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Forsmark site investigation

Ground geophysical measurements near the lineament trench AFM001265

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Abstract

The report presents the execution and the results from ground geophysical measurements carried out near the lineament trench AFM001265, across the lineament XFM0159A0, in the Forsmark site investigation area. The objective is to gain knowledge about the physical characteristics of the overburden and bedrock related to the lineament.

A grid was staked with four parallel survey lines with a line spacing of 10 m. The magnetic measurement was carried out along all profiles with a 5 m point distance and the electric resistivity measurements were performed along two of the profiles, 20 m apart. The resistivity measurement was carried out with the ABEM Lund Imaging system with 2 m electrode distance.

Magnetic susceptibility measurements carried out during the geological mapping of the outcrops in the trench have been processed and compiled to facilitate comparison with the magnetic survey results.

The magnetic survey indicates a central low magnetic zone striking N60°E, which corresponds well with the previously interpreted, airborne magnetic lineament. This also coincides with a very low magnetic susceptibility encountered in the central part of the trench. Two distinct, low resistivity intercepts also coincide with the low magnetic zone.

The linked lineament in this area is represented by two segments XFM015904 and XFM015905. XFM015904 is only identified on airborne magnetic data and consequently this segment fits rather well with the magnetic lineament. On the other hand, the segment XFM015905 is also based on a topographic lineament and a conductivity lineament. In this case the position has previously been judged from the topographic lineament and is placed about 40 m southeast from the magnetic lineament. In other words, the displacement of the linked lineament is a result of the linking process and is within the precision limits obtained in the lineament coordination.

Sammanfattning

Denna rapport presenterar utförande och resultat av markgeofysiska mätningar utförda vid ett undersökningsdike, AFM001265, över det tidigare tolkade lineamentet XFM0159A0 inom Forsmark kandidatområde. Lineamentet har tidigare identifierats från flyggeofysiska och topografiska data. Målsättningen med insatsen är att erhålla geofysisk information om berggrundens och jordarternas egenskaper vid lineamentet.

Fyra parallella profiler har stakats ut med 10 m linjeavstånd och 20 m stickavstånd. Magnetiska mätningar utfördes längs samtliga profiler med 5 m punktavstånd och elektriska resistivitetsmätningar utfördes längs två av profilerna med 20 m profilavstånd. Resistivitetsmätningen genomfördes med ABEM Lund Imaging System med 2 m elektrodavstånd.

Mätning av magnetisk susceptibilitet på hällar i diket har utförts i samband med den geologiska berggrundskarteringen. Dessa data har sammanställts för en jämförelse med de magnetiska mätresultaten.

I den centrala delen av mätområdet indikerar magnetmätningen ett smalt, lågmagnetiskt område som utbreder sig i riktning N60°. Området sammanfaller väl med ett tidigare, från flyggeofysik, tolkat magnetiskt lineament. Den magnetiska susceptibiliteten i det närliggande diket är i motsvarande position mycket låg.

Två partier i berggrunden med låg resistivitet överensstämmer också väl med det lågmagnetiska området.

Det länkade lineamentet, XFM0159A0, representeras i detta område av två segment, XFM015904 and XFM015905. Segment 04 har enbart identifierats i flygmagnetiska data och därför stämmer denna del relativt väl med den lågmagnetiska zonen. Segmentet 05 däremot, har koordinerats från såväl ett magnetiskt, topografiskt samt resistivitetslineament. I denna process har beslut fattats om att låta det topografiska lineamentet återge det samlade läget vilket leder till en förskjutning på 40 m mot sydost från det magnetiska lineamentet. Detta är inom den förväntade osäkerheten i läget i samband med koordinering och länkning av lineament.

Contents

1 Introduction

The work presented in this report has been carried out by GeoVista AB in accordance with the instructions and guidelines presented by SKB in the method descriptions MD 212.004 and MD 212.005 and the activity plan AP PF 400-05-083 (SKB internal controlling document).

This document reports the results gained from the ground geophysical measurements of the magnetic total field and resistivity at the lineament trench AFM001265, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with the activity plan AP PF 400-05-083. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

Identification of topographic and airborne geophysical lineaments has been carried out in the site investigations at Forsmark /1, 2, 3, 4, 5/. The lineaments have mainly been identified as topographic lows, magnetic lows and, in some cases, resistivity lows. Lineaments have in some cases been verified as representing deformation zones in the bedrock or have been explained by other grounds.

