R-06-53

A comparison of two independent interpretations of lineaments from geophysical and topographic data from the Simpevarp area

Rune Johansson, Sveriges Geologiska Undersökning

January 2006

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

ISSN 1402-3091
SKB Rapport R-06-53

A comparison of two independent interpretations of lineaments from geophysical and topographic data from the Simpevarp area

Rune Johansson, Sveriges Geologiska Undersökning

January 2006

Keywords: Simpevarp, Laxemar, Oskarshamn, Forsmark, Site investigation, Lineament interpretation, Coordinated lineaments, Linked lineaments, Airborne geophysics, Topography.

Abstract

SKB performs site investigations for localization of a deep repository for high level radioactive waste at two sites, Forsmark and Oskarshamn. Lineament interpretation from topographic and airborne geophysical data is an essential part of the investigations at both sites, for the construction of a deformation zone model.

This report deals with the Oskarshamn study site and the objective of the work was to compare a primary lineament interpretation carried out by GeoVista AB with an alternative interpretation carried out by the Geological Survey of Finland (GTK). A brief comparison with the corresponding results from the Forsmark site has also been made.

The comparison carried out is based on the lineament interpretations reported. No attempt has been made here to compare the interpretation with the outcome of executed lineament investigations by means of drilling, trenching, etc. Neither did the work aim at any quality assessment or ranking of the two interpretations.

The following main conclusions were drawn:

- The comparison of the two lineament patterns revealed that the results are, in principle, reproducible.
- Although the interpreted lineament patterns are quite consistent, the assigned lineament attributes (length, uncertainty etc) differ significantly.
- The primary lineament interpretation is, in many cases, more detailed and should therefore form the basis for further evaluations. However, in order to make use of the more detailed primary interpretations of method specific lineaments, coordination and linking of also the shorter lineaments (< 1,000 m) must be carried out. The alternative interpretation should be seriously taken into consideration and the discrepancies between the two interpretations must be further assessed.
- The assigned lineament attributes offer the possibility to effectively display the characteristics of the inferred lineaments, but they can not be used, neither single nor combined, to decide if a lineament is related to a deformation zone.
- The further assessment of the inferred lineaments will require additional investigations such as trenching, drilling and ground geophysics. Not only the linked lineaments, but also the corresponding method specific lineaments should then be considered.
- It is in practice impossible to gain direct information (verification) on all lineaments, which implies that generalisations based on expert judgements have to be made. However, the assessment of strategic lineaments in key areas must be supported by outcrop data or observations in trenches and/or drill holes.
- The conditions for lineament interpretation from airborne geophysical data and topographic data at the Oskarshamn and Forsmark sites appear to be quite similar, although the topographic data at the Oskarshamn site allows for a more detailed interpretation. The similarities are at least valid as far as the possibilities to identify and outline lineaments are concerned (the density of lineaments, assigned uncertainties of the lineaments etc are similar). The conditions relevant to the coupling of lineaments to deformation zones have not been analysed in the present study.

Sammanfattning

SKB genomför platsundersökningar av två platser, Oskarshamn och Forsmark, för lokalisering av ett slutförvar för högaktivt radioaktivt avfall. På bägge platserna är lineamentstolkning av flyggeofysiska och topografiska data ett viktigt inslag för upprättandet av en deformationszonsmodell.

Föreliggande rapport behandlar platsundersökningsområdet Oskarshamn och målet med det presenterade arbetet var att jämföra en primär lineamentstolkning utförd av GeoVista AB med en alternativ tolkning utförd av Geologiska Forskningscentralen (GTK) i Finland. En ytlig jämförelse med motsvarande resultat från Forsmarksområdet har också gjorts.

Den utförda jämförelsen är baserad på de lineamentstolkningar som rapporterats. Ingen ansats har här gjorts till att jämföra tolkningsresultaten med utfallet av utförda lineamentsundersökningar i form av borrning, grävning etc. Arbetet har inte heller omfattat någon kvalitetsgranskning eller gradering av de utförda tolkningarna.

Utifrån den genomförda jämförelsen har följande slutsatser dragits:

- Jämförelsen av de två tolkningarna (lineamentsmöntren) visar att resultaten är i princip reproducerbara.
- Mönstret av tolkade lineament är tämligen konsistent medan de ansatta lineamentsattributen (längd, osäkerhet etc) skiljer sig.
- Den primära lineamentstolkningen, som i många fall är mer detaljerad, bör utgöra grunden för vidare utvärderingar, men för att kunna dra nytta av de mer detaljerade primära tolkningarna av metodspecifika lineament måste även ”linked lineaments” kortare än 1 000 m beaktas. Den alternativa tolkningen måste noga studeras och skillnaderna mellan det två tolkningsresultaten följas upp.
- De attribut som ansatts de tolkade lineamenten utgör ett utmärkt hjälpmedel för att visualisera deras egenskaper men attributen kan inte användas, vare sig ensamma eller i kombination, för att avgöra om ett lineament är relaterat till en deformationszon.
- Den vidare utvärderingen av de tolkade lineamenten kommer att kräva kompletterande undersökningar i form av exempelvis grävning, borrning och markgeofysiska mätningar. Inte bara ”linked lineaments”, utan även de underliggande metodspecifika lineamenten skall då beaktas.
- Det är i praktiken ogörligt att inhämta direkt information (verifikation) om alla lineament, vilket betyder att generaliseringar baserade på kvalificerade bedömningar måste göras. Utvärderingen av framträdande lineament i nyckelområden måste dock baseras på direkta observationer i häll, diken och/eller borrhål.
- Förutsättningarna för lineamentstolkning av flyggeofysiska och topografiska data i Oskarshamns- och Forsmarksområdena är i stort sett likartade, även om den topografiska informationen i Oskarshamnsområdet tillåter en något mer detaljerad tolkning. Detta gäller åtminstone förutsättningarna för att identifiera lineament. Förutsättningarna avseende kopplingen till deformationszoner har inte utvärderats i denna studie.

Contents

1 Introduction

SKB performs site investigations for localization of a deep repository for high level radioactive waste. The site investigations are performed at two sites, Forsmark and Oskarshamn. Lineament interpretation from topographic and airborne geophysical data, outlining e.g. possible deformation zones, is an essential part of the investigations at both sites.

One component in the characterisation work is the development of a site descriptive model that constitutes an integrated description of the site and its regional setting, covering the current character of the geosphere and the biosphere as well as the ongoing natural processes that affect their long-term evolution.

In the development of the site descriptions, uncertainties in the modelling work have been, and will continue to be given much attention. One aspect of this is the development of *alternative models*. Given the importance of the lineaments for the continued deformation zone modelling, it was regarded important to carry out an alternative, independent lineament interpretation using another team, in order to explore the sensitivity to “modelling style”.

In both Oskarshamn and Forsmark, GeoVista AB has been commissioned by SKB to carry out lineament interpretations, not only as part of the site investigations but also during preceding regional studies and feasibility studies of the two municipalities. Also at both sites, the Geological Survey of Finland (GTK) has been asked to perform an alternative interpretation of lineaments.

The comparison of the two independent interpretations of lineaments from geophysical and topographic data in Oskarshamn, presented in this report, has been preceded by a corresponding study at the Forsmark site /Johansson 2005/.

The site investigation is an ongoing process, continuously providing new information, and the conclusions and proposals presented in this report must therefore be considered with respect also to more recent information. The lineament interpretations discussed were made during 2003 and 2004 (GeoVista AB) and during the spring and summer of 2005 (GTK).

2 Objective and scope

The objective of the work was to compare the interpretations carried out by GeoVista AB and the Geological Survey of Finland (GTK). Based on the results of the comparative study, the conditions for further evaluation of the inferred lineaments and the requirements for supplementary information are discussed. Apart from this main objective, the present study also includes a brief comparison with the corresponding results from the Forsmark site.

Figure 2-1 shows the areas of interpretation involved. Both the primary and alternative interpretations of the airborne geophysical data cover the complete helicopter survey area. However, the two interpretations of topographic data cover slightly different areas and in order to allow for a reasonable statistical comparison, this work is restricted to the common area of interpretation. For the same reason, the discussion of the combined interpretation of lineaments based on all methods in question is restricted to the airborne survey area, within which all methods are available.

It should finally be noted that the present work did not aim at any quality assessment or ranking of the two interpretations.

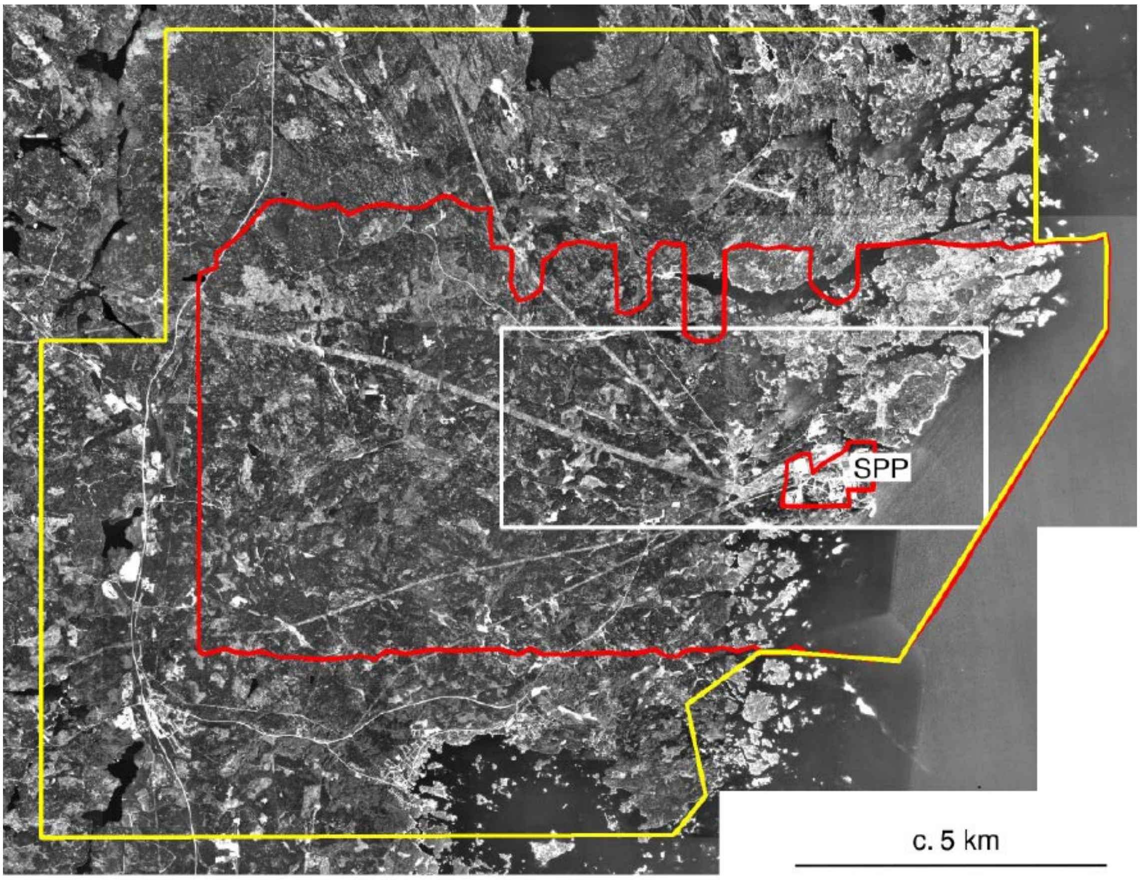

Figure 2-1. The areas of interpretation. The common area for topographic interpretation is outlined in yellow and the helicopter survey area in red. The latter area is also the area for integrated geophysical and topographic interpretation. The white rectangle shows the Laxemar local scale model area. SPP=Simpevarp nuclear power plant.

