P-05-188

Oskarshamn site investigation

Detailed ground geophysical survey at Laxemar

Magnetic total field and resistivity

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June 2005

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Keywords: Laxemar, Ground geophysics, Magnetic total field, Magnetisation, Resistivity, Lineament, Deformation, Bulk resistivity, EW007, ZSMNE040A.

Abstract

Detailed geophysical measurements in the Laxemar area have covered 1×2 km. The methods used were magnetometry, resistivity with the ABEM Lund Imaging System, and resistivity with the Pole-Dipole configuration and the Scintrex system.

The measurements of the magnetic total field were carried out along profiles directed in north-south, with a profile spacing of 10 m and a point distance of 5 m. EW007 appears in the magnetic total field as a broad zone (up to two hundred metres) with decreased magnetisation probably due to oxidation of the magnetite. Modelling of the magnetic total field indicates an almost vertical dip of the EW007 however with a complex geometrical constitution. The identification of lineaments in magnetic data indicates several north-south striking features of which some appear to be continuous over large distances in the strike direction. Furthermore several lineaments striking ENE-WSW are observed in magnetic data. Lineaments in magnetic data striking NW-SE are often short and terminate against the other groups.

Resistivity measurements with the Pole-Dipole configuration (Scintrex system) was carried out along six 2 km long north-south profiles with a nominal profile distance of 200 m. This gave an overview of the resistivity distribution down to considerable depth (probably 300–400 m). Some noise from power lines however have deteoriated the data quality and hence the quality of the inversion products regarding larger depths. Resistivity measurements with the ABEM Lund Imaging system suffered less from noise, however with less depth penetration. They covered one central 360 m broad area with 2 km long north-south profiles and two approximately 360 m broad and 1 km long areas with east-west profiles, one located north of EW007 and the other south of it. The profile separation was 40 m.

A number of lineaments with low resistivity were identified. Much of the directions represented among lineaments in magnetic data are also observed among lineaments in resistivity data. Much of the lineaments in resistivity data are coinciding with lineaments in magnetic data. The number of lineaments in resistivity data is however less than in magnetic data. This could imply that not all of the low-magnetic lineaments necessarily are potentially water-bearing. Some vast areas with low resistivity are also recognised in resistivity data, for example in connection to EW007 and ZSMNE040A. Some anomalies are also interpreted to emanate from electrical grounding of the power lines. There are two major high resistive rock volumes, one north of EW007 and the other south of it. These volumes could be less fractured than the surroundings.

Some areas with potential lithological in-homogeneities have been identified in magnetic total field data, which could be caused by Diorite to gabbro or Fine-grained dioritoid.

Sammanfattning

Detaljerad geofysisk mätning har genomförts med magnetometri, resistivitetsmätning med pol-dipol (100 respektive 200 m dipoler) samt ABEM Lund Imaging System inom en yta på 1×2 km centralt i Laxemarområdet.

Magnetometri genomfördes med profilriktning i N-S, profilavståndet var 10 m och punktavståndet 5 m. EW007 utmärker sig som ett brett stråk med låg magnetisk susceptibilitet som tyder på en allmän oxidering av magnetiten inom en bredd upp till ett par hundra meter. Inom det påverkade området kan också flera korta magnetiska lineament urskiljas som ligger mer eller mindre parallellt med huvudstrykningen av EW007, i synnerhet i dess södra del. Modellering visar att EW007 sannolikt har relativt brant stupning och att den har en komplex geometrisk uppbyggnad. Tolkningen visar även ett stort inslag av N-S strykande magnetiska lineament inom mätområdet. Vidare förekommer relativt uthålliga lineament med utsträckning i ENE-WSW. Lineament med utsträckning i NW-SE är i allmänhet korta och terminerar ofta mot de övriga grupperna.

Resistivitetsmätning med pol-dipol (200 m dipoler) genomfördes längs sex profiler med profilriktning i N-S med ett nominellt profilavstånd av 200 m. Profilerna sträcker sig över hela det område som mäts med magnetometer, dvs en längd på 2 km. Punktavståndet var 100 m för n = 1 och 200 m för n = 2 till 5. Resistivitetsmätning med ABEM Lund Imaging System (5 m avstånd mellan elektroderna) genomfördes i en 360 m bred korridor med riktning i N-S och med ett profilavstånd av 40 m och ett punktavstånd av 5 m. Söder om EW007 mättes en 360 m bred korridor med riktning E-W, likaså norr om EW007.

Baserat på resistivitetsmätningarna har ett antal lågresistiva lineament identifierats. I huvudsak kommer samma riktningar som för magnetmätningarna fram och de flesta av de lågresistiva lineamenten sammanfaller också helt eller delvis med lineament i magnetiska data. Antalet lineament i resistivitetsdata är dock färre i jämförelse med de som konstaterats i magnetiska data, vilket tyder på att inte alla magnetiska lineament behöver motsvaras av vattenledande strukturer. Lineament som identifierats i magnetiska data kan därför också vara läkta eller av plastisk karaktär. Några områden med utbredd låg resistivitet detekteras också av resistivitetsmätningarna, t.ex. EW007 respektive ZSMNE040A. Områden med låg resistivitet förekommer också intill kraftledningarna förorsakade av jordningslinor. Det finns två större högresistiva bergvolymer, en norr respektive en söder om EW007. Volymer med högre resistivitet tolkas motsvaras av områden med lägre sprickintensitet eller innehåll av sprickor med lägre vattenledningsförmåga/sprickbredd.

Möjliga litologiska inhomogeniteter har också identifierats, vilka skulle kunna utgöras av främst Diorit till gabbro eller av finkornig dioritoid.

Contents

1 Introduction

This document reports the results gained from the ground geophysical measurements of the magnetic total field and resistivity at Laxemar, which is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with the activity plan AP PS 400-05-014 and the interpretation was done according to AP PS 400-05-038. Complementary information will be available from laser scanning, AP PS 400-05-035 and field control according to AP PS 400-05-038 and will be reported separately. This report is an interim report of the detailed geophysical investigations. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

The ground geophysical measurements were carried out by GeoVista AB during March to May 2005 at Laxemar in an area covering 1×2 km, Figure 1-1. The survey included measurements of the magnetic total field and resistivity. The resistivity distribution was investigated with two different measuring systems, the ABEM Lund Imaging System and a Pole-Dipole survey based on the use of a powerful current transmitter. The Lund Imaging System was used to reveal the detailed resistivity distribution from surface down to depths typically less than 100 m while the Pole-Dipole survey (with Scintrex IPR-12 and IPC-7) focussed on the major trends in the resistivity distribution at depths typically in the depth interval of approximately 80 to 400 m. The processing and interpretation of the data was performed by GeoVista AB and the results are expected to support the focussing of the future site investigations at Laxemar.

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 PS 400-05-014.

The grid system over the area was prepared by Geocon AB. Personnel from GeoVista AB participated in the preparation of the grid.

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

Activity plan	Number	Version
Detaljerade markgeofysiska mätningar I Laxemar	AP PS 400-05-014	1.0
Flygmätningar med laserskanning och flygfotografering, 2005	AP PS 400-05-035	1.0
Samtolkning av detaljerad markgeofysik, flygfotografering, laserskanning samt geologisk fältkontroll i Laxemar	AP PS 400-05-038	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för magnetometri	SKB MD 212.004	1.0
Metodbeskrivning för resistivitetsmätning	SKB MD 212.005	1.0

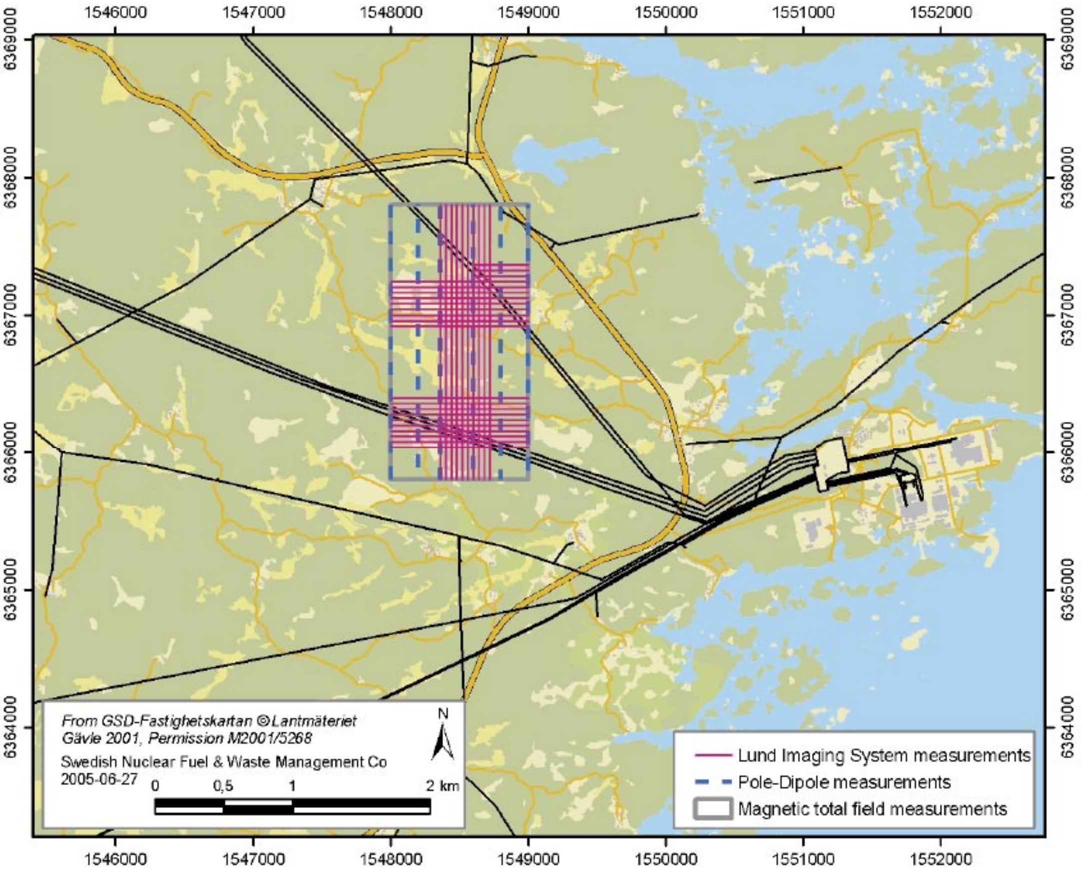

Figure 1-1. *Location of the area (1×2 km) at Laxemar where the detailed ground geophysical survey was carried out in March to May 2005 by GeoVista AB.*

2 Objective and scope

The results of the detailed ground geophysical survey at Laxemar are expected to support the focussing of the future site investigations at Laxemar by reflecting the:

- Deformation of the bedrock by possible regional zones, local major zones, local minor zones and general fracturing.
- Lithological homogeneity of the bedrock.

