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Forsmark site investigation

Detailed ground and marine magnetic survey and lineament interpretation in the Forsmark area – 2006

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GeoVista AB

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Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Abstract

The report presents the execution and the results from detailed, ground and marine magnetic measurements carried out on a 7.24 km² area in the Forsmark site investigation area. The main objective of this activity is to determine a detailed ground magnetic representation of the bedrock. The results from a previous survey were encouraging and have led to a broader geophysical programme for further investigation of lineaments at Forsmark. This report comprises the results from the first phase of an extended magnetic survey programme.

On the ground a grid with parallel lines was staked and marked on preferably every 20 metres. Measurements of the magnetic total field were carried out along profiles, perpendicular to the staked lines, with a profile spacing of 10 metres and a station distance of 5 metres. The marine survey was carried out using a magnetometer and a high accuracy RTK-GPS unit for navigation. The magnetometry reading was taken every 2 second and the RTK-GPS reading every second giving a survey grid with on average 10 metres line spacing and 2–3 metres station spacing.

The magnetic pattern in the survey area can be divided into three main areas with different magnetic character. Along the southwest margin of the survey area the magnetic pattern is characterized by a gentle, banded magnetic pattern of, in general, low to moderate magnetic intensity. The northeast part, at the SFR office and further to the southeast along the coastline, the pattern is intensely banded with rapidly changing low and highly magnetic bands. These two main structures probably forms fold limbs of a common fold with a northwest oriented fold axis. The fold is U-shaped and opens to the southeast. Within the fold the magnetic pattern is more varied with gently banded to more irregular patterns and from low to high magnetic intensity. The fold pattern is most prominent in the Asphällsfjärden area, but is also repeated recurrently from northwest to the southeast. The third main area between Bolundsfjärden and the road to drill site BP6 forms the core of the fold structure with a more dominant irregular magnetic pattern.

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. Areas with a diffuse magnetic pattern might indicate larger depth to the magnetic source or occurrences of fractured and/or altered bedrock surface.

In this work and a total of 1,140 magnetic lineaments have been identified of which 481 are characterized as “minima connections”, 255 and 405 magnetic lineaments have a low and high uncertainty, respectively. 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 magnetic lineaments have been coordinated and linked giving a total of 553 linked magnetic lineaments of which 252 are characterized as “minima connections”. Two linked lineaments are classified as regional and 25 as local major lineaments.

It is clear that the high resolution, ground magnetic data provides the possibility to identify more and shorter lineaments than the airborne survey data. The detailed magnetic, ground and marine survey data give a much better understanding of the local-scale distribution of magnetic lineaments. The data also give detailed information on the extension and fragmentation of large scale magnetic lineaments.

In the south, southwest and southeast part of the ground survey area the lineament pattern is clear with mainly east-northeast, discordant lineaments and northwest trending, mostly minima connections. Further to the north and northeast, around Asphällsfjärden, the east-northeast lineaments more or less disappear and are replaced by a set of lineaments with mainly north-northeast direction. The latter pattern has previously been poorly known and these features can be considered as a new discovery, tracked down initially by this detailed ground magnetic survey.

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. Besides scrutinizing the lineaments as possible fracture zones the comprehensive attributes table also provide a basis for further statistical analysis.

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 7.24 km^2 stort mätområde inom kandidatområdet för platsundersökningen i Forsmark. Målsättningen med insatsen är att erhålla en detaljerad bild av berggrundens magnetfält som underlag för att bestämma utbredning och kontinuitet av lineament i området. Resultaten från en tidigare detaljmätning gav goda resultat och utmynnade i ett utvidgat program av magnetiska detaljmätningar, såväl på marken som på havet, fjärdar och sjöar.

På marken har linjer stakats ut och markerats företrädesvis var 20:e meter. Vinkelrätt mot dessa linjer utfördes magnetiska mätningar med 10 meters linjeavstånd och med 5 meters punktavstånd. Sjömätningar har utförts från båt med RTK-GPS med hög precision för navigering. Magnetmätning varannan sekund och GPS-position varje sekund har resulterat i en datatäthet med i medeltal 10 meters linjeavstånd och 2–3 meters punktavstånd.

Det magnetiska mönstret i området kan delas in i tre huvudområden. Det sydvästra området karaktäriseras av ett mjukt, bandat magnetiskt mönster och låg till måttlig magnetisk intensitet. I den nordöstra delen, vid SFR och längs kusten mot sydost, är mönstret intensivt bandat med snabbt växlande låg till högmagnetiska band. Dessa två huvudstrukturer är troligen veckben av ett gemensamt veck med en nordväst orienterad veckaxel. Veckstrukturen är U-formad och öppen mot sydost. Inom strukturen är det magnetiska mönstret mer varierat med bandat till irreguljärt mönster samt med låg till hög magnetisk intensitet. Veckmönstret är tydligast vid Asphällsfjärden men återkommer vidare mot sydost. Det tredje huvudområdet mellan Bolundsfjärden och borrplats BP6 utgör kärnan av veckstrukturen med ett mer dominerande irreguljärt mönster.

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. 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.

Magnetiska lineament har identifierats och dessa har liksom i tidigare arbeten dokumenterats i attributtabeller. Lineamenten karaktäriseras av diskordanta magnetiska minima, kanter och dislokationer, samt magnetiska minima parallella med den magnetiska bandningen. Lineamenten uppdelas vidare i låg, måttlig och hög osäkerhet. Totalt har 1 140 lineament identifierats av vilka 481 utgörs av magnetiska minima parallella med bandningen. 255 respektive 405 lineament har en låg respektive hög osäkerhet.

De magnetiska lineamenten har koordinerats och byggts samman till totalt 553 länkade lineament av vilka 252 har en karaktär av magnetiska minima parallella med bandningen. Två lineament har klassificerats som regionala (längd > 10 km) och 25 lineament som lokala betydande lineament (längd 1–10 km).

Den högupplösande magnetiska mätningen möjliggör också identifiering av fler och kortare lineament än i tidigare arbeten och ger därmed en bättre förståelse av den geografiska lineamentsfördelningen samt utbredning och uppdelning av större lineament.

I södra och sydöstra delen av området är lineamentsmönstret tydligt med huvudsakligen ostnordostliga diskordanta lineament och nordvästliga minima konnektioner. I norr och nordost, kring Asphällsfjärden, saknas i stort sett de ostnordostliga lineamenten vilka ersätts av ett set med lineament i nordnordostlig riktning. Det senare mönstret har tidigare inte noterats i den omfattningen och kan ses som en ny observation som för första gången kommit fram i den detaljerade markmagnetiska mätningen.

Rapporten innehåller flera exempel på magnetiska data och bearbetningar som utgjort underlag för tolkningsarbetet. Lineamenten levereras i GIS-format som vektorer med en attributtabell. Tabellen kan användas som underlag för att bedömma huruvida lineamenten kan representera en möjlig sprickzon samt vidare som en bas för statistiska analyser.

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 detailed, ground geophysical measurements of the magnetic total field in an area of 7.24 km² at Forsmark, which is one of the activities performed within the site investigation at Forsmark. This work was carried out in accordance with the activity plan AP PF 400-06-034. 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.

In a previous study, "Ground magnetic survey and lineament interpretation in an area northwest of Bolundsfjärden", AFM100206 /10/, the purpose was to assess the continuity of the linked lineaments XFM0060A0 and XFM0061A0, which have formed, in part, a basis for the definition of the deformation zones ZFMNE0060 and ZFMNE0061, respectively /8, 9/. The results were encouraging and have led to a broader geophysical programme for further investigation of lineaments at Forsmark. This report comprises the results from the first phase of an extended magnetic survey programme; see also Figure 1-1. The extended programme comprises four areas:

AFM001292

- By boat on the sea at Asphällsfjärden and the inlet channel.
- On land, southwest of Asphällsfjärden and northwest of the previous survey AFM100206. The measurements were carried out up to the housing area at Forsmark.
- On land, southeast of Asphällsfjärden and northeast of the previous survey.
- On a narrow land area, northwest of Asphällsfjärden and up to the SFR and the Forsmark harbour road.

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

Activity plan	Number	Version
Mark- och sjöbaserad magnetometri i Asphällsfjärden och områden NV och NÖ om Bolundsfjärden.	AP PF 400-06-034	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

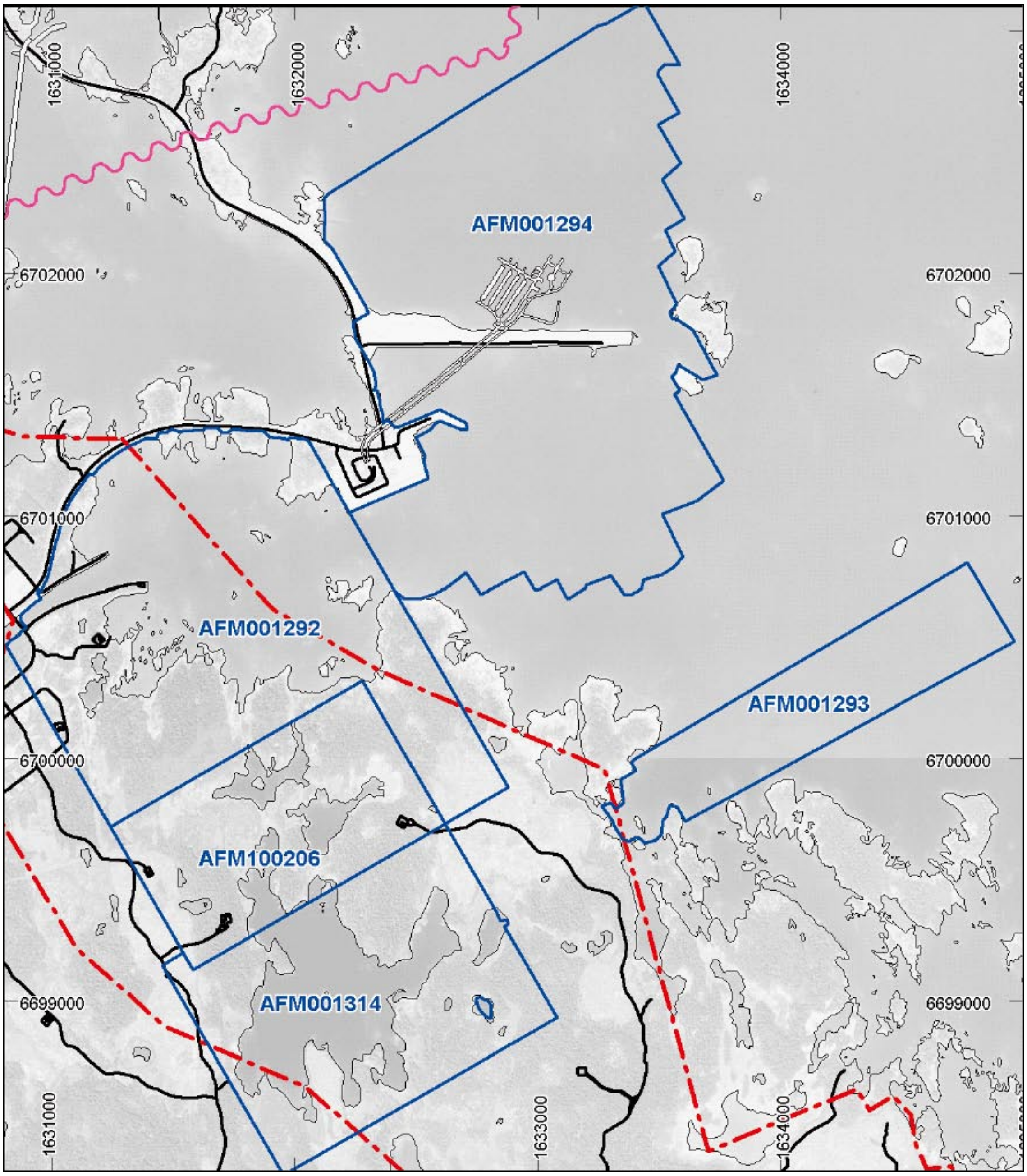

Figure 1-1. Location and extension of magnetic survey areas AFM001292, AFM001293, AFM001294 and AFM001314. Data and interpretation of area AFM100206 was presented in a previous report /10/. The Fenno-Skan HVDC cable between Sweden and Finland is shown as a magenta wave-line in the northern part of the area. The SFR underground facilities and the cooling water tunnel from Forsmark 1 and 2 are shown as white infill lines. The Forsmark candidate area is shown as a thick, dot-dashed, red line. Roads and drill sites in black. (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268.)