3 Lineament interpretations carried out

Prior to the site investigations, lineament interpretations had been carried out in the Simpevarp area and its surroundings, that is the regional study of the county of Kalmar /Antal et al. 1998/ and the feasibility study of the municipality of Oskarshamn /Bergman et al. 1998, 1999, 2000/. These studies also made use of earlier works carried out by for example /Nisca 1987/ and /Tirén et al. 1987/. One important point of departure for the site investigation was the Simpevarp site descriptive model version 0 /SKB 2002/ which was based on a compilation of the, at that time, available data and interpretations.

The present study is focused on the lineament interpretations performed during the initial site investigation phase. These interpretations are based on the more detailed topographic data /Wiklund 2002/ and airborne geophysical data /Rönning et al. 2003/ acquired during the initial phase of the site investigation. The airborne geophysical data comprise magnetics, EM (dipole source), VLF and radiometrics. However, the radiometric data have not been used for lineament interpretation.

The lineament interpretation carried out by GeoVista AB is hereafter referred to as the primary interpretation (or GeoVista interpretation) as opposed to the alternative (or GTK) interpretation.

3.1 Methodology for integrated lineament interpretation

The method for lineament interpretation follows a step-by-step procedure (see /Triumf 2004ab/ for details).

Step 1 involves interpretation of topography, magnetics, EM and VLF separately and each "method specific lineament" is characterised by a set of attribute data.

Step 2 includes coordination of the method specific lineaments into "coordinated lineaments" and the discriminating methods for each lineament are added as attribute data. The length of each lineament is also calculated. A weight attribute is added to illustrate the confidence of the lineaments. The coordination of lineaments is illustrated by Figure 3-1.

In step 3, the coordinated lineaments are linked together. The linking process is illustrated by Figure 3-2. The attribute table facilitates further statistical analysis and scrutiny of the linked lineaments.

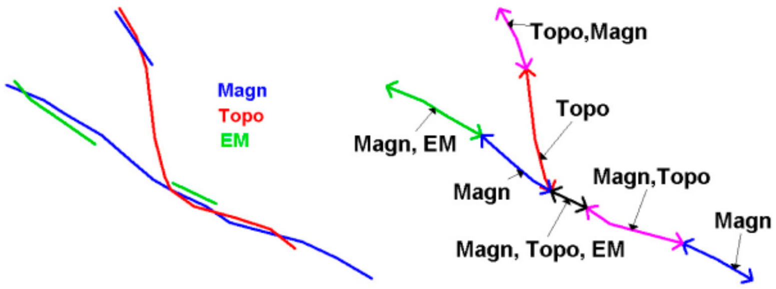

Figure 3-1. *Lineament coordination. Method specific lineaments; magnetic, topographic and EM in blue, red and green, respectively, to the left. From /Isaksson and Keisu 2004/.*

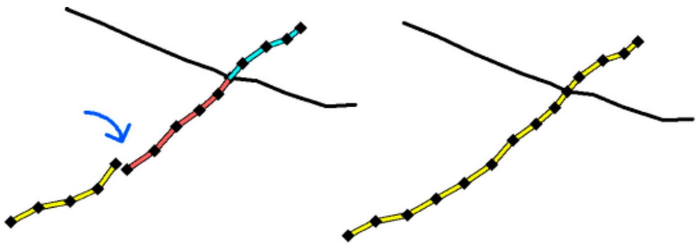

Figure 3-2. *Linking of lineaments, including node adjustment (blue arrow). From /Isaksson and Keisu 2004/.*

3.2 Primary lineament interpretation

The primary interpretation, guided by the method descriptions "Metodbeskrivning för lineamentstolkning baserad på topografiska data" and "Metodbeskrivning för tolkning av flyggeofysiska data" (SKB internal controlling documents), has been carried out in three phases:

The first phase included interpretation of lineaments from topographic data /Triumf 2003/ and covers, with the exception of the off shore areas, the Simpevarp regional model area.

The second phase comprises interpretation of airborne geophysical data e.g. magnetics, EM and VLF /Triumf et al. 2003/. This work included also other aspects than lineaments, although for the present comparison only the lineament interpretation is important.

In the third phase, joint interpretation of lineaments was carried out. This was first made in the eastern part of the local model area /Triumf 2004a/ and later in the entire area covered by the detailed terrain model /Triumf 2004b/. Hence, in the more peripheral parts of the latter area, the joint interpretation is based on detailed topographic data, but not on detailed airborne geophysics (see Figure 2-1). At this time, also data from a marine geological survey /Elhammer and Sandkvist 2005/ were used.

3.3 Alternative lineament interpretation

The alternative lineament interpretation was carried out by the Geological Survey of Finland (GTK) and is documented by /Korhonen et al. 2005/. GTK was instructed to apply the same methodology (given by the method descriptions) as the one used for the primary interpretation. However, a couple of attributes; Identity (SKB identity of linked lineament) and Classification (classification of lineament group) were, in accordance with given instructions, not assigned by GTK. On the other hand, GTK assigned "precision" to the lineaments which was not made by GeoVista. In the corresponding Forsmark interpretations, precision was assigned by both GeoVista and GTK.

In the final stage (phase three above), GeoVista utilised bathymetric data and inverted helicopter EM data to cover the sea area, but this information was not made available to GTK. The reason for this decision was that it was still unclear whether the information (mainly water depth) was to be considered as classified for military defence reasons or not. At present, water depth and depth to the bedrock surface provided by the marine geological survey are classified data.

3.4 Key attributes

As indicated above, all interpreted lineaments; method specific, co-ordinated as well as linked, were assigned a number of attributes describing the origin and character of each lineament. The complete tables are presented in /Triumf et al. 2003, Triumf 2004ab, Korhonen et al. 2005/ whereas the following tables, Table 3-1 and 3-2, present the key attributes for method specific and linked lineaments discussed in the present report.

Table 3-1. Method specific lineaments. Key attributes discussed in the present study.

Attribute	Description	Attribute value
Uncertainty	An expert judgement of the clarity of the lineament.	An estimate of uncertainty of the lineament, graded as 1=low, 2=medium and 3=high.
Class (x)	Classification of lineaments into local major or local minor.	The classification is mainly based on the total length of the sub-segments constituting a possible system of lineaments, Threshold values are: major > 10 km, local major 1–10 km, and local minor < 1 km.
Precision (xx)	An estimate of the uncertainty in the position of the lineament.	E.g. 20 m.

(x) Assigned by GeoVista only.

(xx) Assigned by GTK only.

Table 3-2. Linked lineaments. Key attributes discussed in the present study.

Attribute	Description	Attribute value
Uncertainty	A weighted average of the uncertainties of the coordinated lineament segments according to the length of the segments.	A numerical value in the range of 1 (low uncertainty) – 3 (high uncertainty).
Length	The length of the linked lineament in metres.	E.g. 1,205 m.
Weight	A combination of uncertainty and number of properties (methods). A weighted average of the weight attributes, according to the length, of the coordinated lineaments.	A numerical value in the range of 1 (low weight) – 5 (high weight). See also section 4.5.3.
Precision (x)	An estimate of the uncertainty in the position of the lineament.	E.g. 20 m.

(x) Assigned by GTK only.

4 Comparison of the primary and alternative interpretations

The comparison of the primary and the alternative interpretation is made by first comparing the method specific lineaments and then the linked lineaments.

The linked lineaments constitute the final product of the lineament interpretation and are the most important ones to study in the present comparison. However, since the linked lineaments are constructed by coordination and linking of the method specific lineaments, it is also important to study this first step of the interpretation process.

The coordination of lineaments includes, among other things, decision-making as to which method should be used to outline the lineament in those cases when e.g. the topographic and magnetic lineaments are slightly displaced but still interpreted as one lineament. The coordination process is difficult to compare in a generalised way and has been left out of this study.

4.1 Topographic lineaments

Figure 4-1 shows the primary (GeoVista) interpretation of topographic lineaments and Figure 4-2 the alternative (GTK) interpretation, superimposed on a shaded grey scale representation of the topographic map (the digital terrain model).

The similarities between the two interpretations are evident, both revealing the same basic lineament pattern. The most striking difference is the very large number of short lineaments in the GeoVista interpretation (compare Figures 4-1 and 4-2), most likely reflecting the time spent on the interpretation by GeoVista as compared to GTK. The number of GeoVista and GTK lineaments, respectively, is

GeoVista	4,875
GTK	1,425

GeoVista /Triumf 2003/ presents a length classification of the topographic lineaments which was, in line with the given instructions, not made by GTK. Instead, the GTK lineaments have been classified as part of the present work. The distribution of the classified lineaments is presented in Table 4-1.

Figure 4-3 displays the distribution of the GeoVista lineaments classified as major or local major on one hand and local minor on the other.

GeoVista only assigned individual uncertainty values to the major and local major lineaments. The local minor elements were by default given medium uncertainty. This is understandable since the assessment of all lineaments in this respect would have been very time consuming and probably of limited value, but it hampers the possibility to compare the two interpretation data sets.

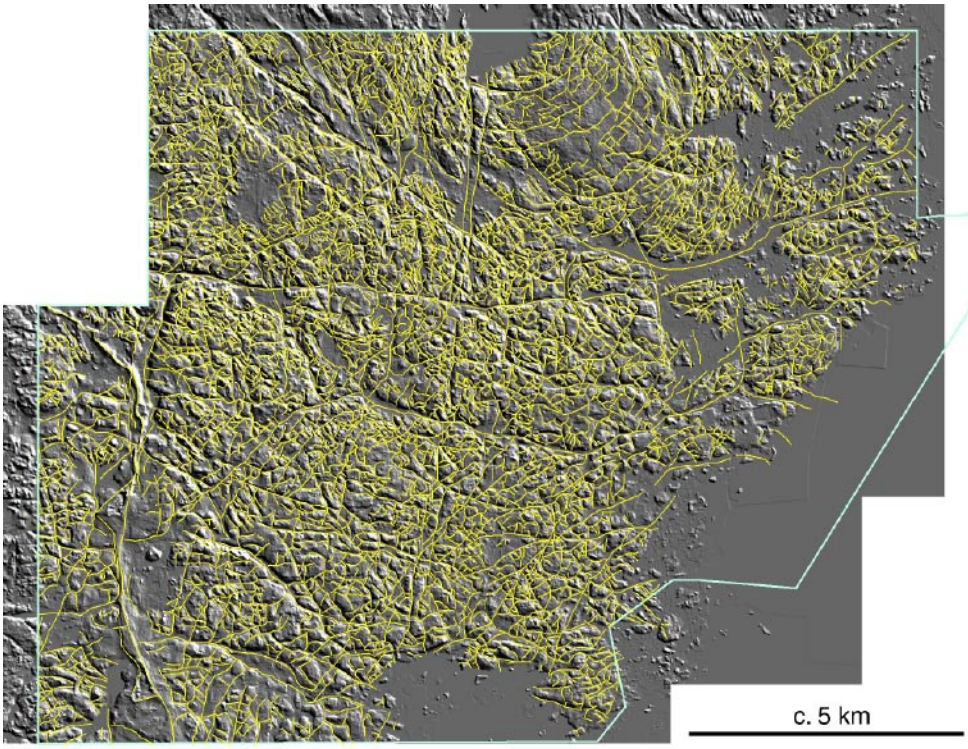

Figure 4-1. *The primary (GeoVista) interpretation of topographic lineaments (yellow) superimposed on a shaded (from NE) grey scale presentation of the digital terrain model. The area of topographic interpretation is outlined in light blue.*

