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Forsmark site investigation

Interpretation of airborne geophysics and integration with topography Stage 2 (2002–2004)

An integration of bathymetry, topography, refraction seismics and airborne geophysics

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GeoVista AB

May 2005

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Keywords: Lineament, Bathymetry, Topography, Elevation, Rock surface, Ground surface, Refraction seismic, Seismic, Airborne geophysics, Magnetics, Electromagnetics, AP PF-400-02-47.

Abstract

This report presents stage 2 of the interpretation of airborne geophysics and integration with topography in Forsmark. Stage 2 comprises interpretation of method specific lineaments in the coastal area, the Forsmarksverket area and the open sea area (Öregrundsgrepen). These lineaments were then coordinated, linked and finally integrated with the stage 1 lineaments covering the mainland area. The interpretation of "linked lineaments" presented in this report is the complete stage 1 and 2 interpretation.

Lineaments can provide important information on the extension of deformation zones in the bedrock. Hence, the work forms a basis for the geological bedrock mapping and site descriptive models in the Forsmark area.

The work was carried out in several phases and made use of several different sources of data:

- Processing and method specific lineament interpretation of ground and rock surface topography based on refraction seismic data from Forsmarksverket and SFR. This phase also included studies of ground and rock surface maps from Forsmarksverket.
- Processing and evaluation of the refraction seismic, rock velocity data from Forsmarksverket and SFR.
- Identifying lineaments in ground geophysical (magnetic and EM) data, covering a small area within Forsmarksverket.
- Processing and method specific lineament interpretation of ground and rock surface topography based on modern marine geological data and bathymetry calculated from the helicopter borne EM survey integrated with detailed ground elevation data and shallow water bathymetry. This phase covered the coastal area.
- Revised interpretation of magnetic lineaments mainly in the coastal area and the sea area based on previous lineament interpretation of airborne geophysical data.
- Method specific lineament interpretation of the open sea area, Öregrundsgrepen, based on sea chart bathymetric data compiled during the SAFE-project and airborne magnetic data compiled during the feasibility study Östhammar and the Forsmark – site descriptive model, version 0.
- Coordination of topographical and geophysical lineaments into a coordinated lineament set for the coastal area.
- Coordination of topographical and geophysical lineaments into a coordinated lineament set for the open sea, Öregrundsgrepen.
- Linking of coordinated lineaments for the coastal area and Öregrundsgrepen and integration with previous linked lineaments for the mainland area (2002).

Sammanfattning

Denna rapport presenterar tolkning av flyggeofysiska mätningar och integration med topografi, fas 2 i Forsmark. Arbetet omfattar tolkning av metodspecifika lineament i kustområdet, vid Forsmarksverket samt i Öregrundsgrepen. Dessa lineament har koordinerats, länkats och slutligen integrerats med de lineament som tolkades under fas 1. Den tolkning av "linked lineaments" som presenteras i rapporten utgör den samlade (fas 1 och 2) tolkningen.

Lineament ger viktig information om var deformationszoner i berggrunden kan vara belägna. De utgör en bas för geologisk kartering och utveckling av platsspecifika modeller för berggrunden i Forsmarksområdet.

Arbetet har utförts i olika delmoment och en mängd olika grunddata har använts för studien:

- Bearbetning och metodspecifik lineamentstolkning av markytans och bergytans morfologi baserad på refraktionssesmiska data från förundersökningar och byggnationer av Forsmarksverket och SFR. I detta moment ingår även studier av topografi från byggnadsritningar.
- Bearbetning och utvärdering av berghastigheter för de refraktionsseismiska undersökningarna i Forsmarksområdet och SFR.
- Identifiering av lineament i markgeofysiska mätningar, magnet och slingram, från ett mindre område vid Forsmarksverket.
- Bearbetning och metodspecifik lineamentstolkning av markytans och bergytans morfologi baserad på moderna maringeologiska undersökningar samt batymetri beräknad från helikopterburen elektromagnetisk mätning integrerad med detaljerad höjddata samt grundvattenbatymetri. Detta moment omfattar kusten, närområdet utanför Forsmark.
- Reviderad identifiering av magnetiska lineament huvudsakligen i kustområdet, baserad på tidigare metodspecifik tolkning av detaljerade flygmagnetiska data.
- Metodspecifik tolkning av lineament i Öregrundsgrepen baserad på sjökortsinformation och batymetriska data, sammanställd under SAFE-projektet samt regionala, flygmagnetiska data sammanställda under förstudie Östhammar och Forsmark, platsbeskrivande modell, version 0.
- Koordinering av topografiska och geofysiska lineament till koordinerade lineament för kustområdet.
- Koordinering av topografiska och geofysiska lineament till koordinerade lineament för Öregrundsgrepen.
- Länkning av koordinerade lineament för kustområdet och Öregrundsgrepen samt integrering med tidigare länkade lineament för fastlandet (2002).

Contents

1 Introduction

This document reports Interpretation of airborne geophysics and integration with topography – Stage 2 (2002–2004), which is one of the activities performed within the site investigation at Forsmark. The work was conducted according to activity plan AP PF-400-02-47 (SKB internal controlling document), by GeoVista AB; Hans Isaksson. Mikael Keisu has been responsible for delivery of data.

The method descriptions: “Metodbeskrivning för lineamentstolkning baserad på topografiska data” (SKB MD 120.001) and “Metodbeskrivning för tolkning av flyggeofysiska data” (SKB MD 211.003) are the principal frames of reference for the work. The document: “Geological site descriptive model. A strategy for the model development during site investigations” /1/ is the main reference for the coordination of geophysical and topographical lineaments.

This work forms a second phase of interpretation of airborne geophysics and integration with topography, stage 1 (2002) /2/.

No field work has been performed.

2 Objective and scope

The purpose of the stage 2 interpretation was to first identify and describe method specific lineaments in the coastal area, the Forsmarksverket area and the open sea area (Öregrundsgrepen). These lineaments were then coordinated, linked and finally integrated with the stage 1 lineaments covering the mainland area. The interpretation of "linked lineaments" presented in this report is the complete stage 1 and 2 interpretation.

Linear features, or lineaments, can provide important information on the extension of deformation zones in the bedrock. Hence, the work forms a basis for the geological bedrock mapping and future site descriptive models in the Forsmark area.

The work was carried out in several phases and made use of several different sources of information:

- Processing and method specific lineament interpretation of ground and rock surface topography based on pre-site investigation, refraction seismic data from Forsmarksverket and SFR. This phase also included studies of ground and rock surface maps from Forsmarksverket /3/.
- Processing and evaluation of the refraction seismic, rock velocity data from Forsmarksverket and SFR /3/.
- Identification of lineament in previous magnetic and EM ground geophysical surveys, covering a small area within Forsmarksverket /3/.
- Processing and method specific lineament interpretation of ground and rock surface topography based on modern marine geological data /4/ and bathymetry calculated from the helicopter borne EM survey /2, 5/, integrated with detailed ground elevation data /6/ and shallow water bathymetry /9a,b/. This phase covered the coastal area.
- Revised interpretation of magnetic lineaments mainly in the coastal area and the sea area based on previous lineament interpretation of airborne geophysical data /2/.
- Method specific lineament interpretation of the open sea area, Öregrundsgrepen, based on sea chart bathymetric data compiled during the SAFE-project /7/ and airborne magnetic data compiled during the Östhammar feasibility study /20/ and the Forsmark – site descriptive model, version 0 /8/.
- Coordination of topographical and geophysical lineaments into a coordinated lineament set for the coastal area.
- Coordination of topographical and geophysical lineaments into a coordinated lineament set for the open sea, Öregrundsgrepen.
- Linking of coordinated lineaments for the coastal area and Öregrundsgrepen and integration with previous (2002) linked lineaments for the mainland area /2/

3 Methodology for method specific and integrated lineament interpretation

The main purpose of the lineament interpretation is to identify linear features that can reveal possible deformation zones in the bedrock. The method of lineament interpretation follows several distinct phases.

Phase I (Section 3.1) includes interpretation of topography, magnetics, VLF, EM, etc separately and each "method specific lineament" is given a set of attribute data.

Phase II (Section 3.2) includes coordination of the method specific lineaments into "coordinated lineaments" and the discriminating methods for each lineament are added as attribute data. A new weight attribute is created to illustrate the confidence of the lineaments. The length of each lineament is also calculated.

In **phase III** (Section 3.3), the coordinated lineaments are linked together. Results from a lineament direction analysis provide help to make priorities in the linking process. The comprehensive attributes table facilitates further statistical analysis and scrutiny of the linked lineaments as possible fracture zones.

Optionally, based on surface geological data, detailed ground geophysics and/or other ground truth data, some lineaments or parts of a lineament can be upgraded to a fracture zone (phase IV). This was carried out in the Stage 1, 2002 /2/ but not in the present work.

Figure 3-1, outlines the integrated lineament interpretation work in stage 1, 2002 /2/, while Figure 3-2 gives an update for the work in stage 2, 2003–2004.

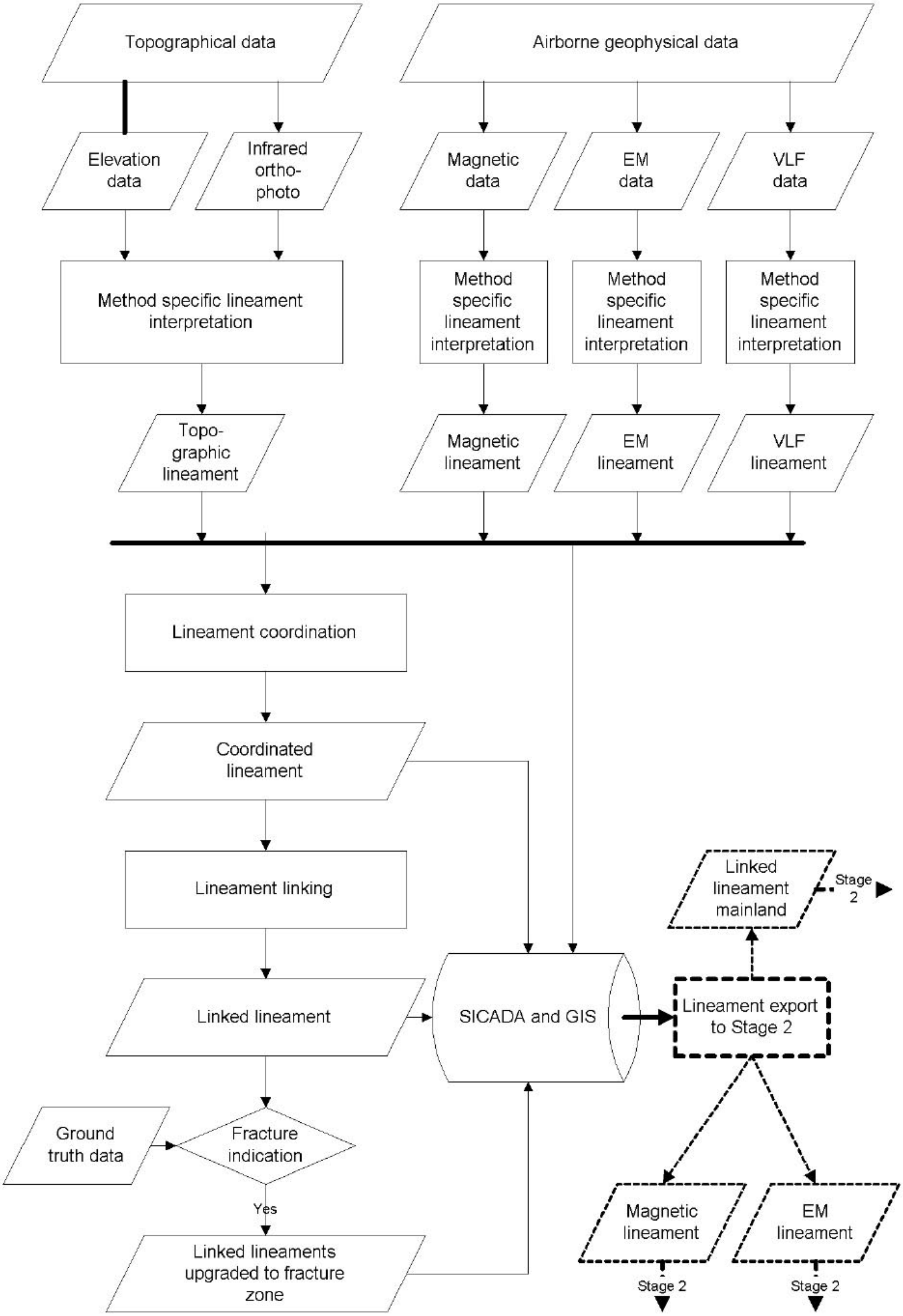


Figure 3-1. *Flowchart for the integrated lineament interpretation Stage 1 /2/ and the export of information to the present activity, stage 2.*

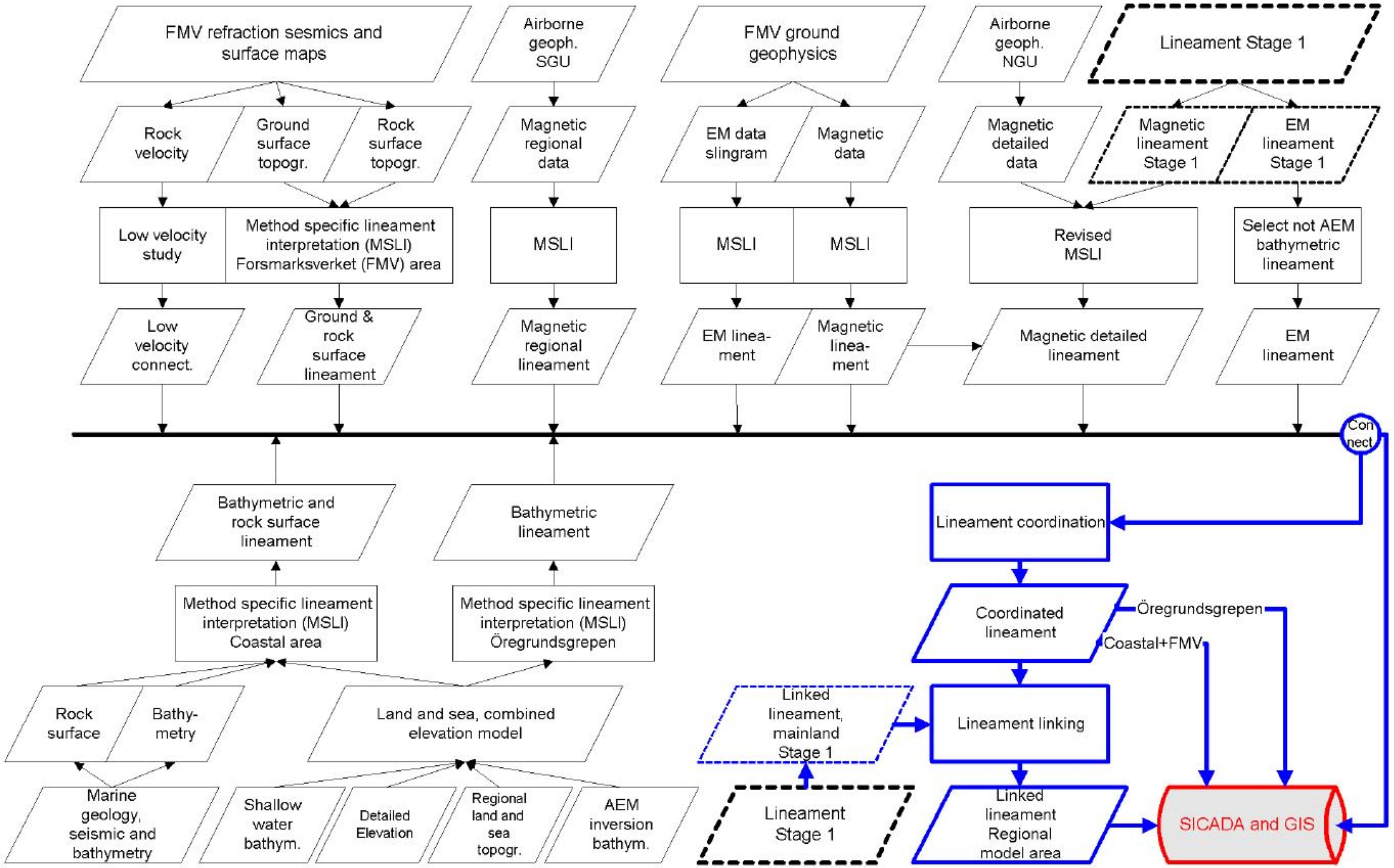


Figure 3-2. *Flowchart for the updated integrated lineament interpretation, stage 2, resulting in lineament coverage for the whole regional model area.*

3.1 Method specific lineaments

This initial phase of the work forms the basis of the subsequent integration and must be adapted to this process. Of most importance is to keep the lineament separate according to the degree of uncertainty and change in orientation.

The uncertainty attribute involves both the clarity in which the lineament is identified and an expert judgement regarding the cause of the lineament, considering e.g. the method specific response in various geological situations and the possible impact of man made features.

3.2 Coordinated lineaments

Coordination of lineaments has been carried out according to the principles described in "Geological site descriptive model. A strategy for the model development during site investigations" /1/. A coordinated lineament is delimited and characterized by a combination of methods, which means that a lineament is split whenever it is defined by such a new combination. This process is adopted even when there is a high degree of confidence that the lineament is continuous. The coordinated lineaments form a basis of the subsequent linking of lineament, see Section 3.3.

The coordination of lineaments was performed according to the following methodology:

- All method specific lineaments are visualized together, with or without the corresponding background images.
- The method specific lineament that is judged to give the best spatial precision, or appear with the best clarity, is selected to represent the location of the coordinated lineament.
- Adjacent method specific lineaments based on other methods are then judged to either represent the same coordinated lineament or, alternatively, another coordinated lineament.
- The clarity of each method that delineates the coordinated lineament also defines a method ranking, i.e. magn, topo, rock, EM, VLF. This ranking is noted in the field "Method_t", in an adherent attribute table, see Table 3-2.
- When the lineament is identified by a new combination of methods, it is split, and a new coordinated lineament is defined with a new method ranking.
- In difficult settlements, different basic method images are studied, to come to a conclusion. In some cases a method specific lineament can be considered as false and rejected. In some cases a lineament can be extended or modified in position.
- When the lineament coordination pocedure reveals a coinciding and, so far, not documented method specific linear feature in the basic method images, the attribute for this method or property is added in the adherent attribute table for the coordinated lineament. However, such observations will have a high uncertainty.
- The length of each coordinated lineament is calculated. However, since a coordinated lineament is strictly divided according to the characterising methods the length measure is only used as a basis of the subsequent formation of a linked lineament, see Section 3.3.
- Also the orientation of each coordinated lineament is calculated.

- To illustrate the confidence of a lineament, a weight attribute is created using a weighting scheme that depends on the degree of uncertainty and the number of methods, or in reality physical properties, used to identify each coordinated lineament, Table 3-1. A lineament identified in either VLF or EM is then considered to originate from a common property, conductivity, in the ground. Note that no property (method) is given a higher rank in this scheme.
- Results from a lineament trend analysis also provided help to make priorities in the linking process /2/. In the Forsmark area, the coordinated lineaments are divided in four direction sets and priorities; NW, NE, NS and EW, with the following critical angles:

  NW: 110–155° and 290–335°

  NE: 20–80° and 200–260°

  NS: 335–20° and 155–200°

  EW: 80–110° and 260–290°

The interpretation results are stored in GIS-format and each unit has an attribute table attached, for simplicity the same as for the linked lineament. For a full description, see Table 3-2.

Table 3-1. Weighting scheme for coordinated lineaments.

Number of indicating properties (methods)	High uncertainty	Medium uncertainty	Low uncertainty
3 of magnetics, topographic and conductivity	3	4	5
2 of magnetics, topographic and conductivity	2	3	4
1 of magnetics, topographic and conductivity	1	2	3

Figure 3-3 shows an example of the lineament coordination procedure.

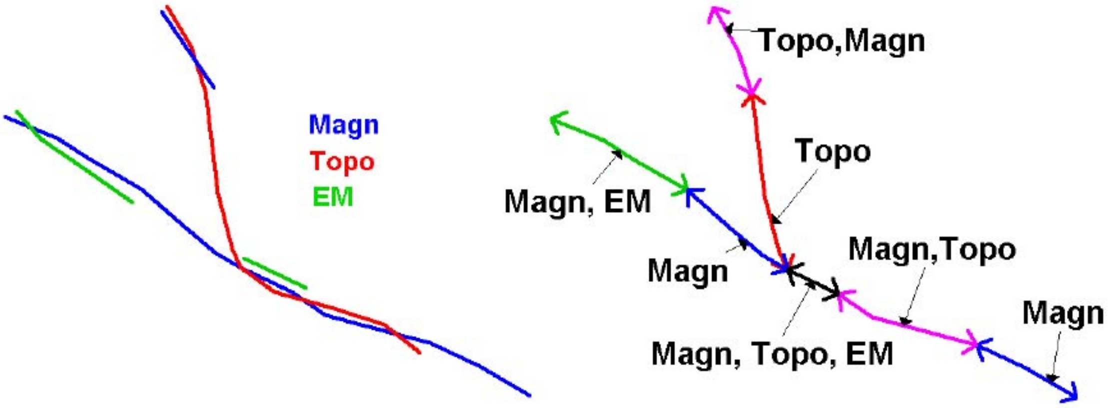


Figure 3-3. *Lineament coordination procedure. Method specific lineaments; magnetic, topographic and EM in blue, red and green respectively, to the left,*

3.3 Linked lineaments

For the safety analysis of the site, the length of a fracture zone is important. However, the length calculated for a coordinated lineament as described in Section 3-1, does not give a good estimate and hence, it is necessary to link the various segments of what is judged with confidence to be the same lineament. A method to link the coordinated lineaments together has been developed in cooperation with Michael B. Stephens and Jan Hermansson (members of the project group for site descriptive modelling) /2/. The linked lineaments obtained by this procedure then form a basis for identification of fracture zones in the bedrock and will also be used in the various site descriptive models. Results from the lineament trend analysis as described in Section 3.2, also provide help to make priorities in the linking process.

The weight and the trend attributes are used as guidance how to link the different coordinated lineament segments. To connect the different vector segments, this work also involved some minor adjustment of the node locations. Figure 3-4 shows a sketch of the linking lineament procedure.

To the "linked lineaments", the most important attributes assigned are:

- *Identity.* Each linked lineament is given identification according to SKB standards.
- *Class.* The total length provides a possibility to discriminate between regional (> 10 km), local major (1–10 km) and local minor (< 1 km) lineaments.
- *Weight.* The combination of uncertainty and number of properties (methods).
- *Count.* The number of original coordinated lineament segments along the linked lineament.
- *Cond, Magn, Topo.* To what extent the linked lineament has been identified by the specific properties (methods), i.e. conductivity, magnetics and topography.
- There are three different attributes used to characterize topographic lineaments: *Topog* describes lineaments occurring in the ground surface, either at the bottom of the sea or on land. *Topor* describes lineaments in the bedrock surface (omitting the soil cover), in this case determined by seismic investigations. Topo describe any topographic lineament, identified in either Topog or Topor.
- *Uncertainty.* The uncertainty is graded as 1 = low, 2 = medium or 3 = high.

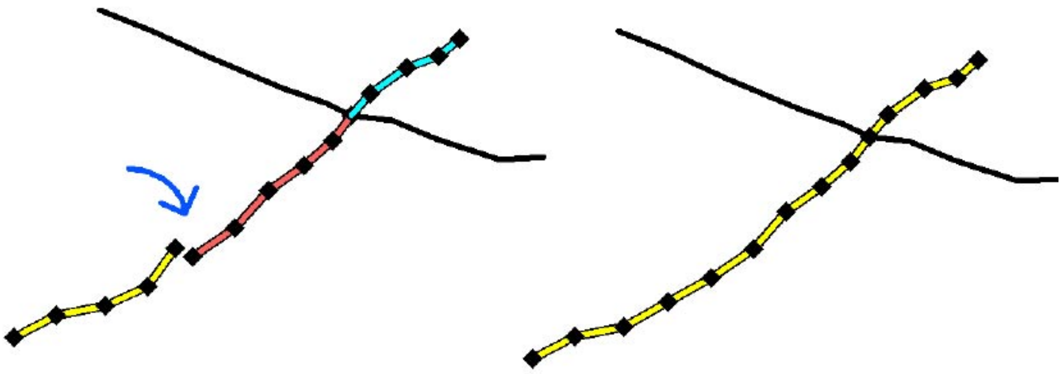


Figure 3-4. *An example of linking lineaments, including node adjustment (blue arrow).*

The attributes like Weight, Uncertainty, Cond, Magn and Topo are all weighted according to the length of each individual lineament that forms part of the linked lineament.

