	8.68	7.90	1.98	-	1.26
Grunnvåg	8.5	27.24	9.50	9.45	1.74	-	3.16
Grunnvåg	9	26.94	6.07	6.96	2.39	-	3.74
Grunnvåg	9.5	27.01	6.90	7.59	1.33	-	1.60
Grunnvåg	10	25.83	10.14	6.77	-	74.06	2.13
Grunnvåg	10.5	20.57	5.33	9.46	3.54	98.48	2.63
Grunnvåg	11	38.39	5.48	4.59	1.76	-	2.60
Grunnvåg	11.5	37.52	6.07	3.46	2.32	-	3.18
Grunnvåg	12	28.57	3.59	3.73	2.00	-	1.45
Grunnvåg	12.5	31.66	4.62	4.95	2.31	-	4.45
Grunnvåg	13	31.27	7.07	5.89	2.07	-	3.58
Grunnvåg	13.5	33.20	6.66	2.19	1.57	-	1.09
Grunnvåg	14	22.39	3.35	10.86	4.60	132.88	10.56
Grunnvåg	14.5	36.46	4.01	3.40	1.22	-	2.50

Drill-hole no	Depth	Si (%)	Al (%)	Fe (%)	Ca (%)	Ni (ppm)	S (%)
Grunnvåg	15	34.81	6.11	4.89	5.16	-	5.06
Grunnvåg	15.5	32.84	5.24	5.87	7.48	-	5.10
Grunnvåg	16	34.60	4.21	5.40	1.48	-	4.94
Grunnvåg	16.5	39.04	6.25	2.64	4.96	-	1.92
Grunnvåg	17	24.15	2.46	3.66	19.86	-	2.68
Grunnvåg	17.5	29.63	8.36	5.45	1.13	-	0.58
Grunnvåg	18	31.50	7.73	4.82	2.05	-	3.08
Grunnvåg	18.5	31.34	6.29	8.56	2.83	-	10.28
Grunnvåg	19	39.56	6.11	4.02	3.02	-	4.60
Grunnvåg	19.5	34.85	5.66	3.84	2.60	-	2.33
Grunnvåg	20	53.44	0.48	1.30	0.20	-	1.81
Grunnvåg	20.5	41.99	5.37	2.35	1.07	-	1.01
Grunnvåg	21	20.26	6.62	17.44	4.23	171.00	15.95
Grunnvåg	21.5	27.39	6.71	3.48	1.50	-	1.31
Grunnvåg	22	31.88	7.49	3.00	1.44	-	2.05
Grunnvåg	22.5	25.56	8.05	7.42	4.57	-	6.07
Grunnvåg	23	35.83	6.26	4.07	1.85	-	3.24
Grunnvåg	23.5	7.25	1.53	0.83	25.21	-	0.56
Grunnvåg	24	41.19	3.08	3.09	0.98	-	3.41
Grunnvåg	24.5	27.62	7.02	1.86	0.82	-	1.26
Grunnvåg	25	28.36	7.55	3.47	2.32	-	3.52
Grunnvåg	25.5	38.00	7.20	1.67	1.93	-	1.35
Grunnvåg	26	25.32	8.31	0.89	1.76	-	0.66
Grunnvåg	26.5	25.78	7.65	5.67	1.60	-	4.93
Grunnvåg	27	29.25	4.55	7.37	1.41	-	7.51
Grunnvåg	27.5	12.99	4.31	24.06	2.00	186.14	25.37
Grunnvåg	28	20.43	4.56	1.59	19.36	-	1.46
Grunnvåg	28.5	19.40	3.46	1.18	22.67	-	0.27
Grunnvåg	29	28.51	5.15	3.84	10.20	-	3.55
Grunnvåg	29.5	27.43	5.11	8.25	5.52	-	7.08
Grunnvåg	30	33.14	7.32	2.77	1.45	-	2.99
Grunnvåg	30.5	27.64	5.33	6.68	2.83	-	5.77
Grunnvåg	31	37.38	5.65	2.56	0.93	-	1.78
Grunnvåg	31.5	33.38	7.21	2.37	0.76	-	1.35
Grunnvåg	32	26.65	6.06	3.26	0.70	-	1.68
Grunnvåg	33	28.71	6.19	3.10	0.70	-	0.64
Grunnvåg	33.5	26.19	8.81	3.21	0.94	-	1.79
Grunnvåg	34	36.15	5.74	3.43	0.83	-	0.27
Grunnvåg	34.5	25.99	5.29	13.29	1.61	67.51	12.48
Grunnvåg	35	24.30	3.74	17.89	2.89	79.72	18.54
Grunnvåg	35.5	20.25	4.42	5.45	13.79	-	2.17
Grunnvåg	36	31.88	6.66	4.69	1.05	-	0.49
Grunnvåg	36.5	32.80	5.51	2.83	0.88	-	0.35
Grunnvåg	37	30.22	7.09	3.77	1.30	-	0.91
Grunnvåg	37.5	30.60	7.39	3.56	0.89	-	0.45

Drill-hole no	Depth	Si (%)	Al (%)	Fe (%)	Ca (%)	Ni (ppm)	S (%)
Grunnvåg	38	30.17	8.09	5.23	1.00	-	0.42
Grunnvåg	38.5	34.48	6.10	3.83	0.94	-	0.09
Grunnvåg	39	31.14	6.54	3.70	0.75	-	0.84
Grunnvåg	39.5	6.61	1.96	39.56	2.00	200.63	34.00
Grunnvåg	40	4.19	-	0.18	25.18	-	0.06

Appendix 5: Analyses of total sulphur (TS) and Total Carbon (TC) on field samples.

Coordinates in UTM 84 zone 33N. Available in excel format upon request.

NGU _no.	Year	Province	Area	Locality	Easting	Northing	Sampler	Sample no.	Text	TS (%)	TC (%)	TOC (%)
90402	2014	Senja	Bukken	Bukken	612088	7704441	Håvard Gautneb	HG2-14	Graphite schist	11.90	3.41	
90405	2014	Senja	Bukken	Bukken	612088	7704441	Håvard Gautneb	HG5-14	Graphite schist	7.35	4.61	
90419	2014	Senja	Bukken	Bukkemoen	612198	7703410	Håvard Gautneb	HG19-14	Graphite schist	4.09	2.71	
90420	2014	Senja	Bukken	Bukkemoen	612261	7703725	Håvard Gautneb	HG20-14	Graphite schist	2.44	4.17	
90403	2014	Senja	Bukken	Bukken	612088	7704441	Håvard Gautneb	HG3-14	Graphite schist	2.37	4.63	
90415	2014	Senja	Bukken	Bukkemoen	612028	7702975	Håvard Gautneb	HG15-14	Graphite schist	0.85	3.03	
90401	2014	Senja	Bukken	Litjkollen	613975	7704663	Håvard Gautneb	HG1-14	Low grade graphite schist	0.84	0.28	
90417	2014	Senja	Bukken	Bukkemoen	612028	7702975	Håvard Gautneb	HG17-14	Graphite schist	0.84	3.30	
90404	2014	Senja	Bukken	bukken	612088	7704441	Håvard Gautneb	HG4-14	Graphite schist	0.58	8.23	
90418	2014	Senja	Bukken	Bukkemoen	611911	7703188	Håvard Gautneb	HG18-14	Graphite schist	0.55	5.09	
90426	2014	Senja	Vardfjellet Hesten	Hesten	609430	7702309	Håvard Gautneb	HG26-14	Graphite schist	0.39	3.69	
90416	2014	Senja	Bukken	Bukkemoen	612028	7702975	Håvard Gautneb	HG16-14	Graphite schist	0.38	3.94	
90431	2014	Senja	Vardfjellet Hesten	Hesten	609293	7702727	Håvard Gautneb	HG31a-14	Graphite schist	0.19	8.60	