This is done by the processing and interpretation of the collected data of the magnetic total field and resistivity. The magnetic total field reflects the magnetisation of the ground. The magnetisation in the Laxemar area is dependent on the rock type and the deformation of the rock which is shown by thorough investigations of the magnetic properties of the area, see /1, 2, 3, 4, 5/. There is also a clear correlation between fracturing of rocks and the resistivity of rocks. The bulk resistivity of the bedrock in the type of geological environment found at Laxemar is directly coupled to the fracture frequency, the resistivity of the water in the fractures and pores, and the fracture width see /3/ and /6/.

3 Equipment

3.1 Description of equipment/interpretation tools

The measurements of the magnetic field were performed with magnetometers Gem Systems GSM-19 of which one was used as a diurnal base station.

The measurements of the resistivity were carried out using two different systems. The ABEM Lund Imaging System used a distance of 5 m between the electrodes and a gradient configuration, Figure 3-1. The Scintrex IPR-12 (receiver) and Scintrex IPC-7 (transmitter) used dipole lengths of 100 and 200 m and the pole-dipole configuration. Both systems used steel electrodes.

Figure 3-1. *Measurements of the resistivity with the Lund Imaging System (ABEM AB).*

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

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

Grapher v4 (Golden Software)
Oasis Montaj 5.0 (Geosoft Inc)
RES3DINV version 2.14u (Geotomo Inc)
ModelVision Pro 6.00.28 (Encom Technology)
Profile Analyst 5.50 (Encom Technology)
MapInfo Professional 7.5 (MapInfo Corporation)
Discover 4.000 (Encom Technology)
ArcView (Environmental Systems Research Institute Inc)
Microsoft Excel (Microsoft Corp)
Microsoft Word (Microsoft Corp)
Adobe Acrobat and Adobe Distiller (Adobe Systems Inc)

4 Measurements, processing and interpretation

4.1 General

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

- preparation of a grid system,
- measurements of the magnetic total field,
- measurements of the resistivity by the use of the ABEM Lund Imaging System with a gradient protocol and an electrode spacing of 5 m,
- measurements of the resistivity by the use of the Pole-Dipole configuration with the Scintrex IPR-12 and IPC-7,
- processing, interpretation and reporting.

4.2 Preparation of a grid system

The main preparation of the grid system was effectuated in a supporting activity separate from the activity reported here. As however the preparation of the grid was critical for the time plan, and as the progress was slow, personnel from GeoVista AB participated in the grid preparation. Partly the delayed progress was due to the unusual snow conditions in the Oskarshamn area and the effects of the storm Gudrun which had caused severe damage on the forest with a lot of fallen trees. The fallen trees and the partly dense forest consumed quite substantial resources for the preparation of the grid.

The preparation of the entire grid system was based on the use of two lines with direction north-south. The lines, 1548360/6365800–6367800 and 1548520/6365800–6367800, were staked using a high resolution GPS (accuracy better than 0.5 m in general) and marked every 10^{th} m. From these two north-south lines, perpendicular lines were staked using a combination of hand-held GPS, compass and measuring tape. Normally the distance between these perpendicular lines was 100 m though less in some areas. Along these perpendicular lines a mark was positioned in the terrain every 20^{th} metre.

The entire grid covered the area 1548000–1549000/6365800–6367800.

4.3 Measurements

4.3.1 Measurements of the magnetic total field

The magnetic total field survey was conducted with several Gem Systems GSM-19 magnetometers of which one was used as a diurnal base station. One reading at the base station was registered every 10 seconds and was used to make a diurnal correction of the data collected with the mobile magnetometer.

During the part of the survey that was carried out in May 2005 data from the Geological Survey of Sweden were obtained to serve as base station data. The data were collected in Uppsala at the magnetic observatory located in Fiby.

The magnetometers were time synchronized every morning before starting the survey.

Magnetic readings were taken along profiles with a station interval of 5 m; the profile separation was 10 m. The profiles were directed in north-south covering the entire area of 1×2 km.

Diurnal base station locations:

1548325E/6366910N (file names of base station data "Bas1_datum.dmp").

1549127E/6366217N (file name of base station data "Bas_datum.dmp").

The measurements of the magnetic total field were carried out according to the method description (Metodbeskrivning för magnetometri, SKB MD 212.004, version 1.0, SKB internal document).

4.3.2 Measurements of the resistivity with ABEM Lund Imaging System

Electric resistivity was measured with the gradient configuration using an ABEM Lund Imaging System with an electrode distance of 5 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 400 m.

Resistivity measurements with the Lund Imaging System were carried out along ten profiles directed north-south with an internal distance of 40 m, see Figure 1-1. The westernmost profile was located at 1548360E and the easternmost at 1548720E. Furthermore two areas were measured with profiles directed east-west, the profile distance was kept at 40 m. The southernmost area consisted of ten east-west profiles, with the southernmost profile at 6366040 and the northernmost at 6366400. In the northern area nine long east-west profiles and three short east-west profiles were measured (Figure 1-1). The southernmost long profile was at 6366920 and the northernmost short profile at 6367360.

The measurements of the resistivity with the ABEM Lund Imaging System was carried out according to the method description (Metodbeskrivning för resistivitetsmätning, SKB MD 212.005, version 1.0, SKB internal document).

4.3.3 Measurements of the resistivity with Pole-Dipole (Scintrex IPR-12 and IPC-7)

Electric resistivity was measured with the Pole-Dipole configuration using a Scintrex IPR-12 receiver and a Scintrex IPC-7 2500W transmitter. The drawing in Figure 4-1 shows the station separation interval and the five dipoles employed. The dipole length was 100 and 200 m. Resistivity measurements were conducted along six north-south profiles 1548000, 1548200, 1548360, 1548600, 1548800 and 1549000, all between 6365800-6367800.

The measurements were performed with the current electrode at lower profile coordinate compared to the potential electrodes.

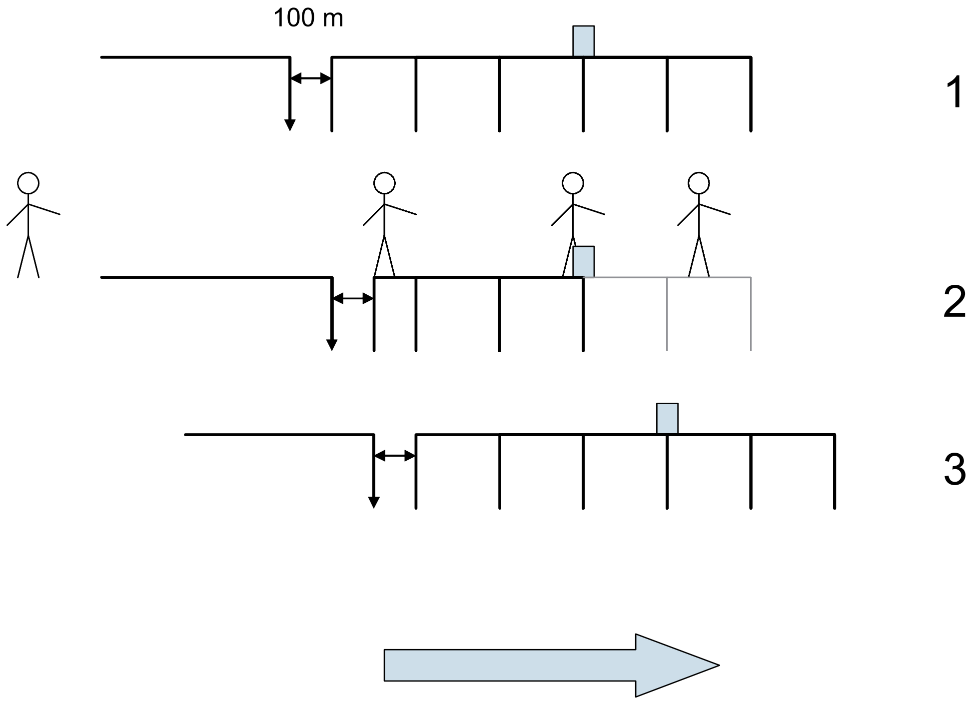

Figure 4-1. *Drawing showing the principle of the resistivity measurements with the Pole-Dipole configuration and the Scintrex IPR-12 and IPC-7. The distance between the current electrode and the first potential electrode is 100 m. The distance between the first potential electrode and the second is 100 m or 200 m. The number of potential electrode pairs is five.*

4.4 Data processing and interpretation

4.4.1 Processing and interpretation of magnetic total field data

The processing performed on the magnetic data was the removal of diurnal variations recorded by the base magnetometer or by the Fiby observatory.

The magnetic total field anomaly from each group of profiles was interpolated to a grid with a node spacing of 5 by 5 m. Based on these grids, filtering has been carried out in order to produce different types of maps used for the identification of in-homogeneous rock and lineaments. Filtering has included reduction to the pole, vertical derivatives, upward continuation, and depth slicing /7/.

Numerical modelling has been performed on the magnetic data. Four profiles have been modelled, three covering the western, central and eastern portion of the deformation zone EW007 and one covering a number of north-south striking lineaments in the north-eastern part of the surveyed area. The three profiles covering EW007 are:

1548050/6366520-6367000
1548500/6366200-6366750
1548750/6366125-6366825

The profile covering the north-south striking lineaments is:

6367440/1548570-1549000

The interpretation of magnetic data has included:

- Identification of possibly in-homogeneous rock.
- Identification of lineaments.
- Identification of areas with low magnetisation.
- Investigation of anomaly source geometry through numerical modelling.

4.4.2 Processing and interpretation of resistivity data

All resistivity data from the ABEM Lund Imaging System with a standard deviation higher than 0.8% were rejected. The rejection of bad data from the resistivity survey with the Scintrex system was based on a subjective comparison between different measuring cycles.