The interpretation results are stored in GIS-format and each lineament has an attribute table attached, for full descriptions see Table 3-2.

Table 3-2. Attribute table for the lineaments, in this case adapted to linked lineaments but the structure is the same and the content very similar also for method specific and coordinated lineaments.

Field name	Name	Description	Attribute used to describe lineaments
Id_t	Identity	Identity of the coordinated lineament.	ID-number according to SKB (XFM……). Only valid for Linked lineaments.
Origin_t	Origin	Major type of basic data.	Basic data or Method specific or Coordinated lineaments.
Class_t	Classification	Classification of the coordinated lineament.	Regional (> 10 km), local major (1–10 km) and local minor (< 1 km) lineaments. Only valid for Linked lineaments.
Method_t	Method	The type of data in which the observation is identified.	Not assigned in the linking work.
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.
Char_t	Character	Character of the observation.	Method characteristics or Coordinated or Linked lineament.
Uncert_t	Uncertainty	Gradation of identification, in terms of uncertainty. In effect, this attribute is an expert judgement concerning the degree of clarity of the lineament.	An estimate of uncertainty of the linked lineament, graded as 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.	Image analysis, GIS.
Date_t	Date	Point of time for interpretation.	Date.
Scale_t	Scale	Scale of interpretation.	10,000–20,000, 50,000.
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.	10–100 m.
Count_n	Count	The number of original segments along the lineament.	Integer.
Cond_n	Conductivity	Shows how much of the lineament that has been identified by EM and/or VLF.	0.00–1.00. A weighted average has been calculated, according to the length of each segment in the linked lineament. 0.00–1.00 = 0–100%.
Magn_n	Magnetic	Shows how much of the lineament that has been identified by magnetics.	0.00–1.00. A weighted average has been calculated, according to the length of each segment in the linked lineament. 0.00–1.00 = 0–100%.

Field name	Name	Description	Attribute used to describe lineaments
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.	0.00–1.00. A weighted average has been calculated, according to the length of each segment in the linked lineament. 0.00–1.00 = 0–100%.
Topog_n	Ground surface	Shows how much of the lineament that has been identified by topography in the ground surface.	0.00–1.00. A weighted average has been calculated, according to the length of each segment in the linked lineament. 0.00–1.00 = 0–100%.
Topor_n	Rock surface	Shows how much of the lineament that has been identified by topography in the bedrock surface.	0.00–1.00. A weighted average has been calculated, according to the length of each segment in the linked lineament. 0.00–1.00 = 0–100%.
Prop_n	Property	Shows in average, how many properties that has identified the lineament.	1.00–3.00. A weighted average has been calculated, according to the length of each segment in the linked lineament.
Length_n	Length	The length of the lineament.	
Direct_n	Direction	The average trend of the lineament.	0–360 degrees.
Platform_t	Platform	Measuring platform for the basic data.	Airborne geophysics 30–60 m altitude, air photos from 2,300 m altitude.
Sign_t	Signature	Work performed by.	hi (Hans Isaksson), GeoVista AB.

3.4 Uncertainties

The most important uncertainties in the coordination and linking process are:

It can be questioned if lineaments identified by different methods should be coordinated. They can at least in some cases either have different origins or, due to different method specific depth penetration, indicate a dip of a structure.

In the linking process it can be difficult to decide which lineaments to join and this decision might have a great impact on the final length of the linked lineament. Furthermore, different segments of a linked lineament have different confidence in terms of weight and the presence of a weak link will also have influence on the final length. If the weak link is short it will not have any major effect in the weighted averages.

However, in the process of understanding the origin of the lineaments, different categories can be evaluated from the question at issue. The individual method specific lineaments can always be reviewed when major uncertainty is at hand or when details are requested.

4 Topographic lineaments in the coastal area

4.1 Input data

Input to the lineament interpretation in the coastal area has been the following data sets, representing the ground surface topography:

1. The sea bottom terrain model (ground surface) from a marine geological survey, 5 m grid, xyz line data and 1 m depth contours /4/.
2. A sea bottom terrain model (salt water thickness) based on inversion of airborne EM, xyz line data /5/.
3. The detailed elevation data in a 10 m grid /6/.
4. The Land survey elevation data, 50 m grid /8/.
5. Sea bottom terrain model based on sea charts, 50 m grid /7/.
6. Water depth sounding xyz line data, in shallow bays /9a/ and lakes /9b/.
7. Shoreline data, GSD Terrängkartan Lantmäteriet Gävle 2001.

Input to the lineament interpretation of the bedrock surface topography in the coastal area has been:

A. The sea bottom, hard rock terrain model (rock surface) from a marine geological survey, 5 m grid and 1 m depth contours /4/.

Data processing

Two sets of grid data were produced to represent the sea bottom terrain model, one based on the marine geological survey (1. above) and one based on the inversion of airborne EM (2. above). To get better visual representation of the overall, ground surface topographical models and to the most avoid boundary effects from each data source, the different data sets were organized into mosaics. To enhance structures, gradient enhancement filtering and slope calculation were applied to the compiled terrain models.

Marine geological survey, terrain models

Both sea bottom terrain grids (1. and A.) were obtained in an interpolated 5×5 m grid and the hard rock terrain model grid and contours (A.) were used as delivered from SGU /4/.

However, the interpolation method used in /4/ to represent the sea bottom terrain (1.) was not adapted to lineament identification work. The method used give large areas with equal minimum depth, which is more adapted to sea chart creation. Instead, the original line data (x, y, z) were interpolated (linear Kriging), resulting in a more dynamic representation of the sea bottom surface. The marine geological survey /4/ was carried out with approximately 100 m line-spacing and the appropriate grid cell was set to 20 m.

The following mosaic data were used to create this sea bottom terrain grid:

- The marine geological, sea bottom terrain model, xyz line data.
- The detailed elevation data from the 10 m grid.
- Water depth soundings in shallow bays and lakes, xyz line data.
- Shoreline from the GSD Terrängkartan.

The data obtained in the marine geological survey /4/ have been used in the lineament interpretation but is classified for military defence reasons (SKB routine SDP-516) /10 and 11/ and no images describing this information are presented.

Airborne EM inversion, sea bottom terrain model

The sea water in the Forsmark area is electrically well conducting. An inversion of the airborne EM data /12/ can be done for the sea areas. The upper layer will then correspond to the sea water that has a known electric resistivity. The lower layer represents the seafloor. Such an inversion has been carried out /5/ and the resulting line data with the sea water thickness has been used in a similar way as the marine geological survey data. The airborne geophysical survey /12/ was carried out with approximately 50 m line spacing and an appropriate grid cell size is 10 m. This data set also gives better coverage in the shallow bays and other areas with water depth < 3 m.

The following mosaic data were used to create this sea bottom terrain grid based on airborne EM data and to combine it with other topographic data to an integrated terrain model:

- Sea bottom terrain model based on inversion of airborne EM, xyz line data.
- The detailed elevation data from the 10 m grid.
- Water depth soundings in shallow bays and lakes, xyz line data.
- The Land survey elevation data, 50 m grid.
- Sea bottom terrain model based on sea charts, 50 m grid.

A compilation of the basic data used to produce this integrated terrain model is presented in Figure 4-1, and a resulting grid image in Figure 4-2.

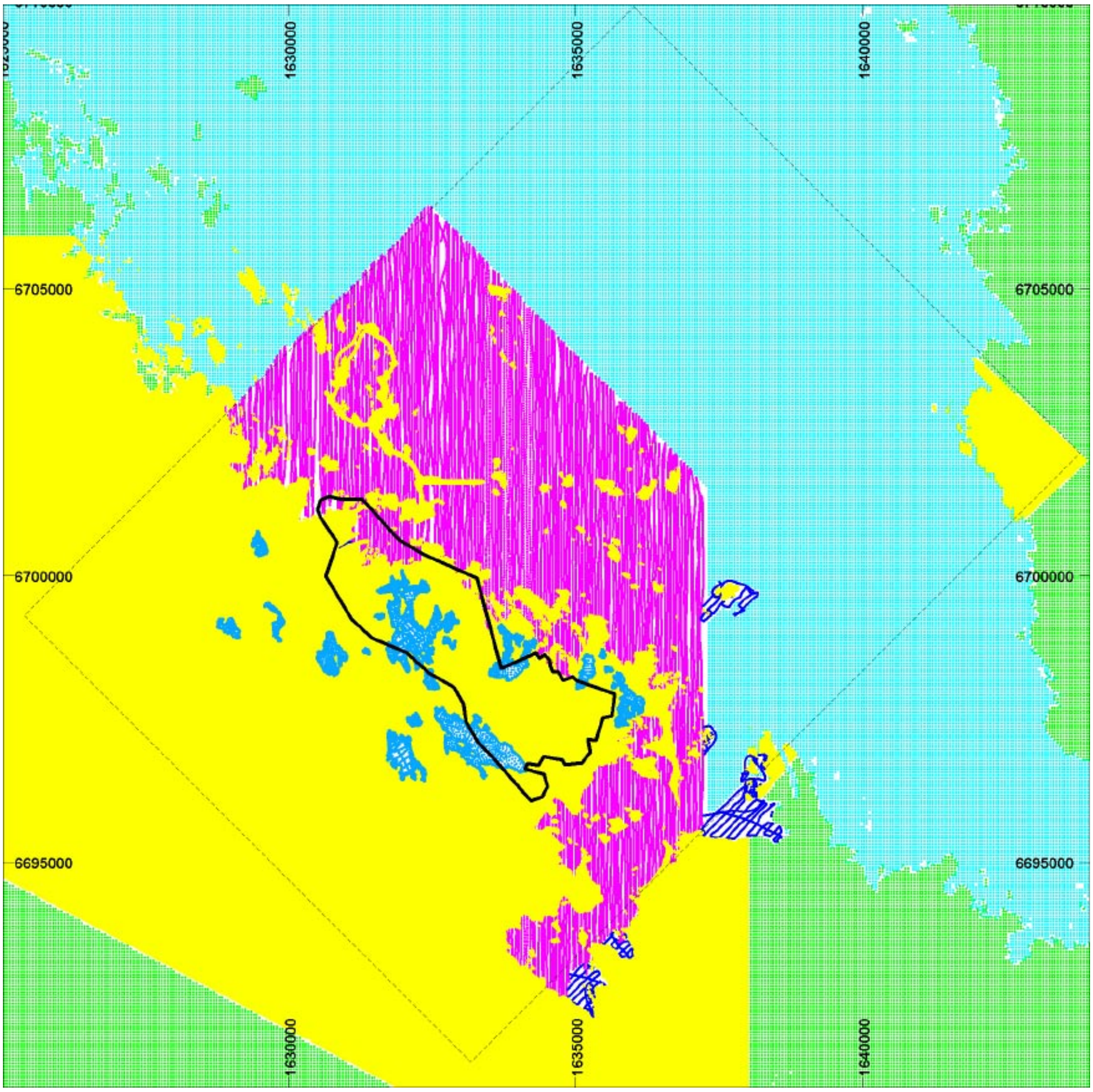


Figure 4-1. *Compilation of basic data for construction of an integrated, topographic ground surface data set. Land based elevation data: Yellow = detailed 10 m grid, Green = Land survey 50 m grid. Bathymetric data: Cyan = sea chart based 50 m grid, Magenta = airborne EM inversion, Dark blue = shallow, marine water depth soundings, Light blue = shallow water depth soundings in lakes. The site descriptive model area is outlined with a thin black, dashed line and the Forsmark candidate area with a thick black, solid line. GSD-terrängkartan © Lantmäteriet Gävle 2001, permission M2001/5268.*

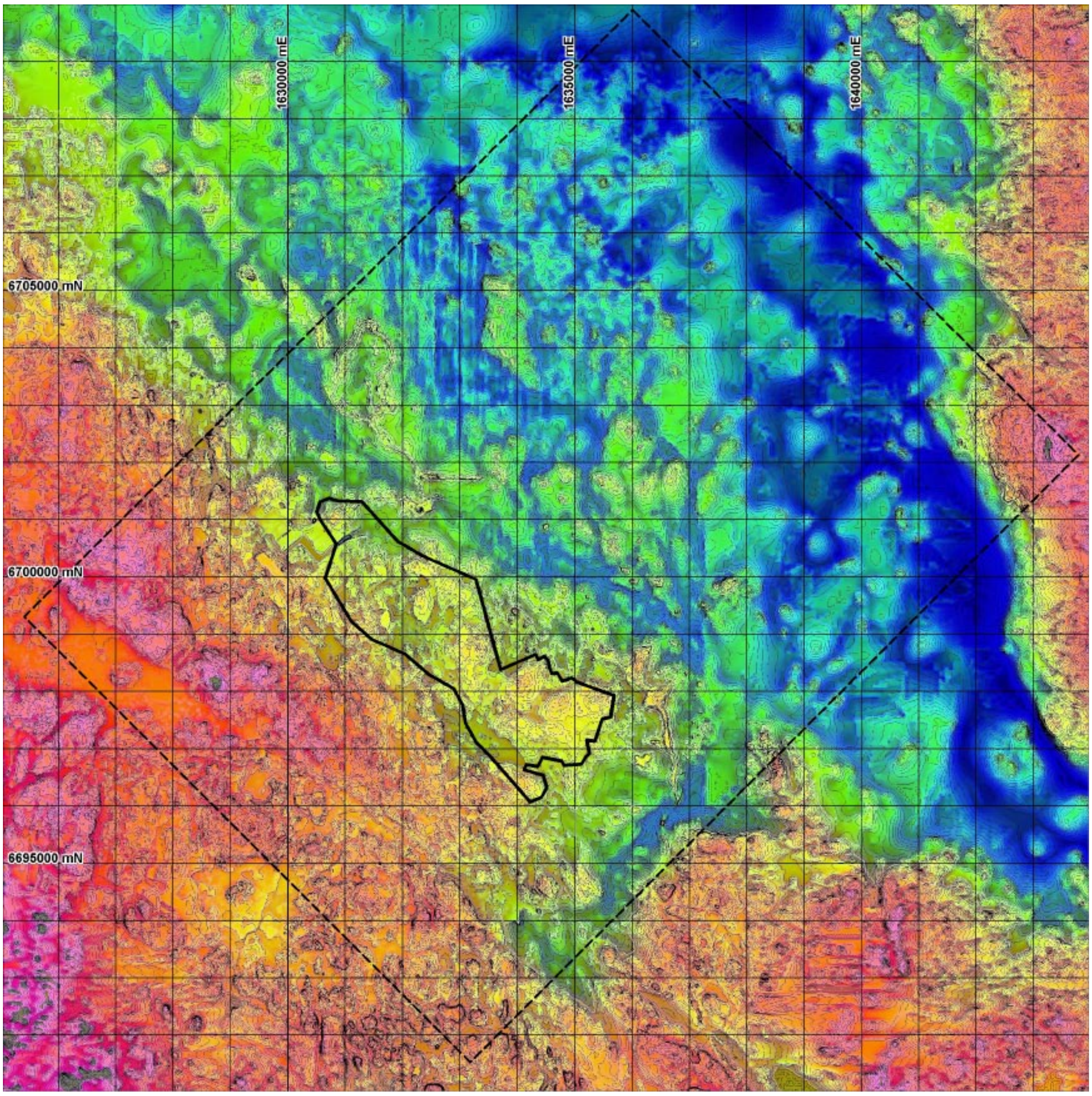


Figure 4-2. *The combined ground surface topography based on topographic and bathymetric data in Figure 4-1, structurally enhanced. The site descriptive model area is outlined with a black, dashed line and the Forsmark candidate area with a black, solid line. Note the data boundary effect in north – south along approximately 1637300. North-south stripes around 1633000, 6705000 are due to small levelling or gain errors in the EM-data /5/. Permission to publish: Sjöfartsverket 010305-04-17297:22.*

4.2 Lineament identification in the coastal area

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

A total of 467 topographical lineaments were identified in the coastal area as presented in Figure 4-3. The lineaments are stored in a GIS-format with the same attribute table as presented in Chapter 3. The most important attributes in this stage are presented in Table 4-1.

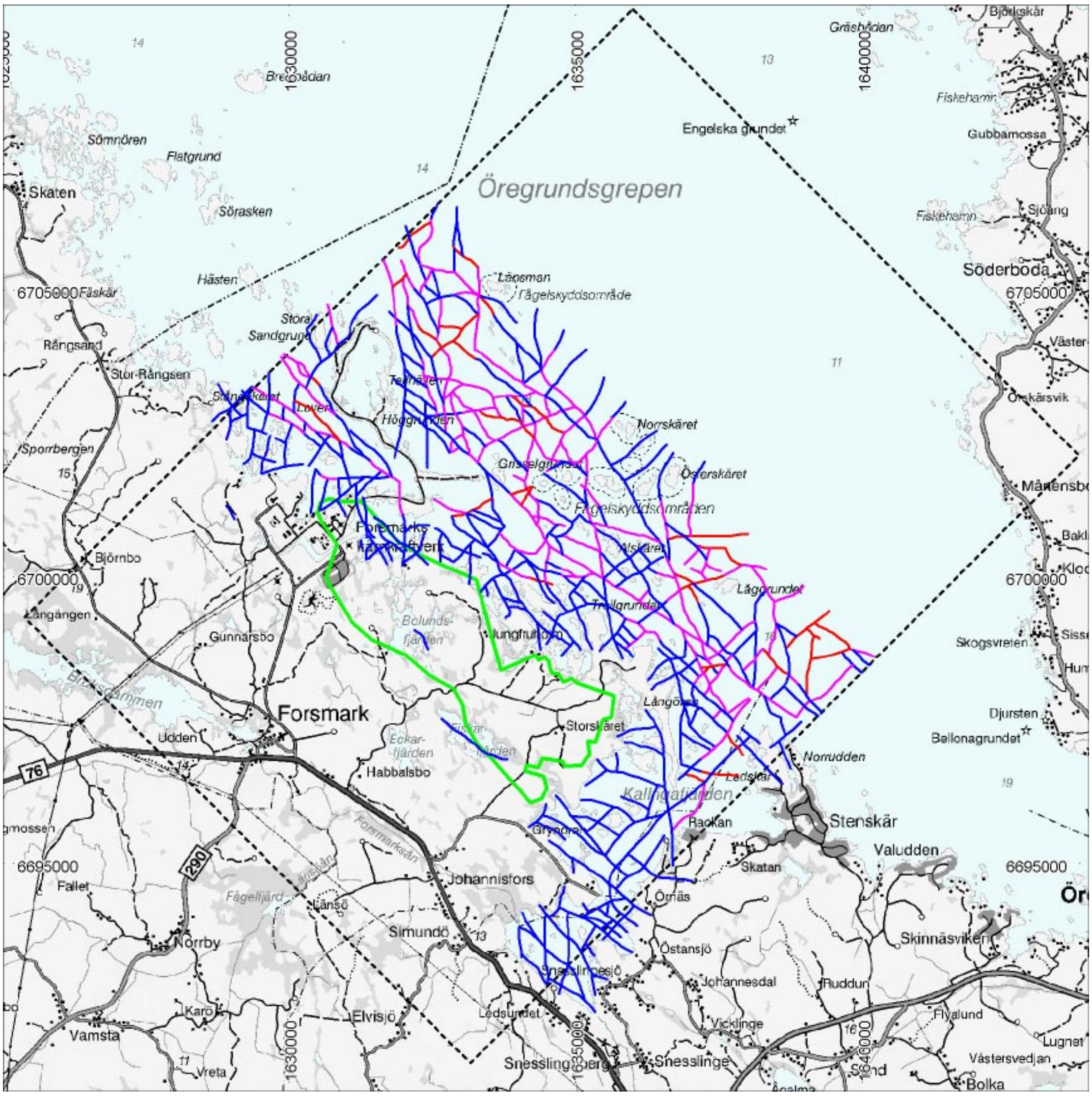


Figure 4-3. *Topographic lineaments identified in the coastal area. Blue = Lineaments identified in sea bottom, ground surface only. Red = Lineaments identified in bedrock surface only. Magenta = Lineaments identified in sea bottom, ground surface and bedrock surface. The site descriptive model area is outlined with a black, dashed line and the Forsmark candidate area with a green, solid line. Background © Lantmäteriverket, Gävle, 2001 permission M2001/5268.*

Table 4-1. Important attributes selected from the lineament attribute table.

Field name	Description	Attributes
Method	The type of data in which the observation is identified.	Bathy = sea bottom surface, marine geological survey. EM-bathy = sea bottom surface, EM inversion. Rock = bedrock surface (marine seismic). Topo = structure mainly above shoreline (only 4 occurrences).
Uncertainty	Gradation of identification, in terms of uncertainty.	1 = Low 2 = Medium 3 = High.
Topog	Identification in ground surface.	1 = Yes, 0 = No.
Topor	Identification in bedrock surface.	1 = Yes, 0 = No.
Topo	Identification in either ground or bedrock surface.	1 = Yes, 0 = Not applicable.

The access to both ground surface and bedrock surface data makes it possible to investigate how many of the different bathymetric lineaments that have been identified in either of the surfaces or in both and with what clarity. Results of this comparison are presented in Table 4-2, but can also be seen in Figure 4-3.

Table 4-2. Comparison between number of lineaments identified in ground and/or rock surface and the uncertainty.

Attribute	Low uncertainty	Medium uncertainty	High uncertainty	Total
Topog, only	35	177 *	97 **	309
Topor, only	7	17	15	39
Topog and Topor	39	68	12	119
Total	81	262	124	467

Two lineaments were identified in the lake bathymetrical data /9b/: one in Fiskarfjärden * and one in Bolundsfjärden **, Figure 4-3.

Uncertainties

The identified lineaments are graded in low, medium and high uncertainty (1, 2 and 3) mainly with respect to the clarity in which they appear as noted in Section 4.2. However, also some other specific uncertainties can be pointed out regarding the lineaments and their character.

The two major data sets used in the interpretation are based on different survey line directions and in this way give complementary information. The inversion data are based on airborne survey lines with a NS direction, while the marine geophysical survey was carried out in a SW-NE line direction. This will make it easier to identify structures with an EW extension (that is, approximately EW ± 30°) in the first case and SE-NW direction in the latter case. However, lineaments oriented NS to NE-SW will be more difficult to identify and are possibly underestimated.

Boundary effects between different survey data as well as anomalies along the survey lines give higher uncertainty in the identification. North-south stripes in the sea bottom data in the area between Biotestsjön and the island Länsman, Figure 4-2, are due to small levelling or gain errors in the EM-data /5/. Hence, the lineaments identified in this area with NS extensions are mainly identified or confirmed by the marine geological data.

Horizontal to sub-horizontal structures are difficult to identify.

5 The Forsmarksverket area

5.1 Input data

The following three data sources have been used for the lineament interpretation of the Forsmarksverket area.

Extensive refraction seismic surveys were carried out in connection with the construction of Forsmarksverket in the 1970's, and later for the construction of SFR /3/. The available information provides the possibility to identify lineaments both in the ground and rock surface, and also indications of sections with low rock velocity and to some extent, connections of low velocity indications between survey lines.

Many maps from the feasibility and construction work contain information about the topographic setting in the Forsmarksverket area prior to the construction work in both overview and detailed scales /3/.

A small area within the Forsmarksverket area has also been subject to other ground geophysical surveys; magnetic Z-anomaly and EM slingram /3/.

5.1.1 Refraction sesmic data

The refraction seismic data, delivered in /3/, was restructured into a shot-point orientated information table, adapted for the processing of ground and rock surface elevation. The table structure is described in Table 5-1. Observe that all depth and elevation figures used refer to the local levelling system (RH70 + 100 m).

Table 5-1. Structure of shot-point orientated refraction seismic data. Note: all velocities are compression wave velocities (P-wave velocities).

