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# Ground magnetic survey and lineament interpretation in an area northwest of Bolundsfjärden

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May 2006

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Keywords: Geophysics, Geology, Magnetometry, Lineament, Deformation zone, Forsmark, AP PF 400-05-082.

# Abstract

The report presents the execution and the results from magnetic measurements carried out on the ground in an area covering 680×1,200 metre northwest of Bolundsfjärden in the Forsmark site investigation area. The main objective of this activity is to determine a detailed ground magnetic representation of the bedrock and by these means provide help in investigating the extension of the local major lineaments XFM0060A0 and XFM0061A0.

A grid with eight parallel lines was staked and marked on every 20 metre. Measurements of the magnetic total field were carried out along profiles, perpendicular to the staked lines, with a profile spacing of 10 metre and a point distance of 5 metre.

The magnetic pattern in the survey area can be divided in three main areas with different magnetic character. The southwest part of the area shows a gentle, banded magnetic pattern of low-moderate magnetic intensity. The northeast part is characterized by high magnetic intensity and a banded – irregular pattern. The southeast part shows a similar magnetic pattern but with a low-moderate magnetic intensity.

The interpretation of the magnetic data has been directed towards identification of linear features but also a few areas with very low magnetisation and low magnetic relief has been outlined. The origin for these features is uncertain but the occurrences might need further investigations.

A total of 286 magnetic lineaments (or lineament segments) have been identified. The lineaments outlined are characterized as linear magnetic minima, minima connections, edges and dislocations. The lineaments are graded in low, medium and high uncertainty mainly with respect to the clarity in which they appear but also in some cases involving an expert judgement regarding the specific geological situation and considering the possible cause of the lineament.

The extensions of linked lineaments, XFM0060A0 and XFM0061A0 are both supported by this survey and the possible break of XFM0060A0 indicated by lineament interpretation of the Geological survey of Finland does not find any support in the ground magnetic data.

It is clear that the high resolution, ground magnetic data provides the possibility to identify more and shorter lineaments than the airborne survey data. Of previously not identified lineaments, three longer lineaments in ENE direction are commented. Areas showing a higher degree of diffuse magnetic pattern or low intensity possibly indicate a deeper bedrock source and/or the presence of fractured and altered surface rock

The interpretation results are delivered in GIS-format and each lineament has an attribute table attached. The table is the same adapted for linked lineaments in previous work.

Several examples of the magnetic survey and processed magnetic data, forming the basis for identifying lineaments are presented in the report.

# Sammanfattning


Denna rapport presenterar utförande och resultat av markgeofysiska mätningar utförda med magnetometer i ett 680×1 200 meter stort mätområde nordväst om Bolundsfjärden inom Forsmarks kandidatområde. Målsättningen med insatsen är att erhålla en detaljerad bild av berggrundens magnetfält som underlag för att bestämma utbredningen och kontinuiteten av lineamenten XFM0060A0 samt XFM0061A0.

Åtta stycken parallella linjer har stakats ut och markerats var 20:e meter. Vinkelrätt mot dessa linjer utfördes magnetiska mätningar med 10 meters linjeavstånd och med 5 meters punkttäthet.

Det magnetiska mönstret i området kan delas in i tre huvudområden. Det västra området karaktäriseras av ett mjukt, bandat magnetiskt mönster och låg – måttlig magnetisk intensitet. Den nordvästra delen uppvisar hög magnetisk intensitet och ett bandat – irreguljärt mönster. Sydvästra delen visar ett liknande mönster men med låg – måttlig magnetisk intensitet.

Tolkningen av data har inriktats på att identifiera lineament men också några områden med låg magnetisk intensitet och låg relief har markerats. Orsaken till dessa områden är oklar och kan behöva ytterligare undersökningar.

Totalt har 286 magnetiska lineament (eller segment av lineament) identifierats och dessa har liksom i tidigare arbeten dokumenterats i attributtabeller. Lineamenten karaktäriseras av magnetiska minima, kanter, dislokationer och magnetiska minima parallella med den magnetiska bandningen. Lineamenten uppdelas vidare i låg, måttlig och hög osäkerhet.

Utbredningen av tidigare identifierade lineamenten XFM0060A0 and XFM0061A0 stämmer väl med mätresultaten. Den uppdelning av XFM0060A0 som indikerats av Finlands geologiska undersökning, GTK, har dock inte kunnat bekräftas.

Den högupplösande markmagnetiska mätningen möjliggör också identifiering av fler och kortare lineament än i tidigare arbeten. Tre ”nya” och längre lineament i riktning ONO kommenteras i rapporten. Områden med ett diffust anomalimönster har också markerats eftersom dessa kan indikera större djup till den magnetiska källan och/eller förekomst av uppsprucket och omvandlat ytberg.

Rapporten innehåller flera exempel på magnetiska data och bearbetningar som utgjort underlag för tolkningsarbetet. Resultaten levereras i GIS-format.

# Contents

# 1 Introduction

The work presented in this report has been carried out by GeoVista AB in accordance with instructions and guidelines presented by SKB in the method descriptions MD 212.004 for the fieldwork, and MD 120.001 as well as SKB R-03-07 /1/ for the interpretation work.

This document reports the results gained from the ground geophysical measurements of the magnetic total field in an area of 680×1,200 metre northwest of Bolundsfjärden, 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 400-05-082. The controlling documents for performing this activity are listed in Table 1-1. Both the activity plan and the method descriptions form SKB's internal controlling documents.

Identification of topographic and airborne geophysical lineaments has been carried out in the site investigations at Forsmark /2/, /3/, /4/, /5/, /6/. The lineaments have mainly been identified as topographic lows, magnetic lows and, in some cases, resistivity lows. In several cases, linked lineaments /5/ have been verified as representing deformation zones in the bedrock or have been explained by other grounds /7/.

Linear features, or lineaments, can provide important information on the extension of deformation zones in the bedrock. The magnetic susceptibility of rocks is often low in fractured, altered or porous bedrock due to destruction of ferromagnetic minerals. Hence, the work forms a basis for the geological bedrock mapping and the site descriptive models /8/, /9/ in the Forsmark area. The linked lineaments XFM0060A0 and XFM0061A0, which show a significant magnetic component, were identified and documented in previous interpretation work /3/, /5/ and have formed, in part, a basis for the definition of the deformation zones ZFMNE0060 and ZFMNE0061 /8/, /9/, respectively. The prime purpose of the present investigation has been to assess the continuity of these lineaments and, as a consequence, the respective deformation zones. The location of the study area was defined in connection with the recognition of a broader programme for the further investigation of lineaments at Forsmark /7/.

The staking of a survey grid and ground magnetic measurements were carried out by GeoVista AB in two phases during the periods January 24–February 22, 2006 and March 7–March 18, 2006. The survey area covered 680×1,200 m, Figure 1-1. 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 with the help of the activity plan number AP PF 400-05-082.