The resistivity data from the survey with the ABEM Lund Imaging System was entered into the inversion program RES3DINV. Data were inverted in 3D in five different runs:

1. North-south profiles, entire area.
2. East-west profiles, entire southern area.
3. East-west profiles, entire northern area.
4. The northern area with crossing north-south and east-west profiles.
5. The southern area with crossing north-south and east-west profiles.

The inversion results are presented as maps where the resistivity at different depths can be observed. A few chosen vertical sections of resistivity are also produced from the inversion results in order to reflect the interpreted dip of some electrical low resistive anomaly sources.

The resistivity data from the survey with the Scintrex system were also entered into the inversion program RES3DINV. Data were inverted in 3D in one run for the entire data set. The inversion results were presented similarly as for the ABEM Lund Imaging survey, however was a 3D voxel model also produced displaying high resistive rock volumes.

The inversion process is to some degree already part of an interpretation process as it reveals one possible resistivity distribution in the ground which could explain the distribution of the apparent resistivity that is measured in field. However the interpretation has also included further analysis of the inverted resistivity data, such as:

- Identification of lineaments both in maps of apparent resistivities for different configurations, and from inversion results
- Discretisation of volumes with comparatively high resistivity

4.5 Nonconformities

In comparison to the activity plan AP PS 400-05-014 three east-west striking short profiles to be measured with the ABEM Lund Imaging System replaced one long east-west striking profile in the northern part of the area.

The power lines in the area have disturbed data. Data of the magnetic total field could not be used near the power lines. The affected areas are easily recognised in the maps of the magnetic total field as blanked areas. Resistivity data were also apparently affected by the power lines, probably through electromagnetic coupling and possibly also by direct detection of the grounding system of the power lines. The data have however not been blanked and thus the maps and vertical sections should be observed with care.

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 PS 400-05-014).

5.1 The magnetic total field

The map of the total magnetic field from the detailed ground geophysical survey together with the magnetic total field from the helicopter-borne survey /8, 9/ are shown in Figure 5-1. Both data sets have been reduced to the pole, however they are displayed with different colour scales.

The map of the magnetic total field reduced to the pole from the detailed ground geophysical survey is shown in Figure 5-2 with the first vertical derivative of the same.

The map of the magnetic total field reduced to the pole and with very high field intensities enhanced is shown in Figure 5-3.

The process applied by Jacobsen /7/ to present the anomaly from sources at different depth intervals have been applied on the data from the detailed magnetic ground survey. Though the criteria for a succesful application of the process presented by Jacobsen are probably not entirely met, it is believed that the maps give some indication of the distribution of the magnetic sources with depth. Examples of the different depth slices are displayed in Figure 5-4.

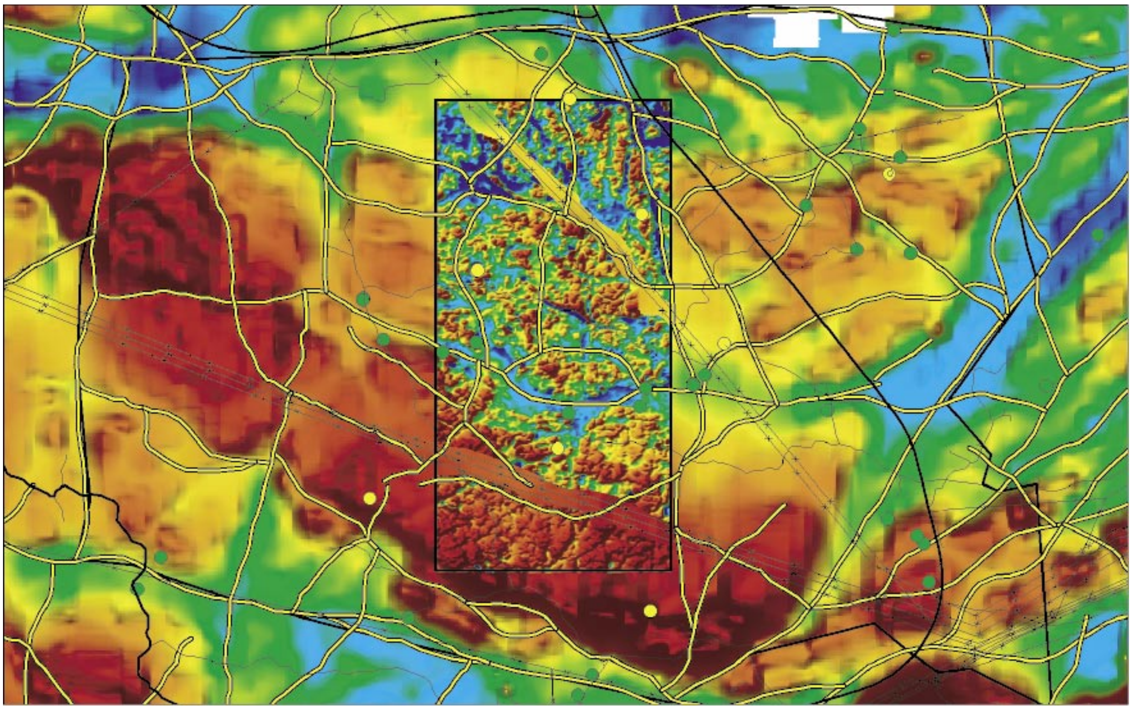

Figure 5-1. *The magnetic total field from the detailed ground geophysical survey of 2005 displayed on the magnetic total field from the helicopter-borne survey of 2002. Both data sets are reduced to the pole. Note the different colour scales applied.*

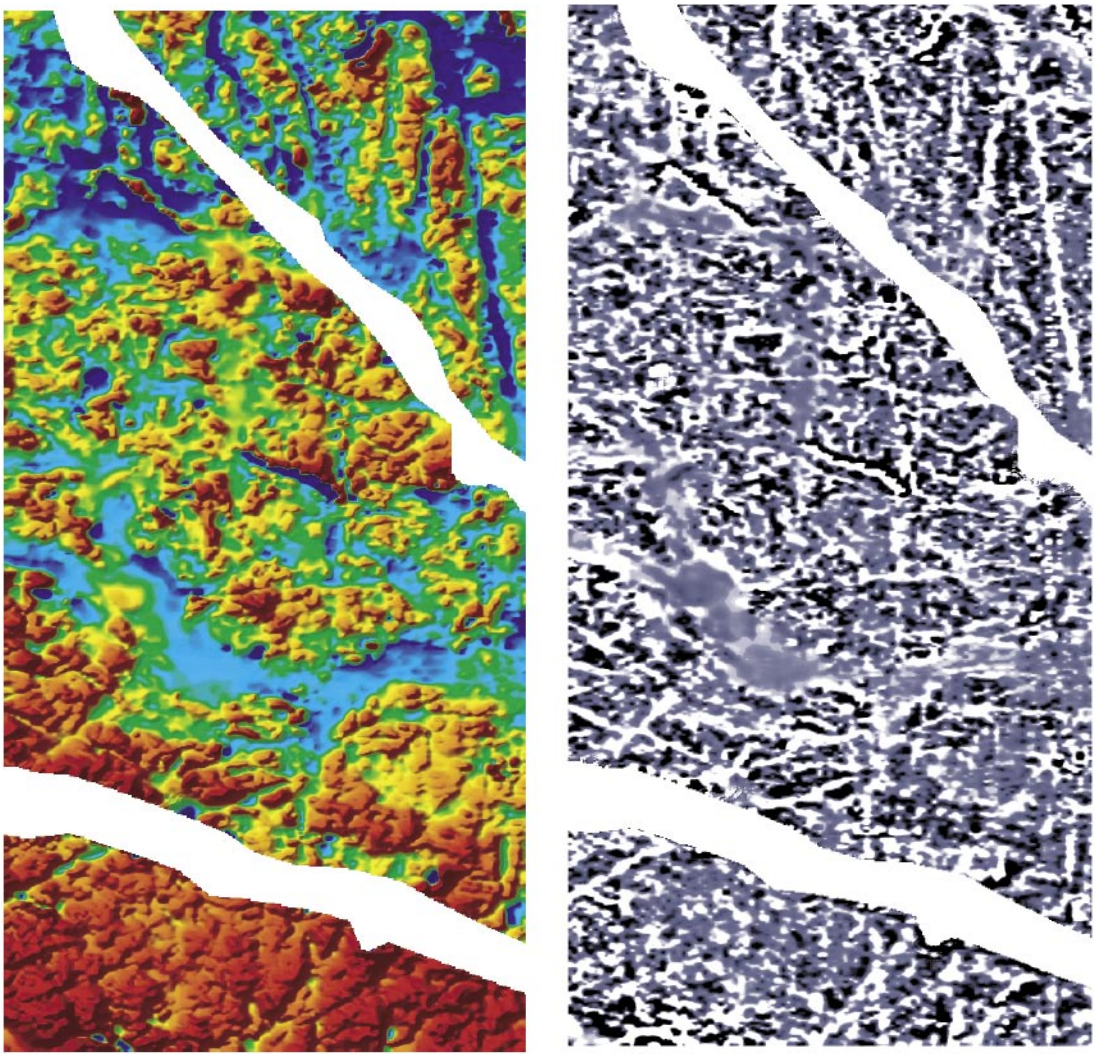

Figure 5-2. *To the left the magnetic total field, reduced to the pole, from the detailed ground geophysical survey of 2005. Brownish colours indicate high relative magnetic field. To the right the 1st vertical derivative of the magnetic total field reduced to the pole. White indicates low relative gradient. Areas with noisy data from power lines have been blanked.*