The lineament XFM0159A0 was identified and documented in previous interpretation work /2, 4/. The location decided for this investigation is based on a larger program suggested for further investigations of lineaments /6/.

The ground geophysical measurements were carried out by GeoVista AB during October 5–7, 2005 along four survey lines in an area covering 30×200 m, Figure 1-1. The survey comprised measurements of the magnetic total field and the electric resistivity. The resistivity distribution was investigated with CVES, "Continous Vertical Electrical Sounding", with a configuration used to reveal the detailed resistivity distribution from surface down to depths typically less than 30 m. The processing and interpretation of the data was carried out by GeoVista AB.

The original results of the survey are stored in the primary data bases (SICADA and GIS) and they are traceable by the activity plan number AP PF 400-05-083.

Table 1-1. Controlling documents for the performance of the activity.

Activity plan	**Number**	**Version**
Markgeofysiska mätningar vid lineamentsdiket AFM001265	AP PF 400-05-083	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för magnetometri	SKB MD 212.004	1.0
Metodbeskrivning för resistivitetsmätning	SKB MD 212.005	1.0

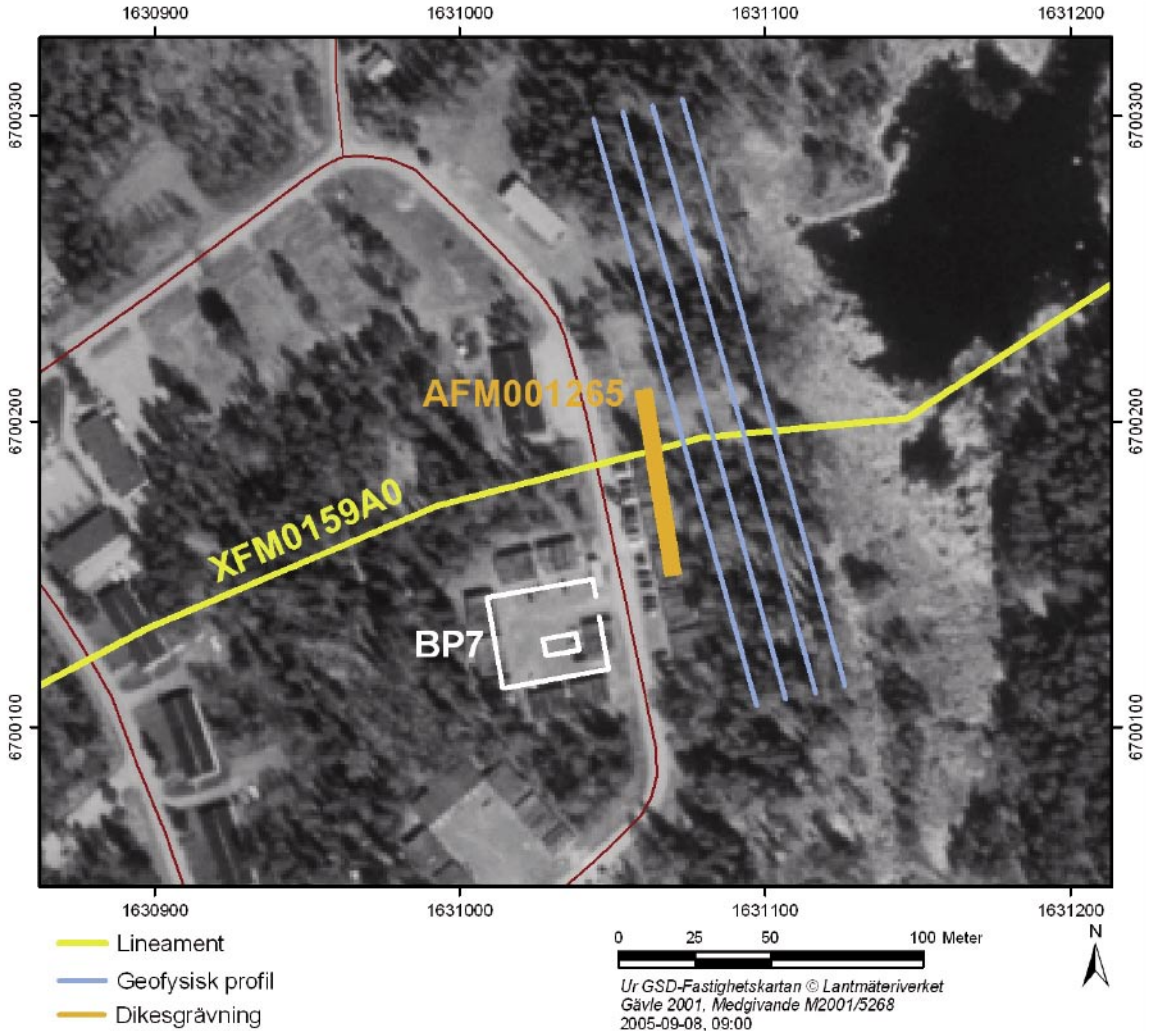

Figure 1-1. *Forsmark. site investigation. Trench AFM001265 for the investigation of the linked lineament XFM0159A0. The location of the profiles for ground geophysical measurements is shown as blue lines. Magnetic survey on all four lines, resistivity survey on the lines LFM00925 and LFM00927 only. From west to east; LFM00924–LFM000927.*

2 Objective and scope

The purpose of the ground geophysical measurements across the lineament XFM0159A0, is to gain knowledge about the physical characteristics of the related overburden and bedrock. Fractured and/or porous rock is expected to have low electric resistivity. Low resistivity can also be caused by clay-rich soil in local depressions of the bedrock topography. The magnetic susceptibility of rocks is often low in altered, oxidized rock due to destruction of ferromagnetic minerals. Information about geometry like width and dip can also be obtained.

3 Equipment

3.1 Description of equipment and interpretation tools