Field name	Alias	Data type	Size	Contents
Start_date		date	8	Start date for the field survey
Stop_date		date	8	Stop date for the field survey
Idcode		string	12	New idcode received from SKB
Old_id		string	12	Old id in reports
Length		double	9	Point location along the profile
Northing		double	12	Northing coordinate in RT90
Easting		double	12	Easting coordinate in RT90
Depth_to_r		double	14	Depth to rock in meter. (Ground elevation minus Rock elevation)
Ground_ele		double	14	Ground elevation in meter.
Rock_eleva		double	14	Rock elevation in meter.
Comment		string	11	Occurrence of ytberg (fractured rock surface)
L1		double	10	Ground surface elevation, layer 1
L1_N		long	9	Velocity in m/s in layer 1
L1_T		string	9	Layer 1 description, soil, mud, peat
L2		double	10	Elevation where layer 2 starts
L2_N		long	9	Velocity in m/s i layer 2
L2_T		string	9	Layer 2 description, soil, mud, peat

Field name	Alias	Data type	Size	Contents
L3		double	10	Elevation where layer 3 starts
L3_N		long	9	Velocity in m/s i layer 3
L3_T		string	9	Layer 3 description, soil, mud, peat
R1		string	9	Level for the first rock layer
R1_N		string	9	Velocity for the first rock layer
R1_T		string	9	Rocklayer description, always rock
R2		string	9	Level for the second rock layer
R2_N		string	9	Velocity for the second rock layer
R2_T		string	9	Rocklayer description, always rock
R3		string	9	Level for the third rock layer
R3_N		string	9	Velocity for the third rock layer
R3_T		string	9	Rocklayer description, always rock
R4		string	9	Level for the fourth rock layer
R4_N		string	9	Velocity for the fourth rock layer
R4_T		string	9	Rocklayer description, always rock

Ground and rock surface elevation data

In this work, the ground elevation and rock elevation data have been interpolated to a 10 m grid for each of the variables, using linear Kriging (Surfer 8). The grid data have been processed mainly with edge sharpening filters and slope calculations to enhance linear features. Also 1 m elevation contours have been produced. A map of the ground elevation and rock elevation is presented in Section 5.2.1 (Figure 5-2a,b and 5-3a,b). Data from two refraction seismic profiles 1 km north of SFR were added at the final stage of the interpretation work and is not included in the interpolated grids. However, the depth information in the survey shot points has been studied to confirm other bathymetric or bedrock surface lineaments (Chapter 4).

Velocity data

The refraction seismic survey and interpretation techniques normally adapted at the time of the surveys in Forsmark resulted in a description of the layering and the corresponding velocities in the ground. The description of the velocity in the bottom-most layer (the bedrock) covered every point where there was a geophone i.e. the velocity profile of the bedrock was more or less continuous along the surveyed section. However, reliable results of the velocities and thicknesses of the individual layers above the bedrock were normally only achieved in the shot points. In summary, this gives a discrete description of thicknesses and velocities of the layers above the bedrock and a roughly continuous description of the bedrock velocity, see Figure 5-1. Information on rock and soil velocity is thus available in two forms:

- One data set, henceforth referred to as “line data” consists of data with information on rock velocity for each surveyed section as well as the start and end coordinates of the sections.
- Another data set, henceforth referred to as “shot point data”, carries the information on thickness and velocity for soil and rock layers in every shot point, Table 5-1. Here also a vertical velocity “sounding” in the bedrock can be included. Shot points typically occur with a separation of 35 m but 25 m is also common.

In this work, both data sets have been transferred to GIS format.

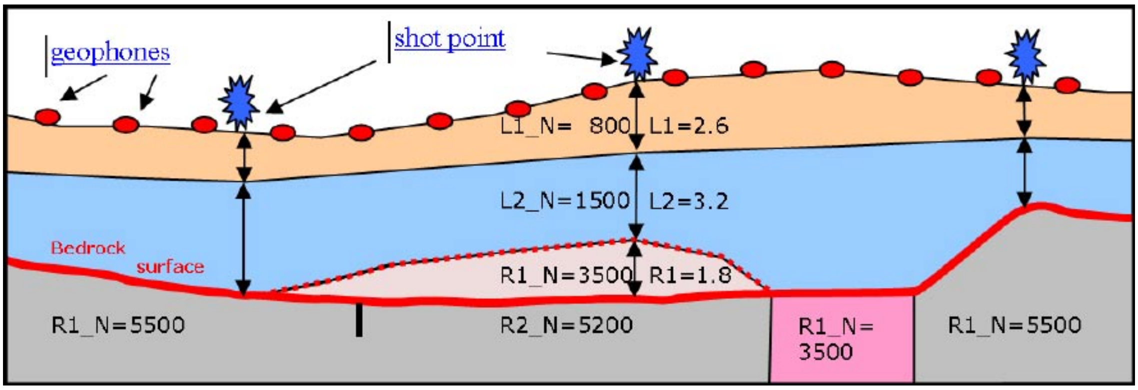


Figure 5-1. *Refraction seismic, vertical section. The red solid line outlines the bedrock surface. A horizontal projection of the bedrock velocity in the section corresponds to the velocity "line data". The red, dotted line outlines a fractured bedrock unit at the surface of the intact bedrock. At the central shot point an example is given on parameters of the "shot point" table, Table 5-1, including data for two soil layers and two rock layers.*

5.1.2 Surface plan, map data

The old topographic maps of the ground and rock surface form a complementary source of information. Commonly, the ground and rock elevation is expressed with 1 m contours. The following surface plans have been used for the topographic lineament interpretation. The identities are the ones found in the Vattenfall archive /3/:

- bedrock surface map 748291,
- bedrock surface map 905015,
- bedrock surface map 905016,
- ground surface map 742499 blad 1–7 (sheet 1–7),
- ground surface map 973531 blad 1–3 (sheet 1–3).

An example of a surface plan map is presented in Section 5.2.2 (Figure 5-4). It shows the topographic setting in the area around Forsmarksverket, reactor 1, 2 and 3 prior to the construction work.

5.1.3 Ground magnetic and EM data

The ground geophysical surveys cover an area of approximately 0.6 km^2. Station and line spacing are 10 m and 40–50 m respectively. The SE part (around Forsmarksverket, reactor 3) is measured in two perpendicular directions, EW and NS and the area further to the NW is measured in EW direction (Section 5.2.3, Figure 5-12). The magnetic Z-anomaly and slingram EM, in-phase and out-of-phase components are all gridded to a 10 m grid using minimum curvature (Surfer 8).

5.2 Lineament identification

The 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 noted that this work has been carried out in the scale of 1:5,000–1:10,000, concentrating on major two-dimensional features. However, the original information, either in paper form or as digitized data, provides more detailed information both regarding the soil cover and the local bedrock conditions than what is extracted in the present activity.

5.2.1 Ground and rock surface topographic lineaments

The topographic data described in Section 5.1.1 and 5.1.2 have formed a basis for a data set of ground and rock surface topographic lineaments in the Forsmarksverket area, see also Figure 3-2.

A total of 96 topographical lineaments were identified in the Forsmarksverket area, as presented in Figure 5-2b and 5-3b. 68 lineaments have been identified in the seismic refraction ground surveys and 28 lineaments in the surface plan maps. The lineaments are stored in GIS-format with the same attribute table structure as presented in Chapter 3. The most important attributes are presented in Table 5-2.

Table 5-2. Selection of important attributes in the lineament attribute table.

Field name	Description	Attributes
Method	The type of data in which the observation is identified	Bathy = sea bottom surface, surface maps Rock = bedrock surface (refraction seismic or surface maps) Topo = ground surface (refraction seismic or surface maps)
Uncertainty	Gradation of identification, in terms of uncertainty	1 = Low 2 = Medium 3 = High
Topog	Identification in ground surface	1 = Yes, 0 = No
Topor	Identification in bedrock surface	1 = Yes, 0 = No
Topo	Identification in either ground or bedrock surface	1 = Yes, 0 = Not applicable

The access to both ground surface and bedrock surface data makes it possible to investigate how many of the different topographic lineaments that have been identified in either of the surfaces or in both and with what uncertainty. Results of this comparison are presented in Table 5-3, but can also be seen in Figure 5-2b and 5-3b.

Table 5-3. Comparison between number of lineaments identified in ground and/or rock surface and the uncertainty.

Attribute	Low uncertainty	Medium uncertainty	High uncertainty	Total
Topog, only	0	5	19	24
Topor, only	8	24	4	36
Topog and Topor	5	25	6	36
Total	13	54	29	96

Figure 5-4 presents the identified lineaments overlaying a topographic surface map of the area around Forsmarksverket, reactor 1, 2 and 3 prior to construction work. Most of the area is presently covered by extensive landfill. Noteworthy is that a NS trending lineament, identified only in the ground surface, occurs in the present position for reactor 1. This topographic depression is also seen in an old geological map from the year 1887 /13/, Figure 5-5. A topographic lineament identified also in the bedrock surface occurs in the position of reactor 3. However, these features have not been investigated further in this work; see also comment in Uncertainties, below.

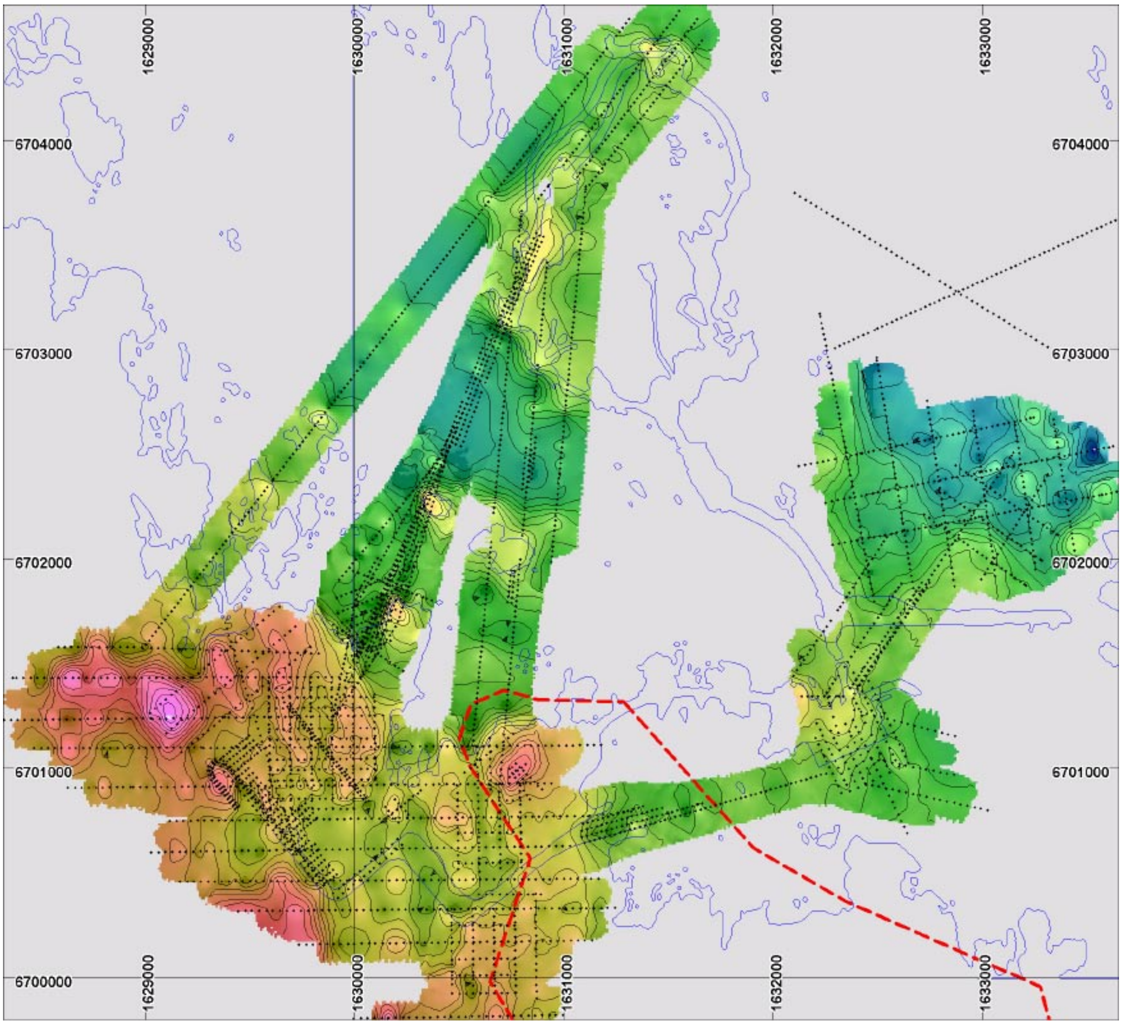


Figure 5-2a. *Ground surface elevation based on refraction seismic surveys, dotted lines. 1 m contour, dark blue colour at 83 m, magenta colour at 114 m. Sea level at 100 m. Forsmark candidate area as a red, dashed line. GSD-Fastighetskartan © Lantmäteriet, Gävle 2001, Permission M2001/5268.*

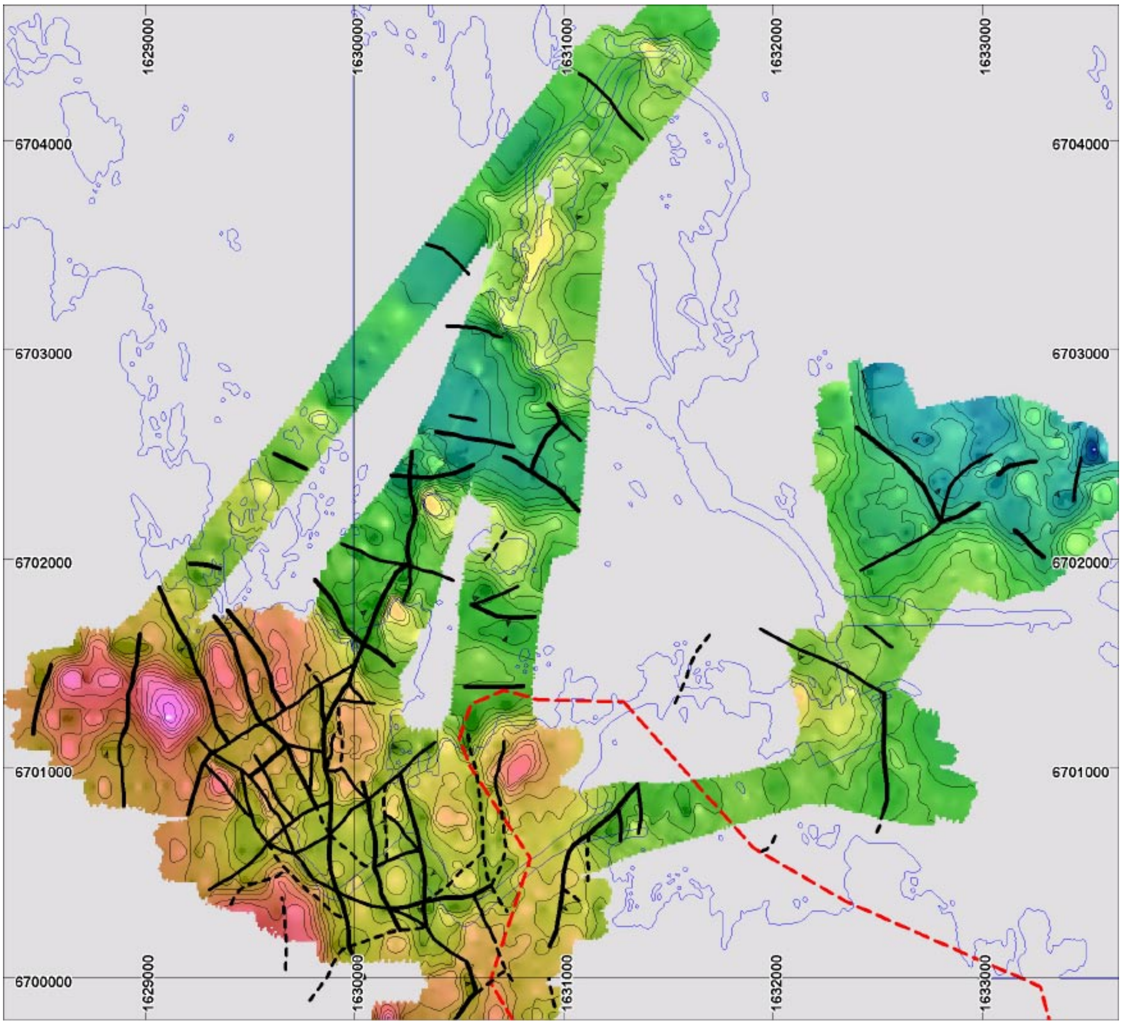


Figure 5-2b. *Same as 5-2a with the identified ground and rock surface lineaments superimposed. Lineaments identified in rock surface, solid black line. Lineaments identified in ground surface only, dashed black line.*

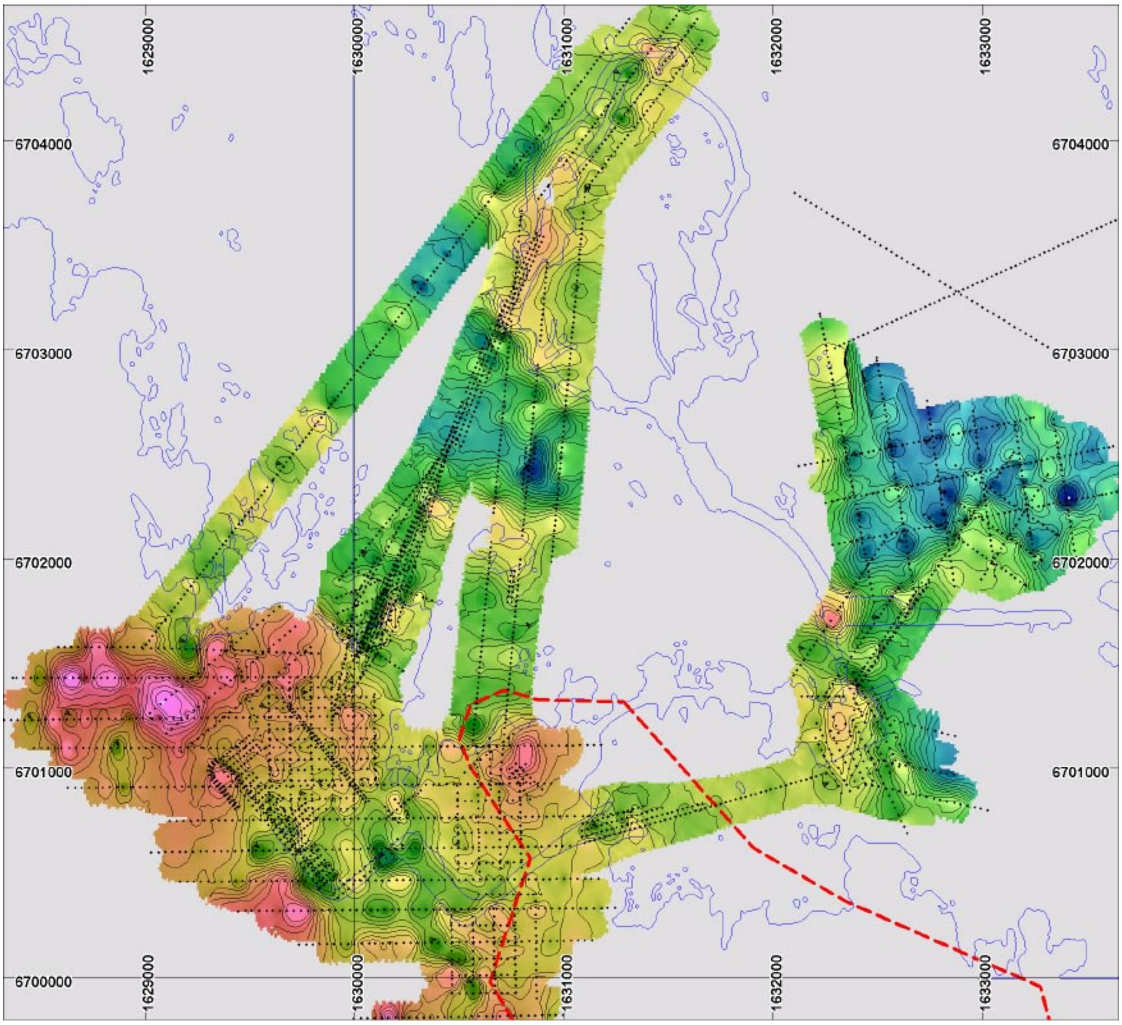


Figure 5-3a. *Bedrock surface elevation based on refraction seismic surveys, dotted lines. 1 m contour, dark blue colour at 77 m, magenta colour at 112 m. Sea level at 100 m. Forsmark candidate area as a red, dashed line. GSD-Fastighetskartan © Lantmäteriet, Gävle 2001, Permission M2001/5268.*

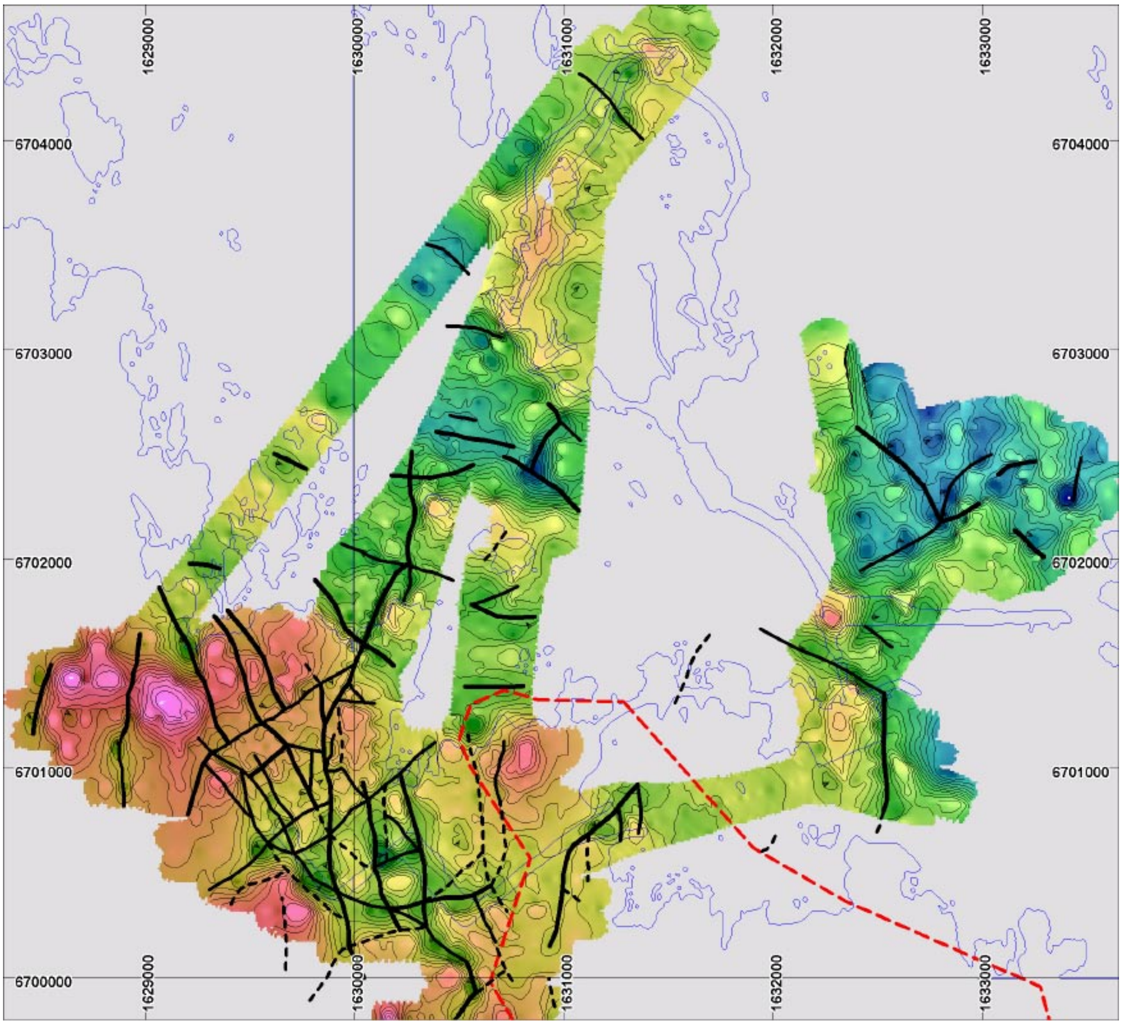


Figure 5-3b. Same as 5-3a with the identified ground and rock surface lineaments superimposed. Lineaments identified in rock surface, solid black line. Lineaments identified in ground surface only, dashed black line.

