NGU REPORT 2017.014

Geophysical investigations of graphite occurrences in Bø and Øksnes municipalities, Vesterålen, Nordland County, Northern Norway 2015-2016

GEOLOGY FOR SOCIETY

SINCE 1858

GEOLOGICAL SURVEY OF NORWAY

- NGU -

NORGES GEOLOGISKE UNDERSØKELSE - NGU -

REPORT

Geological Survey of Norway
P.O.Box 6315 Sluppen
NO-7491 TRONDHEIM
Tel.: 47 73 90 40 00

Report no.: 2017.014	ISSN: 0800-3416 (print) ISSN: 2387-3515 (online)	Grading: Open

Title:
Geophysical investigations of graphite occurrences in Bø and Øksnes municipalities, Vesterålen, Nordland County, Northern Norway 2015-2016

Authors: Jan S. Rønning, Bjørn E. Larsen, Harald Elvebakk, Håvard Gautneb, Frode Ofstad and Janja Knežević		**Client:** Nordland Fylkeskommune / NGU	
County: Nordland		**Commune:** Bø and Øksnes	
Map-sheet name (M=1:250.000) Svolvær		**Map-sheet no. and -name (M=1:50.000)** 1132 I Nykvåg and 1132 III Stokmarknes	
Deposit name and grid-reference: WGS 84 UTM Zone 33N Møkland, Sommarland, Kvernfjorddalen, Haugsnes and Smines (for coordinates, see summary text)		**Number of pages:** 50 **Price (NOK):** 150,- **Map enclosures:**	
Fieldwork carried out: 2015 - 2016	**Date of report:** 31.03.2017	**Project no.:** 370800	**Person responsible:** Marco Brönner

Summary:

Geological and geophysical investigations in Vesterålen were carried out during 2015 and 2016 with additional funds from the Nordland County Administration. A first report (Gautneb, et al., 2017) emphasizes the geological aspects of the graphite prospecting (trenching, sampling, analyses, mineralogy and beneficiation tests). This report describes the results from ground geophysical mapping of graphite mineralisations at five locations in the Vesterålen area. These are: Møkland (UTM 486848 – 7627365), Sommarland (UTM 488080 - 7625780), Kvernfjorddalen (UTM 488445 – 7619975) and Haugsnes (UTM 488600 - 7619375) in Bø municipality and Smines in Øksnes (UTM 498793 – 7639018) municipality.

At **Møkland**, a helicopter-borne EM anomaly can be followed for ca. 5 km. One graphite showing within this zone was known from before and several new graphite mineralisations were found during our work. Follow-up work shows that the mineralisations are not continuous and each individual deposit could have a limited size, with lengths along strike of the order of a few hundred meters. Thickness of these graphite bodies can be up to 8-10 m. The average graphitic carbon (Cg) content (37 samples) is 9 % with a maximum value of 25.7 %. The area has a high potential for economical graphite mineralisations, and investigated area should be expanded in 2017.

At **Sommarland**, the previously known graphite showing seems to be limited in size, but one 2D resistivity/IP profile show another ca. 40 m wide possible graphite mineralisation in the area. This is situated in the continuation of the abandoned Kråkberget graphite mine and can be followed for about 3 – 4 km length towards the south. Further follow-up work in this area is recommended for the 2017 follow-up work.

At **Kvernfjorddalen**, one graphite showing is located at a ca. 2.5 km long EM low-resistivity anomaly. SP and EM31 measurements confirm several parallel graphite mineralisations, however, they do not seem to be continuous. Further work here should be detailed localization of graphite deposits and drilling not to be performed by NGU.

At **Haugsnes**, several graphite showings appear along a ca. 2 km long EM low-resistive anomaly. Here, two 2D resistivity/IP lines indicate graphite mineralization within a ca. 80 m wide zone. Graphite analyses on 11 samples from an outcrop at Haugsnes show an average graphitic carbon content of 19.3 % and a maximum value as high as 33.8 %. Further follow-up work in this area is recommended for the 2017 follow-up work.

At **Smines**, several graphite showings were discovered during follow-up work after the 2013 helicopter-borne EM measurements. Eleven samples from the trench show an average grade of 7.7 % Cg with a maximum of 17.1 %. This area is not fully explored and further follow-up work in this area is recommended for the 2017 follow-up work.

In addition geophysical and geological follow-up work is recommended at 5-6 other locations in Lofoten and in Vesterålen.

Keywords:	Graphite	Carbon
Geophysics	Electromagnetic methods	Electrical methods
		Scientific report

Table of Contents

List of Figures

List of Tables

1. INTRODUCTION

This report is the second of two that describe NGU's investigations of graphite occurrences in the Vesterålen area in 2015 and 2016. A first report (Gautneb, et al., 2017) emphasizes the geological aspects of the graphite prospecting (trenching, sampling, analyses, mineralogy and beneficiation tests). This report describes the results from ground geophysical mapping of graphite mineralisations in the Vesterålen area, and focus more on new occurrences and on quantitative aspects of known ones.

As a part of the Norwegian government's project to map Minerals In Northern Norway (MINN), high-resolution airborne geophysical surveys were conducted over Langøya in Vesterålen in 2013 (Rodionov, et al., 2013). In the search for potential graphite ore bodies, known localities with graphite were compared with airborne electro-magnetic (EM) data. The main results from this geophysical survey were a large extension of the areas with potential graphite mineralisation, and a better definition of the areal extent of known occurrences. Geophysical and geological investigations were carried out during 2015 and 2016 with additional funds from the Nordland County Administration. As a preliminary stage, five sites on Langøya with high potential for graphite were selected for further geophysical investigations, Møkland, Sommarland, Kvernfjorddalen and Haugsnes, all in Bø municipality and one at Smines in Øksnes municipality. These localities were selected for further investigation based on one or more of the following criteria: a) Airborne geophysics indicating new mineralisation, b) Exposed rocks showing a good grade of graphite and c) Localities with a favourable location relative to houses and infrastructure. The location of these sites is shown in Figure 1.1.

The follow-up methods were electromagnetic profiling using the ground conductivity meter EM31, Geonics (1984), electrical methods called Charged Potential (CP) and Self Potential (SP) and 2D resistivity in combination with Induced Polarisation (IP). The CP measurements were combined with Self Potential measurements (SP) which is a robust method to locate graphite mineralisation.

The geophysical follow-up work was performed by the following persons during the autumn of 2015 and the summer of 2016:

Bjørn Eskil Larsen: CP/SP, 2D resistivity/IP, processing and reporting
Harald Elvebakk: CP/SP, 2D resistivity/IP
Frode Ofstad: CP/SP, 2D Resistivity/IP
Janja Knežević: EM31, CP/SP
Håvard Gautneb: EM31
Jan Steinar Rønning: Project leader, helicopter-borne geophysics, quality control and reporting.

Aknowledgements: The authors like to thank our colleagues Janusz Koziel for renewing the measuring equipment and Ron Boyd for improving the language.

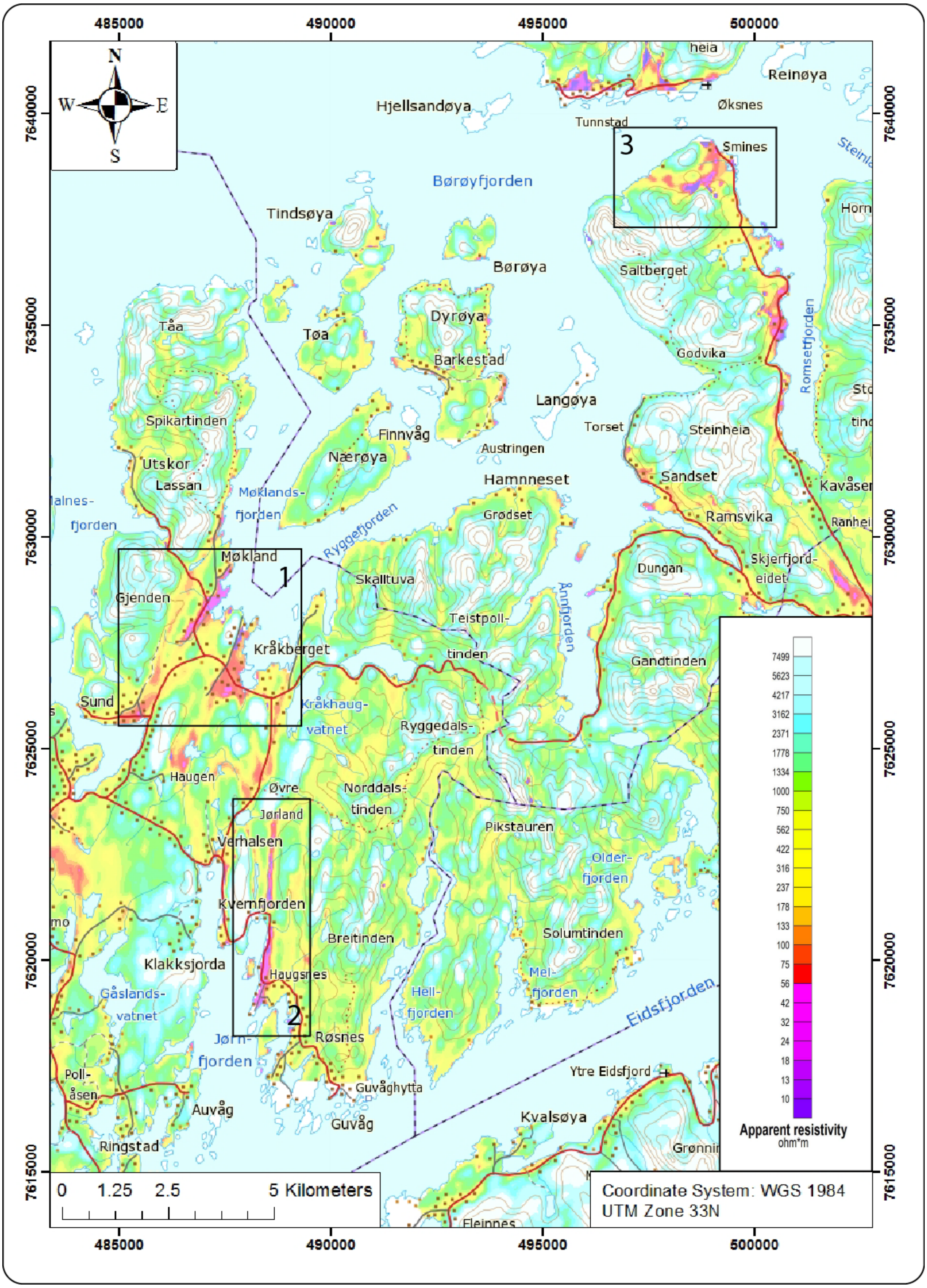

Figure 1.1: Overview map showing investigated areas labelled 1: Møkland (west) and Sommarland (east), 2: Kvernfjorddalen (north) and Haugsnes (south) and 3: Smines. Apparent resistivity 6600 Hz used as background (after Rodionov et al. (2013)).

2. PREVIOUS INVESTIGATIONS AND GEOLOGICAL SETTING

Previous investigations of graphite in the Vesterålen (and Lofoten) area are well described by Gautneb et al. (2017). The earlier investigations which are most important for this follow-up work are the helicopter-borne electromagnetic measurements performed in September 2013 (Rodionov, et al., 2013).

The geological setting of the areas we have investigated is also described by Gautneb et al. (2017).

3. GEOPHYSICAL METHODS

In this chapter we describe the different geophysical methods used in the graphite investigations, helicopter-borne EM, ground EM (EM31), Charged Potential (CP), Self Potential (SP), 2D resistivity (also called Electric Resistivity Traversing, ERT) and Induced Polarization (IP).

3.1 Helicopter-borne electromagnetic method

A new helicopter-borne geophysical survey was performed from July to August 2012, with a total of 5650 line km covering 1050 km^2 on Langøya in the Vesterålen area. The full technical description, including details on processing of the data collected was reported by Rodionov et al. (2013). The survey included the following instrumentation (Table 3.1).

Table 3.1: Instrumentations used in helicopter-borne geophysical survey.

Instrument	Producer/Model	Accuracy	Sampling Frequency/Interval
Magnetometer	Scintrex Cs-2	0,002 nT	5 Hz
Base magnetometer	GEM GSM-19	0.1 nT	3 sec
Electromagnetic	Geotech Hummingbird	1 – 2 ppm	10 Hz
Gamma spectrometer	Radiation Solutions RSX-5	1024 ch's, 16 liters down, 4 liters 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 meter	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 3.2.

Table 3.2: Configuration and frequencies of the Hummingbird EM recorder.

Coils:	Frequency	Orientation	Coil separation
A	7700 Hz	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

Figure 3.1: Equipment used in the helicopter-borne geophysical survey in Vesterålen.

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.

Inverted resistivity sections can be produced based on the measured "In Phase" and "Out of phase" components for each frequency. Available software is EM1DFM (Electromagnetic 1D Frequency Measurements, UBC (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 Vesterålen were performed but are not reported here. NGU has considered 2D or 3D inversion of EM data from Vesterålen, but commercial software for this purpose is not yet available.

The main result from this geophysical survey was a large extension of the area with potential graphite mineralisations, 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. Several of the occurrences described in this report were not previously known and 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).

3.2 Ground conductivity meter, Geonics EM31

Electromagnetic measurements from helicopter in the Vesterålen area (Rodionov, et al., 2013) show many anomalies that may be caused by graphite. Some of these coincide with known graphite showings, others do not. The area is largely covered by soil and vegetation, so detailed geophysical measurements were necessary to locate possible new graphite mineralisations. In our first attempt to map known and possibly unknown graphite deposits, a ground conductivity meter Geonics EM31 (Geonics, 1984) was used. This instrument is calibrated in such way 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 9800Hz.

Figure 3.2: 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. Exposed graphite deposits in trenches like this were later used as grounding points for CP measurements.

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 -99 mS/m, and given a special color in the data presentation.

3.3 Charged Potential and Self Potential methods

Charged Potential (CP) measurements are acquired by connecting a current electrode directly to the conductive body and locate 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 borehole 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 ore-body (Figure 3.3). By measuring the potential around a known graphite ore-body, the body's length, dip and size can be mapped. In addition, an outline of unknown ore-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 (1978).

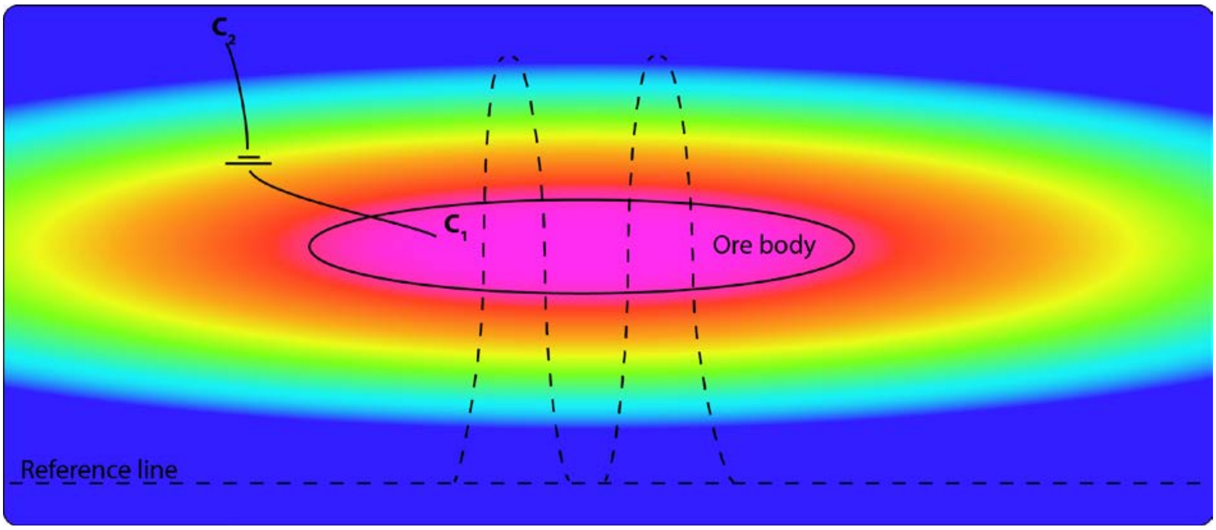

Figure 3.3: Conceptual illustration of the CP- method. The current electrode (C_1) is connected to the ore body and the remote electrode (C_2) is placed far outside the survey area. The color indicates the strength of the charged potential above an ore-body. The dashed line shows the survey path along 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 current injected into the ore body is applied in pulses, two seconds on and two seconds off. SP is measured just before a current pulse while 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 mineralisations. Measured 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 3.3) and the remote electrode (C_2 in Figure 3.3) 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 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.

Figure 3.4: Data acquisition in combined CP and SP measurements in Vesterålen.

3.4 2D resistivity and Induced Polarization (IP)

To be able to calculate the size of graphite plates, it is necessary to know the resistivity of the host rock. Using 2D resistivity measurements, also caller ERT (Electrical Resistivity Tomography), the thickness of an ore-body can be evaluated and the true resistivity (electric conductivity) of EM anomalies may be calculated. Induced Polarization (IP) responds to electronic conducting minerals which are not in electric contact. This means that massive graphite deposits should not give an IP effect. However, IP effects are often seen in the contacts between graphite bodies and surrounding host rock where graphite grains are not connected.

