P-06-15

Oskarshamn site investigation

Coordinated presentation of topographic and geophysical lineaments in selected areas, including field assessment – Laxemar area

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January 2006

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Abstract

This report presents the results from an activity in the Oskarshamn site investigation involving:

- the identification of new lineaments in a high-resolution digital terrain model based on airborne laser scanning data (LIDAR),
- a revision of previously identified lineaments in topographical data (orthophoto and digital terrain model) and geophysical data (airborne and ground measurements),
- a field reconnaissance of new, local minor lineaments,
- a field check of lineaments from remote sensing (topography, orthophotos, geophysics).

The processing of LIDAR–data (airborne laser scanning) resulted in a high-resolution digital terrain model. This model was used to identify local minor topographical lineaments of which many later were verified and characterised in the field. It was also used to confirm the location and orientation of local minor lineaments identified in the field.

The work concentrated on seven subareas distributed over the Laxemar area with surroundings, each subarea covering 400 m by 400 m. During the field check, attributes were assigned to lineaments, primarily based on their field characteristics. The attributes give information in what type of data each individual lineament was identified, the level of uncertainty, how the lineament manifests itself in the morphology, if signs of rock deformation are visible in outcrops etc. The fieldwork was concentrated in areas where bedrock outcrops.

The results indicate that a major part of the identified lineaments may be explained by, or is directly related to observations of deformed rock. This is true not only for the newly identified local minor lineaments, but also for the lineaments based on geophysical data.

Sammanfattning

Denna rapport presenterar resultaten av en aktivitet i Oskarshamns platsundersökningar som omfattar:

- identifiering av nya lineament i en högupplösande terrängmodell baserad på flygburen laserskanning,
- revidering av tidigare identifierade lineament i topografiska data (ortofoton och digitala terrängmodeller) samt i geofysiska data (flyg- och helikopterburen mätning och markmätningar),
- fältrekognosering av nytolkade lokala mindre lineament,
- fältkontroll av lineament.

Bearbetning av s k LIDAR data (flygburen laserskanning) resulterade i en högupplöst digital terrängmodell. Modellen användes för att identifiera lokala mindre topografiska lineament, av vilka många sedan verifierades och karaktäriserades i fält. Den användes också för att bekräfta läge och orientering för lokala mindre lineament som identifierats i fält.

Arbetet med att identifiera, revidera och kontrollera lineament koncentrerades till sju kontrollrutor (400 m × 400 m) i Laxemarområdet. Under fältkontrollen karaktäriserades lineamenten via attributsättning, i huvudsak för att beskriva dess geologiska karaktär. Ur parametrarna går bl a att utläsa i vilka datamängder det enskilda lineamentet har identifierats, om och i så fall vilken typ av direkta observationer av deformation som finns i häll etc. Fältkontrollerna koncentrerades i första hand till områden där hällar förväntades förekomma.

Resultaten visar att en stor del av lineamenten kan förklaras av eller är direkt relaterade till observationer av deformationer i berggrunden eller indirekta orsaker därav. Detta gäller inte bara de nya lokala mindre lineamenten, utan även lineament baserade på geofysiska data.

Contents

1 Introduction

This document reports the data gained by the activity named as "A joint interpretation of lineaments using detailed geophysical and topographic data Laxemar – Simpevarp" in the activity plan. It is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance to activity plan SKB AP PS 400-05-038. In Table 1-1 all controlling documents are listed for performing this activity. Also activity plans that the activity is directly dependent on are listed. Both activity plans and method descriptions are SKB's internal controlling documents.

The work was carried out mainly as a co-operation between Swedpower AB and GeoVista AB during 2005 following the instruction and guidelines from SKB under the supervision of Peter Hultgren, SKB.

The focus of the study has been in seven field-control areas located in the Laxemar area with surroundings, Figure 1-1.

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

Activity Plan	Number	Version
Samtolkning av detaljerad markgeofysik, flygfotografering, laserskanning samt geologisk fältkontroll i Laxemar	AP PS 400-05-038	1.0
Detaljerade markgeofysiska mätningar i Laxemar	AP PS 400-05-014	1.0
Flygmätningar med laserskanning och flygfotografering, 2005	AP PS 400-05-035	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för lineamentstolkning baserad på topografiska data	SKB MD 120.001	1.0
Metodbeskrivning för tolkning av flyggeofysiska data	SKB MD 211.003	1.0

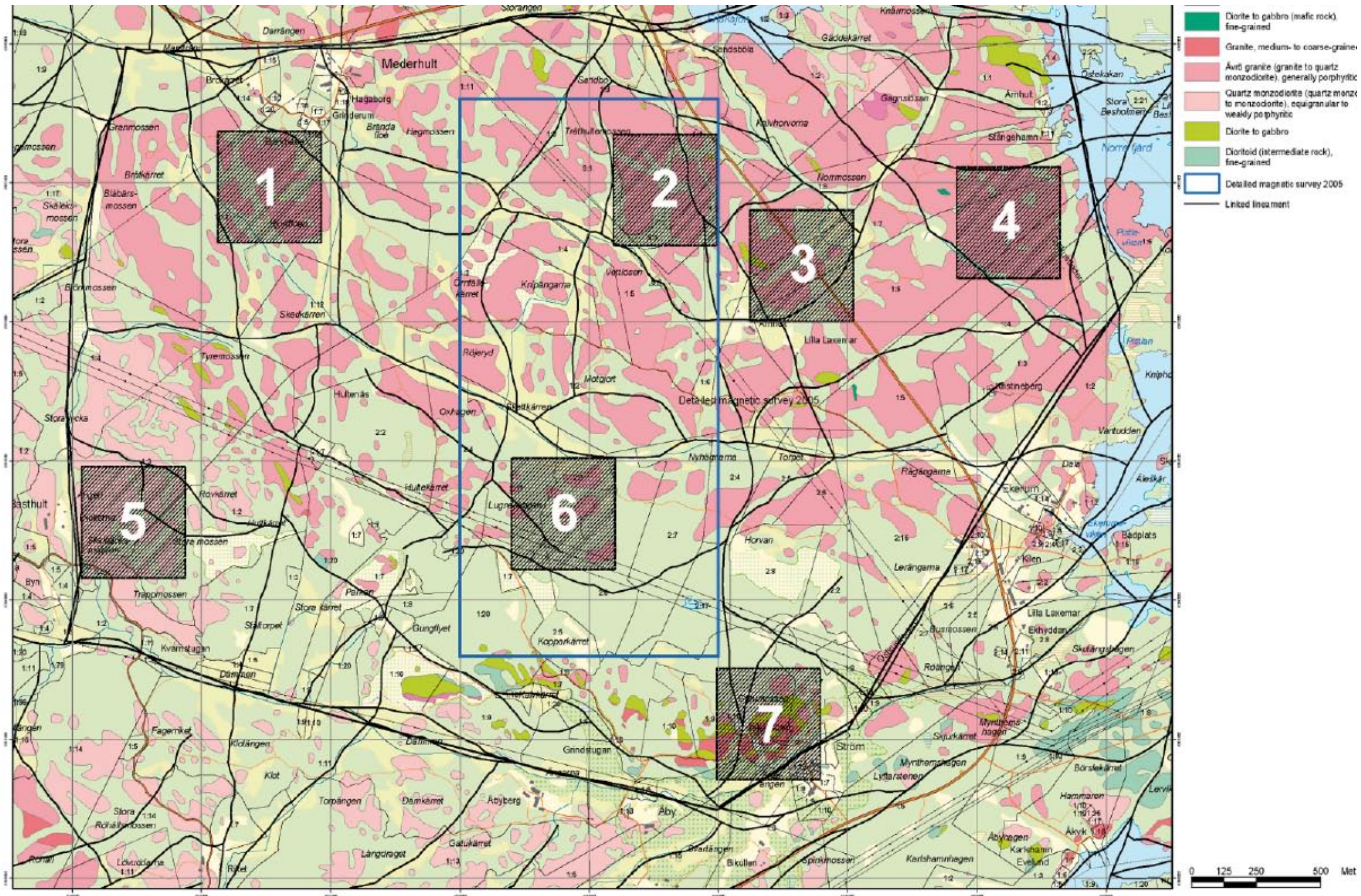

Figure 1-1. Map showing the entire inventory area. The outline and numbering of the seven fieldcontrol areas has been superimposed.