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

| Activity plan | Number | Version |
|---|---|---|
| Markbaserad magnetometri i område nordväst om Bolundsfjärden | AP PF 400-05-082 | 1.0 |
| **Method descriptions** | **Number** | **Version** |
| Metodbeskrivning för magnetometri. | SKB MD 212.004 | 1.0 |
| Metodbeskrivning för lineamentstolkning baserad på topografiska data | SKB MD 120.001 | 1.0 |

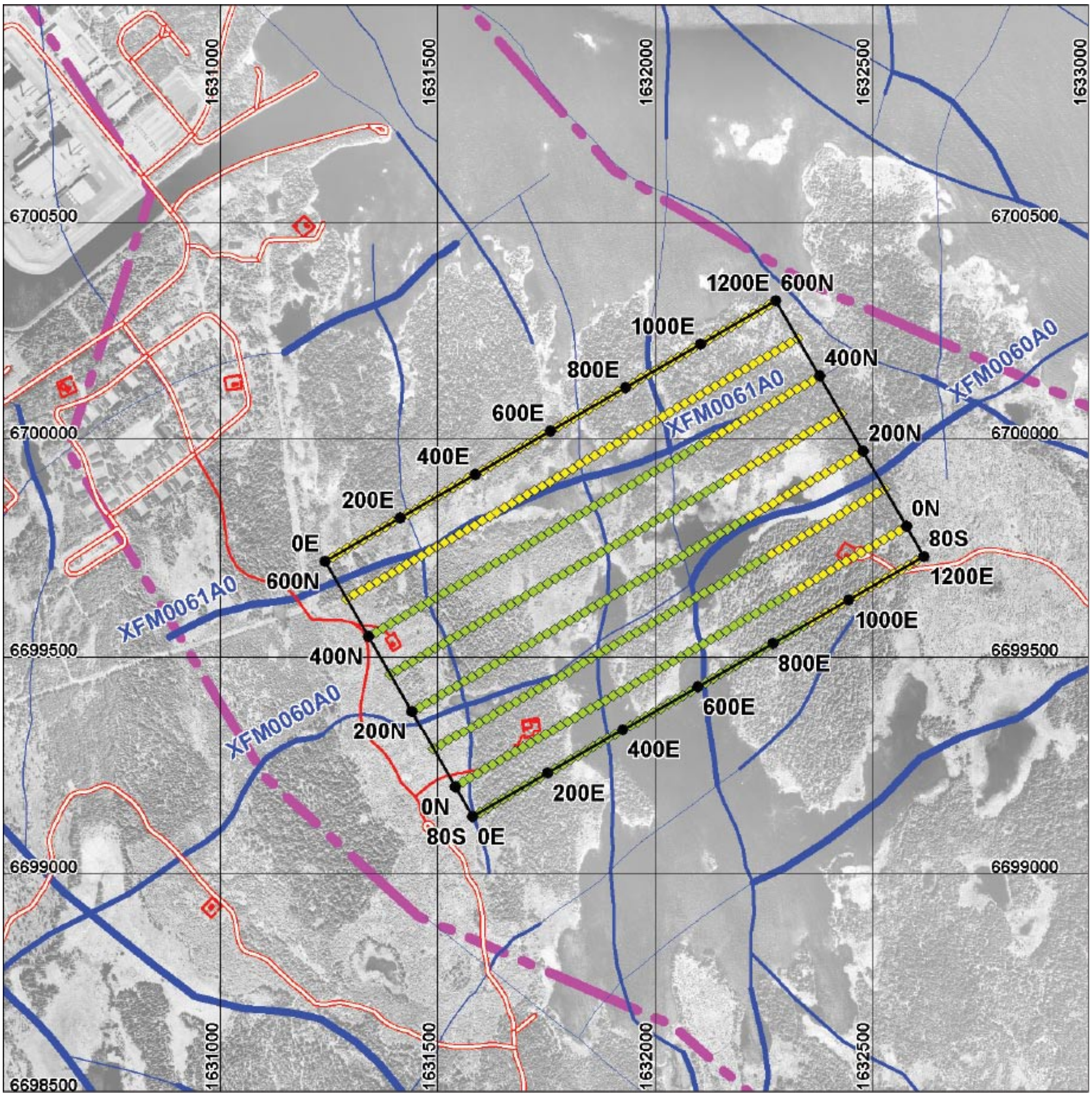


***Figure 1-1.*** *Magnetic survey area AFM100206 carried out for the investigation of the linked lineaments XFM0060A0 and XFM0061A0. Grid lines for the first phase are shown with green dots and with yellow dots for the extended survey area, phase two. Coordinated, local major lineaments from /5/ and /7/ are shown as blue lines with thickness according to weight (thicker = higher weight). The Forsmark candidate area is shown as thick, dot-dashed, magenta line. Roads and drill sites in red (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268).*

# 2 Equipment

## 2.1 Description of survey equipment and interpretation tools

For the gridding, a RTK-GPS Trimble R8 Rover was used in the first phase of the survey together with a GSM-telephone with Bluetooth and, in the second phase, with a built in GPRS. The SWEPOS national network of permanent reference stations was used as base stations. Every morning, before using the RTK-GPS, a benchmark (PP1202) was visited to secure the quality of the survey. The co-ordinate system used in this survey was a local grid based on the Swedish National Grid RT90 2.5 gon W with the geoid model SWEN 01L.

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

The magnetometers 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 magnetic data were affected by the D.C. current in the Fenno-Skan HVDC cable that runs to the north of the survey area. Data from the magnetic observatory at Fiby, supplied by the Geological Survey of Sweden, were used to estimate this effect.

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

Surfer 8 (Golden software)

Oasis Montaj 5.0 (Geosoft Inc)

Geomatica 10 (PCI Inc)

MapInfo Professional 8 (Mapinfo Corp.)

Discover 7 (Encom Technology Pty Ltd)

MathCAD 2001 (MathSoft Engineering & Education, Inc.)

Compaq Visual Fortran 6.6 (Compaq Computer Corporation)

# 3 Measurements and processing

## 3.1 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,
- processing, interpretation and reporting.

## 3.2 Preparation of a grid system

The preparation of the grid system, AFM100206, Figure 1-1, was carried out during two periods, January 24–February 1, 2006 and March 7–12, 2006, using a RTK-GPS, a compass and measuring-tape. The RTK-GPS was used to locate and mark as many points as possible along several parallel lines sited perpendicular to the survey direction. Normally, the distance between these lines was 100 m, except for the two southernmost lines, which lie 80 metre from each other. With the help of the RTK points, all of these lines were staked with a marker positioned every 20 metres. After the first phase of the magnetic survey, the part of the grid located on the ice of Bolundsfjärden was removed.

The origin of the grid system AFM100206 (0/0 in local grid) is 1631540 E, 6699200 N in the Swedish grid RT90 and the azimuth of the grid is 330°. The first phase of the survey covered an area of 480×900 metre. In the second survey phase, 200 metre was added towards local north and 300 metre towards local east giving the final grid and survey co-ordinates as follows:

| East | North | Local E | Local N |
|---|---|---|---|
| 1631580.0 | 6699130.7 | 0 | –80 |
| 1631240.0 | 6699719.6 | 0 | 600 |
| 1632279.2 | 6700319.6 | 1,200 | 600 |
| 1632619.2 | 6699730.7 | 1,200 | –80 |

## 3.3 Measurements of the magnetic total field

The first phase of the magnetic survey was carried out during February 3–21, 2006, with two Gem Systems GSM-19 magnetometers of which one was used as a diurnal base station. At March 12–18, 2006, during the second phase of the survey, three Gem Systems GSM-19 magnetometers were used of which one as a diurnal base station. At the base station, one reading was registered every 10 seconds and was used to make a diurnal correction of the data collected with the mobile magnetometers. The base station was located close to the survey area to minimize the diurnal variation as well as the influence from the D.C. cable between Sweden and Finland, which runs c 3 kilometres to the north of the survey area.

The diurnal base station location is as follows:

| | |
|---|---|
| In the local grid AFM100206: | 200E/86S |
| In the Swedish grid RT90: | 1631756.2 E/6699225.5 N |
| Median total intensity: | 51 353 nT (no HVDC cable correction) |
| Median total intensity: | 51 390 nT (cable correction applied, see below) |
| Calculated total intensity: | 51 314 nT according to /10/ |
| Calculated inclination: | 73.2° /10/ |
| Calculated declination: | 4.5° /10/ |

The magnetometers were calibrated to GMT and time synchronized before starting the survey every morning.