AFM001293

- By boat on the sea, about 2 km southeast of the SFR office and over the suggested deformation zone ZFMNE0062.

AFM001314

- By boat and on land on Bolundsfjärden and its surroundings, southwest of the previous survey area (AFM100206).

AFM001294

- By boat on the sea, south, east and north of the SFR Forsmark harbour area and above the SFR underground facilities. A small, narrow area on a pier above SFR has also been measured on the ground.

The new survey areas cover an area of 6.42 km^2 and in total 7.24 km^2 is now covered by detailed ground magnetic data. This report includes field results from all four areas. However, interpretation is only carried out on three of the four areas. Interpretation on area AFM001292, around SFR, will be carried out in a later stage.

The staking of a survey grid as well as the ground and marine magnetic measurements were carried out by GeoVista AB in three phases during the periods May 22–June 21, June 28–July 21 and August 7–October 4, 2006. 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 400-06-034.

2 Equipment

2.1 Description of survey equipment and interpretation tools

To establish the grid, a real-time kinematic, RTK-GPS Trimble R8 GNSS Rover system with a built in GPRS (General Packet Radio Service) was used. The SWEPOS national network of permanent reference stations was used as base stations. Every morning, before using the RTK-GPS, a fixed point was visited to secure the quality of the survey. The coordinate 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 RTK-GPS was also used for navigation during the seaborne magnetic measurement.

The measurement of the magnetic field was carried out with two – four 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.

For the marine survey a wooden non-magnetic frame was constructed and attached to the front end of a boat. A RTK-GPS and a GPS-antenna for the built-in magnetometer GPS was mounted closely on the frame and around 1.2 metres straight above the magnetometer sensor. For the navigation a handheld survey controller/field computer was used to communicate with the RTK-GPS using Bluetooth® technology.

A series of tests were conducted to try to locate any source of magnetic noise or error before the survey commenced. Both a small boat with small engine and a medium sized boat with a larger engine were used during the three phases of the survey. The use of the medium sized boat was necessary due to security and the higher waves out on the open sea. The medium sized boat had a built-in mooring ring at the stem that was magnetic and hence produced a heading error. The small boat did not produce any significant amount of noise during the measurements at Asphällsfjärden or Bolundsfjärden but on the sea there were some heading errors.

The magnetic data was affected by the D.C. current in the Fenno-Skan HVDC cable that runs to the north of the survey area. The correction of this effect is described in section 3.4.1.

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

Trimble Geomatics Office v.1.63
Surfer 8 (Golden software)
Oasis Montaj 5.0 (Geosoft Inc)
Geomatica 10 (PCI Inc)
MapInfo Professional 8 (Mapinfo Corp.)
Discover 8 (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 frame and testing for the marine measurement,
- 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 was carried out during three periods, May 22–June 21, June 28–July 21 and August 7–October 4, 2006, using a RTK-GPS, a compass and measuring-tape. The RTK-GPS was used to locate and mark as many stations as possible along several parallel lines sited perpendicular to the survey direction and also along lake and sea shorelines and around bogs. Normally, the distance between these lines was 100 metres, but due to the large amount of bogs some of the lines had to be moved. With the help of the RTK stations, all of these lines were staked with a marker positioned every 20 metres.

The origin of the local grid system 0/0 is 1631540 E, 6699200 N in the Swedish grid RT90 and the azimuth of the grid is 330°. The coverage of the different survey areas as well as the number of magnetic survey stations are listed in Table 2-1, see also Figure 1-1.

3.3 Measurements of the magnetic total field

The first phase of the magnetic survey was carried out on Asphällsfjärden during May 22–June 21 with two Gem Systems GSM-19 magnetometers. During June 28–July 21, the second phase of the survey, four Gem Systems GSM-19 magnetometers were used. The third phase, during August 7–October 4, was also carried out with four magnetometers. One of the magnetometers was used as a diurnal base station. At the base station, one reading was registered every 10 seconds and those data were used to make a diurnal correction of the data collected with the mobile magnetometers.

Table 2-1. Survey areas; coverage and survey stations.

AFM	Area [km²]	Survey stations
100206	0.816	16,966
001292	1.935	104,930
001293	0.605	36,863
001294	2.681	127,017
001314	1.201	79,878
Total	7.238	365,654

The base station was located close to the survey area to minimize errors due to diurnal variation as well as the influence from the HVDC cable, which runs adjacent to the northern part of area AFM001294 and at most, c 4 kilometres to the north of survey area AFM001314. The position of the base station was not the same as for AFM100206 /10/. Diurnal readings were taken at both locations for a few hours on May 25th, when the current in the HVDC cable was close to zero, to establish the base level difference between the two stations. The new base station was found to have a base level that is 22 nT (nanoTesla) lower than the previous station. The base level difference between the base magnetometer used in /10/ and the Fiby observatory has previously been estimated to 311 nT, in the absence of current in the Fenno-Skan cable. As a final step in the processing described below, all data were referenced to the base station of /10/ to enable the creation of data mosaics.

The diurnal base station characteristics for the previous survey AFM100206 are given in /10/ and for the new base station the characteristics are as follows:

Coordinates, local grid	78W / 811N
Coordinates, Swedish Grid RT90	1631072.1E / 6699866.3N
Median total intensity (without HVDC correction)	51,310 nT
Median total intensity (HVDC correction applied)	51,385 nT
Minimum total intensity	51,361 nT
Maximum total intensity	51,486 nT
1st quartile of total intensity	51,378 nT
3rd quartile of total intensity	51,392 nT
Standard deviation of total intensity	13.5 nT
Calculated total intensity (2006-07-01 according to /11/)	51,330 nT
Calculated inclination /11/	73.2°
Calculated declination /11/	4.5°

One of the roving magnetometers, with a built-in GPS-unit, was time synchronized to "Coordinated Universal Time" (UTC) every morning. Subsequently, the other magnetometers in use were synchronized to the UTC-synchronized instrument.

In the ground 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, which means that the survey direction was 330° or 150°. On all stations the surveyor turned so that the magnetometer sensor was oriented in the same direction. The maximum deviation from the nominal survey lines is estimated to be no more than 2 to 3 metres and the deviation from nominal station positions is estimated to be no more than one metre along the line.

The marine survey was carried out using a magnetometer with a built-in GPS-unit, set to "walking" mode, Figure 3-1. The built-in GPS was mainly used to get synchronization to UTC and to produce preliminary magnetic maps in the field. The final positions for the survey points were taken from the RTK-GPS, except in a few cases when the RTK signal was lost. UTC was used to link magnetometer and RTK-GPS data to each other.

Magnetometry readings were taken every 2 seconds and RTK-GPS readings every second. The RTK-GPS was also used to navigate along the survey lines. An example demonstrating how the field crew managed to keep the instrument along nominal lines can be seen in Figure 3-2. In general, the deviation from the nominal survey lines during boat measurements is within 3 to 4 metres. The accuracy of the final magnetometer positions is estimated to be better than ± 1 metre, except for the few point where the RTK signal was lost during surveying where the position accuracy is estimated to be within ± 5 metres.

__Figure 3-1.__ Magnetic marine survey on Asphällsfjärden using a small boat. The magnetic sensor is placed on a wooden frame in front of the boat. The RTK-GPS-antenna is mounted approximately one metre above the magnetometer. Photo: Alf Sevastik.

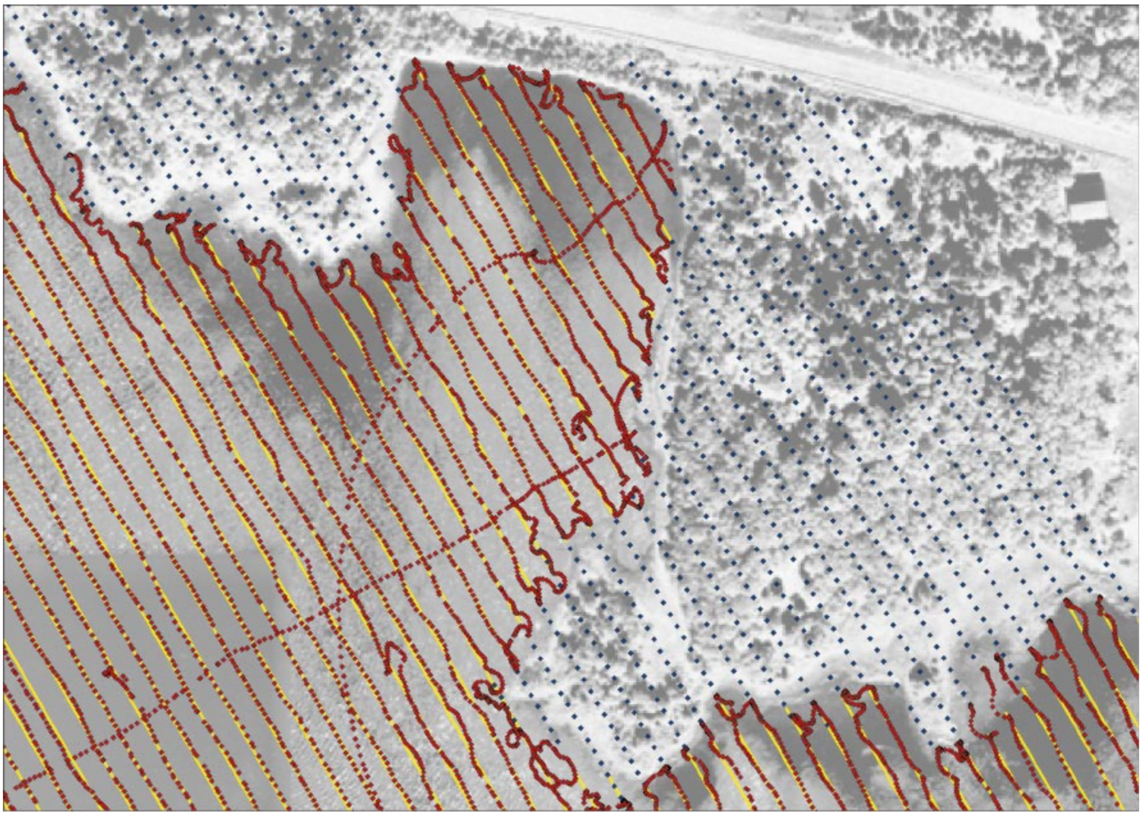

__Figure 3-2.__ Survey station distribution on land (blue dots) and on water (red dots), in an area immediately west of the SFR office. The yellow lines show the nominal line location on water. The survey line running perpendicular is a tie-line. Line spacing is 10 m, station spacing on land 5 m. (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268.)

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. It is estimated that the errors in diurnal corrections due to the use of base magnetometer data from a distant location are within ± 10 nT during these survey periods, and for the large majority of data, the errors are much smaller than that.

The current in the Fenno-Skan HVDC (or high-voltage, direct current) cable produces a magnetic field that decreases the total magnetic field at the base magnetometer stations at Forsmark (Figure 3-3). The current in the cable is often fairly stable but might change rapidly when the power transmission changes. This can create changes in the total magnetic field in the survey area of up to several hundred nT. Figure 3-3 shows magnetometer data for the two base magnetometers at Forsmark and the magnetic observatory data from Fiby. The curves in the figure are almost parallel, except for sudden level changes in the Forsmark stations due to changes in current in the HVDC cable. The new base magnetometer station is closer to the HVDC cable and is therefore more affected. The gentle diurnal variations seen in Figure 3-3 are more or less identical at the three stations.