The measurement of the magnetic field was carried out with two Gem Systems GSM-19 magnetometers of which one was used as a base station.

The resistivity measurement was carried out using the ABEM Lund Imaging System with a distance of 2 m between the electrodes and a gradient configuration. Steel electrodes were used.

The magnetometers and the resistivity systems used are calibrated at the factory and a quality controlled performance is assured by following method descriptions and the internal quality plan of the activity as presented to the client before the survey started.

The processing, interpretation and reporting included the use of the following specialized software:

Oasis Montaj 5.0 (Geosoft Inc)

Surfer 8 (Golden software)

Geomatica 9 (PCI Inc)

MapInfo Professional 8 (Mapinfo Corp.)

Discover 7 (Encom Technology Pty Ltd.)

RES2DINV version 3.54.35 (Geotomo Inc)

4 Measurements, processing and interpretation

4.1 General

The detailed geophysical survey at Forsmark consisted of the following main sub-activities:

- preparation of a grid system,
- measurements of the magnetic total field,
- measurements of the resistivity,
- processing, interpretation and reporting.

4.2 Preparation of a grid system

A station directly above the lineament XFM0159A0 was used as a centre point for the profile closest to the trench (LFM000924). A measuring tape and a compass were used to stake the profile in the length direction of the lineament trench. Every 20 m along the profile was marked with a wooden peg with the line identity and a local co-ordinate. The first profile was then used to stake the remaining three profiles (LFM000925–927) by placing a wooden peg on every 10 m perpendicular to the profile direction.

The preparation of the grid system was originally supposed to be carried out concurrently with the measurement of resistivity but due to a delayed delivery of part of the resistivity equipment the preparation was done in advance.

On the last day of the survey a handheld GPS was used to measure 6 points along two of the profiles but due to low accuracy these points will not be used in this report. Instead a total station was used after the survey to measure the start and end point of all profiles, see Table 4-1. The azimuth of the grid is approximately 344.5°.

Table 4-1. Survey results for profile LFM000924–927.