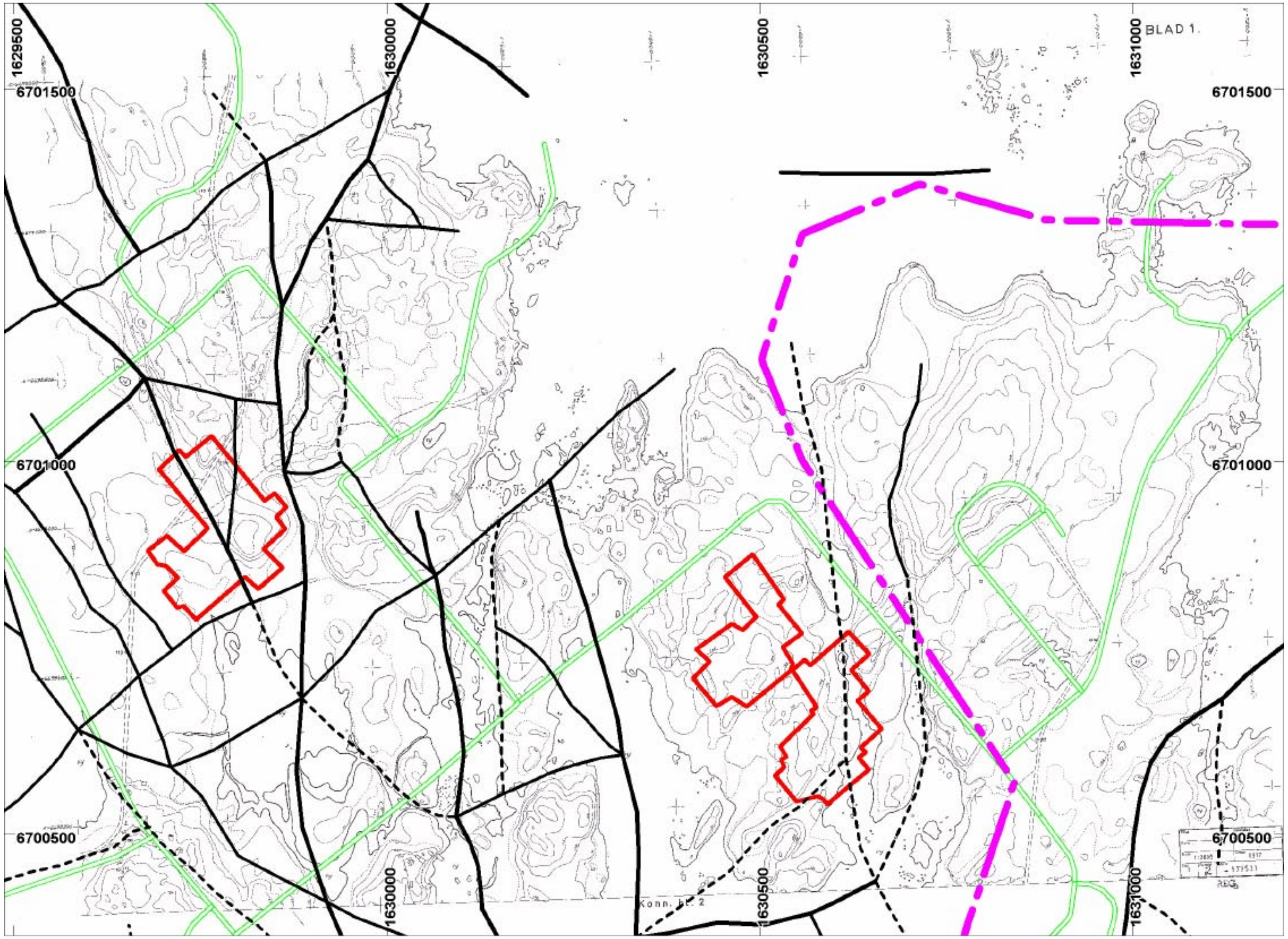


Figure 5-4. *Topographic surface map (1 m elevation contours) around Forsmarksverket reactor 1, 2 and 3 (in red) prior to the construction work overlayed by the identified lineaments (same as in Figure 5-2b). The Forsmark candidate area is outlined with a magenta, dot-dashed line. Present location of roads in green, from GSD-Fastighetskartan © Lantmäteriet, Gävle 2001, Permission M2001/5268.*

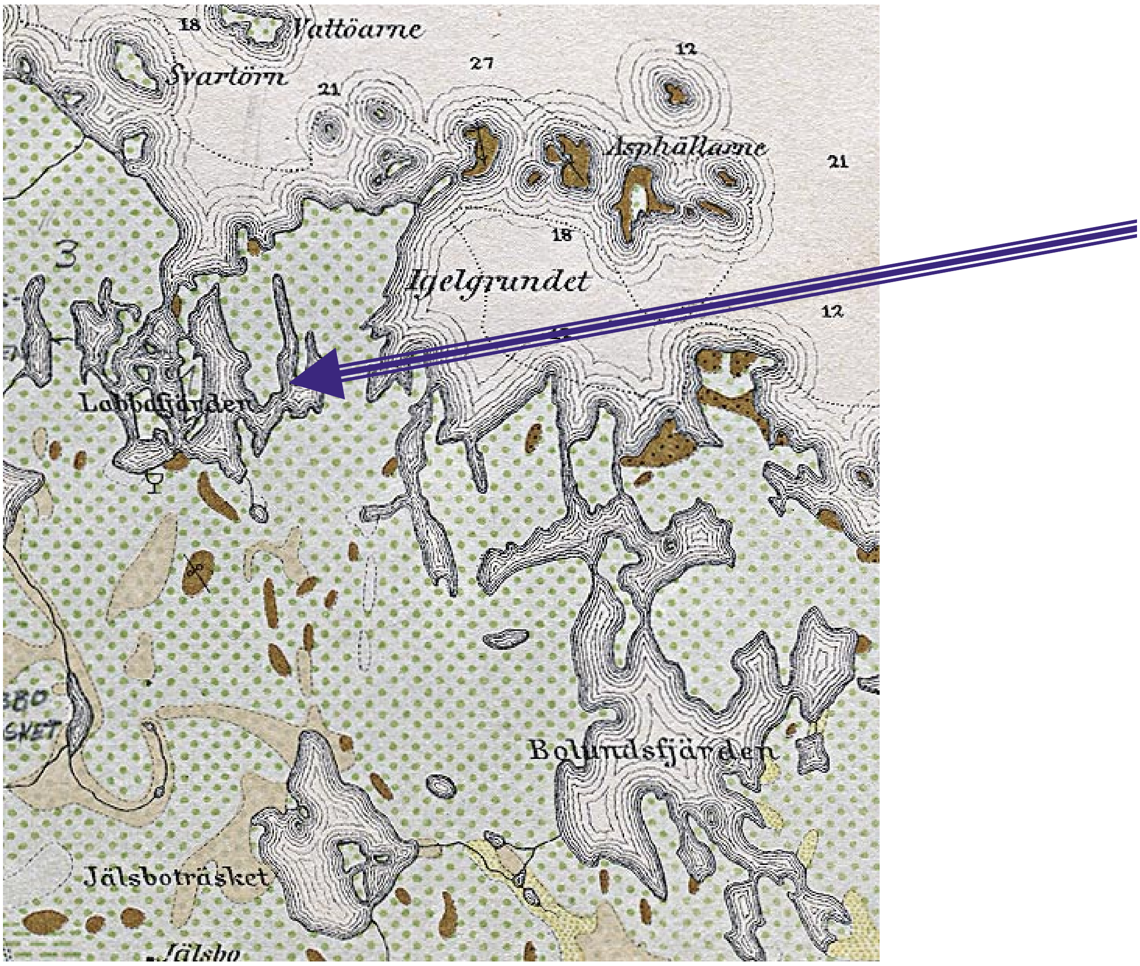


***Figure 5-5.** Geological map SGU Aa 98/9, "Beskrifning till kartbladen Forsmark och Björn" /13/, showing the shoreline location at around 1887. The blue arrow points to the present location of Forsmarksverket, reactor 1 and 2.*

Uncertainties

The identified lineaments are graded in low, medium and high uncertainty (1, 2 and 3) mainly with respect to the clarity in which they appear as noted in Chapter 3. However, also some other specific uncertainties can be pointed out regarding the lineaments and their character.

The seismic refraction data is rather irregular in the spatial coverage and hence, the possibility to identify lineaments in different directions varies in the area. In a few cases, uncertain lineaments extending along a survey line have been verified by perpendicular seismic lines.

The lineaments identified in the Forsmarksverket area have not, in this activity, been verified against other geological information obtained during the constructions /3/. Such a validation would most likely deepen the understanding of the significance and character of the lineaments.

Uncertainties regarding refraction seismic velocity are also discussed in Section 5.2.2.

5.2.2 Low velocity indications in rocks

In stage 1, low velocity indications were to some extent used to upgrade lineaments to fracture zones (phase IV of the lineament integration methodology, see Chapter 3). In the present activity, stage 2, this phase of the work was not carried out.

Hence, the following information concerning the rock velocity data in the Forsmarksverket area forms a basis for further geological modelling and analysis work. No "rock velocity lineament" has been included in the coordination or linking process.

Rock velocity

Velocity determinations in both line data and shot point data have been used to study the rock velocity distribution in the area, Figure 5-6. Of the 107.2 km line data, only 2.0 km or 2% of the total length show rock velocities ≤ 4,000 m/s, Figure 5-6a. An additional 3.1 km, or 3%, show velocities between 4,000–4,500 m/s. About 24% (25.1 line-km) show velocities above 5,500 m/s. The high rock velocities in the area indicate an overall solid bedrock.

The shot point rock velocity data set, Figure 5-6b, also includes velocity determinations in the fractured bedrock surface. In this case velocities ≤ 4,000 m/s constitute 15% of the total amount of determinations, which shows that occurrences of superficial fractured bedrock are common. In this activity, velocities at 4,000 m/s or below are considered as probable fracture zones, which corresponds to previous assessments made in the primary evaluations during the construction work, Figure 5-7 /14, 15/. Velocities in the range 4,000–4,500 m/s can possibly indicate fracture zones and should be studied more carefully, ≤ 4,200 m/s is sometimes mentioned as the threshold for fracture zone indications and below 4,800 m/s as possibly containing narrow sections of fractured rock /15/. Rock velocity at or above 4,500 m/s is generally considered to indicate good rock quality. Figure 5-7 shows an interpretation template typical for the interpretation of refraction seismic data at Forsmarksverket /14/.

Soil velocities have not been studied in this work.

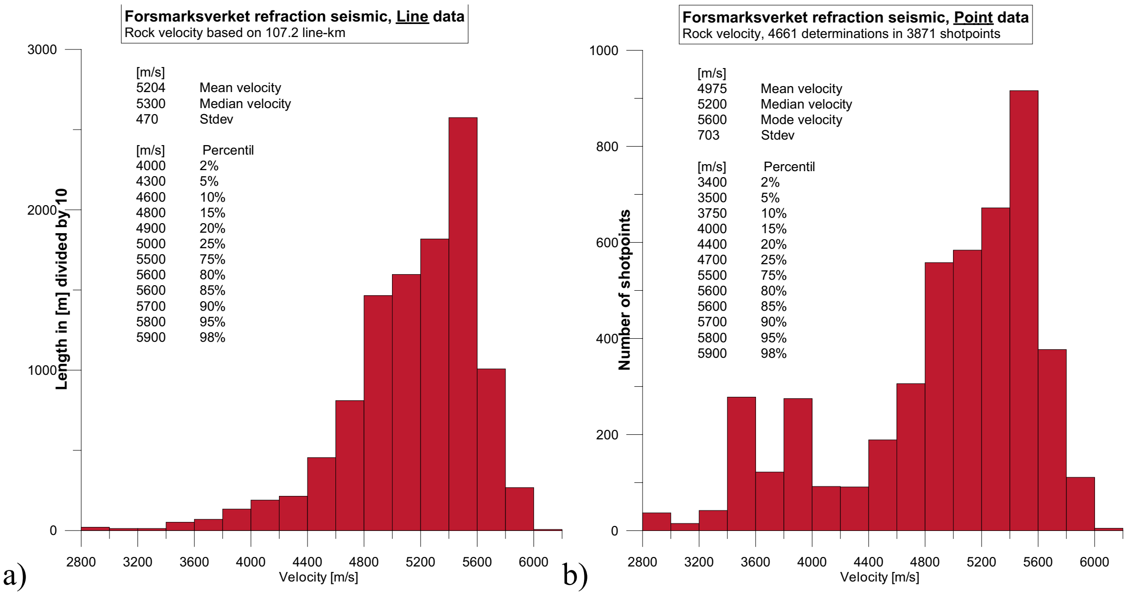
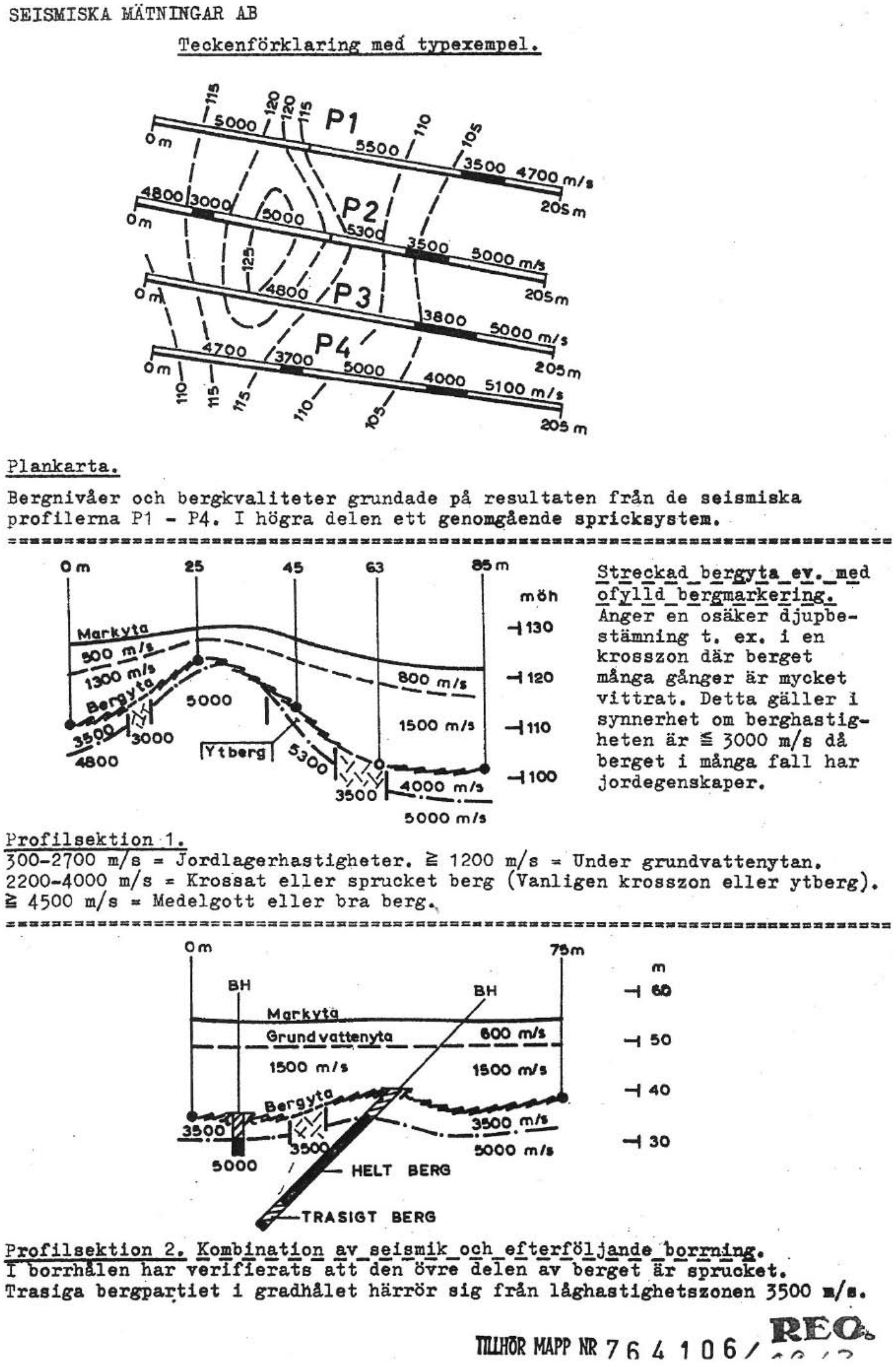


Figure 5-6. *Rock velocity distribution based on a) refraction seismic line data and b) refraction seismic velocity determinations in shot points.*



SEISMISKA MÄTNINGAR AB

Teckenförklaring med typexempel.

Plankarta.

Bergnivåer och bergkvaliteter grundade på resultaten från de seismiska profilerna P1 - P4. I högra delen ett genomgående spricksystem.

Streckad bergyta ev. med ofylld bergmarkering. Anger en osäker djupbestämning t. ex. i en krosszon där berget många gånger är mycket vittrat. Detta gäller i synnerhet om berghastigheten är ≦ 3000 m/s då berget i många fall har jordegenskaper.

Profilsektion 1.

300-2700 m/s = Jordlagerhastigheter. ≧ 1200 m/s = Under grundvattenytan.

2200-4000 m/s = Krossat eller sprucket berg (Vanligen krosszon eller ytberg).

≧ 4500 m/s = Medelgott eller bra berg.

Profilsektion 2. Kombination av seismik och efterföljande borrning.

I borrhålen har verifierats att den övre delen av berget är sprucket.

Trasiga bergpartiet i gradhålet härrör sig från låghastighetszonen 3500 m/s.

Figure 5-7. Template (in Swedish) for seismic refraction surveys during the construction of Forsmarksverket /14/.

Low rock velocity indications

The refraction seismic line data form the most important data set for identifying low rock velocity. The line data set, Figure 5-8, shows continuous sections, while the shot point data set, Figure 5-9, shows the situation at the shot point only.

The presentation of velocity data in Figure 5-8 and 5-9 is divided into 500 m/s intervals, from ≤ 3,000 m/s up to above 5,500 m/s. As mentioned in the rock velocity section, velocities at 4,000 m/s or below probably indicate fracture zones and such sections are highlighted in Figure 5-10. Sections with velocity in the interval 4,000–4,500 m/s are in some cases mentioned as possibly containing narrow fracture zones /15/, and their distribution can be studied in Figure 5-8.

At a first glance it seems rather obvious that low velocity indications can be connected between the survey lines. However, results from adjacent or crossing survey lines commonly show contradictory results and disconnects the possible zone. In many cases it is also not conclusive in what direction a connection should be made. The few cases with connected low velocity indications of higher confidence are presented in Figure 5-10. When low velocity indications of higher confidence coincide with identified topographical, geophysical or coordinated lineaments this has been noted as a comment in the lineament attribute tables.

As a result of the initial refraction seismic surveys in the Forsmarksverket area, reactor 1 and 2, later investigations also more carefully documented occurrences of near-surface fractured bedrock as well as deeper, intact bedrock velocities (up to 4 different rock velocities have been recorded for an individual shot point). Figure 5-11 shows locations where the determined bedrock velocity is above 4,000 m/s while the rock surface velocity is ≤ 4,000 m/s. The thickness of the fractured unit is presented in m.

In refraction seismics it is difficult or even impossible to identify flat lying features that are not outcropping. However, if a sub horizontal fracture zone is outcropping it can possibly be identified by occurrences of deeply fractured rock surface along the outcrop. This possibility has not been studied in this work.

The incoherent velocity pattern in the bedrock (below the fractured superficial bedrock) indicates that fracture zones, if they exist, probably extend with varying thickness, character and/or intensity. Fracture zones narrower than 5 m can be difficult to identify at a geophone spacing of 5 m. However; as further discussed in Uncertainties below, other reasons can not be excluded like; unfavourable profile directions, bedrock anisotropy, screening by fractured bedrock or higher velocity overburden.

Seismic refraction, low velocity connections are delivered as a GIS layer with similar attribute table as for lineaments (Chapter 3, Table 3-2). Important attributes are a comment on velocity ≤ 4,000 m/s and on estimated width along the connection.

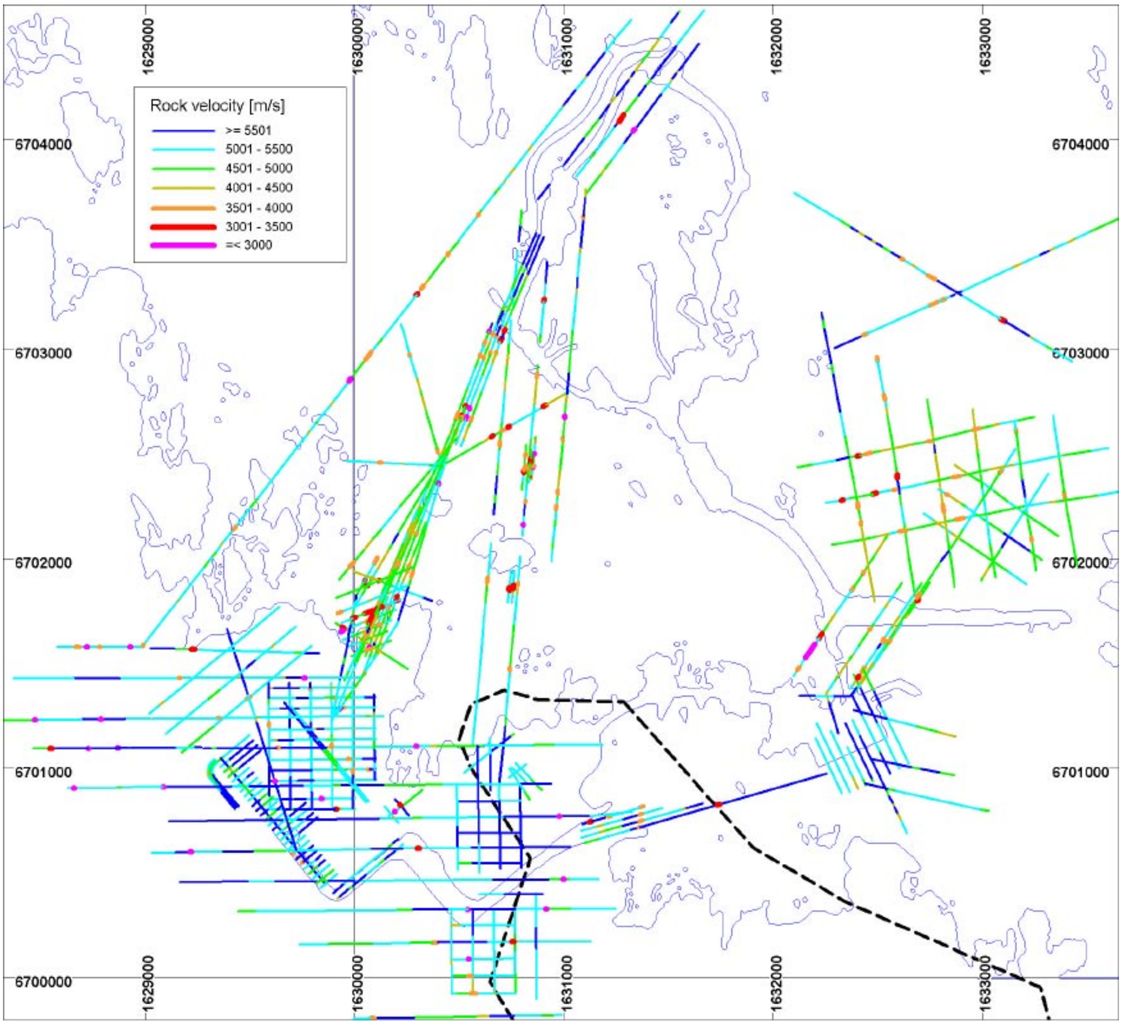


Figure 5-8. *Rock velocity in bedrock according to refraction seismic line data. Forsmark candidate area is outlined by a dashed, black line. Shoreline from GSD-Fastighetskartan © Lantmäteriet, Gävle 2001, Permission M2001/5268.*