2 Objective and scope

Lineaments are line features or patterns on the earth's surface, which may reflect geological structures or features related to a geological structure, such as a deformation zone, a dyke rock or an esker /8/. Lineaments can however also be the result of man-made structures such as transportation networks (roads, railroads, etc) or natural structures such as drainage networks. Lineaments can be observed as more or less linear features in different sets of spatial data. Such datasets could be aerial photographs, digital terrain models or geophysical maps.

Lineaments are identified in a new high-resolution digital terrain model produced from airborne laser scanning (LIDAR) in this study. Previously identified lineaments in topographic data and geophysical data are re-evaluated and both new and re-evaluated lineaments are then controlled in field by means of geological observations. The field control is focused on revealing the connection between the studied lineament and its geological setting. Of special interest are signs of rock deformation, at different scales, that may be attributed to the lineament. The focus has been on lineaments shorter than 1 km, which can be caused by local minor deformation zones.

The final result of the present activity is gathered in GIS ESRI shape files. All found parameters connected to the specific lineament can easily be extracted from the shape files. The result of this activity will be delivered to SKB as shape files and presented in this report.

3 Equipment

3.1 Description of equipment

The desktop part of the study was peformed using the following software:

- Erdas Imagine 8.6 image analysis software package.
- ArcGIS 8 and 9.
- MapInfo Professional 7.5 (MapInfo Corporation).
- Discover 4.000 (Encom Technology).
- Oasis Montaj 5.0 (Geosoft).
- ArcView (Environmental Systems Research Institute Inc).

During field survey the following equipment was used:

- IPAQ handheld computer.
- Trimble Pathfinder GPS.
- Geological hammer.
- Geological compass with inclination needle.

The software PC Mapper and Discover Mobile 2.1 (Encom Technology) were used in the field computers to display maps and identified lineaments. It also displays the position as given by the GPS signal. The same software was also used to enter, edit and document structures found during the survey.

4 Execution

4.1 General

The work proceeded in the following stages:

1. Preparatory work.
2. Identification of lineaments in new high-resolution topographical data. Re-evaluation of previously identified lineaments.
3. Field control, verification and analysis.

The general workflow of the study is described in Figure 4-1, where each individual work task is described.

The work on topographical data has been carried out mainly using the data gained by the aerial photography and airborne laser scanning campaign of the Laxemar – Simpevarp area, which has been one of the activities performed within the site investigation at Oskarshamn during 2005 /1/. The data produced during this campaign comprise topographic data as airborne-borne LIDAR data, a terrain model at 0.25 metre spatial resolution, and aerial photographs as orthoimagery at 0.1-metre spatial resolution.

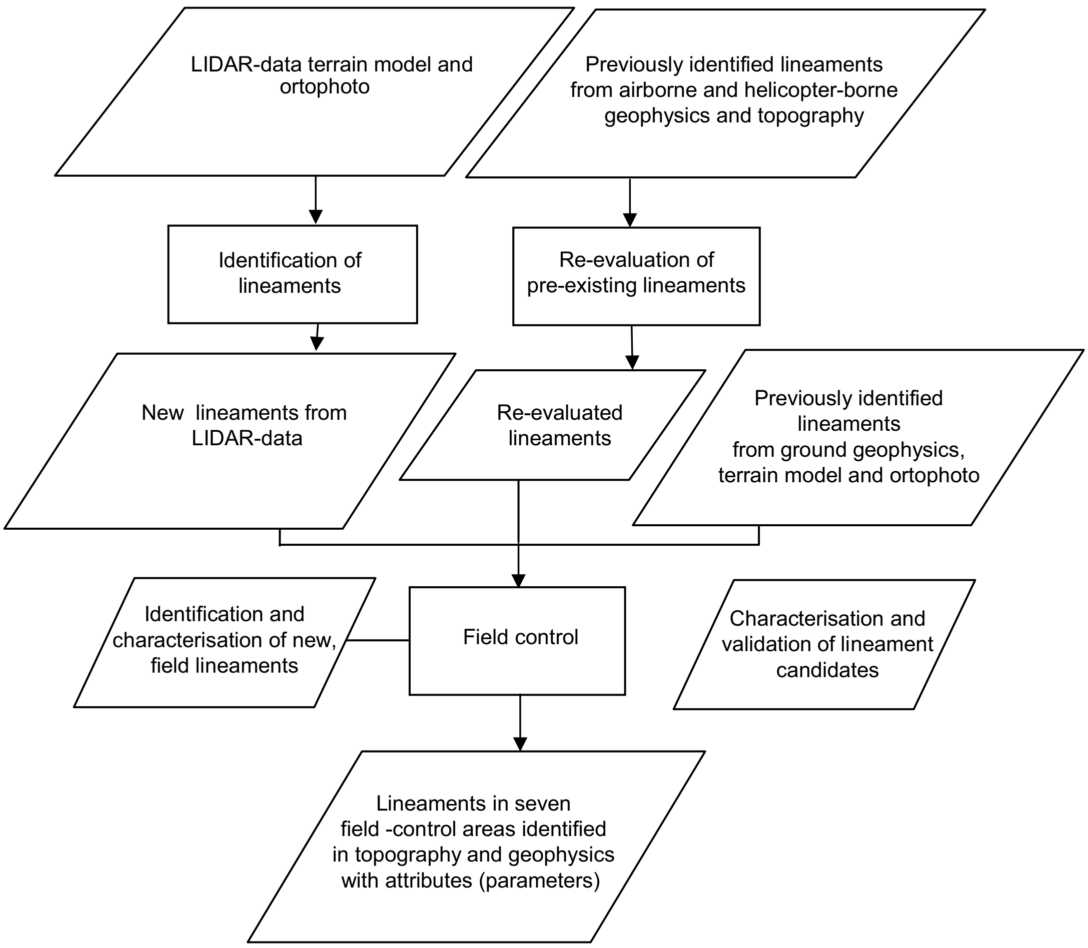

Figure 4-1. *General workflow for the study.*

All interpretations were carried out utilizing GIS software and techniques. The end product of each interpretation stage constitutes one or more GIS themes with accompanying attribute tables. The lineaments are stored in the themes as polylines having unique attributes stored in the table.

4.2 Preparatory work

The preparatory work can be divided into two phases; in the first phase lineaments from earlier method specific interpretations /2,3,4/ and joint interpretations /5,6/ were gathered together with base data and images used in the lineament identification/8,9/. The second phase and most cumbersome in the preparatory work, comprised data processing and map compilation of the new topographical data i.e. aerial photographs and digital terrain models based on laser scanning. Data processing was required to process raw data into a form that is more suitable for map compilation, and to enhance data. Several maps were compiled from the processed data to act as the basis for lineament identification.

Hillshades were produced from the digital terrain model at a pixel size of 0.25 metres /1/. In order to avoid introducing bias into the data, two hillshades were made using sun azimuths 90 degrees apart. The first hillshade was made using a sun azimuth of 270 degrees (sun light from west). The second hillshade was made using sun azimuths of 180 degrees (sun light from south). The elevation angle of the sun was 45 degrees. The resultant image for the 180-degree image is shown in Figure 4-2 below. Lineaments within the seven field control areas were interpreted using the input of images having both light directions.

The aerial photographs grid has been contrast enhanced in order to provide a better colour distribution in the image. Anaglyphs were produced to further enhance the topographical features of the landscape, using the combination of the aerial photography and terrain model (Figure 4-3). Anaglyphs are 3-D stereoscopic images that can be printed, projected, or shown on a computer monitor. Special colour glasses are required to view them. By utilizing the 3-D effect of the anaglyphs a continuous interpretation of the morphology of the landscape is possible, which further enhances the possibility to trace lineaments also in forested areas.