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 vector and electromagnetic effects were also neglected, i.e. assuming a linear relationship between the change in magnetic field at a survey point and the current magnitude in the cable. The current variations in the cable were thereafter estimated with the help of the difference between Fiby and Forsmark base magnetometer readings. The corresponding magnetic field due to the cable was subtracted from the readings at the survey stations, using UTC to link data. The magnetic total field anomaly was thereafter found by subtracting the base magnetometer readings corrected for the effect of the cable. The final product, used to produce the maps below, is thus the

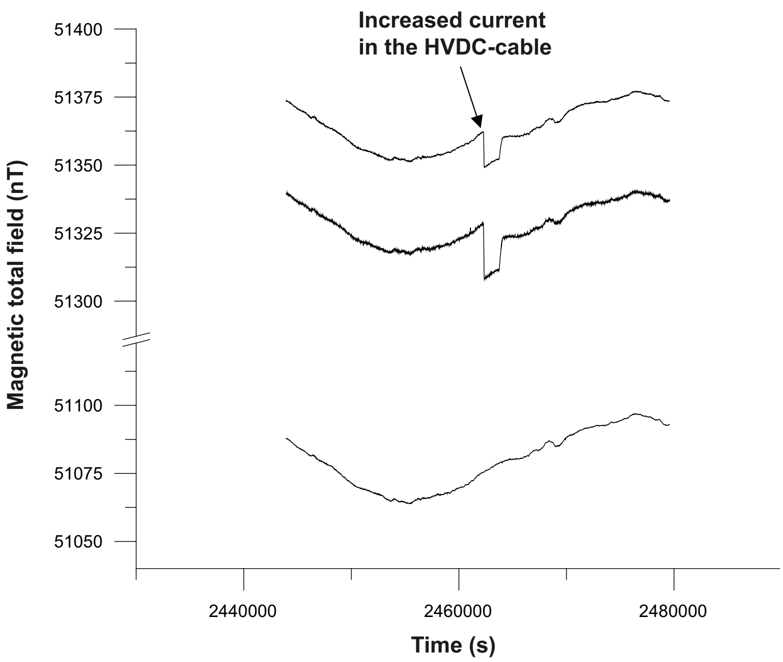

Figure 3-3. *Base magnetometer readings from May 29th, 2006. Base station from /10/ (top), new base station (centre) and Fiby observatory (bottom). The time scale is counted from mid-night UTC, May 1st.*

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 the simplifications above are valid. The final magnetic anomaly values were referred to the base magnetometer position of /10/. The cable-corrected base value was added to the anomaly values in the data stored in SICADA.

Figure 3-4 illustrates the different steps in the processing for AFM100206 /10/ and AFM001292. The top left map shows the total magnetic field due 100 A of current in the HVDC-cable. The top right map shows the total magnetic field from the cable during measurements, as estimated with the help of base magnetometer data. Some areas have fields close to zero since measurements were made in the absence of any current in the cable. However, some areas are affected by an applied field of around 200 nT which is of the same order of magnitudes as the dominating bedrock magnetic anomalies. The base magnetometer readings are subtracted from the survey data. This means that a part of the cable effect is corrected for, since also the base magnetometer is affected by the applied field from the cable. The bottom left map in Figure 3-4 shows the part of the magnetic field from the cable not compensated for by the base magnetometer. Note that different base magnetometer positions were used for these two areas. The south-eastern corner of AFM001292 has been over-compensated by the base magnetometer since that area is located further away from the HVDC-cable than the base magnetometer. The lower right map in Figure 3-4 shows the cable-corrected data. No edges or level variations can be seen in the map that can be related HVDC-cable effects. The maximum magnitude of the cable corrections are around 25% of the dynamic range of the map showing the final result in Figure 3-4.

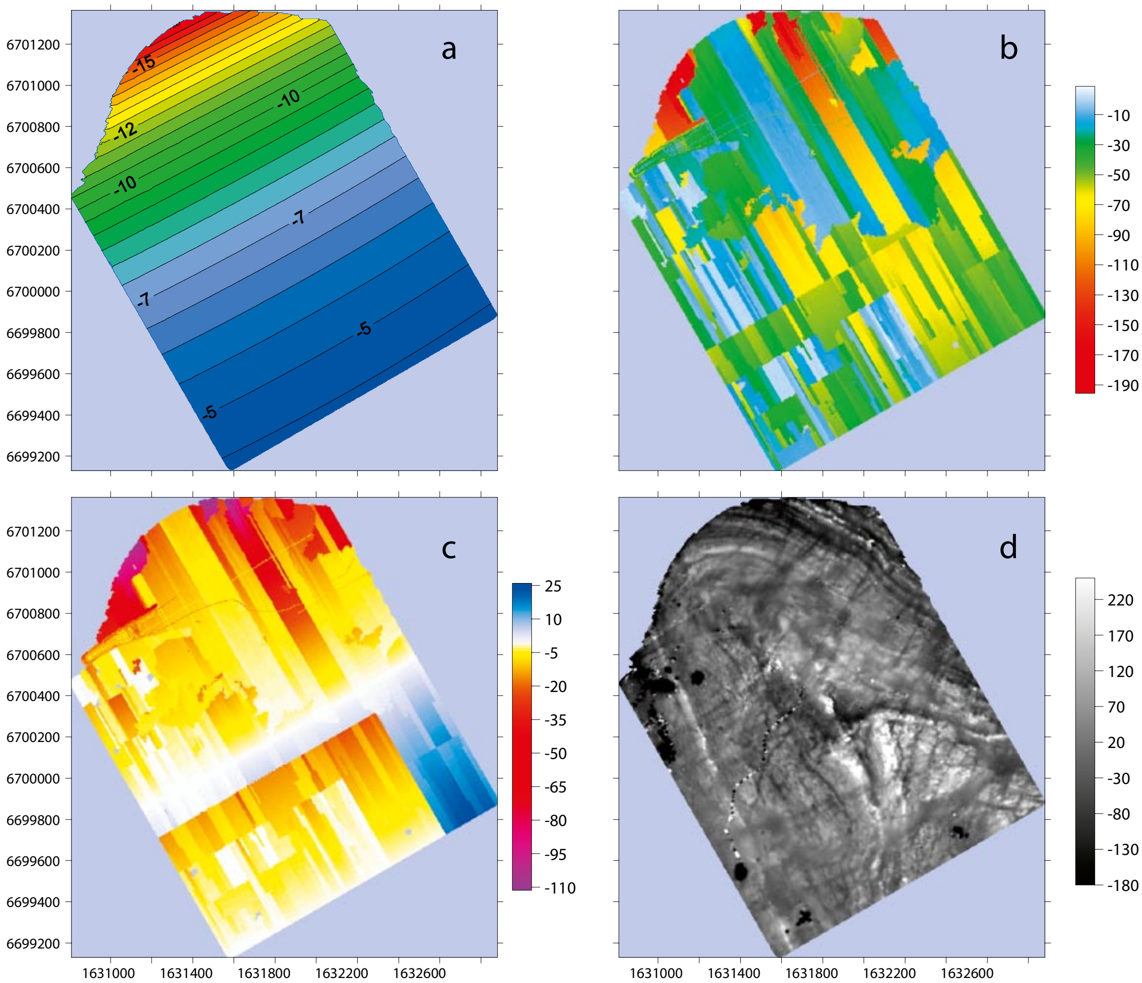

Figure 3-4. *Processing steps in the correction for HVDC cable effects, areas AFM100206 and AFM001292. All units in nT. a) Magnetic field due to 100 A current in the cable. b) estimated magnetic field during survey due to current in the cable. c) magnetic field due to the cable not compensated for by base magnetometer. d) estimated total field anomaly in the absence of any current in the cable.*

3.4.2 Removal of data collected with poor signal strength

The GSM-19 magnetometers report the signal strength of the measurements in the output file data. Poor signal strength was reported for some stations during boat measurements. Such stations typically occurred close to the shore line when the boat was turned for a new line. Fairly magnetic rock is present underneath the southern part of Asphällsfjärden It is suspected that the signal-strength problem was due to vertical wave-motion and horizontal heading motion in the presence of a magnetic gradient during measurement. Points with poor signal strength and obviously bad data were removed from the data set. However, the resulting data coverage was not severely affected anywhere by this.

3.4.3 Corrections for heading errors

It was not practically possible to perform the boat measurements from a completely non-magnetic vessel. Also, for safety reasons most of the measurements on the open sea were performed with a larger boat. The magnetic disturbance was reduced by placing the sensor on a wood construction in front of the boat, Figure 3-1. However two disturbances were noted. The data acquired from August 8th to 15th were found to have a level error of –15 nT, most likely caused by the RTK-GPS-antenna used during this period. All data from that period were therefore corrected for the level error. The data from AFM001293 and AFM001294 had levelling errors related to the heading direction of the boat. Alternating lines had slightly different base levels, resulting in a stripy appearance of magnetic maps. The magnitude of the heading error was determined by trial and error and was found to be approximately ± 1.7 nT for the small boat and ± 2.9 nT for the larger boat. The error was assumed to have a maximum and minimum for 0° and 180° heading respectively. The boat heading was calculated from the RTK-GPS-positions and a correction for the error was applied to the data. Correction for any possible yaw rotation of the boat due to side-wind has not been carried out.

3.4.4 Interpolation and filtering

The magnetic data has been surveyed in two ways, in a regular 5×10 m local grid on land and less regular by boat, see section 3.3 and Figure 3-2, and the magnetic total field anomaly from all survey stations was interpolated to a regular grid with a node spacing of 4×4 metres in the Swedish grid RT90 using linear Kriging (Surfer 8). The magnetic anomaly field is presented in colour, Figure 3-5 and grey tone, Figure 3-6.

Standard type of filtering and transformation (Oasis - ™ Geosoft Inc) has been executed on the dataset in accordance with previous processing of magnetic data, carried out in /3, 5, 7, 10/. A rather new processing method, "tilt derivative", especially useful for structural enhancements and segmentation of magnetic data has also been applied in this work /5, 10, 12/. Examples of the processed magnetic data, separately or in combinations are presented in Figure 3-7 to 3-10 and also in Figure 4-5. The following processing has been carried out:

- 1:st vertical derivative,
- 2:nd vertical derivative,
- horizontal derivatives in east and west direction,
- total horizontal derivative,
- tilt derivative (zero crossing is close to edges of model structures, i.e. magnetic body edges),
- total horizontal derivative of the tilt derivative (depicts magnetic body edges by marked maxima).

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

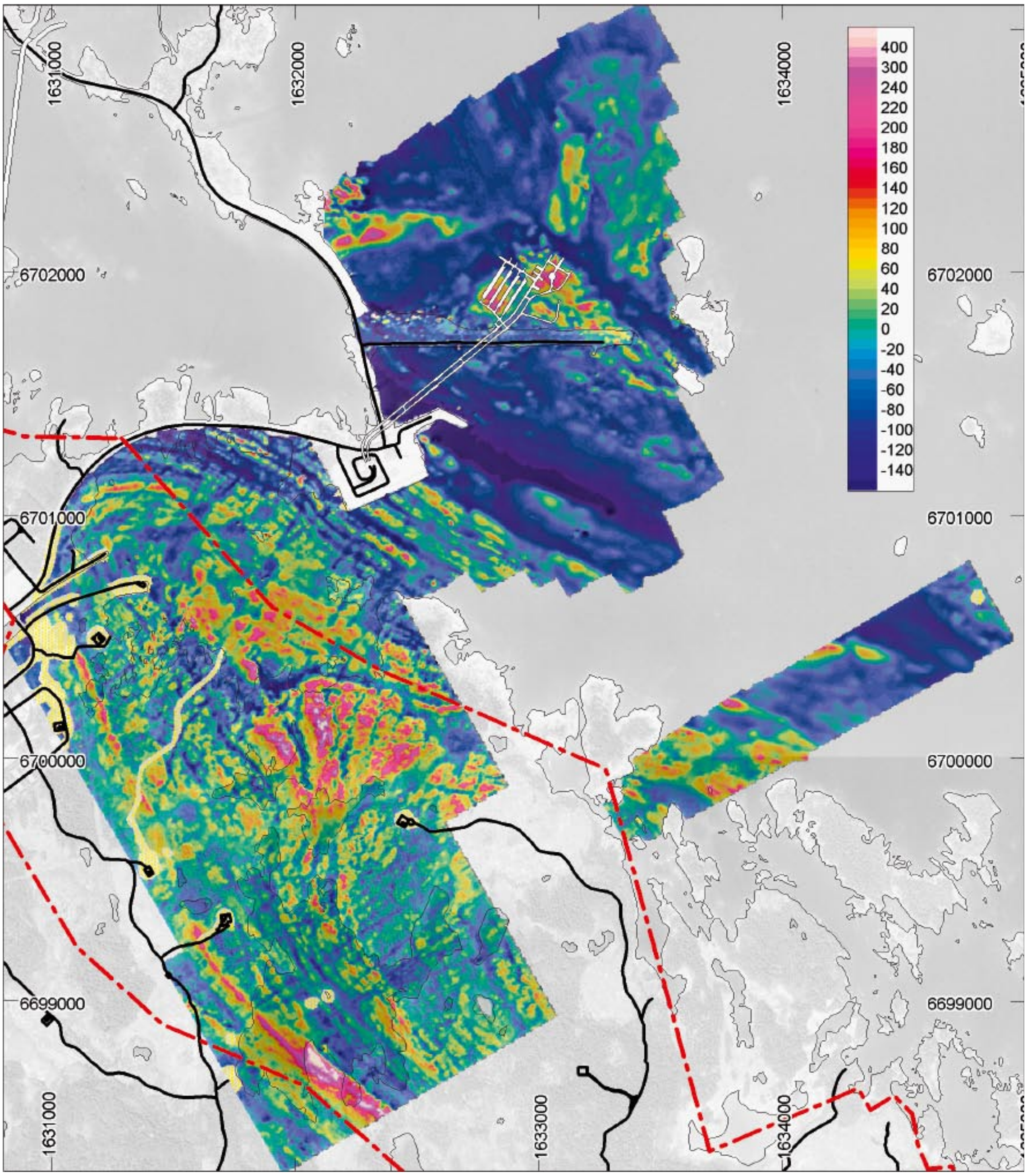

Figure 3-5. Magnetic anomaly field, colour range in nanoTesla [nT]. Disturbed areas in light yellow. The SFR underground facilities and the cooling water tunnel from Forsmark 1 and 2 are shown as black/white infill lines. The Forsmark candidate area is shown as a thick, dot-dashed, red line. Roads and drill sites in black. (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268.)