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 and a geometrical factor dependent on the electrode positions, the apparent resistivity and IP effect can then be calculated.

The Lund System (Dahlin, 1993) was used to connect electrodes to the ground. The instrument ABEM Terrameter LS (ABEM, 2012) was used to acquire data. As seen in Figure 3.5, 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. An electrode separation of 5 m was used for two profiles, while a 2 m electrode separation was used for the rest. A maximum depth range of about 25 m may be reached with the latter configuration, while with 5 m electrode spacing the penetrating depth is ca. 60 m. The resolution decreases with depth and resistivity data deeper than ca. 20 and 40 m, respectively of the two configurations, are by experience of low reliability.

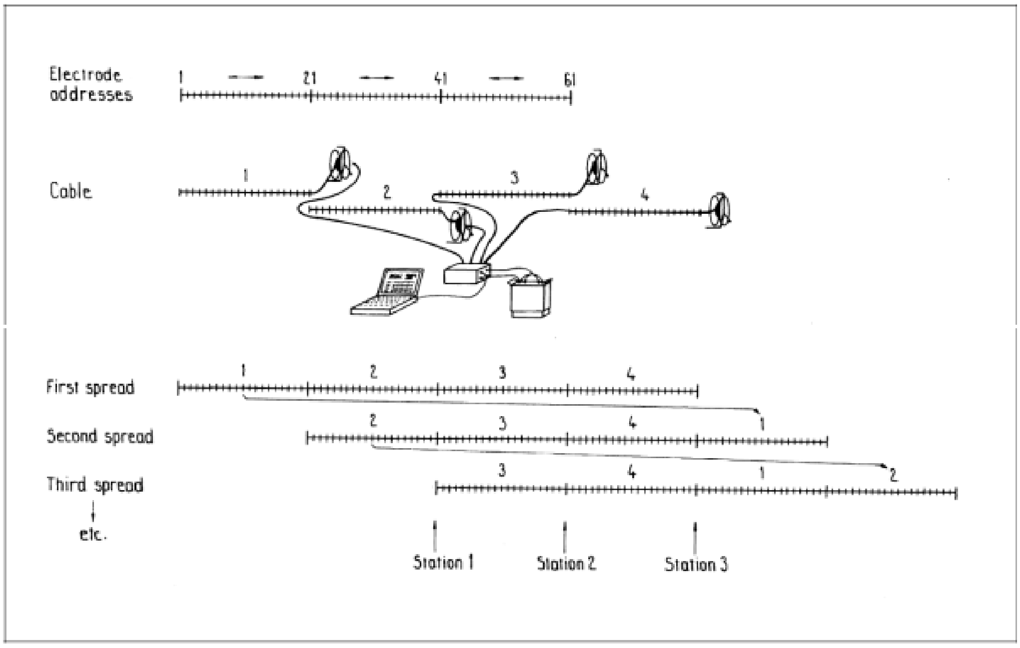

Figure 3.5: Diagram of measuring procedure illustrating the setup of the Lund System and the roll-along method for performing as many measurements as required. From (ABEM, 2012).

Quality of the data

The quality of 2D resistivity/IP data is dependent on current strength, resistivity in the ground and noise level in the area. We conclude, in general, that the quality is good, but some data have a too high standard deviation during inversion according to the software's guidelines. These data points were removed from the dataset and the inversion is repeated. Table 3.3 describes the number of deleted data points and remaining points for the final inversion. Other ways to evaluate data quality is by looking at the absolute error in the inverted sections. Absolute error less than 5 % is very good, 5 – 10 % good, higher than 10 % not that good.

Table 3.3: 2D resistivity/IP. Number of measured, removed and remaining data points for inversion.

Name	Location	Measured data points	Removed data points	Final data points
Profile 1	Møkland	3160	88	3072
Profile 2	Sommarland	1660	87	1573
Profile 3	Møkland	1168	17	1151
Profile 4	Møkland	1168	15	1153
Profile 5	Smines	1168	28	1140
Profile 6	Kvernfjorddalen	1168	26	1142
Profile 7	Haugsnes	1132	126	1006
Profile 8	Haugsnes	1168	125	1043

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 (note: heterogeneous volume in terms of resistivity and size for the purpose of the study). 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 characterized 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, 2014) with robust data constraint.

Interpretation

Graphite is a electronically conducting mineral, and the resistivity in massive graphite ore bodies is commonly less than 2 Ωm, 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 mineralisations 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). Unfortunately, even 2D resistivity/IP measurement may be disturbed by artificial conductivity effects mixing up responses from two or more sub-vertical conducting graphite structures (Rønning, et al., 2014).

4. RESULTS FROM GEOPHYSICAL FOLLOW-UP WORK

Five graphite locations at Langøya in Vesterålen were followed up with ground geophysical measurements during the field season of 2015 and 2016: Møkland, Sommarland, Kvernfjorddalen, Haugsnes and Smines.

4.1 MØKLAND

The location of Møkland in Bø municipality is shown on Figure 1.1.

4.1.1 Background

Figure 4.1 shows the apparent resistivity calculated from the helicopter-borne electromagnetic frequency 6600Hz in the Møkland (and Sommarland) area. Several N-S striking structures with low apparent resistivity are identified as potential graphite bearing rocks. At position red star no 1, graphite was reported in the NGU mineral database (http://geo.ngu.no/kart/mineralressurser_mobil/, Neumann (1952)). This showing is connected to a ca. 5 km long anomalous zone with an apparent resistivity ranging from ca. 300 to ca. 100 Ωm, going from Sletten in the north to Ramnåsbugen in the south (see Figure 4.1). This is not the best conducting zone in the area, but its length suggests high potential for interesting graphite mineralisations and the area was selected for follow-up work. This zone is hereafter called **Møkland 1.** It also has a favourable location in the case economically interesting amounts of graphite should be found in the future.

About 500 m E of Møkland 1, we find another anomalous zone. This zone is ca. 3 km long extending from Møkland in the north to Skoglund in the south. It is wider, and its apparent resistivity is partly < 50 Ωm. We hereafter call this zone **Møkland 2.**

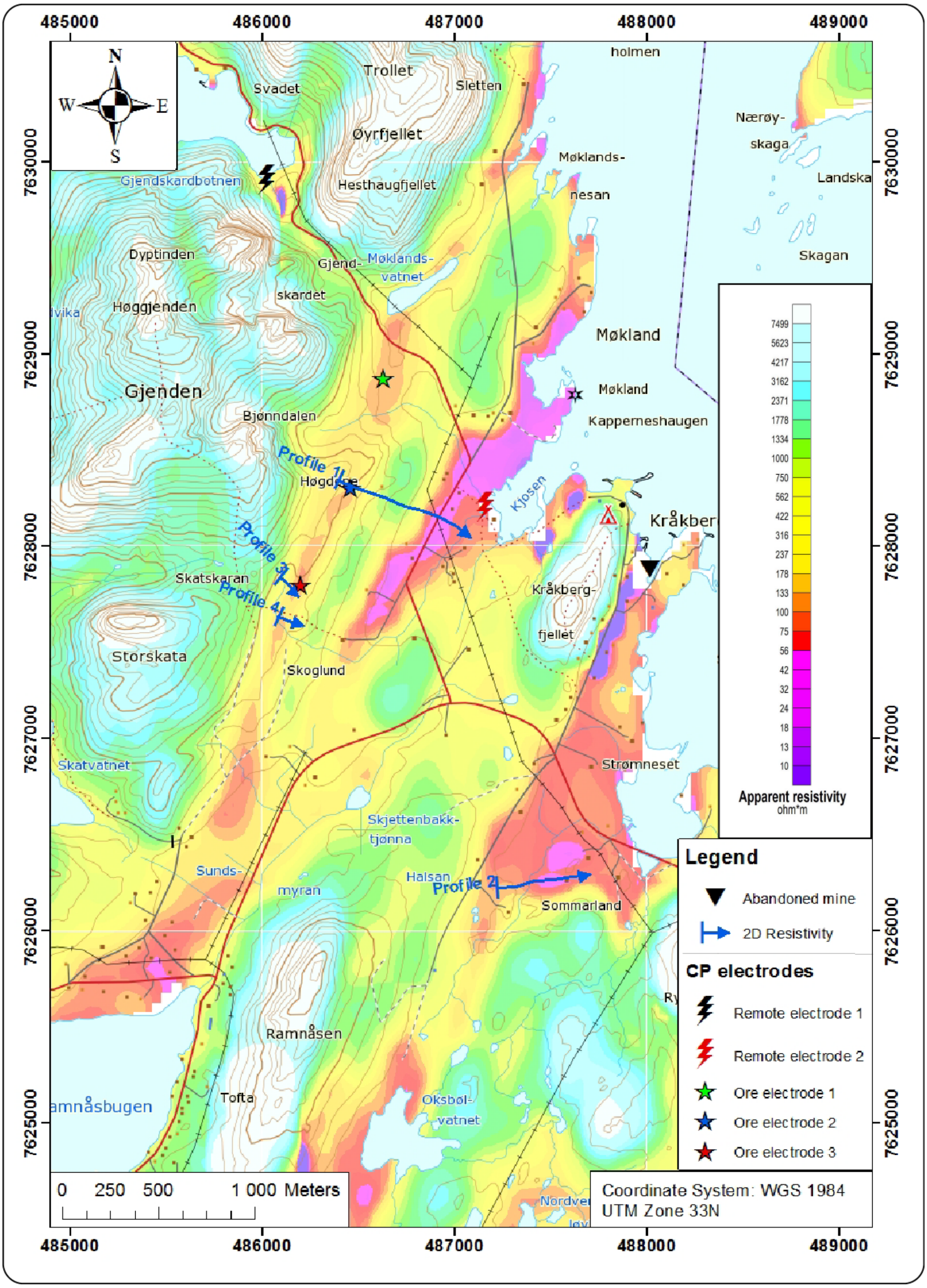

Figure 4.1: Apparent resistivity calculated from EM frequency 6600Hz at Møkland and Sommarland. Known graphite outcrops later used for CP measurements are displayed as stars. The location of 2D-resistivity/IP profiles are shown in blue. Modified from (Rodionov, et al., 2013).

The zone Møkland 1 was followed up with EM31 profiling, CP/SP measurements and 2D resistivity/IP measurements. In addition, we have performed diamond drilling, trenching, sampling and chemical analysis (Gautneb, et al., 2017). Møkland 2 was followed up with one 2D resistivity/IP profile (Profile 1) and in addition some SP measurements.

4.1.2 EM31 measurements at Møkland

Results from measurements with EM31 at Møkland are shown in Figure 4.2. These data are also presented by Gautneb et al. (2017). Apparent electrical conductivity, measured with EM31, coincides more or less with areas with moderately low resistivity (+/- 100 Ωm) from helicopter-borne EM measurements. Being closer to the target, the EM31 readings produce better resolution. However, EM31 has a limited depth extent (6 – 7 m) and mineralisations deeper than this may be overlooked.

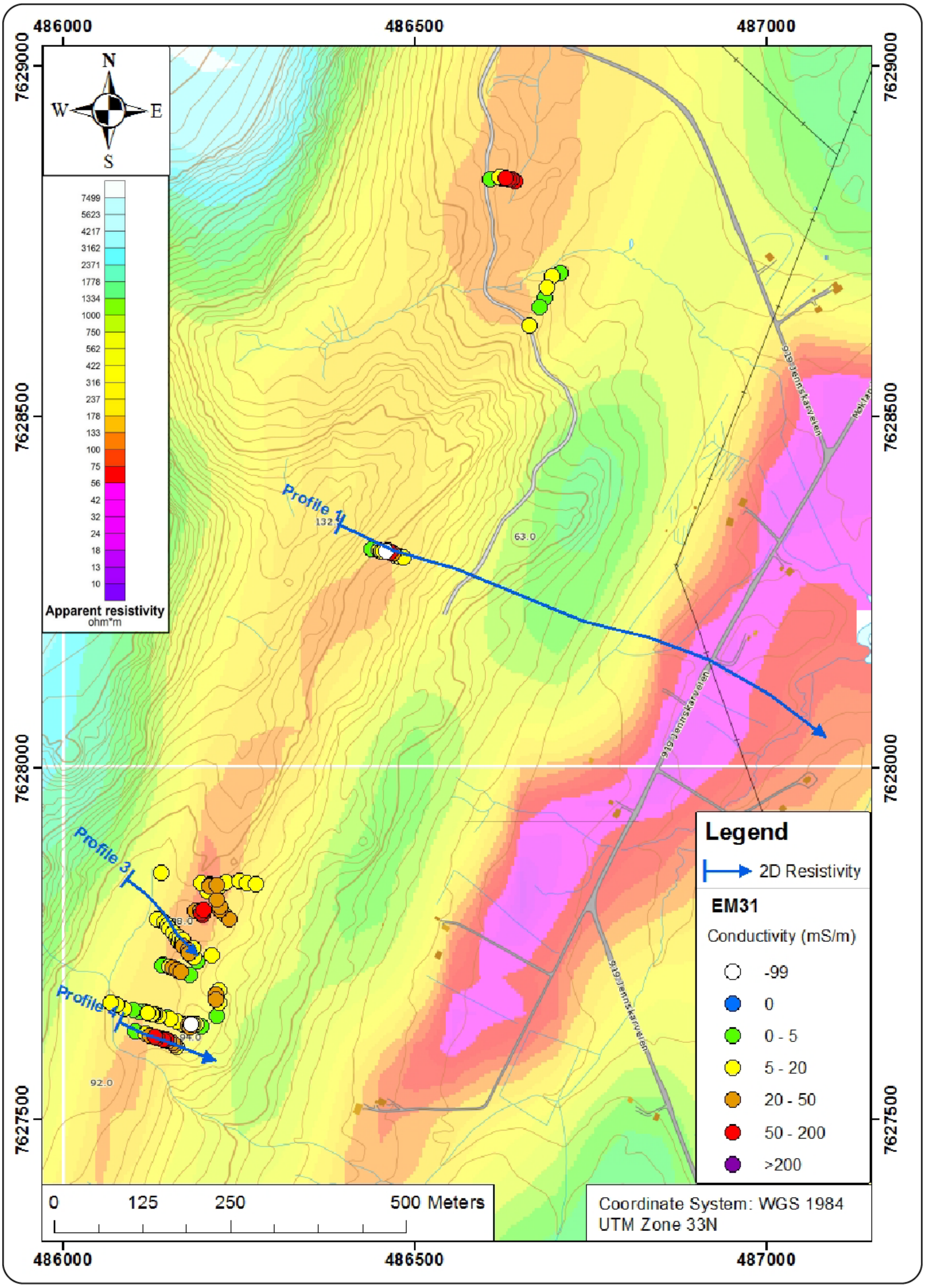

Figure 4.2: Data from measurements with EM31 plotted on top of apparent resistivity (6600 Hz) from helicopter EM-measurements. Locations of 2D resistivity/IP profiles are shown in blue.

4.1.3 CP measurements at Møkland.

Along the zone called Møkland 1, three CP grounding points were measured. The locations of each grounding point are shown in Figure 4.1. The coordinates, applied current, and number of measured stations for these are listed in Table 4.1. The results of all CP measurements are shown in Figures 4.3– Figure 4.6.

Table 4.1: Coordinates (WGS 84, UTM Zone 33), voltage and current for groundings used for CP measurements. R1 and R2 are remote electrodes.

Electrode	X-coordinate	Y-coordinate	Current (A)	No. of measurements
1	486631	7628873	2.2	266
2	486456	7628306	2.4	316
3	486195	7627800	1.0	125
R1	486025	7629907		
R2	487160	7628210		

To visualize the results Geosoft Oasis Montaj software was used for plotting, gridding and contouring the data. A minimum curvature algorithm was used to interpolate between measuring points, and a cell size of 10 m was used for all grids.

As shown in Figure 4.3, the extent of the graphite ore at grounding point no. 1 is very limited along strike. The potential plunges rapidly in all directions from the electrode, meaning that there is little coherent graphite to carry the current from the electrode. The profile data from both CP and SP (Figure 4.4) indicate the same. The indicated strike direction is NNE - SSW. The mineralisation seems to dip steeply to SE. The length along strike seems < 200 m (CP curve along line B – B', Figure 4.4). Using characteristic lengths of CP profiles Kihle & Eidsvig (1978) the vertical depth extent of this mineralisation can be interpreted as less than 100 m.

An SP anomaly of ca. 700 mV indicates that this is graphite. Graphite of good quality is proved in an old showing, by drilling and by trenching (Gautneb, et al., 2017).