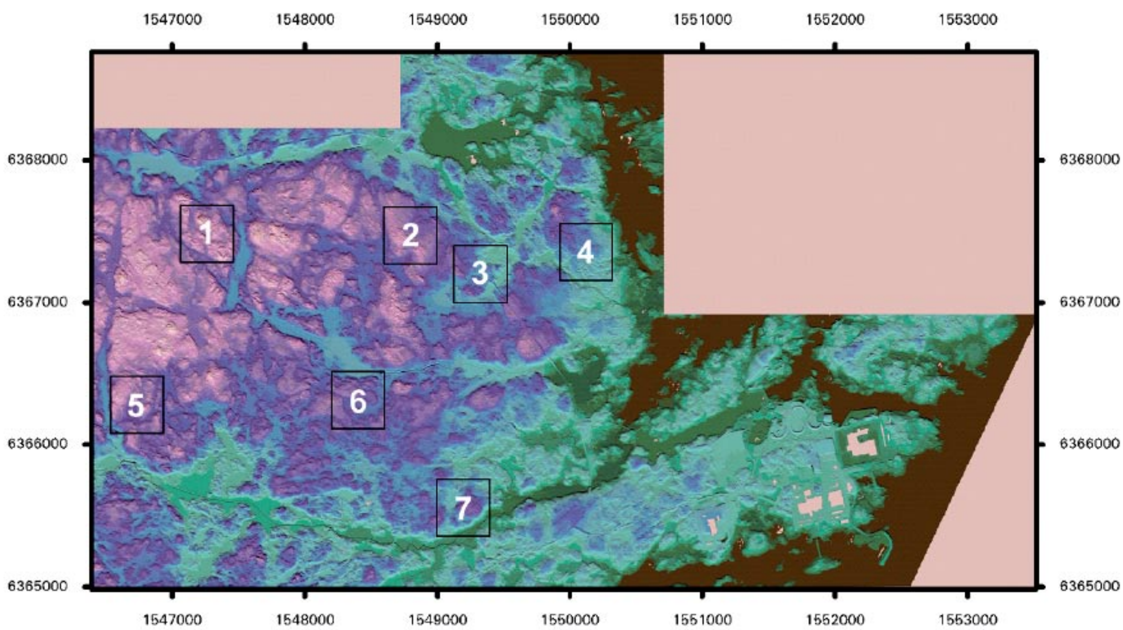

Figure 4-2. *Hillshade of the complete LIDAR-scanned area, with sun azimuth of 180 degrees (from south).*

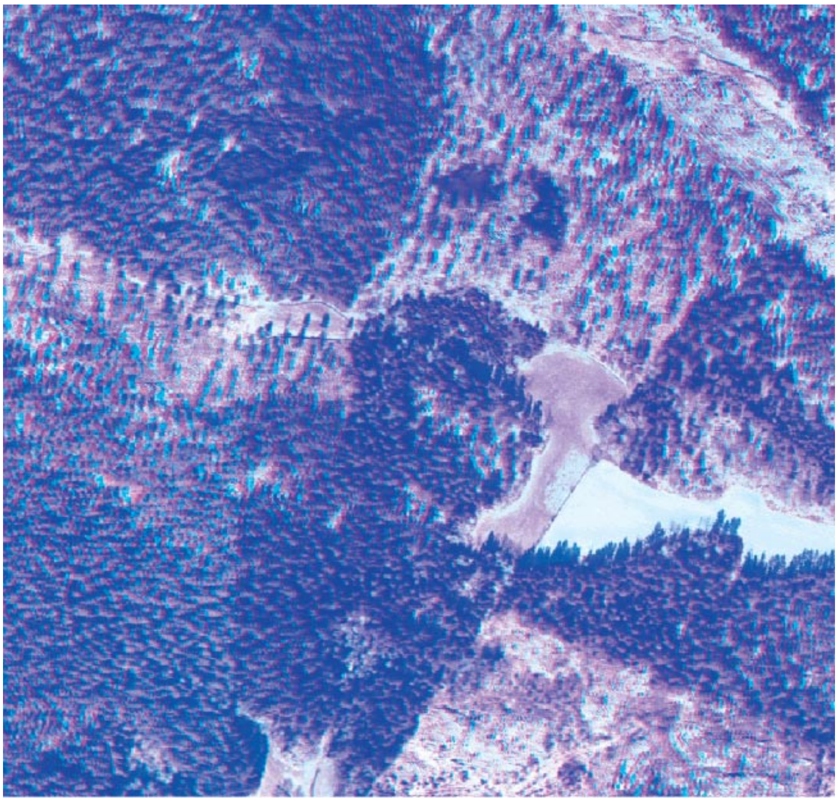

***Figure 4-3**. Using a pair of glasses with a red coloured glass to the left and a blue coloured glass to the right will enable a 3-D stereoscopic view of (anaglyph representation) the landscape within the study area.*

4.3 Identification of lineaments in new high resolution topographical data. Re-evaluation of previously identified lineaments

4.3.1 Topographical lineaments derived from new aerial imagery and terrain model

A lineament is distinguishable in an aerial photograph image by the change in image intensity as measured by gradient. A lineament, identified topographically or geophysically is regarded as a potential deformation zone /8/. By applying edge detection filters to the image in image analysis, numerical methods for lineament detection can be constructed. This methodology, however, is not as good as the human visual system. The human visual system is very good at extrapolating linear features. Thus, to the eye, a lineament, which varies in intensity along its length, may be viewed as a single long lineament whereas to a numerical method, this may appear as several short lineaments. Thus, numerical methods for extracting lineaments may not be the optimal method for lineament detection.

The lineament interpretation has been carried out by visual identification, delineation and characterization, using image analysis and GIS-techniques. If a linear feature seen on a map was judged to represent a lineament it was digitized as a polyline and stored in a GIS theme. The interpretation of a method-specific data set was considered completed when all feasible linear features were identified. The end product of this stage comprises several GIS themes with lineaments, one theme for each method-specific data set.

The interpretation was carried out using the map and image data described above as the basis for lineament identification. The interpreted lineaments were mainly depressions, or slopes (Figures 4-4 to 4-6). Most of the lineaments were identified using a combined analysis of the hillshaded reliefs and the anaglyphs. The maps were viewed at scales ranging from 1:500 to 1:10,000, mostly in the range of 1:1,000 to 1:2,000. Slopes were used to enhance sharp changes in slope values. They were used to identify the maximum rate of change of slope and measure degrees of slope of the hillside. Aspect was used to identify the orientation of the hillside.

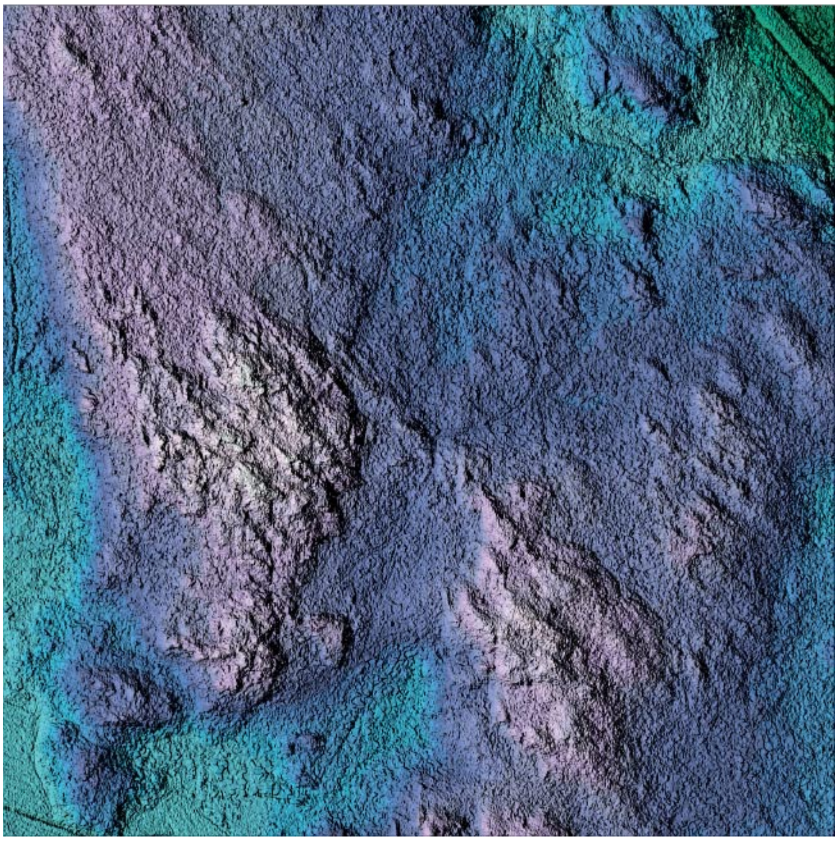

Figure 4-4. *Hillshade of the complete field control area 2 (Location of area in Figure 1-1).*