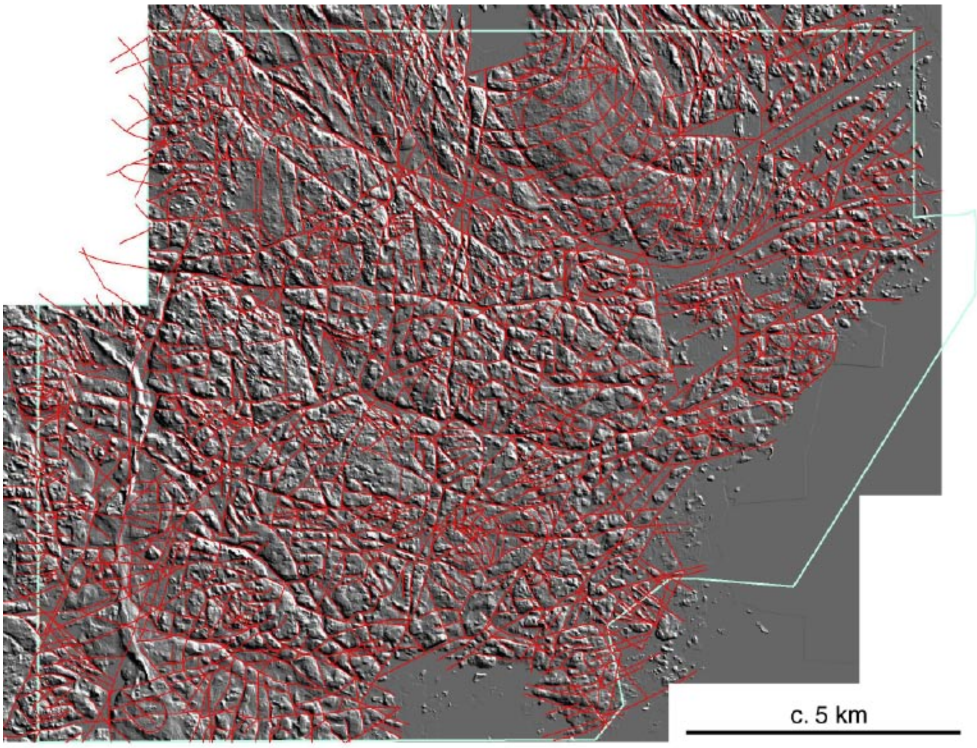

Figure 4-2. *The alternative (GTK) interpretation of topographic lineaments (red) intersecting the area of topographic interpretation superimposed on a shaded (from NE) grey scale presentation of the digital terrain model. The area of topographic interpretation is outlined in light blue.*

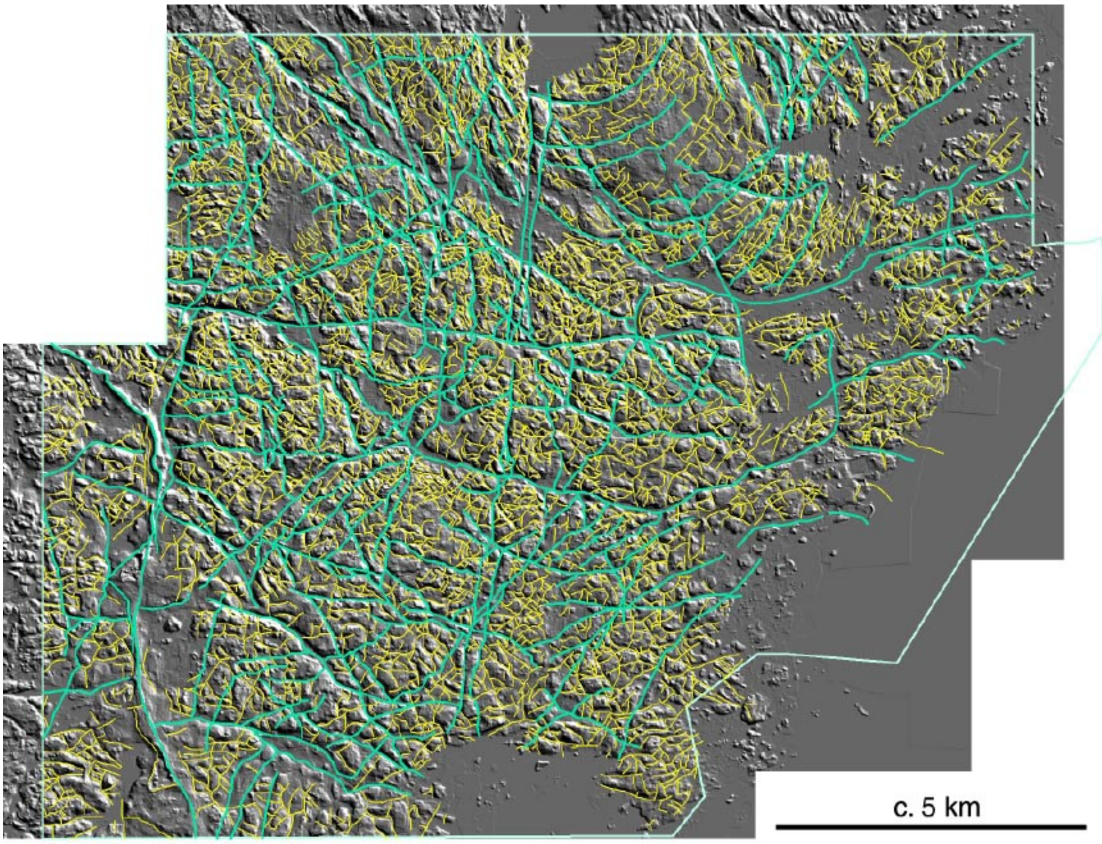

Figure 4-3. *Topographic GeoVista lineaments superimposed on a grey scale presentation of the digital terrain model. Lineaments classified as "major" or "local major" in blue, "local minor" lineaments in yellow. The area of topographic interpretation is outlined in light blue.*

Table 4-1. Distribution of length classified topographic lineaments.

Lineament class	GeoVista	GTK
Major (> 10 km)	47 (1%)	0 (0%)
Local major (1–10 km)	617 (13%)	377 (26%)
Local minor (< 1 km)	4,211 (86%)	1,048 (74%)
Total number of lineaments	4,875	1,425

Hence, the assigned uncertainty values presented in Table 4-2 below must not be over-interpreted. Still it is interesting to note that the number of low uncertainty GTK lineaments (79) is low compared to the corresponding number of low uncertainty GeoVista linements (204), which underlines the subjectivity of the assessment of uncertainty and adds a "personal style" to the interpretations.

Table 4-2. Uncertainty assigned to topographic lineaments.

Uncertainty	GeoVista	GTK
Uncertainty 1 (low uncertainty)	204 (4%)	79 (6%)
Uncertainty 2 (medium uncertainty)	4,650 (95%)	660 (46%)
Uncertainty 3 (high uncertainty)	21 (< 1%)	686 (48%)
Total number of lineaments	4,875	1,425

4.2 Magnetic lineaments

Figure 4-4 shows the primary (GeoVista) and Figure 4-5 the alternative (GTK) magnetic interpretation superimposed on the magnetic map.

The two magnetic interpretations differ notably in style. The GeoVista version is more detailed in the sense that the lineaments follow the magnetic features more "carefully" whereas the GTK lineaments are much more frequently generalised to straight lines. The GeoVista approach, again requiring more time than was available to GTK, also leads to the division of longer lineaments into one or several disconnected segments and, hence, a larger number of lineaments.

The total numbers of inferred GeoVista and GTK magnetic lineaments and their length distribution are shown in Table 4-3. Only the classes "local major" and "local minor" are applicable, since the area for geophysical interpretation is, in practice, to small to allow for the classification of "major lineaments" (> 10 km). Figure 4-6 shows the GeoVista lineaments, displayed according to the length classification.

Table 4-3. Distribution of length classified magnetic lineaments.

Lineament class	GeoVista	GTK
Local major (1–10 km)	74 (17%)	110 (54%)
Local minor (< 1 km)	372 (83%)	92 (46%)
Total number of lineaments	446	202

When the two sets of lineaments are viewed together, Figure 4-7, it is evident that the appearing patterns are very similar. The magnetic interpretation is very stable as regards the identification of lineaments, even though the assessment of uncertainty differs to some extent, see Table 4-4. GeoVista has identified 107 low to medium uncertainty lineaments and GTK 64. The high uncertainty GeoVista lineaments are mainly related to the ones classified as "local minor". As earlier pointed out, the GTK magnetic lineaments are more generalised to be long and straight as compared to the GeoVista lineaments.

Table 4-4. Uncertainty assigned to magnetic lineaments.

Uncertainty	GeoVista	GTK
Uncertainty 1 (low uncertainty)	32 (7%)	25 (12%)
Uncertainty 2 (medium uncertainty)	75 (17%)	39 (19%)
Uncertainty 3 (high uncertainty)	339 (76%)	138 (69%)
Total number of lineaments	446	202

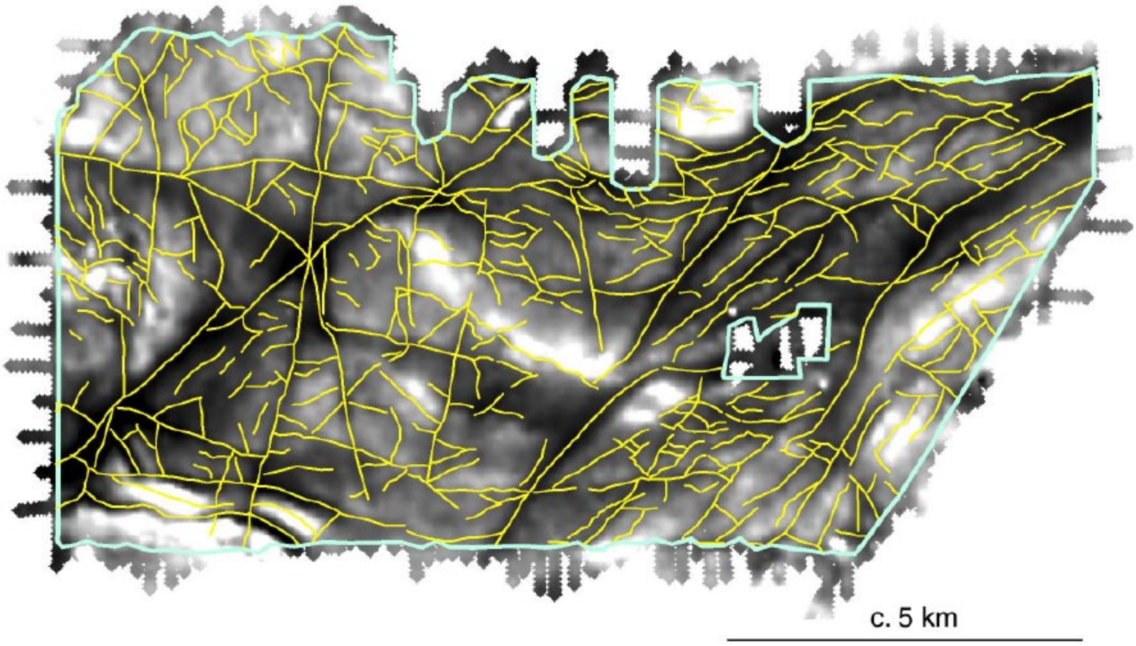

Figure 4-4. *The primary (GeoVista) interpretation of magnetic lineaments (yellow) superimposed on a grey scale presentation (positive anomalies light, negative anomalies dark) of the magnetic anomaly. The area of interpretation is outlined in light blue.*