NGU _no.	Year	Province	Area	Locality	Easting	Northing	Sampler	Sample no.	Text	TS (%)	TC (%)	TOC (%)
90411	2014	Senja	Bukken	Bukken	611823	7704834	Håvard Gautneb	HG11-14	Graphite schist	0.19	5.01	
90414	2014	Senja	Bukken	Bukkemoen	612112	7703404	Håvard Gautneb	HG14-14	Graphite schist	0.18	3.35	
90406	2014	Senja	Bukken	Bukken	611918	7704413	Håvard Gautneb	HG6-14	Graphite schist	0.16	4.64	
90409	2014	Senja	Bukken	Bukken	611877	7704517	Håvard Gautneb	HG9-14	Graphite schist	0.14	3.98	
90412	2014	Senja	Bukken	Bukken	611635	7704649	Håvard Gautneb	HG12-14	Graphite schist	0.12	4.47	
90428	2014	Senja	Vardfjellet Hesten	Hesten	609396	7702427	Håvard Gautneb	HG28-14	Graphite schist	0.11	1.72	
90413	2014	Senja	Bukken	Bukkemoen	612112	7703404	Håvard Gautneb	HG13-14	Graphite schist	0.11	3.13	
90430	2014	Senja	Vardfjellet Hesten	Hesten	609248	7702787	Håvard Gautneb	HG30-14	Graphite schist	0.08	5.48	
90407	2014	Senja	Bukken	Bukken	611918	7704413	Håvard Gautneb	HG7-14	Graphite schist	0.08	8.03	
90425	2014	Senja	Vardfjellet Hesten	Hesten	609632	7702107	Håvard Gautneb	HG25-14	Graphite schist	0.06	3.09	
90410	2014	Senja	Bukken	Bukken	611877	7704517	Håvard Gautneb	HG10-14	Graphite schist	0.06	4.87	
90423	2014	Senja	Vardfjellet Hesten	Hesten	609632	7702107	Håvard Gautneb	HG23-14	Graphite schist	0.04	3.08	
90408	2014	Senja	Bukken	Bukken	611918	7704413	Håvard Gautneb	HG8-14	Graphite schist	0.03	10.50	
90424	2014	Senja	Vardfjellet Hesten	Hesten	609632	7702107	Håvard Gautneb	HG24-14	Graphite schist	0.03	4.00	
90429	2014	Senja	Vardfjellet Hesten	Hesten	609331	7702536	Håvard Gautneb	HG29-14	Graphite schist	0.03	3.80	
90427	2014	Senja	Vardfjellet Hesten	Hesten	609393	7702403	Håvard Gautneb	HG27-14	Graphite schist	0.01	5.38	

NGU _no.	Year	Province	Area	Locality	Easting	Northing	Sampler	Sample no.	Text	TS (%)	TC (%)	TOC (%)
137155	2016	Senja	Grunnvåg	Grunnvåg	617694	7702333	Janja Knezevic	JK-120816-3	Rusty sulphide rich graphite schist	12.50	6.72	
22222	2016	Senja	Grunnvåg	Grunnvåg	617637	7702330	Håvard Gautneb	HG68-16	Rusty sulphide rich graphite schist	5.00	7.41	
137144	2016	Senja	Grunnvåg	Grunnvåg	617637	7702330	Håvard Gautneb	Hg68-16	Medium grade graphite schist sulphide rich	5.00	4.94	
137154	2016	Senja	Grunnvåg	Grunnvåg	617701	7702321	Janja Knezevic	JK-120816-2	Rusty sulphide rich graphite schist	4.58	14.85	
137152	2016	Senja	Bukken	Bukkemoen	612268	7703721	Janja Knezevic	JK110816-1	Rich graphite schist/ roadcut	1.82	5.09	
137156	2016	Senja	Grunnvåg	Grunnvåg	617707	7702339	Janja Knezevic	JK120816-4	Rusty sulphide rich graphite schist/ outcrop along the stream	1.76	6.84	
137148	2016	Senja	Vardfjellet Hesten	Vardfjellet	607834	7705137	Janja Knezevic	JK3-020816	Graphite schist in the contact zone of amphibolite/granite	1.32	6.92	
137114	2016	Senja	Vardfjellet Hesten	Hesten	609243	7702817	Håvard Gautneb	HG38-16	Medium grade graphite schist	0.85	11.64	
137145	2016	Senja	Grunnvåg	Grunnvåg	617697	7702362	Håvard Gautneb	HG69-16	Rusty sulphide rich graphite schist	0.85	8.46	
137112	2016	Senja	Vardfjellet Hesten	Hesten	609368	7702499	Håvard Gautneb	HG36-16	Low grade graphite schist	0.74	3.50	
137129	2016	Senja	Vardfjellet Hesten	Vardfjellet	607423	7705078	Håvard Gautneb	HG53-16	Medium grade graphite schist	0.66	9.54	
137105	2016	Senja	Vardfjellet Hesten	Vardfjellet	607940	7704925	Håvard Gautneb	HG29-16	Medium grade graphite schist	0.58	9.11	
137127	2016	Senja	Vardfjellet Hesten	Hesten	609089	7702916	Håvard Gautneb	HG51-16	Medium grade graphite schist	0.55	1.94	
137151	2016	Senja	Vardfjellet Hesten	Vardfjellet	607414	7705119	Janja Knezevic	JK-0808016	Folded graphite schist (end of big massive weathered outcrop)	0.49	4.32	
137135	2016	Senja	Vardfjellet Hesten	Vardfjellet	608095	7704991	Håvard Gautneb	HG59-16	Medium grade graphite schist	0.48	9.48	