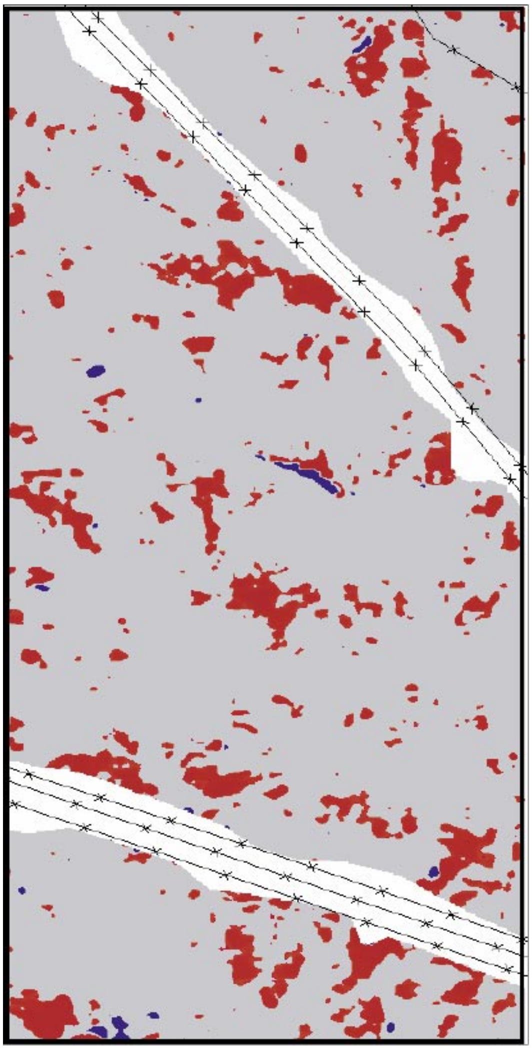

Figure 5-3. *The magnetic total field, reduced to the pole, from the detailed ground geophysical survey of 2005. The highest (red) and the lowest (blue) total field intensities are enhanced. Areas with noisy data from power lines have been blanked.*

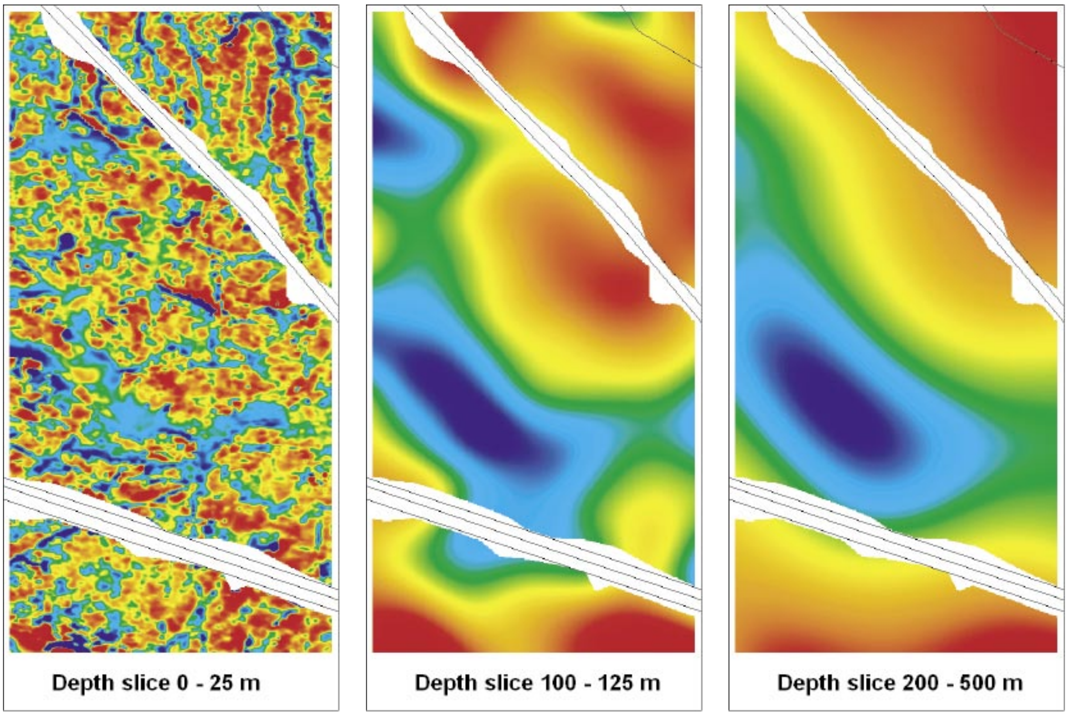

Figure 5-4. *The magnetic field distribution at different depth intervals as recovered from the process outlined by Jacobsen /7/. Bluish colour means low magnetic field.*

5.2 The resistivity from measurements with the ABEM Lund Imaging System

The apparent resistivity from different configurations as measured with the ABEM Lund Imaging System is shown in Figure 5-5. The configurations displayed are the gradient configuration with potential electrode separation – current electrode separation 5-50 m and 30-300 m. The former gives information at surface near depths (probably less than 15 m) while the latter reflects the resistivity at larger depths (around 100 m).

The inverted resistivity at an inverted depth of 15 m from the ABEM Lund Imaging System resistivity survey is shown in Figure 5-6.

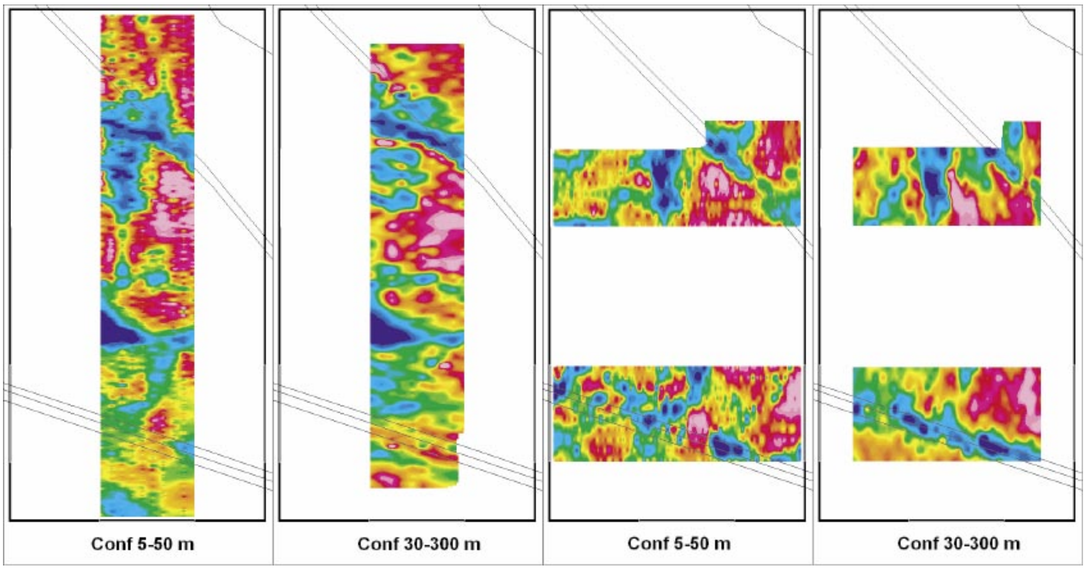

Figure 5-5. *The apparent resistivity shown for different configurations and profile directions from measurements with the ABEM Lund Imaging System. Bluish colours indicate low relative resistivities.*

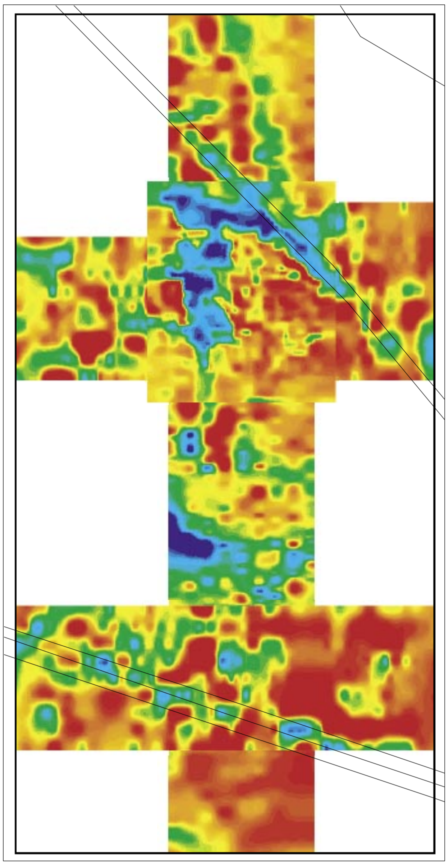

Figure 5-6. *The inverted resistivity from the ABEM Lund Imaging System survey at an inverted depth of 15 m. Bluish colours indicates low resistivities.*

5.3 The resistivity from measurements with the Pole-Dipole configuration with the Scintrex IPR-12 and IPC-7

The inverted resistivity at different depths from measurements with the Pole-Dipole configuration and the Scintrex system is shown in Figure 5-7. At larger depths (below 300 m) the inversion results indicate severe instability in the solutions due to high levels of noise in data.

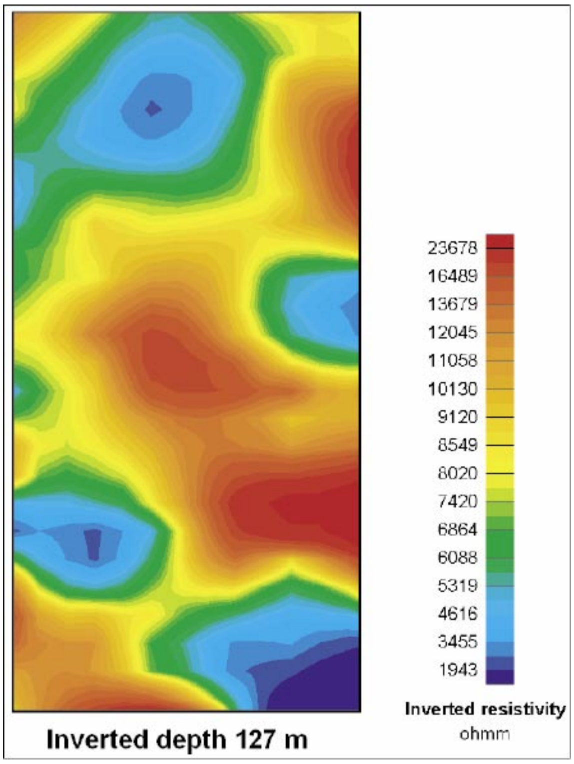

Figure 5-7. *The inverted resistivity from the Pole-Dipole survey with the Scintrex system shown for the inverted depth of 127 m.*

5.4 Lineaments identified in magnetic total field data and resistivity data

Lineaments have been identified in magnetic total field data together with vast areas with low magnetisation. They are shown in Figure 5-8 on the magnetic total field, reduced to the pole.

In the magnetic total field data two anomalies with strange characteristics have been identified, they are marked specially. These two anomalies are believed to emanate from a road (fence along road or tubes?) and from a fence.