During the survey, magnetic readings were taken along profiles with a station interval of 5 metres and with a profile spacing of 10 metres. The profiles were directed perpendicular to the staked lines covering the area with 121 survey lines, each 680 metre long. The magnetometer sensor was located in the same direction on all points. Deviation from the true survey line and the survey station location is considered to be, at the maximum, 2–3 metre and 1 metre, respectively.

## 3.4 Data processing

### 3.4.1 Corrections for the Fenno-Skan HVDC cable

The data recorded by the base magnetometer were compared with the data from the Fiby magnetic observatory. The Fiby data indicated that no major magnetic activity occurred during the survey periods. Magnetic activity with short wave-numbers (< 2 to 3 hours) might be of different magnitude at Fiby compared to Forsmark due to the distance between the places. Such events, with a magnitude of more than 10 nT, occurred during February 20th and 21st. The estimated maximum error in using Fiby data for diurnal corrections is estimated to be around 10 to 15 nT during these periods, and only a small number of stations are affected by such errors.

The variations in difference of the magnetic field magnitude at Fiby and the base magnetometer at Forsmark were treated as being due to the HVDC cable. The differences in readings between the two magnetometers were in general characterized by long periods of more or less constant difference interrupted by sudden shifts of up to a few tens of nT. The total magnetic field due to a unit current in the HVDC cable was calculated for all survey stations and for the base magnetometer station with the help of Biot-Savart's law. The effect due to elevation was neglected since the area is quite flat. The deflection of the magnetic field and electromagnetic effects were also neglected. The current variations in the cable were thereafter estimated with the help of the difference between Fiby and base magnetometer readings. The corresponding magnetic field from the cable was subtracted from the readings at the survey stations. The magnetic field anomaly was thereafter found by subtracting the base magnetometer readings corrected for the effect of the cable. The final product is thus the difference in magnetic total field between the survey stations and the base magnetometer station in the absence of any current in the HVDC cable, assuming that the simplifications above are valid.

The maximum correction made for the current in the HVDC cable is 23 nT and the median correction is less than 5 nT. The largest corrections are made in the northern part of the survey area where the distance to the cable is shorter than the distance between the base magnetometer and the cable.

### 3.4.2 Interpolation and filtering

The magnetic data has been treated in two ways. The original field data collected in 5×10 metre stations was transformed to a 5×10 metre survey grid in the local grid system. The magnetic total field anomaly was also interpolated to a regular grid with a node spacing of 5×5 metres and transformed to the Swedish grid RT90.

Standard type of filtering and transformation (Oasis – ™ Geosoft Inc) has been executed on the datasets in accordance with previous processing of magnetic data, carried out in /3/, /5/, and /7/. A rather new processing method, "tilt derivative", especially useful for structural enhancements and segmentation of magnetic data has also been applied /5/ and /11/, Figure 3-6.

- 1:st and 2:nd vertical derivative,
- horizontal derivative along and perpendicular to the survey direction,
- total horizontal derivative,
- tilt derivative,
- total horizontal derivative of the tilt derivative.

When applicable, reduction to the pole and/or upward continuation has been performed prior to, or included in the applied filter.

## 3.5 Nonconformities

All magnetic data was influenced by the D.C. cable between Sweden and Finland, which is situated c 3 kilometres north of the survey area. For safety reasons, usage of ice-prods was necessary in the areas covered by ice. However, after finding almost non-magnetic ice-prods, tests showed that the influence was only 0.5 nT.

The anthropogenic environments at drill site BP1, BP5 and BP6 and along the roads to the drill sites have given disturbances and loss of data, Figure 4-1. The same is valid for the steel tube releasing salt water from drill site BP1 to the north, into the sea at Asphällsfjärden.