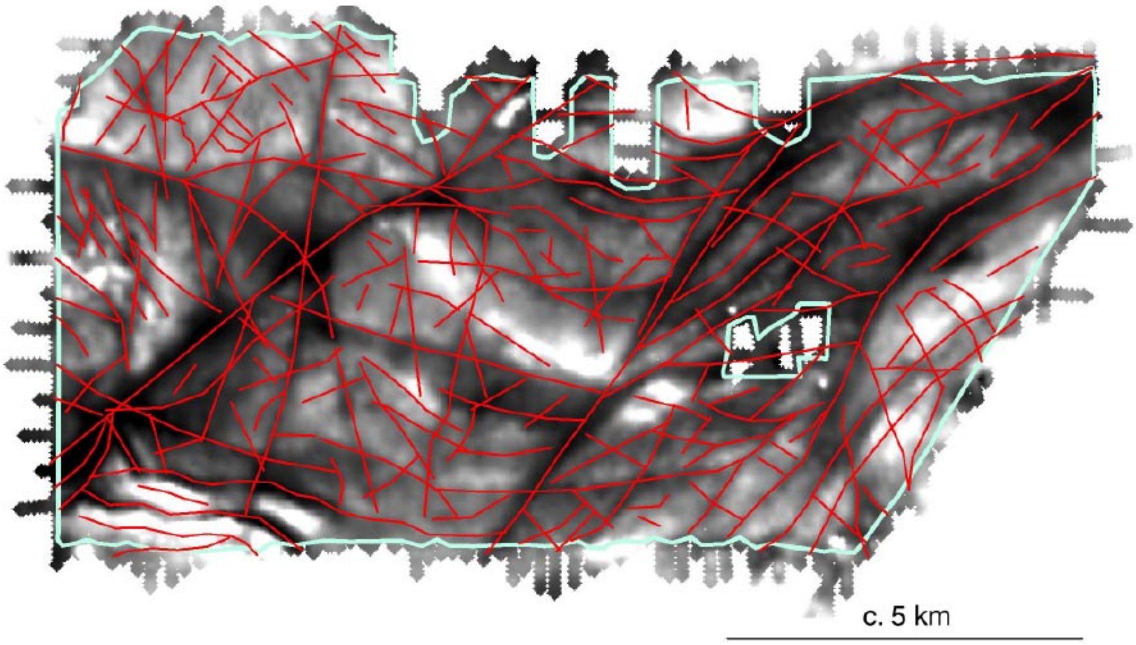

Figure 4-5. *The alternative (GTK) interpretation of magnetic lineaments (red) superimposed on a grey scale presentation (positive anomalies light, negative anomalies dark) of the magnetic anomaly. The area of interpretation is outlined in light blue.*

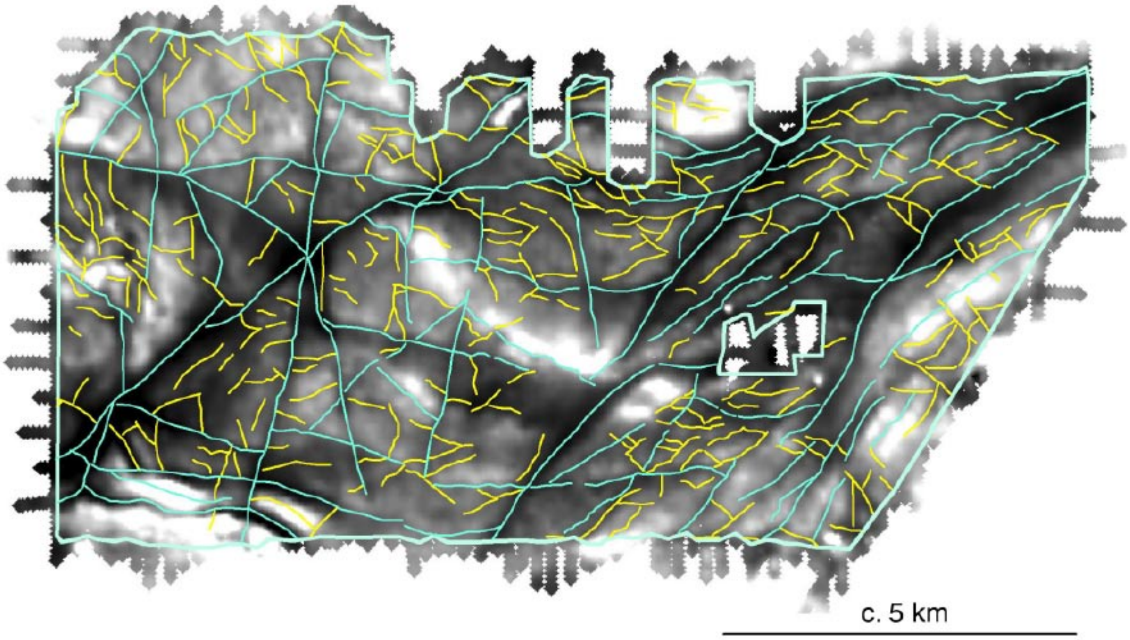

Figure 4-6. *Magnetic GeoVista lineaments superimposed on a grey scale presentation (positive anomalies light, negative anomalies dark) of the magnetic anomaly. Lineaments classified as "local major" in blue, "local minor" lineaments in yellow. The area of interpretation is outlined in light blue.*

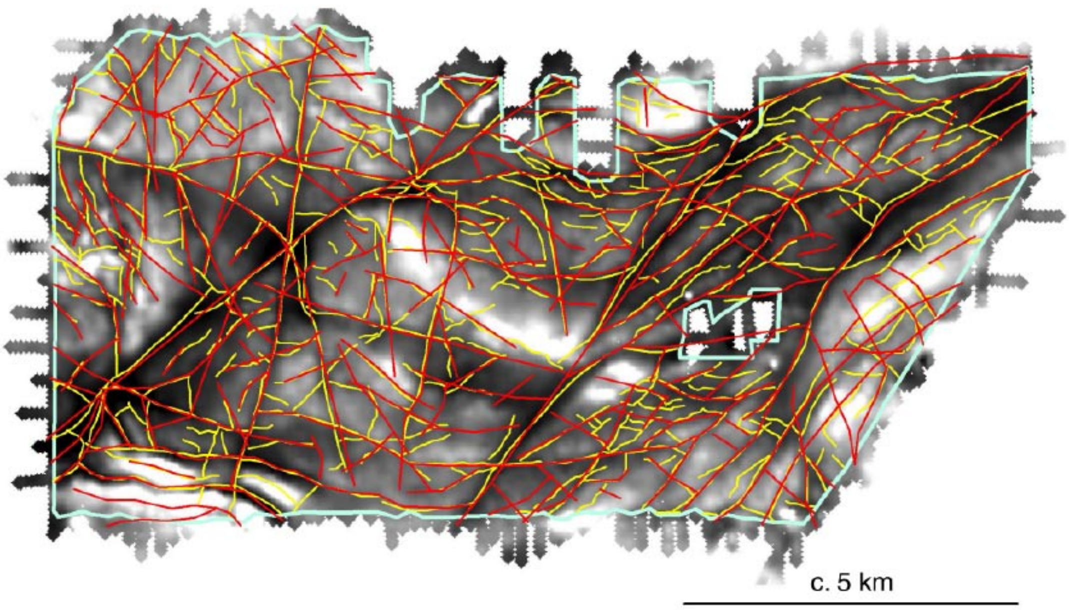

Figure 4-7. *Magnetic lineaments superimposed on a grey scale presentation (positive anomalies light, negative anomalies dark) of the magnetic anomaly. The primary (GeoVista) interpretation is shown in yellow and the alternative (GTK) interpretation in red. The area of interpretation is outlined in light blue.*

4.3 Electromagnetic and VLF lineaments

Figure 4-8 shows the primary (GeoVista) and alternative (GTK) interpretations of the EM data superimposed on the apparent resistivity (800 Hz) map. The GeoVista lineaments based on inverted helicopter EM data not made available to GTK are shown in a different colour and are excluded from the statistics presented below. Figure 4-9 shows the primary (GeoVista) and alternative (GTK) interpretations of the VLF data superimposed on the orthogonal station total field data.

GeoVista has identified a considerably larger number of lineaments, even when the EM lineaments based on EM inversion have been excluded. This is very much in line with the observations made regarding both topographic and magnetic lineaments. Again, the most likely explanation is that more time has been available for the GeoVista work, resulting in a more detailed interpretation.

The total numbers of inferred EM and VLF lineaments and their length distribution ("local major" and "local minor" lineaments) are shown in Tables 4-5 and 4-6.

Table 4-5. Distribution of length classified EM lineaments (GeoVista lineaments based on EM inversion excluded).

Lineament class	GeoVista	GTK
Local major (1–10 km)	32 (11%)	26 (54%)
Local minor (< 1 km)	256 (89%)	22 (46%)
Total number of lineaments	288	48

Table 4-6. Distribution of length classified VLF lineaments.

Lineament class	GeoVista	GTK
Local major (1–10 km)	16 (14%)	21 (39%)
Local minor (< 1 km)	97 (86%)	33 (61%)
Total number of lineaments	113	54

The EM and VLF data are much affected by anthropogenic noise, e.g. from power lines, which has made the interpretation highly uncertain in some areas. However, the frequency of high uncertainty EM and VLF lineaments is not higher (in fact almost equal or lower) compared to the frequency of high uncertainty magnetic and topographic lineaments, compare Tables 4-2, 4-4, 4-7 and 4-8. This may indicate that the uncertainty assessment is "method specific" (i.e. a low uncertainty VLF lineament may be much more uncertain than a low uncertainty magnetic lineament) or, alternatively, that the outlining of EM and VLF lineaments in difficult areas has been avoided.

It is still encouraging to note that at least many longer lineaments coincide with each other. These lineaments show zones of increased electrical conductivity and may, with great caution, be regarded as indications of water bearing and/or clay filled deformation zones.