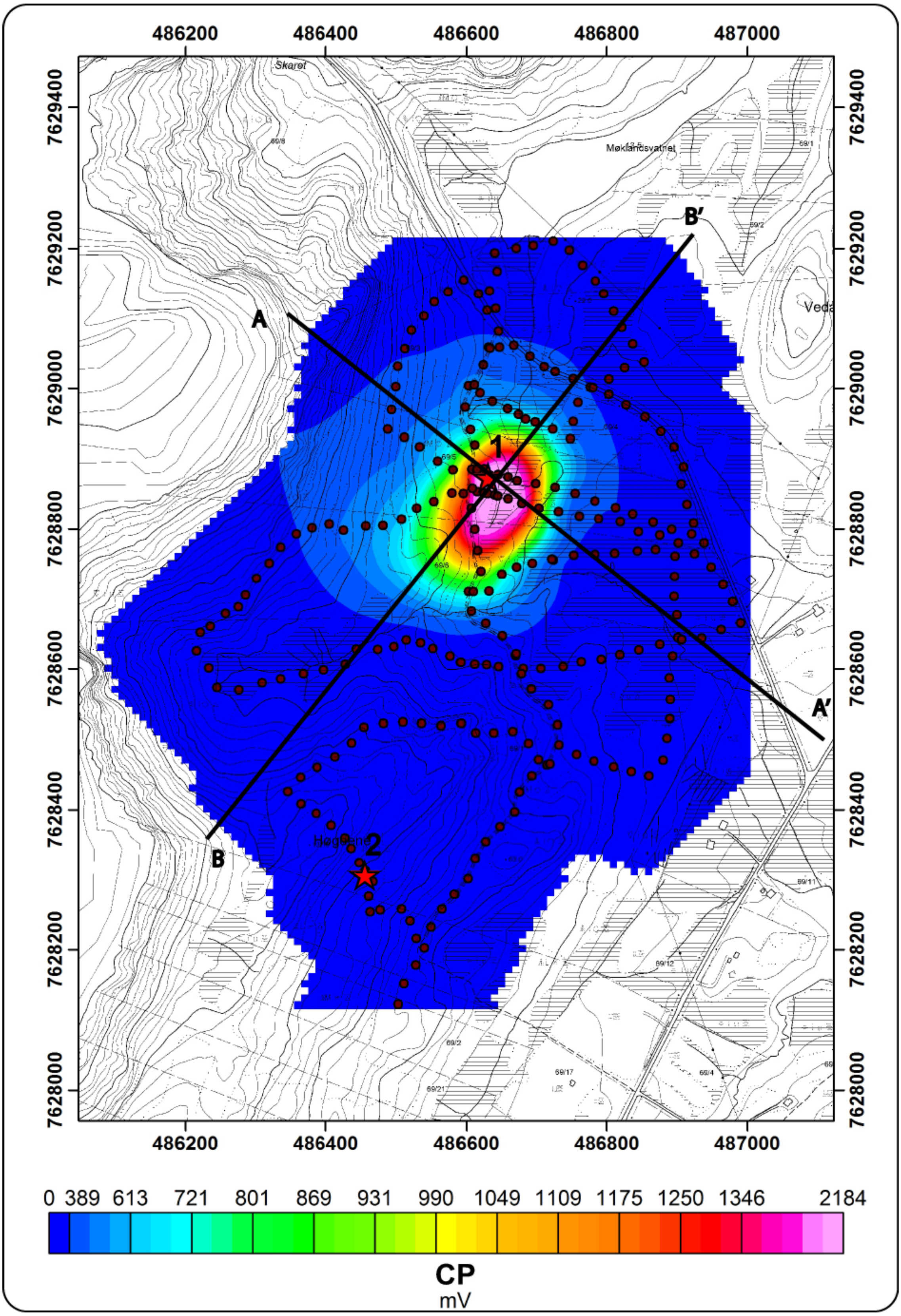

Figure 4.3: CP data collected when charging graphite in grounding no 1 at Møkland. Grounding point is indicated with a star at the intersection of profile lines A and B. The profile lines are shown in Figure 4.4.

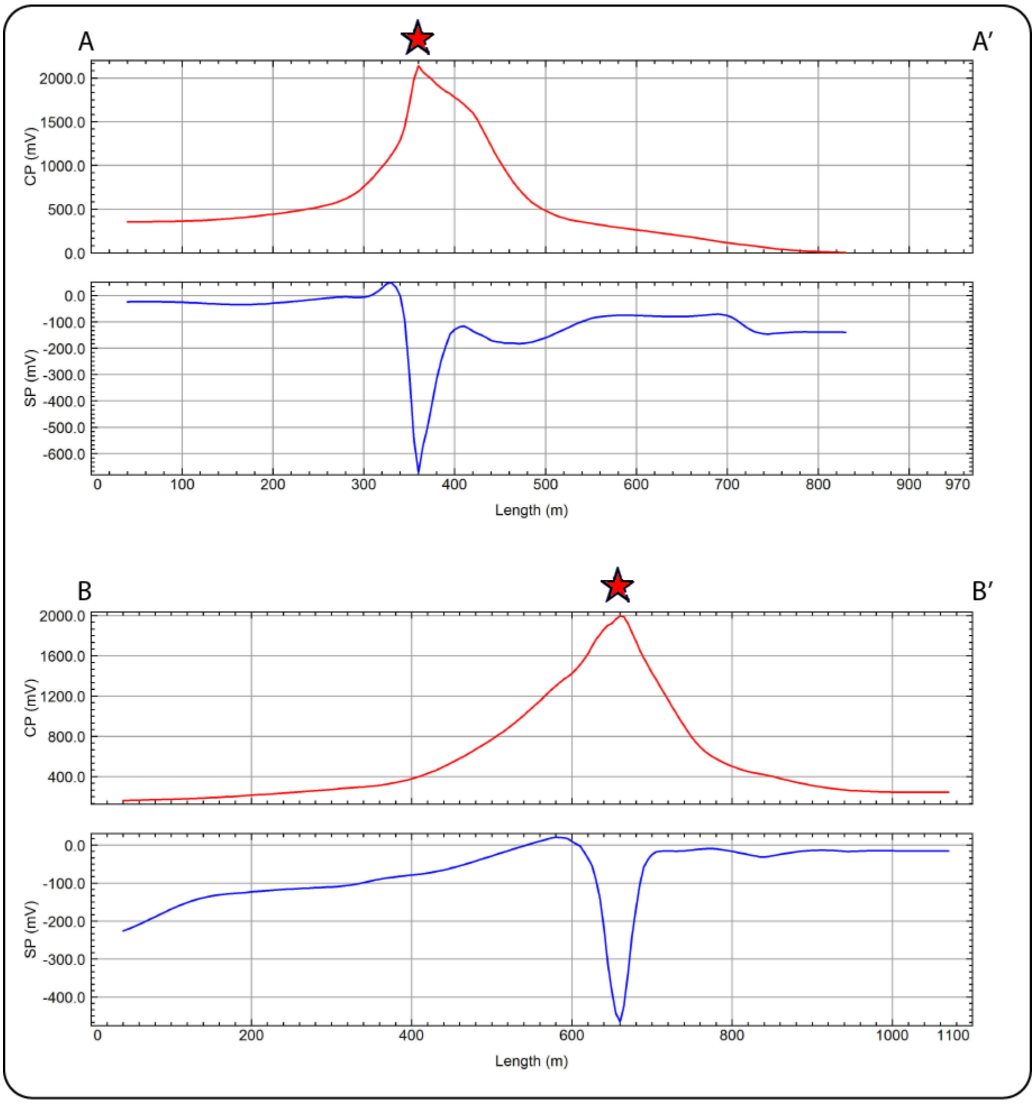

Figure 4.4: Profile lines A and B collected from SP and CP in Figure 4.3 and Figure 4.7. The red star shows the grounding point.

CP data from Grounding 2 (Figure 4.5) gives more or less the same results as in Grounding 1. This is confirmed when looking at the profile data (Figure 4.6). The interpreted length along strike is ca. 350 m and the dip is interpreted to be steep to SE. The depth extent cannot be calculated due to influence from neigbouring conductor (see SP results). The strike direction is turned to NE direction. The high potential around the electrode may indicate that the grounding point is electrically insulated from the main conducting body.

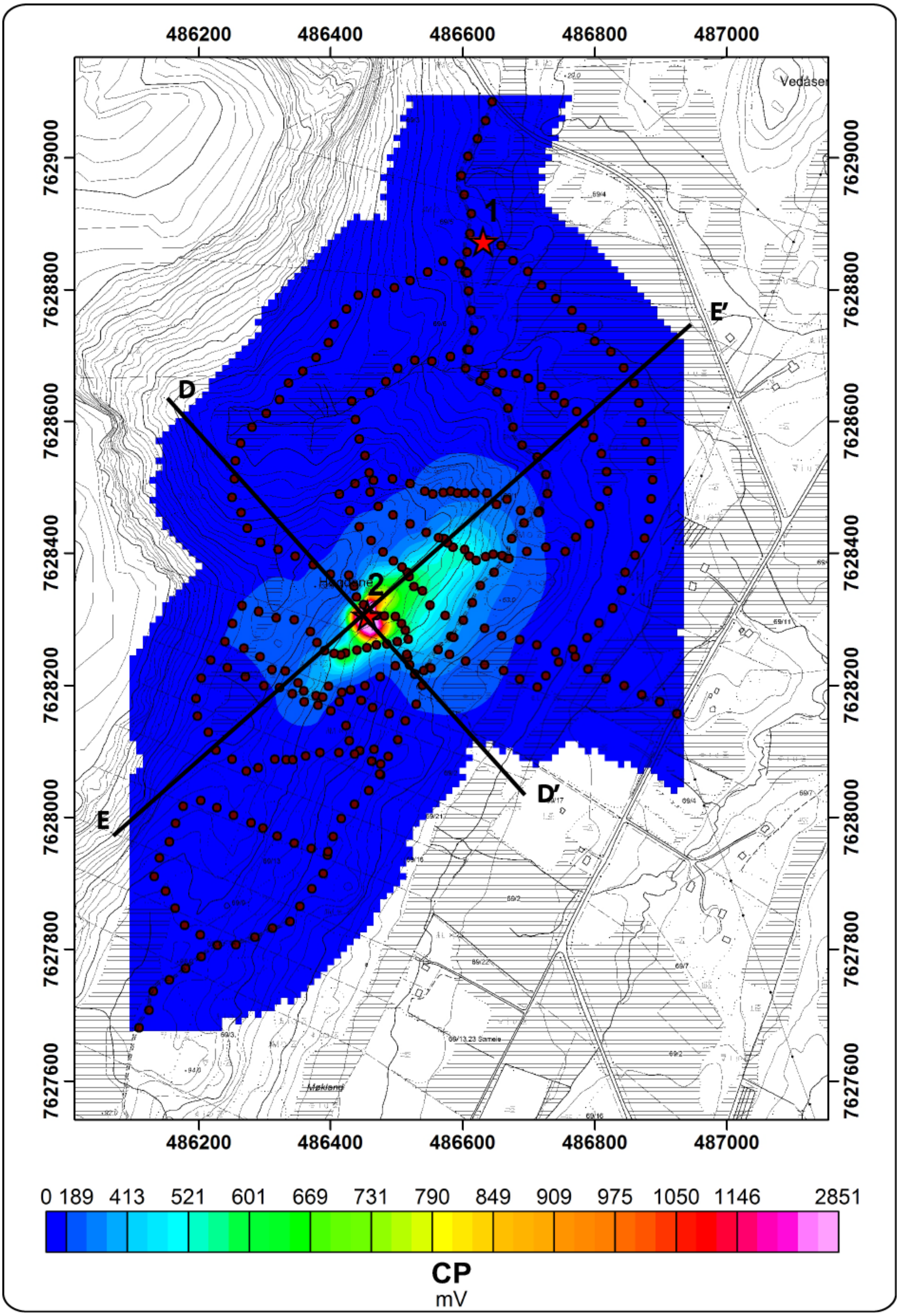

Figure 4.5: CP data collected when charging graphite in grounding no 2. Grounding point is indicated with star at intersection profile lines D and E. Profile data are shown in Figure 4.6.

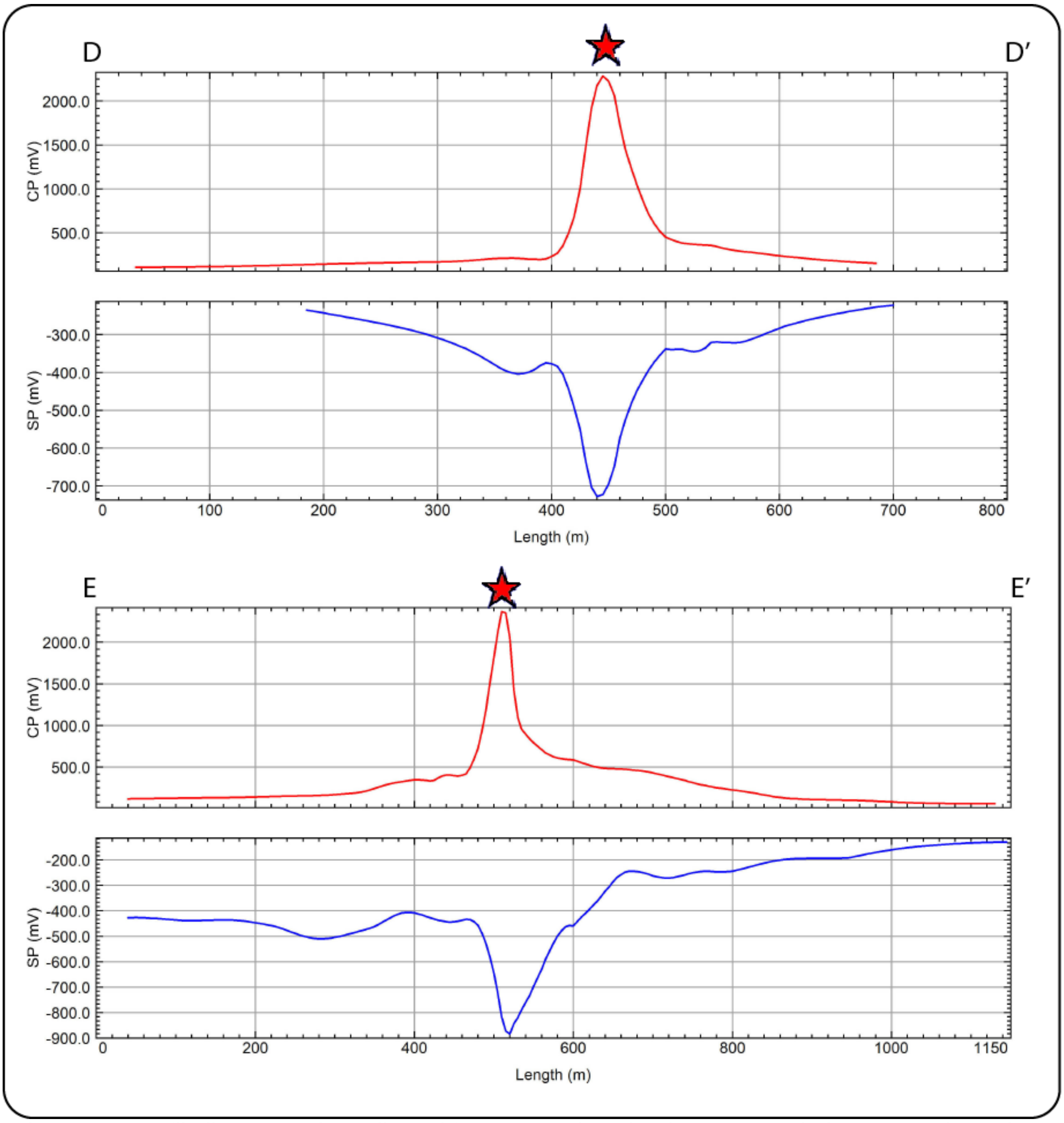

Figure 4.6: Profile lines D and E collected from SP and CP in Figure 4.5 and Figure 4.7. The red star shows the grounding point.

The transmitter failed during CP measurements at grounding 3, and it was not possible to finish the mapping. The available data were not sufficient to give reliable information on the size of the exposed graphite and hence, are not presented here.

4.1.4 SP measurements at Møkland

The SP-data shown in Figure 4.7 were all collected simultaneously with CP measurements at the three grounding points. Data are edited, taking away double measurements, and obvious error points. Data measured in closed loops, are corrected for systematic errors during measurements.