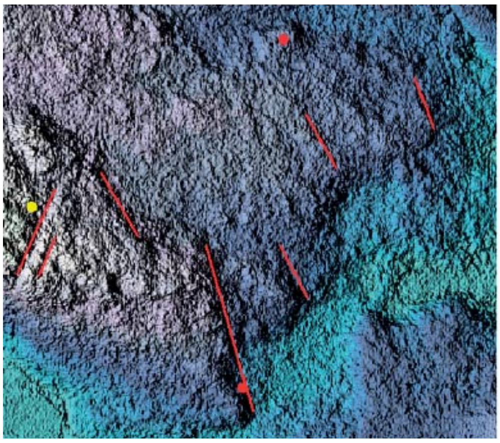

Figure 4-5. *Example of lineament detected in the LIDAR data, field control area 2 (Figure 1-1). The lineament, as viewed from a position marked with a yellow dot in the left hillshade, indicates a sharp but narrow depression in the terrain.*

Figure 4-6. *Example from field control area 4 of a gentle valley type of depression, also indicated in the LIDAR-data. To the right the lineament is viewed from a position marked with the yellow dot in the left hillshade. The relief is flat, nevertheless with a prononced directional component.*

During the characterization phase the identified lineaments have been checked against the orthophoto and cadastral map data. The grade of uncertainty for each lineament has been judged in relation to possible artificial causes such as power lines, roads etc. Supporting features have also been noted, such as very narrow valleys, narrow occurrences of deciduous forest, wetlands and bogs, etc. The lineament extensions have often been adjusted according to features occurring in the aerial imagery or in the terrain model. Finally some additional lineaments, identified solely in the terrain model data, have been outlined.

4.3.2 Re-evaluation of existing lineaments derived from the preceeding digital terrain model, airborne geophysics and ground geophysics

The existing method-specific lineaments, previously identified from pre-LIDAR topographical data (essentially a digital terrain model), airborne geophysics (both fixed-wing airborne and helicopter borne) and ground geophysics /2,3,4/, were re-checked against the corresponding data sets. Some of the method-specific lineaments were hence altered during the re-evaluation; segments of the individual method-specific lineaments were moved or removed, some of the method-specific lineaments were entirely removed or changed in appearance and position, some entirely new lineaments were also identified in the data sets. These changes, as compared to the earlier identified and reported method-specific lineaments, were justified by the change in working scale. In the current work more detail about the lineament was of interest, together with a demand for shorter lineaments.

4.4 Field control, verification and analysis

The first survey in the field was conducted in May 2005. It was focused on reconnaissance with the aim to evaluate a possible target resolution of geological structures, bearing in mind the short time available for the activity. It was decided that a cut-off c 12–15 metres length was possible to achieve within the available time and this cut-off was also considered relevant for the geological structures in question.

To each lineament visited in the field (both new and existing ones), characterizing attributes were assigned. Existing lineaments, interpreted from previously existing orthophotos, topographic terrain models and geophysical measurements, were visited where they passed over outcrops, the way these are displayed on the geological map. The attribute is therefore relevant for shorter sections along the lineaments only. The observation points were marked on the map, but do not have any ID or other attribute connected to them. Used attributes are described in Table 4-1.

4.4.1 Preparation for field control

Existing and re-evaluated lineaments (up to Laxemar model 1.2) for the seven field control areas were implemented into handheld computers. Additional geographic data, such as roads and topographic contour lines, together with images of geophysical data were also imported into the handheld computers. A protocol of attributes was designed for the computer.

As soon as LIDAR-data became available at the end of May 2005, the interpretation of lineaments started. The focus was on the length 5–200 metres. Field control area 1 was chosen to make a first evaluation of lineament analysis from LIDAR-data. The new lineaments identified were successively implemented into the handheld computers.

In Table 4-1 the attribute used to characterize the lineaments are described. The Short names visualize the way they are displayed in the handheld computer.

4.4.2 Execution of field control

The aim with the field control was three folded,

1. Revised earlier identified lineaments /2,3,4/ were characterized in the field if they passed over bedrock outcrop.
2. New, minor linear structures, not covered by earlier lineament interpretations, were mapped and characterized.
3. During the progress of this activity also new local minor lineaments identified in LIDAR-data were characterized in the field. This process involved the exclusion of some lineaments, whereas others were verified as geological structures in the field. All lineaments from LIDAR-data were not possible to field check within the time schedule of this activity.

For field identification purposes only, observed structures which may represent the lineament, were classified into 4 categories:

A. Steep, planar, distinct hillsides on rock surfaces. Minimum length ca 12 metres. One or more fracture parallels the structure.

B. Same as above, but two-sided, i.e. parallel hillsides on each side of a through.

C. Local minor valleys with bedrock on both sides, but no parallel fractures found in the rock. Minimum length ca 15 m.

D. Other geological zone structures of ductile, brittle-ductile, or brittle character (cut-off < 5 m).

Table 4-1. Attribute table.

Short name	Description	Input	Input limit		Code description
Line (Linje-ID)	Identification code	Nxnn (N= Area code; integer) (x= Lineament type code; string) (nn= integer)	 1 to 7 See next column Consecutive numbering		E, m, t denotes existing lineaments identified in electromagnetic, magnetic, topographic data. K denotes complex lineaments. E, M, T, K and N represent lineaments identified in this project
Outcrop	Observable in outcrop or not	Integer	0 or 1		
				0	No outcrop observed
				1	Outcrop observation made
Interpret	Kind of structure	Integer	1 to 5		
				1	No indications
				2	Topography, fracture or fracture zone
				3	Significant escarpment
				4	Vaguely defined
				5	Distinct other geological structure
Orient	Orientation (strike)	Integer	0 to 360 (degrees)		
Width	Width of structure	Integer	0 to 99 (meters)		Approximate width
Adjlenght	Suggested adjustment of lineament length	Integer	–nn to nn (meters)		
				0	No adjustment
				negative value	Reduced length
				positive value	Increased length
Confidence	Relevance of outcrop observation	Integer	1 to 3		
				1	Certain
				2	Probable
				3	Possible
Outcstr (1 and 2)	Identified structure in outcrop (two possible)	Integer	1 to 5		
				1	Increased fracture frequency
				2	Brittle-ductile shear zone
				3	Ductile shear zone
				4	Foliation
				5	No structure
Outcalt (1 and 2)	Identified alteration in outcrop (two possible)	Integer	1 to 3		
				1	Oxidation
				2	Epidotization
				3	Other
Outcsusc (1 and 2)	Averaged measure of magnetic susceptibility in outcrop (two possible)	Integer	0 to 9,999 (SI units $\times 10^{-5}$)		
Endings	How the lineament end in the terrain	Integer	1 to 3		
				1	Ends in soil cover
				2	Ends to other structure or lineament
				3	Ends visible in outcrop

__Figure 4-7.__ Examples of three of the four different types of lineament, separated in the field. a–c represent type A–C respectively. Figure 4-7d show rock uncovered at a drill site. This kind of extreme exposure is normally only present in road cuttings and along coastlines.

Type A and B should be regarded as fracture zones with somewhat increased fracture frequency or occasionally as individual fractures, Figure 4-7a,b.

Type C should be regarded as possible fracture zones on the same basis as unverified more local major lineaments are, Figure 4-7c.

Type D is exposed geological structures and can thus be more precisely characterized, Figure 4-7d.

These field characteristics have been used when creating attributes for each lineament.

4.4.3 Data handling

Lineaments and their attributes mapped and documented in the handheld computer during field survey in the seven field control areas, were stored in a portable computer at lunch-break and in the evening each day. At the office the data was imported into SwedPower's server for further analysis and tabulation.

4.4.4 Analysis and interpretation

In topographically high elevation parts of the investigated areas the frequency of exposed bedrock is rather high and approximates to ca 10–20% of the surface. In these areas not only individual fractures, but also fracture zones and other deformation zones are sometimes exposed and can be studied. Often faults and structures in the bedrock have caused the surface to break up. As a result, escarpments, steep hillsides, cliffs and that alike have been formed in the terrain.

When looking for deformation zones in the bedrock thus, major gradients in the topography are of interest. Steep, straight hillsides in the bedrock most often represent a fracture zone of some kind. Some steep hillsides may represent a single fracture plane, or fractures lying en echelon, but normally there are several sub-parallel fractures along the structure. Depending on what definition is used this kind of structure may represent a fracture zone or a zone of increased fracturing.

Lineaments found explicitly in LIDAR-data are delivered as new “field”-lineament if verified in the field. Attributes have been attached according to Table 4-1, but are also tabulated in Appendix 1 to this report.