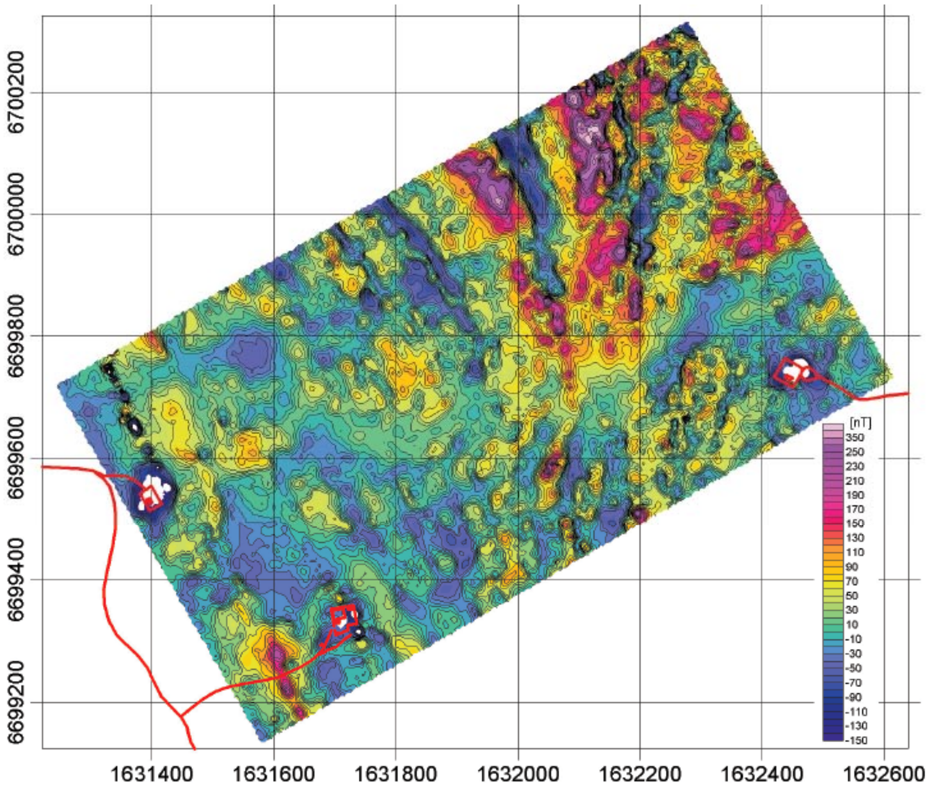


***Figure 3-1.*** *Magnetic anomaly field in the area AFM100206. Drill sites BP1, BP5 and BP6 in red.*

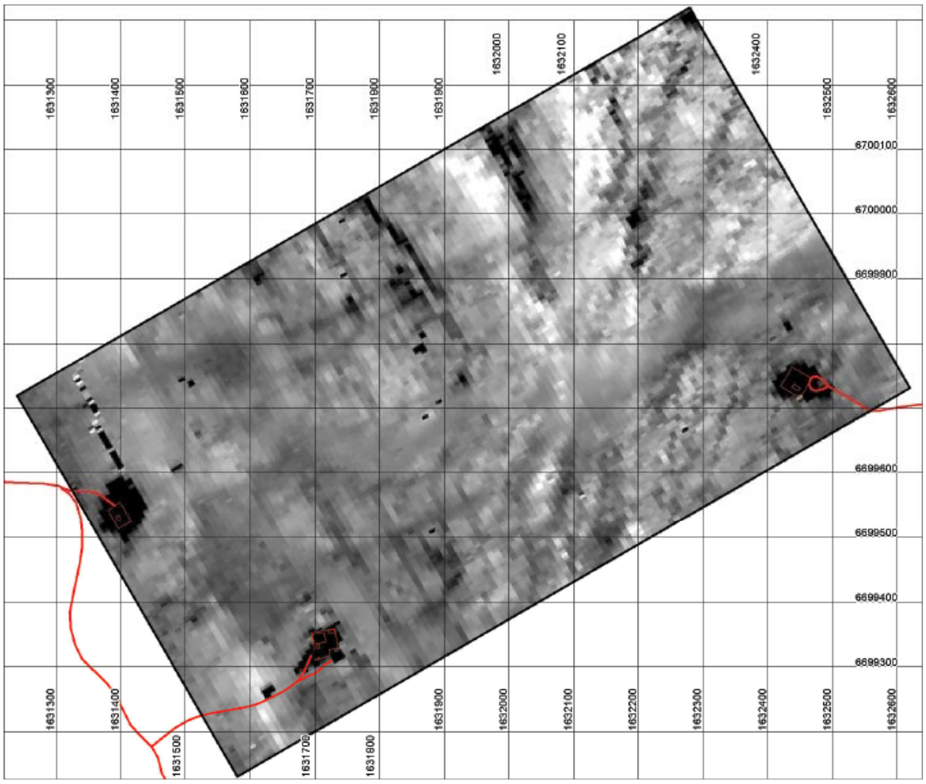


***Figure 3-2.*** *Magnetic anomaly field, greytone.*

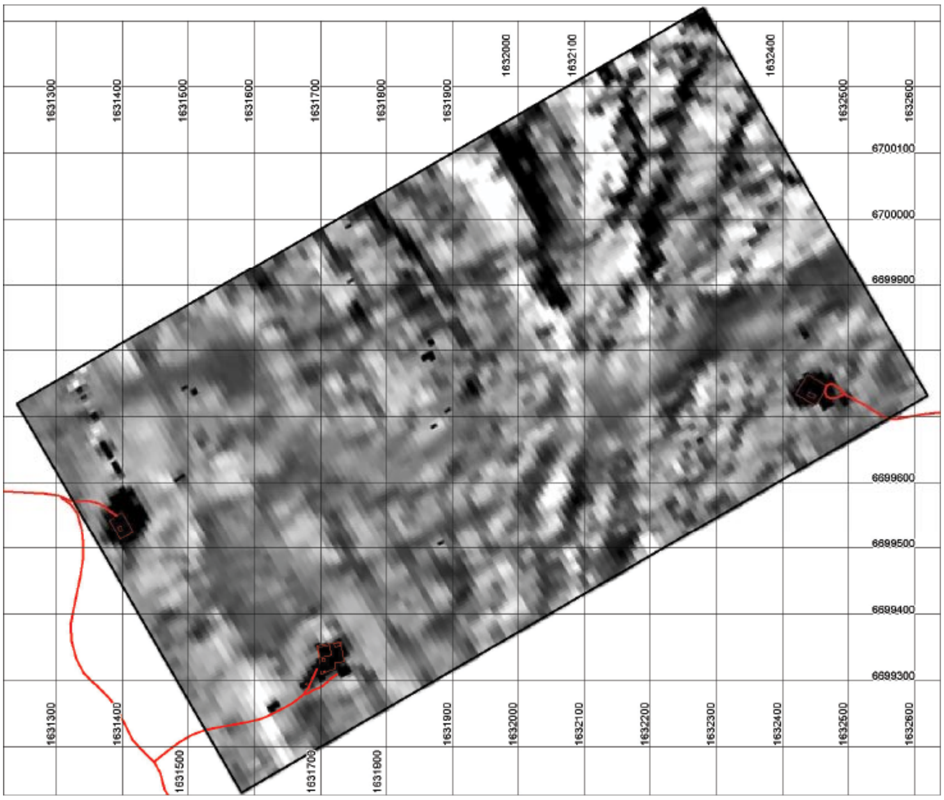


***Figure 3-3.*** *Magnetic anomaly field, 1.st vertical derivative, greytone.*

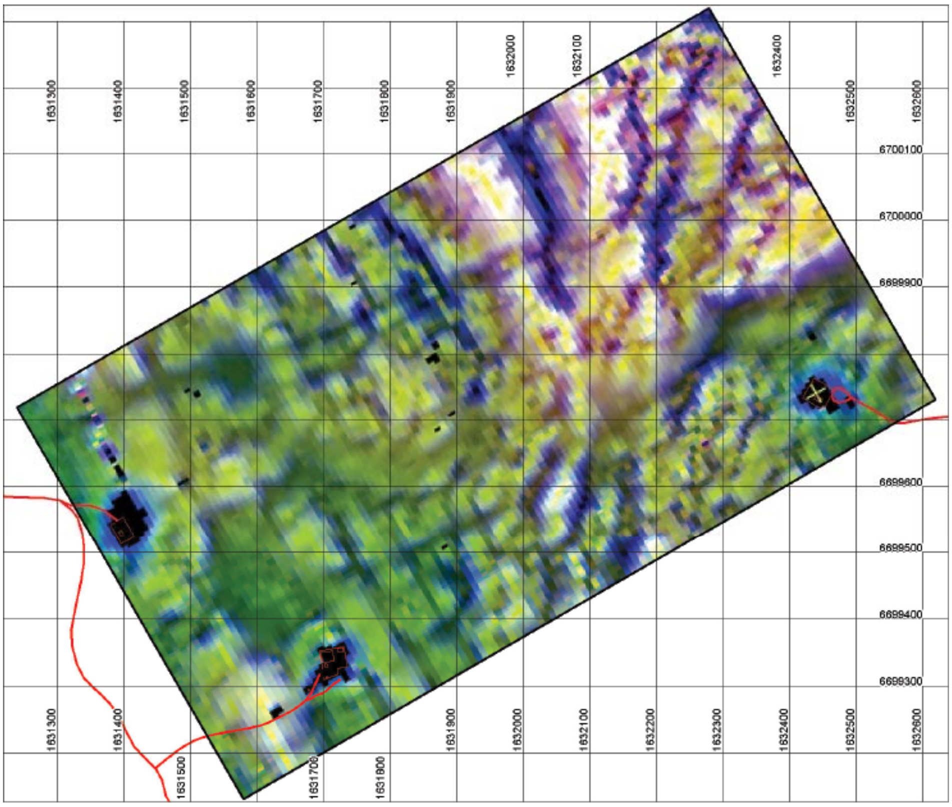


***Figure 3-4.*** *Colour composite of the magnetic anomaly field; reduced to the pole (red), 1:st vertical derivative (green) and total horizontal derivative (blue).*

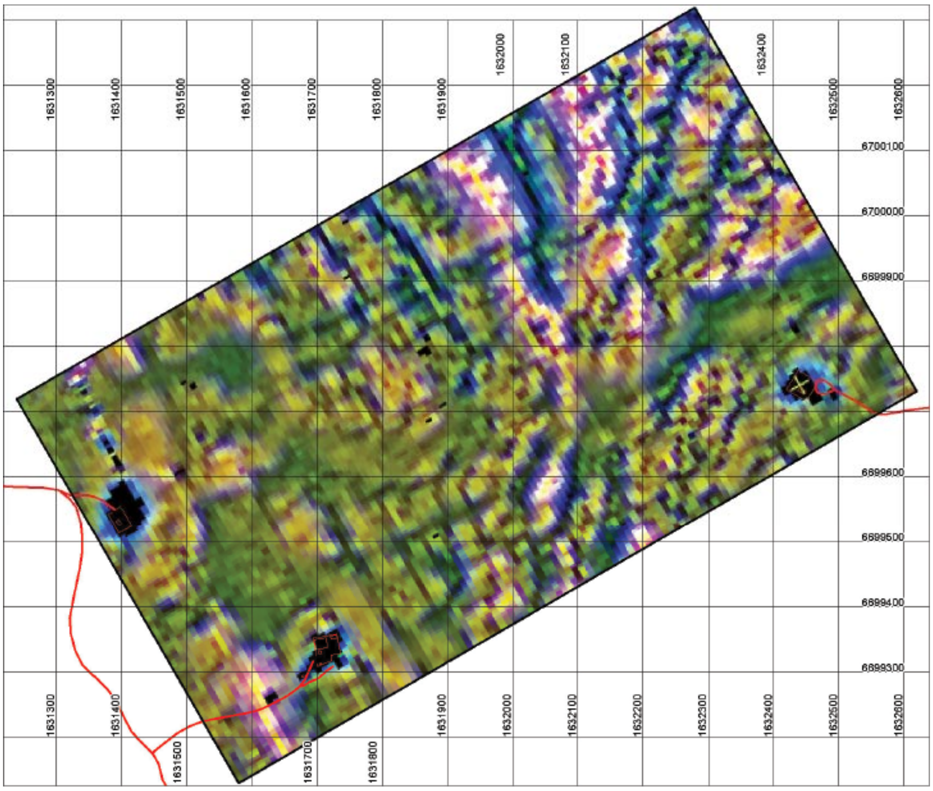


***Figure 3-5.*** *Colour composite of the magnetic anomaly field; reduced to the pole. The 1:st vertical derivative (red),2:nd vertical derivative (green) and total horizontal derivative (blue).*