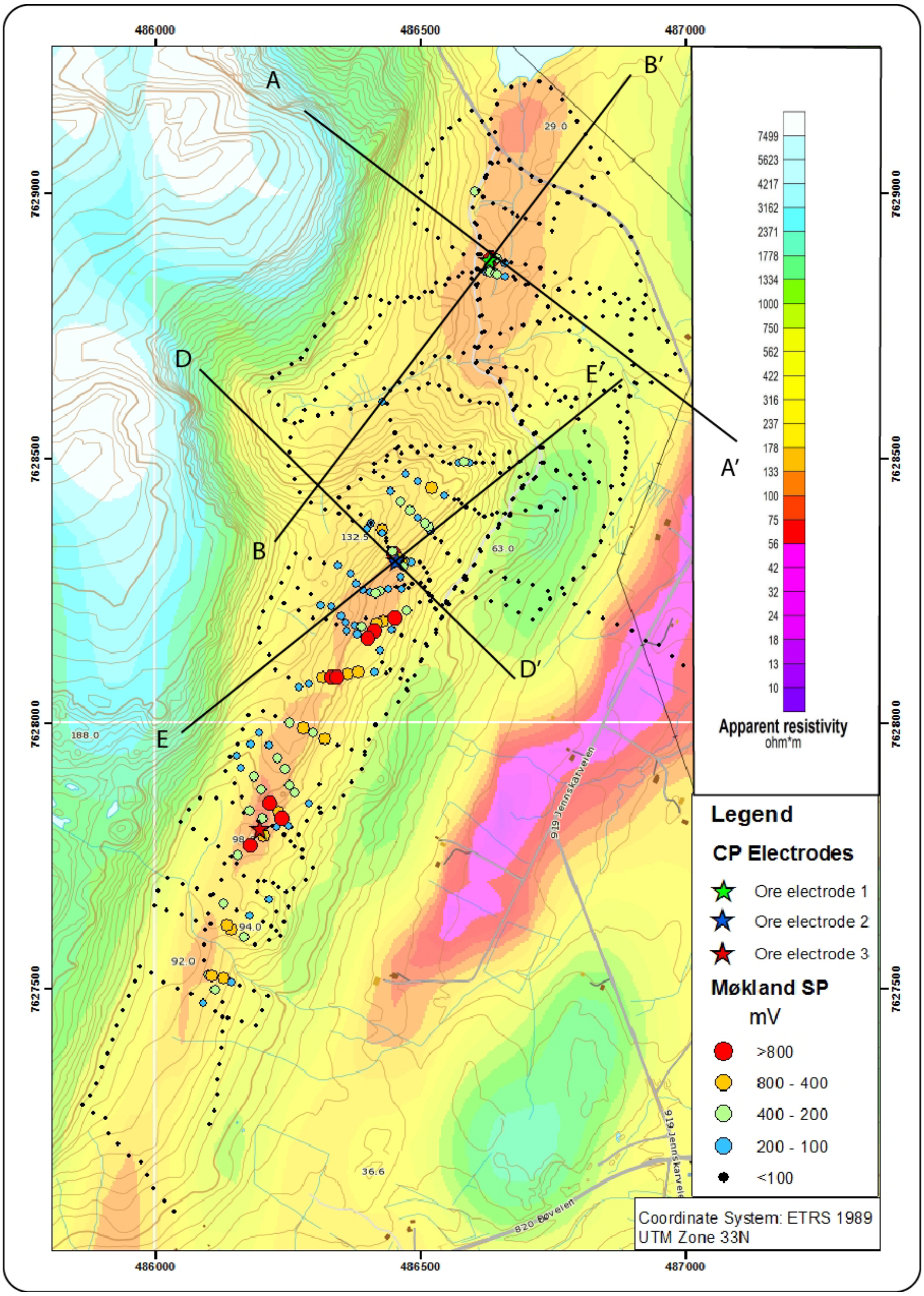

Figure 4.7: SP data at Møkland collected from all three datasets combined. Grounding points are indicated with stars.

The SP data confirm what the CP-data indicated; the bodies used for Grounding 1, 2 and 3 are limited in size. However, there is an anomaly of considerable size and magnitude just S of Grounding 2. This is, in some way, also visible in the CP measurements from Grounding 2 shown in Figure 4.5 where there is a slight “dent” in the contour-lines just S of the grounding point. This dent may be caused by a separate conductor close by (Lile, 1971).

4.1.5 2D resistivity and IP at Møkland

Three 2D resistivity/IP profiles were measured at Møkland. Figure 4.1 and Figure 4.2 show their location. Profile 1 is measured with 5 m electrode separation, starts at zone Møkland 1 next to CP grounding 2 and goes eastwards into the zone called Møkland 2. Profiles 3 and profile 4 are measured with 2 m electrode separation and both crossing the graphite mineralisations along zone Møkland 1 next to CP grounding 3 (see Figure 4.2).

The only known graphite outcrop along resistivity **Profile 1** (Figure 4.8) is in the western part of the measured profile, at coordinate 90. This mineralisation is confirmed by resistivity values < 4 Ωm, EM31 anomalies, a clear SP anomaly (> 800 mV) and exposed graphite. High IP values are observed in the same area, partly surrounding the resistivity anomaly which is often characteristic for graphite. Note that electronically conducting massive graphite will not give an IP effect, only when conductivity is switching between electronic and ionic. The graphite layer seems to have an apparently sub-vertical dip direction to E, which is in agreement with the dip interpreted from CP data.

East of the mineralisation the resistivity values are >1000 Ωm, which is typical for crystalline bedrock. There is an abrupt change in resistivity around 440 m where resistivity drops down to ca 30-80 Ωm to the E. The eastern area has also very low IP effect except for some minor peaks near the surface. SP measurements along one line in this area gave no anomaly indicating graphite (Figure 4.5). Based on these observations we can conclude that the conductive zone called Møkland 2 is not caused by graphite mineralisations. The area is mostly covered with soil, and an explanation for the relatively good electric conductivity in the ground is so far not clear. It is assumed that exposures can be found in the coastal areas.

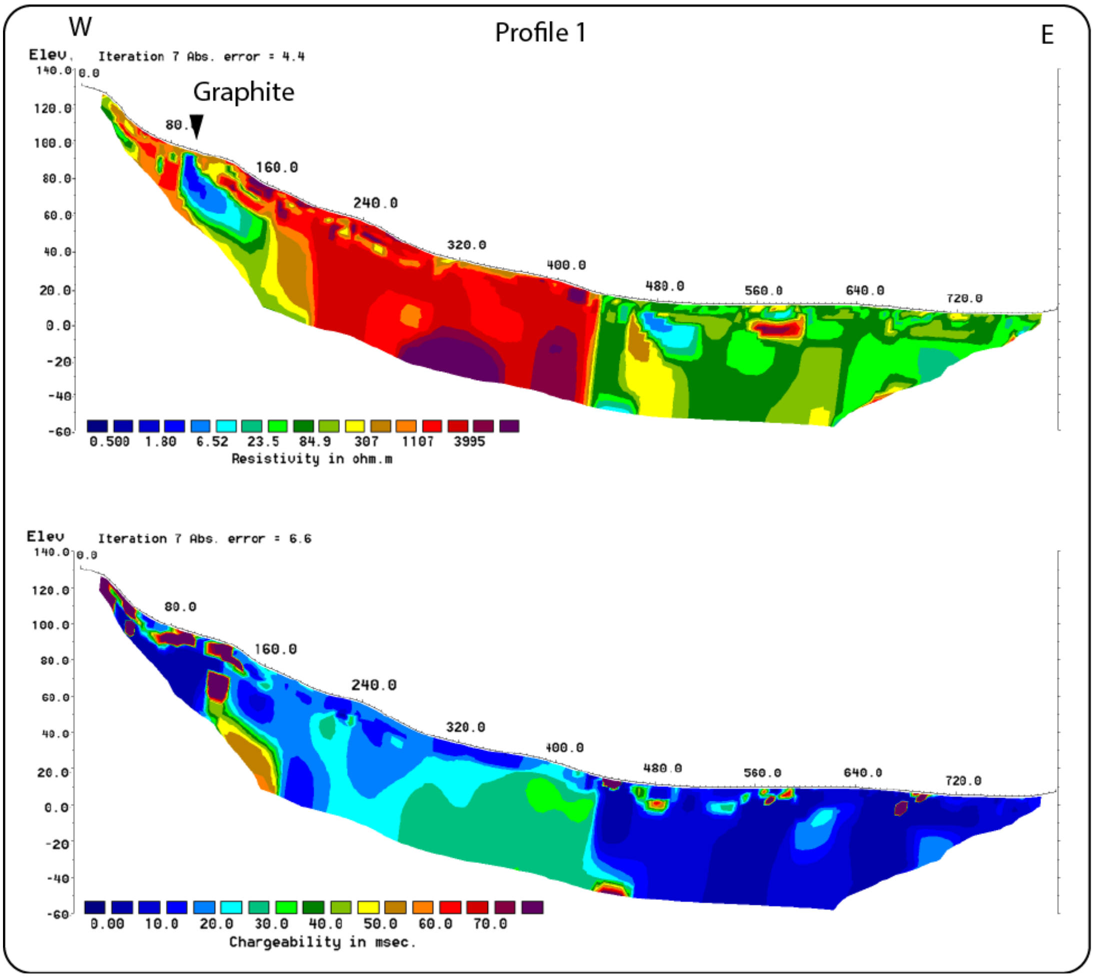

Figure 4.8: Resistivity and IP measured along Profile 1. The electrode spacing is 5m.

Profile 3 (Figure 4.9) is located 600 m S of Profile 1, next to CP grounding point 3. A lot of geological work was performed in this area (Gautneb, et al., 2017). Three separate zones of resistivity <5 Ωm, interpreted as being graphite bearing were detected along profile 3. The westernmost zone seems to be the only one to crop out, but it does not extend to more than 15 m depth. The thickness of this zone seems to be 4 m or more. The middle zone is both very narrow and shallow: it almost outcrops and seems to have an apparent dip to the W. The economic significance of this zone is negligible. The eastern zone seems to be 8 m thick and is covered with an almost 5 m thick layer with resistivity ~1000 Ωm. This could be fractured bedrock, dry sand/gravel or dry moraine. The two most dominating low-resistivity zones coincide with EM31 anomalies and lie in the continuation of graphite exposures. There is however, in this area, no SP anomaly which could indicate that the known graphite mineralisation terminates here.

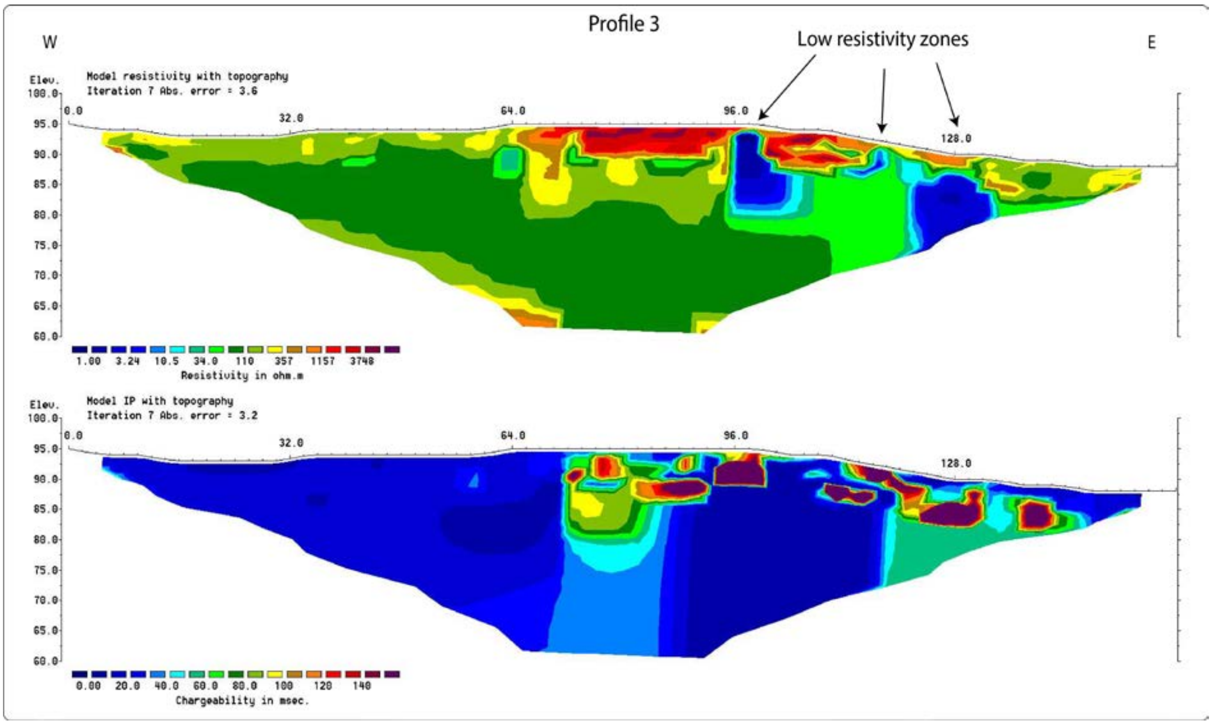

Figure 4.9: Resistivity and IP measured along Profile 3. The electrode spacing is 2m.

The entire profile is dominated by resistivity values of about 100 Ωm (green colour), except the graphite zones and the high-resistivity bedrock (>3000 Ωm). The dominant mid-range values are most likely caused by water-saturated porous rock, and may be an explanation for the moderate resistivity in a larger area, as shown on the helicopter EM resistivity maps (Figure 4.1 and Figure 4.2). The IP section responds well, although not entirely exclusively above the low resistivity graphite zones.

In **Profile 4** (Figure 4.10), it is more difficult to separate different vertical zones. It is however assumed that all the graphite occurrences in the area dip sub-vertically with N-S strike (Gautneb, et al., 2017). It has also been shown that several narrow vertically dipping graphite zones can appear to be a massive body instead of narrow zones in the inversion (Rønning, et al., 2014). The presence of separated, vertical zones is also supported by the IP measurements. Four zones coincide with the interpreted vertical zones in the resistivity section. Both sets of measurements indicate that only the easternmost of the four zones outcrops, the other being covered with highly resistive material. There is also a small low-resistivity anomaly in the western end of the profile. This could also be a small graphite body, appearing as an outlier in the hosting bedrock due to deformation. Altogether, possible vertical graphite mineralisations may appear in a ca. 50 m wide low-resistivity zone. Trenching and geological mapping have shown that graphite appears in zones of thickness 3 – 8 m in the area, however the quality of these may vary (Gautneb, et al., 2017).

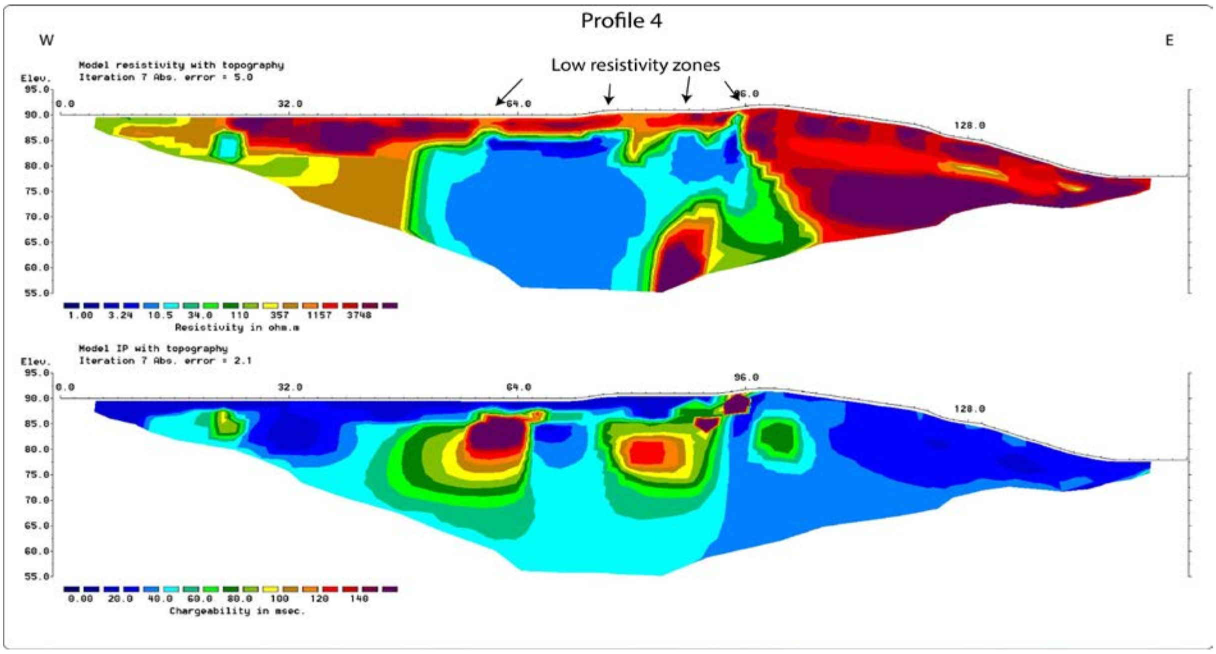

Figure 4.10: Resistivity and IP measured along Profile 4. The electrode spacing is 2m.

4.1.6 Summary Møkland

At Møkland, two conductive zones are recognized from the helicopter-borne electromagnetic measurements. The westernmost of these, here called **Møkland 1**, can be traced for a total length of ca. 5 km. One graphite showing within this zone was known from before (Neumann, 1952) and several new graphite mineralisations were found during our work. The thickness of the graphite might be several meters (3 – 8 m). The average graphitic carbon (Cg) content (37 samples) is 9 % with a maximum value of 25.7 % (Gautneb, et al., 2017). However, the follow-up work shows that the mineralisations are not continuous, and, unfortunately, that each individual deposit could have a limited size, with lengths along strike of the order of a few hundred meters.

We have not been able to map the Møkland 1 zone in detail to the south. However, we expect that graphite mineralisations will show up in the same manner all the way towards Ramsåsbugen where the helicopter EM anomalies terminate towards the fjord. Further work should be carried out in this area.

The conductive zone called **Møkland 2**, laying 500 m E of Møkland 1, does respond to the geophysical measurements in such a way that we can conclude that this zone is not caused by graphite. The origin of the elevated electric conductivity in this area is not yet known, and needs further investigations.

An interpretation map of possible graphite showings in the Møkland area, based on all our geophysical data and geological work is presented in Figure 4.11.