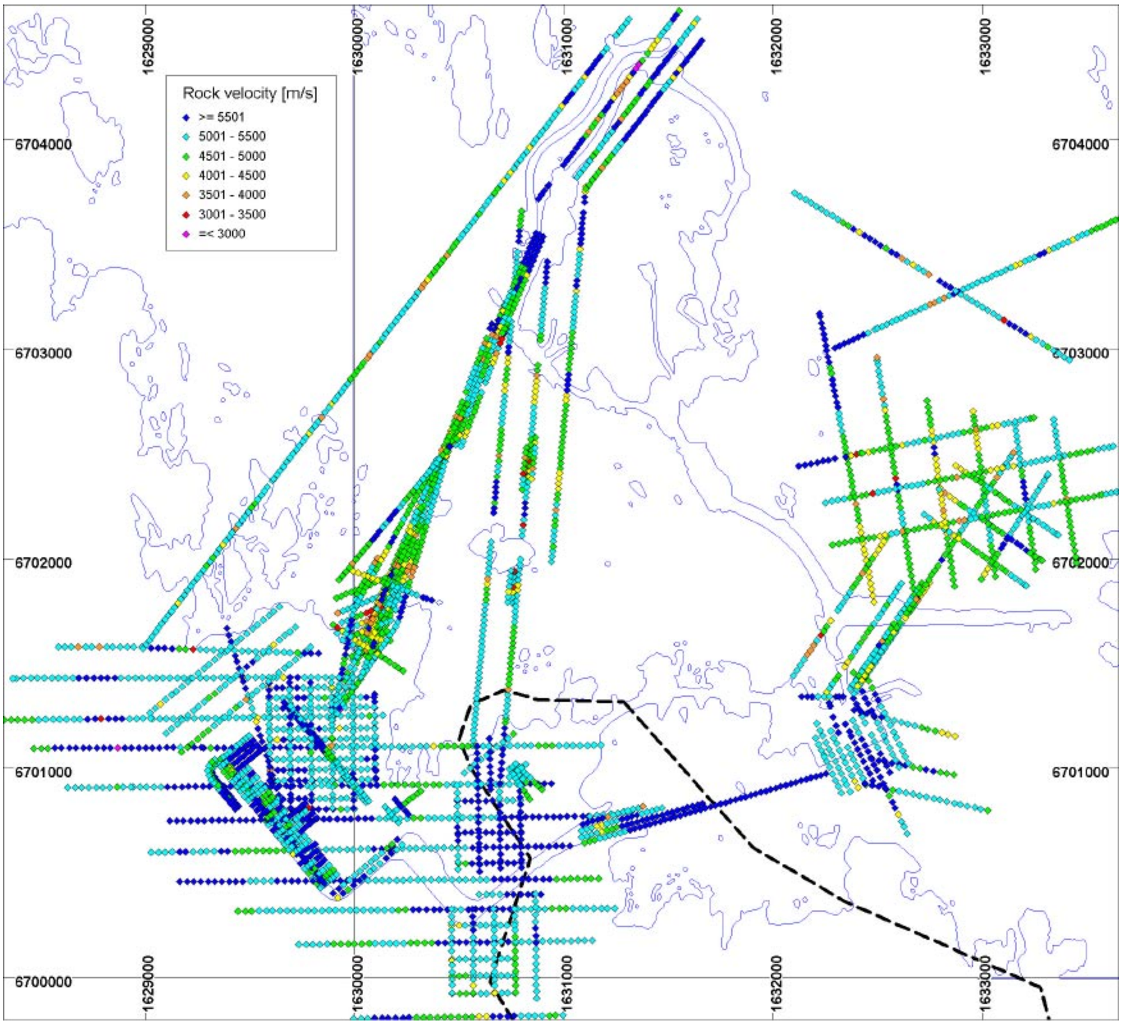


Figure 5-9. *Rock velocity in refraction seismic shot points. When several bedrock velocity layers have been reported, the highest velocity is presented on the map. The Forsmark candidate area is outlined by a dashed, black line. Shoreline from GSD-Fastighetskartan © Lantmäteriet, Gävle 2001, Permission M2001/5268.*

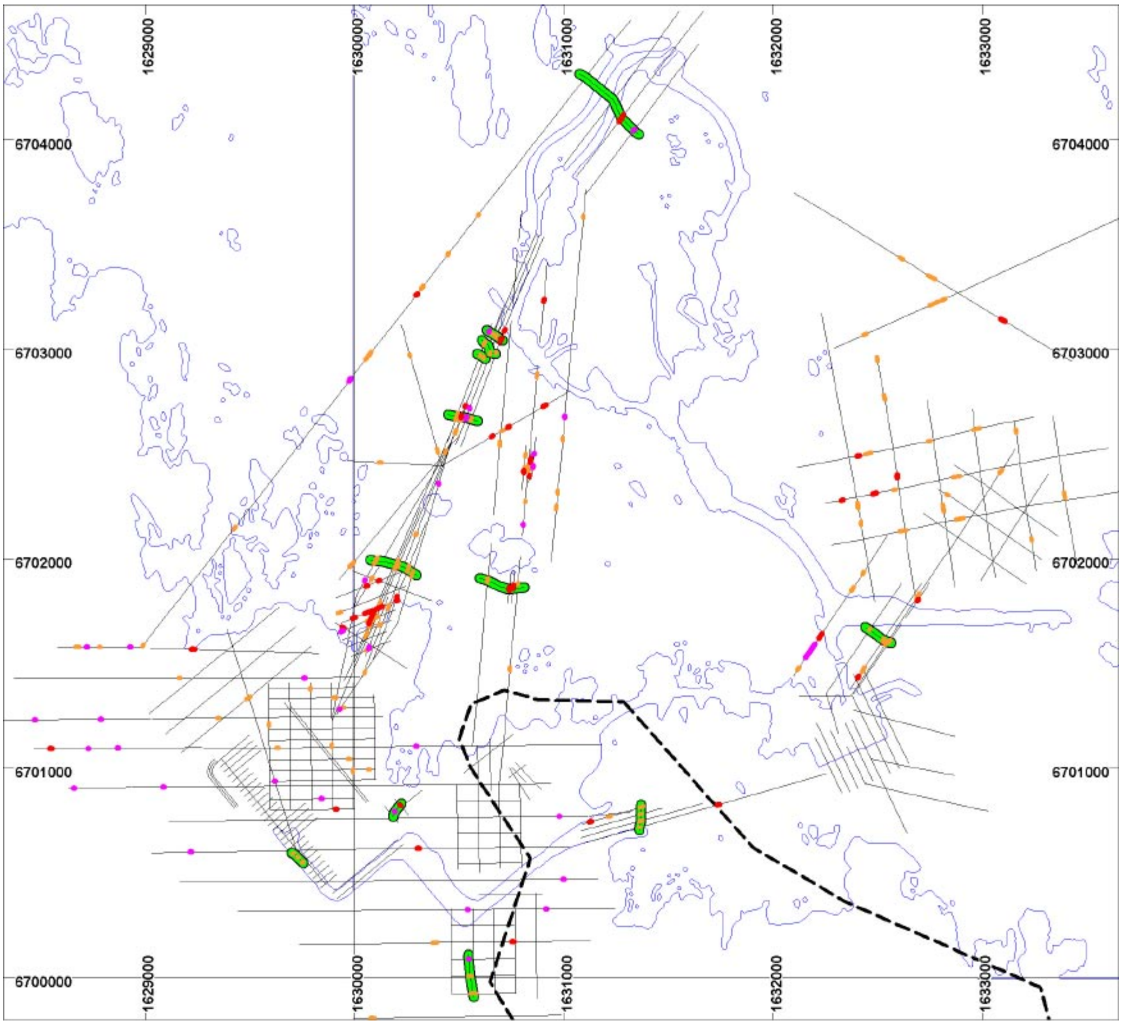


Figure 5-10. *Low velocity indications in bedrock according to refraction seismic line data. Velocity 4,000 m/s or below, see legend in Figure 5-8. Connection of low velocity indications as green thick lines marked when no contradictory information exists on adjacent lines. Forsmark candidate area is outlined by a dashed, black line. Shoreline from GSD-Fastighetskartan © Lantmäteriet, Gävle 2001, Permission M2001/5268.*

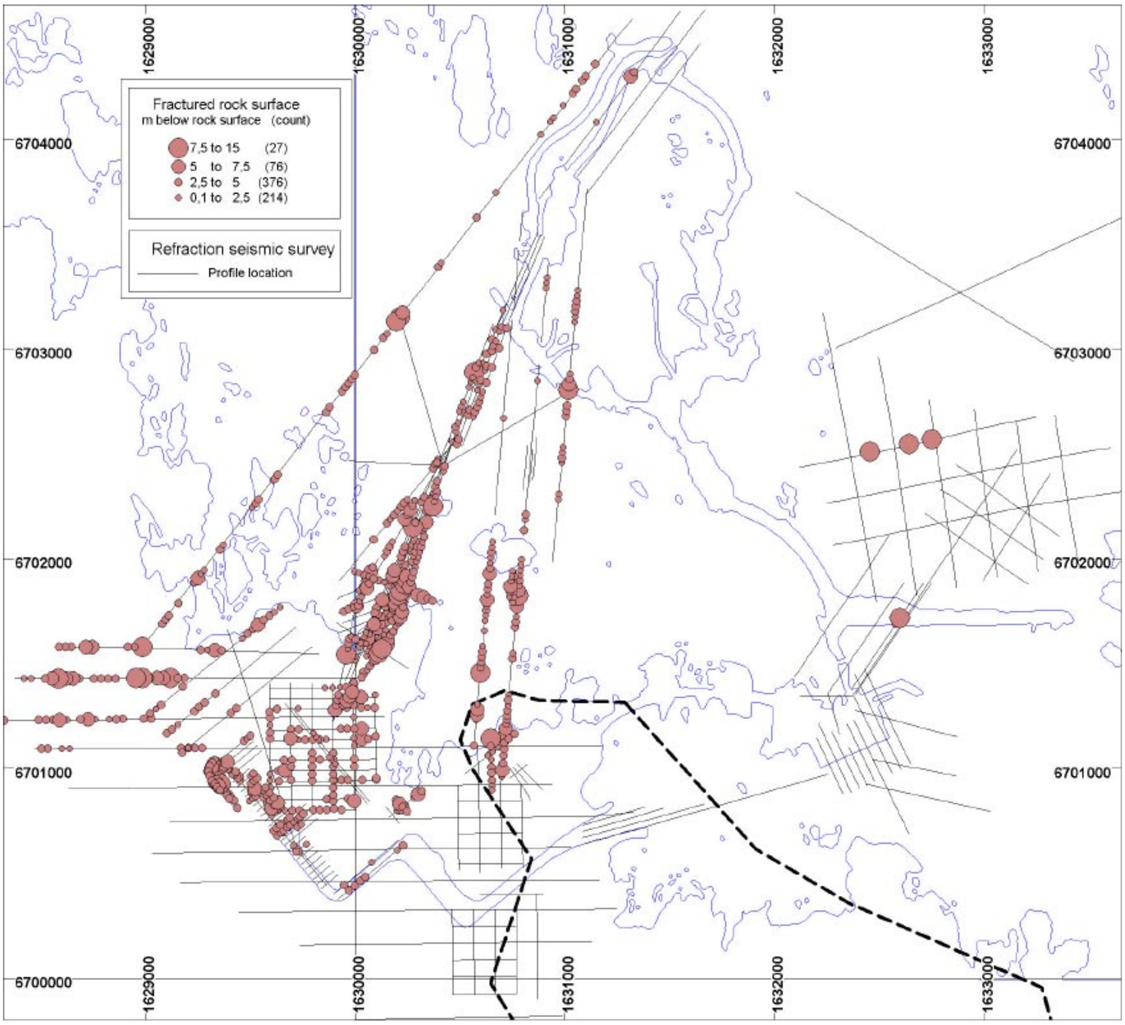


Figure 5-11. *Thickness of fractured rock at the bedrock surface is shown as brown filled circles. Observe that this feature was not recorded for older surveys, especially around Forsmarksverket, reactor 1 and 2, in the southern part of the area. Forsmark candidate area is outlined by a dashed, black line. Shoreline from GSD-Fastighetskartan © Lantmäteriet, Gävle 2001, Permission M2001/5268.*

Uncertainties

The refraction seismic line data contains information on the rock velocity but there is no explicit information on what depth it represents. However, it is clear that the stated velocity is taken at the intact rock surface, below the superficial broken or fractured rock.

The occurrence of rather deeply fractured bedrock is common in the Forsmarksverket area and hence, the previous data often involves "deep" seismic surveys. This means that the shot points are moved outwards from the survey lay out (up to 300 m) to provide better possibilities for the refraction seismic waves to propagate through the more deeply situated unfractured rock, giving a depth penetration about 40–50 m /16, 17/. The fractured bedrock can obscure the occurrences of low velocity zones in the deeper parts of the bedrock and this knowledge is important for the design and interpretation of future refraction seismic surveys in the Forsmark area.

Information on the actual geophone station spacing is lacking in about 50% of the survey reports. In the remaining 50% the geophone spacing is stated to be 5 m. This seems to be a reliable figure for all surveys since these reports cover the years 1970–1982. In the sea area, 10 m geophone spacing is noted in a few cases. Together with the velocity contrasts expected, the geophone spacing has a strong influence on the spatial resolution of the velocity determinations. If a 5 m wide, low velocity (e.g. 3,500 m/s) zone is considered, the retardation of the P-wave in the zone is less than 1.5 ms. It is normally expected that there should be an accuracy better than 0.5 ms in the picking of first arrivals. The retardation in time in the low velocity zone is then only slightly above the accuracy of the reading of the first arrival and zones narrower than 5 m may not be detected.

The shot point data set is produced by manual picking of depths and velocities for the shot point locations only. More detailed information, describing the interpretations between the shot points, is available from the original reports /3/.

Occurrences of a very hard, basal, boulder clay till called "gamle blå (old blue)", first described by Björnbom /18/, are rather common in the Forsmark area. In the previous investigations at Forsmarksverket this clay showed velocities comparable to rock velocities (Rolf Christiansson, oral communication) and hence, both rock surface depressions and fracture zones with low velocity can be screened off by this clay.

It is difficult to identify flat lying fracture zones with refraction seismic surveys.

Incorrect information due to uncertainties in the original data or errors in digitizing the material must be kept in mind /3/.

5.2.3 Ground magnetic and EM lineaments

The area covered by ground magnetic and EM surveys is rather small, and so is the number of identified lineaments. A total of 14 ground magnetic and/or EM lineaments have been identified, see Figure 5-12. 10 lineaments have been identified in the ground EM survey only, 1 lineament in the magnetic survey only and 3 lineaments have been identified in both data sets. The lineaments are stored in GIS-format with the same attribute table as presented in Chapter 3. The most important attributes in this stage are presented in Table 5-4. Magnetic lineaments identified have been transferred to the magnetic lineament interpretation, Chapter 6.

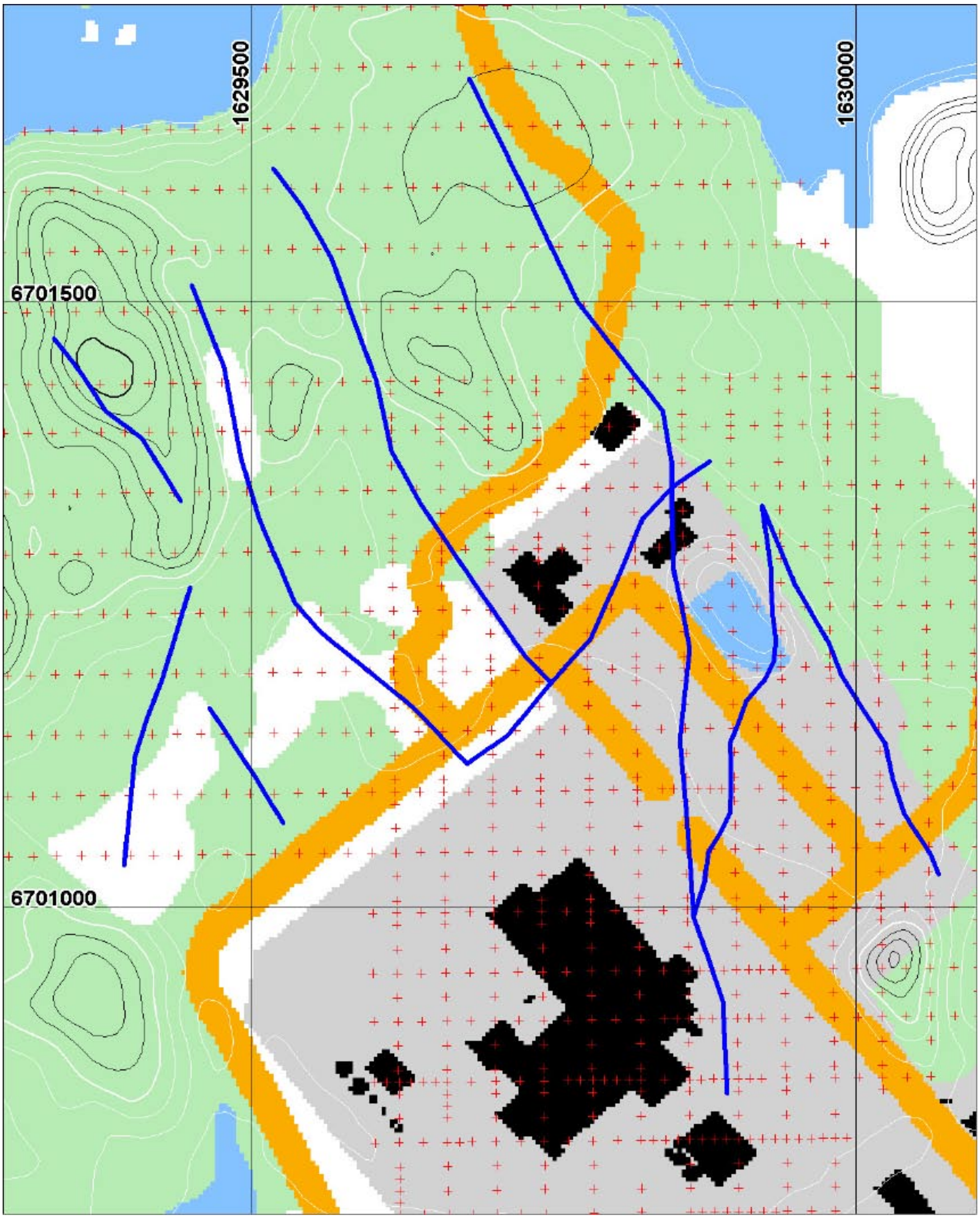


Figure 5-12. *The area around and NW of Forsmarksverket, reactor 3. The surveys stations from the ground geophysical magnetic and EM survey are indicated by red crosses. The identified geophysical lineaments are outlined as blue, solid lines. Background from GSD-Fastighetskartan © Lantmäteriet, Gävle 2001, Permission M2001/5268.*

Table 5-4. Important attributes selected from the lineament attribute table.

Field name	Description	Attributes
Method	The type of data in which the observation is identified	magn = magnetic lineament EM = electromagnetic lineament
Uncertainty	Gradation of identification, in terms of uncertainty	1 = Low 2 = Medium 3 = High

Uncertainties

The identified lineaments are graded in low, medium and high uncertainty (1, 2 and 3) mainly with respect to the clarity in which they appear. However, also some other specific uncertainties can be pointed out regarding the lineaments and their character.

The area around Forsmarksverket, reactor 3 is covered by two survey directions, Section 5.1.3, which gives a better prediction of lineaments and their trend.

It is not known if artificial sources in connection with the construction of Forsmarksverket, reactor 3 have influenced the surveys.

6 Magnetic lineaments

In connection with the geological mapping of the coastal area /19/ it was considered valuable to make an overhaul of the previous magnetic lineament interpretation carried out in 2002 /2/. The revisions are however minor and mainly limited to the coastal and sea area. After the coordination of lineaments in stage 1, no modifications have been made within the Forsmark candidate area. The anomaly pattern presented in /2/ has not been revised.

There was also a need for complementary lineament interpretation to cover the area east of the helicopter borne survey but still within the geological mapping area, Figure 6-1. Magnetic lineaments identified by the previous ground survey at Forsmarksverket (Section 5.2.3) have also been incorporated.

6.1 Input data

Input to the magnetic lineament interpretation has been the following data sets:

- Previous magnetic interpretation results from the helicopter borne survey /2/.
- Processed helicopter borne, magnetic data, NGU, 10 m grid, Figure 6-1, /2 and 12/.
- Processed air borne, magnetic data, SGU, 40 m grid, Figure 6-1, /2, 20 and 8/.
- Magnetic interpretation results from the previous ground survey at Forsmarksverket, Section 5.2.3 and Figure 5-12.

Data processing

Previously processed data from /2/ have been used in this work. In addition, a new processing method, “tilt derivative”, especially useful for structural enhancements of magnetic data has been applied /21/. The latter has contributed to a more detailed delineation of the identified lineaments.

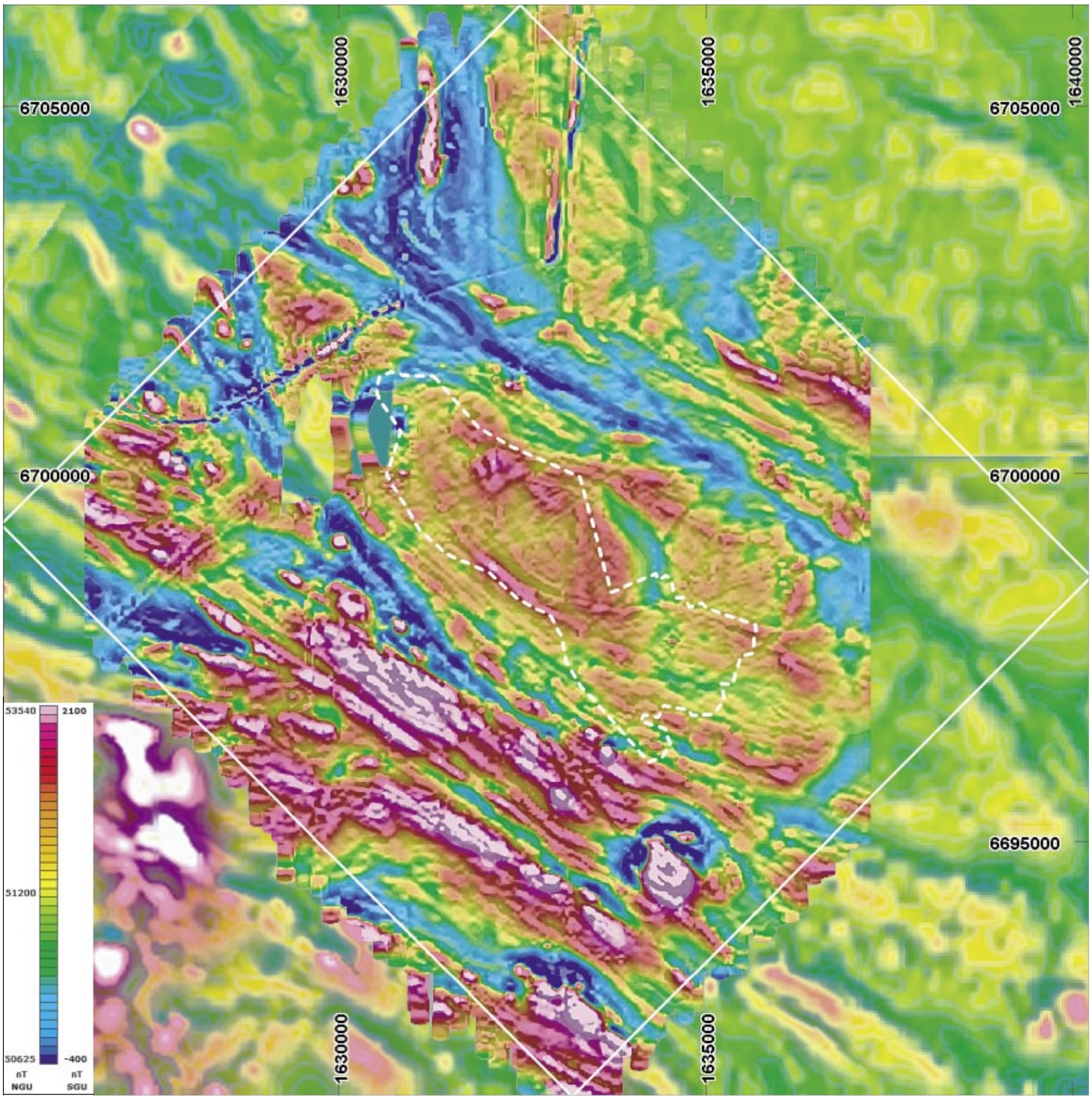


Figure 6-1. The detailed magnetic total field (NGU N-S survey), 10 m grid, superimposed with the 2:nd vertical derivative to enhance bedrock structures, surrounded by regional airborne magnetics (SGU surveys), 40 m grid. Magnetic lows in blue colours and highs in magenta colours, left and right hand side of colour table refer to the NGU survey and the SGU survey respectively. The geological mapping area is outlined with a solid white line and the Forsmark candidate area with a dashed white line. Lantmäteriet Gävle 2003, Permission 601-2003/370. © Swedish Nuclear Fuel & Waste Management Co 2004-09-29.