Line	Local-X	Local-Y	X	Y	Z	Comment
LFM000924	0	0	6700107.04	1631097.12	3.35	Start 0/000.0
LFM000924	0	200	6700299.22	1631043.79	1.76	End 0/199.4
LFM000925	10	0	6700109.07	1631106.78	2.87	Start 0/000.0
LFM000925	10	200	6700301.51	1631053.42	1.36	End 0/199.7
LFM000926	20	0	6700111.16	1631116.52	2.57	Start 0/000.0
LFM000926	20	200	6700303.48	1631063.08	2.26	End 0/199.6
LFM000927	30	0	6700113.45	1631126.29	2.48	Start 0/000.0
LFM000927	30	200	6700305.65	1631072.91	1.97	End 0/199.5

4.3 Measurements

4.3.1 Measurements of the magnetic total field

The magnetic survey was carried out during 2 hours, 2005-10-06, with two Gem Systems GSM-19 magnetometers of which one was used as a diurnal base station. At the base station one reading was registered every second and was used to make a diurnal correction of the data collected with the mobile magnetometer. The base station was located within the survey area to minimize the diurnal variation, influence from the Fennoskan DC cable between Sweden and Finland, which runs approximately 2 km to the north and northwest.

The diurnal base station location:

Local coordinates:	5E/141N (see Figure 5-2)
In the Swedish grid RT90:	1631064E/6700244N
Measured median total intensity:	51 452 nT

The magnetometers were time synchronized before starting the survey. The predicted total magnetic field at the position of the diurnal base station is 51 299 nT according to the *International Geomagnetic Reference Field* /7/.

Magnetic readings were taken along all four profiles (LFM000924–LFM000927) with a station interval of 5 m with a profile separation of 10 m. The profiles were directed along the direction of the lineament trench but not exactly perpendicular to the lineament, Figure 1-1.

4.3.2 Measurements of the resistivity

Electric resistivity was measured with the gradient configuration using an ABEM Lund Imaging System with an electrode distance of 2 m and a roll-along cable system of four active cables. Every cable had twenty-one electrode positions. With one overlapping electrode in every cable connection (three connections), the total distance covered with one layout is 160 m. Each line was started with 3 cables and ended with 2 cables to be able to measure with 2 m point distance along the whole 200 m lines.

The resistivity measurement was carried out along two profiles (LFM000925 and 927) directed along the direction of the lineament trench with a profile distance of 20 m, see Figure 1-1.

4.4 Data processing and interpretation

4.4.1 Processing and interpretation of magnetic total field data

The diurnal variations recorded by the base magnetometer were removed from the magnetic survey data. The variations during the survey time were very small, only a few nT.

The magnetic total field anomaly was interpolated to a grid with a node spacing of 5 by 5 m. The survey area is considered too small to carry out any spatial filtering. The small coverage also makes it difficult to identify smaller and shorter lineaments, previously not identified.

No numerical modelling has been performed on the magnetic data.

The interpretation of magnetic data has included identification of areas with low magnetisation that can account for the identification of the lineament XFM0159A0. Magnetic susceptibility measurements carried out during the geological mapping of the trench outcrops have been processed and compiled to facilitate comparison with the magnetic survey results /8/.

4.4.2 Processing and interpretation of resistivity data

All resistivity readings with a standard deviation higher than 0.8% were rejected and the resistivity data was then entered into the program RES2DINV for inversion of the individual profiles.

The inversion process is to some degree already part of an interpretation process as it reveals possible conductivity distributions in the ground which could explain the distribution of the measured apparent resistivity.

However, the ground conductivity situation at the trench AFM001265 is not optimal for inversion procedures, based on single profiles. Both profiles LFM000925 and 927 runs close to, and along the sea shoreline and the associated salt water. Profile LFM000927 is only 10–20 m from the shoreline and the measured resistivity is much lower than on the adjacent profile LFM000925, which is only 20 m further away from the shoreline. This demonstrates a strong lateral conductivity variation in the ground.

Additional profiles in the same and/or perpendicular direction would have been needed to facilitate 3D inversion.

By this reason, the resistivity results are presented as pseudo sections based on a Schlumberger protocol. Hence, the interpretation of the resistivity data is limited to qualitative assessments.

4.5 Nonconformities

According to the activity plan AP PF 400-05-083 the lowest allowed current level was to be set to 20 mA but due to dry ground conditions a lowest current level of 10 mA was chosen instead. A quality control in the field and later in the office showed that the data quality was acceptable.

5 Results

The results are stored in the primary data bases (SICADA and/or GIS). The data is traceable in SICADA and GIS by the Activity Plan number (AP PF 400-05-083).