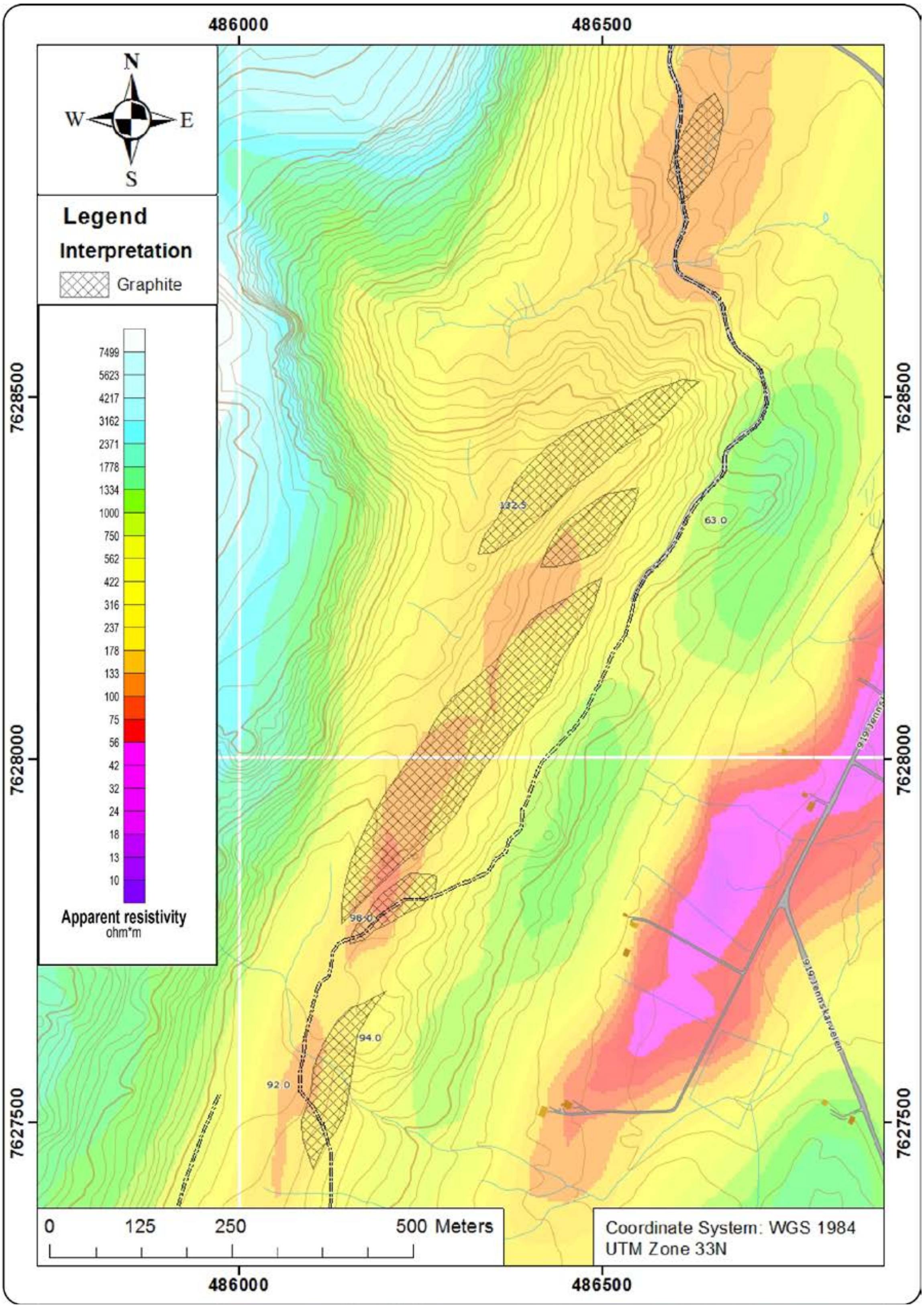

Figure 4.11: Interpreted graphite areas based on EM31, CP/SP measurements and 2D resistivity/IP profiles at the Møkland EM anomaly.

4.2 SOMMARLAND

The location of Sommarland in Bø municipality is shown on Figure 1.1.

4.2.1 Background

At Sommarland, one graphite showing was known prior to NGU's helicopter-borne EM measurements (Neumann, 1952). This showing is located at a 3 – 4 km long EM low-resistivity anomaly starting at the old abandoned graphite mine at Kråkberget in the north extending towards the south-southwest (see Figure 4.1). The average graphite carbon content (Cg) of 5 samples from this location is 7.7 % Cg and the maximum value is 17.1 (Gautneb, et al., 2017). At Sommarland, only one 2D Resistivity/IP profile was measured.

4.2.2 2D resistivity/IP at Sommarland

The location of the 2D resistivity/IP profile at Sommarland is shown in Figure 4.1 . Along this line, one graphite showing was known, located just W of the 400 m marker in Figure 4.12. This is clearly visible in the resistivity data although the graphite seems to stop at ca. 15 m depth.

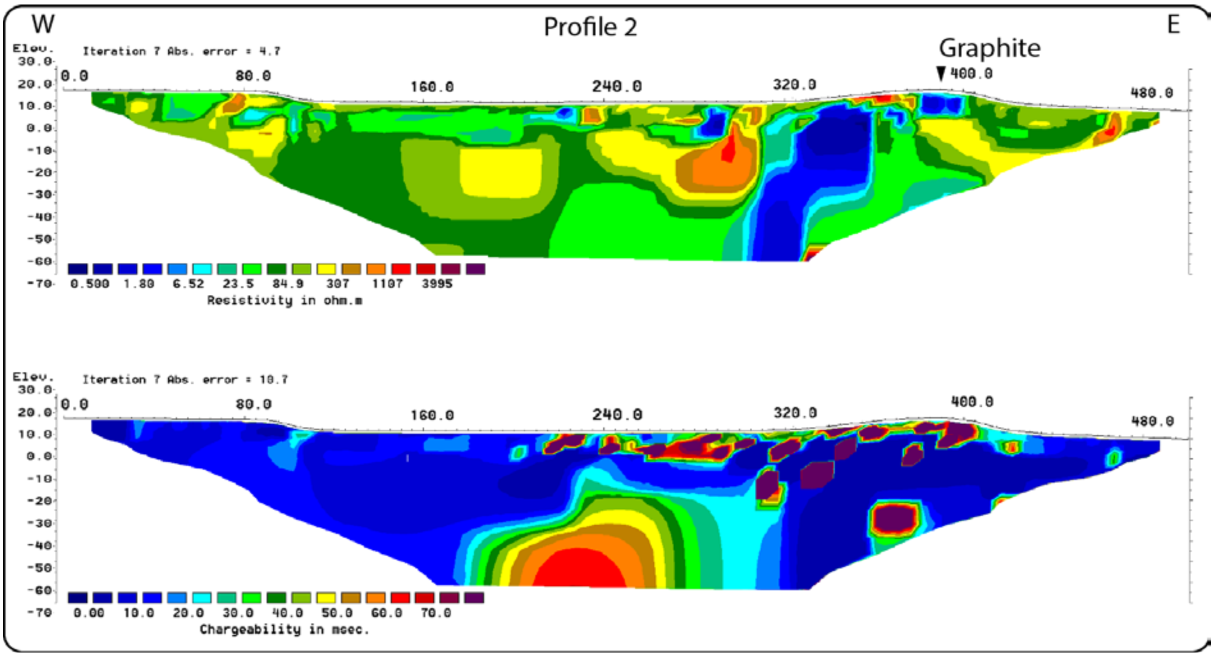

Figure 4.12: Resistivity and IP measured along Profile 2. The electrode spacing is 5m.

However, there is another conducting structure west of the known graphite exposure, between coordinates 320 and 360, which is vastly wider (nearly 40 m) and which extends to a greater depth. The low resistivity in this area, < 2 Ωm, indicates that this may also well be graphite. In that case, this would give a better explanation for the pronounced EM-anomaly in the helicopter-borne EM data, and may indicate a continuation of the graphite at the abandoned mine at Kråkberget. Our experience says that this almost 40 m wide zone may consist of several isolated structures (Rønning, et al., 2014). The anomaly is interesting and must be investigated further, using EM31 profiling, drilling, if possible, and also CP/SP measurements if we can get electrical contact.

There are two smaller low-resistivity areas further west but they are narrow and shallow. These are assumed to have less economic interest. The IP data shows areas with high IP effect which coincide with the low-resistivity areas, although they have a more scattered appearance.

We also notice that the resistivity along the profile in general is quite low, 50 to 300 Ωm. It appears that we may have the same kind of bedrock here as in the Møkland 2 zone. Resistivity at this level is not caused by high-quality graphite. The cause of the low resistivity is of some scientific interest and should be explored in more detail.

4.2.3 Summary Sommarland

Chemical analyses of five samples from the known graphite mineralisation at Sommarland show an average graphitic carbon content of 7.7 % with a maximum value of 17.1 % (Gautneb, et al., 2017). One 2D resistivity/IP profile was measured next to the showing. The showing itself does not give an impressive signature. West of the showing, however, there is a more pronounced resistivity anomaly, and this should be investigated further with ground EM profiling (EM31), core drilling if possible and combined CP/SP measurements. The area should be investigated all the way from the old abandoned graphite mine at Kråkberget where the apparent resistivity from helicopter-borne EM measurements is very good (< 10 Ωm).

4.3 KVERNFJORDALEN

The location of Kvernfjorden in Bø municipality is shown on Figure 1.1.

4.3.1 Background

One graphite exposure in Kvernfjorddalen, N of Kvernfjorden, was known from before (Gautneb et al. 2017). This exposure is connected to a ca. 2.5 km long linear anomaly from the helicopter-borne EM measurements in which the apparent resistivity values are quite low (partly < 20 Ωm). This EM-anomaly continues southwards to Haugsnes. In Kvernfjorddalen, we have made one test with CP measurements. The EM anomaly is crossed by a number of SP lines, and one 2D resistivity/IP profile measured. For the location, see Figure 4.14. In addition, some EM31 profiling was performed, and also some sampling at the graphite exposure (Gautneb, et al., 2017). The average graphitic carbon (Cg) of 5 samples was 6.1 % while the maximum value was 13.7 %.

4.3.2 EM31 measurements at Kvernfjorddalen

EM31 profiling was performed at three locations in Kvernfjorddalen (see Figure 4.13). These measurements confirm the anomalies from the helicopter-borne EM-measurements. Apparent electric conductivities higher than 100 mS/m (apparent resistivity < 10 Ωm) indicate that these EM anomalies are probably caused by graphite. A few negative readings indicate a thickness of individual structures less than the coil spacing of 3.8 m. The EM31 data in the northernmost profile, at the CP grounding, indicate at least two parallel zones of which one is confirmed as graphitic.

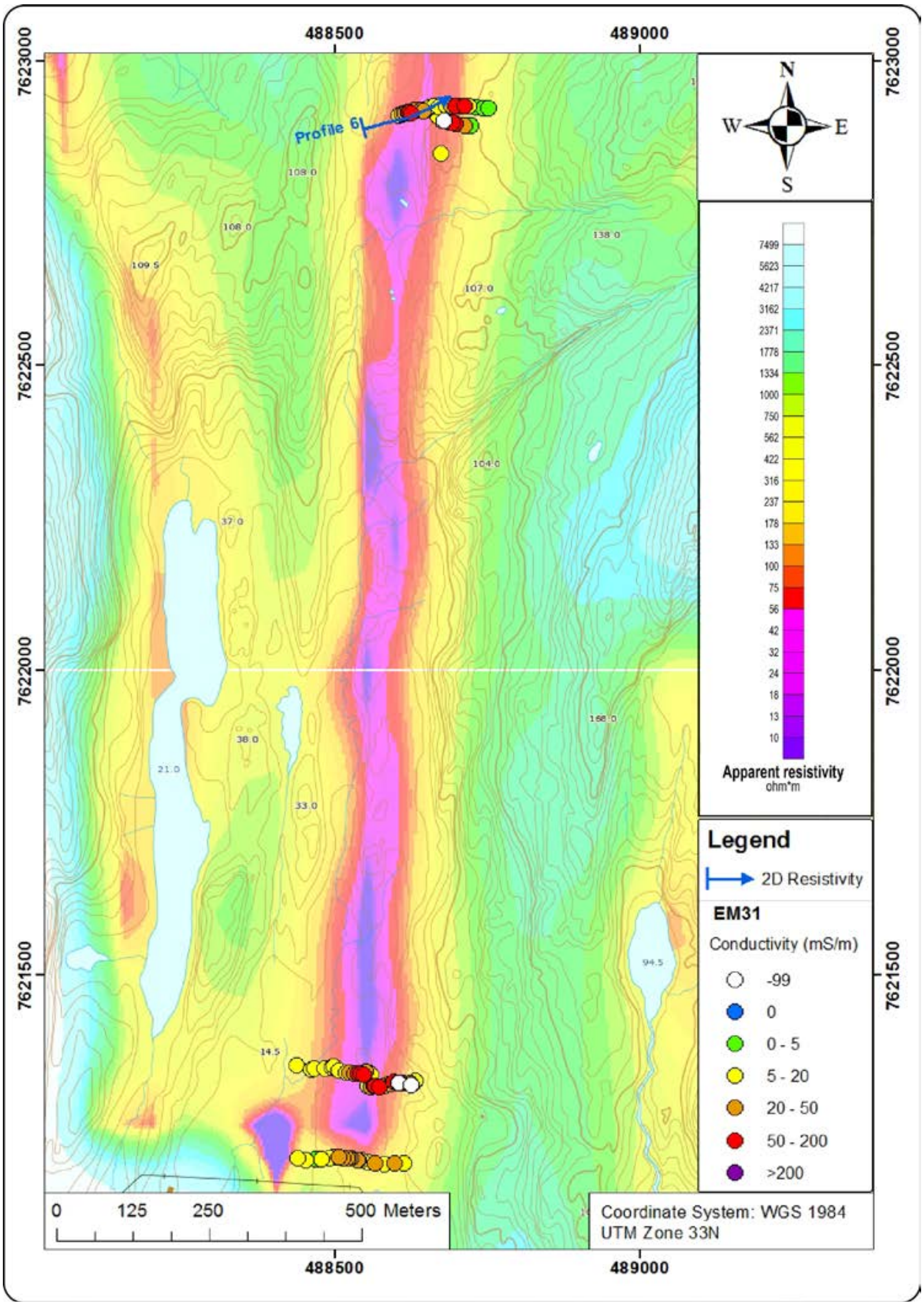

Figure 4.13: EM31 profiles in Kvernfjorddalen, -99 mean negative peak value. The background is apparent resistivity calculated from frequency EM 7000 Hz (modified from Rodionov et al. (2013)).

4.3.3 CP measurements at Kvernfjorddalen

One CP grounding in graphite was tested in Kvernfjorddalen. The location is given in Figure 4.14 and in Table 4.2.

Table 4.2: Technical specifications for the CP measurements in Kvernfjorddalen. R1 is the remote electrode.

Electrode	X-coordinate	Y-coordinate	Current (A)	No. of measurements
1	488628	7622908	1,6	77
R1	488213	7623326	-	

A very special potential effect appeared during the CP measurements. The exposed graphite was not of the best quality, and there were problems establishing a good CP grounding. At the end of the first day of measurements, the grounded body was charged to a voltage of ca. 15 Volts, and during the following night only a part of this was discharged. This previous not described effect made it difficult to go on with the measurements, data are not presented and we had to concentrate on SP measurements. The reason for this effect is under discussion.

4.3.4 SP measurements at Kvernfjorddalen

The results from SP measurements in Kvernfjorddalen, are shown in Figure 4.14. Several SP lines cross a continuous, ca. 2.5 km-long EM anomaly from the helicopter measurements. Several of these show an SP anomaly higher than 800 mV while others show lower anomalies. This is typical for graphite mineralisations which are not continuous. At some crossings, two anomalies are indicated, telling us that the mineralisations may be more complex than shown in the helicopter-borne EM measurements.