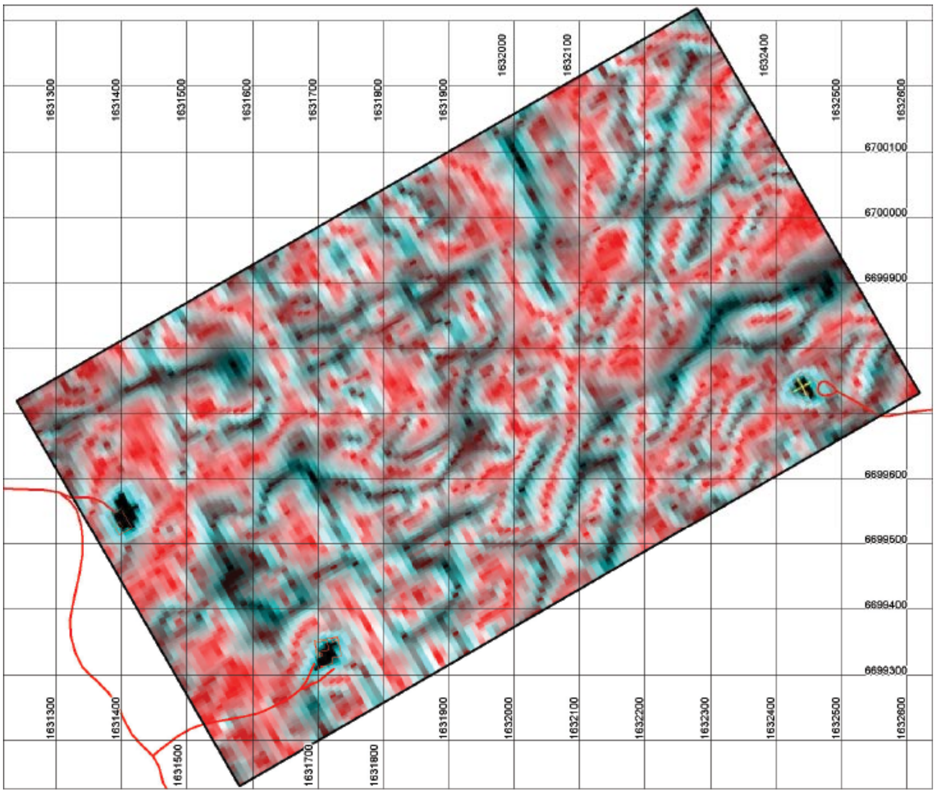


***Figure 3-6.*** *Colour composite of the magnetic anomaly field, reduced to the pole. Tilt derivative (red) and total horizontal derivative of the tilt derivative (green and blue). Upward continuation to 10 metre makes the magnetic pattern smoothed.*

# 4 Data interpretation

Data interpretation has been carried out by visual identification, delineation and characterization of structural features, using image analysis (Geomatica – ™ PCI) and GIS-techniques (Mapinfo – ™ Mapinfo).

The results are stored in the primary data bases (SICADA and/or GIS). The data is traceable in SICADA and GIS with the help of the Activity Plan number (AP PF 400-05-082).

## 4.1 The magnetic anomaly pattern

The magnetic pattern in the survey area can be divided into three main areas with different magnetic character (see Figure 3-1).

The western part of the study area, from 0–600E in the local grid, shows a gentle, banded magnetic pattern of low to moderate magnetic intensity. The northeast part (600–1200E, 200–600N) is characterized by high magnetic intensity and a banded to irregular pattern. The southeast part (600–1,200E, 80S–200N) shows a similar magnetic pattern but with a low to moderate magnetic intensity. A few minor areas with very low magnetisation and low magnetic relief have been identified and outlined, Figure 4-1. The origin of these features is uncertain and may require further investigations.

Areas of diffuse magnetic pattern can also be seen along a WSW-ENE trend from drill site BP1 to north of drill site BP6, Figure 4-1. The exact boundaries are difficult to outline and hence, the areas are marked with the letters A-A and B-B. The origin of this pattern is further discussed in Section 4.4.

Verduzco, et al. /11/ has shown that the zero crossing of the tilt derivative of the total magnetic field can indicate magnetic rock boundaries. The same is valid for the maximum of the total horizontal derivative of the tilt derivative. Lines possibly representing boundaries between different magnetic rock units have in that way been extracted using the tilt derivative processed data, Figure 4-2.