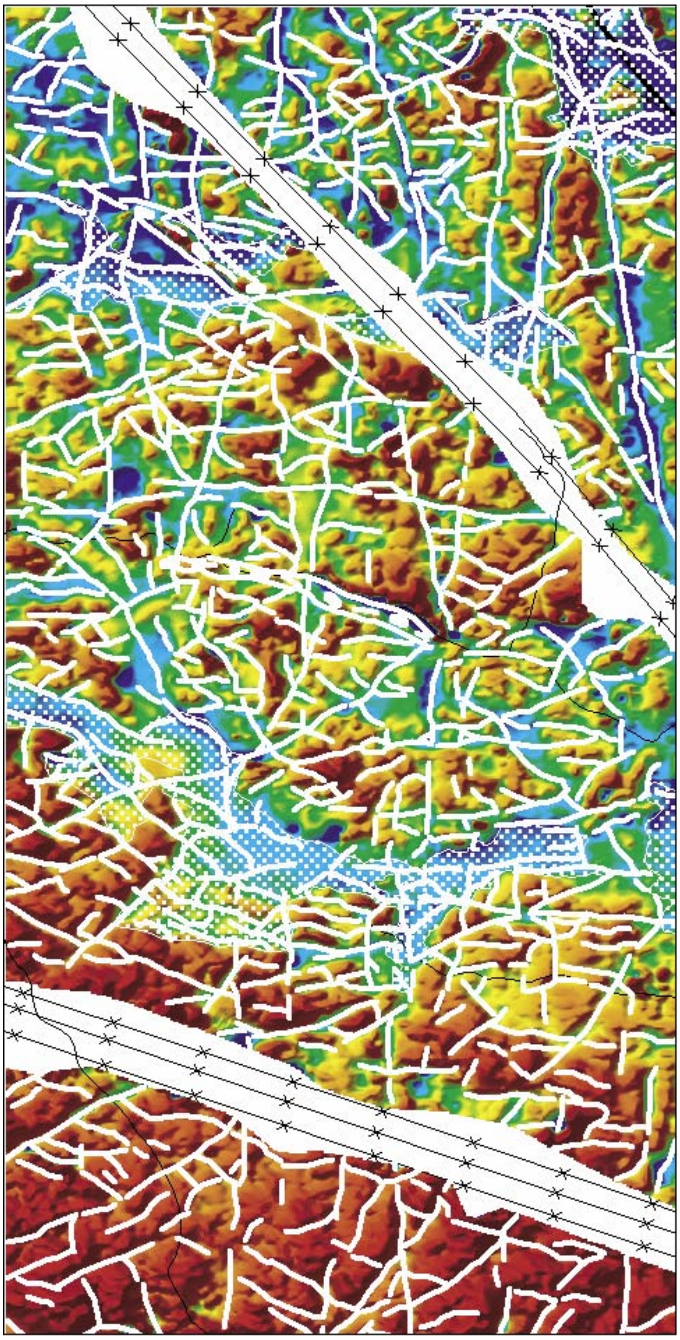

Figure 5-8. *The lineaments in white identified in magnetic total field data. Vast areas with low magnetisation are marked with dots. In the background the magnetic total field reduced to the pole.*

The identified lineaments with vast areas of low magnetisation are shown in Figure 5-9 where also a comparison with earlier identified linked lineaments /10/ is made.

Lineaments identified in maps of the apparent resistivity from the measurements with the ABEM Lund Imaging System are shown in Figure 5-10. Note that the lineaments are identified from maps of the apparent resistivity as the results from the final inversion procedure are yet not fully quality controlled. This will be controlled by 3D- inversion and vertical sections through the volume. Dip of low resistivity lineaments will be controlled by inversion. This will be done in a final report in October according to activity plan AP PS 400-04-014.

Figure 5-9. *The lineaments identified in magnetic total field data to the left. The two anomalies interpreted to emanate from installations are marked with dotted lines. Vast areas with low magnetisation are marked in grey. To the right thick black lines indicate lineaments from the image to the left that could be considered to form longer lineaments. In yellow linked lineaments are marked from an earlier joint interpretation of lineaments from digital elevation models, topography and helicopter-borne geophysics /10/.*

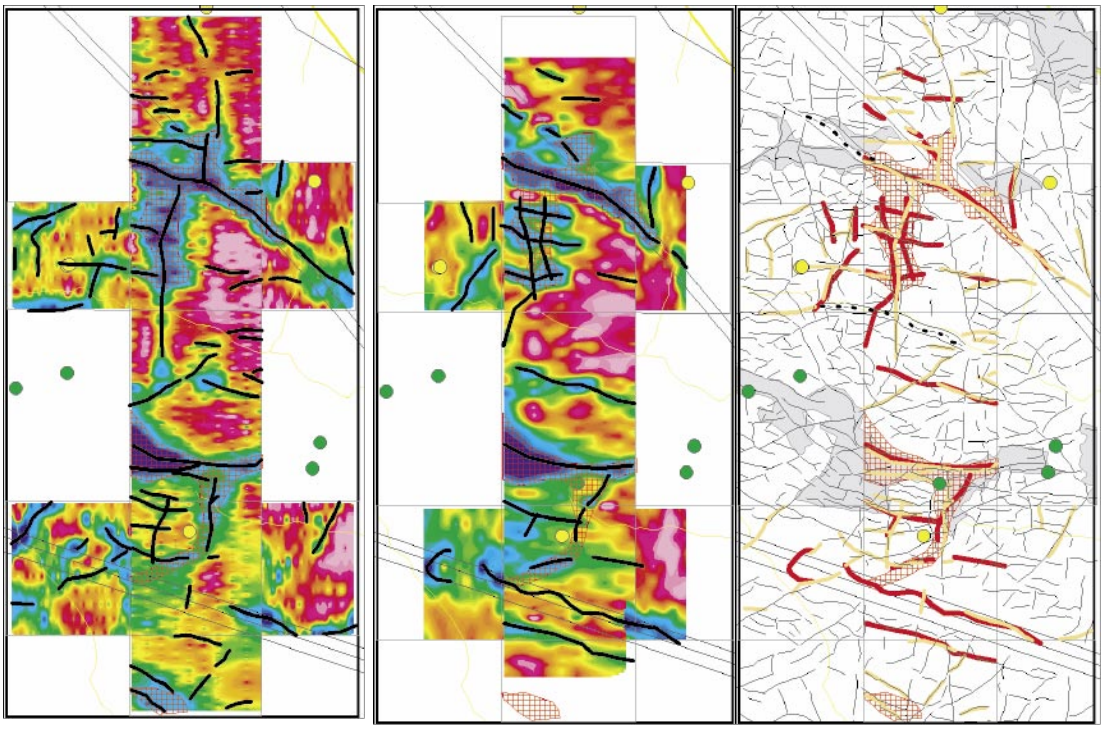

Figure 5-10. *Lineaments and vast areas with low resistivity as identified in resistivity data from measurements with the ABEM Lund Imaging System. Left: surface near positions of the identified lineaments (in background the survey with gradient configuration 5–50 m). Middle: deeper positions of the identified lineaments (in background the survey with gradient configuration 30 m – 300 m). Right: Comparison between lineaments in magnetic data with surface near and deeper lying lineaments from resistivity data. Green dots mark percussion boreholes, yellow mark core boreholes (planned or drilled).*

The interpretation of magnetic total field data and resistivity data is confirming the existence of EW007 as a structure with low magnetisation and low resistivity which is interpreted to reflect an increased fracturing of the rock. In the joint interpretation of lineaments /10/ EW007 was represented by a single line in order to preserve information economy at early stages of the site investigations. It was however obvious already from the helicopter-borne geophysics and digital terrain models, and the profile measurements carried out on ground with resistivity, magnetics and refraction seismics /11, 12/ that the EW007 is a deformation zone with a complex structure. The detailed ground geophysics reported here confirms the complexity and now details about it are possible to study. From the detailed geophysical survey results it appears as if the northern part of EW007, forming an "eye-like" structure probably is not genetically linked to EW007, Figure 5-9. It does not appear to be part of the same kinematical process. The northern part of this eye-like structure instead appears to be composed of other sets of lineaments.

The linked lineament ZSMNE040A is confirmed by the detailed ground geophysical measurements. It has a low magnetisation and a low resistivity in the part covered by the surveyed area. These physical parameters indicate possible brittle fracturing as a cause to the anomaly.

Among the linked lineaments /10/, one almost north-south striking was identified in the north-eastern part of the area surveyed with detailed ground geophysics. It is confirmed by the detailed measurements as bedrock with low relative magnetisation and partly low relative resistivity. These physical parameters indicate possible brittle fracturing as a cause to the anomaly, at least in sections.

Several others of the linked lineaments in the surveyed area are confirmed by the detailed ground geophysics.

The detailed survey has shown that several north-south striking lineaments with low magnetisation exist in the area of which one could be rather continuous for a distance of almost 2 km.

5.5 Bulk resistivity

The bulk resistivity of the bedrock in the type of geological environment found at Laxemar is directly coupled to the fracture frequency, the resistivity of the water in the fractures and pores, and the fracture width /6/. In rock volumes with low resistivity it is thus probable that the intensity of fracturing is higher as compared to volumes with high resistivity in the Laxemar area.

A 3D voxel model of the bulk resistivity as the result of the inversion of resistivity data from the Pole-Dipole Scintrex survey is shown in Figure 5-11. Though some disturbances from the power lines in the area have deteoriated the model slightly, the major character of the resistivity distribution in the bedrock is probably reflected in the figure. In the southern part of the investigated area there is a volume of rock with high relative resisitivity. To the north of the EW007 and south of the linked lineament ZSMNE040A also a high resistive sub-volume is delineated.

In Figure 5-12 the 3D voxel model of high resistive rock volumes is presented together with the magnetic field from sources in the depth slice between 150-200 m. It is indicated that low resistive volumes are coinciding with low magnetisation.