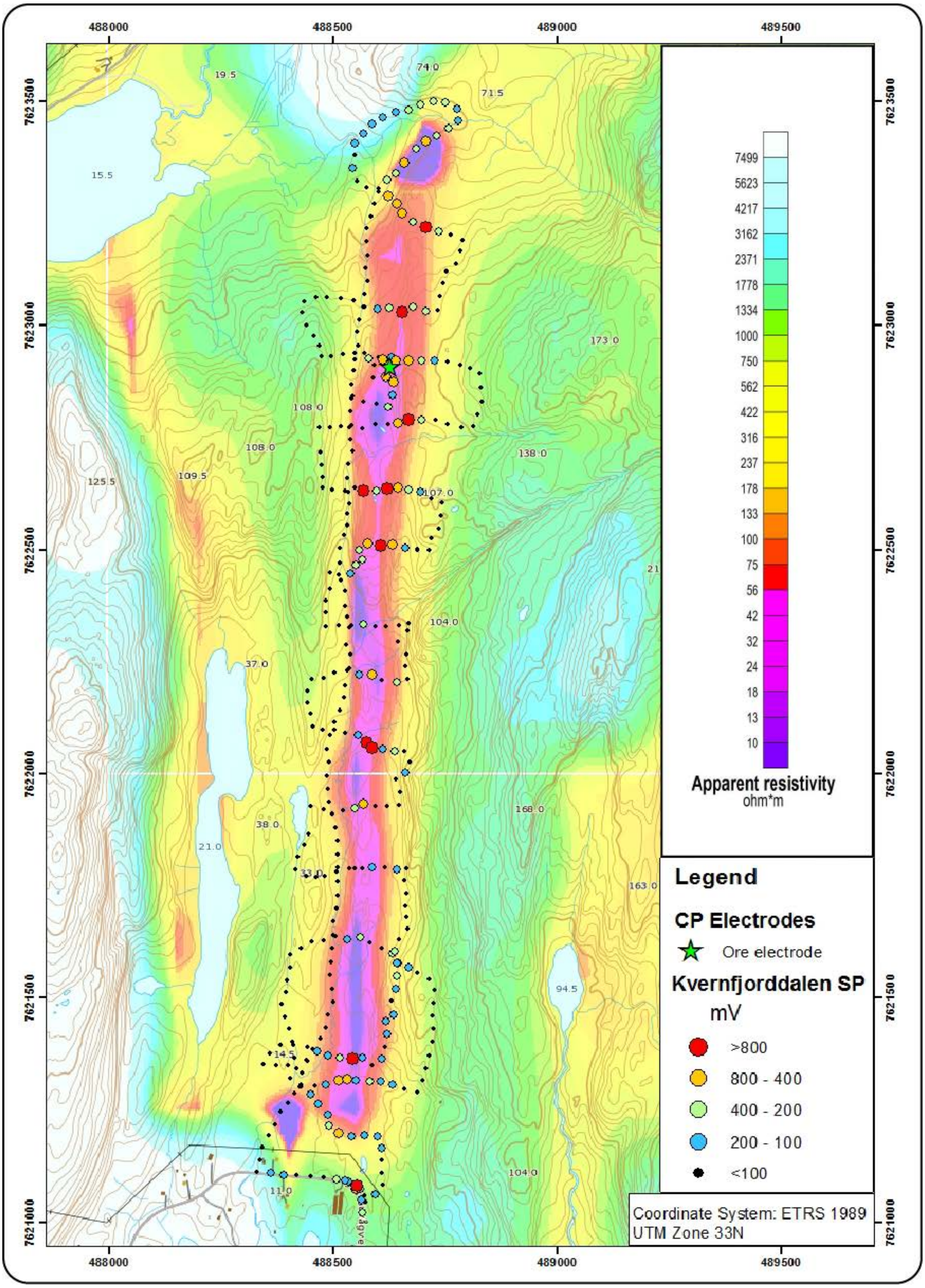

Figure 4.14: Map of the investigated area in Kvernfjorddalen with SP-points superposed on airborne apparent resistivity calculated from 6600 Hz coplanar coils.

4.3.5 2D Resistivity/IP at Kvernfjorddalen

In Kvernfjorddalen, one 2D resistivity/IP profile was placed over the known graphite outcrop (for location see Figure 4.13). Inverted data from the line are shown in Figure 4.15.

In the middle part of the profile, there is a ca. 30 m-wide zone with resistivity < 5 Ωm. The low resistivity value indicate graphite minaralisation. The shape of this anomaly indicates that this might be due to at least two separate subvertical zones. The western zone almost outcrops but the eastern zone seems to be covered by ca. 2m of resistive material. The thickness of the zones appears to be 2 – 4 m, possible more.

There are also two smaller low-resistivity anomalies in the section, a narrow horizontal anomaly at the western end and a small body at the eastern end. The resistivity level indicate graphite here too, but these anomalies appears to have less economic potential.

The two highlighted zones also give a response in the IP section. The outcropping zone extends almost to the bottom of the section and the second zone extends to the same depth. The smaller anomalies on the edges also give good responses in the IP-data. High IP effect may be an indicator of lower graphite quality.

The resistivity/IP anomalies fit well with results from EM31 and SP measurements in the area and with the relatively wide EM anomaly from helicopter-borne measurements.

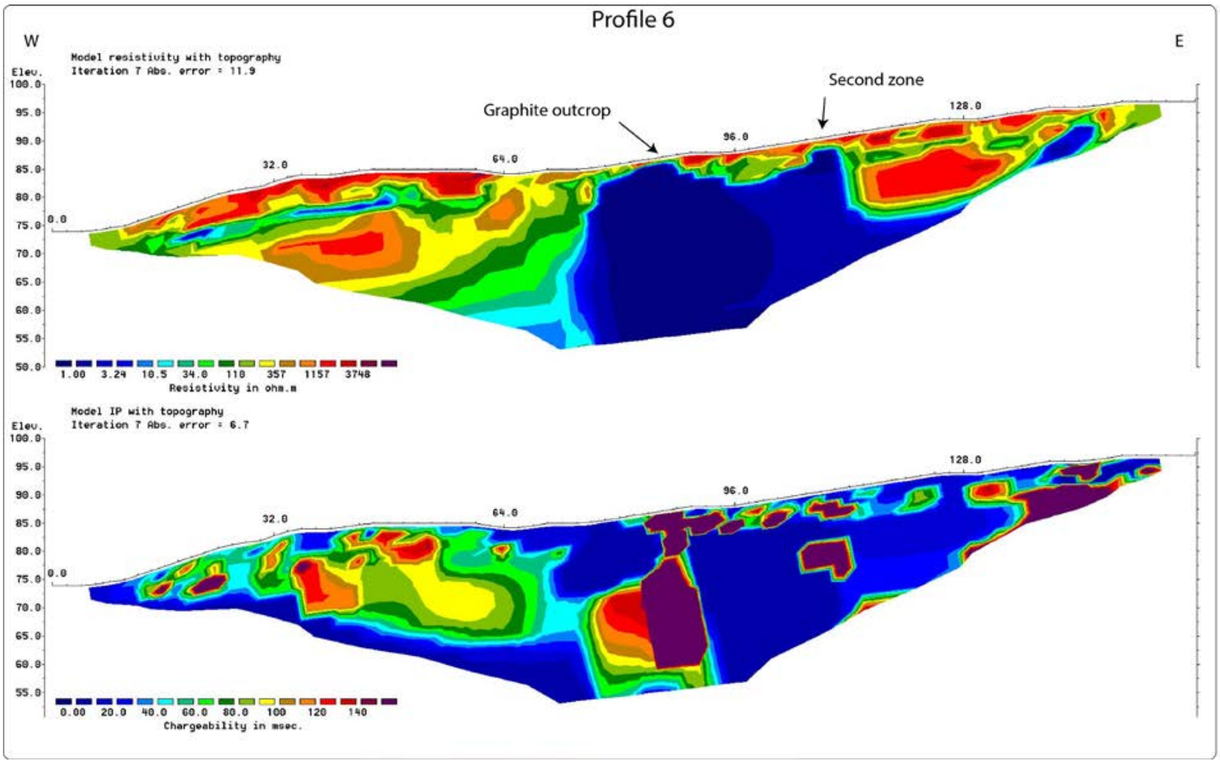

Figure 4.15: Resistivity and IP measured Profile 6, Kvernfjorddalen. The electrode spacing is 2m.

4.3.6 Summary Kvernfjorddalen

In Kvernfjorddalen, a continuous, linear helicopter-borne EM anomaly showing very low resistivity values can be followed for ca. 2.5 km. This anomaly is confirmed by EM31 measurements, numerous SP measurements, and one 2D resistivity/IP line in the area. Graphite is exposed at one location, and the geophysical measurements indicate graphite along the entire anomaly. However, the geophysical measurements indicate separated graphite bodies and also several parallel mineralisations. The average graphite carbon content (Cg) of 5 samples at the only exposure in the area was 6.1 % with a maximum of 13.7 %. The problems with establishing a CP grounding point in the exposure tells us that this may not be a representative quality for the entire mineralisation. Kvernfjorddalen is interesting for further investigations. The next steps should be EM profiling and core drilling.

An interpretation map of possible graphite showings in the Kvernfjorddalen area, based on all our geophysical data and geological work is presented in Figure 4.16.

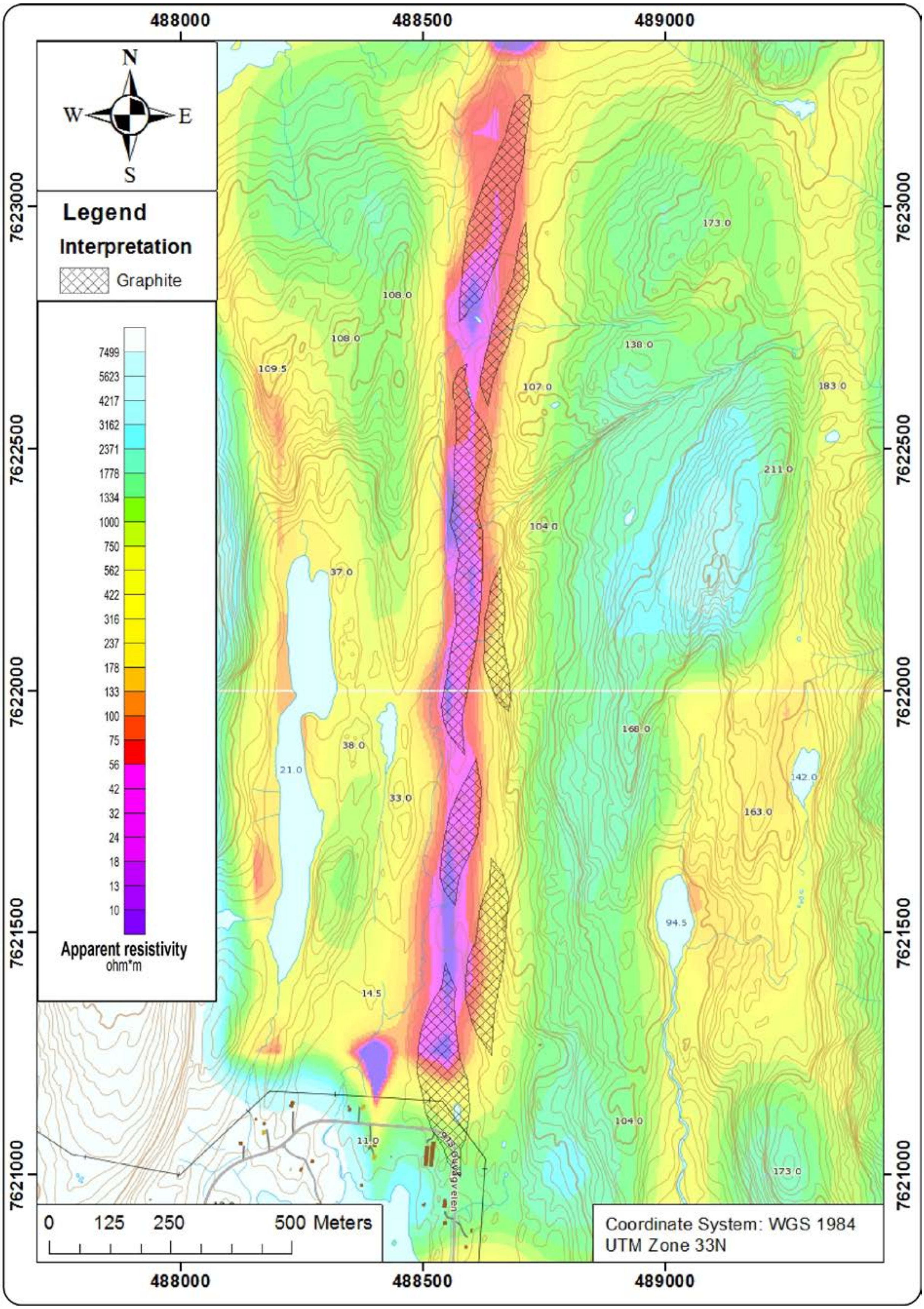

Figure 4.16: Interpreted graphite areas based mainly on SP measurements along the Kvernfjorddalen EM anomaly.

4.4 HAUGSNES

The location of Haugsnes in Bø municipality is shown on Figure 1.1.

4.4.1 Background

At Haugsnes an anomaly from helicopter-borne EM measurements can be followed for ca. 2 km. The anomaly is partly wider than ca. 100 m, and apparent resistivity is quite low. However, the anomaly strikes parallel to the ocean, and the influence of quite conductive seawater may partly explain the anomaly (see Figure 4.17). Two 2D resistivity/IP profiles were measured in the area. We have also sampled in the area. Graphite is exposed at several locations: the average graphite carbon content (Cg) of 11 samples was 19.3 % with a maximum value of 33.8 %.

4.4.2 2D Resistivity/IP at Haugsnes

At Haugsnes, only two 2D resistivity/IP profiles were measured, profile 7 and profile 8. Figure 4.17 shows the location of these.

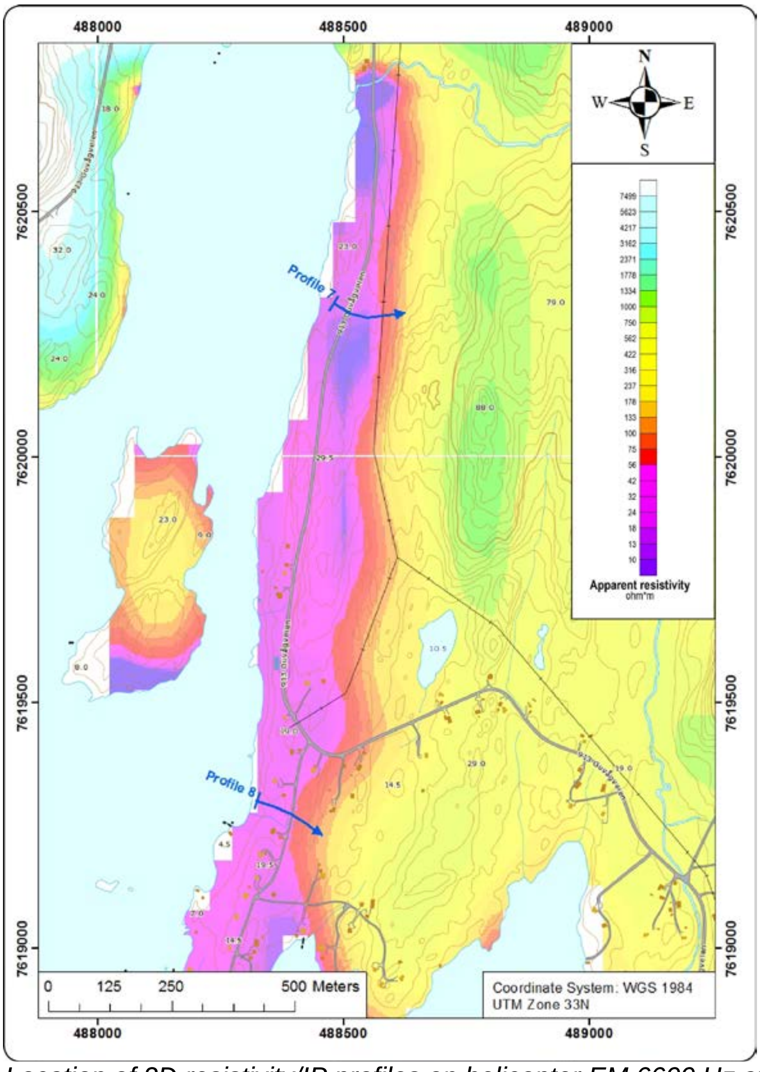

Figure 4.17: Location of 2D resistivity/IP profiles on helicopter EM 6600 Hz at Haugsnes.

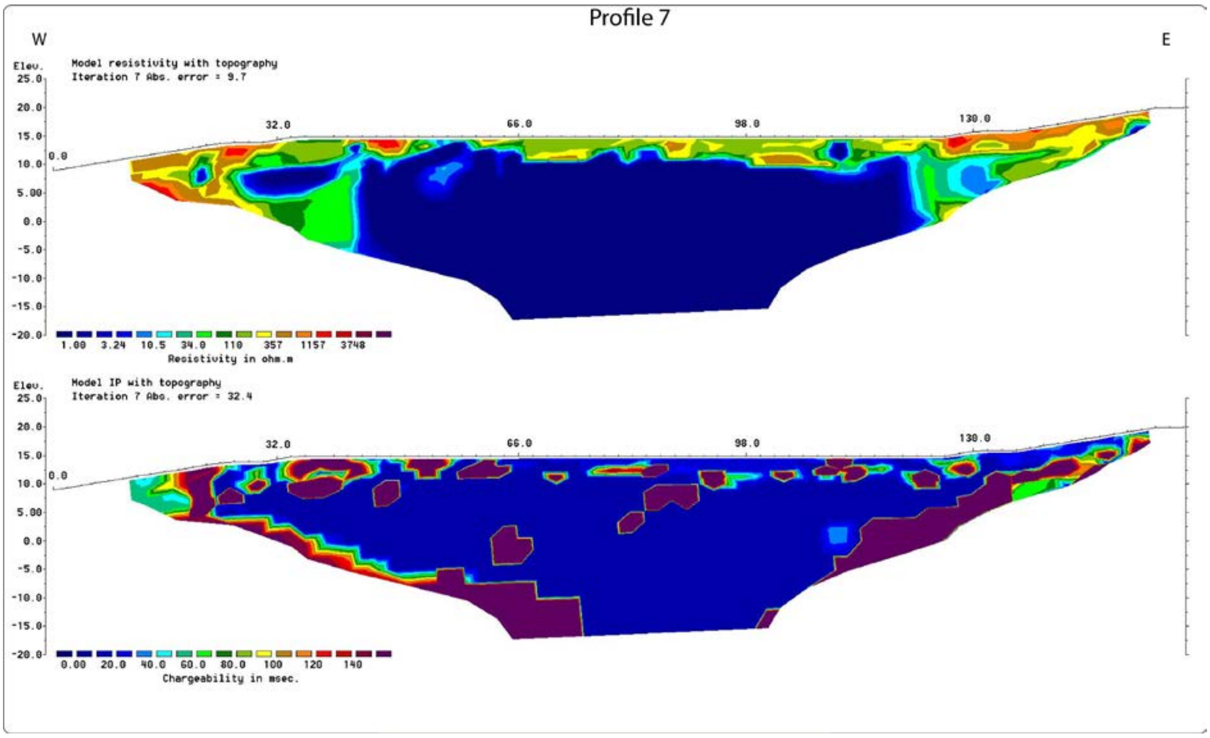

Figure 4.18: Resistivity and IP measured along Profile 7. The electrode spacing is 2m.