NGU _no.	Year	Province	Area	Locality	Easting	Northing	Sampler	Sample no.	Text	TS (%)	TC (%)	TOC (%)
1371 04	2016	Senja	Vardfjellet Hesten	Vardfjellet	607618	7705037	Håvard Gautneb	HG28-16	Medium grade graphite schist	0.47	5.57	
1371 47	2016	Senja	Vardfjellet Hesten	Vardfjellet	607902	7705097	Janja Knezevic	JK2-020816	Low grade graphite schist	0.42	8.10	
1371 37	2016	Senja	Vardfjellet Hesten	Vardfjellet	608085	7704848	Håvard Gautneb	HG61-16	Medium grade graphite schist	0.42	5.34	
1371 02	2016	Senja	Vardfjellet Hesten	Vardfjellet	607861	7705123	Håvard Gautneb	HG26-16	Medium grade graphite schist	0.41	4.77	
1371 03	2016	Senja	Vardfjellet Hesten	Vardfjellet	607857	7705123	Håvard Gautneb	HG27-16	Medium grade graphite schist	0.38	6.86	
1371 42	2016	Senja	Vardfjellet Hesten	Vardfjellet	607208	7705023	Håvard Gautneb	HG66-16	Medium grade graphite schist	0.38	5.43	
1371 20	2016	Senja	Vardfjellet Hesten	Vardfjellet	607410	7705025	Håvard Gautneb	HG44-16	Very rich graphite schist	0.36	7.08	
1371 01	2016	Senja	Vardfjellet Hesten	Vardfjellet	607873	7705186	Håvard Gautneb	HG25-16	Medium grade graphite schist	0.35	5.22	
1371 30	2016	Senja	Vardfjellet Hesten	Vardfjellet	607727	7705409	Håvard Gautneb	HG54-16	Very rich graphite schist	0.34	5.48	
1371 39	2016	Senja	Vardfjellet Hesten	Vardfjellet	608092	7704682	Håvard Gautneb	HG63-16	Medium grade graphite schist	0.34	6.56	
1371 28	2016	Senja	Vardfjellet Hesten	Hesten	609272	7702769	Håvard Gautneb	HG52-16	Medium grade graphite schist	0.33	6.14	
1371 24	2016	Senja	Vardfjellet Hesten	Vardfjellet	607620	7705036	Håvard Gautneb	HG48-16	Medium grade graphite schist	0.30	5.76	
1371 06	2016	Senja	Vardfjellet Hesten	Vardfjellet	608092	7704991	Håvard Gautneb	HG30-16	Rich graphite schist	0.30	10.38	
1371 16	2016	Senja	Vardfjellet Hesten	Hesten	609633	7702117	Håvard Gautneb	HG40-16	Medium grade and strongly weathered graphite schist	0.26	5.51	
1371 19	2016	Senja	Vardfjellet Hesten	Vardfjellet	607397	7705070	Håvard Gautneb	HG43-16	Low grade graphite schist	0.26	7.07	
1371 46	2016	Senja	Vardfjellet Hesten	Vardfjellet	608079	7704699	Janja Knezevic	JK1-020816	Medium grade graphite schist	0.24	6.42	

NGU _no.	Year	Province	Area	Locality	Easting	Northing	Sampler	Sample no.	Text	TS (%)	TC (%)	TOC (%)
1371 38	2016	Senja	Vardfjellet Hesten	Vardfjellet	608096	7704677	Håvard Gautneb	HG62-16	Medium grade graphite schist	0.22	6.50	
1371 10	2016	Senja	Vardfjellet Hesten	Vardfjellet	608002	7705049	Håvard Gautneb	HG34-16	Medium grade and strongly weathered graphite schist	0.21	12.60	
1371 11	2016	Senja	Vardfjellet Hesten	Hesten	609328	7702683	Håvard Gautneb	HG35-16	Medium graphite weathered graphite schist	0.20	10.37	
1371 43	2016	Senja	Vardfjellet Hesten	Vardfjellet	607364	7705122	Håvard Gautneb	HG67-16	Medium grade graphite schist	0.20	3.99	
1371 50	2016	Senja	Vardfjellet Hesten	Vardfjellet	607560	7705042	Janja Knezevic	JK4-0208161	Amphibolite/graphite schist	0.19	6.69	
1371 53	2016	Senja	Bukken	Bukkemoen	612214	7703515	Janja Knezevic	JK110816 -2	Graphite schist +qz veins 1-2cm / big outcrop	0.18	14.13	
1371 40	2016	Senja	Vardfjellet Hesten	Vardfjellet	607583	7705249	Håvard Gautneb	HG64-16	Medium grade graphite schist	0.18	1.12	
1371 25	2016	Senja	Vardfjellet Hesten	Hesten	609056	7702936	Håvard Gautneb	HG49-16	Medium grade graphite schist	0.18	4.43	
1371 33	2016	Senja	Vardfjellet Hesten	Vardfjellet	607911	7705081	Håvard Gautneb	HG57-16	Good quality graphite schist	0.17	10.98	
1371 26	2016	Senja	Vardfjellet Hesten	Hesten	609078	7702923	Håvard Gautneb	HG50-16	Medium grade graphite schist	0.16	5.73	
1371 21	2016	Senja	Vardfjellet Hesten	Vardfjellet	607419	7705060	Håvard Gautneb	HG45-16	Very rich graphite schist	0.14	23.60	
1371 23	2016	Senja	Vardfjellet Hesten	Vardfjellet	607569	7705058	Håvard Gautneb	HG47-16	Medium grade graphite schist	0.14	6.12	
1371 32	2016	Senja	Vardfjellet Hesten	Vardfjellet	607903	7705096	Håvard Gautneb	HG56-16	Good quality graphite schist	0.13	9.98	
1371 17	2016	Senja	Vardfjellet Hesten	Hesten	609581	7702693	Håvard Gautneb	HG41-16	Medium grade and strongly weathered graphite schist	0.12	6.69	
1371 08	2016	Senja	Vardfjellet Hesten	Vardfjellet	607993	7705036	Håvard Gautneb	HG32-16	Weathered rusty low-grade graphite schist	0.12	8.36	