5.1 Magnetic susceptibility measurements

In connection with the bedrock, geological mapping in the trench AFM001265, magnetic susceptibility measurements have been carried out on the outcrops. For approximately each metre in the trench, one station with eight individual measurements has been compiled using a geometric mean, Figure 5-1. The south end of the trench, 0–2 m, is characterrized by a low magnetic susceptibility, 10×10^{-5} SI-units, followed by 3–18 m with susceptibility around 200×10^{-5} SI-units. From 19–35 m along the trench the susceptibility is $15–20\times10^{-5}$ SI-units, with very low values at 29 m and 32–33 m, from $0–5\times10^{-5}$ SI-units. At the north end of the trench, the susceptibility is slightly higher, from $40–50\times10^{-5}$ SI-units. Figure 5-1 also shows the bedrock topographic relief.

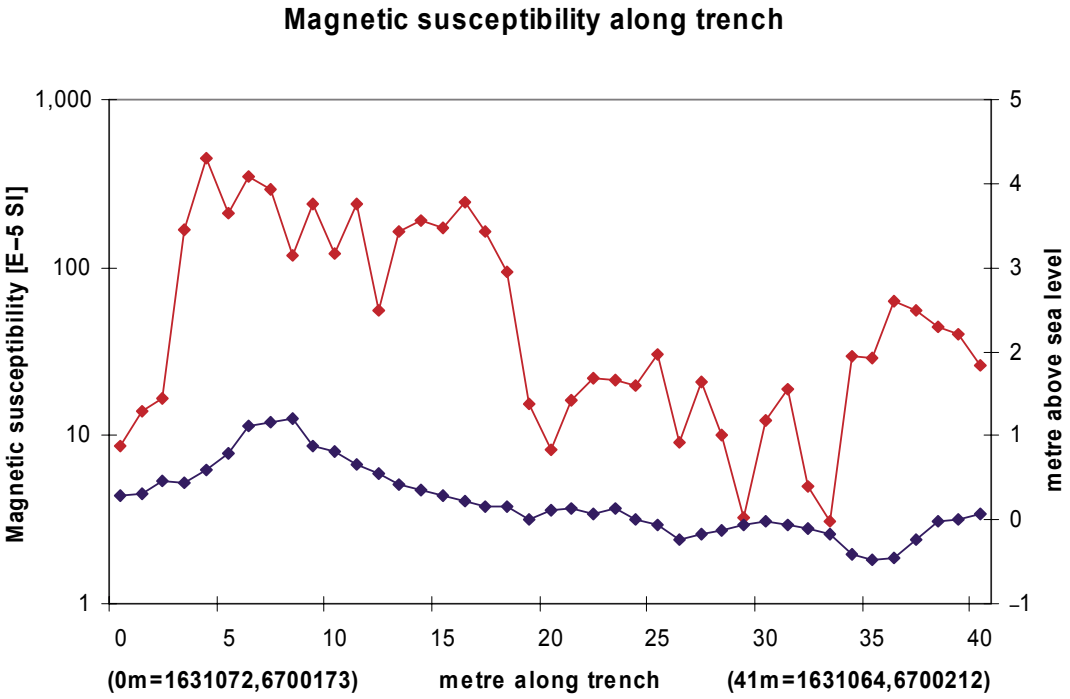

Figure 5-1. *Magnetic susceptibility measurements along the trench outcrops (red line) and the bedrock topographic relief (black line). Each susceptibility value presented is based on the geometric mean of eight individual measurements.*

5.2 The magnetic anomaly field

The magnetic survey, Figure 5-2, has a limited extension which makes it difficult to clearly identify magnetic patterns that can reveal magnetic bands (foliation) or deformation zones in the bedrock.