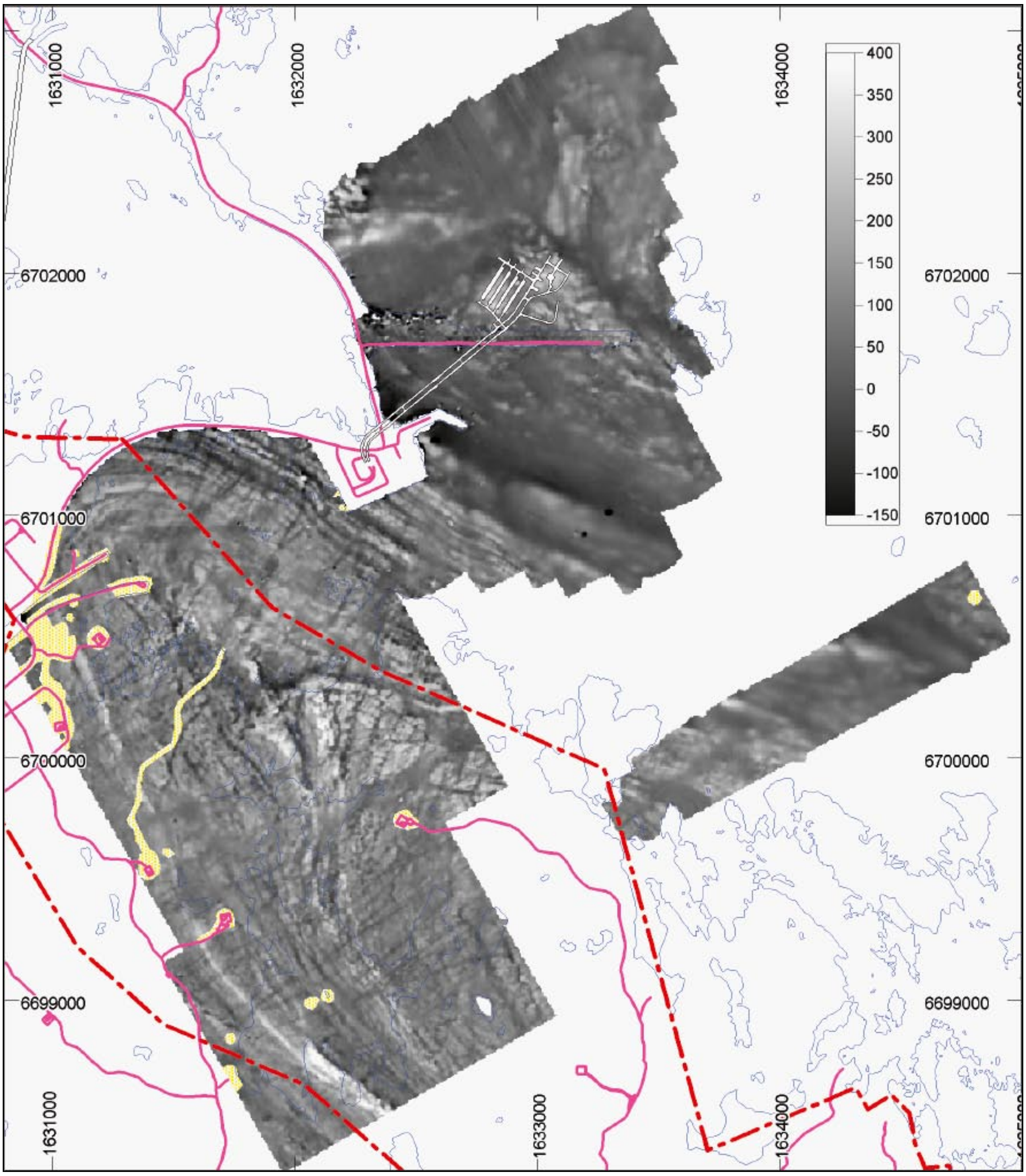

Figure 3-6. *Magnetic anomaly field, grey tone scale in nT. Disturbed areas in light yellow. The SFR underground facilities and the cooling water tunnel from Forsmark 1 and 2 are shown as black/white infill lines. The Forsmark candidate area is shown as a thick, dot-dashed, red line. Roads and drill sites in magenta. (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268.)*

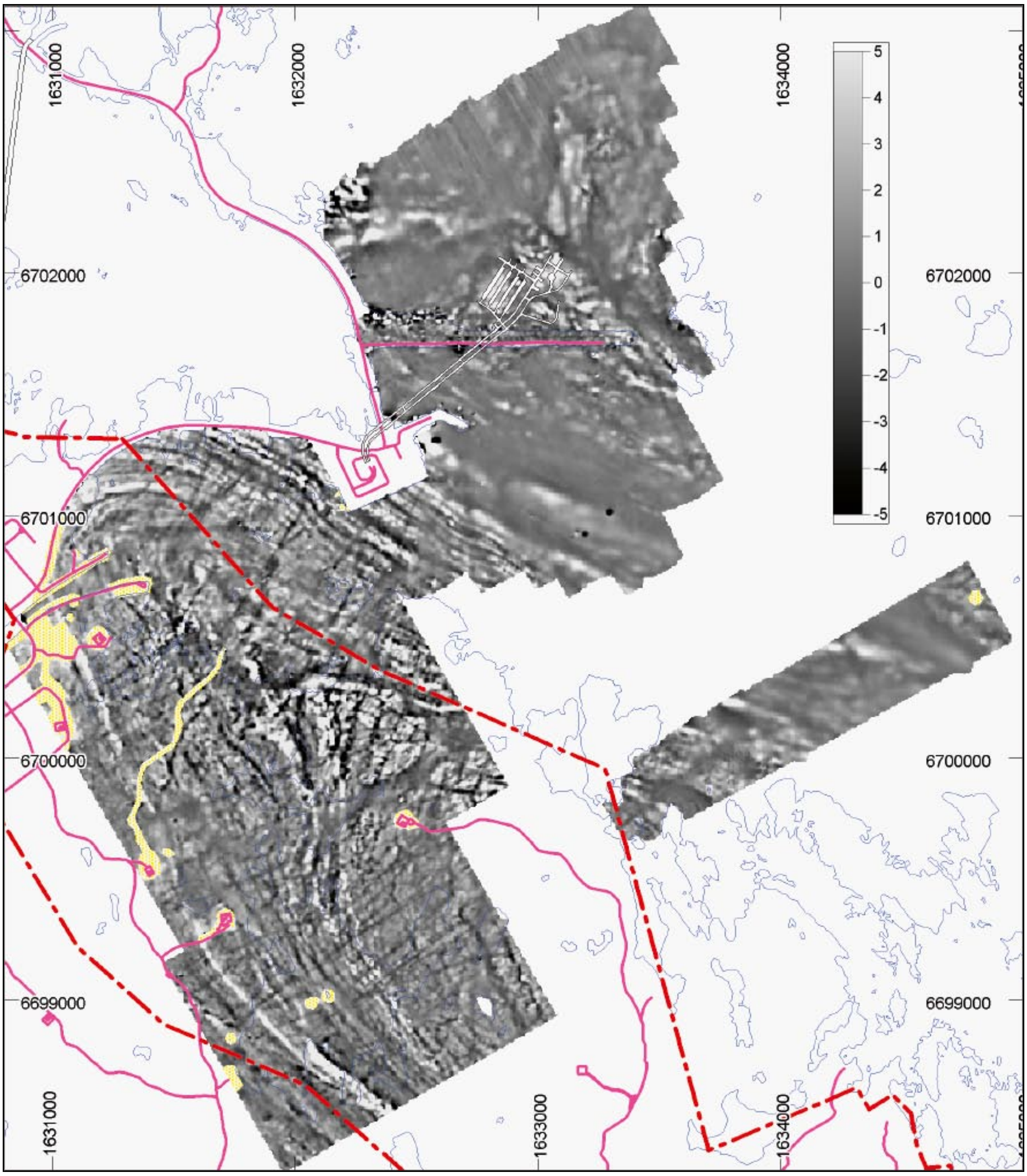

Figure 3-7. Magnetic anomaly field, reduced to the pole, 1.st vertical derivative, greytone scale in nT/m. Disturbed areas in light yellow. The SFR underground facilities and the cooling water tunnel from Forsmark 1 and 2 are shown as black/white infill lines. The Forsmark candidate area is shown as a thick, dot-dashed, red line. Roads and drill sites in magenta. (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268.)

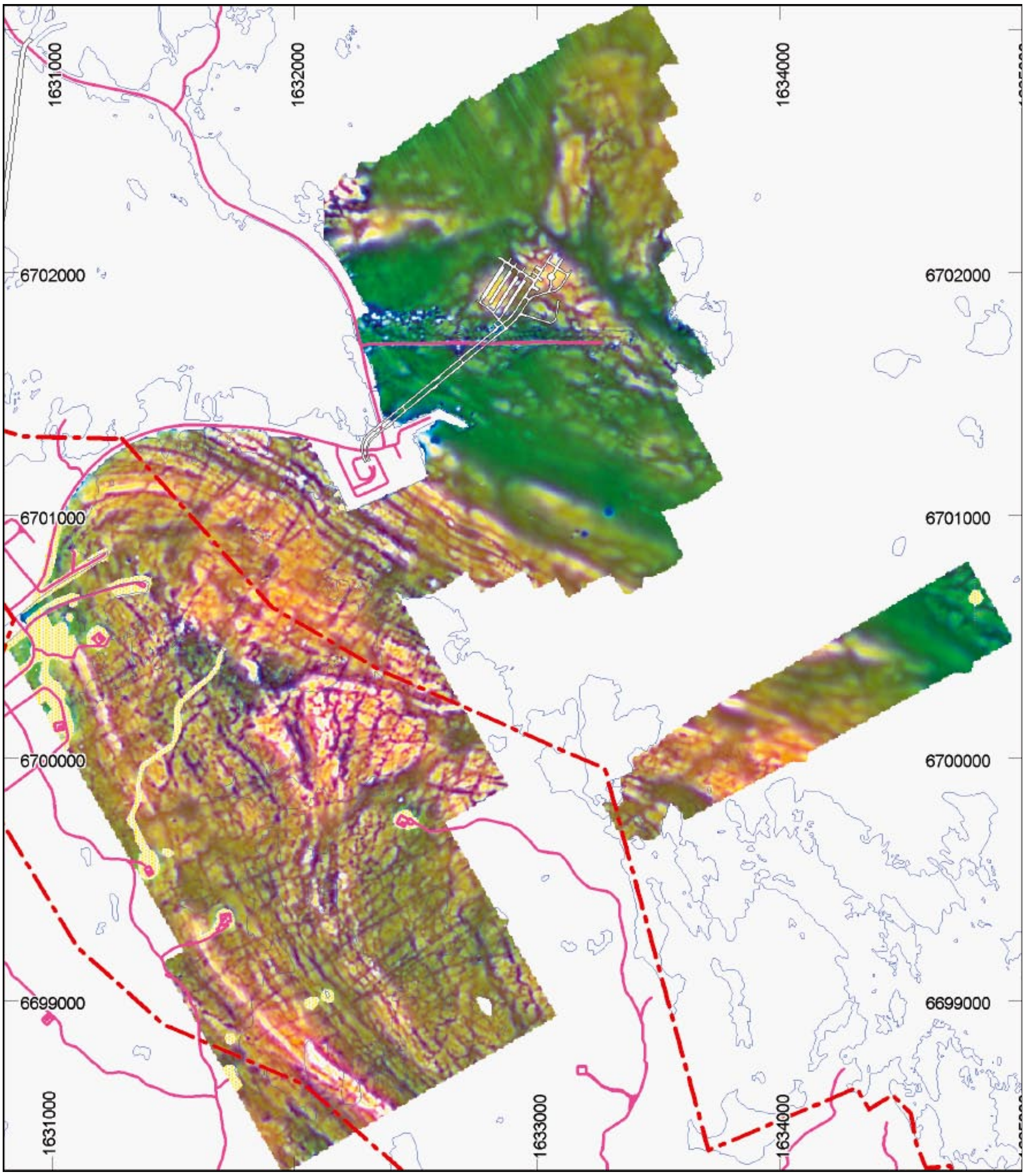

Figure 3-8. *Colour composite of the magnetic anomaly field; reduced to the pole (red), 1:st vertical derivative (green) and total horizontal derivative (blue). Disturbed areas in light yellow. The SFR underground facilities and the cooling water tunnel from Forsmark 1 and 2 are shown as black/white infill lines. The Forsmark candidate area is shown as a thick, dot-dashed, red line. Roads and drill sites in magenta. (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268.)*