NGU _no.	Year	Province	Area	Locality	Easting	Northing	Sampler	Sample no.	Text	TS (%)	TC (%)	TOC (%)
137136	2016	Senja	Vardfjellet Hesten	Vardfjellet	608063	7704863	Håvard Gautneb	HG60-16	Medium grade graphite schist	0.12	9.48	
137113	2016	Senja	Vardfjellet Hesten	Hesten	609245	7702815	Håvard Gautneb	HG37-16	Low grade graphite schist	0.10	7.92	
137115	2016	Senja	Vardfjellet Hesten	Hesten	609246	7702815	Håvard Gautneb	HG39-16	Medium grade and strongly weathered graphite schist	0.10	12.81	
137141	2016	Senja	Vardfjellet Hesten	Vardfjellet	607228	7705022	Håvard Gautneb	HG65-16	Medium grade graphite schist	0.09	4.56	
137149	2016	Senja	Vardfjellet Hesten	Vardfjellet	607824	7705112	Janja Knezevic	JK4-020816	Folded graphite schist	0.09	14.07	
137118	2016	Senja	Vardfjellet Hesten	Hesten	609553	7702741	Håvard Gautneb	Hg42-16	Medium grade and strongly weathered graphite schist	0.08	5.76	
137122	2016	Senja	Vardfjellet Hesten	Vardfjellet	607421	7705060	Håvard Gautneb	HG46-16	Very rich graphite schist	0.06	40.30	
137131	2016	Senja	Vardfjellet Hesten	Vardfjellet	607823	7705245	Håvard Gautneb	HG55-16	Medium grade graphite schist	0.03	6.53	
137107	2016	Senja	Vardfjellet Hesten	Vardfjellet	607993	7705045	Håvard Gautneb	HG31-16	Weathered rusty low-grade graphite schist	0.03	6.77	
137109	2016	Senja	Vardfjellet Hesten	Vardfjellet	607998	7705038	Håvard Gautneb	HG33-16	Medium grade and strongly weathered graphite schist	0.02	7.70	
137134	2016	Senja	Vardfjellet Hesten	Vardfjellet	607972	7705045	Håvard Gautneb	HG58-16	Good quality graphite schist	0.02	31.35	
191216	2018	Senja	Bukken	Litjkollen	614226	7704730	Janja Knezevic	JK-22818-2	Low graphite in biotite-hornblende gneiss(px?)	0.01		
191220	2018	Senja	Bukken	Bukkemoen	612036	7703761	Janja Knezevic	JK-22818-5	Feldspar rich gneiss	0.01		
191176	2018	Senja	Grunnvåg	Grunnvåg	618696	7702007	Janja Knezevic	JK-17818-8	Graphite schist	6.33	3.91	
191223	2018	Senja	Grunnvåg	Grunnvåg	618292	7702022	Janja Knezevic	JK-23818-1	Gneiss with graphite	5.11	0.37	

NGU _no.	Year	Province	Area	Locality	Easting	Northing	Sampler	Sample no.	Text	TS (%)	TC (%)	TOC (%)
191189	2018	Senja	Grunnvåg	Grunnvåg	618257	7701906	Janja Knezevic	JK-19/23818-4	Graphite schist	3.74	3.93	
191175	2018	Senja	Grunnvåg	Grunnvåg	618616	7702020	Janja Knezevic	JK-17818-7	Graphite schist	3.69	6.38	
191125	2018	Senja	Grunnvåg	Grunnvåg	618613	7702022	Håvard Gautneb	hg18-25	Medium grade graphite schist	3.65	4.59	
191198	2018	Senja	Skarsvåg	Skarsvåg	617178	7710418	Janja Knezevic	JK-20818-4	Graphite schist	3.55	1.52	
191201	2018	Senja	Skarsvåg	Skarsvåg	617031	7710558	Janja Knezevic	JK-20818-7	Graphite schist	3.21	1.77	
191193	2018	Senja	Skarsvåg	Skarsvåg	617439	7710340	Janja Knezevic	JK-19818-8	Amphibolite	3.09	0.42	
191129	2018	Senja	Grunnvåg	Grunnvåg	618764	7702012	Håvard Gautneb	hg18-29	Massive high-grade graphite schist	3.06	4.49	
191118	2018	Senja	Grunnvåg	Grunnvåg	618212	7702146	Håvard Gautneb	hg18-18	Medium grade graphite schist	2.81	2.06	
191137	2018	Senja	Skarsvåg	Skarsvåg	617105	7710466	Håvard Gautneb	hg18-37	Low grade graphite schist sulphide rich	2.81	1.42	
191195	2018	Senja	Skarsvåg	Skarsvåg	619266	7701844	Janja Knezevic	JK-20818-1	Graphite schist	2.56	2.83	
191136	2018	Senja	Skarsvåg	Skarsvåg	617003	7710588	Håvard Gautneb	hg18-36	Low grade graphite schist sulphide rich	2.54	1.83	
191214	2018	Senja	Skarsvåg	Skarsvåg	617449	7709150	Janja Knezevic	JK-21818-11	Amphibole rich gneiss	2.31	0.38	
191222	2018	Senja	Bukken	Bukkemoen	612236	7703537	Janja Knezevic	JK-22818-7	Gneiss with graphite	2.31	0.03	
191168	2018	Senja	Grunnvåg	Grunnvåg	617729	7702350	Janja Knezevic	JK-17818-2	Graphite schist	2.26	6.05	
191199	2018	Senja	Skarsvåg	Skarsvåg	617060	7710509	Janja Knezevic	JK-20818-5	Quartz schist	2.13	0.52	
191126	2018	Senja	Grunnvåg	Grunnvåg	618639	7702015	Håvard Gautneb	hg18-26	Very rotten graphite schist	1.98	7.81	

NGU _no.	Year	Province	Area	Locality	Easting	Northing	Sampler	Sample no.	Text	TS (%)	TC (%)	TOC (%)
191186	2018	Senja	Grunnvåg	Grunnvåg	617700	7702358	Janja Knezevic	JK-19818-1	Quartz schist	1.94	0.79	
191202	2018	Senja	Skarsvåg	Skarsvåg	616953	7710707	Janja Knezevic	JK-20818-8	Quartz schist	1.93	0.20	
191135	2018	Senja	Skarsvåg	Skarsvåg	616981	7710707	Håvard Gautneb	hg18-35	Low grade graphite schist sulphide rich	1.90	0.51	
191138	2018	Senja	Skarsvåg	Skarsvåg	618271	7702045	Håvard Gautneb	hg18-38	Low grade graphite schist sulphide rich	1.90	1.27	
191192	2018	Senja	Grunnvåg	Grunnvåg	617698	7702363	Janja Knezevic	JK-19818-7	Graphite schist	1.89	9.21	
191196	2018	Senja	Skarsvåg	Skarsvåg	617288	7710356	Janja Knezevic	JK-20818-2	Amphibolite	1.88	0.03	
191203	2018	Senja	Skarsvåg	Skarsvåg	616818	7710819	Janja Knezevic	JK-2018-9	Amphibolite schist	1.75	0.10	
191128	2018	Senja	Grunnvåg	Grunnvåg	618677	7702012	Håvard Gautneb	hg18-28	massive high-grade graphite schist	1.71	9.50	
191132	2018	Senja	Skarsvåg	Skarsvåg	616751	7710853	Håvard Gautneb	hg18-32	Low grade graphite schist	1.64	0.41	
191131	2018	Senja	Skarsvåg	Skarsvåg	616706	7710921	Håvard Gautneb	hg18-31	Low grade graphite schist	1.58	0.13	
191134	2018	Senja	Skarsvåg	Skarsvåg	616876	7710786	Håvard Gautneb	hg18-34	Low grade graphite schist sulphide rich	1.56	0.20	
191171	2018	Senja	Grunnvåg	Grunnvåg	618543	7701972	Janja Knezevic	JK-17818-5	Graphite schist	1.50	7.82	
191197	2018	Senja	Skarsvåg	Skarsvåg	617203	7710401	Janja Knezevic	JK-20818-3	Graphite schist	1.37	2.29	
191127	2018	Senja	Grunnvåg	Grunnvåg	618658	7702013	Håvard Gautneb	hg18-27	Medium grade graphite schist	1.31	4.90	
191194	2018	Senja	Skarsvåg	Skarsvåg	617742	7710005	Janja Knezevic	JK-19818-9	Graphite schist	1.26	4.41	
191181	2018	Senja	Grunnvåg	Grunnvåg	618742	7702027	Janja Knezevic	JK-18818-6	Graphite schist	1.15	6.30	
191119	2018	Senja	Grunnvåg	Grunnvåg	618214	7702043	Håvard Gautneb	hg18-19	Very weathered medium grade graphite schist	0.95	5.64	