4.4.5 Nonconformities

Larger deformation zones are generally more likely to be located in lower terrain, such as valleys, where they cannot be studied without larger effort. Most lineaments from previous studies and from LIDAR-data preferentially run along valleys and these parts have therefore not been characterized along such section in the field. Only at locations where valleys become narrow and where lineaments run over topographically higher areas relevant outcrops may be found.

In the title of the activity plan corresponding to the present activity the expression “joint interpretation” is mentioned. In order not to cause any misunderstanding the use of the expression has been avoided here, since no joint interpretation in the meaning stated earlier /6/ has been carried out within the present activity.

Existing lineaments lacking attributes from this study (Appendix 1) have not been visited in the field.

5 Results

The lineaments from the re-evaluation of existing method-specific lineaments from the seven field control areas are shown in Figure 5-1 to 5-7, together with the new lineaments identified in the new LIDAR-data. In the figures method-specific lineaments are shown, emanating from digital terrain models of 2002 and 2005 /9,1/, magnetic total field measured from the helicopter borne survey of 2002 /7,3/ and the detailed ground survey of 2005 /4/, and electromagnetic data, both multi-frequency EM and VLF, from the helicopter borne survey and from the fixed wing survey of 1986 /3/.

Most findings of new field lineaments were successively identified in LIDAR-data and the vast majority of the 123 lineaments represent steep escarpment in outcropping rock. 42 of these lineaments do not outcrop, but represent valleys controlled by the bedrock surface. Only in rare cases does a field lineament end in another lineament or in outcropping bedrock. The normal case is that they end beneath soil cover. For a complete list of characterizing attributes see Appendix 1.

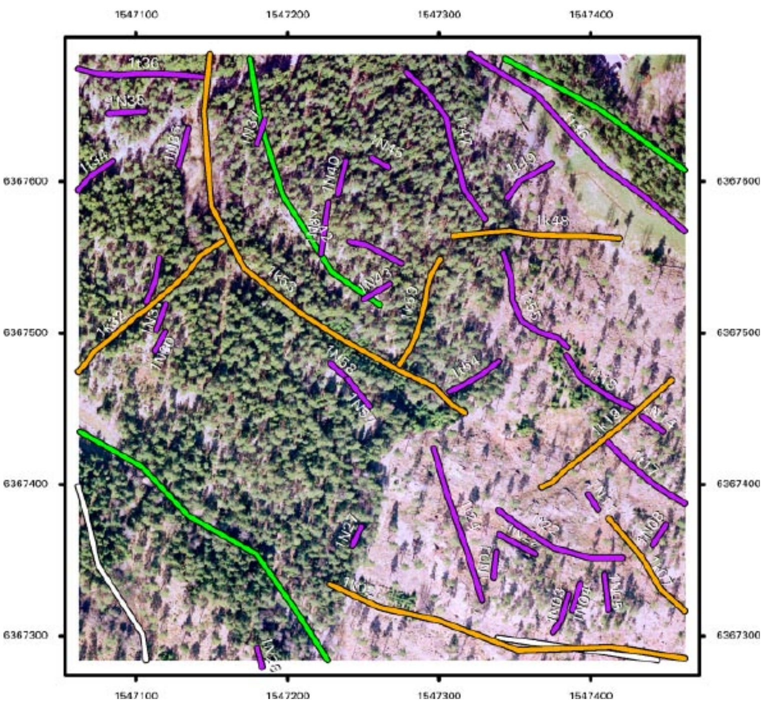

Figure 5-1. *Re-evaluated lineaments from different data sources together with new topographical lineaments in field control area 1. Violet colour represents structures related to topography found in the terrain models (primarily LIDAR-data), white are from magnetic total field (helicopter borne survey and detailed ground survey) data and green from EM (helicopter borne and fixed wing surveys). Brown colour represents complex lineaments indicated in several sources (e.g. magnetic field and topography). For abbreviation clarifications and lineament details please find Table 4-1 and Appendix 1.*

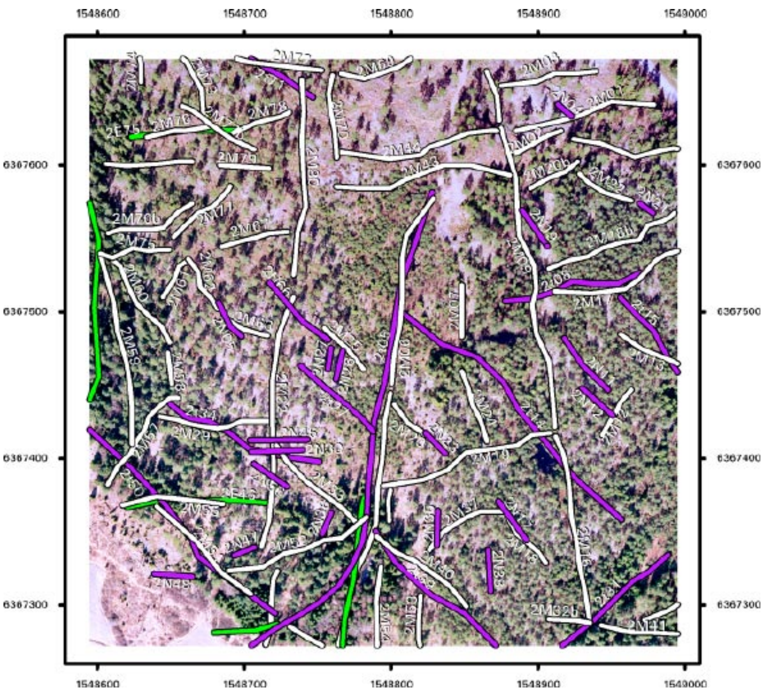

Figure 5-2. *Re-evaluated lineaments from different data sources together with new topographical lineaments in field control area 2. Violet colour represents structures related to topography found in the terrain models (primarily LIDAR-data) and through field survey, white are from magnetic total field data (helicopter borne and detailed ground survey) and green from EM (helicopter borne and fixed wing surveys). For abbreviation clarifications and lineament details please find Table 4-1 and Appendix 1.*

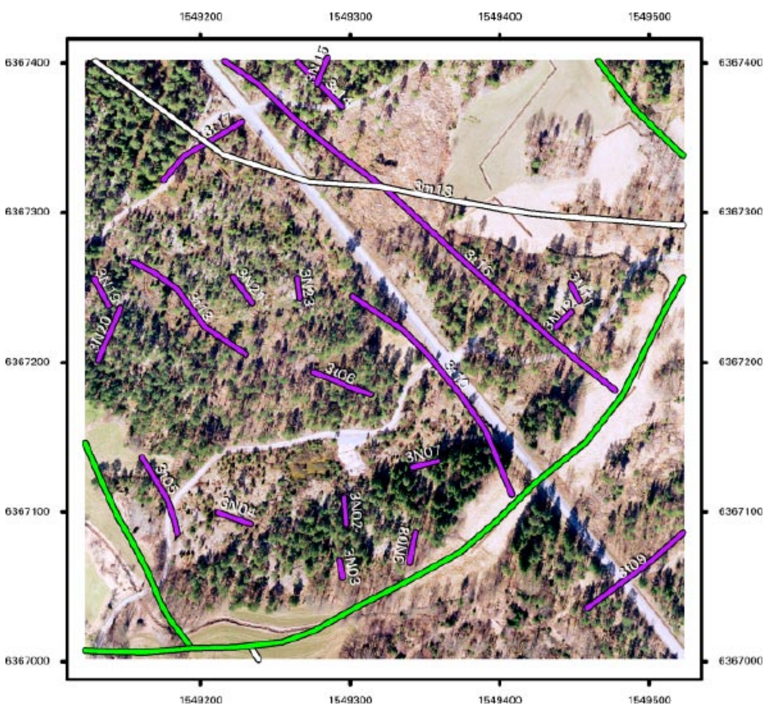

Figure 5-3. *Re-evaluated lineaments from different data sources together with new topographical lineaments in field control area 3. Violet colour represents structures related to topography found in the terrain models (primarily LIDAR-data), white are from magnetic total field data (helicopter borne survey) and green from EM (helicopter borne and fixed wing surveys). For abbreviation clarifications and lineament details please find Table 4-1 and Appendix 1.*