6.2 Results

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

Lineament identification

The outlined lineaments are linear magnetic minima and other linear dislocations in the magnetic field. 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.

The structural geology in the Forsmark area is characterised by rather strong ductile deformation of both supracrustal and intrusive rocks and also intrusive rocks often tend to show a rather strong, banded component in the magnetic pattern. Magnetic connections appearing as minima parallel to the general bedrock structures are difficult to judge as being caused by fracture zones or simply by low magnetic rock types. In this work they are identified as potential fracture zones and noted as lineaments with the separate denomination "minima connection".

In total, 318 magnetic lineaments have been identified, Figure 6-2. Based on the attached attribute table, Table 6-2, some general statistical results are presented, see Table 6-1. The interpretation results are an updated version from 2002 /2/ and hence the attribute table attached to each lineament follows an older structure, see also Table 6-2.

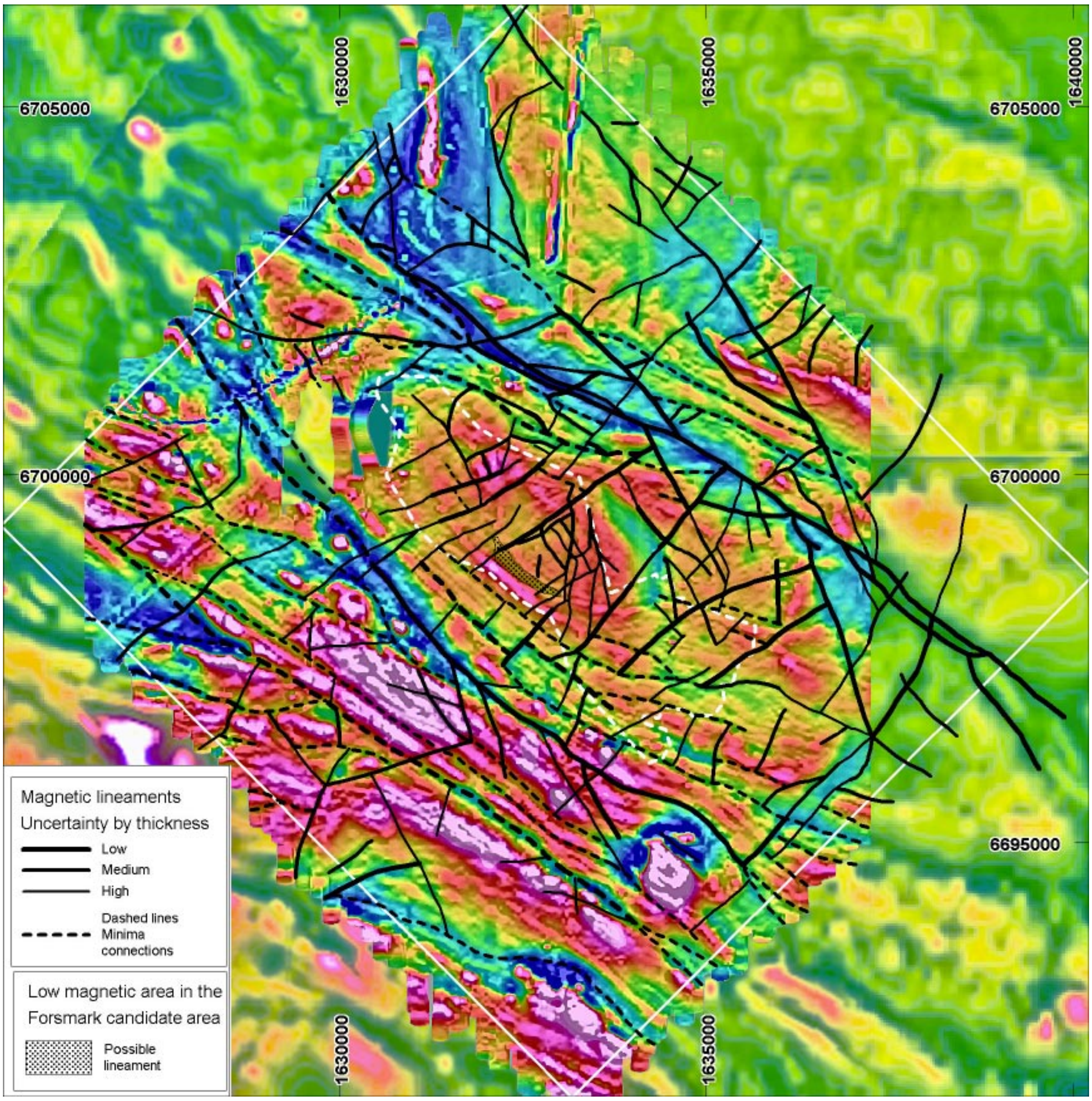


Figure 6-2. *As Figure 6-1, with an overlay of magnetic lineaments. A low magnetic anomaly in the central part of the candidate area that in 2002 /2/ was decided to be represented as an area caused by low magnetic rock units is here highlighted as it also possibly can include a minima connection lineament. The geological mapping area is outlined with a solid white line and the Forsmark candidate area with a dashed white line. Lantmäteriet Gävle 2003, Permission 601-2003/370. © Swedish Nuclear Fuel & Waste Management Co 2004-09-29.*

Table 6-1. Compilations of some attribute information for magnetic lineaments. Figures show number of occurrences.

Character	Low uncertainty	Medium uncertainty	High uncertainty	Total no
Minima / edge / dislocation	41	88	111	240
Minima connection	16	57	5	78
Total	57	145	116	318

Table 6-2. Attribute table for structural magnetic anomaly interpretation. The column with "Attribute used to describe anomaly patterns" is the same as for 2002 /2/.

Field name	Name	Description	Attributes used to describe anomaly patterns. Refers to 2002 /2/ only.	Attribute used to describe magnetic lineaments
Id_t	Identity	Identity of the anomaly pattern	Not assigned in this work	Not assigned in this work
Origin_t	Origin	Major type of basic data	Magnetics	Magnetics
Class_t	Classification	Classification of the anomaly pattern	Not assigned in this work	Not assigned in this work
Method_t	Method	The type of data in which the observation is identified	Magnetic 10 m grid	Magnetic 10 m grid, Ground survey
Char_t	Character	Character of the observation	Banded or irregular pattern. Very high, high, medium (low and high) or low magnetic intensity. Connection.	Minimum, edge, minima connection
Uncert_t	Uncertainty	Gradation of identification, in terms of uncertainty	Low/Medium/High	Low/Medium/High
Comment_t	Comment	Specific comments to the observation		
Process_t	Processing	Data processing performed	Filtering, image analysis	Filtering, image analysis
Date_t	Date	Point of time for interpretation	20030412	20030411–20040428
Scale_t	Scale	Scale of interpretation	20,000	10,000, 20,000, 50,000
Platform_t	Platform	Measuring platform for the basic data	Helicopter borne, 30 m altitude	Helicopter borne, 30 m altitude. Airborne 60 m altitude.
Width_t	Width	Width on average	Not assigned in this work	Not assigned in this work
Precis_t	Precision	Spatial uncertainty of position	10–100 m, 20 m in general	10–100 m, 20 m in general
Sign_t	Signature	Work performed by	hi (Hans Isaksson), GeoVista AB	hi (Hans Isaksson), GeoVista AB

The condition for lineament interpretation is somewhat different within different parts of the investigated area. The area SW of the Forsmark candidate area is dominated by a very strongly elongated ductile deformation which makes it more difficult to identify brittle structures. The candidate area shows a rather distinct and gently folded magnetic pattern and a moderate magnetization, which makes discordances and linear minima more easily identified. The area immediately NE of the candidate area is again affected by strong ductile deformation and further to the NE the rocks shows low magnetization which makes it more difficult to identify lineaments.

The central area of investigation and the candidate area are covered by two survey directions /2/, which gives a better prediction of lineaments and their trend. Solely NS survey direction makes it more difficult to identify lineaments in an NS trend (± 30°).

In the work of 2002, several examples of processed magnetic data and identified lineament were presented /2/. In this report, magnetic lineaments identified within the geological mapping area are presented in Figure 6-3.

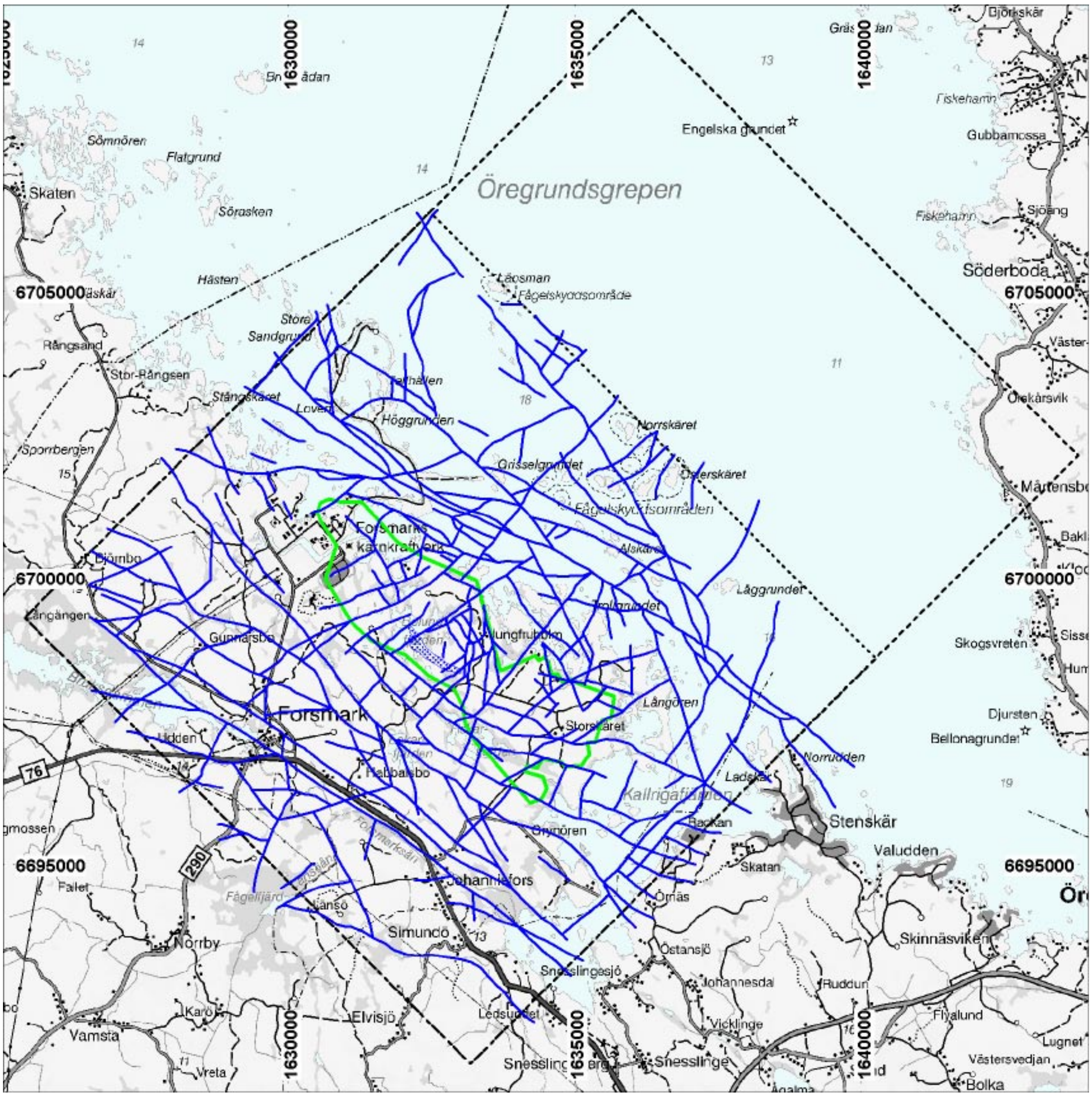


Figure 6-3. Magnetic lineaments (blue) identified within the geological mapping area. The site descriptive model area is outlined with a black, dashed line, the geological mapping boundary with a dotted black line and the Forsmark candidate area with a green, solid line. Background © Lantmäteriverket, Gävle, 2001, permission M2001/5268.

Uncertainties

The lineaments are graded in low, medium and high uncertainty mainly 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.

A discrete, linear low magnetic feature with a discordant appearance in the magnetic pattern often originates from fracture zones in the bedrock. However, in the Forsmark area, with the strong ductile and elongated deformation pattern it can be difficult to distinguish between a concordant, narrow rock type with low magnetization and a lineament caused by a fracture zone.

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 not necessarily corresponding 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 structures.

The airborne magnetic data east of 1637300E is of regional character and lower resolution.

7 Öregrundsgrepen – method specific lineaments in the open sea area

7.1 Input data

Input to the lineament interpretation in the open sea area has been the following data sets:

- The combined ground surface terrain model based on elevation and bathymetric data presented in Chapter 4, Figure 4-1 and 4-2. In this area, mainly contributed by the sea chart bathymetric data compiled during the SAFE-project /7/.
- The sea bottom terrain model (ground and rock surface), xyz line data, from the regional, marine geological survey, SGU /4/.
- Airborne, magnetic data, SGU, 40 m grid, compiled during the feasibility study Östhammar /20/ and the Forsmark – site descriptive model, version 0 /8/ and further processed in /2/.

The data obtained in the marine geological survey /4/ have been used in the lineament interpretation but is classified for military defence reasons (SKB routine SDP-516) /10, 11/ and no figures describing this information are presented in the report.

Data processing

The magnetic total field has been filtered and transformed (Oasis – ™ Geosoft Inc) to enhance structural features:

- Reduction to the pole.
- 1:st and 2:nd vertical derivative.
- Total horizontal derivative.

When applicable, reduction to the pole and/or upward continuation has been performed prior to, or has been included in the filtering. The same is valid for IGRF-correction which in some transformations is needed for further processing.

The combined ground surface terrain model has also been subject to enhancement by filtering (Geomatica – ™ PCI Inc):

- Gradient enhancement.
- Slope calculation.

The marine sea bottom ground and rock surface profiles /4/ have been plotted as stacked profiles and used as vector overlays.

7.2 Results

The work has comprised method specific lineament interpretation of airborne magnetic data and topography. The interpretation has been carried out by visual identification, delineation and characterization of structural features, using image analysis (Geomatica – ™ PCI) and GIS-techniques (MapInfo – ™ MapInfo).

Topographic lineament identification

A total of 55 topographical lineaments were identified in the area as presented in Figure 7-1. The lineaments are stored in a GIS-format with the same attribute table as presented in Chapter 3. The most important attribute is uncertainty. Most lineaments are identified as minima (valleys), 9 have an edge character or is coincident with shorelines. Two lineaments are also in agreement with depressions or slopes in ground and rock surface data from the marine geological profiles.

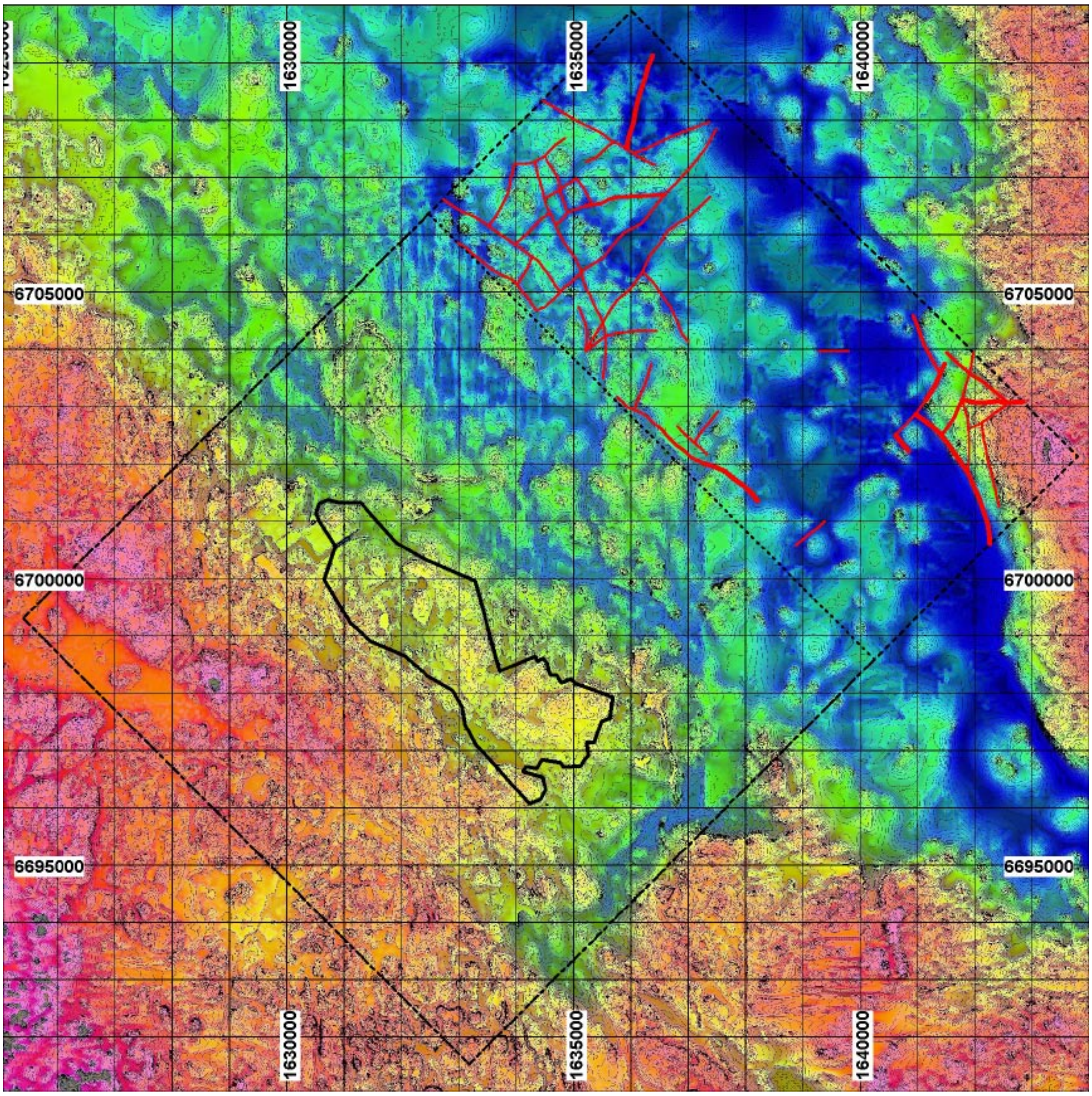


Figure 7-1. *Bathymetric lineaments in the open sea area, Öregrundsgrepen. Thin – thick red lines shows high – low uncertainty. Combined ground surface topography as in Figure 4-2. The site descriptive model area is outlined with a black, dashed line, the geological mapping boundary with a dotted black line and the Forsmark candidate area with a black, solid line. Permission to publish: 010305-04-17297:22.*

Magnetic lineament identification

A total of 69 magnetic lineaments were identified and presented in Figure 7-2. The lineaments are stored in GIS-format with the same attribute table as presented in Chapter 3. The most important attribute is uncertainty. All lineaments are identified as minima, except for 7 lineaments that have an edge character.

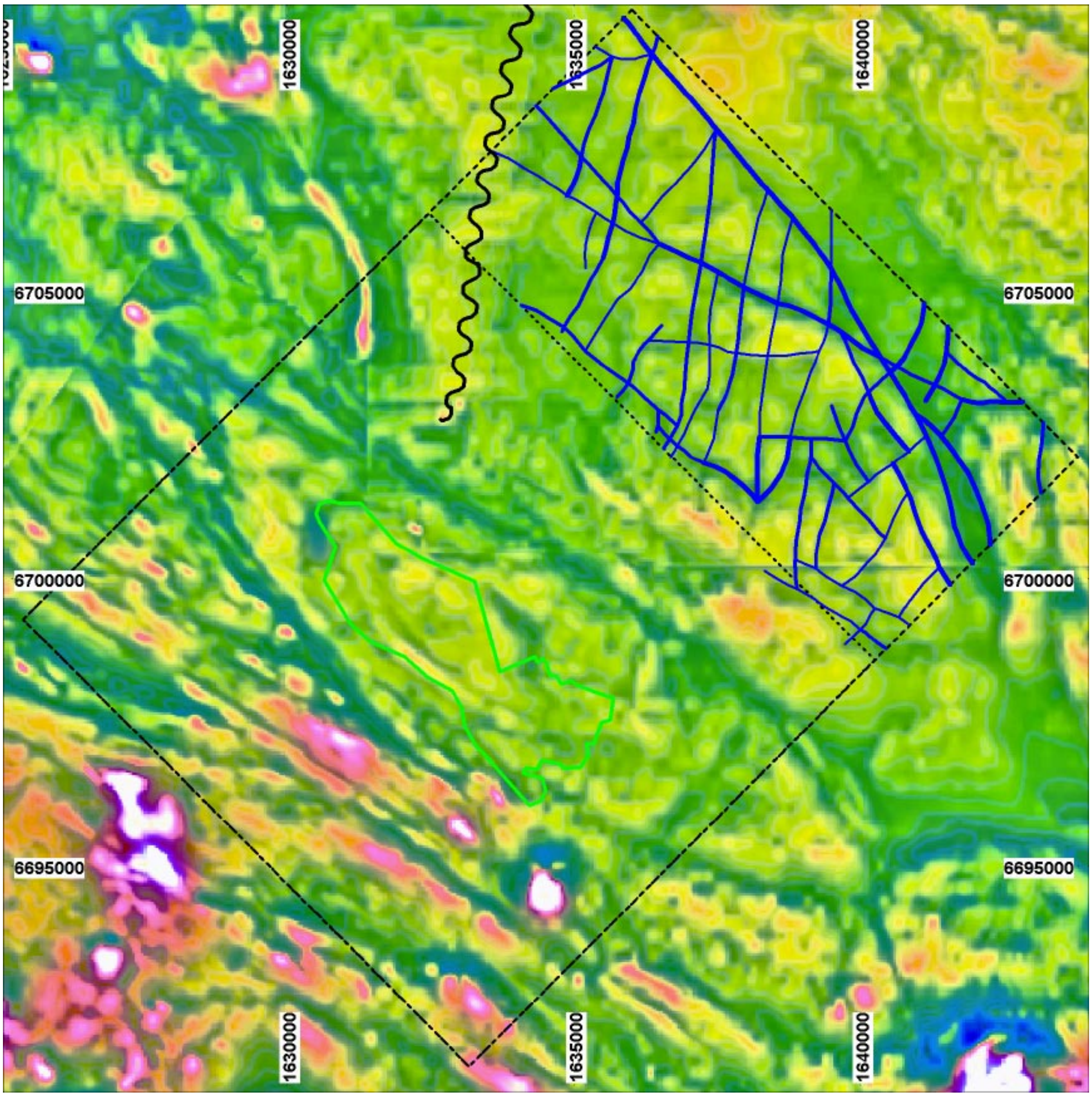


Figure 7-2. *Magnetic lineaments in the open sea area, Öregrundsgrepen. Thin – thick blue lines shows high – low uncertainty. Regional airborne magnetics (SGU surveys), 40 m grid. Magnetic lows in blue colours and highs in magenta colours, for colour table, see Figure 6-1. The site descriptive model area is outlined with a black, dashed line, the geological mapping boundary with a dotted black line and the Forsmark candidate area with a green, solid line. Undulating black line shows location of disturbed area due to a DC-cable.*

Uncertainties

The lineaments are graded in low, medium and high uncertainty mainly 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.

The regional data in the open sea area matches a lineament representation at a scale of 1:50,000–1:100,000, while the data in the coastal area and the mainland matches a scale of 1:20,000–1:10,000. Work in a detailed scale based on 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, often be divided into shorter, non-coherent segments.

The available bathymetric data in Öregrundsgrepen, especially in the deeper parts, have very low spatial resolution with respect to the needs for lineament identification. Gradients are also very much dependent on the location of the individual depth contours giving high uncertainty in position, direction and extent of possible lineaments. The marine geological survey provides detailed information, but only along sparse profiles.

The regional character and lower resolution also leads to low precision in the location of the lineaments.

8 Coordination of lineaments

8.1 Coordinated lineaments in the coastal and Forsmarksverket area

8.1.1 Input data

Input to the coordinated lineament interpretation has been the following method specific lineament data sets:

- Bathymetric / topographic lineaments, Chapter 4, Figure 4-3.
- Magnetic lineaments, Chapter 6, Figure 6-2.
- Refraction seismic, ground and rock surface topographic lineaments, Section 5.2.1, Figure 5-2b, 5-3b *.
- Ground magnetic and EM lineaments at Forsmarksverket, Section 5.2.3, Figure 5-12.
- EM lineaments in the sea area, report of Stage 1 /2/, Figure 4-15 **.
- Basic processed images, covering the different methods.