NGU _no.	Year	Province	Area	Locality	Easting	Northing	Sampler	Sample no.	Text	TS (%)	TC (%)	TOC (%)
191226	2018	Senja	Grunnvåg	Grunnvåg	618180	7702129	Janja Knezevic	JK-23818-4	Graphite schist	0.76	4.13	
191200	2018	Senja	Skarsvåg	Skarsvåg	617030	7710556	Janja Knezevic	JK-2088-6	Low grade graphite schist	0.75	1.76	
191160	2018	Senja	Bukken	Bukkemoen	611908	7703174	Janja Knezevic	JK-16818-2	Graphite schist	0.74	4.68	
191133	2018	Senja	Skarsvåg	Skarsvåg	616805	7710828	Håvard Gautneb	hg18-33	Low grade graphite schist	0.72	0.11	
191130	2018	Senja	Skarsvåg	Skarsvåg	617077	7710396	Håvard Gautneb	hg18-30	Low grade graphite schist	0.72	0.40	
191167	2018	Senja	Grunnvåg	Grunnvåg	617711	7702352	Janja Knezevic	JK-1718-1	Low grade graphite schist	0.67	0.54	
191111	2018	Senja	Bukken	Bukken	611722	7704645	Håvard Gautneb	hg18-11	Medium grade graphite schist	0.64	1.84	
191180	2018	Senja	Grunnvåg	Grunnvåg	618774	7702018	Janja Knezevic	JK-18818-4	Graphite schist	0.62	5.55	
191117	2018	Senja	Grunnvåg	Grunnvåg	618184	7702124	Håvard Gautneb	hg18-17	Medium grade graphite schist	0.54	4.88	
191161	2018	Senja	Bukken	Bukkemoen	611893	7703203	Janja Knezevic	JK-16818-3	Graphite schist	0.50	4.57	
191121	2018	Senja	Grunnvåg	Grunnvåg	618153	7702172	Håvard Gautneb	hg18-21	Very weathered medium grade graphite schist	0.43	4.26	
191178	2018	Senja	Bukken	Bukkemoen	618742	7701980	Janja Knezevic	JK-18818-2	Graphite schist	0.42	3.68	
191115	2018	Senja	Bukken	Bukken	612344	7705136	Håvard Gautneb	hg18-15	Medium grade graphite schist	0.42	3.25	
191184	2018	Senja	Grunnvåg	Grunnvåg	618715	7701945	Janja Knezevic	JK-18818-9	Graphite schist	0.41	2.37	
191123	2018	Senja	Grunnvåg	Grunnvåg	618544	7701990	Håvard Gautneb	hg18-23	Medium grade graphite schist	0.39	2.79	
191102	2018	Senja	Bukken	Bukken	612369	7705141	Håvard Gautneb	hg18-2	Low grade graphite schist	0.38	2.69	
191188	2018	Senja	Grunnvåg	Grunnvåg	618706	7701791	Janja Knezevic	JK-19818-3	Biotite gneiss	0.38	0.11	

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191210	2018	Senja	Skarsvåg	Skarsvåg	616293	7710027	Janja Knezevic	JK-21818-7	Weathered biotite gneiss	0.36	1.10	
191107	2018	Senja	Bukken	Bukken	611617	7704512	Håvard Gautneb	hg18-7	Medium grade graphite schist	0.36	5.44	
191153	2018	Kvæfjord	Sørli	Sørli	557119	7624208	Håvard Gautneb	hg18-53	Amorphous black schist	0.35	3.71	
191151	2018	Kvæfjord	Sørli	Sørli	557028	7624186	Håvard Gautneb	hg18-51	Amorphous black schist	0.35	2.87	
191109	2018	Senja	Bukken	Bukken	611687	7704592	Håvard Gautneb	hg18-9	Medium grade graphite schist	0.33	19.70	
191104	2018	Senja	Bukken	Bukken	612219	7705119	Håvard Gautneb	hg18-4	Medium grade graphite schist	0.32	0.80	
191124	2018	Senja	Grunnvåg	Grunnvåg	618580	7702009	Håvard Gautneb	hg18-24	Medium grade graphite schist	0.28	4.15	
191139	2018	Kvæfjord	Finn-gammen	Finn-gammen	549925	7617980	Håvard Gautneb	hg18-39	Amorphous black schist	0.26	23.10	
191162	2018	Senja	Bukken	Bukkemoen	611807	7703322	Janja Knezevic	JK-16818-4	Graphite schist	0.26	4.12	
191116	2018	Senja	Bukken	Bukkemoen	612748	7705075	Håvard Gautneb	hg18-16	Medium grade graphite schist	0.25	6.39	
191225	2018	Senja	Grunnvåg	Grunnvåg	618220	7702141	Janja Knezevic	JK-23818-3	Graphite schist	0.25	2.64	
191191	2018	Senja	Grunnvåg	Grunnvåg	617705	7702383	Janja Knezevic	JK-1919-6	Biotite gneiss	0.24	0.63	
191204	2018	Senja	Skarsvåg	Skarsvåg	616607	7711155	Janja Knezevic	JK-20818-10	Mica schist	0.23	0.08	
191103	2018	Senja	Bukken	Bukken	612300	7705122	Håvard Gautneb	hg18-3	Low grade graphite schist	0.23	0.58	
191185	2018	Senja	Grunnvåg	Grunnvåg	619116	7702107	Janja Knezevic	JK-18818-10	Biotite gneiss	0.22	0.11	
191122	2018	Senja	Grunnvåg	Grunnvåg	618398	7701899	Håvard Gautneb	hg18-22	Medium grade graphite schist	0.21	6.81	