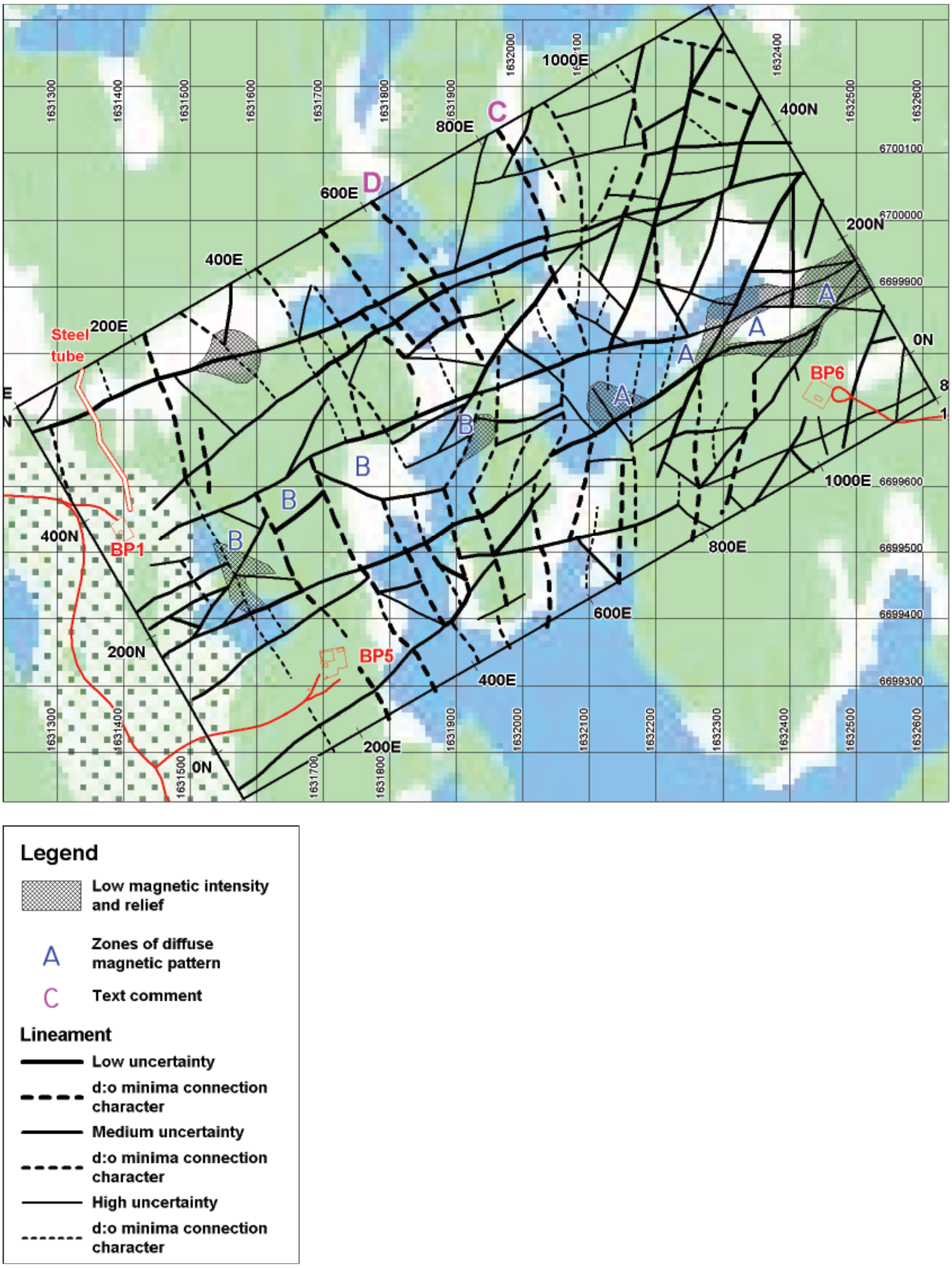


***Figure 4-1.*** *Ground magnetic lineaments identified in the area AFM100206. Line thickness is related to uncertainty. Thicker lines represent lineaments with lower uncertainty. Dashed lines have a "minima connection" character. Cross-hatched areas have a low magnetic intensity and relief. Text symbols for zones of diffuse magnetic pattern and other features are commented in the text.*

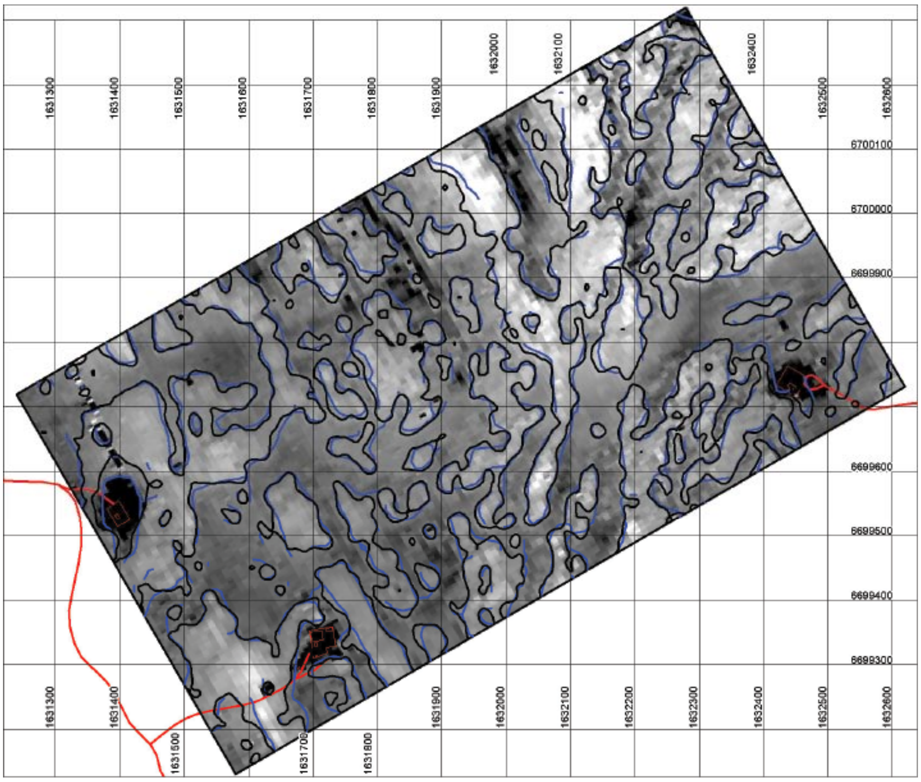


***Figure 4-2.*** *Magnetic anomaly field, greytone, in the area AFM100206. Overlay by the zero contour of the tilt derivative (black line) and the maxima of the total horizontal derivative of the tilt derivative (blue line). These lines possibly represent boundaries between rock types of different magnetic character.*

## 4.2 Lineament interpretation

The lineaments identified are graded in low, medium and high uncertainty mainly with respect to the clarity in which they appear but also, in some cases, involving a judgement regarding the specific geological situation and the possible cause of the lineament. Typically lineaments appear as linear magnetic minima, edges and dislocations in the magnetic field but in the Forsmark area other linear magnetic characters have also been outlined.

The structural geology in the Forsmark area is characterized by variably intense ductile deformation of both supracrustal and intrusive rocks. Also the intrusive rocks commonly show a strongly banded component in the magnetic pattern. It is difficult to decide whether lineaments appearing as minima parallel to the general bedrock structures are related to fracture zones or to rock types with low magnetization and in that sense could be characterized as magnetic connections. In this work, these linear features are identified as lineaments with a separate character called "minima connection".

The identified magnetic lineaments, low magnetic areas and areas with diffuse magnetic pattern are all presented in Figure 4-1. The interpretations are stored in GIS-format and each lineament has an attribute table attached (Table 4-1). The table is the same as that adapted for linked lineaments in /5/, which means that many attributes are not of direct interest in this presentation. In total, 286 magnetic lineament segments have been identified (Figure 4-1). Based on the attached attribute table (Table 4-1), some general statistical results are presented (Table 4-2). The lineament segments have not been linked and the presented figures represent each individual identified segment.

**Table 4-1. Attribute table for the magnetic lineaments. A more comprehensive description of the parameters is found in /3/ and /5/.**

| Field name | Name | Description | Attribute used to describe lineaments |
|---|---|---|---|
| Id_t | Identity | Identity of the coordinated lineament | Not assigned in this work |
| Origin_t | Origin | Major type of basic data | Magnetic ground survey |
| Class_t | Classification | Classification of the coordinated lineament | Not assigned in this work |
| Method_t | Method | The type of data in which the observation is identified | Magnetics (Magn) |
| Weight_n | Weight | A combination of uncertainty and number of properties (methods). An overall assessment of the confidence of the linked lineament. This assessment is based on both the number of properties upon which the lineament has been identified and the degree of uncertainty. | Not assigned in this work |
| Char_t | Character | Character of the observation | Minima, minima connection or edge |
| Uncert_t | Uncertainty | Gradation of identification, in terms of uncertainty. In effect, this attribute involves both the degree of clarity of the lineament as well as a judgement regarding the possible cause of the lineament | 1=low, 2=medium and 3=high. |
| Comment_t | Comment | Specific comments to the observation | |
| Process_t | Processing | Data processing performed | Grid, filter, image analysis, GIS |
| Date_t | Date | Point of time for interpretation | Date 2006-04-21 |
| Scale_t | Scale | Scale of interpretation | 5,000 |
| Width_t | Width | Width on average | Not assigned in this work |
| Precis_t | Precision | Spatial uncertainty of position. An estimate of how well the lineament is defined in space. | 10 m |
| Count_n | Count | The number of original segments along the lineament. | Always 1 in this work |
| Cond_n | Conductivity | Shows how much of the lineament that has been identified by EM and/or VLF. | Always 0 in this work |
| Magn_n | Magnetic | Shows how much of the lineament that has been identified by magnetics. | Always 1 in this work |
| Topo_n | Topography | Shows how much of the lineament that has been identified by topography, either in the ground surface or in the rock surface. | Always 0 in this work |
| Topog_n | Ground surface | Shows how much of the lineament that has been identified by topography in the ground surface. | Always 0 in this work |
| Topor_n | Rock surface | Shows how much of the lineament that has been identified by topography in the bedrock surface. | Always 0 in this work |
| Prop_n | Property | Shows in average, how many properties that has been identified the lineament. | Always 1 in this work |
| Length_n | Length | The length of the lineament | Not assigned in this work |
| Direct_n | Direction | The average trend of the lineament | Not assigned in this work |
| Platform_t | Platform | Measuring platform for the basic data | Ground survey grid, 5×10 m |
| Sign_t | Signature | Work performed by | GeoVista AB/hi (Hans Isaksson) |