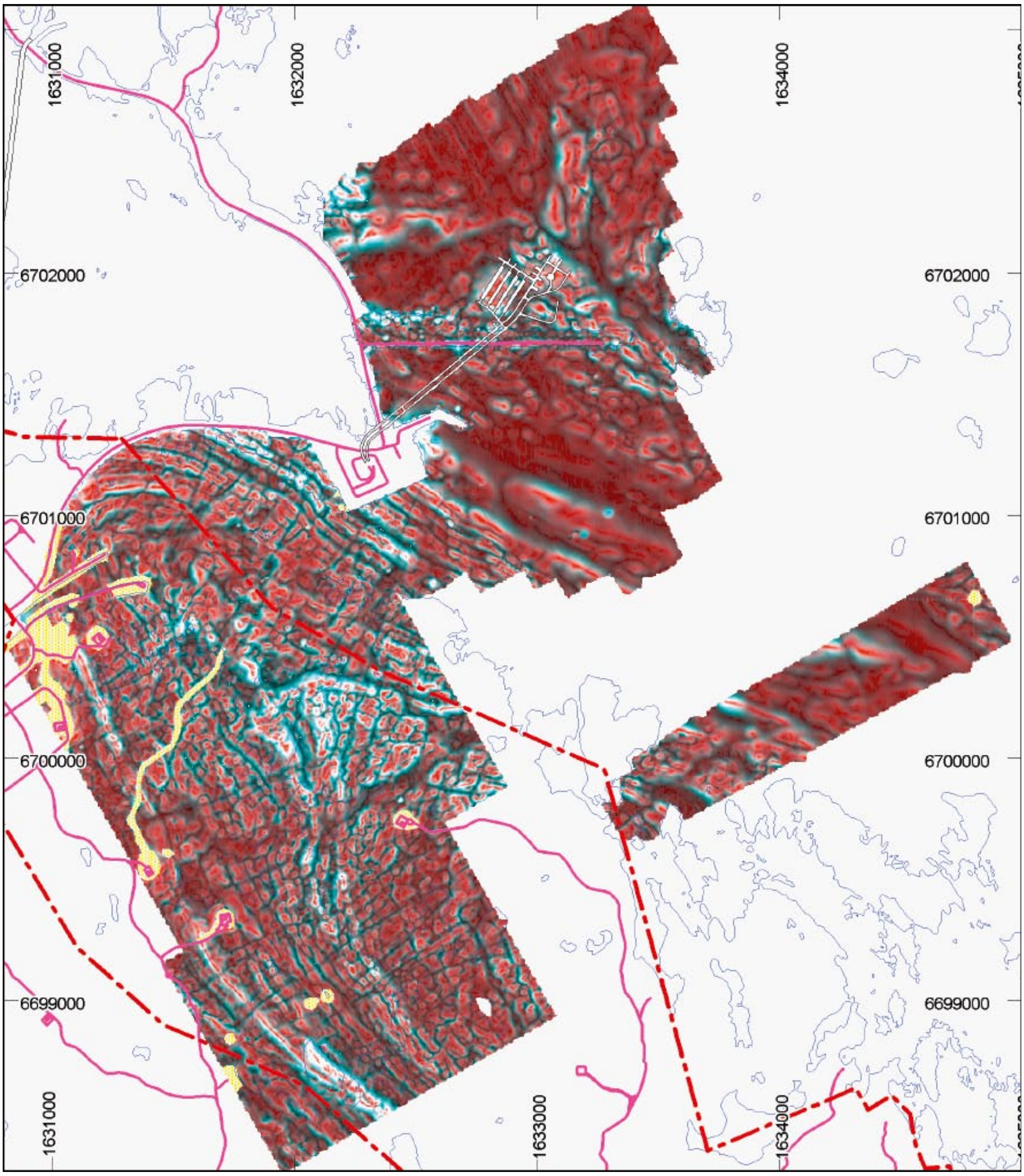

Figure 3-9. *Colour composite of the magnetic anomaly field; reduced to the pole. The 1:st vertical derivative (red) and total horizontal derivative (cyan). Disturbed areas in light yellow. The SFR underground facilities and the cooling water tunnel from Forsmark 1 and 2 are shown as black/white infill lines. The Forsmark candidate area is shown as a thick, dot-dashed, red line. Roads and drill sites in magenta. (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268.)*

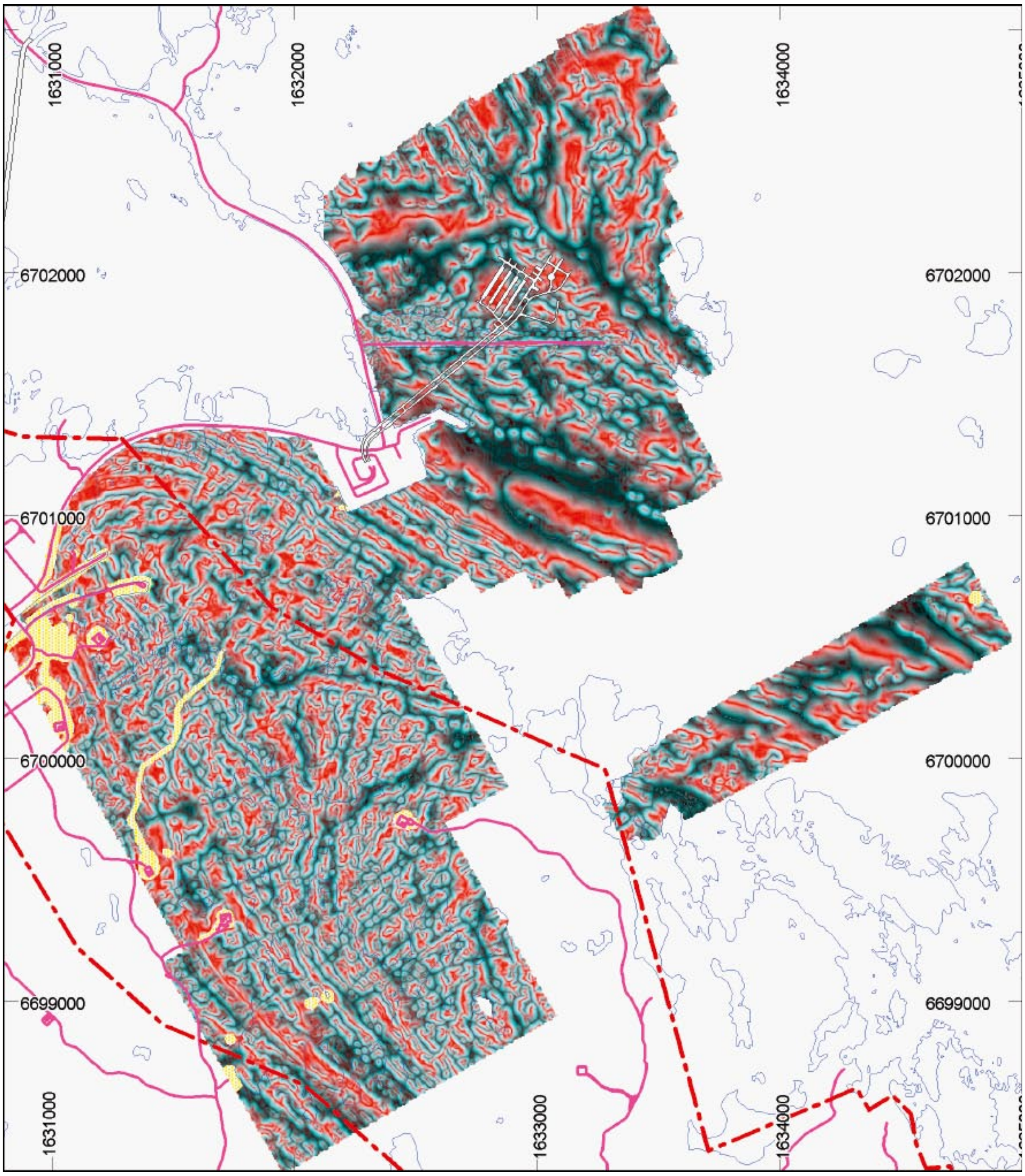

Figure 3-10. *Colour composite of the magnetic anomaly field, reduced to the pole. The tilt derivative (red) and total horizontal derivative of the tilt derivative (cyan). Upward continuation to 10 m makes the magnetic pattern smoothed. Disturbed areas in light yellow. The SFR underground facilities and the cooling water tunnel from Forsmark 1 and 2 are shown as black/white infill lines. The Forsmark candidate area is shown as a thick, dot-dashed, red line. Roads and drill sites in magenta. (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268.)*

3.5 Nonconformities

All magnetic data was influenced by the D.C. cable between Sweden and Finland, which is situated at a distance of 0 to 4 kilometres to the north of the survey stations. The anthropogenic environments at drill sites, along the roads to the drill sites and around housing and industry areas have given disturbances and loss of data. These areas are marked as disturbed areas in the interpretation, Figure 4-1, 4-2, 4-3 and 4-4. The same is valid for the steel tube releasing salt water from drill site BP1 to the north, into the sea at Asphällsfjärden.

The larger boat had a magnetic mooring ring in the stem. This resulted in a magnetic heading error. A small heading error was also noted with the small boat at the areas AFM001293 and AFM001294. A correction for this was applied to the data (see section 3.4.3).

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). It should be emphasized that the previous interpretation results from AFM100206 /10/ have been incorporated in this work and furthermore, that the area AFM001294 around the SFR underground facilities, Figure 1-1, has not been included in this stage of the interpretation work.

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 400-06-034).

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 also Figure 3-5 to 3-10). Along the southwest margin of the survey area the magnetic pattern is characterized by a gentle, banded magnetic pattern of, in general, low to moderate magnetic intensity. The northeast part, at the SFR office and further to the southeast along the coastline, the pattern is intensely banded with rapidly changing low and highly magnetic bands. These two structures probably forms fold limbs of a common fold with a northwest oriented fold axis. The fold is U-shaped and opens to the southeast. Within the fold the magnetic pattern is more varied with gently banded to more irregular patterns and from low to high magnetic intensity. The fold pattern is most prominent in the Asphällsfjärden area, Figure 4-1, but is also repeated recurrently from northwest to the southeast. The area between Bolundsfjärden and the road to drill site BP6 forms the core of the fold structure with a more dominant irregular magnetic pattern.

A few minor areas with very low magnetic intensity and low magnetic relief have been identified and outlined, Figure 4-1 and 4-2. The origin of these features is uncertain and may require further investigations.