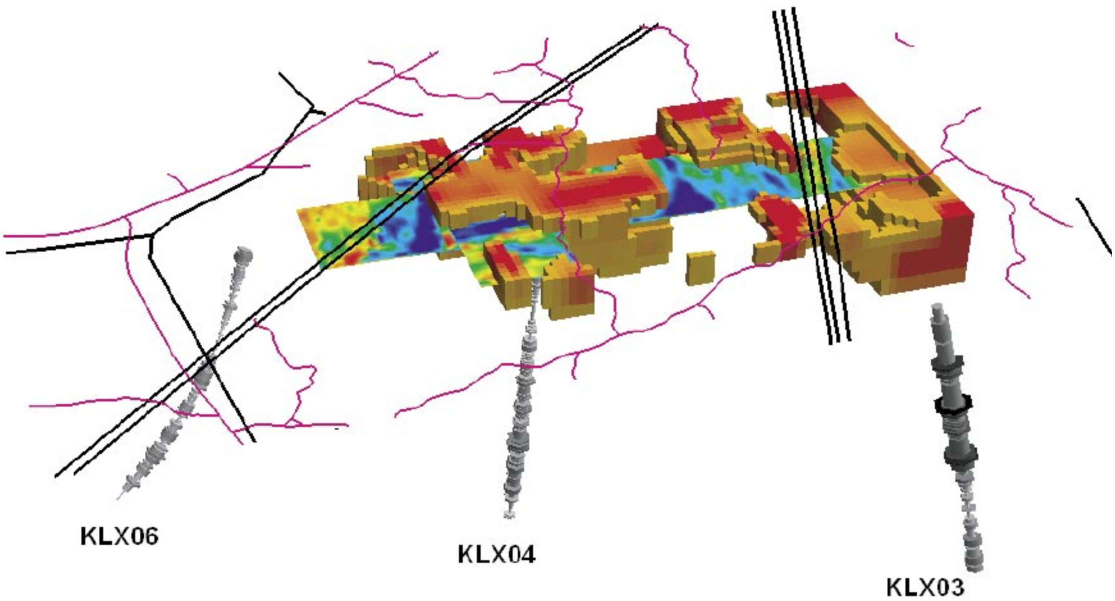

Figure 5-11. *3D Voxel model of rock volumes with high relative bulk resistivity in the Laxemar area (reddish brown colour). Presented in the image is also data from the resistivity measurements with the ABEM Lund Imaging System, where both EW007 and ZSMNE040A are represented by low resistive areas (bluish colour). Magnetic susceptibility from logging of the core boreholes KLX03, KLX04 and KLX06 is presented. View from north-west.*

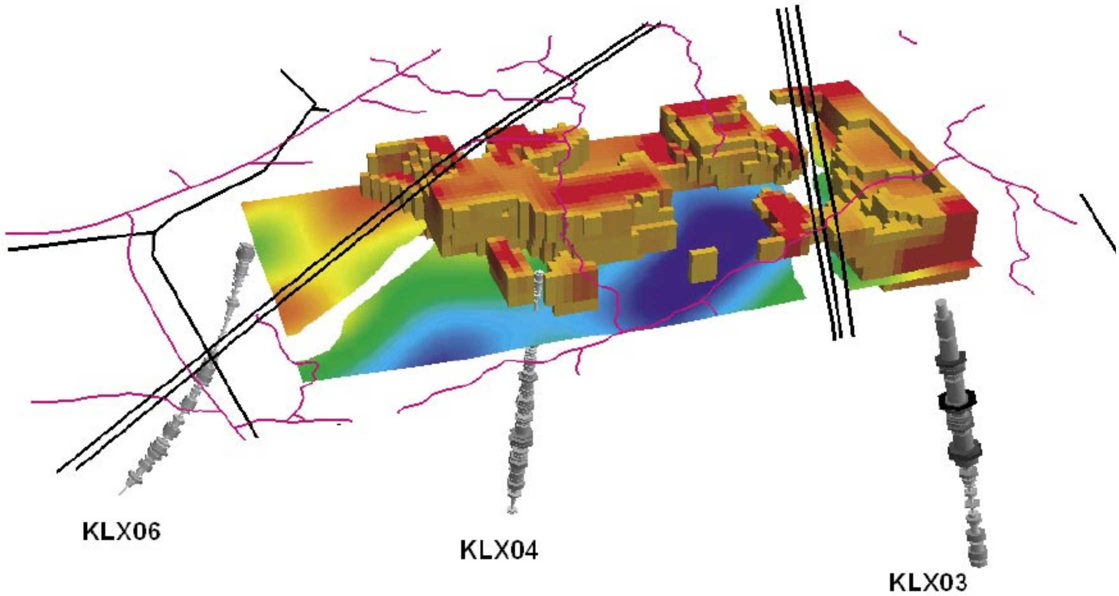

Figure 5-12. *3D Voxel model of rock volumes with high relative bulk resistivity in the Laxemar area (reddish brown colour). Presented in the image is also a map of the magnetic field from sources in the depth slice between 150–200 m with low magnetisation areas in bluish colour. Magnetic susceptibility from logging of the core boreholes KLX03, KLX04 and KLX06 is presented. View from north-west.*

5.6 Numerical modelling of magnetic data

Data from four profiles were extracted and implemented into a numerical modelling program. The location of the four profiles is shown in Figure 5-13 together with the magnetic field, reduced to the pole.

In Figures 5-14 to 5-16 the results of the modelling of the magnetic total field above EW007 are shown. The dip of EW007 is sub-vertical; the dip varies between slightly to the north and slightly to the south. The magnetic field along the central profile shows the complexity of EW007. The complexity also affects the level of prognosis of the dip to be more uncertain.

In Figure 5-17 a 3D view is shown of the modelling results for EW007 related to a map of the magnetic field together with the magnetic susceptibility as recorded in geophysical logging in boreholes. Figure 5-17 shows that EW007 is clearly indicated by the low susceptibility in one of the logged boreholes.

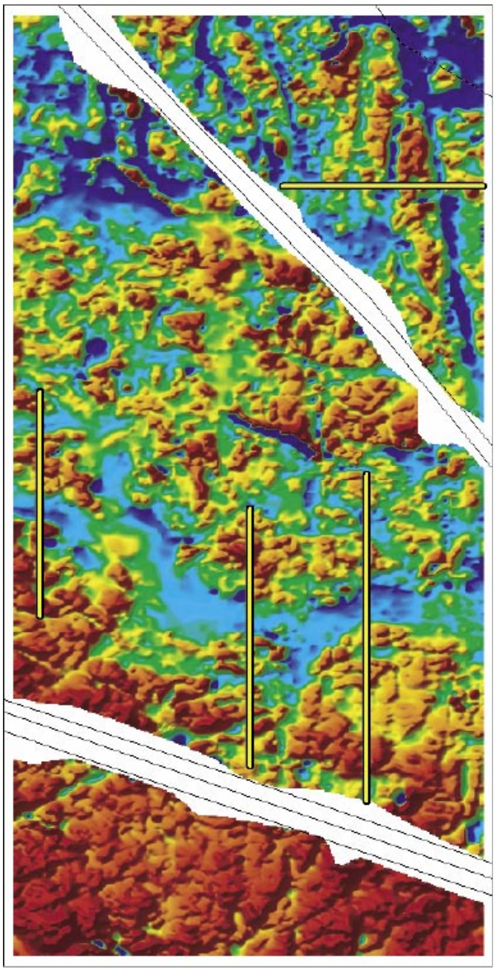

Figure 5-13. *The location of the four numerically modelled profiles displayed on the magnetic total field reduced to the pole. The three profiles oriented north-south are traversing EW007. The single east-west oriented profile at northeast is traversing at least four lineaments striking approximately north-south.*

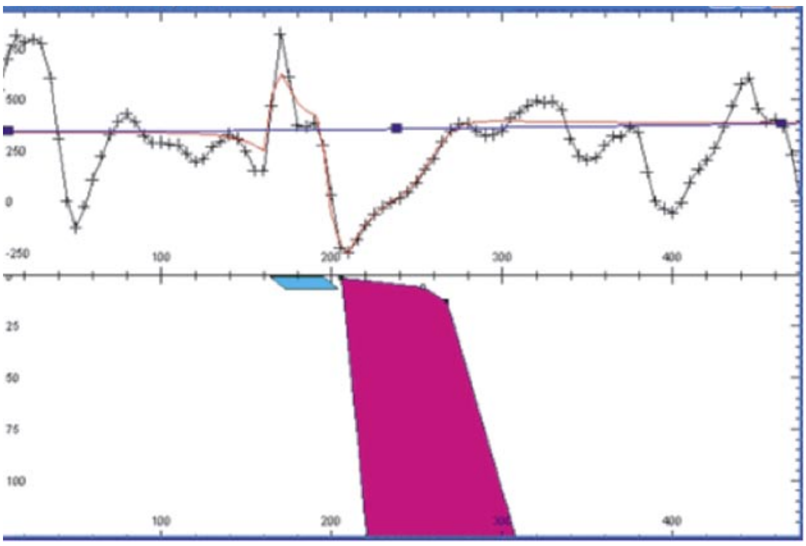

Figure 5-14. *Modelling of the magnetic total field over the westernmost profile (Figure 5-13) passing the deformation zone EW007. The pinkish body has a low magnetisation as is expected from EW007. The dip is almost vertical or slightly towards north. The bluish body has a high magnetisation and is used only to model the high anomaly at the southern flank of magnetic minima. View from east.*

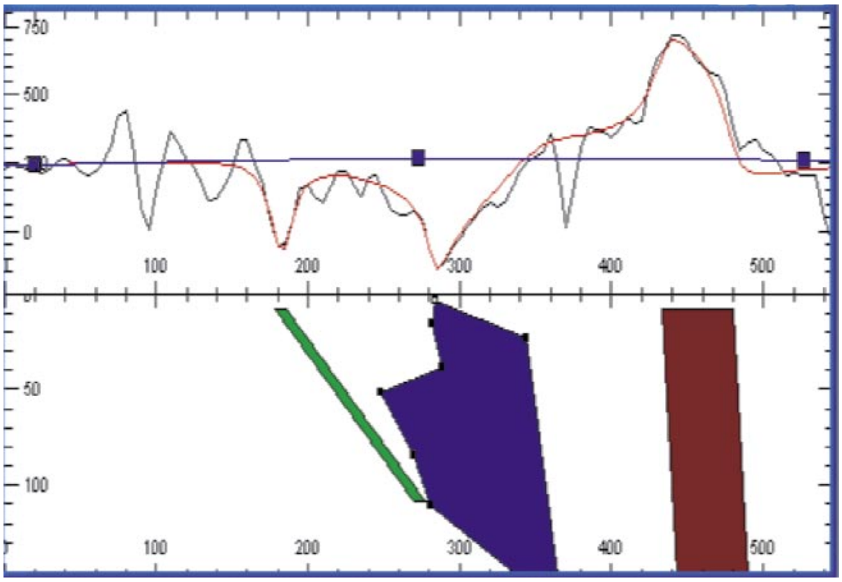

Figure 5-15. *Modelling of the magnetic total field over the central profile (Figure 5-13) passing the deformation zone EW007. The central dark blue body has a low magnetisation as is expected from EW007. The green thin body with low magnetisation probably marks the southern border of EW007 and is used to model a local minimum. As seen EW007 can be expected to have influenced the magnetisation in the rock at a horizontal distance of more than 150 m. The main dip appears to be slightly towards north, though the level of significance is rather low due to the complicated anomaly. The brown body has a high magnetisation and is used only to model the high anomaly at the northern flank. View from east.*