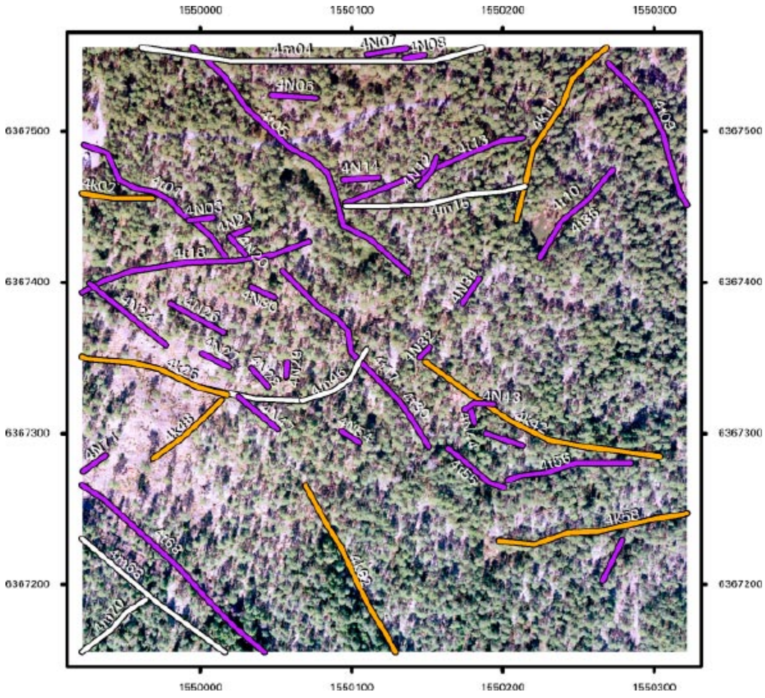

Figure 5-4. *Re-evaluated lineaments from different data sources together with new topographical lineaments in field control area 4. Violet colour represents structures related to topography found in the terrain models (primarily LIDAR-data), white are from magnetic total field data (helicopter borne survey). Brown colour represents complex lineaments indicated in several sources (e.g. magnetic field and topography). For abbreviation clarifications and lineament details please find Table 4-1 and Appendix 1.*

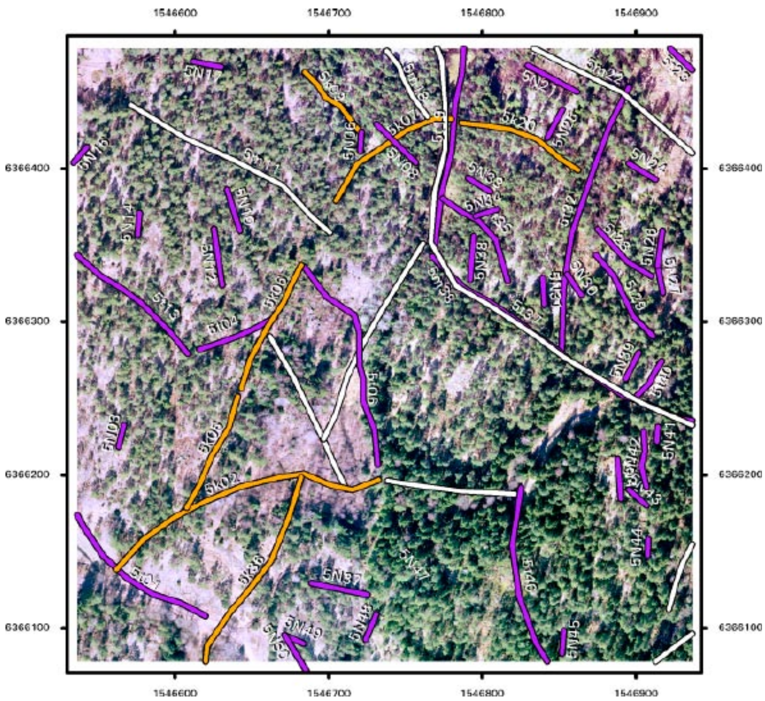

Figure 5-5. *Re-evaluated lineaments from different data sources together with new topographical lineaments in field control area 5. Violet colour represents structures related to topography found in the terrain models (primarily LIDAR-data), white are from magnetic total field data (helicopter borne survey). Brown colour represents complex lineaments indicated in several sources (e.g. magnetic field and topography). For abbreviation clarifications and lineament details please find Table 4-1 and Appendix 1.*

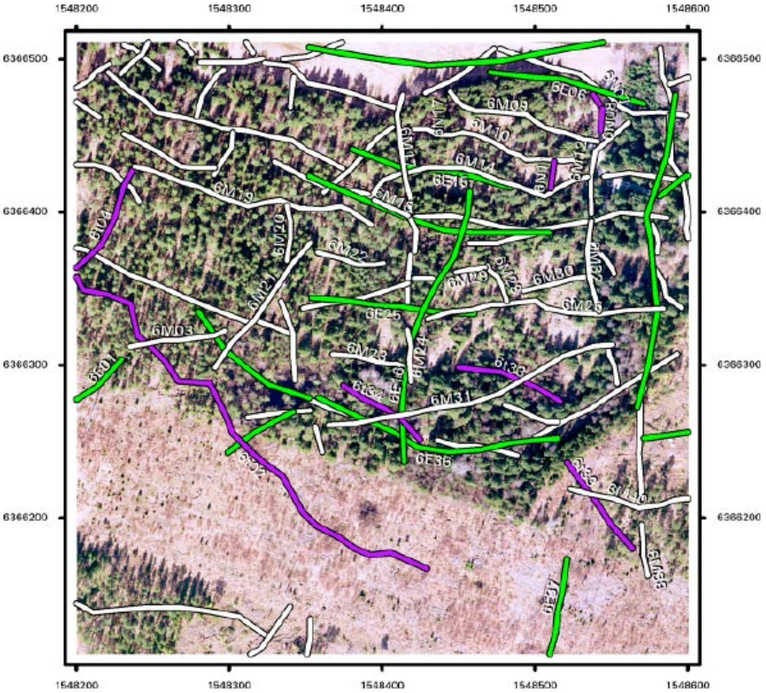

Figure 5-6. *Re-evaluated lineaments from different data sources together with new topographical lineaments in field control area 6. Violet colour represents structures related to topography found in the terrain models (primarily LIDAR-data), white are from magnetic total field data (helicopter borne survey and detailed ground survey) and green from EM (helicopter borne and fixed wing surveys). For abbreviation clarifications and lineament details please find Table 4-1 and Appendix 1.*

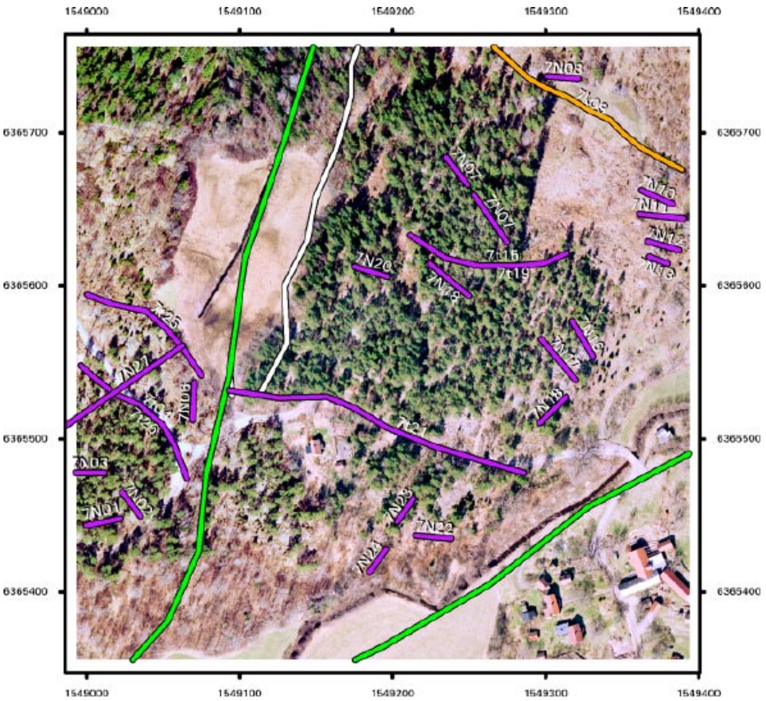

Figure 5-7. *Re-evaluated lineaments from different data sources together with new topographical lineaments in field control area 7. Violet colour represents structures related to topography found in the terrain models (primarily LIDAR-data), white are from magnetic total field data (helicopter borne survey) and green from EM (helicopter borne and fixed wing surveys). Brown colour represents complex lineaments indicated in several sources (e.g. magnetic field and topography. For abbreviation clarifications and lineament details please find Table 4-1 and Appendix 1.*

In Table 5-1 the number of new local minor lineaments (typically a length shorter than 20–30 metres) identified in LIDAR-data and in the field are shown. However, it should be kept in mind that even though each area is of the same size, 400 × 400 m, the amount of outcropping bedrock differs significantly.