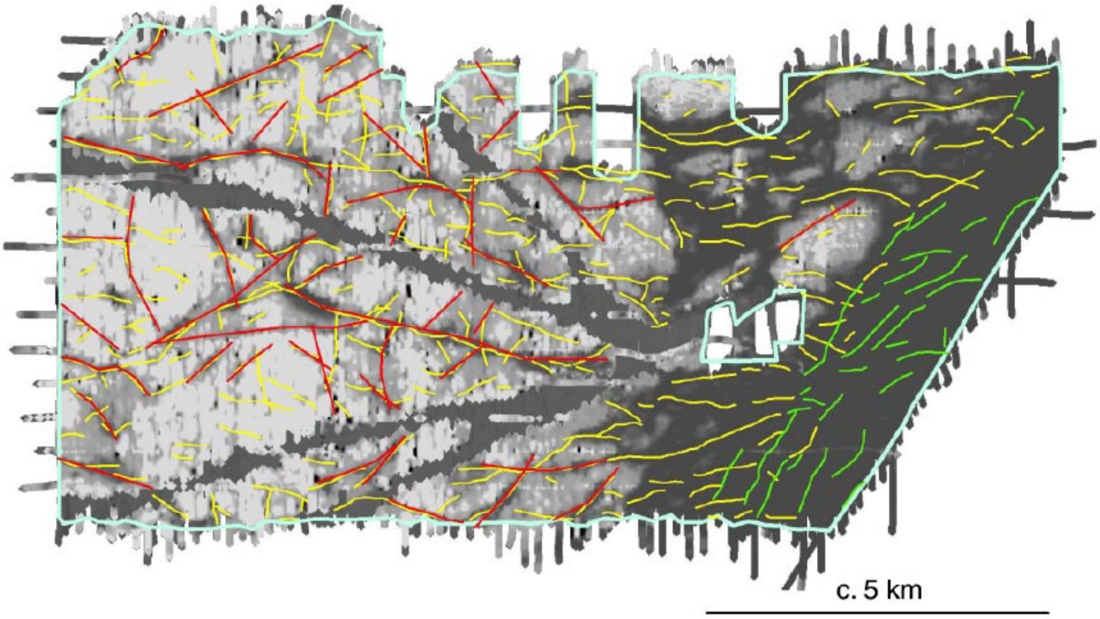

Figure 4-8. *Electromagnetic (dipole source) lineaments superimposed on a grey scale presentation (high resistivity areas light, low resistivity areas dark) of the apparent resistivity (800 Hz) map. The primary (GeoVista) interpretation is shown in yellow and the alternative (GTK) interpretation in red. GeoVista interpretation in the sea area based on inverted helicopter EM data (sea-floor depressions) is shown in green. The area of interpretation is outlined in light blue.*

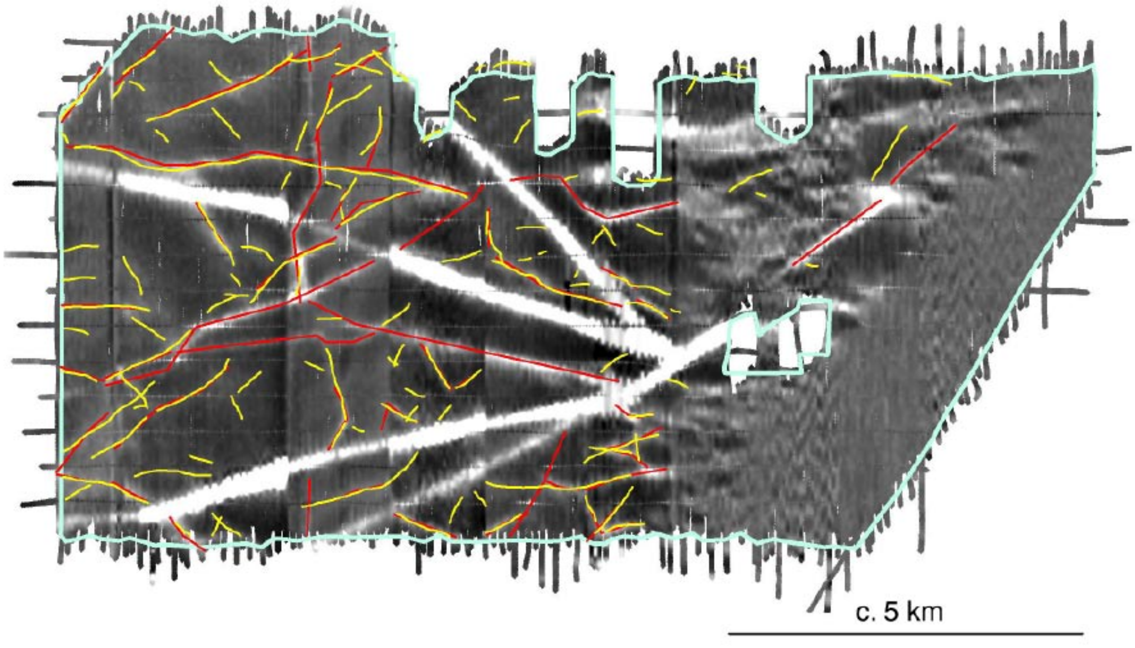

Figure 4-9. *VLF lineaments superimposed on a grey scale presentation (positive anomalies light, negative anomalies dark) of the VLF total field orthogonal station data. The primary (GeoVista) interpretation is shown in yellow and the alternative (GTK) interpretation in red. The area of interpretation is outlined in light blue.*

Table 4-7. Uncertainty assigned to EM lineaments (30 GeoVista lineaments based on inverted helicopter EM data excluded).

Uncertainty	GeoVista	GTK
Uncertainty 1 (low uncertainty)	37 (13%)	6 (12%)
Uncertainty 2 (medium uncertainty)	133 (46%)	18 (38%)
Uncertainty 3 (high uncertainty)	118 (41%)	24 (50%)
Total number of lineaments	288	48

Table 4-8. Uncertainty assigned to VLF lineaments.

Uncertainty	GeoVista	GTK
Uncertainty 1 (low uncertainty)	15 (13%)	11 (20%)
Uncertainty 2 (medium uncertainty)	38 (34%)	22 (41%)
Uncertainty 3 (high uncertainty)	60 (53%)	21 (39%)
Total number of lineaments	113	54

4.4 Linked lineaments

The linking processes applied by GeoVista and GTK differ in some important respects. GeoVista has applied a threshold value of 1,000 m which means that only linked lineament longer than 1,000 m are included /Triumf 2004ab/. However, shorter linked lineaments appear if they are considered to be a part (segment) of a longer lineament. In other words, the linked GeoVista lineaments sometimes appear as a number of segments with minor gaps in between ("linked but not completely joined"). GTK has carried out the linking in a more straightforward way, i.e. the linked lineaments have no gaps and no threshold value has been applied. Of the GTK linked lineaments, 491 (66%) are shorter than 1,000 m and the shortest lineament is 186 m.

To overcome this obstacle to the comparative statistical analyses (Section 4.5), those linked GeoVista lineaments which are built up of several segments have been merged to form single segment lineaments. As regards length, this has been done by simply adding the lengths of the individual segments. Since the gaps are not counted, this results in a slight underestimation of the total length, presumed to be insignificant in this context. Regarding uncertainty and weight, the merged attributes are weighted values calculated in the same way as during the standard linking process. Furthermore, when the two data sets of linked lineaments are compared, the minor (< 1,000 m) GTK lineaments are not included. The resulting total numbers of GeoVista (merged as described above and original version) and GTK linked lineaments are as follows:

GeoVista (original)	389
GeoVista (merged)	213 (204 lineaments > 1,000 m)
GTK (all)	742
GTK (> 1,000 m)	251

Nine merged GeoVista lineaments are shorter than 1,000 m. These lineaments are all close to 1,000 m long (880–998 m) which explains why they have been incorporated in the data set. However, they have been excluded from the uncertainty and weight statistics presented in this report.

An interpretation is always a result of a subjective process and the lineament interpretation discussed here is no exception. On the contrary, the process involves so much data and so many interpretation steps, that one would actually expect the interpretation results to diverge somewhat. Nevertheless, the two groups of geoscientists have produced very similar results as far as the identification and outlining of lineaments are concerned, see Figures 4-10 and 4-11. The assigned attributes (especially uncertainty and weight) differ more, indicating a much higher dependence on the individual interpreter. The linked lineament attributes are discussed in Section 4.5.

Although the interpreted lineament patterns are very similar, there are some differences which have to be considered during the further assessment of the lineaments. Generally speaking, when longer lineaments differ in length or position, the discrepancies reflect differing method specific interpretations as well as differing judgements concerning coordination (which method specific lineament rules the outline of the coordinated lineament) and linking (when and how lineaments are linked). The interpretations of shorter lineaments, on the other hand, basically reflect different results from the method specific interpretations.

The linked lineaments in the sea area are not fully comparable since the GeoVista lineaments are based also on inverted helicopter EM data and bathymetric data, two sets of data not used by GTK (see Section 3.3).

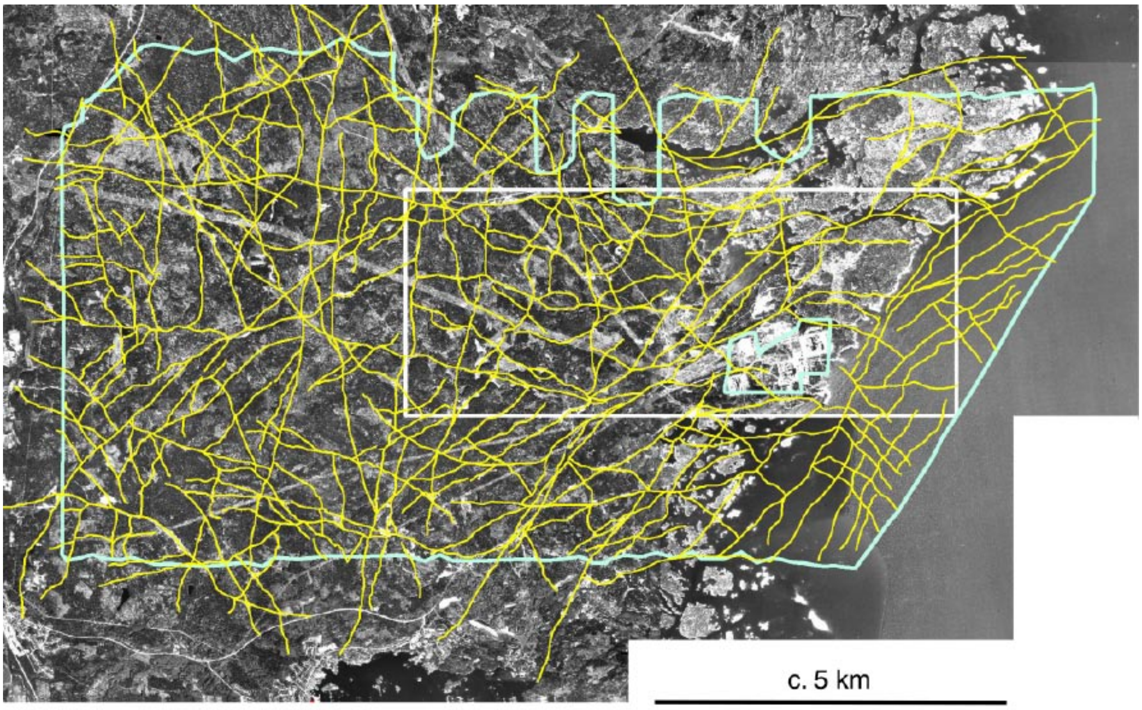

Figure 4-10. *The primary (GeoVista) interpretation of linked lineaments (yellow) superimposed on a mosaic of grey scale orthophotos. The area of combined interpretation is outlined in light blue and the Laxemar local scale model area in white.*