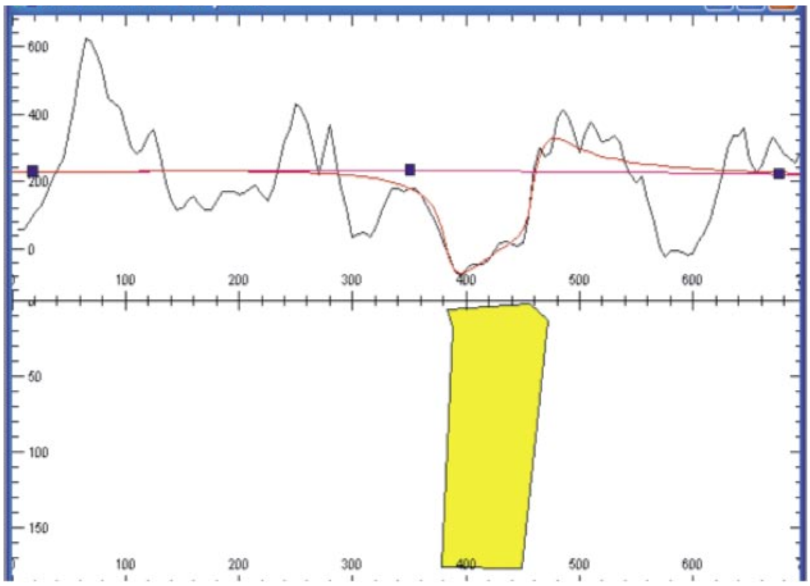

Figure 5-16. *Modelling of the magnetic total field over the easternmost profile passing the deformation zone EW007 (Figure 5-13). The yellow body has a low magnetisation as is expected from EW007. The body has a slight dip towards south.*

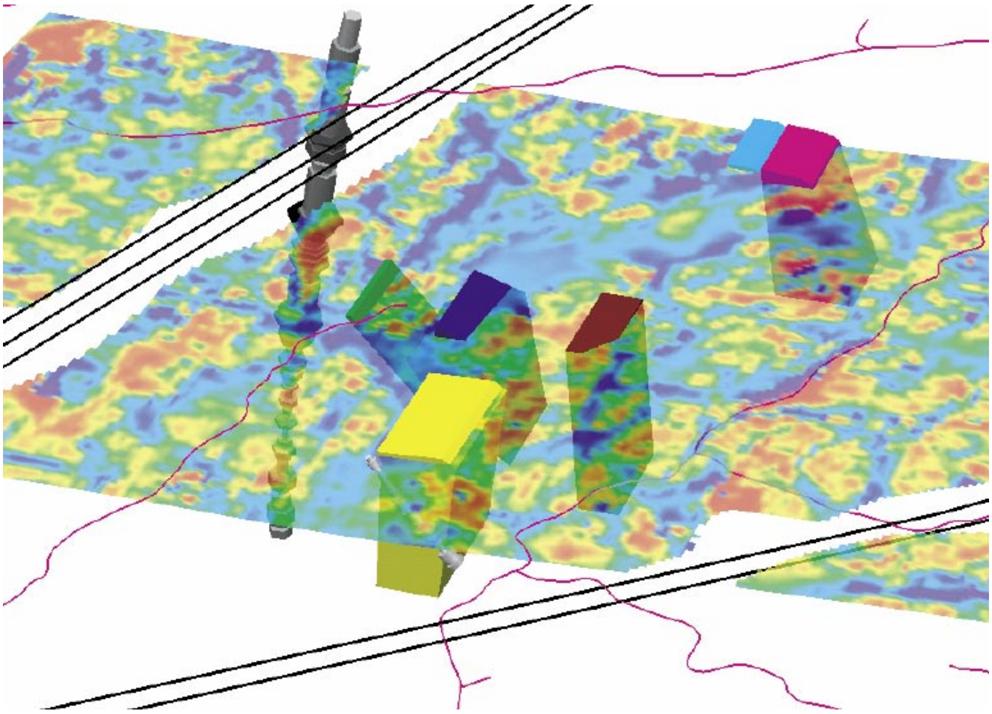

Figure 5-17. *Modelling of the magnetic total field above EW007. The models of the three profiles are presented in detail in Figures 5-14 to 5-16. A short percussion borehole is found immediately at this side of the yellow body, the magnetic susceptibility logged in the borehole is clearly lower as compared to the core borehole KLX03 in the background. In background the magnetic total field. The power lines are also marked. View from north-east.*

The models of the three profiles over EW007 are related to the 3D voxel model of the high resistive rock volumes in Figure 5-18 where it becomes obvious that EW007 is low resistive and has a low magnetisation.

In Figure 5-19 is shown the results of the modelling of the magnetic total field above several approximately north-south striking lineaments with low magnetisation found in the north-eastern part of the investigated area. The dip varies of the sources to the three major lineaments.

In Figure 5-20 a 3D view is showing the modelling results for the north-south striking lineaments in Figure 5-18. In the background the source bodies modelled for EW007.

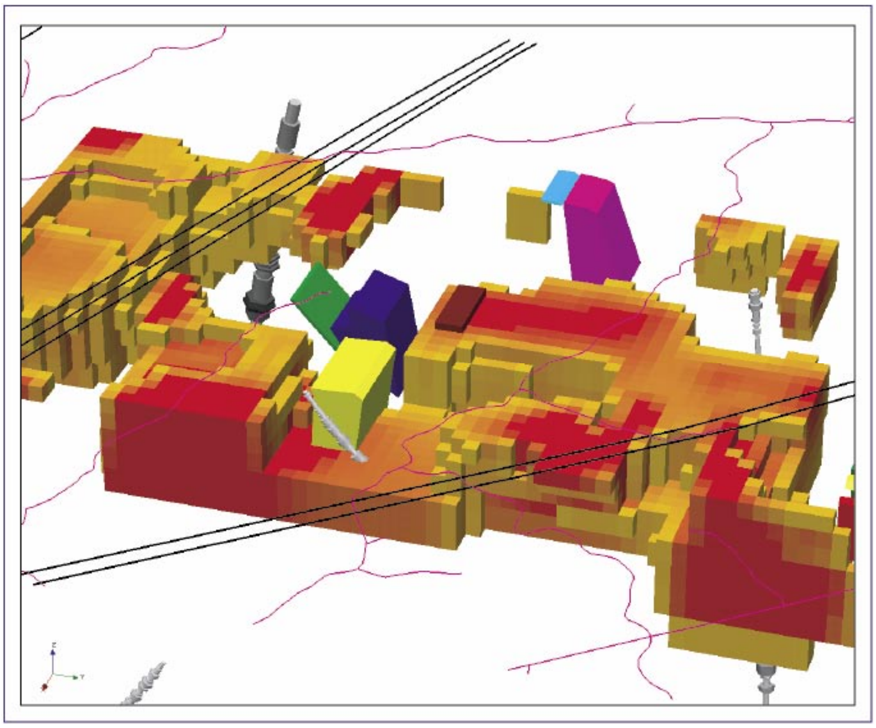

Figure 5-18. *Results of the modelling of the magnetic total field above EW007 in relation to the 3D voxel model of comparatively high resistive rock volumes. The models of the three profiles are presented in detail in Figures 5-14 to 5-16. A short percussion borehole is found immediately at this side of the yellow body, the magnetic susceptibility logged in the borehole is clearly lower as compared to the core borehole KLX03 in the background. The power lines are also marked. View from north-east.*

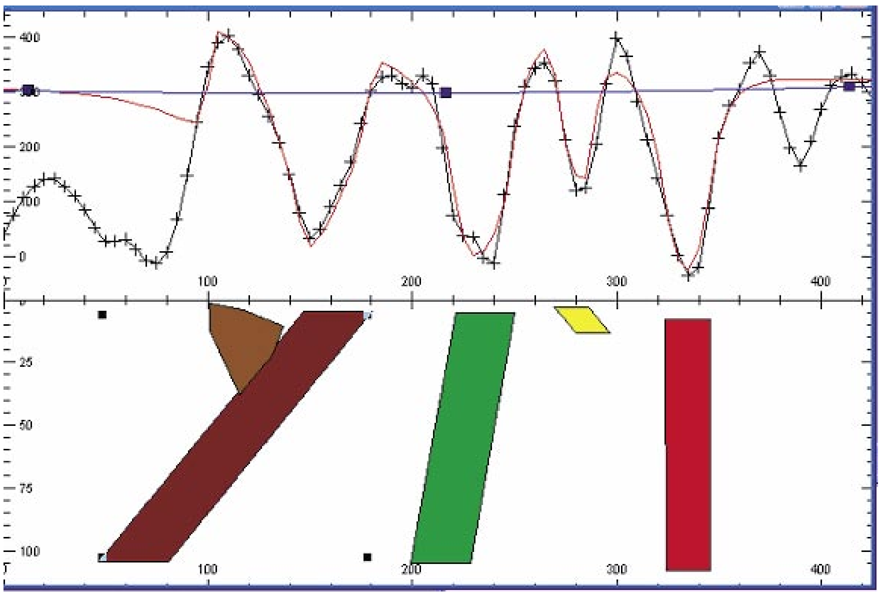

Figure 5-19. *Modelling of the magnetic total field in the northern profile over several of the approximately north-south striking lineaments in the north-eastern part of the measured area (Figure 5-13). As seen the dip is varying, but one of the major lineaments (modelled with the red body) has an almost vertical dip in the model. View from south.*