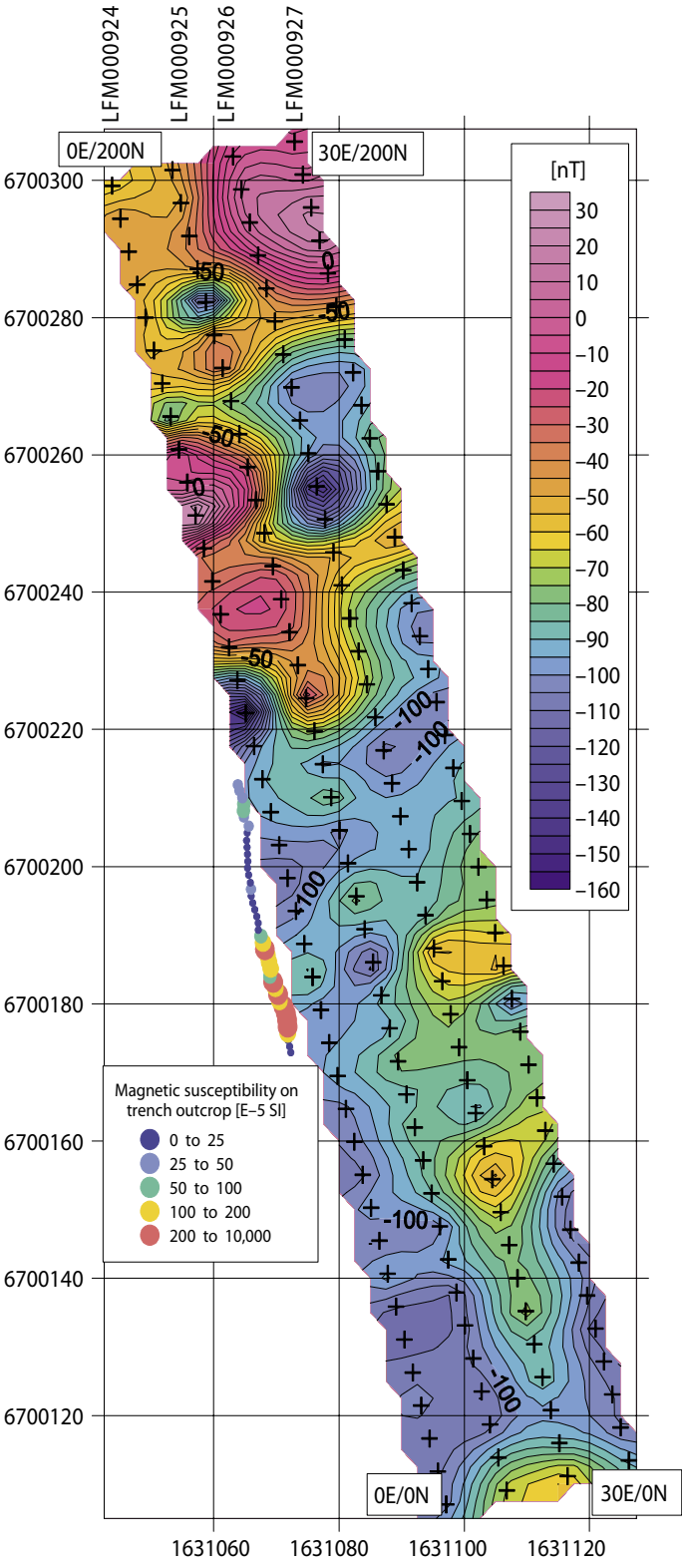

Figure 5-2. *Magnetic anomaly field along the survey profiles LFM000924–927 (Local 0E-30E). Magnetic susceptibility measured on the trench outcrops on the left hand side.*