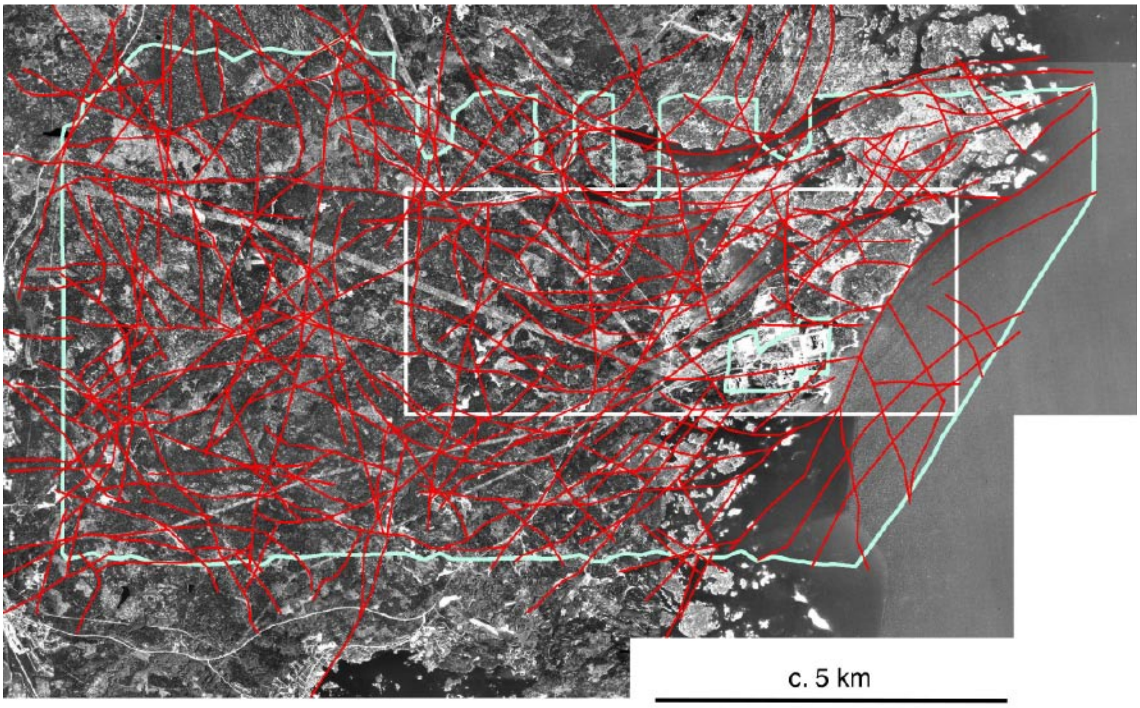

Figure 4-11. *The alternative (GTK) interpretation of linked lineaments longer or equal to 1,000 m (red) superimposed on a mosaic of grey scale orthophotos. The area of combined interpretation is outlined in light blue and the Laxemar local scale model area in white.*

4.5 Linked lineament attributes

Table 4-9a–c presents the selected statistics concerning length, uncertainty and weight of the linked lineaments as assigned by GeoVista and GTK.

Table 4-9a. Length attribute assigned to the linked lineaments.

Length Number of lineaments	< 500 m	500–999 m	1,000–2,999 m	≥ 3,000 m	Mean length (m)
Primary interpretation Sub segments merged Lineaments > 1,000 m	0	0	163 (80%)	41 (20%)	2,440
Alternative interpretation	164 (22%)	327 (44%)	212 (29%)	39 (5%)	1,126 (all) 2,150 (> 1,000 m)

Table 4-9b. Uncertainty attribute assigned to the linked lineaments.

Uncertainty (see Table 3-2 for explanation) Number of lineaments	1.0–1.5	1.5–2.5	2.5–3.0	Mean uncertainty
Primary interpretation Sub segments merged Lineaments > 1,000 m	23 (11%)	129 (63%)	52 (26%)	2.17
Alternative interpretation Lineaments > 1,000 m	70 (28%)	124 (49%)	57 (23%)	1.98
Alternative interpretation All lineaments	77 (10%)	340 (46%)	325 (44%)	2.35

Table 4-9c. Weight attribute assigned to the linked lineaments.

Weight (see Table 3-2 and Section 4.5.3 for explanation) Number of lineaments	1.0–2.5	2.5–3.5	3.5–5.0	Mean weight
Primary interpretation Sub segments merged Lineaments > 1,000 m	66 (32%)	89 (44%)	49 (24%)	2.90
Alternative interpretation Lineaments > 1,000 m	162 (64%)	60 (24%)	29 (12%)	2.30
Alternative interpretation All lineaments	630 (85%)	77 (10%)	35 (5%)	1.79

4.5.1 Length

The most relevant way to compare the two data sets in this respect is to study the length distribution of the merged (> 1,000 m) GeoVista lineaments and GTK lineaments exceeding 1,000 m (Figures 4-10, 4-11 and Table 4-9a), and these results are very similar.

However, a closer look at the distribution of lineaments exceeding 3,000 m (Figure 4-12), reveals some important differences. Persistent lineaments (if verified as deformation zones) require a respect distance in the order of 100 m which reduces the available repository volume considerably if they cut the repository area /Hökmark and Munier 2004/. It is therefore important to note that there are a few lineaments of this dignity appearing in only one of the two interpretations. However, this does generally not mean that the lineament is not found in the other interpretation, but rather that it is divided into two or more shorter lineaments.

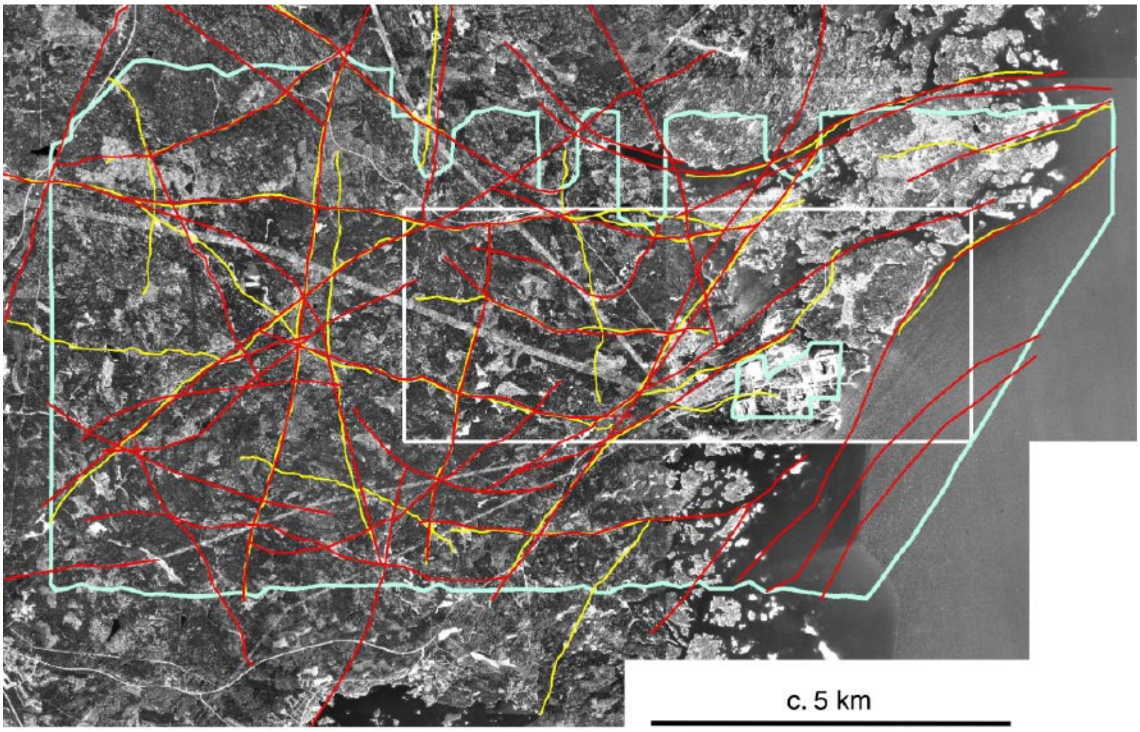

Figure 4-12. Linked lineaments longer than 3,000 m, superimposed on a mosaic of grey scale orthophotos. The primary (GeoVista) interpretation is shown in yellow and the alternative (GTK) interpretation in red. The area of combined interpretation is outlined in light blue and the Laxemar local scale model area in white.

The length of a lineament is difficult to define and there are no objective criteria to tell when two lineaments should be kept separate or linked to form one single lineament. The linking is also scale dependent; lineaments linked in large-scale models will in many cases be divided into a number of shorter lineaments when studied in a more detailed model. An attempt to use the length criterion as a stand alone tool to define this important group of lineaments based on the GeoVista and the GTK interpretations, respectively, would lead to significantly deviating results.

4.5.2 Uncertainty

The distribution of the assigned uncertainty (Table 4-9b) to the linked lineaments differ above all as regards the low uncertainty (1.0–1.5) lineaments which are more frequent (28%) among the GTK lineaments compared to the merged GeoVista lineaments (13%).

Figure 4-13 shows the low uncertainty linked lineaments and demonstrates the larger number of GTK lineaments in this category. It is also interesting to note that, with very few exceptions, all the low uncertainty GeoVista lineaments correspond to low uncertainty GTK lineaments. The results, as shown in Figure 4-13, underline the subjective nature of the assessment of uncertainty. The "missing" low uncertainty GeoVista lineaments are instead found among the medium uncertainty lineaments, while the frequency of high uncertainty lineaments is almost the same (see Table 4-9b).

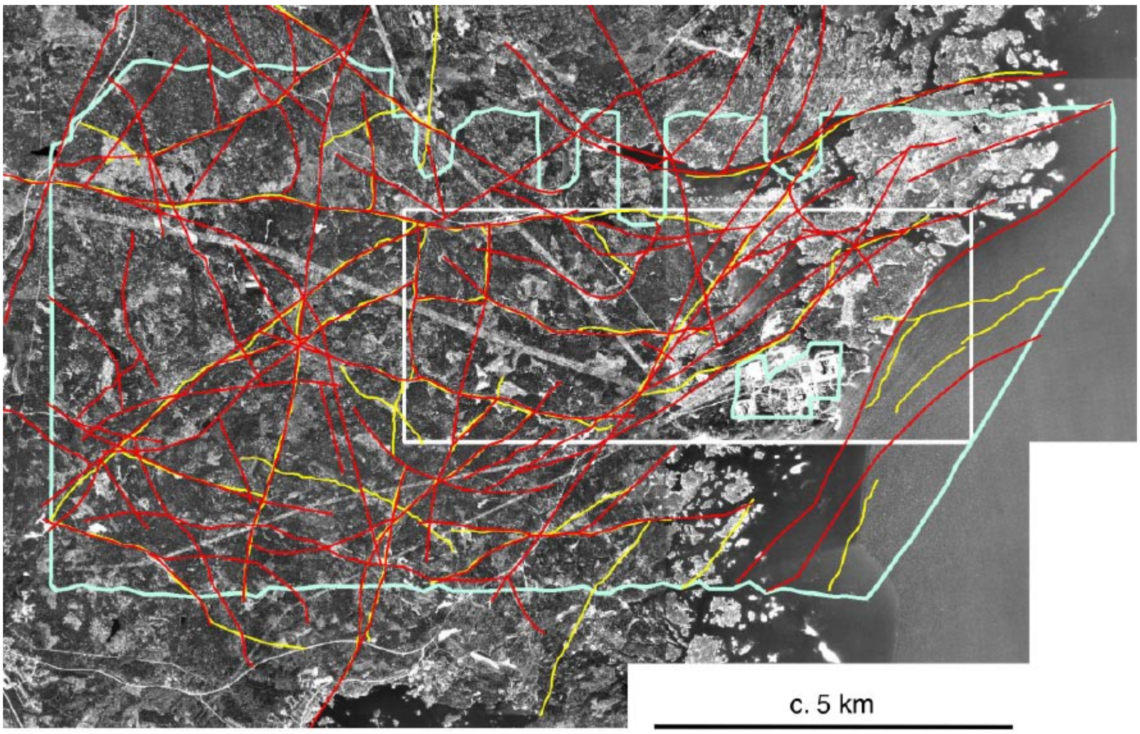

Figure 4-13. *Linked lineaments, uncertainty 1.0–1.5, superimposed on a mosaic of grey scale orthophotos. The primary (GeoVista) interpretation is shown in yellow and the alternative (GTK) interpretation in red. The area of combined interpretation is outlined in light blue and the Laxemar local scale model area in white.*

4.5.3 Weight

The weight attribute (Table 4-9c), assigned to coordinated and linked lineaments, is a combination of uncertainty and number of properties (methods) indicating the lineament /Triumf 2004ab/. Low weight lineaments are lineaments of high uncertainty, indicated by a low number of methods. For example, a coordinated lineament of high uncertainty indicated by one method is assigned weight = 1 while a low uncertainty lineament indicated by three properties (topography, magnetics and conductivity) is assigned weight = 5. For the linked lineaments, a weighted average is calculated according to the length of the segments (coordinated lineaments) involved.