The field control of re-evaluated method-specific lineaments from interpretation of airborne electromagnetic data (both helicopter borne and fixed wing borne) has shown that about 50% of the controlled lineaments, may directly be related to deformation in the bedrock, manifested in topography, escarpments, or as fracture zones in outcrops.

Lineaments identified in magnetic data were controlled in field at 84 locations. Approximately 65% of the magnetic lineaments are related to a direct observation of low relative magnetic susceptibility and/or observed deformation in outcrops and/or structural elements in morphology.

Table 5-2 summarises the different kind of lineaments that has been dealt with in this activity, what source they derive from and the outcome related to the lineaments from this work.

Table 5-1. The number of field verified local minor lineaments per field control area. See also Figures 5-1 to 5-7.

Study area	1	2	3	4	5	6	7
Number of lineaments	20	19	12	21	28	3	20

Table 5-2. Summary of lineament data for field verification. See also Figures 5-1 to 5-7.

Lineament type	Input data	Output in this study	Field controlled
Large scale topographic	DTM /9/	Re-evaluated lineaments	Only partly
Electromagnetic Control area 1, 3, 4, 5 and 7	Helicopter /3,7/	Re-evaluated lineaments	On outcrops
Electromagnetic Control area 2 and 6	Ground survey /4/	Detailed lineaments	On outcrops
Magnetic Control area 1, 3, 4, 5 and 7	Helicopter /3,7/	Re-evaluated lineaments	On outcrops
Magnetic Control area 2 and 6	Ground survey /4/	Detailed lineaments	On outcrops
Small scale topographic	LIDAR-data /1/	Small scale lineaments (length 10–200 m)	Partly
Morphological	Orthophoto /1,5/		Partly
Field defined	Field reconnaissance		Yes

6 Discussion

The assignment of attributes from the field characteristics was done where relevant observations were possible to make. For new, local minor lineaments recognized in the field, obviously, the character was described by means of the attributes. Other lineaments, derived from interpretation of topographic and geophysical data, were characterized if they passed over, or close to outcropping bedrock. Lineaments not related to outcropping valleys, for example in flat-lying soil-covered areas, have not been characterized in the field. Note, that the outcrop pattern as it appears on the geological map includes thin soil cover. Also a few lineaments running along valleys were characterized, especially where they run close to outcropping bedrock.

In field control areas 2 and 6 the number of lineaments from magnetic data is higher than elsewhere. Furthermore, the number of short lineaments is higher as compared to the other areas. A major reason to this is that these areas are covered by the detailed ground geophysical survey from which the increased number of lineaments as well as the short length is emanating /4/. Other factors that cause large differences in the frequency of especially shorter lineaments are the topographic relief and the percentage of outcrop bedrock.

There is a general experience from extensive fieldwork in the Laxemar and Simpevarp areas that the magnetic susceptibility could be rather low without any visible coupling to deformed rock. Some of these low values in magnetic susceptibility surely can be attributed to primary variations in magnetite content of rocks. It is however strongly suspected that low magnetic susceptibilities at many locations are a sign of secondary metamorphic or hydrothermal changes in the rock and indirectly to fracturing. A study to clarify uncertainties in this hypothesis could be a task for future work.

From this limited study it can be concluded that in field control area 2 and 6 a more comprehensive joint interpretation would be possible, since both LIDAR-data, ortophotos and ground geophysical data are present. In general, the interpretation of lineaments followed by field assessment has shown to be an appropriate approach to locate and characterize minor deformation zones, but also to discriminate such structures from other geological features.

7 References

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Appendix 1

List of characterized topographical lineaments (for geographical location please find Figures 5-1 to 5-7)

LINE	OUTCROP	INTERPRET	ORIENT	WIDTH	ADJLENGTH	CONFIDENCE	OUTCSTR1	OUTCALT1	OUTCSUSC1	OUTCSTR2	OUTCALT2	OUTCSUSC2	ENDINGS
1t17	1	4				2	1	1	2,000				
1t18	0	1											
1t22	1	4				3			1,200				
1t24	0	2		20									
1t34	1	1											
1t36	0	1											
1t46	0												
1t47	1	4											
1t49	1	4				2		1	200				
1t54	0												
1t55	0												
2t05	0	4											
2t08	1	4											
2t14	0	2											
2t15	0	2											
2t27	1	2											
2t31	0	4											
2t34	1	4											
2t39	1	4											
2t50	0	2											
2t71	0	4											
3t05	0	4											
3t06	0	3											
3t09	0	4											
3t10	0	4											
3t14	0	4											
3t16	1	4											
3t17	0	1											
3t18	0	2											
4t01	0	4											

4t05	1	4					
4t09	1	4					
4t10	1	1					
4t13	0	4					
4t17	1	3					
4t18	0	4					
4t30	0	2					
4t36	1	4					
4t55	1	3					
4t56	0	2					
4t68	0	2					
5t01	0	2					
5t04	0	2					
5t06	0	2					
5t13	0	4					
5t19	0	2					
5t23	0	4					
5t28	0	4					
5t29	0	4					
5t32	1	2					
5t35	0	4					2,500
5t37	0	2					
5t40	1	3					
5t46	0	4					
6t02	0	4					
6t04	1	4					
6t33	0	3					
6t34	1	3					
6t39	0	2					
7t04	0	4					
7t15	0	4					
7t19	0	2					
7t21	1	2	125	2	1	1	1,000
7t25	1	2					
7t26	1	4					

List of characterized complex lineaments (for geographical location please find Figures 5-1 to 5-7)

LINE	OUTCROP	INTERPRET	ORIENT	WIDTH	ADJLENGTH	CONFIDENCE	OUTCSTR1	OUTCALT1	OUTCSUSC1	OUTCSTR2	OUTCALT2	OUTCSUSC2	ENDINGS
1k02	1	5		10		2		1			1		
1k07	1	2				2	5	1					
1k19	1	4				2	5		600	1	1	400	
1k32	1	4				2	1	1	500				
1k48	1	2				2			900				
1k50	0	2											
1k53	1	2				3			600				
4k02	0	1											
4k11	0	4											
4k25	1	3				2	1	1	300				
4k42	0	2											
4k48	1	4							2,000				
4k58	0	2											
4k62	0	2											
5k02	1	2				2			2,000				
5k05	1	2				2			2,000				
5k06	0	2											
5k07	0	4											
5k09	1	4				2			1,500				
5k20	0	2											
5k36	1	4							500				
7k09	1	2				2			150				

List of characterized magnetical lineaments (for geographical location please find Figures 5-1 to 5-7)

LINE	OUTCROP	INTERPRET	ORIENT	WIDTH	ADJLENGTH	CONFIDENCE	OUTCSTR1	OUTCALT1	OUTCSUSC1	OUTCSTR2	OUTCALT2	OUTCSUSC2	ENDINGS
2M01	1	2				1	2	1	60				
2M02	1	1				3	5	1	400				
2M03	1	2				2	1	1	200				
2M06	0	4											
2M07	0	1											
2M09	1	4				3	5		80			100	
2M12	0	1											
2M13	1	1											
2M16	1	5		2		2	3	1	700				
2M17	1	1				3	5		50				
2M18	1	2				3			600				
2M18b	1	4				3			600				
2M19	1	4				3	5		1,500				
2M20	0	1											
2M20b	0	1											
2M22	1	1				3			200				
2M24	0	4											
2M25	0	2											
2M29	1	2				2	1	1	70	1	1	100	
2M32	1	5		2		2	2	1	50				
2M32b	0	1											
2M33	0	2											
2M37	1	1				3	5						
2M40	0	2											
2M41	1	1				3			2,000				
2M43	0	1											
2M44	0	2											
2M51	0	2											
2M52	0	4											