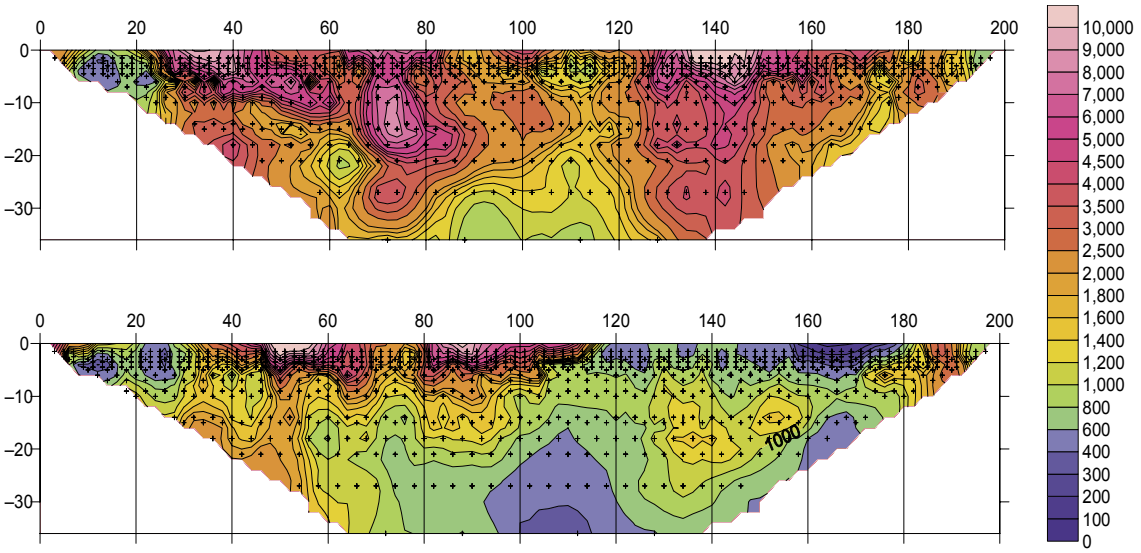

Figure 5-3. *Resistivity pseudo sections, profile LFM000925 (upper) and LFM000927 (lower), unit ohm-m. The pseudo depths are based on Schlumberger configuration with combinations of different current electrode distances.*

The area is characterized by a lower magnetic anomaly level in the south and a higher anomaly level in the north, divided by a consistent, 10–20 m wide, magnetic low, running in approximately N60°E. No dip estimation has been performed in this evaluation and can be difficult since surrounding, real two-dimensional structures are lacking.

The lower magnetic susceptibility measured in the central part of the trench correlates well with the magnetic minima identified in the survey.

The low magnetic anomaly encountered in the south part of, and along line LFM000924 can possibly have an origin in the anthropogenic environment, immediately to the SW. However, a bedrock origin can not be eliminated, since the survey direction is close to the main geological foliation in the area.

5.3 The resistivity measurement

As stated in Section 4.4.2, the area around the lineament trench AFM001265 is strongly affected by resistivity variations perpendicular to the profiles. This is not very suitable for lineament investigations based on single profiles and 2D inversion. 2D inversion was tested, but the results were found to be unstable and changed considerable with minor changes of the software parameters and constraints. Therefore, from the raw resistivity data, readings were extracted representing Schlumberger configurations with different current electrode separations and pseudo depths. The resistivity pseudo sections for profile LFM000925 and 927 are presented in Figure 5-3.

The general, lower resistivity in profile LFM000927 is probably caused by the nearby salt water. This is probably also the major reason for the indicated lower resistivity at depth in both profiles.

Lower resistivity indications that most likely originate from the bedrock and possibly are caused by fractured rock are listed in Table 5-1. These lower resistivity intercepts are also marked in the interpretation compilation, Figure 5-4.

Table 5-1. Low resistivity, bedrock indications in profile LFM000925 and 927.

Profile	Intercept, (m) along profile
LFM000925	62
LFM000925	110–115
LFM000925	175
LFM000927	60
LFM000927	75
LFM000927	105–125
LFM000927	165

5.4 Lineament XFM0159A0 in the magnetic total field and resistivity data

A compilation of the geophysical survey results in relation to the linked lineament XFM0159A0 is presented in Figure 5-4. The central magnetic low and the low magnetic susceptibility on trench outcrops correspond well with the previously interpreted, magnetic lineament. The two major, low resistivity intercepts encountered are also in accordance with this interpretation.

The linked lineament in this area is marked with the two segments XFM015904 and XFM015905. XFM015904 is only identified on airborne magnetic data and consequently this segment fits rather well with the magnetic lineament. However, the segment XFM015905, which is marked with a thick line (high weight), is also based on a topographic lineament and a conductivity lineament. In this case the position has been judged from the topographic lineament and is placed about 40 m southeast from the magnetic lineament. In other words, the displacement of the linked lineament is a result of the linking process and is within the precision limits obtained in the lineament coordination.

The low resistivity intercepts, north and south of XFM0159A0, are both correlated with lower magnetic features and can possibly reveal minor deformation zones in the bedrock. However, these statements have a high uncertainty and needs verification.