Areas of diffuse magnetic pattern can also be seen in different parts of the survey area. The most prominent example is a WSW-ENE trend along MFM0060A0, from drill site BP1 and north of drill site BP6, Figure 4-1. The exact boundaries of diffuse areas are very difficult to outline and hence, the areas are marked with a letter D as a point in the centre of the occurrence. Another cluster of occurrences is located in Asphällsfjärden and towards Klubbudden. It is possible that the diffuse magnetic pattern can indicate a deeper bedrock source and/or the presence of fractured and altered surface rock. Observation of this type of feature is only valid if the magnetic bedrock source is rather shallow. Hence, no indication of diffuse magnetic pattern has been marked in area AFM001293 due to the deeper sea water; see also discussion in section 4.4.

Verduzco et al. /12/ has shown that the zero crossing of the tilt derivative of the 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 this way been extracted using the tilt derivative processed data, Figure 4-1. To further enhance the structural magnetic setting, positive magnetic connections have also been outlined, Figure 4-1.

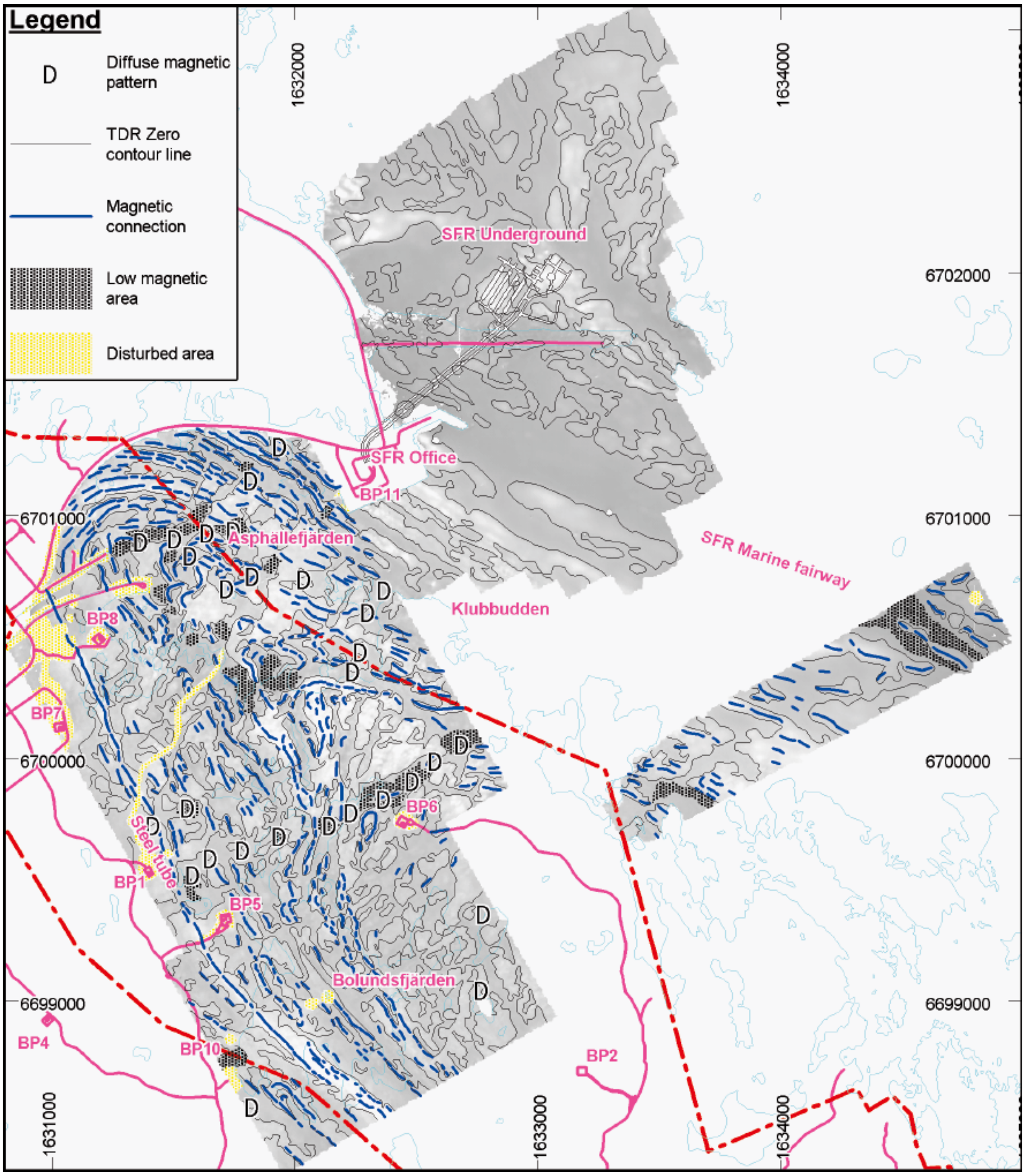

Figure 4-1. *Magnetic anomaly pattern in the detailed ground survey area. The zero contour of the tilt derivative is outlined, indicating possible boundaries of bedrock units with different magnetic properties. Areas with low magnetic intensity and no anomaly relief are shown and also diffuse magnetic patterns. Higher magnetic connections enhance the structural pattern. Disturbed areas in light yellow. The SFR underground facility is shown with black/white infill lines. The Forsmark candidate area is shown as a thick, dot-dashed, red line. Roads and drill sites in magenta. Printed on a blurred version of the magnetic total field. (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268.)*

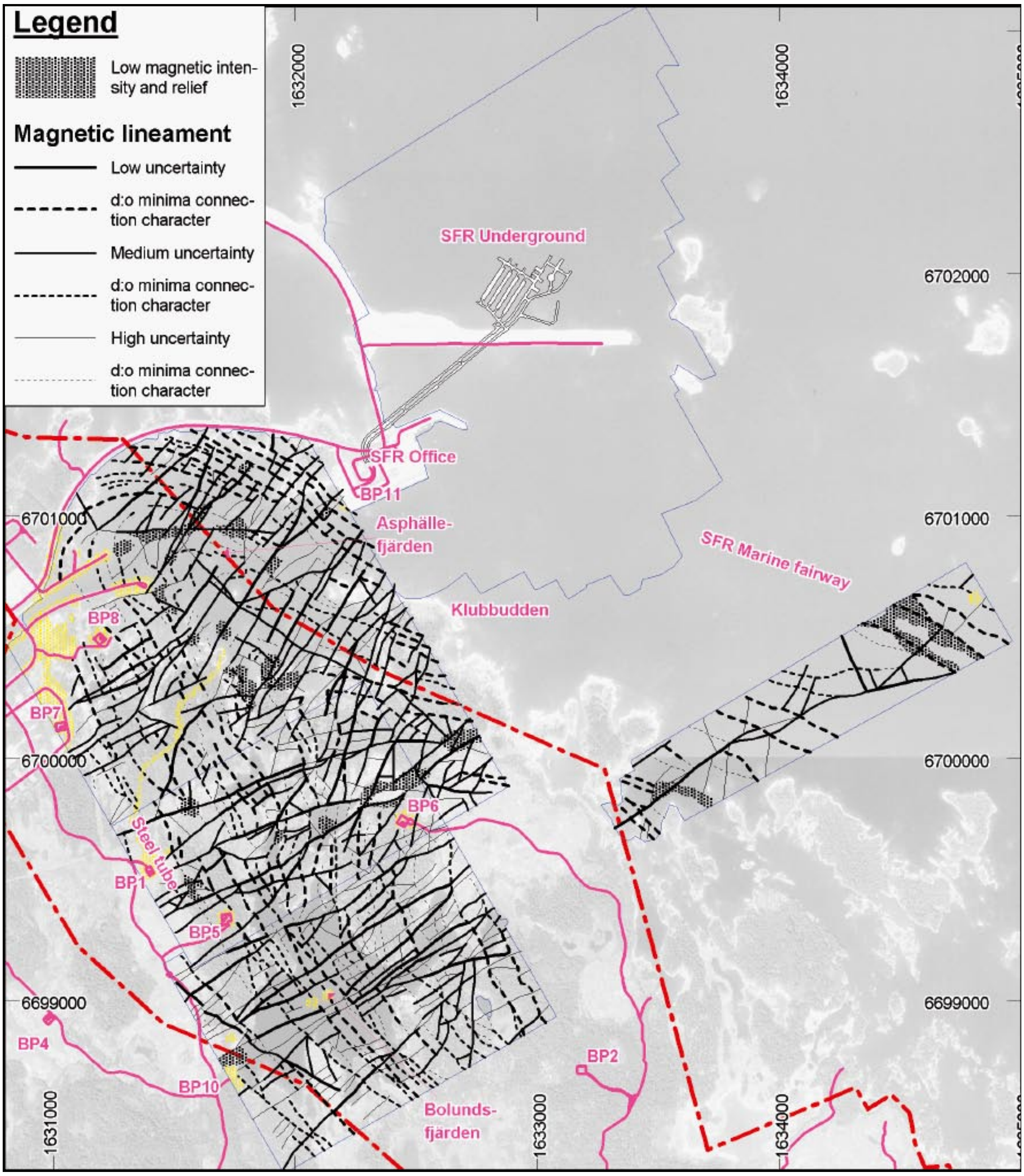

Figure 4-2. *Distribution of coordinated, magnetic lineaments in the ground survey area. Areas with low magnetic intensity and no anomaly relief are also outlined. Disturbed areas in light yellow. The SFR underground facilities is shown with black/white infill lines. The Forsmark candidate area is shown as a thick, dot-dashed, red line. Roads and drill sites in magenta. Printed on orthophoto. (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268.)*

4.2 Lineament interpretation

The method specific lineament interpretation involves only one data set; the magnetic total field. The magnetic 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. Hence, 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 bedding 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 interpretations are stored in GIS-format and each lineament has an attribute table attached, Table 4-1, similar as the one adapted for linked lineaments in /5/. The table is the same for method specific, coordinated and linked lineaments, which means that the significance of the individual attributes is somewhat different for each presentation. Origin, method, character and uncertainty are the most important attributes for the method specific lineament. A new attribute that was introduced in this work is the character of the observation translated from text to an integer, to facilitate weighting according to length of the character attribute. The length and direction of each lineament segment is calculated. Besides scrutinizing the lineaments as possible fracture zones the comprehensive attributes table also provide a basis for further statistical analysis.

In this work a total of 1,140 magnetic lineaments have been identified of which 481 are characterized as "minima connections". 255 and 405 magnetic lineaments have a low and high uncertainty, respectively. Based on the attribute data some general statistical results are presented in Table 4-2. The lineaments have not been linked in this stage and the presented figures thus represent each individual segment identified.

The identified magnetic lineaments and low magnetic areas are presented in Figure 4-2. A rose diagram based on the azimuth of the individual magnetic lineaments is shown in Figure 4-3.