Figure 4-14 presents the GeoVista and GTK lineaments with weight exceeding 3.5. As was the case with the low uncertainty lineaments (Figure 4-13) there are some lineaments only appearing in one of the two interpretations. This is again underlining the subjectivity of the assignment of the attributes.

4.5.4 Precision

The precision attribute, which is intended to indicate how well the linked lineament is defined in space, has only been assigned by GTK. The results are presented in Table 4-10 below.

The majority of all lineaments (68%) have been assigned precision values equal to or better than 25 m. Among lineaments longer than 1,000 m, the corresponding figure is 41%. Generally speaking, the longer lineaments show lower precision than the shorter ones. This is not surprising, since the precision varies along the lineaments and the mean precision will be lower than the precision of the best defined segment of the lineament (as well as

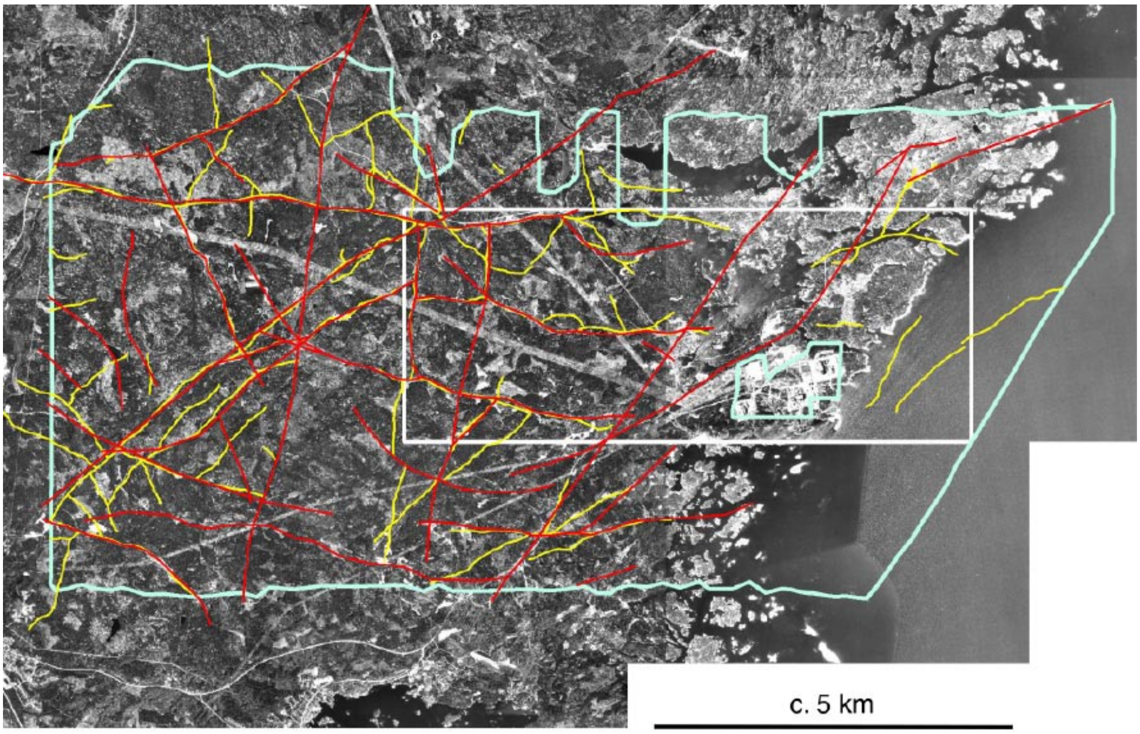

Figure 4-14. *Linked lineaments, weight > 3.5, superimposed on a mosaic of grey scale ortho-photos. The primary (GeoVista) interpretation is shown in yellow and the alternative (GTK) interpretation in red. The area of combined interpretation is outlined in light blue and the Laxemar local scale model area in white.*

Table 4-10. Precision assigned to the GTK linked lineaments.

Precision (m)	No of linked lineaments (all)	No of linked lin > 1,000m
10	14 (2%)	5 (2%)
15	143 (19%)	29 (12%)
20	244 (33%)	34 (14%)
25	106 (14%)	32 (13%)
30–40	70 (9%)	33 (13%)
45–55	25 (3%)	15 (6%)
60–75	49 (7%)	31 (12%)
80–100	56 (8%)	40 (16%)
> 100	35 (5%)	32 (13%)
Total no of lineaments	742	251

higher than the least well defined segment). For example, 51% of the lineaments exceeding 3,000 m have been assigned precision 100–250 m but they are locally very much better defined.

Bearing in mind the similarities between the GeoVista and GTK lineament interpretations in other respects, it seems reasonable to conclude that the precision assigned by GTK quite well represents the possible precision of lineament interpretation based on topographic and airborne geophysical data in the area.

The precision of the linked lineaments is important to consider when investigations, especially by means of trenching, are planned. To avoid very long trenches, the excavations should as far as possible be made on parts of the lineaments which are spatially well defined. A revision of the method specific lineaments involved is also important. Detailed investigations, by means of e.g. ground geophysics, will very much facilitate the siting of trenches and boreholes.

4.6 Comments on the comparison carried out

The present study shows that it is not a simple, straightforward task to compare the results of two lineament interpretations.

To begin with, there are some differences in the applied methodology (e.g. the threshold value of 1,000 m applied by GeoVista during the linking process).

Furthermore, the various steps of the interpretation process, from the method specific interpretation through the coordination of lineaments to the linking of the coordinated lineaments involve many subjective decisions (expert judgements) which are difficult to assess just by simply comparing the interpretation results.

Finally, there are no objective guidelines available for the comparison of the interpretation results and, hence, the comparison itself is to some extent subjective.

It is also important to remember that the two groups of geoscientists have worked under highly different conditions. GeoVista AB has been working in the area for a substantial period of time and has therefore a profound knowledge of the geological setting. GTK, on the other hand, has been presented the topographic and geophysical data along with some basic geological information only. These different conditions might very well have affected some expert judgements involved in the interpretation process.

4.7 Oskarshamn versus Forsmark – a brief comparison

Similar comparisons of primary and alternative lineament interpretations have been carried out at the two sites where SKB conducts site investigations (/Johansson 2005/ and the present report). In both cases, the teams of geoscientists are from the same organisations, GeoVista AB (primary interpretation) and GTK (alternative interpretation), respectively. However, the staff representing the organisations involved has not been kept entirely identical.

Below, the results of the lineament interpretation from topography and airborne magnetic data are briefly compared. The underlying data are fully comparable in terms of quality and resolution and since the amount of man made artefacts is also comparable, any deviating conditions for the interpretations almost completely depend on the geological setting.

Figure 4-15 presents the topographic data from the two sites and the inferred lineaments reported by GeoVista and GTK, respectively. The lineaments inferred by GeoVista in Forsmark and GTK in Oskarshamn are quite similar in terms of density but the GTK lineaments (Oskarshamn) are significantly more persistent. The GeoVista interpretation in Oskarshamn displays a large number of minor lineaments in addition to the longer ones, which generally coincide with the GTK lineaments. In brief, the topographic data at the Oskarshamn site seems to allow for a more detailed and more distinct lineament interpretation than the Forsmark data.

Figure 4-16 presents the airborne magnetic data and the inferred lineaments reported by GeoVista from the two sites. The GeoVista and GTK magnetic interpretations are similar in both areas and the GTK interpretations are therefore not presented in Figure 4-16. When the results from the two sites are compared, and if the interpreter-dependent “style” is overlooked, it seems reasonable to conclude that the conditions for lineament interpretation from airborne magnetic data are very similar.

The linked lineaments representing the final interpretation product are to a very high degree based on the topographic and magnetic lineaments, while the EM and VLF data are of minor importance. Consequently, the similarities and differences presented above highly influence the final results. It can therefore be concluded that the conditions for lineament interpretations from topographic and airborne magnetic data at the two sites are quite similar, although the topographic data at Oskarshamn allows for a somewhat more detailed interpretation. However, the coupling between lineaments and deformation zones at the two sites has not been analysed here. Such an analysis requires a detailed study of the results from lineament investigations by means of drilling, trenching etc which is beyond the scope of the work presented in this report.

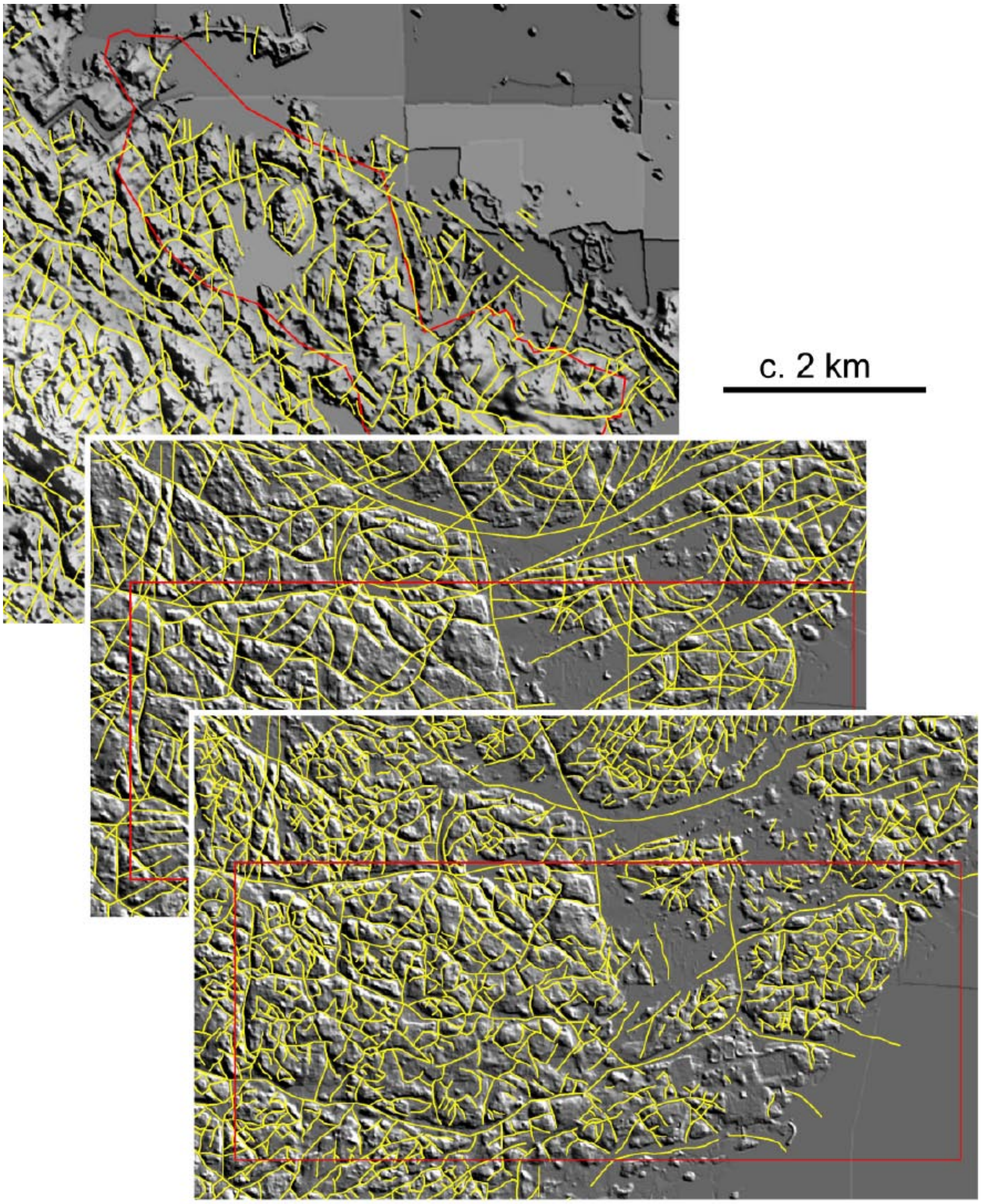

Figure 4-15. *Forsmark topographic data and GeoVista lineament interpretation (upper), Oskarshamn topographic data and GTK (middle) and GeoVista (lower) lineament interpretations. The Forsmark candidate area and the Laxemar local scale model area are outlined in red.*