Profile 7 (Figure 4.18) shows a nearly 80 m-wide zone with resistivity < 5 Ωm which indicates graphite mineralisation. This zone probably consists of several vertical structures. It is difficult to separate individual zones based on resistivity and IP data alone, but there is a significant amount of very low resistivity material along the section. High IP effects distributed around the resistivity anomalies do also indicate graphite mineralisation. Resistivity values > 1000 Ωm in the western end of the profile, show that the conductive anomaly is disconnected from seawater.

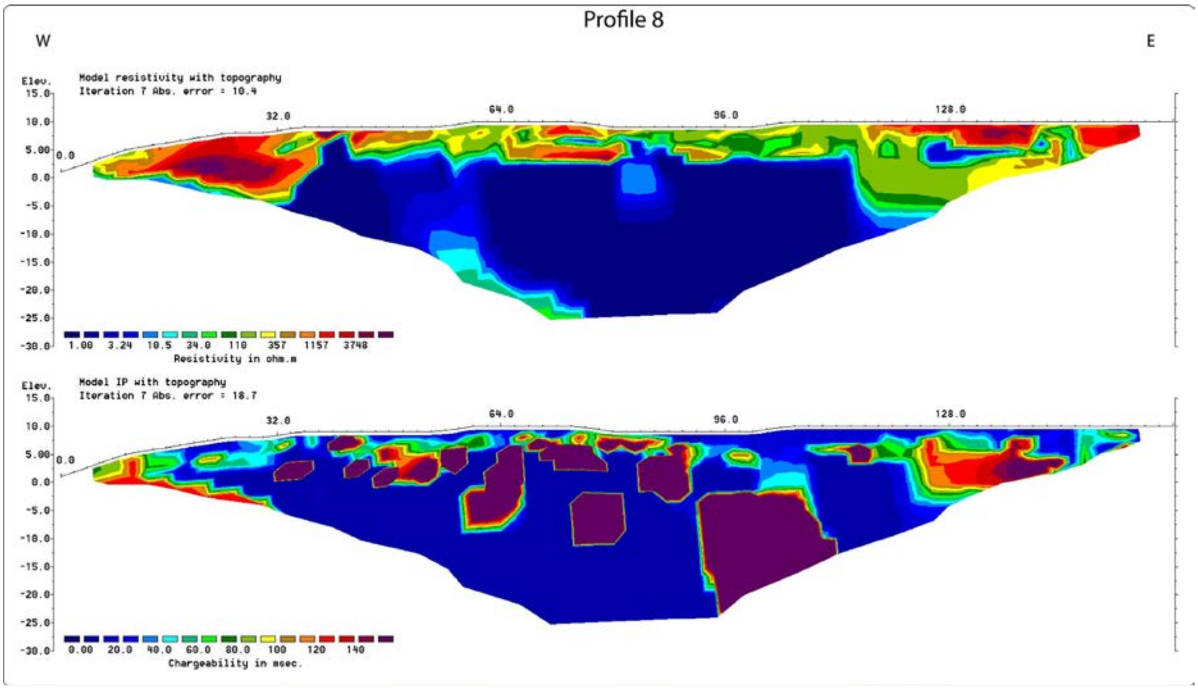

Figure 4.19: Resistivity and IP measured along Profile 8. The electrode spacing is 2m.

Profile 8 (Figure 4.19), like Profile 7, has a nearly 80 m-wide zone of very low resistivity material (< 5 Ωm). The low resistivity value in combination with IP effect, also here, indicates graphite mineralisation, and there is a known graphite outcrop just N of the westernmost low-resistivity anomaly at around coordinate 40 m (Gautneb, et al., 2017). Here too, it is difficult to distinguish between separate zones, and several parallel zones may be present. Resistivity values > 1000 Ωm in the western end of the profile, show that the conductive anomaly is disconnected from seawater also here.

4.4.3 Summary Haugsnes

Graphite analyses on 11 samples from an outcrop at Haugsnes show an average graphitic carbon content of 19.3 % and a maximum value as high as 33.8 %. This, in combination with a ca. 2 km long EM anomaly from helicopter measurements, and possible graphite mineralisations in a width of up to 80 m, makes this area of special interest. Although this area is populated, NGU aims to do more work on this location: EM31 profiling, possible drilling, trenching, sampling and chemical analysis. Combined CP/SP measurements are also of interest.

4.5 SMINES

The location of Smines in Øksnes municipality is shown on Figure 1.1.

4.5.1 Background

This graphite occurrence was discovered when the 2013 airborne geophysics were available. Apart from some small shoreline exposures the graphite-bearing rocks are completely covered by soil.

The calculated apparent resistivity from helicopter-borne EM at Smines is, in part, quite low (see Figure 4.20). EM 31 traverses indicated several graphite-bearing conductors under thin cover and a trench was excavated in the area that was most accessible. Several zones of graphite mineralisation were revealed: they have a total width in the trench of about 6 m (Gautneb, et al., 2017).

Eleven samples from the trench show an average graphitic carbon grade (Cg) of 7.7 % with a maximum value of 17.1 %.

In addition to EM31 measurements, CP and SP measurements were performed and one profile 2D resistivity/IP.

4.5.2 EM31 measurements at Smines

Measured apparent conductivity with EM31 is presented on top of apparent resistivity from helicopter-borne EM measurements (6600 Hz coplanar coils) in Figure 4.20. Several points show apparent conductivity > 50 mS/m which corresponds to apparent resistivity < 20 Ωm. Some values are even higher (> 200 mS/m, resistivity < 5 Ωm) which indicate well-conducting graphite. Large areas within the helicopter EM anomalies may be caused by graphite.

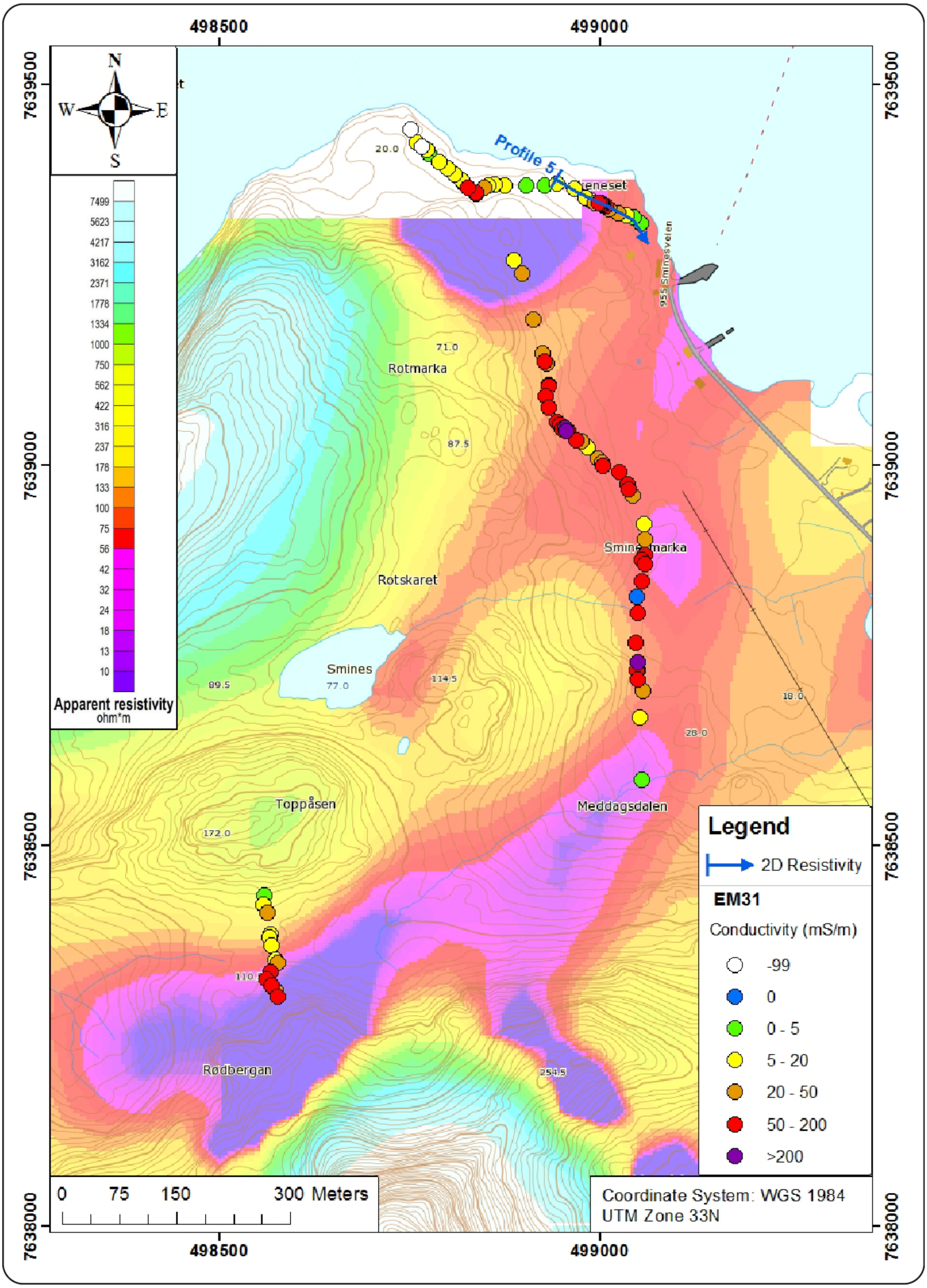

Figure 4.20: EM31 readings on top of EM 6600. Measured 2D resistivity/IP profile is shown in blue.

4.5.3 CP Measurements at Smines

At Smines one CP grounding was measured with the ore electrode in the trench and the remote electrode 2 -3 km along the road towards Møkland in the south. Table 4.3 gives details.

Table 4.3: Technical specifications for the CP grounding at Smines. R1 is the remote electrode.

Electrode	X-coordinate	Y-coordinate	Current (A)	No. of measurements
1	499005	7639343	2	248
R1	499758	7636925	-	

The CP contour map shown in Figure 4.21 indicates a limited size for the actual graphite body towards the south. It probably continues towards the sea N of the trench in which graphite is exposed, which means that its strike length on land is ca. 100 m. The low potential at the current electrode (≈ 200 mV) indicates current leakage directly to the sea.

Measurements towards the south and west were performed in order to map SP anomalies.

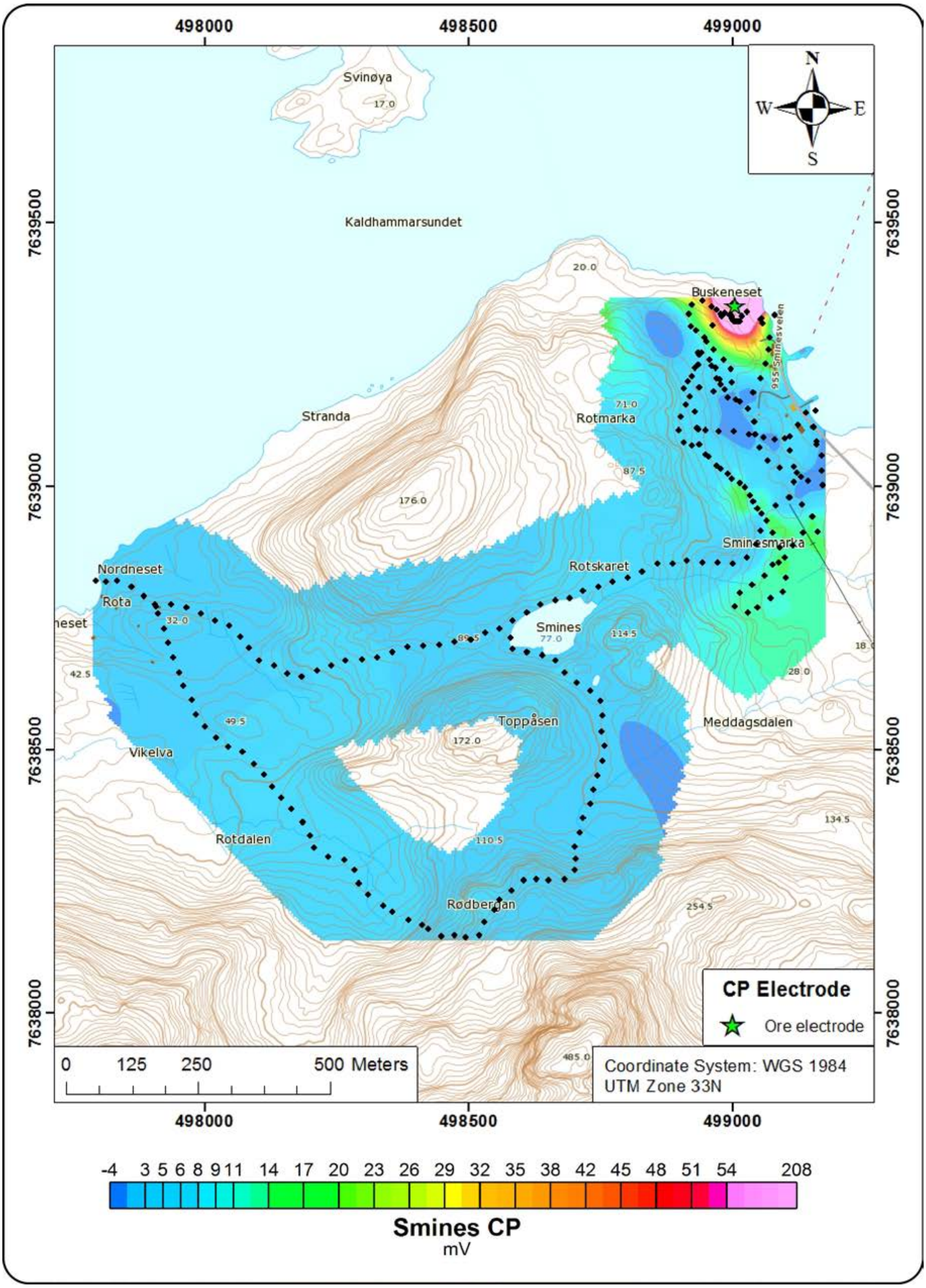

Figure 4.21: Results of CP measurements at Smines.

4.5.4 SP measurements at Smines

Results from the SP measurements at Smines are shown in Figure 4.22. Astonishingly, there is no SP anomaly in the area outside the CP grounding and south of it. The absence of such a SP anomaly may indicate other reasons than graphite for the low apparent resistivity from helicopter-borne EM south of the CP grounding point at Buskneset. SP anomalies appear next to Rotmarka, Sminesmarka and especially at Rødbergan (red rock). Some of them are higher than 800 mV indicating the presence of graphite.

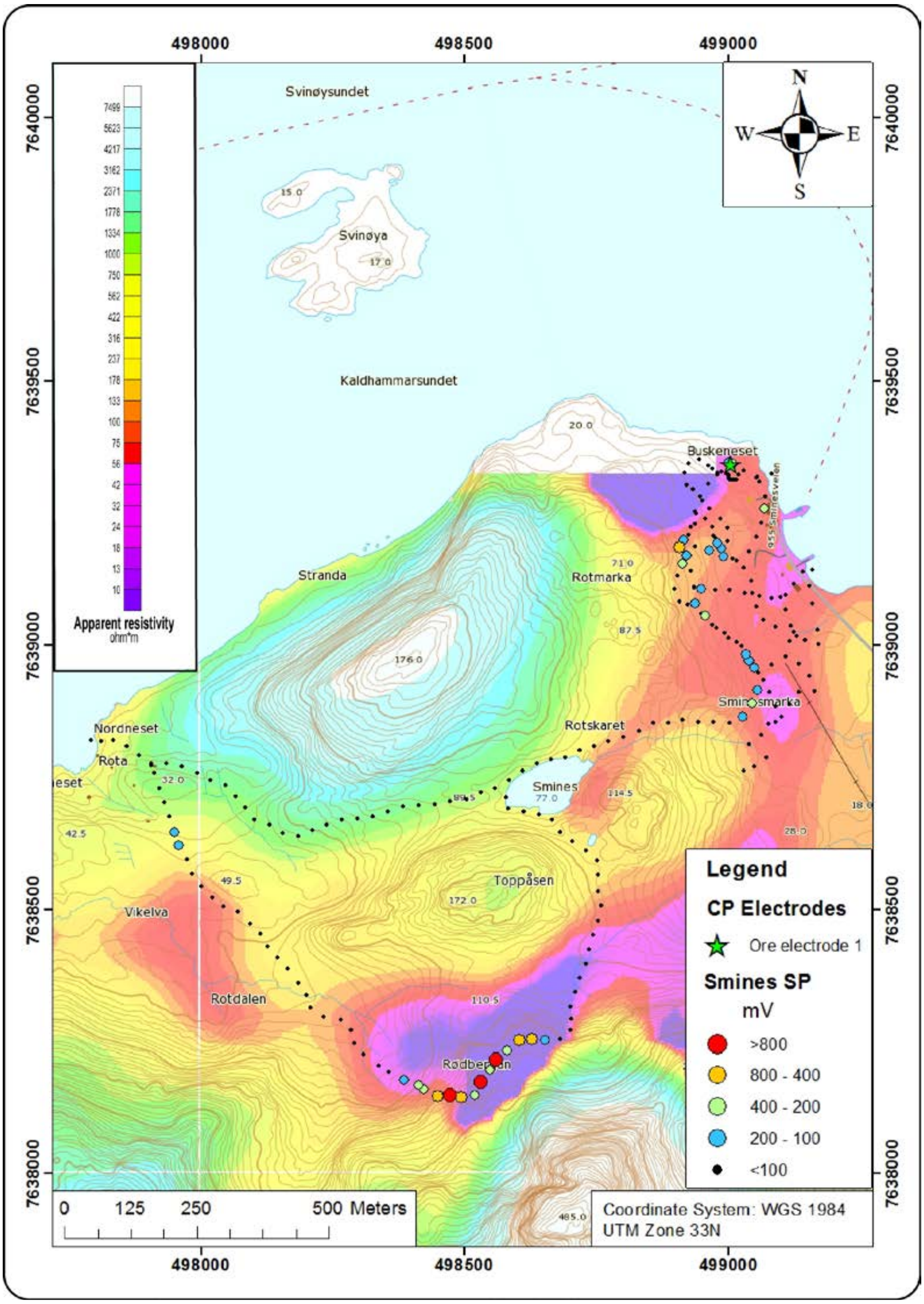

Figure 4.22: Map of investigated area in Smines with SP-points superposed on airborne resistivity.