**Table 4-2. Compilations of some attribute information for magnetic lineaments. Figures show number of occurrences.**

| Character | Low uncertainty | Medium uncertainty | High uncertainty | Total number |
|---|---|---|---|---|
| Minima/edge/dislocation | 38 | 87 | 56 | 181 |
| Minima connection | 40 | 37 | 28 | 105 |
| Total | 78 | 124 | 84 | 286 |

## 4.3 Discussion

### *Continuity of XFM0060A0 and XFM0061A0*

The extensions of linked lineaments, XFM0060A0 and XFM0061A0 are both supported by this survey, Figure 4-3. XFM0061A0 follows the new ground magnetic lineaments very well until the final segment in the NE part of the survey area, where a deviation occurs. In the previous interpretations this segment was considered as uncertain and other smaller lineaments have probably caused the change of direction in the interpretation. This difference can be more easily understood looking at the magnetic ground survey upward continued 40 metre, up to the helicopter borne survey level, Figure 4-4.

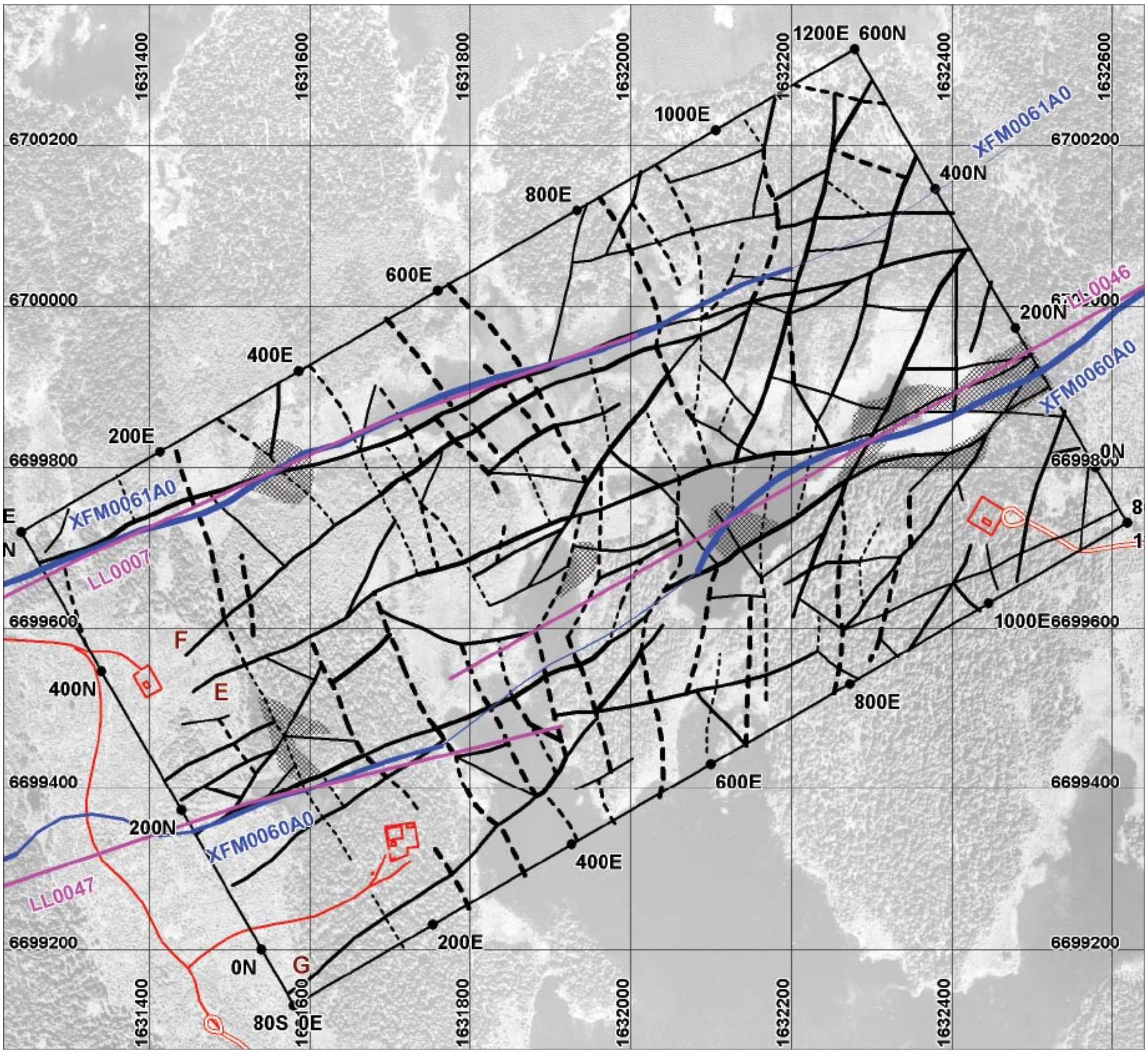


*Figure 4-3. Ground magnetic lineaments from Figure 4-1 overlaid by previous linked lineament XFM0060A0 and XFM0061A0 (blue lines). Thicker lines represent coordinated segments with higher weight (higher confidence) /3/ and /5/. Linked lineaments from GTK /4/ are represented as magenta lines with equal thickness. Roads and drill sites in red. Background – grey tone representation of infrared air photos. (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268).*