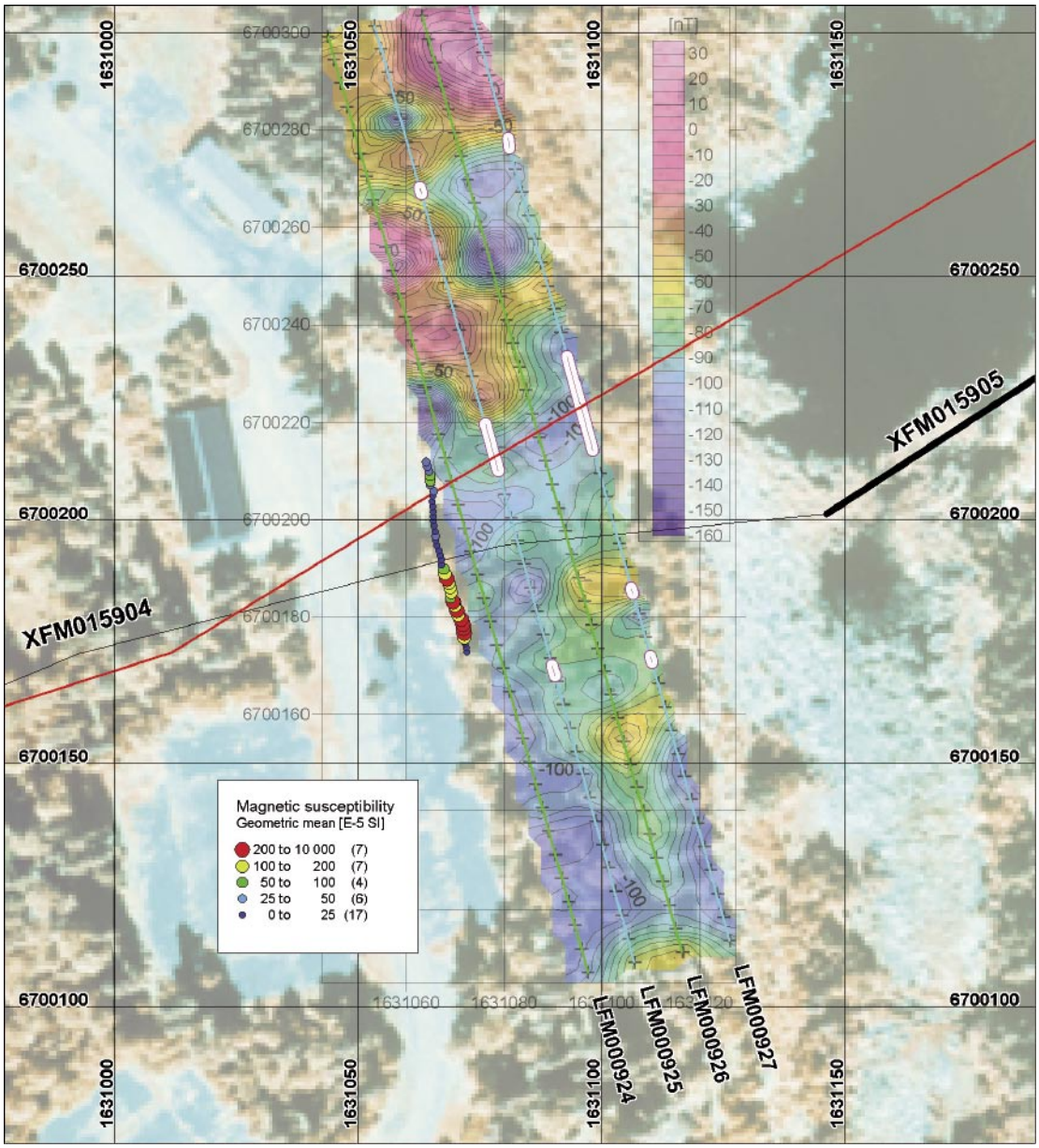

Figure 5-4. *Compilation of the geophysical survey results in relation to the linked lineament XFM0159A0. Magnetic survey and magnetic susceptibility on trench outcrops (Figure 5-2) is superimposed. Low resistivity intercepts (Figure 5-3 and Table 5-1) are shown as thick, magenta-white lines. Linked lineament segments XFM015904–05 are marked as a black line with thickness depending on lineament weight. An infrared orthophoto is used as background.*

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