Note that large areas with low apparent resistivity from helicopter-borne EM are not covered by either EM31 or SP measurements. The area is underexplored, and ground measurements should be continued.

4.5.5 2D resistivity/IP at Smines

One 2D resistivity/IP profile was measured at Smines. The centre of Profile 5 (Figure 4.23) was located right on top of outcropping graphite in the trench at which CP grounding was established (see Figure 4.20 for the location).

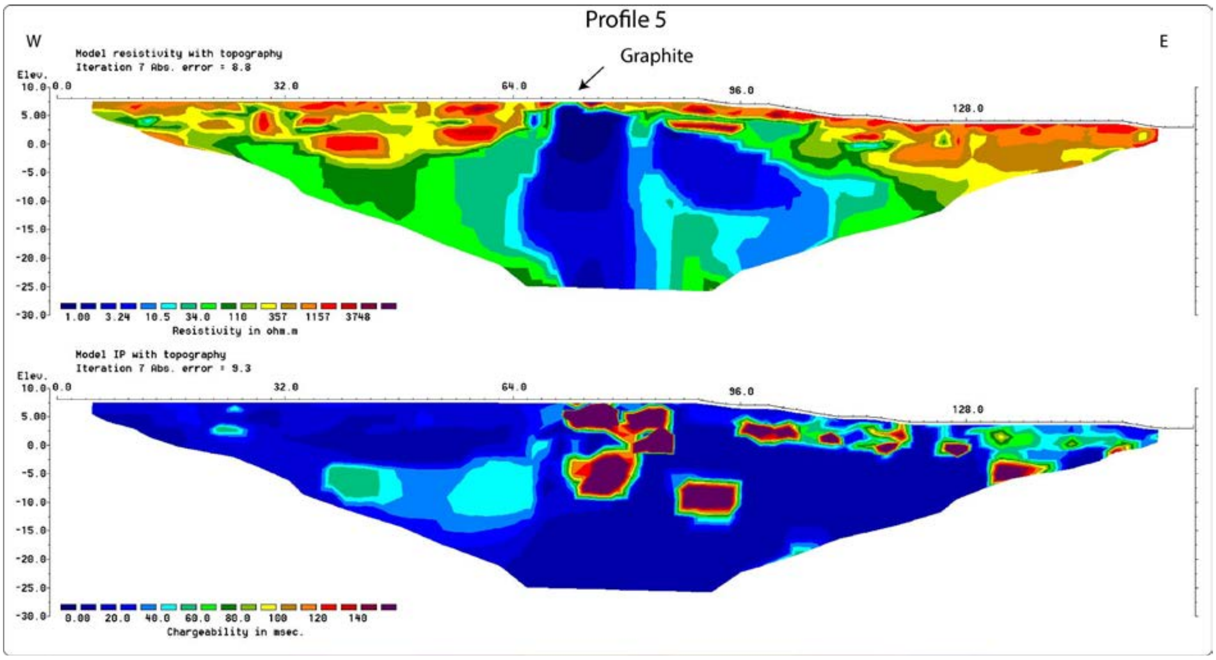

Figure 4.23: Resistivity and IP measured along Profile 5, Smines. The electrode spacing is 2m.

The graphite mineralisation shows up as a ca. 10 m-wide zone of very low resistivity (< 5 Ωm) extending from the outcrop all the way down to the bottom of the section. This zone is also detected by IP, but it does not extend to the same depth as indicated by the resistivity. The IP effect might indicate graphite of moderate quality. Just E of this layer there is a low-resistivity zone with an apparent dip to the E. It has resistivity that may be caused by graphite. The dip towards east is in agreement with decreasing EM31 response in this direction.

4.5.6 Summary Smines

The graphite occurrence at Smines was discovered when the 2013 airborne geophysical data where available. Apart from some small seaside exposures, the graphite bearing-rocks are completely covered by soil and vegetation. EM 31 traversing indicated several graphite-bearing conductors under thin cover and a trench was made in the area that was most accessible. Several zones of graphite mineralisation were revealed: they have a total width in a trench of ca. 6 meters (Gautneb et al. 2017). CP measurement showed that also this mineralisation has limited length along strike.

Eleven samples from the trench show an average grade of 7.7 % Cg with a maximum of 17.1 %.

EM31 and SP measurements gave indications of graphite S of the exposure in the trench. However, due to limited time for field work, large areas showing very low resistivity at helicopter-borne EM data were not included in follow-up work yet, and the area covered by ground measurements at Smines should be extended. No graphite interpretation map is presented in this report due to the need for future work.

5. CONCLUSIONS AND FUTURE WORK

5.1 Økland

At Økland, two conductive zones are recognized from the helicopter-borne electromagnetic measurements. The westernmost of these, here called **Økland 1**, can be traced for a total length of ca. 5 km. One graphite showing within this zone was known from before (Neumann, 1952) and several new graphite mineralisations were found during our work. The thickness of the graphite might be several meters (3 – 8 m). The average graphitic carbon (Cg) content (37 samples) is 9 % with a maximum value of 25.7 % (Gautneb, et al., 2017). However, the follow-up work shows that the mineralisations are not continuous, and, unfortunately, that each individual deposit could have a limited size, with lengths along strike of the order of a few hundred meters.

We have not been able to map the Økland 1 zone in detail to the south. However, we expect that graphite mineralisations will show up in the same manner all the way towards Ramsåsbugen where the helicopter EM anomalies terminate towards the fjord. Further work should be carried out in this area.

The conductive zone called **Økland 2**, laying 500 m E of Økland 1, does respond to the geophysical measurements in such a way that we can conclude that this zone is not caused by graphite. The origin of the elevated electric conductivity in this area is not yet known, and needs further investigations.

5.2 Sommarland

Chemical analyses of five samples from the known graphite mineralisation at Sommarland show an average graphitic carbon content of 7.7 % with a maximum value of 17.1 % (Gautneb, et al., 2017). One 2D resistivity/IP profile was measured next to the showing. The showing itself does not give an impressive signature. West of the showing, however, there is a more pronounced resistivity anomaly, and this should be investigated further with ground EM profiling (EM31), core drilling if possible and combined CP/SP measurements. The area should be investigated all the way from the old abandoned graphite mine at Kråkberget where the apparent resistivity from helicopter-borne EM measurements is very good (< 10 Ωm).

5.3 Kvernfjorddalen

In Kvernfjorddalen, a continuous, linear helicopter-borne EM anomaly showing very low resistivity values can be followed for ca. 2.5 km. This anomaly is confirmed by EM31 measurements, numerous SP measurements, and one 2D resistivity/IP line in the area. Graphite is exposed at one location, and the geophysical measurements indicate graphite along the entire anomaly. However, the geophysical measurements indicate separated graphite bodies and also several parallel mineralisations. The average graphite carbon content (Cg) of 5 samples at the only exposure in the area was 6.1 % with a maximum of 13.7 %. The problems with establishing a CP grounding point in the exposure tells us that this may not be a representative quality for the entire mineralisation. Kvernfjorddalen is interesting for further investigations. The next steps should be EM profiling and core drilling.

5.4 Haugsnes

Graphite analyses on 11 samples from an outcrop at Haugsnes show an average graphitic carbon content of 19.3 % and a maximum value as high as 33.8 %. This, in combination with a ca. 2 km long EM anomaly from helicopter measurements, and possible graphite mineralisations in a width of up to 80 m, makes this area of special interest. Although this area is populated, NGU aims to do more work on this location: EM31 profiling, possible drilling, trenching, sampling and chemical analysis. Combined CP/SP measurements are also of interest.

5.5 Smines

The graphite occurrence at Smines was discovered when the 2013 airborne geophysical data where available. Apart from some small seaside exposures, the graphite bearing-rocks are completely covered by soil and vegetation. EM 31 traversing indicated several graphite-bearing conductors under thin cover and a trench was made in the area that was most accessible. Several zones of graphite mineralisation were revealed: they have a total width in a trench of ca. 6 meters (Gautneb et al. 2017). CP measurement showed that also this mineralisation has limited length along strike.

Eleven samples from the trench show an average grade of 7.7 % Cg with a maximum of 17.1 %.

EM31 and SP measurements gave indications of graphite S of the exposure in the trench. However, due to limited time for field work, large areas showing very low resistivity at helicopter-borne EM data were not included in follow-up work yet, and the area covered by ground measurements at Smines should be extended.

5.6 Others

According to the original plan for the project, more geophysical and geological work should be performed at several other possible graphite showings. In this report, based on the geophysical work, we recommend more work at Haugsnes, Sommarland, Møkland and Smines. Based on geological knowledge, Gautneb et al. (2017) have recommended more work on Vikeid, Raudhammaren, Romsetfjorden and Frøskeland. All these recommendations are summarized in Table 5.1.

Table 5.1: Localities at which follow-up work is regarded as necessary.

Locality	**Municipality**	**Comment and activity**
Morfjord	Vågan	EM profiling, trenching and sampling
Frøskeland (Grønjorda)	Sortland	EM profiling, electrical profiling, trenching and sampling. Possibly also CP/SP
Romsetfjord (New)	Sortland	EM profiling, electrical profiling, trenching and sampling. Possibly also CP/SP and core drilling
Vikeid (Vedåsen)	Sortland	EM profiling, electrical profiling, trenching and sampling. Possibly also CP/SP
Haugsnes	Bø	EM profiling, trenching and sampling. Possibly also CP/SP and core drilling.
Sommarland	Bø	EM profiling, trenching and sampling. Possibly also CP/SP and core drilling.
Møkland	Bø	Extension of existing measured area
Smines	Øksnes	Extension of existing measured area
Myre East and Raudhammeren	Øksnes	EM profiling, electrical profiling, trenching and sampling. Possibly also CP/SP

6. REFERENCES

AarhusInv, 2013. *Manual for Iversion software ver 6.1,* Aarhus, Denmark: Hydro Geophysics Group (HGG), University of Aarhus. http://www.hgg.geo.au.dk/HGGsoftware/em1dinv/em1dinv_manual.pdf .

ABEM, 2012. *ABEM Terrameter LS. Instruction Manual, release 1.11,* Sundbyberg: ABEM Instrument AB, Sweden.

Dahlin, T., 1993. *On the automation of 2D resistivity surveying for engineering and environmental applications..* Lund: Department of Engineering Geology, Lund Institute of Technology, Lund University. 187pp, ISBN 91-628-1032-4.

Dahlin, T. & Zhou, B., 2006. Multiple-gradient array measurements for multichannel 2D. *Near Surface Geophysics, Vol 4, No 2*, April, pp. 113-123.

Dalsegg, E., 1994. *CP-, SP- og ledningsevnemålinger ved grafittundersøkelser ved Hornvannet, Sortland, Nordland,* Trondheim: NGU Report 94.003.

Gautneb, H. et al., 2017. *Geological and ore dressing investigations of graphite occurrences in Bø, Sortland, Hadsel and Øksnes,municipalities, Vesterålen, Nordland County Northern Norway 2015-2016,* Trondheim: NGU Report 2017.015.

Geonics, 1984. *Operating manual EM31-D Non-contacting terrain conductivity meter. Revised June 1984,* Mississauga, Ontario Canada: Geonics LTD.

Geosoft, 1997. *HEM System (Helicopter Electromagnetic data Processing, Analysis and Presentation System,* Toronto, Ontario Canada: Geosoft.

Geotech, 1997. *Hummingbird Electromagnetic System, User manual,* s.l.: Geotech Ltd.

Kihle, O. & Eidsvig, P. D., 1978. *Nye tolkninger for tolkning av CP-målinger,* Trondheim: NGU.

Lile, O. B., 1971. *CP - Oppladet potensial.* Trondheim: Lic.grad avhandling. Universitetet i Trondheim, Norges Tekniske Høgskole, Institutt for gruvedrift.

Loke, M. H., 2014. Geoelectrical Imaging 2D & 3D. Instruction Manual. Res2DInv ver 4.00. http://www.geotomosoft.com/.

Neumann, H., 1952. *Dagbok fra Nord-Norge 26.5 - 19.8,* s.l.: Ba report 7709.

Rodionov, A., Ofstad, F., Stampolidis, A. & Tassis, G., 2013. *Helicopter-borne magnetic, electromagnetic and radiometric geophysical survey at Langøya in Vesterålen, Nordland,* Trondheim: NGU Report 2013.044.

Rønning, J. S. et al., 2014. *Oppfølgende grafittundersøkelser i Meløy og Rødøy kommuner, Nordland,* Trondheim: NGU (Report nr 2014.046).

Rønning, J. S., Rodionov, A., Ofstad, F. & Lynum, R., 2012. *Elektromagnetiske, magnetiske og radiometriske målinger fra helikopter i området Skaland - Trælen på Senja,* Trondheim: NGU Report 2012.061.

Sato, M. & Mooney, H. M., 1960. The elctrochemical mechanism of sulphide self-potentials. *Geophysics,* Volume 25, pp. 226-249.

UBC, 2000. *Manual for EM1DFM.,* Vancouver, Canada: UBC - Geophysical Inversion facility, Department of Earth and Ocean Sciences, University of British Columbia.

A. APPENDICES

A.1 Coordinates for 2D resistivity and IP profiles

Table A.1: Coordinates for resistivity Profile 1 in WGS 84, UTM Zone 33.

Station (m)	X-coordinate	Y-coordinate
0	486390	7628348
100	486468	7628310
200	486556	7628285
300	486645	7628249
400	486740	7628209
500	486831	7628187
600	486918	7628154
700	487005	7628105
800	487083	7628045

Table A.2: Coordinates for resistivity Profile 2 in WGS 84, UTM Zone 33.

Station (m)	X-coordinate	Y-coordinate
0	487219	7626224
100	487321	7626232
200	487417	7626259
300	487515	7626265
400	487613	7626284
500	487708	7626293

Table A.3: Coordinates for resistivity Profile 3 in WGS 84, UTM Zone 33.

Station (m)	X-coordinate	Y-coordinate
0	486088	7627844
40	486118	7627820
80	486143	7627793
120	486162	7627761
160	486191	7627733

Table A.4: Coordinates for resistivity Profile 4 in WGS 84, UTM Zone 33.

Station (m)	X-coordinate	Y-coordinate
0	486077	7627639
40	486111	7627623
80	486149	7627610
120	486185	7627595
160	486216	7627584

Table A.5: Coordinates for resistivity Profile 5 in WGS 84, UTM Zone 33.

Station (m)	X-coordinate	Y-coordinate
0	498939	7639378
40	498970	7639359
80	499008	7639342
120	499043	7639323
160	499063	7639290

Table A.6: Coordinates for resistivity Profile 6 in WGS 84, UTM Zone 33.

Station (m)	X-coordinate	Y-coordinate
0	488545	7622888
40	488581	7622898
80	488620	7622907
120	488656	7622923
160	488689	7622942

Table A.7: Coordinates for resistivity Profile 7 in WGS 84, UTM Zone 33.

Station (m)	X-coordinate	Y-coordinate
0	488478	7620314
40	488512	7620293
80	488548	7620284
120	488589	7620289
160	488626	7620295

Table A.8: Coordinates for resistivity Profile 8 in WGS 84, UTM Zone 33.

Station (m)	X-coordinate	Y-coordinate
0	488321	7619301
40	488357	7619289
80	488393	7619273
120	488427	7619251
160	488457	7619230

GEOLOGICAL
SURVEY OF
NORWAY
- NGU -

Geological Survey of Norway
PO Box 6315, Sluppen
N-7491 Trondheim, Norway

Visitor address
Leiv Eirikssons vei 39
7040 Trondheim

Tel (+ 47) 73 90 40 00
E-mail ngu@ngu.no
Web www.ngu.no/en-gb/