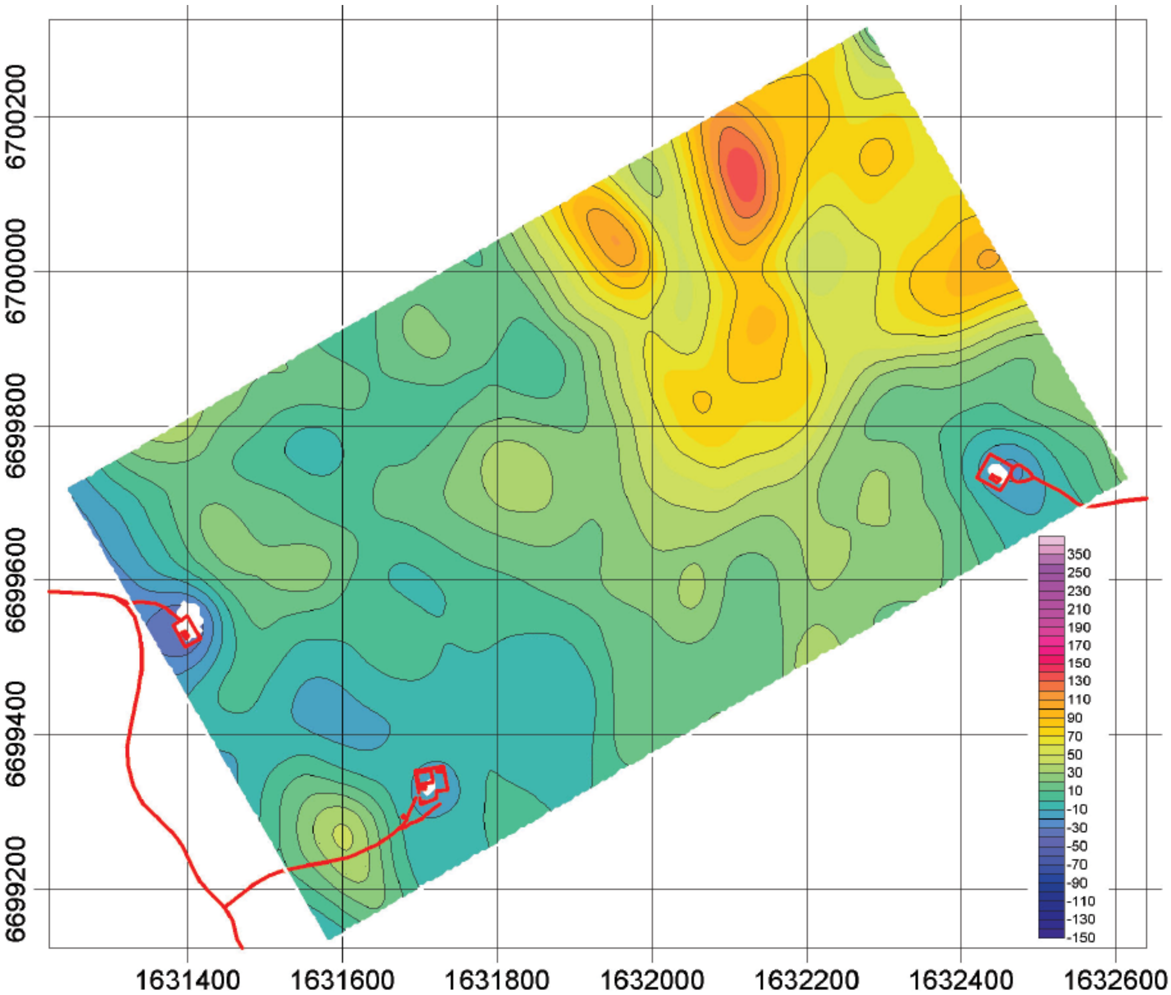


***Figure 4-4.*** *Magnetic anomaly field in the area AFM100206. Upward continuation to 40 metre above ground, which is similar to the helicopter, magnetic survey level. The same colour legend as in Figure 3-1.*

The new lineaments identified also shows a very good correlation with XFM0060A0 in the southwest part of the survey area. Further to the northeast XFM0060A0 extends along a broad low magnetic area and the finer details presented in this work could not be resolved from the airborne survey data in previous interpretations. In the centre of the survey area the new interpretation indicates a short segment that has a minima connection character. This indication should not be considered as a break of the lineament in a linking process, see further discussion below.

Three lineaments identified by the Geological survey of Finland, GTK, /4/ and mainly coinciding with XFM0060A0 and XFM0061A0 also follow the new lineament pattern rather well. However, the possible break of XFM0060A0 indicated by LL0047 and LL0046 does not find any support in the ground magnetic data.

#### *Longer lineament previously not identified*

It is clear that the high resolution, ground magnetic data provides the possibility to identify more and shorter lineaments than the airborne survey data. Of previously not identified lineaments, three longer lineaments in ENE direction are commented. Lineament E in Figure 4-3 can possibly be considered as a splay from XFM0060A0 and the area between the two lineaments show a higher degree of areas with diffuse or low magnetic intensity. It is possible that this diffuse magnetic pattern can indicate a deeper bedrock source and/or the presence of fractured and altered surface rock

Lineaments F and G can possibly be interpreted as more NE oriented, minor splays from XFM0061A0 and XFM0060A0 respectively.

#### *Lineament of magnetic minimum character*

It has been pointed out that narrow rock types of low magnetic intensity can be a likely explanation for linear features with a magnetic minima connection character, that is, lineaments concordant with the general bedrock structures and the banded magnetic pattern. However, it should be observed that a fracture zone can not be ruled out and this characterization has to be treated with caution.

In some cases the main magnetic trend is also difficult to determine. This is especially the case in the northeast part of the survey area, in which a north-north-west to north-westerly trend meets a west-north-west trend. The picture in this area might be clearer with an enlarged magnetic survey.

In some cases the magnetic minimum is related to a magnetic maximum and can be caused by the dip of a magnetic body. This is the case at C in Figure 4-1 in which the minimum at least to some extent can be explained by a northwest striking magnetic body, located immediately to the southwest and also dipping to the southwest, see also Figure 4-2. About 100 metre to the southwest, at D in Figure 4-1, a strong narrow magnetic minimum occur alone and has to be explained by a narrow, northwest striking; low magnetic rock type, a rock type with reversed magnetization, a fracture zone or a very narrow and deep bedrock surface depression.

## 4.4 Uncertainties

The lineaments are graded in low, medium and high uncertainty basically with respect to the clarity in which they appear. However, also some other specific uncertainties can be pointed out regarding magnetic lineaments and their character.

Differences in overburden thickness also give different conditions for lineament identification. Large areas with a thin overburden give a better spatial and dynamic resolution of the magnetic pattern and hence, lineaments are more easily identified.

Topographical subsurface features like narrow depressions in the bedrock surface can give rise to a locally deeper overburden and hence, also cause a linear magnetic low which not necessarily correspond to a change in bedrock susceptibility due to fracturing.

Horizontal to sub-horizontal structures are more difficult to identify in the magnetic field and when they occur they often appear as curved features.

The survey direction SSE-NNW makes it easier to identify structures with a WSW-ENE extension. However, by the small difference in line density compared to the station density, 10 metre and 5 metre respectively, this effect is rather small.

Some simplifications have been made in the correction of data for current in the Fenno-Skan HVDC cable. The resulting errors are however small enough not to have affected the interpretation.

# References


/1/ **Munier R, Stanfors R, Milnes A G, Hermansson J, Triumf C-A, 2003.** Geological site descriptive model. A strategy for the model development during site investigations. SKB R-03-07. Svensk Kärnbränslehantering AB.

/2/ **Isaksson, H, 2003.** Interpretation of topographic lineaments 2002. Forsmark site investigation. SKB P-03-40. Svensk Kärnbränslehantering AB.

/3/ **Isaksson H, Thunehed H, Keisu M, 2004.** Interpretation of airborne geophysics and integration with topography. Forsmark site investigation. SKB P-04-29. Svensk Kärnbränslehantering AB.

/4/ **Korhonen K, Paananen M, Paulamäki S, 2004.** Interpretation of lineaments from airborne geophysical and topographic data. An alternative model within version 1.2 of the Forsmark modelling project. SKB P-04-241. Svensk Kärnbränslehantering AB.

/5/ **Isaksson H, Keisu M, 2005.** Interpretation of airborne geophysics and integration with topography Stage 2 (2002–2004). An integration of bathymetry, topography, refraction seismics and airborne geophysics. Forsmark site investigation. SKB P-04-282. Svensk Kärnbränslehantering AB.

/6/ **Johansson R, 2005.** A comparison of two independent interpretations of lineaments from geophysical and topographic data at the Forsmark site. Forsmark site investigation. SKB P-05-23. Svensk Kärnbränslehantering AB.

/7/ **Johansson R, Isaksson H, 2005.** Assessment of inferred lineaments in the north-western part of the Forsmark site investigation area. Present knowledge and recom mendations for further investigations. Forsmark site investigation. SKB P-05-261. Svensk Kärnbränslehantering AB.

/8/ **SKB, 2004.** Preliminary site description. Forsmark area – version 1.1. SKB R-04-15. Svensk Kärnbränslehantering AB.

/9/ **SKB, 2005.** Preliminary site description. Forsmark area – version 1.2. SKB R-05-18. Svensk Kärnbränslehantering AB.

/10/ http://www.ngdc.noaa.gov/seg/geomag/jsp/struts/calcPointIGRF

/11/ **Verduzco B, Fairhead J D, Green C M, MacKenzie C, 2004.** New insights into magnetic derivatives for structural mapping. The Leading Edge, February 2004, Vol. 23, No. 2, pp 116-119. ISSN 1070-485X.