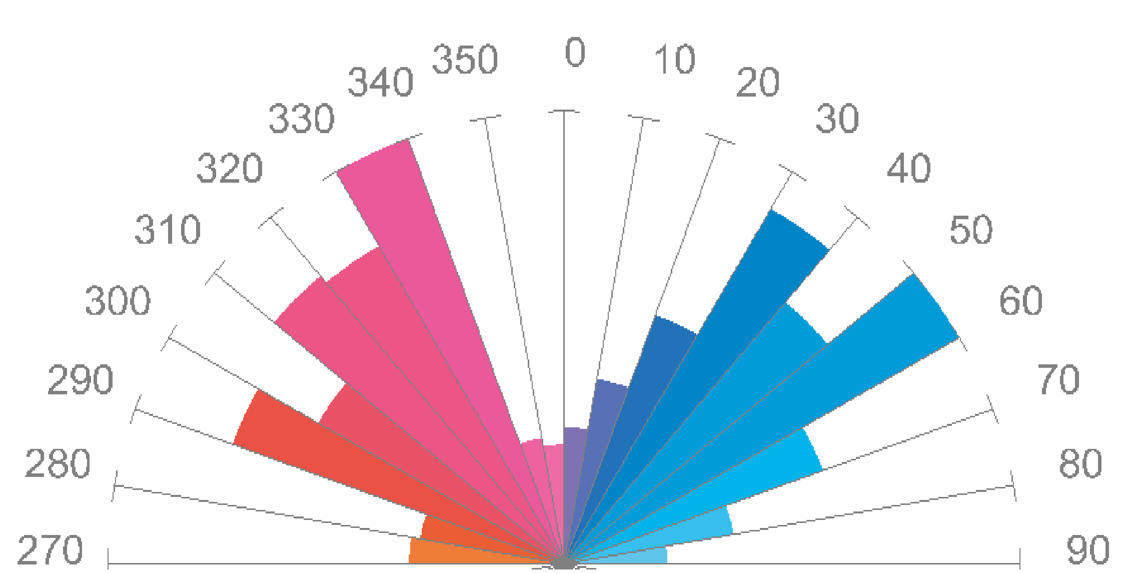

Figure 4-3. *Rose diagram showing the lineament trend distribution based on the azimuth of the individual magnetic lineament segment.*

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

Field name	Name	Description	Attribute used to describe lineaments
Id_t	Identity	Identity of a linked lineament.	ID-number according to SKB (MFM……). Assigned only for linked lineaments.
Origin_t	Origin	Major type of basic data.	Basic data or Method specific or Coordinated lineaments.
Class_t	Classification	Classification of a linked lineament.	Regional (> 10 km), local major (1–10 km) and local minor (< 1 km) lineaments. Valid only for linked lineaments.
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.	Graded from 1 = low confidence to 5 = high confidence for Coordinated lineament. A weighted average according to the length of each segment in linked lineament. Valid only for linked lineaments and only if more then one method is used.
Char_t	Character	Character of the observation in letters.	Method characteristics like minima, edge, minima connection or Coordinated or Linked lineament.
Char_n	Character	Character of the observation translated to an integer or number between 0–1.	1 = minima or edge 0 = minima connection. A weighted average has been calculated according to the length of each segment in the linked lineament.
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. A weighted average has been calculated according to the length of each segment in the linked lineament.
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.
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 is an estimate for all observations.
Count_n	Count	The number of original segments along the lineament.	Always 1 for a method specific lineament.
Cond_n	Conductivity	Shows how much of the lineament that has been identified by EM and/or VLF.	Not applicable when only magnetic lineaments are concerned. In this work always 0.
Magn_n	Magnetic	Shows how much of the lineament that has been identified by magnetics.	A weighted average has been calculated, according to the length of each segment in the linked lineament. 0.00–1.00 = 0–100%. When only magnetic lineaments are concerned, always 1.
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.	Not applicable when only magnetic lineaments are concerned. In this work always 0.
Topog_n	Ground surface	Shows how much of the lineament that has been identified by topography in the ground surface.	Not applicable when only magnetic lineaments are concerned. In this work always 0.

Field name	Name	Description	Attribute used to describe lineaments
Topor_n	Rock surface	Shows how much of the lineament that has been identified by topography in the bedrock surface.	Not applicable when only magnetic lineaments are concerned. In this work always 0.
Prop_n	Property	Shows in average, how many properties that have been identifiying the lineament.	A weighted average has been calculated, according to the length of each segment in the linked lineament. 0.00–1.00 = 0–100%. When only magnetic lineaments are concerned, always 1.
Length_n	Length	The length of the lineament.	In metres.
Direct_n	Direction	The average trend of the lineament.	In degrees [°].
Platform_t	Platform	Measuring platform for the basic data.	Ground survey grid.
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	98	308	253	659
Minima connection	157	172	152	481
Total	255	480	405	1,140

4.3 Lineament coordination and linking

The lineament linking has followed a working scheme previously used in /5, 10/, in detail described in /5/. Since only one type of data, magnetics, has been used, the coordination phase of the process has been limited to adjustment of vector nodes and connections between lineaments. As a basis for the linking of these coordinated magnetic lineaments, the following data was used:

- Linked, large scale, magnetic lineaments as presented in the preliminary site description, Forsmark area – version 2.1 (Appendix 2.2) /13/.
- Coordinated magnetic, small scale lineaments from AFM100206 /10/.
- Coordinated magnetic, small scale lineaments from this study.
- Magnetic images, covering the different processing.

Going from a method specific or coordinated lineament to a "linked" lineament, the most important attributes assigned are, see also Table 4-1:

- Identity. Each linked lineament is given identification according to SKB standards.
- Length. Total length of all segments.
- Direction. Average trend of the lineament.
- Class. The total length provides a possibility to discriminate between regional (> 10 km), local major (1–10 km) and local minor (< 1 km) lineaments.
- Count. The number of original coordinated lineament segments along the linked lineament.
- Uncertainty. The uncertainty is graded between 1–3.
- Character. The character number is graded between 0–1.

The identity is built up by 9 positions, at first 8 positions MFMxxxxG; where M stands for Magnetic, FM for Forsmark, xxxx is a serial number and G stands for Ground. Position 9 is a number 0–9, used to describe when a lineament form separate segments of what is judged with confidence to be part of the same lineament.

The attributes like Uncertainty and Character are weighted according to the length of each individual lineament segment that forms part of the linked lineament.

At first the geographical position and extension of a new, small-scale, linked magnetic lineament have been compared to the large-scale magnetic lineaments in the version 2.1, preliminary site description data set. The lineament that gives a good fit is denominated according to the identity of the previous large-scale lineament. At the same time the large-scale lineament has been deleted in the part where it traverses the detailed survey area, adapted to the small-scale lineament at the survey boundaries and also in some cases modified outside the ground survey areas. It is important to notice that small-scale and large-scale lineaments have not been linked together in this work. Of previous large-scale magnetic lineaments, 30 MFM-identities have been utilized and affected in this work; see also Figure 4-4:

- MFM0044, 60A0, 60A1, 61, 62, 103, 123, 130, 133, 159, 167, 168, 169, 236, 401, 408, 414, 725, 803, 805, 809, 811, 818, 1053, 1054, 1056, 1127, 1196, 1198 and 1199.

The identities marked with an underline have been fully exchanged by a new small-scale representation within the detailed survey area while the others, in part, still extend outside the survey area.

A few large-scale magnetic lineaments have been fully dropped since they have no acceptable small-scale representation in the detailed survey:

- MFM0098, 731, 1043, 1061, 1064 and 1202.

The new lineament identities occupy the serial numbers MFM2001–2506. In this series, 3 numbers have been dropped in connection with the delivery:

- MFM2129G has been added to MFM2238G.
- MFM2422G and 2423G has been added to MFM2421G.

In total, 553 small-scale, linked magnetic lineaments have been defined in this work. 12 lineaments have a different denomination in position 9 in the identity code. These lineaments have several separate segments that form adjacent, alternative and often parallel routes:

- MFM0044, 60, 61, 62, 236, 401, 811, 1199, 2054, 2326, 2332, and 2410.

3 lineaments are judged to run in and out of the detailed survey area twice (the identity is then the same for both segments):

- MFM0044G0, 62G0 and 809G.

In the linking process the two main characterizations, minima and minima connection have been kept apart so that linked lineaments mainly are composed of only one character. In a few cases the two groups coincide and hence, two linked lineaments can share the same segment(s) along a shorter distance.

Based on the attached attribute table, for content see Table 4-1, some general statistical results are presented in Table 4-3. A total of 553 linked magnetic lineaments have been constructed of which 252 are characterized as “minima connections”. 2 and 25 linked lineaments are regional and local major lineaments, respectively. Figure 4-4 shows the linked lineaments, classified as regional (> 10 km), local major (1–10 km) or local minor (< 1 km), and the relation to previous large-scale magnetic lineaments.

Table 4-3. Compilations of some attribute information for linked magnetic lineaments. Figures show number of occurrences.

Character	Local minor (< 1 km)	Local major (1–10 km)	Regional (≥ 10 km)	Total number
Minima / edge / dislocation in > 50% of the length	286	15	0	301
Minima connection in > 50% of the length	240	10	2	252
Total	526	25	2	553

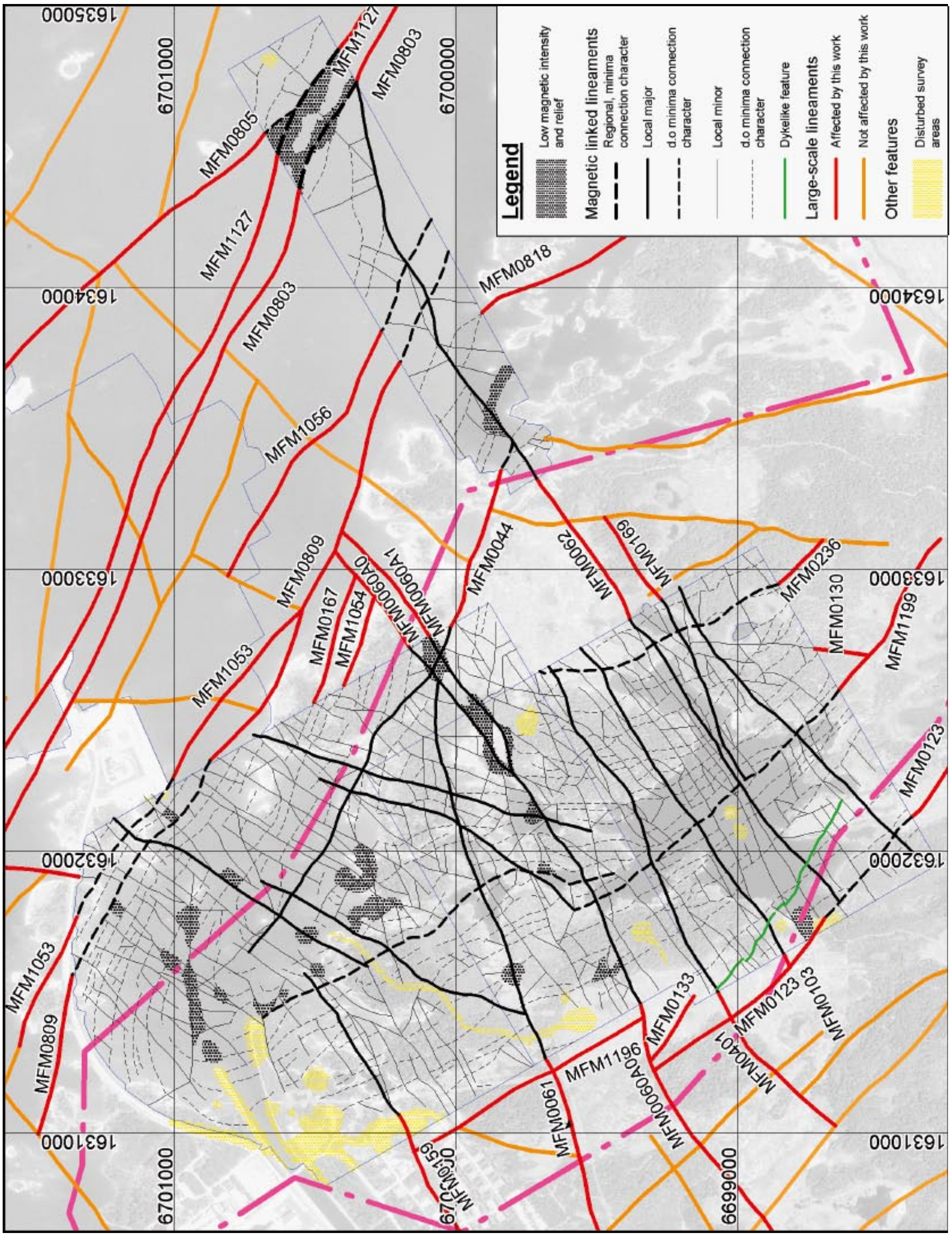

Figure 4-4. *Linked lineaments; regional, local major and local minor. From detailed ground magnetics in black. Previous large-scale magnetic lineaments in red and orange. The labels and the red colour indicate lineaments that have been affected and changed within the detailed survey areas. The Forsmark candidate area is shown as a dot-dashed, magenta line. Printed on orthophoto. (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268.)*

4.4 Discussion

General conclusions

It is clear from previous work /10/ and this work, that the high resolution, ground magnetic data provides the possibility to identify more and shorter lineaments than the airborne survey data. The difference in resolution of structures using airborne magnetic data or ground data can be more easily understood looking at the magnetic ground survey upward continued 40 m, up to the helicopter-borne survey level, Figure 4-5. This shows how the detailed "ground" magnetic data would look like if it was carried out 40 m above ground. One should also remember that the helicopter-borne survey was carried out with an average line spacing of 50 m compared to 10 m line spacing in the ground survey. This also contributes to the finer details presented in this work that could not be resolved from the airborne survey data in previous interpretations.