2M53	0	2					
2M54	0	3					
2M55	0	2					
2M57	0	2					
2M58	1	2		3	5	1,500	
2M59	1	3	15	3		1,000	
2M60	1	4					
2M61	0	4					
2M62	1	2		3		150	
2M63	1	2		3		1,500	
2M67	0	4					
2M69	0	4					
2M70	0	2					
2M72	0	2		3		2,000	
2M73	0	4					
2M74	0	2					
2M75	1	1		3		1,500	
2M76	0	1					
2M76b	1	1		3		2,000	
2M77	1	1					
2M77b	0	1					
2M78	0	2					
2M79	0	1					
2M80	1	1					
3m13	1					300	
4m04	1	5				100	400
4m15	1	1				500	
4m46	1	4				700	
4m68	1	1				1,000	
4m70	1	3				100	
5m11	1	1		2		1,500	

5m18	1	1					1,000				
5m22	1	4					2,000			1,500	
5m38	1						1,500				
6M03	1	4		3	5	1	1,500				
6M09	0	2									
6M10	1	2	2	2	1	1	600			2,000	11
6M12	1	3		3	1	1	400				
6M14	1	3		2	1	1	500				
6M17	1	3		3	1		1,500				
6M18	1	4				1	200				
6M19	1	4		2		1	400				
6M20	0	4									
6M21	0	1									
6M22	0	1									
6M23	1	4		3			500				
6M24	1	3		3	2		2,500				
6M26	1	4		3	1		1,500				
6M28	1	4		3		1	500				
6M29	0	1									
6M30	0	1									
6M31	1	3		2		1	10	1	1	50	
6M32	1	3		2	1	1	150				
6M38	1	4		3	5		800				
6M40	1	1		3		1	1,000				

List of characterized new lineaments, i.e. unique for this study (for geographical location please find Figures 5-1 to 5-7)

LINE	OUTCROP	INTERPRET	ORIENT	WIDTH	ADJLENGTH	CONFIDENCE	OUTCSTR1	OUTCALT1	OUTCSUSC1	OUTCSTR2	OUTCALT2	OUTCSUSC2	ENDINGS
2N19	0	2	125	10									11
2N05	0	2	160	10									11
1N01	1	3	185	0		1	1						11
3N07	1	3	80	0		1	1	1	500				11
4N44	1	2	165	0		1	1	1	500				11
5N24	0	2	125	15									11
1N35	1	3	75	0		1	1		600				11
1N36	1	3	10	0		1	1	1	600				11
1N37	1	3	5	0		1	1	1	250				11
1N31	1	3	0	0		2	1	1	200				11
1N30	1	3	30	0		1	1	1	200				11
1N40	1	1	10	0		1	1	1	200				11
1N41	1	2	10	1		1	1	1	300				12
1N58	1	3	130	0		1	1	1	2,500				11
1N57	1	3	140	0		1	1	1	1,500				13
1N43	1	2	60	0		1	1	1	200				11
1N27	1	3	20	0		1	1	1	2,500				11
1N28	1	3	170	0		1	1	1	400				11
1N22	1	3	0	0		1	1	1	1,500				11
1N03	1	3	180	1		1	1	1	400				11
1N04	1	3	180	1		1	1	1	450				11
1N05	1	3	180	1		1	1	1	100				11
1N11	1	3	145	0		1	1	1	600				11
1N08	1	2	30	5		1	1	1	500				11
1N14	1	3	110	0		1	1	1	2,000				11
2N04	0	2	0	0									11
2N21	1	3	105	0		1	1		150				
2N11	0	2	0	10									11
2N12	0	2	0	15									11

2N17	0	2	0	0					
2N38	1	2	5	1	1	1	1	400	11
2N35	1	3	5	0	1	1	1	60	11
2N66	1	2	140	0	1	1	1	50	11
2N27	1	3	0	0	1	1	1	200	
2N26	1	3	15	0	1	1	1	50	11
2N45	1	4	95	5	1	1	1	60	11
2N30	1	5	100	5	1	2	1	40	11
2N56	0	2	0	0					
2N36	1	3	20	0	1	1	1	50	11
2N47	1	3	70	0	1	1	1	200	11
2N48	1	3	85	0	1	1	1	200	11
2N23	0	2	130	10					11
3N15	0	2	25	5					11
3N11	1	3	150	0	1	1	1	500	11
3N12	1	3	45	0	1	1		1,500	11
3N23	1	5	155	1	1	2	1	200	11
3N21	0	2	145	10					11
3N19	0	2	145	5					11
3N20	1	2	25	0				30	11
3N04	0	2	100	5					11
3N02	0	2	165	3					11
3N03	1	3	160	0	1	2	1	100	11
3N08	1	3	5	0	1	1	1	400	13
4N07	1	2	60	5	1	1			11
4N08	0	2	95	5					11
4N06	0	2	95	5					11
4N14	0	2	85	10					11
4N12	1	3	20	0	1	1	1	500	11
4N03	1	3	85	0	1	1	1	300	11
4N21	1	2	55	0	1	2	1	50	11

4N20	1	3	145	0	1	1		2,000	12
4N24	0	2	0	20					
4N26	1	3	110	0	1	1		1,000	11
4N30	0	2	0	0					
4N34	1	5	35	0	1	2	1	100	11
4N27	1	3	110	0	1	1	1	100	11
4N28	0	2	130	0					11
4N29	1	3	0	0	1	1	1	2,500	11
4N32	1	5	45	0	1	2	1	100	11
4N71	1	3	55	0	1	1	1	300	11
4N47	0	2	130	10					11
4N54	1	2	120	10	1	1	1	300	11
4N43	1	2	85	0					
5N17	0	2	100	5					11
5N16	1	2	35	2	1	1	1	250	11
5N06	0	2	0	0					11
5N08	0	2	0	0					11
5N33	0	2	110	0					11
5N34	0	2	60	0					11
5N25	0	2	20	5					11
5N21	0	2	105	15					11
5N14	0	2	5	5					11
5N12	0	2	165	10					11
5N10	0	2	160	10					11
5N38	0	2	5	15					11
5N31	1	2	15	0				250	11
5N30	1	3	140	0				250	11
5N27	1	3	160	0				400	
5N26	1	3	0	0	1	1	1	400	11
5N03	1	2	10	0	2	1		2,000	13
5N39	0	2	25	0					11

5N42	1	3	175	0	1	1	1	400	11
5N43	0	2	140	15					11
5N42	1	3	5	0	1	1	1	500	11
5N41	1	3	10	0	1	1	1	100	11
5N37	0	2	95	15					11
5N49	1	3	115	0	1	1	1	1,500	11
5N50	0	2	0	0					
5N48	1	2	30	0	1	1	1	300	11
5N45	1	3	174	0	1	1		1,500	11
5N44	1	3	5	0	1	1	1	100	11
6N11	1	3	10	0	1	1	1	500	11
6N07	1	3	145	0	1	1	1	1,000	11
6N08	1	3	5	0	1	1	1	1,800	11
7N08	1	5	95	0	1	2	1	250	11
7N07	1	3	145	0	1	1	1	100	11
7N07	1	3	145	1	1	1	1	2,000	11
7N10	1	3	110	0	1	1	1	400	11
7N11	0	2	0	0					
7N12	1	3	110	0	1	1	1	300	11
7N13	1	3	105	0	1	1	1	2,500	11
7N20	0	2	90	15					
7N18	0	2	125	15					
7N16	1	3	140	0	1	1	1	200	11
7N17	0	2	135	20					
7N18	1	3	40	0	1	1	1	40	11
7N27	1	5	55	3	1	3	1	40	11
7N06	0	2	0	0					
7N03	1	3	100	0	1	1	1	50	11
7N02	1	3	145	0	1	1		7,000	11
7N01	1	3	75	0	1	1	1	30	11
7N24	1	3	35	0	1	1	1	500	11
7N23	0	2	45	5					11
7N22	1	3	100	0	1	1	1	40	11

List of characterized electro-magnetical lineaments (for geographical location please find Figures 5-1 to 5-7)

LINE	OUTCROP	INTERPRET	ORIENT	WIDTH	ADJLENGTH	CONFIDENCE	OUTCSTR1	OUTCALT1	OUTCSUSC1	OUTCSTR2	OUTCALT2	OUTCSUSC2	ENDINGS
1e42	1	2		5		2	1						
2E46	1	4											
2E75	0	1											
6E01	0	1											
6E06	0	3				3	1		2,500				
6E15	0	2											
6E16	1	1											
6E25	0	1											
6E36	1	3				2	1	1	2,000				
6E37	1	2				2	1	1	40				