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191120	2018	Senja	Grunnvåg	Grunnvåg	618214	7702044	Håvard Gautneb	hg18-20	Very weathered medium grade graphite schist	0.20	4.90	
191224	2018	Senja	Grunnvåg	Grunnvåg	618325	7701998	Janja Knezevic	JK-23818-2	Graphite Schist	0.19	3.77	
191149	2018	Kvæfjord	Sørli	Sørli	556945	7624087	Håvard Gautneb	hg18-49	Amorphous black schist	0.19	2.72	
191150	2018	Kvæfjord	Sørli	Sørli	557013	7624148	Håvard Gautneb	hg18-50	Amorphous black schist	0.19	3.43	
191152	2018	Kvæfjord	Sørli	Sørli	557099	7624149	Håvard Gautneb	hg18-52	Amorphous black schist	0.18	2.76	
191219	2018	Senja	Bukken	Bukkemoen	612036	7703761	Janja Knezevic	JK-22818-5	Graphite Schist	0.18	3.90	
191172	2018	Senja	Grunnvåg	Grunnvåg	618582	7702005	Janja Knezevic	JK-17818-5c	Graphite Schist	0.16	4.35	
191183	2018	Senja	Grunnvåg	Grunnvåg	618766	7701976	Janja Knezevic	JK-18818-8	Graphite Schist	0.16	4.50	
191156	2018	Senja	Bukken	Litjkollen	613010	7704726	Iain Henderson	ihbm-001	Graphite schist	0.14	1.38	
191166	2018	Senja	Bukken	Bukkemoen	611966	7703674	Janja Knezevic	JK-16818-8	Felsic gneiss with graphite	0.14	3.55	
191110	2018	Senja	Bukken	Bukken	611716	7704612	Håvard Gautneb	hg18-10	Medium grade graphite schist	0.13	6.18	
191112	2018	Senja	Bukken	Bukken	611966	7704978	Håvard Gautneb	hg18-12	Medium grade graphite schist	0.13	7.99	
191148	2018	Kvæfjord	Sørli	Sørli	556999	7623982	Håvard Gautneb	hg18-48	Amorphous black schist	0.12	2.68	
191230	2018	Senja	Bukken	Litjkollen	613638	7704716	Janja Knezevic	JK-15818-5	Biotite gneiss	0.12	0.14	
191105	2018	Senja	Bukken	Bukken	612085	7705099	Håvard Gautneb	hg18-5	Medium grade graphite schist	0.12	13.40	
191179	2018	Senja	Grunnvåg	Grunnvåg	618764	7702013	Janja Knezevic	JK-18818-3	Graphite schist	0.11	4.79	

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191146	2018	Kvæfjord	Finn-gammen	Finn-gammen	551059	7619626	Håvard Gautneb	hg18-46	Amorphous black schist	0.11	19.10	
191142	2018	Kvæfjord	Finn-gammen	Finn-gammen	550399	7617952	Håvard Gautneb	hg18-42	Amorphous black schist	0.11	25.80	
191140	2018	Kvæfjord	Finn-gammen	Finn-gammen	550150	7617977	Håvard Gautneb	hg18-40	Amorphous black schist	0.10	20.50	
191190	2018	Senja	Grunnvåg	Grunnvåg	617744	7702401	Janja Knezevic	JK-19818-5	Amphibolite	0.10	0.07	
191212	2018	Senja	Skarsvåg	Skarsvåg	617330	7709138	Janja Knezevic	JK-21818	Graphite schist	0.10	5.41	
191158	2018	Senja	Bukken	Litjkollen	613731	7704818	Iain Henderson	ihbm-003	Graphite schist	0.10	2.87	
191164	2018	Senja	Bukken	Bukken	611756	7704343	Janja Knezevic	JK-16818-6	Graphite schist	0.09	5.61	
191114	2018	Senja	Bukken	Bukken	612033	7705095	Håvard Gautneb	hg18-14	Medium grade graphite schist	0.08	17.20	
191221	2018	Senja	Bukken	Bukkemoen	612113	7703664	Janja Knezevic	JK-22818-6	Amphibolite	0.08	2.21	
191101	2018	Senja	Bukken	Bukken	612385	7705139	Håvard Gautneb	hg18-1	Low grade graphite schist	0.08	4.83	
191170	2018	Senja	Grunnvåg	Grunnvåg	618133	7701985	Janja Knezevic	JK-17818-4	Biotite gneiss	0.07	0.03	
191217	2018	Senja	Bukken	Litjkollen	613879	7704843	Janja Knezevic	JK-22818-3	Amphibolite	0.07	0.15	
191108	2018	Senja	Bukken	Bukken	611615	7704524	Håvard Gautneb	hg18-8	Medium grade graphite schist	0.07	6.14	
191213	2018	Senja	Grunnvåg	Grunnvåg	617441	7709177	Janja Knezevic	JK-21818-10	Amphibolite	0.07	0.11	
191163	2018	Senja	Bukken	Bukkemoen	611892	7703930	Janja Knezevic	JK-16818-5	Graphite schist	0.07	14.10	
191169	2018	Senja	Grunnvåg	Grunnvåg	617869	7702202	Janja Knezevic	JK-17818-3	Felsic gneiss	0.06	0.07	