* Low velocity indications, Section 5.2.2, Figure 5-10, are not included as individual lineaments. Low velocity indications probably belonging to a specific lineament are noted as a comment in the lineament attribute table.

** Only a few EM lineaments which have not been explained by the sea water depth in the EM inversion results, Section 4.1.

8.1.2 Result

The coordination of lineaments has been carried out as described in Chapter 3, by use of GIS-techniques (MapInfo – ™ MapInfo) and to some extent image analysis (Geomatica – ™ PCI). The methodology includes calculation of length and direction for the coordinated lineaments (using available routines in Mapinfo 7.0 and Encom Discover 6.0), as well as a ranking of methods and introduction of a weighting scheme.

The lineaments are stored in a GIS-format with the same attribute table as presented in Chapter 3. The most important attributes in this stage are presented in Table 8-1.

Figure 8-1 shows the result of the lineament coordination. In total, 691 coordinated lineaments have been defined in the coastal and Forsmarksverket areas. Based on the attached attributes, some general statistical results are presented in Table 8-2.

Table 8-1. Description of the most important attributes for coordinated lineament.

Field name	Description	Attributes
Method	The type of data in which the observation is identified. Order tells about ranking of the methods.	Bathy = sea bottom surface, marine geological survey
		EM-bathy = sea bottom surface, EM inversion
		Rock = bedrock surface (seismic)
		Topo = structure mainly above shoreline
		Magn = airborne / ground magnetics
		EM = electromagnetic lineament
Uncertainty	Gradation of identification, in terms of uncertainty	1 = Low 2 = Medium 3 = High
Prop	Number of indicating properties	1, 2, 3
Weight	Weighting scheme depending on number of properties and uncertainty	1, 2, 3, 4, 5
Topog	Identification in ground surface	1 = Yes, 0 = No
Topor	Identification in bedrock surface	1 = Yes, 0 = No
Topo	Identification in either ground or bedrock surface	1 = Yes, 0 = No
Magn	Identification in magnetic data	1 = Yes, 0 = No
EM	Identification in EM data	1 = Yes, 0 = No

Table 8-2a–c. Compilation of some attributes information for coordinated lineaments. Figures give number of occurrences, except for "Average length" in metre and "Weight" dimension less.

a. Uncertainty

Coordinated lineament	Low uncertainty	Medium uncertainty	High uncertainty	Total number	Average length (metre)
All	124	386	181	691	523

b. Weight

Coordinated lineament	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5
All	173	281	190	47	N/A

N/A: not applicable since conductivity as a property is not, with a few exceptions, available in the sea area or around Forsmarksverket.

c. Method related to uncertainty

Method	Low uncertainty	Medium uncertainty	High uncertainty	Total number	Average Weight	1:st rank in combination with other methods	Solely one method
Bathymetry, ground surface topography	86	297	112	495	2.2	104	234
Rock surface topography	64	143	36	243	2.4	163	69
Magnetics	66	148	35	249	2.8	5	89
EM	0	10	22	32	1.6	6	21

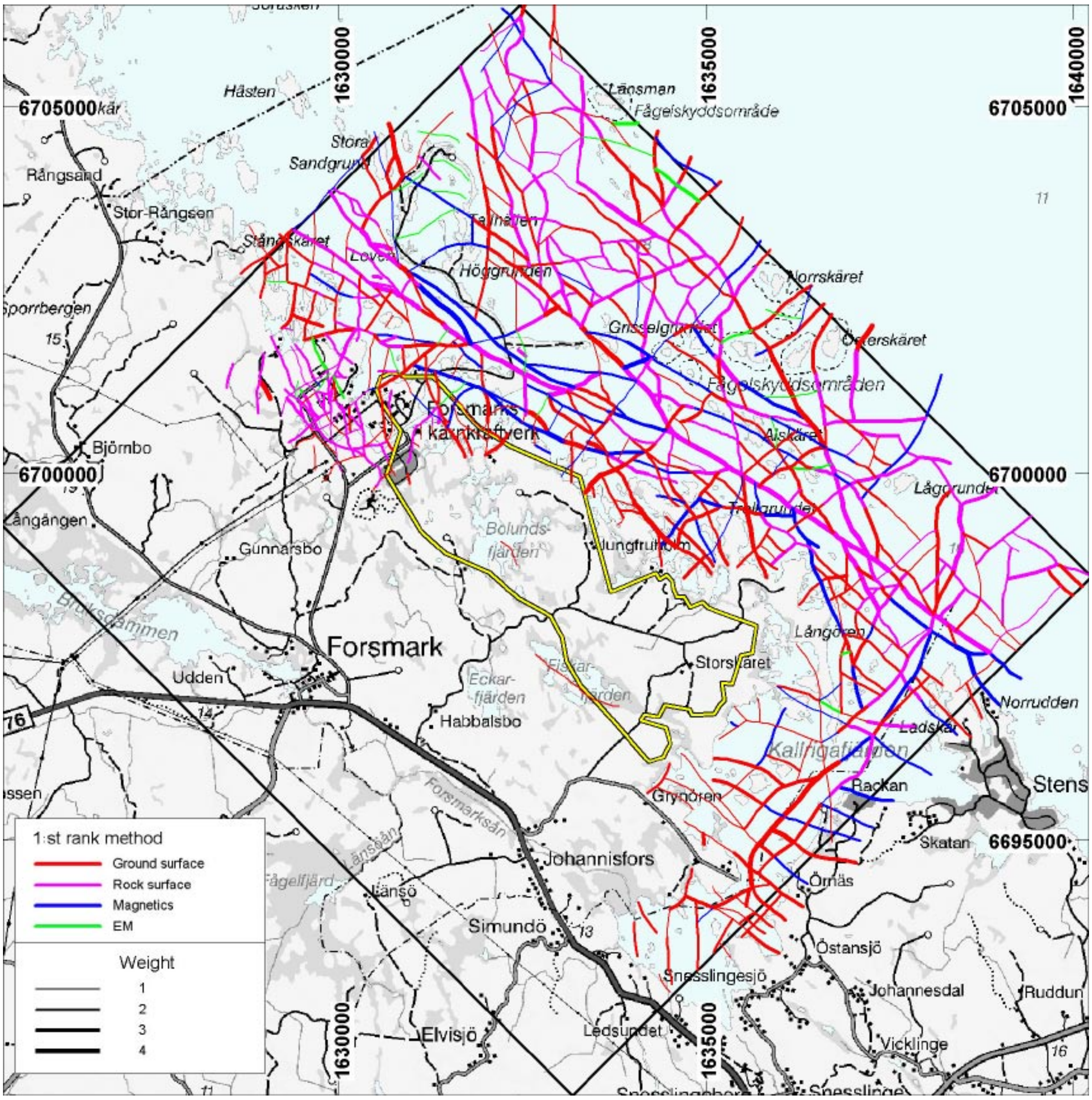


Figure 8-1. Coordinated lineaments in the coastal and Forsmarksverket area. The lineament colour and thickness corresponds to the first ranking method identifying the lineament and the weight (combination of number of properties and the uncertainty), respectively. "Rock surface" refer to the bedrock surface morphology. Forsmark candidate area is outlined with a black-yellow line. Solid black line outlines the geological mapping area. Background © Lantmäteriverket, Gävle, 2001, permission M2001/5268.

Uncertainties

At first the uncertainties for each method have to be taken into account; Section 4.2, 5.2 and 6.2.

The available rock surface data from both the modern marine seismic investigations in the sea and the previous refraction seismic surveys at Forsmarksverket – SFR have given the topographic/bathymetric lineament interpretation an overall higher confidence. However, this highlights the comparatively higher uncertainties in the other parts of the investigated area.

The marine seismic survey has been carried out with c 100 m line spacing, while the helicopter borne geophysics is performed with 50 m line spacing. A first contemplation of the basic magnetic and bathymetric data indicates a small difference in scale and resolution.

However, this difference is somewhat compensated by the fact that the water depth and commonly occurring sediment cover increase the distance to the aircraft magnetometer and hence, lower the spatial resolution.

The airborne magnetic data east of 1637300E is of regional character and hence, the magnetic lineaments are of lower spatial resolution.

Compared with the open sea area, Öregrundsgrepen, the difference in scale and resolution of structures is a major uncertainty as discussed in Section 7.2 and 8.2.2.

8.2 Coordinated lineaments in the open sea area, Öregrundsgrepen

8.2.1 Input data

Input to the coordinated lineament interpretation has been the following method specific lineament data sets:

- Bathymetric / topographic lineaments (see Figure 7-1)
- Magnetic lineaments (see Figure 7-2)
- Basic processed images, covering the different methods

8.2.2 Result

The coordination of lineaments has been carried out as described in Section 3.1, by use of GIS-techniques (MapInfo – ™ MapInfo) and to some extent image analysis (Geomatica – ™ PCI). The methodology includes calculation of length and direction for the coordinated lineaments as well as a ranking of methods and introduction of a weighting scheme.

The lineaments are stored in a GIS-format with the same attribute table as presented in Chapter 3. The most important attributes in this stage are presented in Table 8-3.

Table 8-3. Description of the most important attributes for coordinated lineaments.

Field name	Description	Attributes
Method	The type of data in which the observation is identified. Order tells about ranking of the methods.	Bathy = sea bottom surface, marine geological survey Topo = structure mainly above shoreline Magn = airborne / ground magnetics
Uncertainty	Gradation of identification, in terms of uncertainty	1 = Low 2 = Medium 3 = High
Prop	Number of indicating properties	1, 2, 3
Weight	Weighting scheme depending on number of properties and uncertainty	1, 2, 3, 4, 5
Topog	Identification in ground surface	1 = Yes, 0 = No
Topor	Identification in bedrock surface	1 = Yes, 0 = No
Topo	Identification in either ground or bedrock surface	1 = Yes, 0 = No
Magn	Identification in magnetic data	1 = Yes, 0 = No

Figure 8-2 shows the result of the lineament coordination. In total, 112 coordinated lineaments have been defined in the open sea area, Öregrundsgrepen. Based on the attached attributes some general statistical results is presented, see Table 8-4.

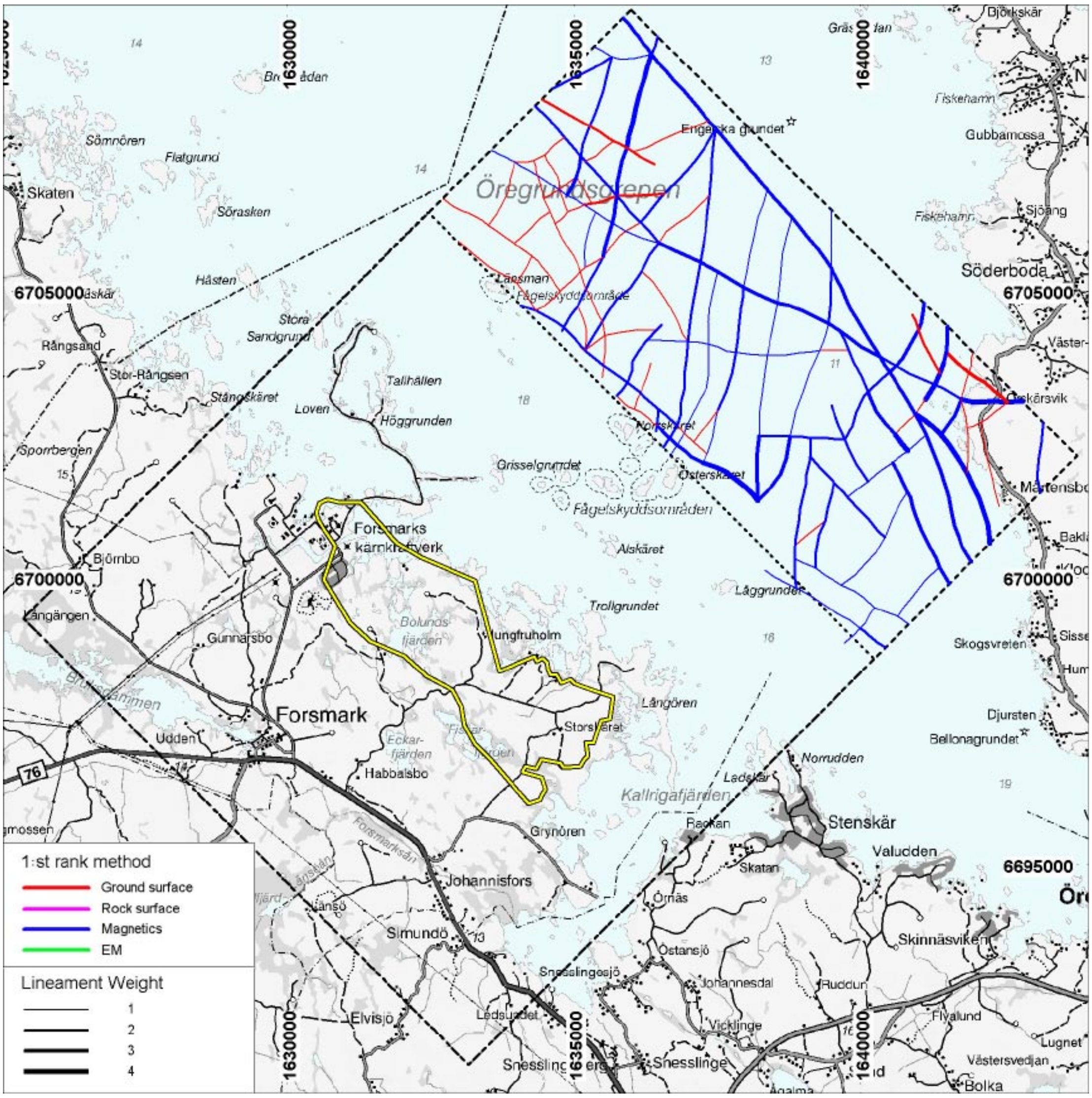


Figure 8-2. Coordinated lineaments in the open sea area, Öregrundsgrepen. The lineament colour and thickness corresponds to the first ranking method identifying the lineament and the weight (combination of number of properties and the uncertainty), respectively. "Rock surface" and "EM" is not applicable as first rank method in this area. The site descriptive model area is outlined with a black, dashed line, the geological mapping boundary with a dotted black line and the Forsmark candidate area with a black-yellow line. Solid black line outlines the geological mapping area. Background, © Lantmäteriverket, Gävle, 2001 permission M2001/5268.

Table 8-4a–c. Compilation of some attributes information for coordinated lineaments. Figures give number of occurrences, except for "Average length" in metre and "Weight" dimension less.

a. Uncertainty

Coordinated lineament	Low uncertainty	Medium uncertainty	High uncertainty	Total number	Average length (metre)
All	19	29	64	112	1,332

b. Weight

Coordinated lineament	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5
All	62	28	16	6	N/A

N/A: not applicable since conductivity as a property is not, with a few exceptions, available in the sea area or around Forsmarksverket.

c. Method related to uncertainty

Method	Low uncertainty	Medium uncertainty	High uncertainty	Total number	Average Weight	1:st rank in combination with other methods	Solely one method
Bathymetry, ground surface topography	6	6	42	54	1.5	1	43
Rock surface topography*				*			
Magnetics	19	26	24	69	2.1	10	58

* Two lineaments have coincident rock surface indications from regional, marine seismic profiles. The coverage of this survey is only along sparse profiles and hence, this number is omitted.

Uncertainties

At first the uncertainties for each method have to be taken into account, Section 7.2.

An important lack of balance in the coordination of method specific lineaments within the open sea area derives from the fact that the basic magnetic and bathymetric data are of different resolution. The magnetic lineaments show a higher confidence.

Compared with the coastal and mainland areas, the difference in scale and resolution of structures is a major uncertainty as discussed in Section 7.2 and 8.1.2.

8.3 Coordinated lineaments in the Forsmark candidate area

Figure 8-3a and 8-3b visualizes the distribution of the coordinated lineaments in the Forsmark candidate area and can be compared with the corresponding figures for linked lineaments (Section 9.3, Figure 9-3a and 9-3b). The coordinated lineaments for the mainland have been collected from the work of 2002 /2/ and revised, giving the same attribute contents as for the coastal-FMV area and the open sea area, Section 8.1 and 8.2.

The colour in the figures shows the first rank method, that is, the method that will represent the location of the lineament, the thickness represents the weight and the presence of magnetic indication as a dotted or solid line.

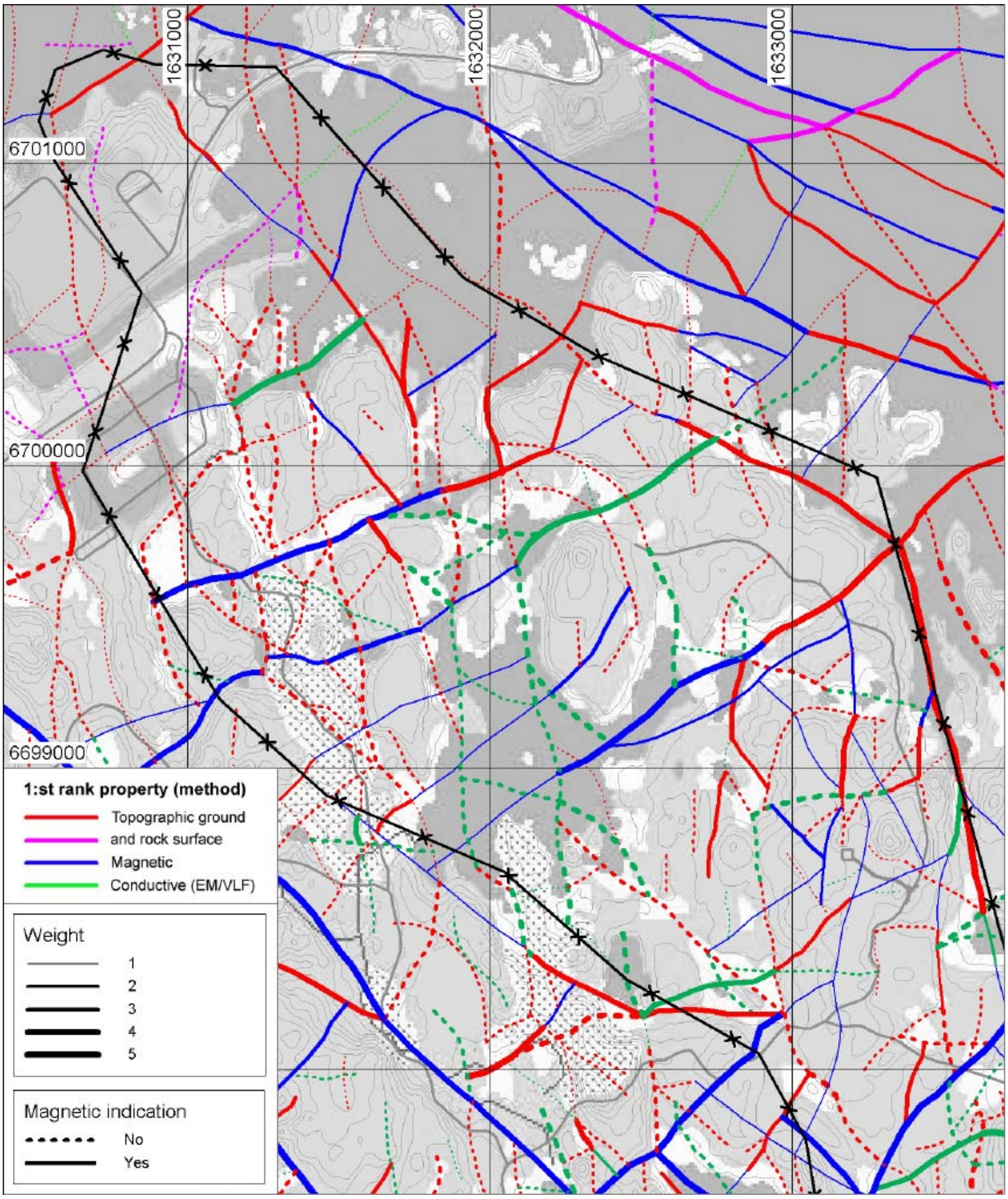


Figure 8-3a. *Coordinated lineaments in the NW part of the Forsmark candidate area. Lineaments are delineated according to the first rank method colour, weight thickness and presence of magnetic indication as dashed or solid line. The Forsmark candidate area is outlined with a black solid fence-line. Background GSD-Fastighetskartan © Lantmäteriet, Gävle 2001, Permission M2001/5268.*

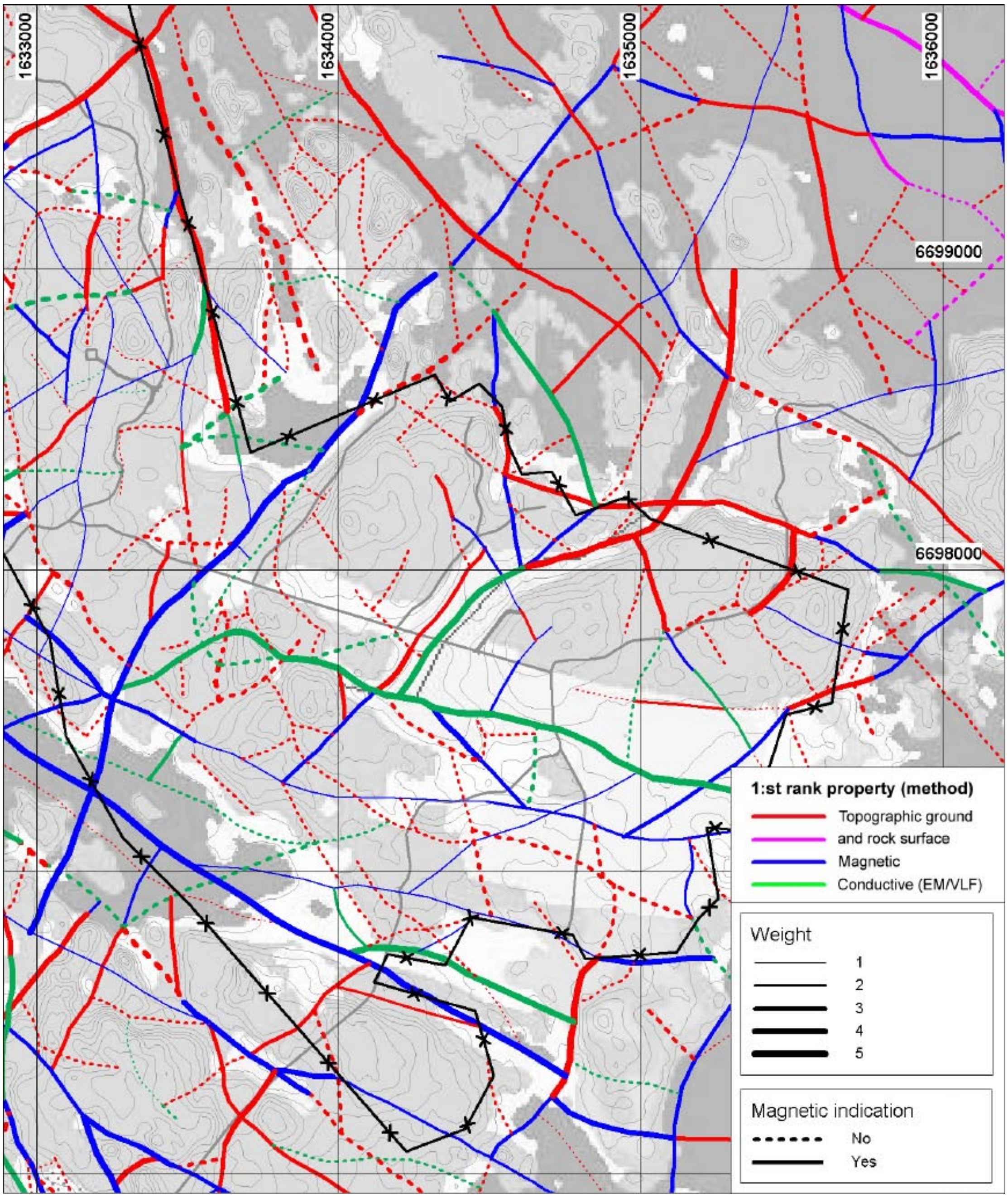


***Figure 8-3b.** Coordinated lineaments in the SE part of the Forsmark candidate area. Lineaments are delineated according to the first rank method colour, weight thickness and presence of magnetic indication as dashed or solid line. The Forsmark candidate area is outlined with a black solid fence-line. Background GSD-Fastighetskartan © Lantmäteriet, Gävle 2001, Permission M2001/5268.*

9 Linked lineament

9.1 Input data

The following data were used as input to the linking lineament procedure. See also Figure 9-1:

- Previous linked lineaments on the mainland, slightly modified at the boundary to the coastal and Forsmarksverket coordinated lineaments (blue colour in Figure 9-1).
- Coordinated lineaments in the coastal and Forsmarksverket area (red colour in Figure 9-1).
- Coordinated lineaments in Öregrundsgrepen, the open sea area in the NE part of the regional model area (green colour in Figure 9-1).
- Processed images, covering the different methods.