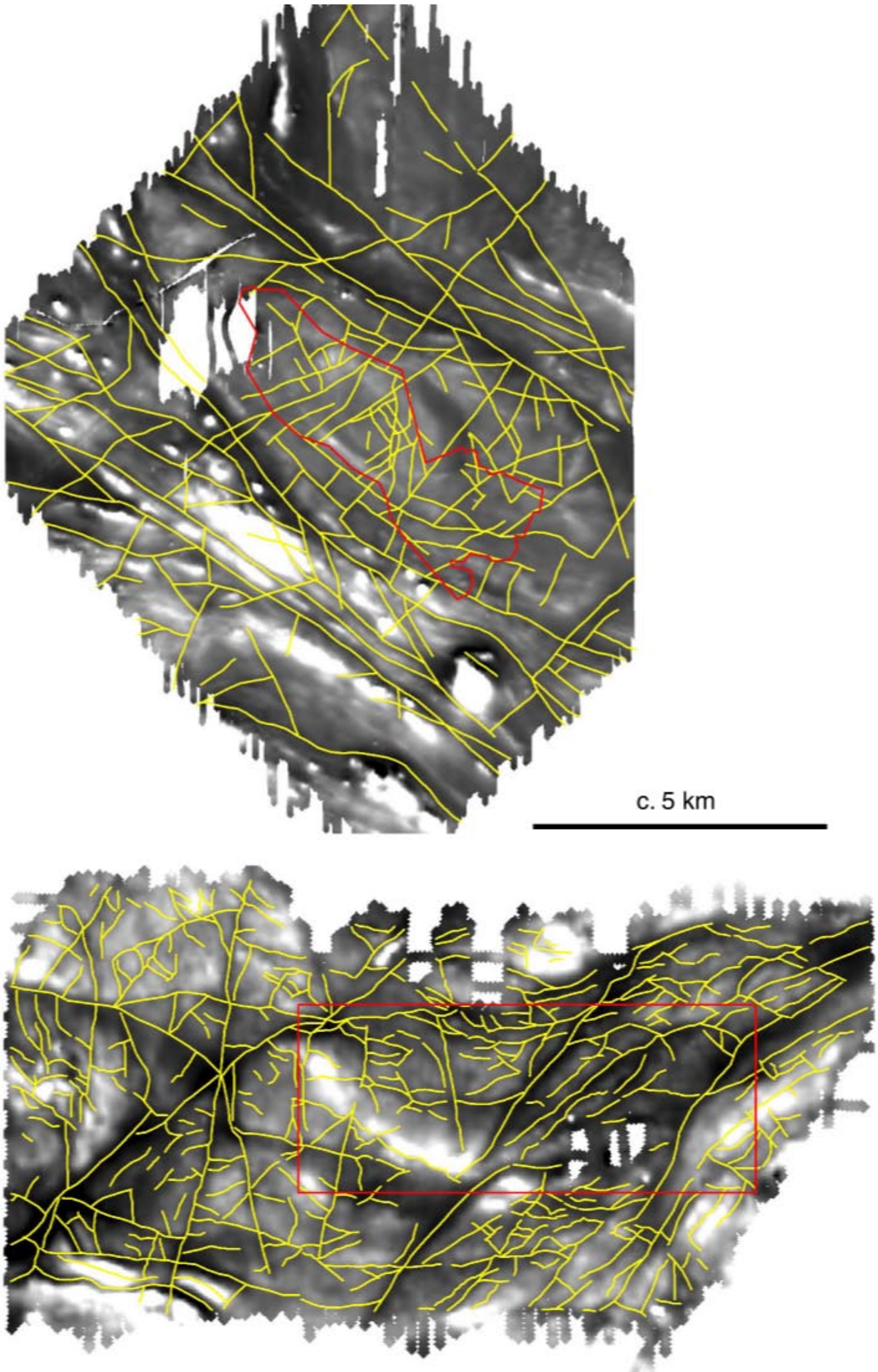

Figure 4-16. *Forsmark airborne magnetic data and GeoVista lineament interpretation (upper) and Oskarshamn airborne magnetic data and GeoVista lineament interpretation (lower). The Forsmark candidate area and the Laxemar local scale model area are outlined in red.*

5 Conclusions

The present work comprises the comparison of two independent interpretations of lineaments from airborne geophysical data and topographic data in the Simpevarp area at the Oskarshamn study site. A primary interpretation carried out by one team of geoscientists has been compared with an alternative interpretation, independently carried out by another team. A brief comparison with the corresponding results from the Forsmark site has also been made.

It is concluded that:

- The comparison of the two lineament patterns has revealed that the results are, in principle, reproducible.
- Although the interpreted lineament patterns are quite consistent, the assigned lineament attributes (length, uncertainty etc) differ significantly.
- The primary lineament interpretation is, in many cases, more detailed and should therefore form the basis for further evaluations. However, in order to make use of the more detailed primary interpretations of method specific lineaments, coordination and linking of also the shorter lineaments (< 1,000 m) must be carried out. The alternative interpretation should be seriously taken into consideration and the discrepancies between the two interpretations should be further assessed.
- The assigned lineament attributes offer the possibility to effectively displaying the characteristics of the inferred lineaments but they can not be used, neither single nor combined, to decide if a lineament is related to a deformation zone.
- The further assessment of the inferred lineaments will require additional investigations such as trenching, drilling and ground geophysics. Not only the linked lineaments, but also the corresponding method specific lineaments should then be considered.[1]
- It is in practice impossible to gain direct information (verification) on all lineaments, which implies that generalisations based on expert judgements have to be made. However, the assessment of strategic lineaments in key areas must be supported by outcrop data or observations in trenches and/or drill holes.
- The conditions for lineament interpretation from airborne geophysical data and topographic data at the Oskarshamn and Forsmark sites appear to be quite similar, although the topographic data at the Oskarshamn site allows for a somewhat more detailed interpretation. The similarities are at least valid as far as the possibilities to identify and outline lineaments are concerned (the density of lineaments, assigned uncertainties of the lineaments etc are similar). The coupling of lineaments to deformation zones have not been analysed in the present study.

[1] Such selective verification through surface and borehole investigations is in fact a presently ongoing activity.

6 References

Antal I, Bergman T, Gierup J, Johansson R, Rudmark L, Stephens M, Thunholm B, Wahlgren C-H, 1998. Översiktsstudie av Kalmar län: Geologiska förutsättningar. SKB R-98-24, Svensk Kärnbränslehantering AB (in Swedish).

Bergman T, Isaksson H, Johansson R, Lindén A H, Lindgren J, Lindroos H, Rudmark L, Wahlgren C-H, 1998. Förstudie Oskarshamn. Jordarter, bergarter och deformationszoner. SKB R-98-56. Svensk Kärnbränslehantering AB (in Swedish).

Bergman T, Follin S, Isaksson H, Johansson R, Lindén A H, Lindroos H, Rudmark L, Stanfors R, Wahlgren C-H, 1999. Förstudie Oskarshamn. Erfarenheter från geovetenskapliga undersökningar i nordöstra delen av kommunen. SKB R-99-04. Svensk Kärnbränslehantering AB (in Swedish).

Bergman T, Isaksson H, Johansson R, Rudmark L, Stanfors R, Wahlgren C-H, 2000. Förstudie Oskarshamn. Kompletterande geologiska studier. SKB R-00-45. Svensk Kärnbränslehantering AB (in Swedish).

Elhammer A, Sandkvist Å, 2005. Detailed marine geological survey of the sea bottom outside Simpevarp. SKB P-05-35. Svensk Kärnbränslehantering AB.

Hökmark H, Munier R, 2004. Respect distances. Rationale and means of computation. SKB R-04-17. Svensk Kärnbränslehantering AB.

Isaksson H, Keisu M, 2004. Interpretation of airborne geophysics and integration with topography. Stage 2 (2002–2004).SKB P-04-282. Svensk Kärnbränslehantering AB.

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

Korhonen K, Kuivamäki A, Ruotoistenmäki T, Paananen M, 2005. Interpretation of lineaments from airborne geophysical and topographic data. An alternative model within version Laxemar 1.2 of the Oskarshamn modelling project. SKB P-05-247. Svensk Kärnbränslehantering AB.

Nisca D H, 1987. Aerogeophysical interpretation. Bedrock and tectonic analysis. SKB PR 25-87-04. Svensk Kärnbränslehantering AB.

Rønning H J S, Kihle O, Mogaard J O, Walker P, 2003. Simpevarp site investigation. Helicopter borne geophysics at Simpevarp, Östhammar, Sweden. SKB P-03-25. Svensk Kärnbränslehantering AB.

SKB, 2002. Simpevarp – site descriptive model version 0. SKB R-02-35. Svensk Kärnbränslehantering AB.

Tirén S, Beckholmen M, Isaksson H, 1987. Structural analysis of digital terrain models, Simpevarp area, SE Sweden. Method study EBBA II. SKB PR 25-87-21. Svensk Kärnbränslehantering AB.

Triumf, C-A, 2003. Identification of lineaments in the Simpevarp area by the interpretation of topographical data. SKB P-03-99. Svensk Kärnbränslehantering AB.

Triumf, C-A, 2004a. Joint interpretation of lineaments in the eastern part of the site descriptive model area. SKB P-04-37. Svensk Kärnbränslehantering AB.

Triumf, C-A, 2004b. Joint interpretation of lineaments. SKB P-04-49. Svensk Kärnbränslehantering AB.

Triumf C-A, Thunehed H, Kero L, Persson L, 2003. Interpretation of airborne geophysical survey data. SKB P-03-100. Svensk Kärnbränslehantering AB.

Wiklund S, 2002. Digitala ortofoton och höjdmodeller. Redovisning av metodik för platsundersökningsområdena Oskarshamn och Forsmark samt förstudieområdet Tierp Norra. SKB P-02-02. Svensk Kärnbränslehantering AB (in Swedish).