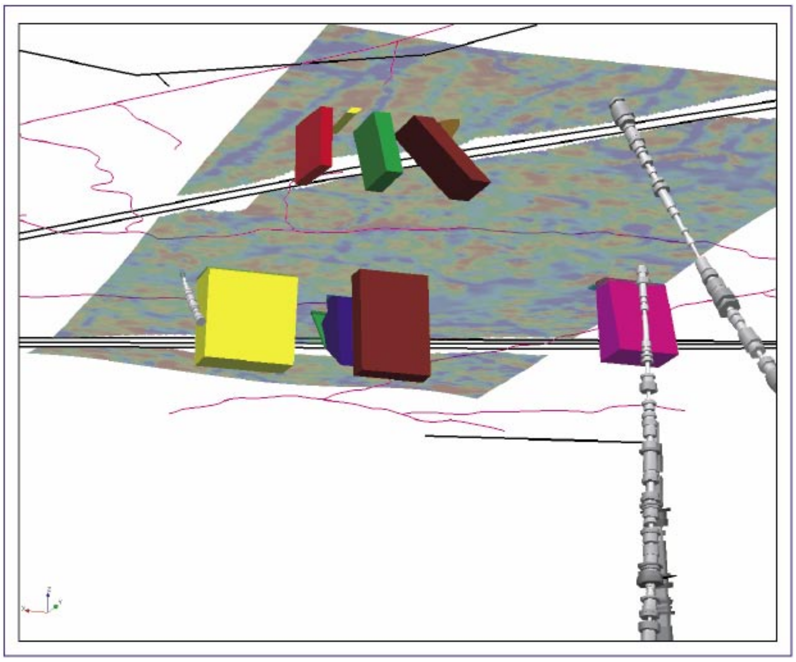

Figure 5-20. *3D presentation of the modelling of the magnetic total field. In the front the source bodies to the low magnetic lineaments striking approximately north-south. In the background source bodies from modelling of EW007. The magnetic susceptibility from logging of some boreholes in the area is also shown together with power lines. View below surface from north-north-east.*

5.7 Lithological in-homogeneities in rock

Among the lithological in-homogeneities in the Ävrö granite expected to be found within the measured area, are mainly the following rock types:

- Fine-grained granite
- Diorite to gabbro
- Fine-grained dioritoid

According to petrophysical studies /3/ the magnetisation of the Diorite to gabbro is often slightly higher as compared to Ävrö granite. Though units of Diorite to gabbro with low magnetisation are also recorded, field work indicates that both types occur in the same areas. This means that high magnetic anomalies could be expected in areas where bodies of Diorite to gabbro (or fine-grained dioritoid) occur.

The Fine-grained granite often shows magnetisation levels that are lower as compared to the Ävrö granite. The Fine-grained granite has high content of U and Th in relation to the Ävrö granite. This implies that larger outcropping volumes occupied by Fine-grained granite should cause a low magnetic anomaly coupled to high relative radiation in the thorium and uranium channels.

The Fine-grained dioritoid has a very broad distribution in a frequency diagram of the magnetic susceptibility. Some measurements indicate very high magnetic susceptibilities.

In areas with very high magnetisation levels it could thus be expected that Diorite to gabbro (or Fine-grained dioritoid) would more often be observed as compared to areas with a normal magnetisation. This is also shown in Section 5.1 of /3/.

In Figure 5-21 is shown the results from the helicopter-borne gamma ray spectrometry together with all observations of Diorite to gabbro (violet dots). As seen many observations are found at the southern border of the Ävrö granite near the contact to Quartz monzodiorite /13/. The green band, forming a half-circle, shows increased relative content of potassium at the southern border of the Ävrö granite. This green half-circle correspond well with less content of quartz in the Ävrö granite. It is obvious that observations of Diorite to gabbro are absent near the northern border of the green band. Further north however, where the spectrometry data indicate higher relative content of uranium and thorium (reddish) in the Ävrö granite, observations of Diorite to gabbro are more frequent.

As larger volumes of outcropping Fine-grained granite probably would be indicated by increased relative content of uranium and thorium in the gamma ray data, this type of in-homogeneities are probably less common in the southern part of the investigated area (within the green half-circle).

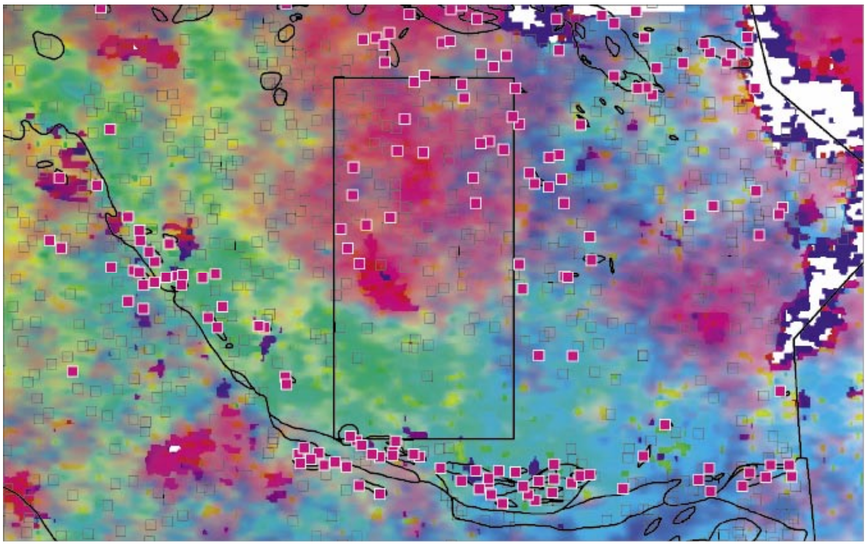

Figure 5-21. *Helicopter-borne gamma ray spectrometry map showing relative contents of potassium, uranium and thorium. The rectangle marks the survey area were the detailed geophysical survey reported here has been carried out. Also in black borders between geological units on the bedrock map is outlined /13/. In violet observations of Diorite to gabbro in outcrops are marked. Diorite to gabbro is absent in the northern part of the green (potassium) half-circle marking the Ävrö granite type with lower quartz content as compared to the area where spectrometry indicates higher content of U (blue) and Th (red).*

By comparing magnetic susceptibility measurements on outcrops, mapping of Diorite to gabbro and Fine-grained dioritoid, and the magnetic total field as measured in the detailed ground geophysical survey reported here, a map of possible in-homogeneities has been prepared, Figure 5-22. The following criteria have been used to mark where a possible in-homogeneity may occur. It is where:

1. A clear magnetic high anomaly is found reasonably near observations of Diorite to gabbro, also within nearby outcropping areas where no observations of Diorite to gabbro have been made.
2. A clear magnetic high anomaly is found within an outcrop with no observations of Diorite to gabbro, if the magnetic susceptibility observed on the outcrop is below approximately 1000-1500*10-5 SI.
3. A clear magnetic high anomaly is found outside outcropping areas in the southern part of the measured area, if the elongation of the anomaly is more or less east-west.
4. A clear magnetic high anomaly is found outside outcropping areas in the northern part of the measured area, independently of shape.

In the northern part of the green band thus only sparse in-homogeneities of Diorite to gabbro (and Fine-grained dioritoid) have been marked as could be observed in Figure 5-22.

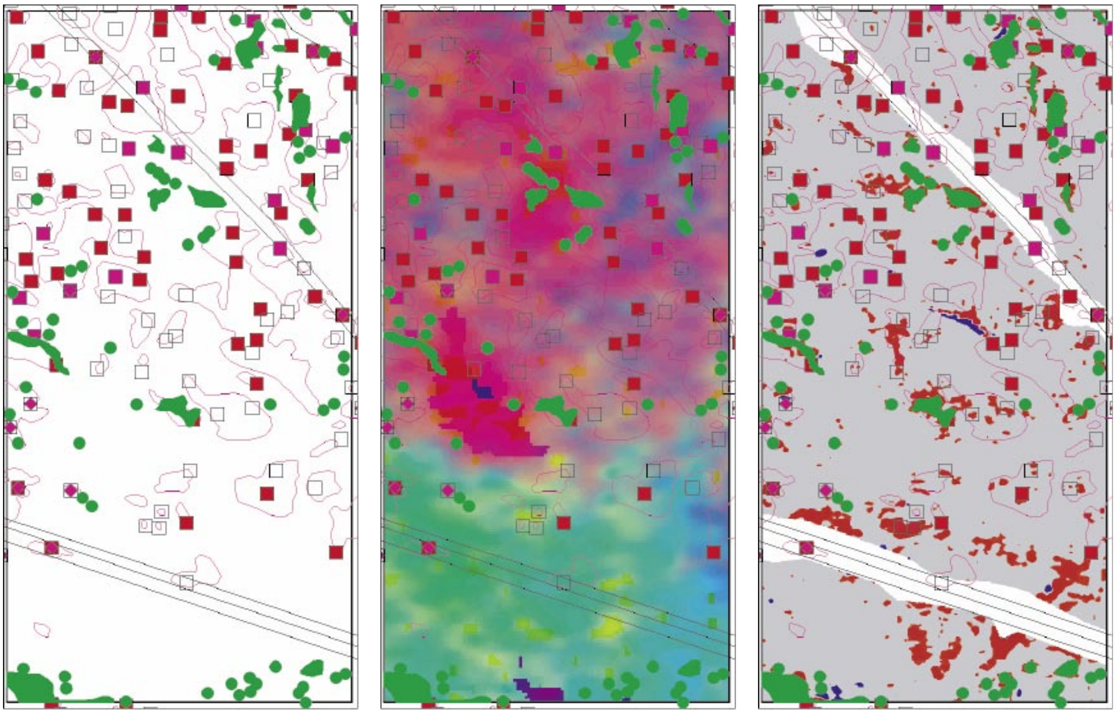

Figure 5-22. *Left: Possible in-homogeneities of Diorite to gabbro (or fine-grained dioritoid) are marked in green. Outcrops are outlined in violet bounderies. Empty squares are geological observations made at locations on outcrops. Red squares are observed Fine-grained granite, violet squares – Diorite to gabbro, violet tilted squares – Fine-grained dioritoid. Center: all on the helicopterborne gamma ray spectrometry (see Figure 5-21). Right: all on the map of the magnetic total field in Figure 5-3. The highest (red) and the lowest (blue) total field intensities are enhanced.*

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