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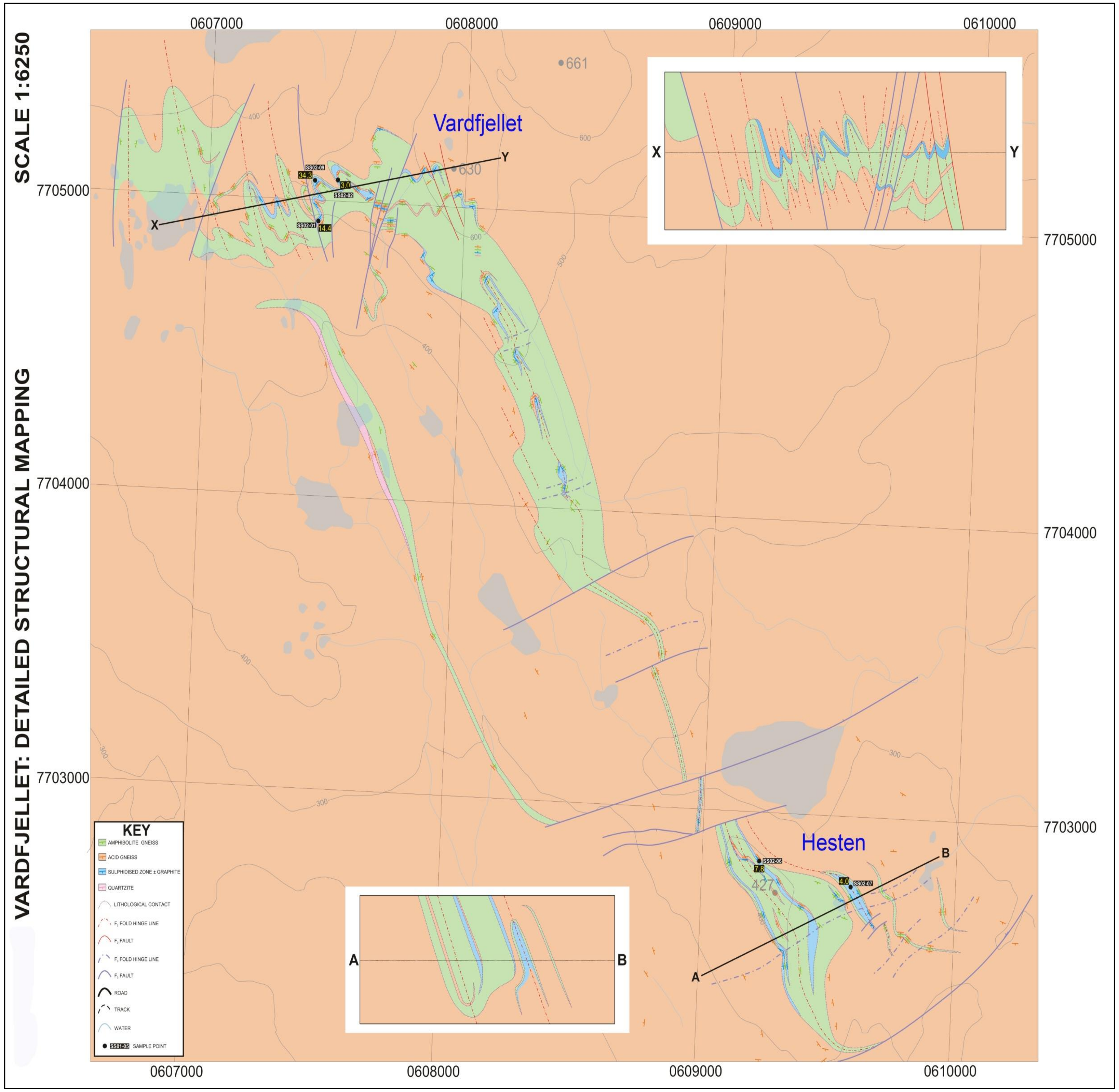
1911 57	2018	Senja	Bukken	Litjkollen	613421	7704919	Iain Hender-son	ihbm-002	Graphite schist	0.05	16.30	
1911 06	2018	Senja	Bukken	Bukken	612062	7705018	Håvard Gautneb	hg18-6	Medium grade graphite schist	0.05	9.36	
1912 28	2018	Senja	Bukken	Bukken	612621	7704328	Janja Knezevic	JK-15818-3	Felsic gneiss	0.05	0.19	
1912 18	2018	Senja	Bukken	Bukkemoen	612061	7703771	Janja Knezevic	JK-22818-4	Graphite schist	0.05	7.97	
1911 65	2018	Senja	Bukken	Bukkemoen	611849	7703781	Janja Knezevic	JK-16818-7	Amphibolite	0.05	0.11	
1911 54	2018	Kvæfjord	Kveøy	Kveøy	543295	7631363	Håvard Gautneb	hg18-54	Amorphous black schist	0.05	28.10	
1911 41	2018	Kvæfjord	Finn-gammen	Finn-gammen	550414	7617953	Håvard Gautneb	hg18-41	Black schist	0.04	19.10	
1911 55	2018	Kvæfjord	Kveøy	Kveøy	543290	7631363	Håvard Gautneb	hg18-55	Amorphous black schist	0.04	3.01	
1911 59	2018	Senja	Grunnvåg	Grunnvåg	611997	7703052	Janja Knezevic	JK-16818-1	Biotite gneiss	0.03	0.10	
1911 45	2018	Kvæfjord	Finn-gammen	Finn-gammen	551075	7619338	Håvard Gautneb	hg18-45	Amorphous black schist	0.02	8.69	
1911 13	2018	Senja	Bukken	Bukken	612032	7705049	Håvard Gautneb	hg18-13	Medium grade graphite schist	0.02	9.12	
1911 87	2018	Senja	Grunnvåg	Grunnvåg	618743	7701740	Janja Knezevic	JK-19818-2	Biotite gneiss	0.02	0.13	
1911 77	2018	Senja	Grunnvåg	Grunnvåg	618456	7701883	Janja Knezevic	JK-18818-1	Biotite gneiss	0.02	0.03	
1911 43	2018	Kvæfjord	Finn-gammen	Finn-gammen	550392	7618199	Håvard Gautneb	hg18-43	Amorphous black schist	0.01	15.10	
1911 44	2018	Kvæfjord	Finn-gammen	Finn-gammen	550850	7619281	Håvard Gautneb	hg18-44	Amorphous black schist	0.01	5.26	
1911 47	2018	Kvæfjord	Sørli	Sørli	556989	7623908	Håvard Gautneb	hg18-47	Amorphous black schist	0.01	2.23	