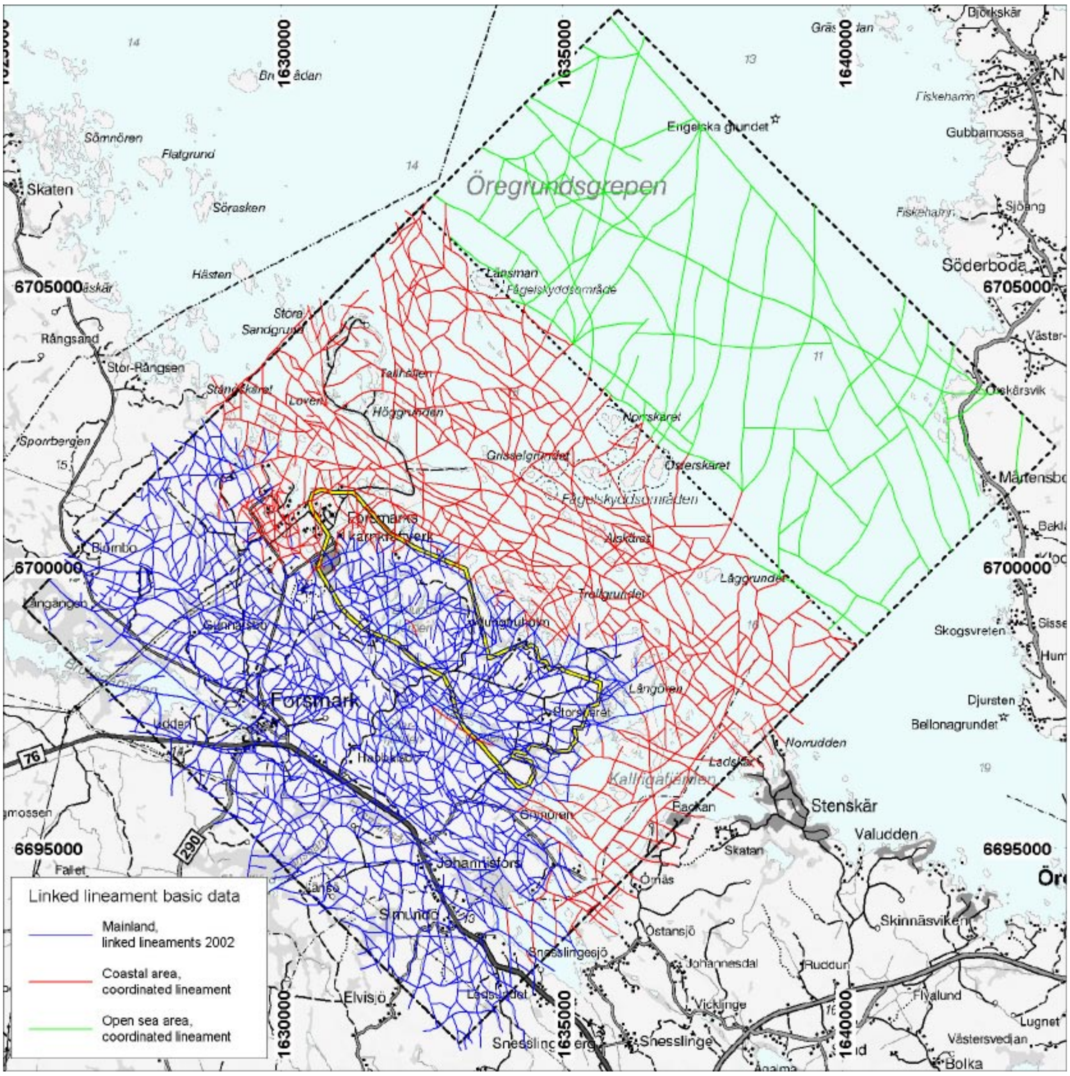


Figure 9-1. Coordinated lineament sets forming the basis for linked lineaments. The site descriptive model area is outlined with a black, dashed line, the geological mapping boundary with a dotted black line and the Forsmark candidate area with a black-yellow line. Plotted on "Blå kartan", © Lantmäteriverket, Gävle, 1996.

9.2 Results

The work has followed the scheme described in Chapter 3, with a few exceptions. In the mainland area the previous linked lineaments /2/ form the basis instead of the coordinated lineaments. Identities used in the mainland data set have been used when the lineament extends into the coastal and open sea area. Lineaments have not been upgraded to fracture zones in this work.

In total, 1,169 linked lineaments have been defined compared to 879 lineaments 2002 /2/. 1,156 lineaments have a unique identity name (first 7 positions of the identity code, XFMxxxx). This means that 13 lineaments form separate segments of what is judged with confidence to be part of the same lineament. These segment lineaments have different denomination in position 8–9 in the identity code. The ground for this special treatment is that the separate segments:

1. form alternative routes for regional or local major lineaments; XFM0014 (A0–A4), XFM0015 (A0–A5), XFM0017 (A0–A2) and XFM0025 (A0–A1),
2. are continuous but with a very weak joining link; XFM0137 (A0, B0).

The lineament identities occupy the serial numbers XFM0014 – XFM1186. 17 numbers have been dropped for the following reasons:

- When joining lineaments originally defined from the different data sets, only one final number is necessary (369, 787, 788, 794, 834, 862, and 863).
- Numbers have been used for Z-codes in the preliminary site description Forsmark area – version 1.1 /22/: (865, 866, 867, 868, 869, and 871).
- Some lineaments were defined on the fringe of the available data, but fully outside the regional modelling area and were dropped in the final stage: (274, 319, 847 and 870).

5 linked lineaments, together composed of 14 segments, are classified as regional lineaments (length ≥ 10 km).
272 lineaments, together composed of 275 segments, are classified as local major (length 1–10 km), and
880 lineaments are classified as local minor lineaments (length < 1 km).
The average length of all linked lineaments and the adherent segments is 851 m.

93 linked lineaments have a weight of 4 or higher
216 lineaments have a weight between 3 and 4
570 lineaments have a weight of 2 to 3, and
290 lineaments have a weight below 2.

121 linked lineaments have been observed in all three properties.
56 lineaments are only observed in conductivity, that is, EM and/or VLF.
71 lineaments are identified only in magnetics, and
620 lineaments are identified only in topography / bathymetry.

The comprehensive attributes table, Table 3-2 described in Section 3.3, is built up to provide a basis for further statistical analysis and scrutiny of the linked lineaments as possible fracture zones.

A figure of the linked lineaments is not presented here, since it will give a very similar picture as Figure 9-1 showing the input lineaments. However, a selection of linked lineaments, classified as regional or local major (1 km and longer) is presented in Figure 9-2.

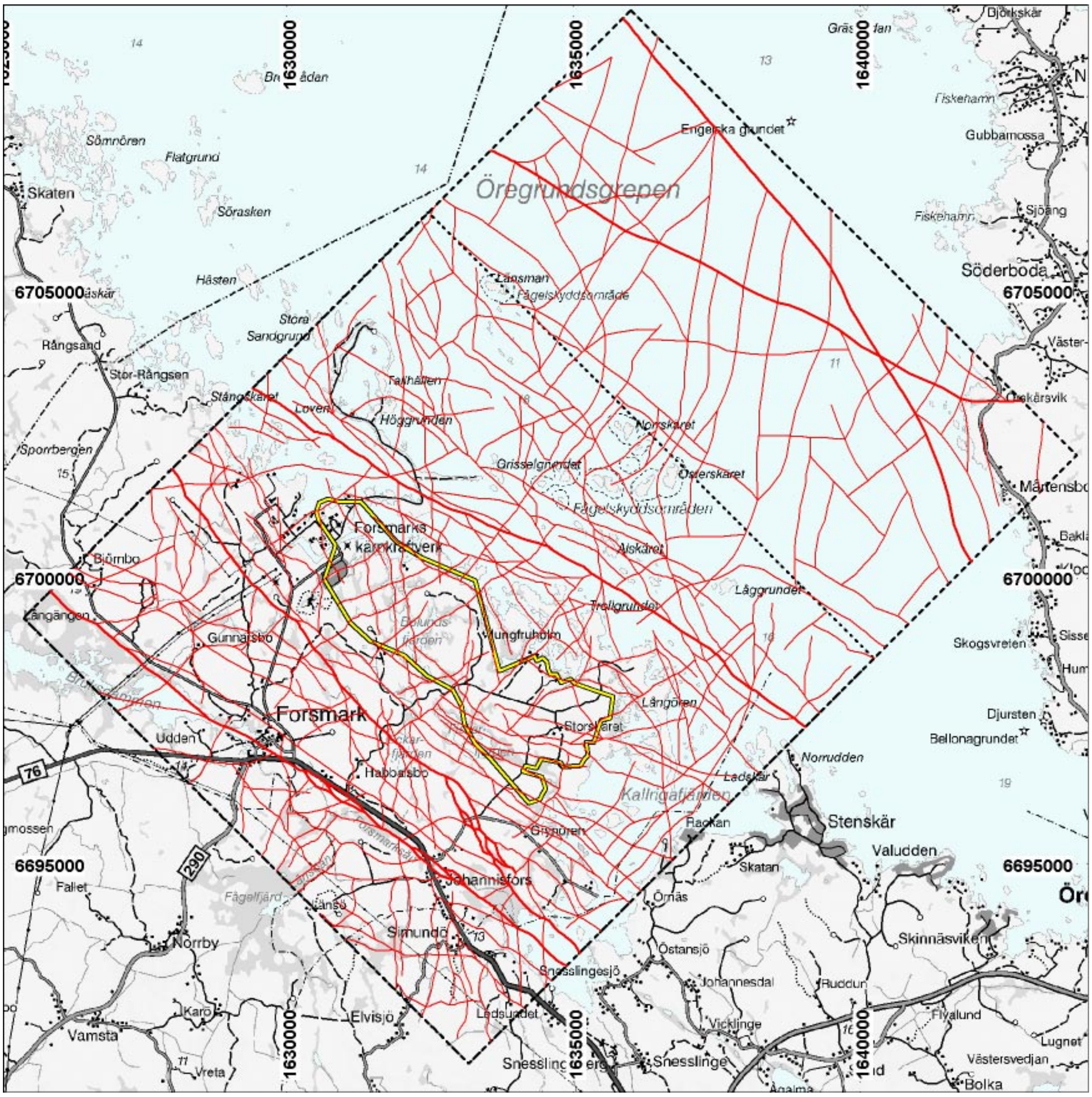


Figure 9-2. Linked lineaments, regional and local major (length ≥ 1 km), are shown as solid red lines. Thicker lines are classified as "Regional". The site descriptive model area is outlined with a black, dashed line, the geological mapping boundary with a dotted black line and the Forsmark candidate area with a black-yellow line. Background © Lantmäteriverket, Gävle, 2001, permission M2001/5268.

Uncertainties

When linking two coordinated lineament it is in some cases more then 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.

In this version, lineaments have not been cut when crossing regional fracture zones like the Singö zone and the Forsmark zone /8, 22/. Such decisions will need more information or other presumptions as a part of the analysis work.

The difference in details, scale and resolution of structures between the different basic data sets for the mainland, the coastal area and the open sea area, Öregrundsgrepen, has been discussed in previous sections. The lineament density visible in Figure 9-1 also illustrates this fact rather well.

9.3 Linked lineaments in the Forsmark candidate area

Figure 9-3a and 9-3b visualizes the linked lineament distribution in the Forsmark candidate area and can be compared with the corresponding figures for coordinated lineaments (Section 8.3, Figure 8-3a and 8-3b). The first rank method is not accessible in the linked lineament version. Instead, the dominating property occurring along the lineament is colour-coded in Figure 9-3a and 9-3b. Two or more properties of equal dominance along the lineament are given a common expression.

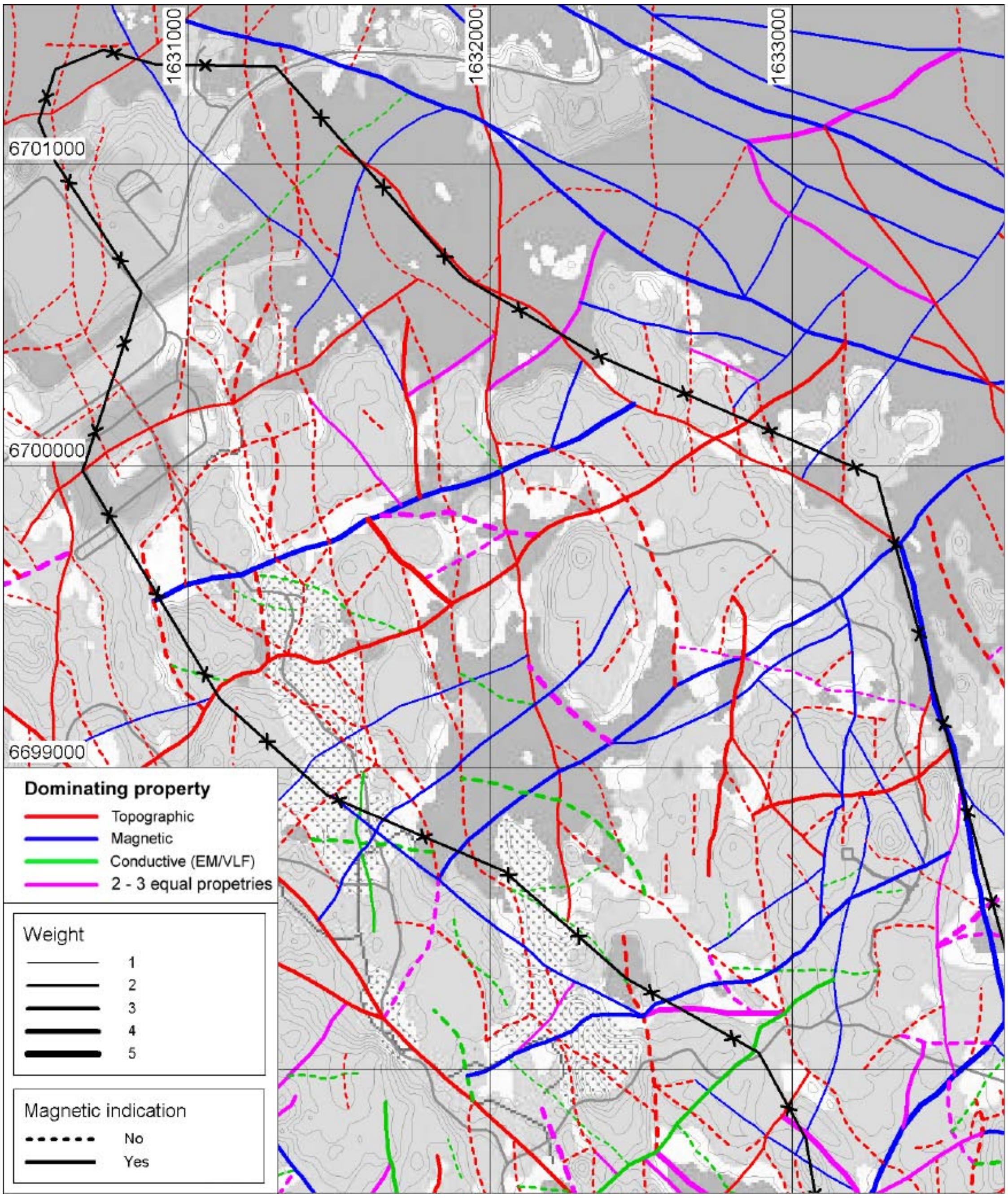


Figure 9-3a. *Linked lineaments in the NW part of the Forsmark candidate area. Lineaments are delineated according to the dominating property along the line colour, weight thickness and presence of magnetic indication as dashed or solid line. The Forsmark candidate area is outlined with a black solid fence-line. Background GSD-Fastighetskartan © Lantmäteriet, Gävle 2001, Permission M2001/5268.*

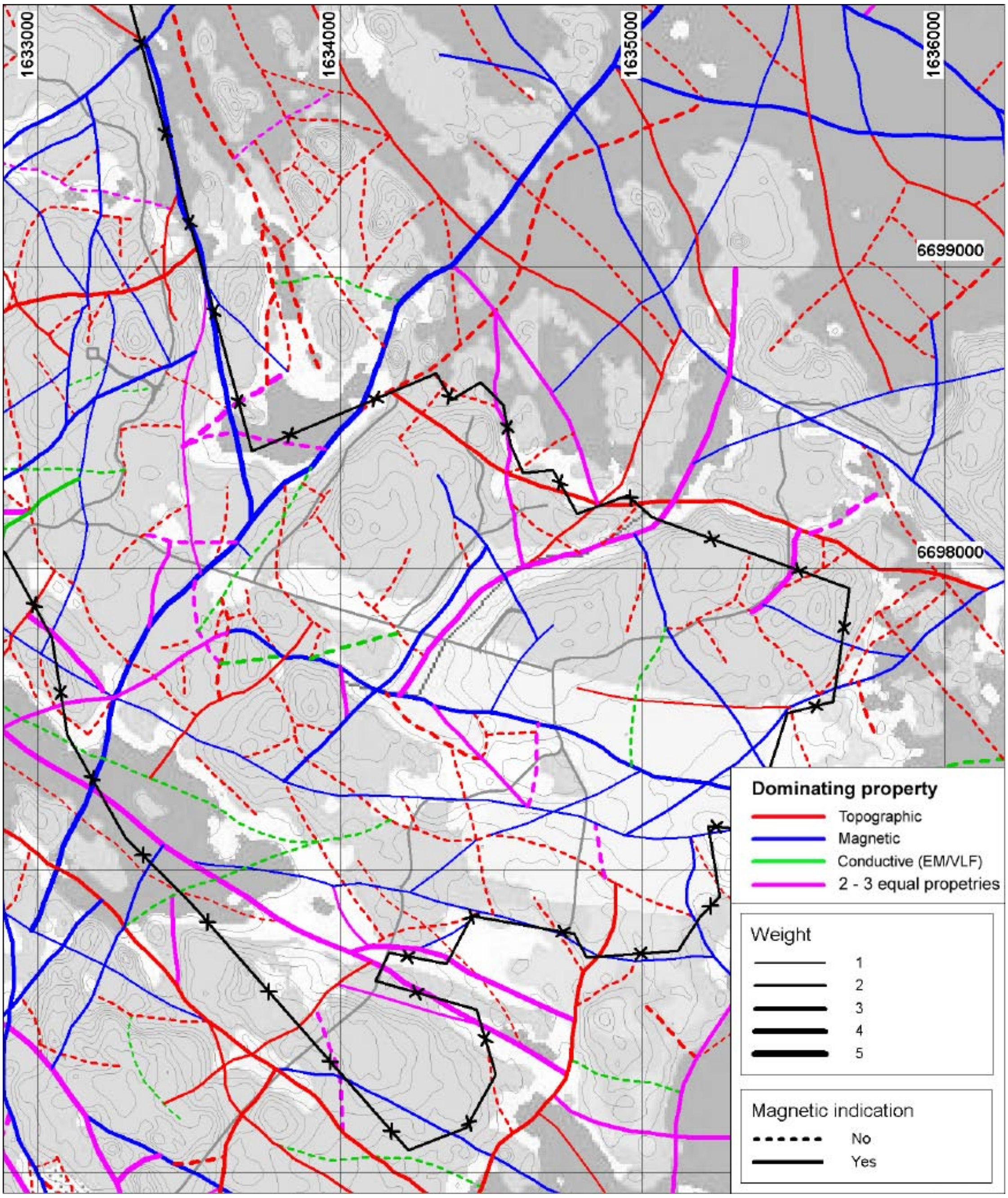


***Figure 9-3b.** Linked lineaments in the SE part of the Forsmark candidate area. Lineaments are delineated according to the dominating property along the line colour, weight thickness and presence of magnetic indication as dashed or solid line. The Forsmark candidate area is outlined with a black solid fence-line. Background GSD-Fastighetskartan © Lantmäteriet, Gävle 2001, Permission M2001/5268.*

10 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 “GIS – Inleverans av data”, SKB SD-081 (SKB internal controlling document).

Data have been delivered in three data formats for storage in the GIS-database. Grid-files image files and information that has resulted in some kind of interpreted vector; point, line or polygon information has been stored in Shape format. A listing of delivered products is shown in Appendix 1. Files marked in italics in the appendix should be considered as working material.

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Appendix 1

Delivered data

Files marked in italics should be considered as working material.

Shape/files

Filename	File type	Content
XFM_Linked_Lineament_20040609_line	Shp	Linked lineaments from coordinated lineaments
XFM_Bathymetric_Coastal_line	Shp	Lineaments for the coastal area, interpreted from bathymetric data
XFM_Coordinated_Coastal_FMV_line	Shp	Coordinated lineaments for the coastal area
XFM_Magnetic_20040628_line	Shp	Lineaments interpreted from magnetic airborne survey, revised version 2004
FM_AEM_bathymetry_and_Topography_Mosaic_1m_ contour_line	Shp	Contours created from the combined elevation and AEM-inversion, bathymetric grid
HEM_Inversion_area_region	Shp	Shows the coverage of the inversion
XFM_FMV_Ground_magnetic_EM_line	Shp	Lineaments interpreted from pre site investigation magnetic and EM measurements at Forsmarksverket (ground geophysics)
XFM_FMV_Rock_ground_surface_line	Shp	Lineaments interpreted from pre site investigation seismic refraction measurements at Forsmarksverket (ground and rock surface elevation)
XFM_FMV_Seismic_Refraction_Low_velocity_connection_line	Shp	Low velocity connections interpreted from pre site investigation seismic refraction measurements in Forsmarksverket
FM_old_seismic_point	Shp	Pre site investigation seismic refraction measurement presented as points (with surface levels, traveltime, medium)
FM_old_seismic_profiles	Shp	Pre site investigation seismic refraction measurement presented as profiles with information about traveltime in rock
FMV_Seismic_refraction_Ground_Elevation_line	Shp	Contours created from the grid containing ground surface elevation in Forsmarksverket (pre site investigation data)
FMV_Seismic_refraction_Rock_Elevation_line	Shp	Contours created from the grid containing rock surface elevation in Forsmarksverket (pre site investigation data)
XFM_Bathymetric_Grepen_sea_line	Shp	Lineaments in the Grepen area interpreted from bathymetric data
XFM_Coordinated_Grepen_sea_line	Shp	Coordinated lineaments in the Grepen area
XFM_Magnetic_Grepen_sea_line	Shp	Lineaments interpreted from magnetic airborne survey
Cut_HEM_NS_line_point	*Shp*	*Depth data based on the EM-inversion*
H_YTTRE_Land_point	*Shp*	*Elevation grid from National Land Survey of Sweden.*
id_djupvärden_forsmark_point	*Shp*	*Ground elevation data for some lakes in the Forsmark area. Umeå University*
Land_fm_h_4600_point	*Shp*	*Detailed elevation model (10 * 10 m) based on aerial photo 4,600 m*
Land-sjo_fm_h_2300_point	*Shp*	*Detailed elevation model (10 * 10 m) based on aerial photo 2,300 m*
UmU_Select_point	*Shp*	*Ground elevation data for shallow sea, some bays and lakes in the Forsmark area. Umeå University*
Yttre_Djup_point	*Shp*	*Ground elevation data from the SAFE-project*

Shape/image files

Filename	**File type**	**Content**
elevation_map	jpg	Figure showing the combined elevation an AEM-inversion, bathymetric data

Grid/files

Filename	**File type**	**Content**
FM_AEM_Bathymetry_and_topography_mosaic_grid	grid	Grid created from combined elevation and AEM-inversion, bathymetric data
FMV_seismic_refraction_ground_elevation_grid	grid	Grid created from pre site investigation seismic refraction ground surface elevation data in Forsmarksverket
FMV_seismic_refraction_rock_elavtion_grid	grid	Grid created from pre site investigation seismic refraction rock surface elevation data in Forsmarksverket