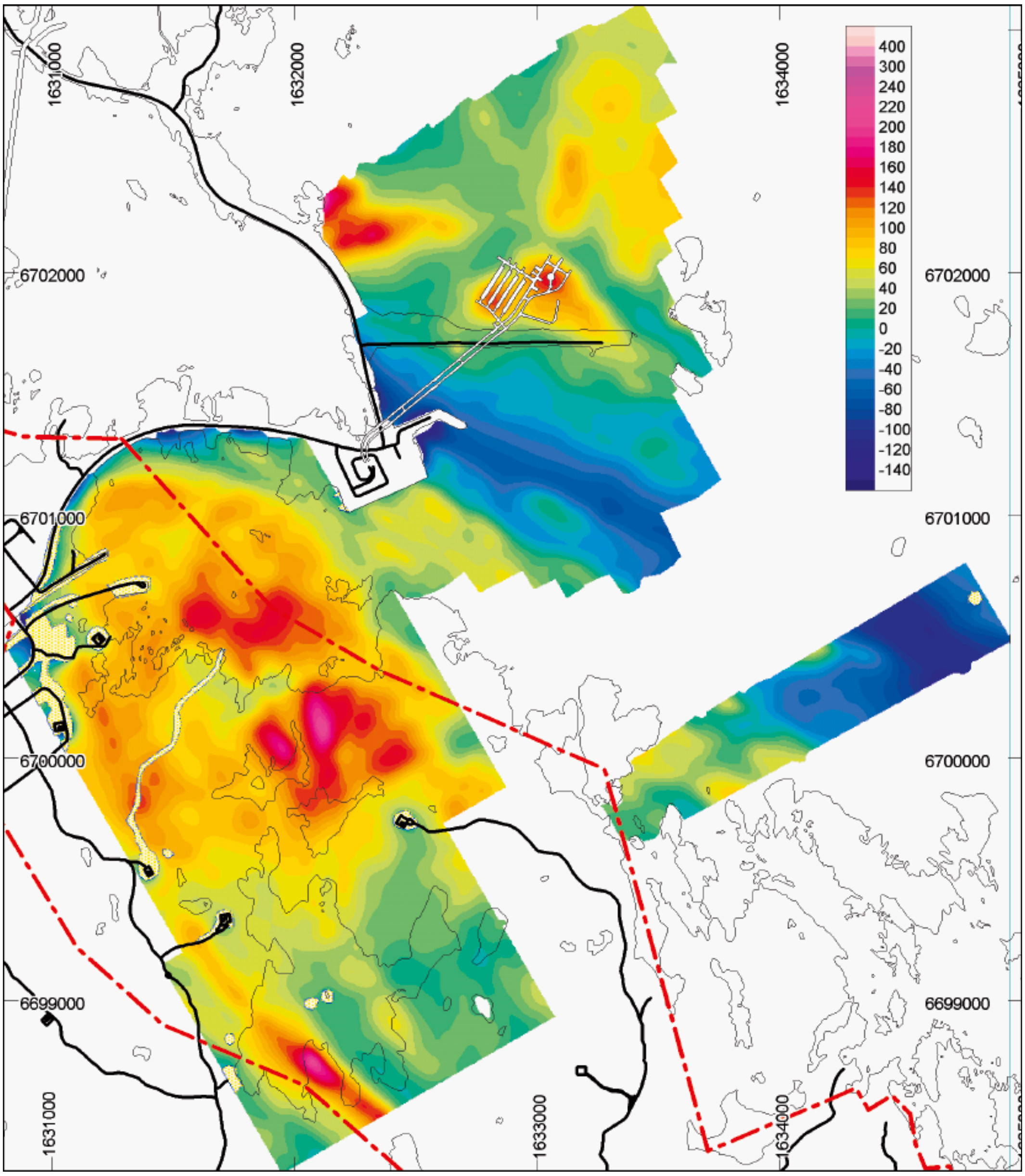

Figure 4-5. *Magnetic anomaly field, the ground survey data presented in Figure 3-5, upward continuation to a survey level of 40 m above ground, similar to previous helicopter borne survey. Colour range in nanoTesla [nT] is the same as in Figure 3-5. Disturbed areas in light yellow. The SFR underground facilities and the cooling water tunnel from Forsmark 1 and 2 are shown as black/white infill lines. The Forsmark candidate area is shown as a thick, dot-dashed, red line. Roads and drill sites in black. (GSD-Fastighetskartan © Lantmäteriet Gävle 2001. Medgivande M2001/5268.)*

The detailed magnetic, ground and marine survey data give a much better understanding of the small-scale distribution of magnetic lineaments. The data also give detailed information on the extension and fragmentation of the large scale magnetic lineaments, previously identified.

Large-scale lineaments identified in previous interpretations

An investigation of linked lineaments, XFM0060A0 and XFM0061A0 was the main objective in the previous detailed survey and the work showed that the large-scale extensions were supported by the detailed magnetic data /10/. The present enlargement of the survey indicates that XFM0060A0, probably extends towards northeast as two close, parallel lineaments, now called MFM0060A0 and MFM0060A1, enclosing low magnetic areas, Figure 4-4. The survey enlargement also shows that MFM0061A0 connects to MFM0060 at its east-northeast end.

The new extended survey covers several other previously identified lineaments that in some cases also have been modelled in the preliminary site descriptions /8, 9, 13/. MFM0062 (XFM0062A0) is rather clearly visible in the ground magnetic data from Bolundsfjärden and further to the east-northeast and also in the sea at AFM001293. Several subordinate lineaments run parallel, in Bolundsfjärden and further to the west-southwest and in this area it is difficult to decide the principal location of the MFM0062 lineament.

Other major lineaments previously identified and where the extension in the survey area has been clarified are as follows, Figure 4-4:

ENE-lineaments: MFM0103, MFM0401, MFM0159.

NW-lineaments: MFM0123, MFM1199, MFM0236, MFM0809, MFM1053, MFM1056, MFM0803, MFM1127 and MFM0805.

MFM0044 needs a special remark. It runs west-northwest, more or less parallel to the magnetic banding and close to the large-scale fold axis. The lineament forms a dislocation of parasitic folds on the large-scale fold structure and can possibly indicate a slip fault plane.

MFM0803 and MFM1127 are located to the Singö deformation zone and form two separate and parallel, rather wide low magnetic linear features. The character of these lineaments and also MFM0805 will be investigated further in the next phase of the interpretation covering also survey area AFM001294.

Many of the new, previously not identified lineaments can possibly be considered as minor splays from the large-scale lineaments.

Lineament patterns

From the previous ground survey /10/ a few longer, previously not identified, east-northeast trending lineaments were commented. However, in this work the number of newly identified lineament are numerous and only an important change in the general lineament pattern is further discussed in this report.

In the south, southwest and southeast part of the ground survey area the lineament pattern is clear with mainly east-northeast, discordant lineaments and northwest trending, mostly minima connections, Figure 4-2 and 4-3. Further to the north and northeast, around Asphällsfjärden, the east-northeast lineaments more or less disappear and are replaced by a set of lineaments with mainly north-northeast direction. The latter pattern has previously been poorly known and these features can be considered as a new discovery, tracked down initially by the detailed ground magnetic survey.

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.

The main magnetic trend can also be difficult to determine. This is especially the case in the bended structures close to the axial plane of the large fold structure. In some cases the magnetic minimum is related to a magnetic maximum and can be caused by the dip of a magnetic body. In the previous report /10/ two examples were given of a case in which a minimum to some extent can be explained by the strike and dip of a magnetic body, and another case where a strong narrow magnetic minimum occur alone and has to be explained by a narrow, low magnetic rock type, a rock type with reversed magnetization, a fracture zone or a very narrow and deep bedrock surface depression. These types of situations have been considered in the lineament identification work.

Dykelike lineament feature

Anomalies of dyke-like character, that is discordant and often high magnetic narrow linear anomalies, have previously not been identified in the Forsmark area. However, within this work one possible anomaly of dyke-like character has been identified in the south-western part of Bolundsfjärden, Figure 4-4 (green line). The lineaments are denominated by MFM2497G, 2498G, 2499G and 2500G and consist of a combined, narrow and parallel magnetic minima and maxima, Figure 3-6, 3-7 and 3-8. The magnetic minima can be a shadow effect due to the dip of a magnetic dyke giving the positive anomaly. Drill core or other exposed bedrock in this area should be checked for rock types and sequences from which this magnetic pattern can originate.

4.5 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 magnetic properties in the bedrock give different opportunities to identify lineaments. A higher magnetic and homogenous rock unit makes it easier while an inhomogeneous or low magnetic rock unit will make it harder.

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 m and 2–5 m respectively, this effect is rather small.

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

When linking two coordinated lineaments, there is in some cases more than one way to do it. How the linking is made will also have a major influence on the final length of the linked lineament.

In some cases, a lineament with low uncertainty over a long length can have an uncertain but short link between the longer segments. This information is not much considered by the applied methodology. The weighted average according to the length of each segment will give the possible break a very low significance.

Several lineaments are not terminated, but have an open end at the interpretation boundary. Consequently these lineaments are given a minimum length.

The airborne magnetic data used in previous regional, large-scale lineament interpretations /3, 4, 5/ matches a lineament representation at a scale of 1:50,000–1:100,000 in the open sea area (Öregrundsgrepen), and a scale of 1:20,000–1:10,000 in the coastal area and on the mainland. This work and /10/ has been carried out in a detailed scale of 1:5,000 or less. Work based on more detailed data will commonly provide a finer resolution of structures that will fade away in coarser scales and data. Longer lineaments at a regional scale will, at a detailed scale, be divided into shorter and often non-coherent segments.

In this work and due to an increase in water depth along the marine fairway to SFR, this part of the survey AFM001293, give a somewhat less detailed magnetic pattern. The lineament density visible in Figure 4-1 also illustrates this fact rather well.

5 Delivered data

The processed data and interpretation results have been delivered to SKB as described in Appendix 1. All data have been documented according to "Inleverans av data", SKB SD-111 (SKB internal controlling document).

Data have been delivered in three data formats for storage in the GIS-database. Grid-files, image files (report figures) and information that has resulted in some kind of interpreted vector; point, line or polygon data has been stored in Shape format. A listing of the format for each delivered product is shown in Appendix 1. Survey data have been stored in a Microsoft Excel template received from SKB.

Data for the survey area AFM100206 have been previously delivered /10/.

The following data have been delivered:

Survey data

- Magnetic total field (GP330 in SICADA) for the following idcodes: AFM001292, AFM001293, AFM001294 and AFM001314.

Grid data

- Interpolated grid created from magnetic anomaly field data jointly for areas: AFM001292, AFM001293, AFM001294 and AFM001314 and also including AFM100206.

Interpretation data

- Linked lineaments.
- Coordinated magnetic lineaments.
- Magnetic connections.
- Low magnetic areas.
- Diffuse magnetic pattern.
- Disturbed areas.
- Tilt derivative zero contour.

References

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Appendix 1

Delivered data

Shape/files

Filename	File type	Content
MFM_3km_RMA_ver2-2_line	Shp	Linked magnetic lineaments larger than 3 km in the regional model area
MFM_0-3km_LMA_ver2-2_line	Shp	Linked magnetic lineaments shorter than 3 km and affecting the local model area
AFM100206_1292_1293_1314_LL_070116_line	Shp	Linked lineaments interpreted from the detailed magnetic ground survey
AFM100206_1292_1293_1314_CL_070108_line	Shp	Coordinated magnetic lineaments interpreted from the detailed magnetic ground survey
FM_Diffuse_magnetic_pattern_point	Shp	The centre point of an area with diffuse magnetic pattern
FM_Disturbed_Areas	Shp	Disturbed survey areas
FM_Low_Magnetic_Areas	Shp	Areas with low magnetic intensity and relief
FM_Magnetic_connection_line	Shp	Magnetic connections
FM_Survey_Areas	Shp	Magnetic survey areas
FM_TDR_Zero_contour_line	Shp	Zero contour of the tilt derivative of the total magnetic field

Grid/files

Filename	File type	Content
FM_mag	grid	Interpolated grid created from magnetic anomaly field data, areas: AFM001292, AFM001293, AFM001294 and AFM001314 and also AFM100206.

SICADA

Filename	File type	Content
AFMxxxxxx_delx_GP330 - Profile, total magnetic field	xls	Magnetic total field (GP330 in SICADA) for the following idcodes: AFM001292, AFM001293, AFM001294 and AFM001314. In total 7 files.