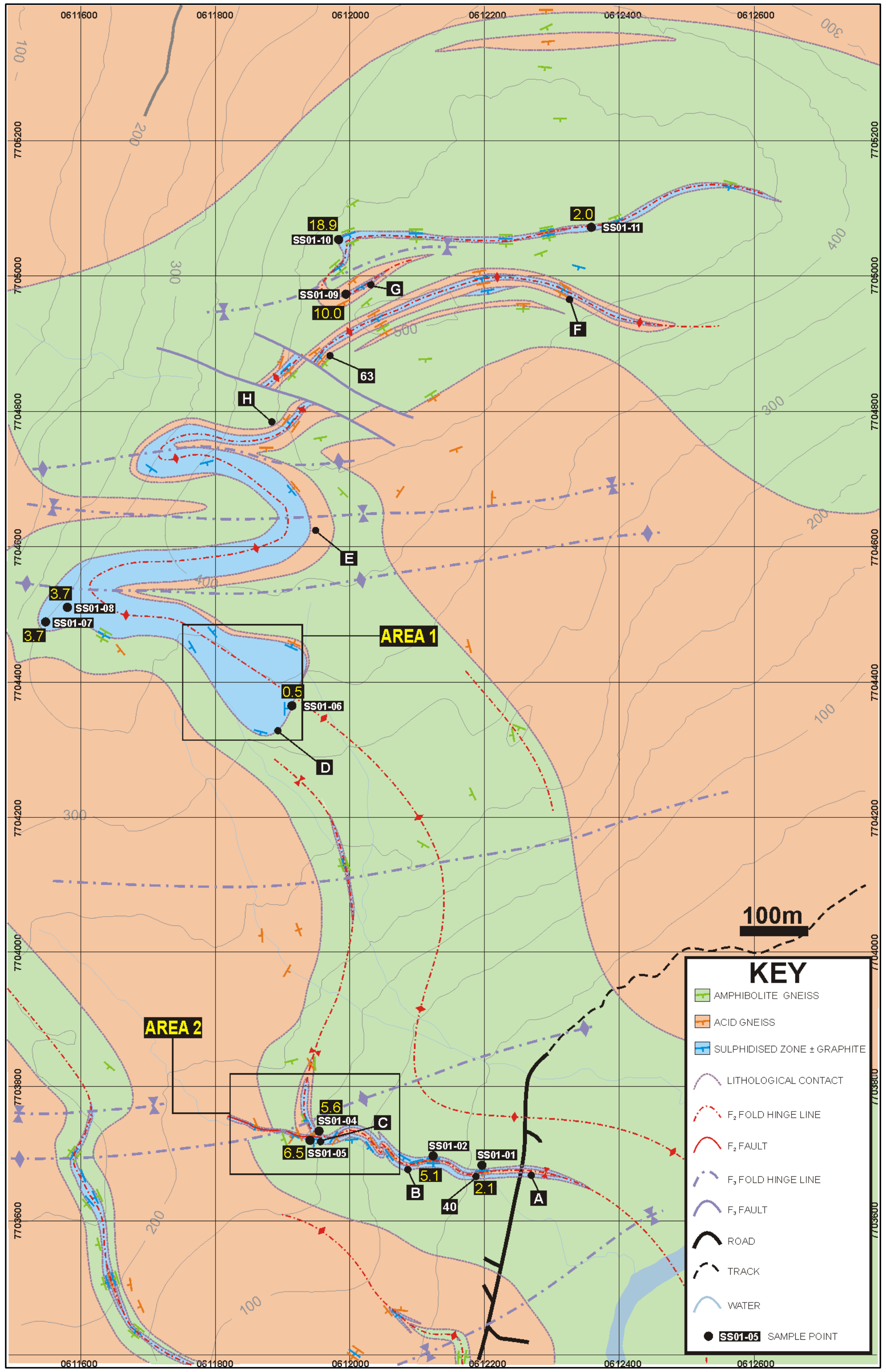
NGU _no.	Year	Province	Area	Locality	Easting	Northing	Sampler	Sample no.	Text	TS (%)	TC (%)	TOC (%)
1911 74	2018	Senja	Grunnvåg	Grunnvåg	618558	7701974	Janja Knezevic	JK-17818-6	Quartz schist	0.01	0.03	
1911 82	2018	Senja	Grunnvåg	Grunnvåg	618789	7702028	Janja Knezevic	JK-18818-7	Amphibolite	0.01	0.03	
1912 05	2018	Senja	Skarsvåg	Skarsvåg	616978	7709631	Janja Knezevic	JK-21818-1	Amphibolite	0.01	0.11	
1912 06	2018	Senja	Skarsvåg	Skarsvåg	616901	7709630	Janja Knezevic	JK-21818-2	Biotite gneiss	0.01	0.35	
1912 07	2018	Senja	Skarsvåg	Skarsvåg	616636	7709711	Janja Knezevic	JK-21818-4	Biotite gneiss	0.01	0.36	
1912 08	2018	Senja	Skarsvåg	Skarsvåg	616583	7709740	Janja Knezevic	JK-21818-5	Biotite gneiss	0.01	0.34	
1912 09	2018	Senja	Skarsvåg	Skarsvåg	616373	7710070	Janja Knezevic	JK-21818-6	Amphibolite	0.01	0.08	
1912 11	2018	Senja	Skarsvåg	Skarsvåg	616015	7710195	Janja Knezevic	JK-21818-8	Amphibolite	0.01	0.03	
1912 15	2018	Senja	Bukken	Litjkollen	614442	7704651	Janja Knezevic	JK-22818-1	Biotite-amphibole gneiss(px?)	0.01	0.64	
1912 27	2018	Senja	Bukken	Bukkemoen	612437	7704062	Janja Knezevic	JK-15818-2	Mafic gneiss	0.01	0.16	
1912 29	2018	Senja	Bukken	Litjkollen	613347	7704796	Janja Knezevic	JK-15818-4	Felsic gneiss with biotite	0.01	0.21	
	2016	Kvæfjord	Kveøya	Øynes	543315	7631378	Børre Davidsen	BD Kvæ 1602a	Graphite schist	0.05	16.9	
	2016	Kvæfjord	Kveøya	Øynes	543315	7631378	Børre Davidsen	BD Kvæ 1602b	Graphite schist	0.03	20.6	
	2018	Kvæfjord	Finn-gammen	Finn-gammen	550148	7 617977	Børre Davidsen	BD Kvæ 1813	Graphite schist	0.06	21.10	21.00
	2018	Kvæfjord	Finn-gammen	Finn-gammen	550172	7 617988	Børre Davidsen	BD Kvæ 1814	Graphite schist	0.01	8.61	8.66
	2018	Kvæfjord	Finn-gammen	Finn-gammen	550829	7 619264	Børre Davidsen	BD Kvæ 1818b	Graphite schist	0.03	4.10	4.15
	2018	Kvæfjord	Finn-gammen	Finn-gammen	550829	7 619264	Børre Davidsen	BD Kvæ 1818c	Graphite schist	0.03	7.32	7.45

NGU _no.	Year	Province	Area	Locality	Easting	Northing	Sampler	Sample no.	Text	TS (%)	TC (%)	TOC (%)
	2018	Kvæfjord	Finn-gammen	Finn-gammen	551064	7 619359	Børre Davidsen	BD Kvæ 1819	Graphite schist	0.08	2.33	2.29
	2018	Kvæfjord	Sørli	Durmåls-haugen	556870	7 624371	Børre Davidsen	BD Kvæ 1821	Graphite schist	0.33	2.43	2.31
	2018	Kvæfjord	Sørli	Durmåls-haugen	557013	7 624224	Børre Davidsen	BD Kvæ 1822	Graphite schist	0.60	2.77	2.72
	2018	Kvæfjord	Sørli	Middags-haugen	556994	7 623947	Børre Davidsen	BD Kvæ 1823	Graphite schist	1.66	2.67	2.58



Appendix 6

Geological map over Vardfjellet and Hesten from Henderson & Kendrick (2003).
The sulphide bearing zone contain in general less than 1% total sulphur. This mapping was done on paper-based topographic maps and individual graphite zones may be misplaced when compared with present day GPS accuracy and our geophysical maps.



Appendix 7:

Geological & structural map of the Bukken deposit (from Henderson & Kendrick 2003)

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- NGU -

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